MAKING URBAN POLICIES SUSTAINABLE

LONG-TERM BENEFITS OF URBAN PLANNING AND FISCAL POLICIES

vorgelegt von

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Abstract

Humanity is urbanizing rapidly. By now every second world citizen lives in cities. Scenarios suggest that by the middle of this century, almost 70 per cent of the global population will be urban. At the same time, cities constitute both sources but also potential solutions to climate change and other sustainability challenges. While there is an increasingly amount of research dealing with specific aspects of urban sustainability, new approaches that merge different knowledges have great potential in finding optimal, or at least appropriate, pathways that could minimize the negative impacts as well as maximize the positive outcomes of the urbanization process.

The fields of urban and public economics provide a useful framework to analyse urbanization dynamics in terms of its drivers and impacts. Climate change and sustainability literature provide valuable insights to understand urbanization effects other than local ones. The combination of these literatures has great potential to assist local policy-makers in the development of accurate planning interventions for achieving long-term urban sustainability.

The research presented in this thesis identifies public interventions that foster less carbon-intense urban forms, enhance fiscal stability and promote social equity simultaneously. Particularly, two mechanisms are analysed to achieve these outcomes. The first one considers urban planning -including land use and fiscal policies- as a steering mechanism that accounts for externalities arising from urban development. The second one looks at institutional and governance structures that maximize the beneficial effects of public interventions. A combination of theoretical and empirical research is conducted to determine instrument designs that perform better on the above objectives. Having this information at hand, specific policy suggestions on how to maximize positive intervention outcomes are proposed and further discussed. Understanding the interactions between different planning tools, policy agendas and urban contexts is a *sine qua non* condition to long-term sustainability not only in cities, but also worldwide.

Zusammenfassung

Die Menschheit urbanisiert sich rasend schnell. Mittlerweile lebt jeder zweiter Weltbürger in einer Stadt. Projektionen deuten darauf hin, dass bis Mitte dieses Jahrhunderts fast 70 Prozent der Weltbevölkerung in Städten leben werden. Gleichzeitig sind Städte sowohl Verursacher als auch Teil möglicher Lösungen der Herausforderungen von Klimawandels und Nachhaltigkeitsabwägungen. Während sich ein wachsender Teil der Forschung mit spezifischen Aspekten der städtischen Nachhaltigkeit beschäftigt, haben neue Ansätze, die verschiedene Erkenntnisse verschmelzen großes Potenzial bei der Suche nach optimalen oder zumindest geeigneten Wegen, mit dem die negativen Auswirkungen der Urbanisierung minimiert sowie deren positive Aspekte verstärkt werden könnten.

Die Forschungsfelder Ökonomie der Städte und Öffentliche Ökonomie stellen einen nützlichen Rahmen für die Analyse von Urbanisierungsdynamiken in Bezug auf ihre Treiber und Auswirkungen dar. Die Literatur zu Klimawandel und Nachhaltigkeit erlaubt wertvolle Einblicke in die Verstädterung sowie deren globale Wechselwirkungen. Die Kombination dieser Literaturzweige hat großes Potenzial lokale politische Entscheidungsträger bei der Entwicklung von besserer Interventionsplanung zur Unterstützung sowie längerfristig die Nachhaltigkeit in Städten zu unterstützen.

Die Forschung in dieser Arbeit identifiziert institutionelle Interventionsmöglichkeiten, die weniger CO2-intensive urbane Formen fördern, die finanzpolitische Stabilität verbessern und gleichzeitig soziale Gerechtigkeit fördern können. Insbesondere werden zwei Mechanismen analysiert, um diese Ziele zu erreichen. Der erste Mechanismus betrachtet Stadtplanung (einschließlich Landnutzungs- und Steuerpolitik) als Lenkmechanismus der weiteren Externalitäten in der Stadtentwicklung Rechnung trägt. Der zweite Mechanismus befasst sich mit institutionellen und Governance-Strukturen, die die positiven Auswirkungen der staatlichen Interventionen maximieren. Diese Arbeit kombiniert theoretische und empirische Ansätze um Instrumentendesigns zu bestimmen, welche die oben genannten Ziele besser umsetzen können. Auf Grundlage dieser Ergebnisse werden spezifische politische Vorschläge erarbeitet und diskutiert, welche die positive Auswirkungen von Interventionen maximieren. Das Verständnis der Wechselwirkungen zwischen den verschiedenen Planungsinstrumenten, politischen Zielen und städtischen Kontexten ist eine Bedingung *sine qua non* zur Erreichung langfristiger Nachhaltigkeit nicht nur in urbanen Räumen, sondern auch in ländlichen Gegenden weltweit.

Preface

When I finished my Masters in the year 2012, two opportunities knocked on my door to write a PhD in sustainability issues. I remember having doubts about my final choice and asking for advice to one of my closest professors at that time. Having my interests in mind, she advised me to join the Mercator Research Institute on Global Commons and Climate Change (MCC) for my PhD. The underling argument was that it seemed like the perfect place to develop interdisciplinary research skills focused on providing specific answers and solutions to the greatest challenges humanity is and will face. After empirical evidence I confirm that she could not be more right.

Still amazed by the personal and professional development of that girl from 2012, I am aware that none of this would have happened without two main figures: Ottmar Edenhofer and Felix Creutzig.

Every time is precious when you are around Ottmar; it took me 5 minutes from being in a moment where I had to admit -in a very uncomfortable situation of course!- that I was not familiar with Ottmar's scientific reputation, to understand that its not only his research that makes him special, but also the humble approach he uses in everything he does. I remember once at a MCC Christmas dinner that he was concerned because he did not bring a present for the Secret Santa, and I told him: "But Ottmar, you gave us all already a great present!". And it is indeed true: being part of MCC is a unique experience at many levels and Ottmar is the one more to blame.

Without the supervision from Felix Creutzig this thesis would not have been written. I want to thank him for the productive collaboration, research ideas, discussions, lessons on writing skills, and patience, among many other issues, over several years. I also want to thank him for giving me freedom in developing my personal research ideas while at the same time contributing to their improvement. Finally, he was the one that suggested me to apply for a scholarship at the Heinrich Boell Foundation. I very much thank him for that.

The collaborations were essential in writing this dissertation, and I want to thank all the co-authors which whom I have the pleasure to work with.

Thanks to the administrative team of TU Berlin, and the MCC staff in particular; their support was extremely helpful in uncountable times.

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On a personal level, I want to thank my parents and family; a vital lifeline when most needed. Also my friends Alexander Radebach, Karla Elliot, Ana Garcia and Susana Clemente; my welfare stabilizers and catalysts. Finally, I thank Angela, my main source of happiness during these years.

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Chapter 1

Introduction

Introduction

More than every second world citizen lives in urban areas since 2015. Scenarios suggest that by 2050s, that figure will have risen to 6.5 billion people – two-thirds of the global population- (UN 2014a). How these cities[1] develop will affect not only natural ecosystems and planetary resources including our atmosphere, but also the quality of life of future generations (Seto et al. 2014).

But what is so fascinating about cities that every second person of this planet chooses to live in them? Beyond individual preferences (economic wealth and accessibility to public and private goods and services, among others) urbanization represents one of the greatest economic drivers worldwide. A considerable number of nations from southern and northern hemispheres base a significant share of their economic strategies on how their urban areas grow and what they produce. Cities are agents that agglomerate prime locations to create profits and everyone wants its share (Alonso 1964; Mills 1967; Muth 1968; The Economist 2015). Considering the highly dynamic prospects that are to happen in urban areas, it seems crucial to identify public interventions that guarantee both fiscal stability and welfare of its population in the long-term to ensure sustainable development at the city level.

However, housing supply decisions are typically made from the bottom up and due weight is put on short-term profit maximization (The Economist 2015; Fujita 1989; Alterman 2012). An unceasing stream of urban development occurs separately from local and regional economic capacity to uncover the costs of urbanization in the form of public services and infrastructure. Ultimately, this causes either over- or undersupply of local public goods and services. The year 2008 showed the major consequences of such a growth model when the Wall Street engineered financing of housing in the USA and the Great Recession hit economies all around the world. In Europe, nations with higher urbanization dynamics –and their related costs – had to apply for a special package from the European Stability Mechanism to rescue its banks. Local finances were largely based on the short-term profits from development taxes and rezoning and when the real estate market collapsed, so did the municipal revenues (European Commission 2012; European Commission 2014a). While real estate-based revenues declined drastically and newly constructed towns required further investments in urbanization infrastructure, entitlement programs costs started to increase (Council of Europe 2011). Additionally, the increasing uncertainty of the financial market made supranational bodies curtail their financial assistance to municipalities, causing reductions in transfers from 2011 onwards (Council of Europe 2011). Altogether, the gap between revenues and expenditures lead to ambitious budget cuts with multiple adverse effects on the

[1] Following the nomenclature used by UN HABITAT and ICLEI practices, in this document we use the terms “cities” and “urban areas” interchangeably to denote metropolitan areas and all urban centres that have economic or political importance.

welfare of municipal citizens. Crucially, large expenditures associated with urbanization infrastructure still need to be paid.

While loan practices pursued by financial entities caused these disastrous dynamics, planning and fiscal policies exacerbated the crisis of local debts. Unfortunately, a similar story unfolds in other rapidly urbanized world regions like China. The overly ambitious building program has led to hundreds of new cities in China largely empty, a general loss of investors and a colossal public debt (Pan, Huang, and Chiang 2015; Lin and Yi 2011). Local governors encounter the unfortunate consequences of prioritizing immediate gross domestic product growth through real estate development at the expenses of mid and long-term risks associated with excessive debt (Kynge 2016; Feng 2014). The practices of urbanization are state-directed, infrastructure driven and debt-financed (Harvey 2012), leading to an excessive infrastructural development and unstable local government deficits (Rapoza 2015; Shepard 2015; Liu et al. 2016).

This said, greater attention has to be paid to the interrelationship between cities development and local public finance in the ongoing geographical, economic and political urban transformation.

In addition to the above and in view of the recently adopted international climate treaty (UNFCCC 2015), the prospect of an urbanized humanity has put cities in the spotlight for climate action. Although cities are at the forefront of mitigation and adaptation actions (Rosenzweig et al. 2010; Dodman 2009; Hallegatte and Corfee-Morlot 2010), climate strategies are not implemented in a vacuum; they interact with other social and economic local policy goals. These interactions can lead to trade-offs and implementation obstacles, or to synergies (McEvoy, Lindley, and Handley 2006; Viguié and Hallegatte 2012). Moreover, the implementation of climate strategies requires upfront investments that compete with already existing social and economic public budgets.

Having the financial constraints in mind, the identification of urban policy tools that, on the one hand, facilitate the achievement of different agendas, and, on the other hand, ensure the fiscal stability of municipalities, would multiply the prospects of meeting long-term sustainability in cities[2]. Crucially, a new urbanisation paradigm whose foundations are not based on state-led land consumption, suboptimal infrastructure development –both from an economic and environmental point of view- and unsustainable public indebtedness should apply to the cities to come if we want to ensure the quality of life of future generations.

While local finances and wealth optimization have been greatly discussed in the fields of urban and public economics, a growing body of literature has emerged on the issue of urban sustainability strategies. The combination of these two is an

[2] In this thesis, the concept *urban sustainability* includes its temporal approach, thus giving particular attention to intergenerational wellbeing of citizens.

emerging research field with enormous potential to contribute long-term urban sustainability. Ensuring not only short-term wellbeing of urban citizens, but also long-term intergenerational welfare of the generations to come require policy instruments that achieve fiscal stability, social equity and low carbon-intense urban forms simultaneously. This thesis develops new economic and political evaluations to provide policy-relevant advice on how these instruments may actually look like.

The introduction outlines the broader context and structure of this thesis. It starts with a brief recap of the basic dynamics of urbanization, the existing frameworks of analysis, and the main challenges cities face, including that of climate change (1.1). The overview of the urban policy portfolio highlights the fundamental role of urban planning and urban governance in achieving multiple objectives in cities. It further stresses the role of fiscal policies in financing low-carbon infrastructure and shaping urban form towards less carbon-intense spatial configurations (section 1.2). As urban planning instruments are critical for maximizing socioeconomic and environmental outcomes, section 1.3 describes the interactions existing between climate, fiscal and equity objectives in this field. On the one hand, urban planners should be aware of the distortive effects in multiple policy areas derived from suboptimal interventions. On the other hand, it becomes increasingly important to evaluate planning instruments through a multi-objective view that incorporates fiscal, social and environmental objectives. I use the property tax as an example to elaborate a more detailed discussion that illustrates how different policy agendas can be taken into account when designing a single intervention instrument. However, the assessment of multidimensional, value-laden policy issues calls for new scientific and political practices that explore alternative policy pathways, their consequences, overlaps and trade-offs. Section 1.4 discusses how institutions and governance structures need to adapt if they want to act as facilitators in the achievement of a new urbanization paradigms based on -long-term- sustainability. Section 1.5 states the main research questions and provides an overview of the remaining chapters of this thesis.

1. Urbanization dynamics

Typically, the literature distinguishes between two main types of urban dynamics: urban population growth rates and urban land expansion rates. The reason behind is that they imply very different things for the natural ecosystems and resource depletion (including the atmosphere) and the socioeconomic structures of the human settlements.

Although both show positive growth rates, global urban land expansion rates are higher than or equal to urban population growth rates. While urban populations are expected to almost double in 2030 (UN 2014b), urban areas are forecast to triple (Seto, Guneralp, and Hutyra 2012), suggesting that urban growth is becoming more expansive than compact (Seto et al. 2011a; UN 2014a). Tellingly, urban areas are growing faster than any other land-cover form (Grimm et al. 2008).

However, these dynamics vary greatly among world regions, depending on the factors that trigger urbanization. Traditionally, growth in population and Gross Domestic Product (GDP) were the two main explanatory factors. In China for example, economic growth has driven the observed urban land expansion of the last decades by 50%. The incredible high urban population growth rates in India and Africa explain almost all their urban land expansion (Seto et al. 2011a). But although population and economic growth are important drivers of urbanization, additional institutional factors also shape how development occurs –e.g. land use policies and transport costs- (Seto et al. 2011a; Couch, Leontidou, and Petschel-Held 2007; Brueckner 2000).

1.1 Urban threats

Climate change and natural ecosystems

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) leaves no doubt that humanity is on track to warm up the planet beyond 4°C by the end of this century (Stocker et al. 2014) and that the impacts of such changes in climate on human populations will be severe, especially for the most vulnerable populations and places (IPCC 2014a). To limit the damages to ecosystems and human societies around the globe, GHG emissions must be dramatically reduced. AR5 shows that through vigorous actions by all nations, temperature increases could still be limited to approximately 2°C above pre-industrial times until the year 2100 (Edenhofer et al. 2014). But this goal can only be achieved by staying within a global carbon budget of about 1000 $GtCO_2e$. To illustrate this, at current emission rates that exceed 50 $GtCO_2e$ per year, the carbon budget to remain within the 2°C increase would be used in only 20 years.

What does climate change has to do with cities? Cities will not only host 70 per cent of the global population until 2050, but they are also the hotspots of consumption, and great drivers of global environmental change (Grimm et al. 2008). The most recent IPCC report shows that urban areas consume between 67% and 76% of global energy and generate about three quarters of global carbon emissions (Seto et al. 2014). However, the distribution of emissions –both total and per capita- varies widely across different types of cities. Economic activity, transport costs, geographic factors and urban form explain 37% of urban direct energy use and 88% of urban transport energy use (Creutzig, Baiocchi, et al. 2015).

From a mitigation perspective, understanding how urban form shapes GHG emissions is essential. Urban form indirectly influences energy use and GHG emissions of transportation and residential living (Creutzig 2014; Ewing and Cervero 2010; Ewing and Rong 2008). Although about 40% of all transport emissions occur in urban areas (E.G. Agency, 2008), denser cities dramatically reduce transport distances, transport energy use and associated emissions (Newman and Kenworthy 1989; Creutzig, Baiocchi, et al. 2015). This relationship can be explained by more specific urban form indicators, such as ‘distance to work’ and 'connectivity' (Ewing and Cervero 2010). Residential emissions also correlate inversely with population density above a certain density value, which is roughly the same value as the critical density threshold to support minimal modal choice (Baiocchi et al. 2015; Rickwood, Glazebrook, and Searle 2008). Thus, after controlling for geographical and socioeconomic variables, urban form is an important classifier of emission types of human settlements. Given the influence of urban planning interventions on the spatial structure of cities (Alterman 2012; Brueckner 2000; Couch, Leontidou, and Petschel-Held 2007), the policy mix of fiscal and land use policies that compose those interventions appears crucial for the achievement of urban mitigation potentials (Dulal, Brodnig, and Onoriose 2011; Batty et al. 2011; Seto et al. 2014).

And, how does global warming affect urban population? Cities are particularly vulnerable to climate change and climate extremes in part due to their high concentration of people, socioeconomic activities and wealth in limited areas (Hallegatte, Henriet, and Corfee-Morlot 2010). However, climate change impacts are distributed unequally between people because of intrinsic person-specific characteristics –susceptibility- and extrinsic factors (McMichael, Woodruff, and Hales 2006; IPCC 2014b). Whereas the first one includes health and socioeconomic conditions that influence how sensitive people are to climate change impacts, extrinsic factors refer to where and how people live to determine the exposure to the hazard (IPCC 2014b). High exposure and susceptibility often coincide with population living in cities from low- and middle-income nations where capacities to adapt are limited (Fortmann 2010; Revi et al. 2014).

Urbanization also impacts different ecosystems in many other ways besides anthropogenic global warming. Cities provoke changes in land-cover, local climates, hydrological and biological systems. They constitute a major threat to protected areas; affect their local climate through the modification of surface albedo and evapotranspiration, and increased aerosols and anthropogenic heat sources, resulting in elevated temperatures, and changes in precipitation patterns (Seto, Guneralp, and Hutyra 2012; Seto and Shepherd 2009; Revi et al. 2014). Ultimately, this could affect peri-urban zones and nation-states though food, water and the alteration of other natural ecosystem services (Elmqvist et al. 2013).

Socioeconomic effects of urbanization

The development of peri-urban settlements consumes highly productive land located at the urban periphery for historical reasons (Blum 2014; Bringezu 2014; Brown 2014; Seto and Reenberg 2014; Seto et al. 2011b). How these areas develop affect local food production (Ahmad et al. 2016; Bagan and Yamagata 2014; Chen 2007) and livelihoods (Brook and Dávila 2000). In rapidly urbanized regions -e.g. Sub-Saharan Africa and South Asia- newly coming households are excluded from the urban labour market, having no alternative to generate income (Brook and Dávila 2000). Consequently, there is a deterioration of rural livelihoods, a lack of urban employment with concurrent proliferation of slum dwellers and impoverishment of the population (Anderson et al. 2013), and a reduction opportunity for rural and urban subsistence farming that limits food affordability and access. Altogether, it may contribute to the wellbeing of population and ultimately cause political destabilization.

In developed contexts, an overgrowth of urban areas has been related to suboptimal provision of access to public services and infrastructure, excessive budgetary deficits, and growing public and private debt (Carruthers and Ulfarsson 2003; Hortas-Rico and Solé-Ollé 2010; Brueckner and Fansler 1983). In addition, there is an increasing literature evidencing the link between excessive urban land consumption and a number of health diseases (Berrigan et al. 2014; James et al. 2013; Griffin et al. 2013; Ewing et al. 2014).

In summary, cities themselves face major challenges in all policy domains including environmental, social and economic aspects that ultimately affect citizen's welfare. How future urban areas develop is a global challenge, and has been identified as such by policy makers.

1.2 The economics of urban form and urbanization

Conceptually, urbanization dynamics are described through changes in population, income, and transport costs, all of them linked through the price of housing (Alonso 1964; Mills 1967; Muth 1968). Formally, the urban economic budget equation allocates income Y to spurious consumption c, transport costs T=tr (with t marginal transport costs and r the travel distance to the inner city), and land consumption S=sR (with R rental costs per unit land and s the amount of land consumed): Y=c+Tr+Rs (see section 1.3).

Given the importance of urban land expansion in explaining urbanization impacts on natural ecosystems, societies and fiscal stability, urban literature progressively focuses on the dynamics behind. A deep understanding of which factors drive excessive urban land consumption alias urban sprawl[3] will, ultimately, shed light on the design of effective urban mitigation strategies. Under this framework of analysis, population growth, enhanced purchasing power[4] and changes in transport infrastructure and expenditures explain sprawling patterns to a great extent (Baum-Snow 2007; de Bartolome and Ross 2007; Leroy and Sonstelie 1983; Molloy and Shan 2012; Rodriguez 2013; Small 1981). Interestingly, fuel prices play a key causal role: they determine not only urban expansion and urban form but indirectly also the financial viability of public transit (Creutzig 2014). Urban form characteristics also influence land consumption and commuting patterns –e.g. by the physical geography, spatial distribution of local amenities and job ratio balance-

[3] For a detailed definition of urban sprawl see Chapter 6.

[4] Purchasing power aligns with individual preferences for large affordable consumption of land (Fujita 1989).

(Duarte and Tornés Fernández 2014; Fernández and Duarte 2012; Burchfield et al. 2006; Saiz 2010).

But fiscal policies and other public interventions are equally important in explaining recent developments. Literature highlights the role of market failures, fiscal distortions and similar government interventions (Brueckner 2000; Couch, Leontidou, and Petschel-Held 2007). Cheap money fuelling new real estate development (Squires 2002) in the form of mortgage deductions and related housing policies (Burchfield et al. 2006; Hamidi and Ewing 2014; Squires 2002), as well as under-pricing of infrastructures (Baum-Snow 2007; Brueckner 1997) encourage excessive land use conversion for residential use. Crucially, fiscal distortions through property tax regimes are key in explaining urban development patterns (Anderson 1986; Arnott 2005; Brueckner and Kim 2003; Cocconcelli and Medda 2013; Groves 2009; Song and Zenou 2006). Last but not least, an absence of region-wide cooperation, territorial competitiveness, decentralized land use planning polices and permissive urban plans contribute as well to urban sprawl (Carruthers and Ulfarsson 2001; Chorianopoulos et al. 2014; Eicher 2008).

A rapidly growing literature exists on city dynamics in general and on urban climate change strategies in particular. Apart from classic urban economic models, model-building is increasingly popular for the land-use transportation community and those researchers relying on agent-based modelling or cellular automata models (Batty 2009). However, these studies lacks in a framework that integrates multiple policy objectives (Viguié and Hallegatte 2012; Solecki et al. 2015).

2. The sustainability agenda

When talking about different environmental and socioeconomic objectives in cities, literature typically refers to the generic concept of "sustainable cities". A sustainable city has been defined in many ways. The most common understanding is a vision of the city that is able to meet the needs of the present without compromising the future (Hodson and Marvin 2014; Haughton and Hunter 2004). Central to this vision are two ideas: cities should a) meet social needs, especially those of the poor; and b) not exceed the ability of the global environment to meet future needs (Hodson and Marvin 2014). In this thesis the concept of urban sustainability explicitly refers to the long-term, intergenerational aspect, which is then applied to the design and approach of urban policies.

With regards to climate change action, the prioritization for bottom up approaches given by the recent Paris agreement places urban areas at the spotlight. Cities are both a great challenge and opportunity to combating climate change (Seto and Reenberg 2014) and local authorities have to act accordingly (United Nations 2015). Per capita greenhouse emissions of urban areas are often lower than national averages (Dodman 2009; Romero-Lankao and Dodman 2011), however true mitigation potentials are far from being achieved. Urban climate strategies that combine both mitigation and adaptation in cities require a broad spectrum of actions. Only drawing on the full set of available climate policy options at the city level would substantially achieve urban mitigation potentials without compromising other socioeconomic objectives.

Given the contribution of anthropogenic emissions coming from urban transport, reduction efforts increasingly focus on this mitigation potential through urban planning and transport policies (Seto et al. 2014). Three main actions could contribute to a major mitigating share in urban transport: a) increase efficiency, b) reduce carbon intensity, and c) slow growth in demand (Creutzig, Jochem, et al. 2015). The mix of technological innovation and behavioural changes required to enhance efficiencies and trigger a transition towards decarbonized transport will help reducing emissions in the upcoming years, but ambitious mitigation targets require making use of the complete solution space. Demand-side solutions offer additional policy options to facilitate the task of a transition towards low-carbon economy (IPCC 2014a). Shaping demand via infrastructure development, land use policies and behavioural interventions can catalyse further emission reductions up to 20-50% until 2050 (Creutzig, Jochem, et al. 2015; Creutzig 2015).

Surprisingly, literature on climate change solutions emphasizes technologies, but somehow despises climate change policy options via lifestyle changes[5]. Three reasons explain this shortfall: First, demand-side solutions are often embedded in a complex network of social institutions and practices (Spaargaren 2011). Second, they often involve explicit normative positions, or values, making those solutions subject to value-laden discourses (Tribe, Schelling, and Voss 1976; Mattauch, Ridgway, and Creutzig 2015). Finally, as demand-side solutions presuppose modified behaviour, they are less compatible with the revealed-preference framework prevalent in economics.

While the climate change objective moves into the spotlight emphasizing its additional benefits in other policy areas, it is nonetheless valuable to contextualize these policies into other crucial issues encountered by municipalities.

On the one hand, social inequalities, one, if not the greatest burden of the 21st century, manifests itself more sharply in new urban developments. Municipalities are overwhelmed by the vast amount of urban infrastructure that is needed to supply current populations and the urbanites to come. Policymakers seek to address a broad agenda through strategies that combine multiple policy objectives mainly through the joint implementation of land use policies and investment in transport infrastructure (Cervero 2013). The fact that climate change will certainly threat

[5] Reducing the energy intensity of economic growth may be achieved via lifestyle changes (e.g. reducing the share of energy-intensive demand in the total consumption) or through carbon intensity reductions (e.g. reducing carbon intensity of supply either by displacing fossil energy sources and products or achieving more efficient industry and appliances (O Edenhofer et al. 2014).

urban populations differently highlights the role of planning polices and other political actions taken at the local level in exacerbating or minimizing such differences (Seto et al. 2014). Thus, it is of great importance to identify the interactions between climate policies with other development objectives and further develop policy tools that create synergies among them (United Nations 2015; Viguié and Hallegatte 2012).

On the other hand, the environment of budgetary austerity since the financial crisis induces local governments to seek revenues from sources independent of higher-level governance funds (European Commission 2012; Brandt 2014; Seto et al. 2014). Many cities across Europe have had budgets for local services and infrastructure projects cut as a result of the financial crisis. At the same time, cities have to face large upfront investments over the next decades if they wish to finance low-carbon accessibility. Under the present conditions of rapidly rising public debt, loans-based or bonds-financed infrastructure investments do not seem like a feasible option in the years ahead. Municipalities require new local funding methods independent from freezing higher levels of governance funds.

In sum, it is crucial to bear in mind that urban policies closely interact with a broad range of climate, environmental and development objectives (Viguié and Hallegatte 2012), and that these frictions also appear between climate mitigation and adaptation policies themselves (Batty et al. 2011; McEvoy, Lindley, and Handley 2006; Smith and Wollenberg 2012; Laukkonen et al. 2009). New assessment frameworks are required to evaluate policy options from a multi-objective approach that covers all the above mentioned issues. Two main strategies stand out: 1) combining multiple objectives within urban planning (Viguié and Hallegatte 2012; Seto et al. 2014), and 2) investigate on new institutional approaches that can cope with the assessment of policy alternatives with multidimensional, value-laden policy issues (Kowarsch 2015; Edenhofer and Kowarsch 2015). Section 1.3 and Section 1.4 provide arguments that support these views and further elaborate on each individual strategy.

3. Combining objectives through planning and fiscal policies

The great challenges described in the previous sections require policy instruments that take into account direct and indirect urbanization impacts, allow for welfare enhancing development scenarios in cities, and can be financially sustained (Blum 2014; Bringezu 2014; European Commission 2014b; European Commission 2011; Potočnik 2014). Notably, the determination of optimal urban mitigation targets and the design of instruments to implement them must also consider "cross-cutting" issue and across separate goals –e.g. in terms of health, local environmental quality, financial viability and social equity (Woodcock et al. 2009; von Stechow et al. 2015;

Seto et al. 2014; Helliwell, Layard, and Sachs 2015). Three main strategic goals predominate:

First, *limiting urban land take* becomes an increasingly important goal for urban planning. A mainstreaming of land-efficient use strategies that include fiscal instruments as well as zoning regulations promise opportunity to preserve fertile croplands, retain rural employment and shape the spatial development of cities to support climate change mitigation simultaneously (Elmqvist et al. 2013; Seto and Reenberg 2014; Seto et al. 2014).

Second, *investing in transit infrastructure* to guarantee low carbon accessibility is crucial to support the shift towards long term, intergenerational sustainable urban development. Public investment should aim at two things simultaneously: a) a shift towards non-motorized transport modes; and b) long-term economic viability of transit investments that avoid the need of intergovernmental transfers. Crucially, the solution may lie in the continuous increase of urban location values in most cities worldwide. There is a common consensus that the profitability of housing markets in urban areas is highly driven by public intervention (Grieson 1974; Alterman 2012; Oates 1969; Munoz-Raskin 2010). Specifically, literature on land taxation indicates that property taxes based on location values –and hence, exclude structural values of properties- improve the efficiency and equity of local fiscal policy (Mathis and Zech 2006; Dye and England 2009a; Roakes 1996; Mattauch et al. 2013) .

Last but not least, these *planning objectives need to be aligned with other socioeconomic policy goals* that are increasingly demanded by urban populations worldwide (Buhaug and Urdal 2013; Dempsey et al. 2011; Agyeman and Evans 2003; Sharifi and Murayama 2013). In particular, equity issues seem to be at the forefront. Urban planners cannot longer ignore the social differences; on the contrary they have to address them through all possible policy alternatives.

Typically, local governments can influence urban development in three main ways: a) by changing the supply of developable land through land use regulations; b) by creating incentives and disincentives towards certain behaviours though fiscal policies; and c) though the spatial provision of public services and infrastructure (see Chapter 5 for detailed explanation). These planning instruments interact with each other, influence property values and ultimately shape the spatial development of cities. The classic urban economics model as introduced by Alonso, Muth and Mills, referenced to as the AMM model has been widely used to explain urban dynamics, specially related to land take, transport dynamics (alias transport emissions) and local finances (see Section 1.1). This framework indicates that urban sprawl is driven by higher income and lower marginal transport costs, both of which enable a higher amount of land consumption. A restriction of developable land available through land use policies limits land consumption and consequently increases land rents. Transport infrastructure changes marginal transport costs and, by this, also influences urban land take. Everything else being equal, higher expenditures associated with infrastructure investment increases debt levels. Also, a tax on property reduces the value of property compared to the untaxed case and thus, urban sprawl. Together, fiscal policies, land use decisions and transport policies have direct and indirect effects on social equity.

An increasingly growing amount of literature is looking at the so called co-benefits of climate policies in general (Edenhofer et al. 2015), and of transit-oriented development[6] (TOD) in particular (Kamruzzaman et al. 2014; Creutzig, Mühlhoff, and Römer 2012; Creutzig and He 2009). This neighbourhood development concept is a relatively recent term that has been identified by multiple scholars as a *sine qua non* condition to achieve sustainability in cities (Belzer and Autler 2002; Curtis, Renne, and Bertolini 2009; Nahlik and Chester 2014; Newman and Kenworthy 1999; Renne 2008). TOD carries great additional socioeconomic benefits by reducing air and noise pollution, health problems –e.g. respiratory and cardiovascular diseases-, traffic congestion, and oil-dependency, among others (Woodcock et al. 2009; Creutzig, Mühlhoff, and Römer 2012).

In the following subsection I use the case of property taxes to further discuss the sustainability effects of planning and fiscal policies in detail.

3.1 The promise of land value taxes

Taxes on immobile properties have long been recognized as an attractive source of local revenue, demonstrating at least in theory, economic efficiency, sufficiency and simplicity (Brandt 2014; Ingram and Hong 2012a; UN-HABITAT 2011; Bell 2012). They provide an independent source of revenue with political control, fundamental for the well-supported idea of decentralization of government functions (Oates 1972; Peterson 1995; Gramlich 1999; Bird 1993). However, many existing property taxes (PT) are neither well designed nor properly maintained, resulting in serious shortcomings in their contribution to municipal finances[7] (UN-HABITAT 2011; Almy 2013; Walters 2011; Almy 2013; Witte 2009), exacerbations of wealth inequalities (Youngman 2002), and excessive land consumption among other environmental impacts (Brandt 2014; Brueckner 2000; European Environment Agency 2010).

But a specific form of taxation - the location value tax (LVT) - is seen as an option to improve the shortcoming of current property taxation schemes. The LVT is

[6] TOD is associated with the three dimensions of urban sustainability (environmental, economic and social). It aims at decreasing transport distances through diverse land use patterns, moderate to high residential and employment density, frequent and well connected public transport services (PT), and street network design that prioritizes pedestrian and transit users. This results in expanded use of non-motorized transport modes and a shift away from car ridership.

[7] Existing contribution of PT to local revenues has been stable or decreasing in the last decades (European Commission 2014a; Bell 2012), capturing a small share of the ongoing increases in property/land values (UN-HABITAT, 2011).

a tax that recovers the value of properties that has not been created by landowners, the location value (LV). Overall, LVT is seen as a method to increase efficiency, produce sufficient revenues to finance local public goods, raise them in an equitable manner, and shape urban development in ways deemed desirable from an environmental perspective (Bird and Slack 2007, 2003; Brueckner and Kim 2003; Dye and England 2009b; Foldvary 2006; Gurdgiev 2009; Lin 1974; Mathis and Zech 2006; Niou and Tan 1994). The rationale for these arguments is described in the following paragraphs.

3.1.1 Economic arguments

Henry George, a political economist from the 19th century, proposed a tax on LV to finance the entire society's public needs based on the principles of economic efficiency and sufficiency and his conception of justice (George 1879). These arguments have made LVT desired by economists until the present day.

First, a tax on land is efficient, as supply on land is fixed. Taxing away LV does not harm the economy or distorts markets (Choi 2006; Foldvary 2006)[8] in contrast to taxes on labour and capital (Brueckner and Kim 2003; George 1879). Besides, the incentive to use land efficiently and intensively results in higher demand for labour (Library and Stout 1987). Another argument suggests that in times of globalization and fiscal competition, the fact that land ownership is easily identifiable and immobile also provides fiscal reasons for using LV to finance local governments, especially with current technology like GIS (European Environment Agency 2010; Stiglitz 2010; Walters 2011; Bird and Slack 2003; Mirrlees and Institute for Fiscal Studies 2011; UN-HABITAT 2011).

But for Henry George, the equity argument was central: land value is not created by the landowner but is nature's gift, and its value belongs to everyone equally (Fainstein 2012; Roakes 1996; George 1879). This argument has changed since Henry George´s time, but the essence remains: the value of real estate at a specific location is highly driven by public intervention and community actions and other provision of public goods, often financed by the municipality; together these public goods increase location attractiveness, and consequently LV (Albouy 2009, 2012; Brueckner 2000; Arnott and Stiglitz 1979; Mattauch et al. 2013). A LVT would capture that value that has been added by public and community actions but not by the property owner herself. The view that profit from landownership in cities should be recaptured continues to be a mainstay by many economists and urban planners (Lefebvre 1991; Alterman 2012; Fainstein 2012) and draws dedicated followers worldwide (Ingram and Hong 2007, 2012b; Netzer 1998; Bird and Slack 2007; The Economist 2015).

[8] This holds true in particular for assets with a low elasticity of supply, such as land and other natural resources; traditionally this was interpreted as that the tax hardly distort people's behaviour, and does not reduce market output (Hochman 1981; Mattauch et al. 2013; Mirrlees and Institute for Fiscal Studies 2011).

As a consequence of the above, economic theory also suggests that LVT fosters an optimal provision of public goods[9] (Arnott and Stiglitz 1979). While schemes for financing incremental infrastructure necessitated by urban growth based on cost-sharing approaches distorts real estate markets and urban development, a LVT captures the differential value of locations before and after development, internalizes the public costs of providing urbanisation infrastructure, and fosters efficient spatial allocation of incremental infrastructure (Brueckner 1997; Arnott and Stiglitz 1979). Developers are obliged to pay for the additional public infrastructure that needs to be put in place –e.g. water sewage, lighting and public paths-, otherwise paid by the general public (McFarlane 1999; Brueckner 1997; Panella, Zatti, and Carraro 2011).

A counterargument suggests however, that although the supply of land is worldwide inelastic, in practice, the amount of potentially developable land depends on historical and spatial contexts, as well as changes in land use regulation and the creation of new infrastructure *–elasticity of supply developable land-* (Fainstein 2012). Undifferentiated LVT would impose a tax burden for unimproved land, demanding a contribution from those that hardly profit from public improvements. Thus a tax on LV that includes unimproved land subsidies those using the utilities in developed land (Rao 2008).

3.1.2 Environmental considerations

Additional lines of argument have appeared emphasizing the environmental character of LVT (Banzhaf and Lavery 2010; Brandt 2014; Panella, Zatti, and Carraro 2011). According to this view, LVT can also address externalities of urbanization by steering location decision and development into desirable direction, and enhance overall urban sustainability.

The effects on land development have to be considered as compared to the traditional PT. If the tax is levied at equal rates on both LV and capital improvements – a PT-, the tax burden on capital tends to reduce the intensity of land development, which ultimately causes a socially inefficient spatial expansion of the city, hence contributing to urban sprawl (Brueckner and Kim 2003). If, on the other hand, the fiscal instrument imposed on properties excludes additional wedges on improvements, the tax burden on LV incentivizes the development of land to maximize profits per land surface and thus, optimizes the density of development (Batt 2011; Junge and Levinson 2013; Needham and Hong 2007; Roakes 1996). Clearly, the tax design influences behaviour. Furthermore, if the tax liabilities lie below the marginal costs of public investment, development is attractively cheap and fosters excessive development far beyond socially optimal levels (Brueckner and Kim 2003; Brueckner 2001).

[9] In fact, Henry George's "single tax" idea argues that the overall expenditure on public goods equals the differential land value before and after the public intervention; thus, this differential should be taxed out to finance the initial investment (George 1879).

However, this argument has to be assessed in the context of overall land use policy framework, critical in the development of cities in land-scarce contexts (Couch, Leontidou, and Petschel-Held 2007; Romano Grullón 2011). In this regard, theoretical and practical considerations point to the crucial role of land use regulations in fixing the *elasticity of supply* of developable land[10].

3.1.3 Empirical evidence

With regards to revenue potential to finance public investment, empirical studies suggest that LV alone could be a sufficient tax base in some cases, especially when LV changes are related to land use management or public transport investment (Bhatta and Drennan 2003; Canning and Pedroni 2004; Carroll 2008; Franzsen and William 2008; Rybeck 1983, 2004; J. J. Smith and Gihring 2006; Weber, Dev Bhatta, and Merriman 2003; Hui, Ho, and Ho 2004).

The environmental result of moving from a standard PT to a land or split rate tax shows ambiguous effects. The capital to land ratio could rise through an increase in dwelling size — promoting sprawl — and / or through an increase in density or units per acre — promoting compact urban form (Brueckner and Kim 2003). A number of approaches exist to measure these effects: theoretical models, simulation models, regression models, and comparison studies (Anderson 2009; Alterman 2012; Fainstein 2012). Empirical evidence on the role of LVT in promoting compact urban form comes mainly from Pennsylvania (US), where a split-rate tax led to a 5% increase per decade in the number of housing units per hectare, with a minimal increase in unit size (Oates and Schwab 1997; Plassmann and Tideman 2000; Banzhaf and Lavery 2010; Roakes 1996; Junge and Levinson 2013). W. E. Oates and Schwab (1997) found that a move to LVT would not hurt building activity; Plassmann and Tideman (2000) added that LVT may actually increase building activity; Song and Zenou (2006) derived from US-wide panel regressions that urbanized areas with higher property tax consume less total space; and finally Banzhaf and Lavery (2010) found that LVT is a tool for reducing urban sprawl because of a domination of the *density effect* over the *dwelling size effect*. But studies from Australia show controversial results: some have tended to find no effect (Skaburskis 2003), while others report similar results to the Pennsylvanian case (Edwards 1984; Lusht 1992).

In sum, while there seems to be a common consensus on the underlying rationale of a levy on locations for financing public expenses, literature lacks in conclusive outcomes with regards to optimal designs, particularly for fairness and land consumption concerns (Cho et al. 2008; Ingram 2008; Lim 1992; Luca 2011; Maxwell and Vigor 2005; Oates and Schwab 1997; Skaburskis 1995; Song and Zenou 2006; UN-HABITAT 2011).

[10] If a LVT imposes a tax burden on unimproved land as well –e.g. peri-urban land- it may induce its development to maximize economic benefits.

4. Institutional approaches for combining objectives

The alignment of local policy agendas has multidimensional implications, simultaneously affecting different and highly interdependent policy fields from several geographical scales. In addition, value judgments are unavoidable in both policy debates and scientific studies that discuss and evaluate policy alternatives (Kowarsch 2015). Finding best or second best options require new scientific and socio-political paradigms that enable for a transformation of economic, ecologic and social systems towards sustainability (Schellnhuber et al. 2011; National Science Board 2007; Edenhofer, Flachsland, and Knopf 2015). Understanding the interdependency of policy objectives, means, and consequences in the evaluation of policy alternatives require new scientific and governance practices. These must ensure legitimate processes at the science/policy interface that are transparent, balanced and participatory (Edenhofer and Kowarsch 2015).

At the city level, interdependencies become as explicit as they could be, demanding both scientific constituencies that emphasise issues of participation (Portney and Berry 2010), and multilevel governance practices (Bulkeley and Betsill 2005; Rauschmayer, Bauler, and Schäpke 2013) that address different trade-offs and synergies simultaneously. Transformative research -e.g. the research that is actively involved in societal transformation processes – refers to any type of research that shifts or breaks existing scientific paradigms. It explores new ways of thinking, challenging current understandings and provides pathways to new frontiers. It incorporates hybrid methodologies and approaches that can change perspectives of existing fundamental concepts and practices, giving particular emphasis on stakeholder involvement practices (National Science Board 2007; Crockett et al. 2013). Specific to sustainability, transformative research focuses on the dynamics of system change by studying innovation in its various forms –e.g. social, technological, business model, infrastructural and institutional innovation-. It focuses on „real-world problems", it is impact- and solution-oriented, and aims at fostering societal change towards sustainable development (Markard, Raven, and Truffer 2012; Smith, Voß, and Grin 2010; Geels 2010).

These new institutional approaches both at the science-policy and the citizen-policy interfaces are a new niche of sustainability research that requires both theoretical and empirical analysis to identify best practices.

5. Thesis objective and outline

The review of the scientific and political complexity of long-term sustainability in this introduction shows three main points: First, it is necessary to combine different research fields from urban economics to environmental sciences to develop new frameworks of analysis that integrate different policy agendas, particularly in the field of urban planning. Second, adequate planning instruments are crucial in fostering less carbon-intense urban forms, enhancing fiscal stability and ensuring social equity simultaneously. Finally, the complexity and degree of interdependence between different sustainability objectives calls for new institutional structures in science and policy that, on the one hand, facilitate synergies, and on the other hand, explore the solution spectrum without compromising the legitimacy of the process.

Within the next decades, local governments will have to decide on whether and how to devise a local policy portfolio that aligns multiple agendas; paying particular attention to its performance with regards to fiscal stability, social equity and climate change action. The overarching objective of this thesis is to assist decision-makers at the local level in the framing, identification, design and evaluation of a policy portfolio that contributes to the achievement of long-term urban sustainability as it has been defined in this chapter through the enhancement of the planning and fiscal strategies.

In doing so, the articles assembled in this thesis aim at contributing to answer three sets of research questions, each of them being the subject of one of the sections this thesis is composed of:

1. What is the solution portfolio for achieving long-term urban sustainability? What interdependencies exist between different sustainability policy agendas? Which strategies better achieve different objectives simultaneously?

2. How can urban planning and fiscal policies influence long-term urban sustainability? Which local revenue instruments can positively contribute to the stabilization of local budgets, the enhancement of fiscal equity and the reduction of urban land consumption?

3. Which governance structures enhance the success of public interventions in achieving long-term urban sustainability particularly in the context of urban planning? How can the effect of these practices be evaluated? Are these structures also desired to explore the solution portfolio for achieving long-term urban sustainability in science?

The first part of this thesis *"I. Policy portfolio for urban sustainability"* is devoted to the first set of questions. Chapter 2 offers a pioneer framework to look at urban policies that combines climate action objectives with those stated in the Sustainable Development Goals (SDGs)[11]. It focuses on equity considerations particularly. This chapter has been submitted to Environment and Urbanization.[12]

[11] The United Nations (UN) General Assembly has recently adopted the Sustainable Development Goals (SDGs) to mark the path for more sustainable human development. They consist on a set of 17 goals expected to shape political policy worldwide for the next 15 years. The 11th SDG refers to sustainable cities and communities. Make cities inclusive, safe, resilient and sustainable involves investment in public transport, creating green public spaces, and improving urban planning and management in a way that is both participatory and inclusive (United Nations 2015).

Chapter 3 investigates the currently understudied demand-side solution portfolio for long-term sustainability, particularly with regards to climate change mitigation. It further discusses key analytical considerations for the integration of demand-side options into overarching mitigation assessments. Special attention is given to urban areas and how changes in habits, norms and behavioral can offer significant potential for reducing overall energy demand and GHG emissions through changes in urban form. This chapter has been submitted to Annual Review of Environment and Resources.[13]

Chapter 4 and Chapter 5 take the specific urban sustainability challenges of heat risk and domestic water inequality to give exemplary answers on how specific policy strategies could better achieve different objectives at the same time. Chapter 4 reviews the literature on heat stress and its heterogeneous distribution among population. It evaluates public health and urban planning strategies according to their potential in reducing absolute and relative risks simultaneously. Chapter 4 has been published in Current Opinion of Environmental Sustainability.[14] Chapter 5 uses the case of water inequalities in cities to investigate the role of institutions and governance structures in the long-terms sustainability of water resources and water distribution. Chapter 5 has been submitted to Habitat International. [15]

The second part of this thesis *"II Urban planning under sustainability objectives"* addresses the second set of questions by exploring the link between urban planning decisions, fiscal equity and stability and urban land consumption. Chapter 6 uses the Spanish recent urban development to empirically analyse the effects of land use policies and property taxes on land consumption, municipal budgets and wealth accumulation in urban location values. Chapter 6 has been published in Land Use Policy.[16] Chapter 7 follows up the recommendations arising from the previous Chapter on the potential of LVT in enhancing the overall sustainability of local taxation. It merges different streams of literature to identify LVT instrument designs that better perform in this matter. Urban economics address efficiency, sufficiency and equity issues; public finances and value capture literatures focus on ways of self-financing public intervention. In doing so, it develops a framework to assess environmental and socioeconomic outcomes of

[12] Reckien, Diana, Felix Creutzig, Blanca Fernandez, Shuaib Lwasa, Marcela Tovar-Restrepo, Darryn McEvoy, and David Sattherthwaite. 2016. Climate Change, Equity and Sustainable Development Goals: An Urban Perspective.

[13] Creutzig, Felix, Blanc Fernandez, Helmut Haberl, Radhika Khosia, Yacob Mulugetta, and Karen C. Seto. 2016. Beyond technology: demand-side solutions to climate change mitigation.

[14] Fernandez Milan, Blanca, and Felix Creutzig. 2015. Reducing urban heat wave risk in the 21st century. *Current Opinion of Environmental Sustainability* 14, 221-231.

[15] Fernandez Milan, Blanca. 2016. Water security in an urbanized world: An equity perspective.

[16] Fernandez Milan, Blanca, and Felix Creutzig. 2016. "Municipal Policies Accelerated Urban Sprawl and Public Debts in Spain." *Land Use Policy* 54: 103–15.

different design characteristics and further applies it to evaluate European experiences. Chapter 7 has been published in Land Use Policy. [17]

Finally, the third part of this thesis *"III Governance for urban sustainability"* deals with the third question on governance structures in science and policy that better assist in the achievement of long-term sustainability. Chapters 8 to 10 focus on the potentials from stakeholder involvement. While the first two look at this potential in the context of urban planning policies, Chapter 10 focuses on the case of sustainability science. Chapter 8 provides an extensive review of the literature on TOD and social sustainability to explore the additional social benefits from participatory TOD; if they have been acknowledged in the literature and exploited in practice. Chapter 9 uses the case of Medellin -identified in Chapter 8- to empirically evaluate these effects. Chapter 8 has been published in the Journal of Environmental Studies and Sciences[18] and Chapter 9 has been submitted to Cities[19]. Chapter 10 discusses the legitimacy issues arising from stakeholder involvement in sustainability science using the example of the energy transition. Chapter 10 has been accepted in the Energy Research & Social Science Journal[20]. Chapter 11 again uses the energy transition to exemplify how institutional barriers influence the practical alignment of different sustainability objectives. Chapter 11 has been published in Renewable and Sustainable Energy Reviews. [21]

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Part I

Policy portfolio for urban sustainability

Chapter 2

Climate Change, Equity and Sustainable Development Goals: An Urban Perspective[1]

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Climate Change, Equity and Sustainable Development Goals: An Urban Perspective

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Abstract

Climate change is acknowledged as the largest threat to our societies in the coming decades, affecting large and diverse groups of residents in urban areas in this century of urbanization. The focus of climate change impact discussions conceivably shifts to who in cities will be affected how by climate change, bringing the urban equity question to the forefront and co-aligning with a set of key Sustainable Development Goals. Here we assess how climate change events may amplify urban inequity. We find that heat waves, but also flooding, landslides, and even mitigation and adaptation measures affect specific population groups more than others. As underlying sensitivity factors we consistently identify socio-economic status and gender. We synthesize the findings with regard to equity types, meaning outcome, procedural and context-related equity, and suggest solutions for avoiding increased equity and justice concerns as a result of climate change impacts, adaptation and mitigation.

Keywords: Equity, Environmental Justice, Equality, Climate Change, Impacts, Adaptation, Mitigation, Assessment, Gender, Women, Socio-economic, Poverty, Low-income.

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1. Introduction

Cities are melting pots of people with diverse backgrounds, cultures and positions within social and economic networks. In addition to these intra-city diversities cities differ with respect to their political and economic functions, development stages, locations and climates. As climate change becomes an increasingly pressing issue, the question of how these urban diversities interact and cities react to climate change becomes an increasingly important issue demanding systematic investigations (Reckien et al. 2014, Creutzig et al. 2015, Reckien et al. 2015, Shi et al. 2016). Arguably, the most important issue deals with the question of *who* will be impacted by climate change, and *how* to address co-occurring injustices and underlying equity concerns.

WHO: There are two main distributional categories of climate change and cities. First, a number of climate hazards, from heat waves, to flooding, landslides, and droughts impact urban populations differently, depending on a number of economic, social and individual factors. Second, while high-income cities, mostly in the North, have contributed most to climate change, it will be cities in the low-income countries, mostly in the South, that might be impacted most. HOW: Like climate change-related impacts and risks affect urban populations differently, so do measures of mitigation and adaption to climate change. This is especially pronounced in cities where people of different abilities, resources and coping capacities concentrate. Adaptation and mitigation policies may affect vulnerable populations proportionately stronger if not properly designed and therefore manifest inequities and inequalities in cities. However, if properly designed—addressing the concerns of the most vulnerable urban populations—policy measures can alleviate burden and reduce equity concerns of climate change. It is the main goal of this article to review the impact of climate change and related adaptation and mitigation policy measures on equity concerns in cities.

Addressing equity and equality issues has reached overarching global importance, documented not only by the recent advancements of the UNFCCC negotiations towards a post-Kyoto Agreement in Paris, but also by the Sustainable Development Goals (SDGs). Sustainable development is a global focus reasoned by the observation that the substantial progress towards a number of the Millennium Development Goals (MDGs) was not universal, nor the benefits evenly shared (WEDO and REDD+SES 2013, United Nations 2015, Bundesministerium für Arbeit und Soziales 2013). It is also documented that reaching the goal of gender equality was missed (United Nations 2015). Wide gaps remain in women's access to paid work in at least half of all world regions (UN Women's Major Group 2014, UN Women's Major Group 2015). In this paper we argue that equity issues caused by climate change impacts, adaptation and mitigation in cities (Revi et al. 2014, IPCC 2014) closely interact with reaching a number of the SDGs.

It is the interface of climate change and cities with equity and equality that we examine by focusing on the unequal impacts of climate change, adaptation and mitigation on people in poverty and on women. We proceed as follows: We first provide crucial background by disentangling various equity perspectives and introducing climate change and equity concerns in cities (Section II). We then shortly explain the type of research and assessment done (Section III). We then systematically summarize differential impacts of a number of climate hazards on urban populations, as well as the differential outcomes of mitigation and adaptation policies on certain groups, particularly on women and the poor (Section IV). We finally summarize our findings and highlight policy implications for addressing climate change in cities related to the SDGs (Section V).

2. Background

In this section we shortly explain the main types, domains and principles of equity as distinguished in the climate change literature. The main types are used as a framework to return to in the conclusion and summary of the article. We then shortly introduce how aspects of climate change impact, adaptation and mitigation relate to equity concerns.

2.1 Equity types, domains, and principles

Promoting equity is an implicit (and sometimes explicit) goal of many local and regional climate initiatives (McDermott and Schreckenberg 2009), aiming at current and future generations. However, it is often unclear which type of equity concern is being referred to. Commonly three types are identified:

1. Outcome-based/ distributive/ consequential equity, relating to the consequences of a policy, action or developmental trend; e.g. equity in the distribution of costs and benefits or in privileges and burdens; between women and men or between households; between urban districts (including peri-urban districts), or generations of urban residents;

2. Process-oriented/ procedural equity, referring to the impartiality and fairness in the process of delivering and administering the justice, such as access to decision making processes (Metz 2000, McDermott, Mahanty, and Schreckenberg 2011);

3. Contextual equity, linking the first two dimensions by taking into account pre-existing political, economic and social conditions (McDermott and Schreckenberg 2009).

To operationalize equity concerns McDermott, Mahanty, and Schreckenberg (2011) relate the three content-related types to three parameters: the targets (and scale) of equity, the goals of equity, and the process of setting targets and goals. Operationalization is further based on principles and indicators, of which a large number have been proposed (Metz 2000, Klinsky and Dowlatabadi 2009, Cazorla and Toman 2000). The large number of principles converge to a limited set of equity domains (Table 1, based on (Kallbekken, Sælen, and Underdal 2014)).

Table 1: Commonly applied equity domains in international climate change mitigation efforts. Domains are distinguished by causes versus consequences and costs versus benefits.

	Object to be allocated on basis of …	
Focus on	Costs (obligations)	Benefits (rights)
Causes of the problem	I) Moral responsibility ("guilt" in having caused the problem)	III) Previous contributions (to providing the benefits under consideration)
Consequences of the solution	II) Capabilities (capacity to contribute to problem solving)	IV) Need for (or right to) the outcome to be achieved, i.e. goods or services of a policy

Support for equity domains, principles and indicators differ between countries (Shukla 1999, Kallbekken, Sælen, and Underdal 2014) and potentially even more between regions and cities—underlining the need for consideration of procedural and contextual equity. For example, among delegates to the UNFCCC climate change negotiations the 'polluter pays' principle (example of I) had most support in a short- term perspective, i.e. ≤ 20 years. This was followed by 'the exemption of the poorest' (II) and 'ability to pay' (II). An 'egalitarian' principle (equal mitigation pledges) was not supported by many and even more objected to the 'sovereignty' principle, i.e. the full right and power to decide on its mitigation pledges (Kallbekken, Sælen, and Underdal 2014, Lange et al. 2010).

Stressing the need for consideration of process-related equity and inclusion of related stakeholders, for example, even within the UNFCCC gender balance and women's participation on boards and bodies is highly unequal. Women's rights groups have made important contributions to the UNFCCC, including several decisions stating the need of women's participation in UNFCCC thematic areas and their right to decide on mitigation, adaptation, climate change finance, technology and capacity-building. However, so far only resolutions regarding adaptation have included robust gender-sensitive language. Few decisions on mitigation refer to gender, with no guiding mandate for gender-sensitive mitigation actions (see (WEDO 2014)).

2.2 Equity and climate change impacts and risk, adaptation and mitigation

Equity, equality and environmental justice issues first entered the debate on climate change when it was recognized that countries that historically have contributed least to global warming might be impacted the most by climate change in the future (UNDP 2004, Revi et al. 2014). Consequently, initial discussions revolved around mitigation responsibility and pledges. It is now recognized that impacts are also increasing in high-income countries due to, e.g., supply chain interdependencies

(Nabangchang et al. 2015), which broadens the discussions. Metz (2000) stresses that the climate change equity discussions should not only consider mitigation, but also take account of impact and adaptation. This is of particular importance for urban areas, as it is at local and regional scales where differential impacts and adaptation needs will unfold. However, impacts and risks of climate change are reduced by adaptation and mitigation, hence all three dimensions play a role for cities.

Impacts of climate change differ across (Fig. 1) and also within cities. The latter are caused by intrinsic, person-related characteristics determining a person's sensitivity and extrinsic, location-specific conditions determining the exposure to a climate or weather event. Intrinsic and extrinsic characteristics interact, influencing where people live and how sensitive they are to climate change impacts. However, it is not just the most susceptible that are impacted; regularly occurring events can also gradually undermine the resource base of more resilient groups in society, ultimately leading to increases in the scale and depth of urban poverty overall (Tyler and Moench 2012, Tompkins et al. 2013).

High exposure and sensitivity to climate impacts often coincide with low adaptive capacity (Mearns and Norton 2010). In that respect it is important to recognize the current vulnerability of many cities in low- and middle-income nations and their inhabitants and their limited capacity to adapt to a changing climate (Revi et al. 2014). Such differential vulnerability may be attributed to deficiencies with respect to the quality, location and access of and to infrastructure and housing, availability of social services and facilities, opportunities and access to education, effectiveness of planning systems; as well as the lack of resources and low levels of community adaptive capacity (Taylor 2013, Revi et al. 2014, Sen 1999). Adaptive capacity can be eroded over time through repeated coping and 'risk accumulation processes' (Satterthwaite et al. 2007, Rodin 2014), with knock-on effects for chronic poverty (UNISDR 2009).

Mitigation issues are a concern of contemporary urban planning, too, as the contribution of Greenhouse gases emissions (GHGs) of urban areas to the global total is estimated at between 37% and 49% (Seto et al. 2014)— although principally from cities in middle and high-income nations. Some cities have shown farsighted leadership in setting targets and devising and implementing plans to reduce GHG emissions (Reckien et al. 2014) but it is important to evaluate such commitments with respect to the distribution of the benefits and burdens. Curbing GHG emissions should be central for high-income residents; whereas greater, sustained and affordable access to energy and electricity are often of key importance for low-income residents. In order to ensure the resilience of communities in the future, considerations of equity need to be central to all three domains—impacts and risks, adaptation, and mitigation—of the contemporary urban climate change debate.

Box 1: Explanation of important gender concepts

Sex is a biological term and indicates the physical differences between women and men, based on their sexual and reproductive functions. **Gender** refers to the socially constructed differences between women and men. It involves gender identities and attributes, roles and relationships, including power relations. Gender roles vary substantially across different cultures and societies and shape the gender division of labor, the access, use, control and property of assets, goods and opportunities. These can be used as an analytical tool to analyze social processes and be changed over time. Gender roles cause that women spend more hours in the household and the community sphere, performing reproductive and care-work that is not paid or under-paid. For example: women work two-thirds of the world working hours yet they receive only 10% of the world's income. Of the 550 million low-paid workers in the world, 330 million (60%) are women. In Pakistan in 2001, women owned less than 3% of the plots, even though in most cases, legal regulations allowed them to own land (GGCA 2009).

Gender equality means that women and men have equal conditions for realizing their full human rights and the equal valuing by society of both the similarities and differences between women and men, and the varying roles that they play.

Gender equity is the process of being fair to women and men. To ensure fairness, measures must often be available to compensate for historical and social disadvantages that prevent women and men from otherwise operating on a level playing field.

Gender sensitive is to take into consideration socio-cultural norms and discriminations in order to acknowledge the different rights, roles & responsibilities of women and men in the community and the relationships between them. Gender sensitive policy, program, administrative and financial activities, and organizational procedures will: differentiate between the capacities, needs and priorities of women and men; ensure that the views and ideas of both women and men are taken seriously; consider the implications of decisions on the situation of women relative to men; and take actions to address inequalities or imbalance between women and men.

Gender mainstreaming is the process of assessing the implications of any planned action for women and men, in all areas and at all levels, and as a strategy for making women's as well as men's concerns and experiences an integral dimension of the design, implementation, monitoring and evaluation of policies in political, economic and social spheres so that women and men benefit equally and inequality is not perpetuated. The ultimate goal is gender equality. Gender mainstreaming was formally introduced at the Fourth World Conference on Women in Beijing 1995; ECOSOC: 'Resolution 1997/2' and 'Resolution 1998/34'.

3. Methods

This study is a review of the current scientific knowledge on climate change impacts, mitigation and adaptation in urban areas and their relation to equity and environmental justice issues. Data included in the review comprise scientific publications controlled by commercial publishers, such as scientific journal papers, but also a limited number of grey literature, such as reports or working papers. We try to maintain a balance in looking at cities in low-, medium- and high-income countries.

The main part of the review draws from an international assessment exercise on climate change and cities–the Assessment Report for Climate Change in Cities 2 (ARC3.2)–and its chapter 4 „Climate Change Interactions with Equity and Environmental Justice" (Reckien et al. 2015). Here, we extend the mentioned piece of research by focusing and reflecting on the relation of climate change impacts, adaptation and mitigation policies and the equality of gender (see Box 1 for gender-related terms) as well as the distribution of poverty in cities. For the full description of findings including other aspects of climate change and equity in cities see Reckien et al. 2016.

4. Findings

4.1 Equity in urban climate change impacts

4.1.1 Common equity concerns related to CC impacts

Gradual changes in climate and extreme weather events pose risks to urban residents (Adelekan 2010, Fuchs 2010) that are influenced by following factors: 1) physical exposure determined by the location of a community, 2) urban development processes that 'construct risk' (Eiser et al. 2012, McBean 2012), 3) the social, economic and demographic characteristics of urban populations (Barrios, Bertinelli, and Strobl 2006), and 4) a number of institutional, power and governance aspects at play (Bulkeley et al. 2009, UN-Habitat 2008b, a). Most of these factors are closely related, and play out in low, middle and high-income nations as well as in large, medium and small cities (Adelekan 2012, Awuor, Orindi, and Adwera 2008, Fuchs 2010).

There is evidence that impacts of both gradual climate change and extreme weather events disproportionately affect people with low incomes and low social status (Reckien, Wildenberg, and Bachhofer 2013, Reckien 2014, Bartlett et al. 2009), especially women (Bartlett et al. 2009, Hardoy and Pandiella 2009). But regularly occurring events like droughts and floods have also gradually undermined the resource base of better-off groups (Tyler and Moench 2012, Tompkins et al. 2013). Evidence shows that in cities such as Cairo, Alexandria (Hereher 2010), Rio de Janeiro (de Sherbinin and Hogan 2011), and Dhaka (Khan et al. 2011, Fuchs 2010) residents with low social status and low incomes characteristically inhabit areas more exposed to climate risk. The risks of low-income residents are also related to high population densities and poor quality buildings (UNISDR 2009), the lack of risk-reducing infrastructure and services (Revi et al. 2014), and the failure to draw or implement lessons from previous disasters (Singh and Fazel 2010).

Together with governance and management shortfalls, this has resulted in the accumulation of risk over time (Annez, Buckley, and Kalarickal 2010, David and Enarson 2012), documented by records of increasing disaster losses in cities from mega-debris flows, floods, earthquakes, and tsunamis and, in the last two decades, tropical storms (Allen 2006, Rao 2013).

Fig. 1 shows that many large cities across the world are located in middle and low-income nations. The current rate of warming in these regions is moderate, but warming is expected to continue entailing large anticipated risks in the future. Additionally, many of the cities in middle- and low-income nations experience high growth rates, i.e. increasing the risks for even more residents in the future.

Specific equity concerns

Heat-related equity concerns

Heat-related impacts are one of the main hazards associated with climate change in cities. Two dynamics converge: 1) the global increase in average temperature and 2) the urban heat island effect, i.e. the temperature gradient between dense human built environments and rural environments around the city. These dynamics can be beneficial when reducing the mortality and morbidity risks of cold temperatures, but result in heightened morbidity and mortality during periods of excessive heat or heat waves (White-Newsome et al. 2009, Kinney 2012). Heat waves pose a major climate-related risk: more fatalities—as one measure of impact—occur as a result of heat waves than other climate hazards such as floods and hurricanes (Satterthwaite et al. 2007, Klinenberg 2003).

Heat waves in cities can cause increased morbidity and mortality rates (Kinney 2012) as a result of direct heat stress and other indirect effects. Direct heat stress is particularly harmful when night-time temperatures are high, which prevents the human body from resting, repose and regeneration (Amengual et al. 2014). Indirect effects on health arise principally through the interaction of heat and other environmental factors, particularly air and water pollution (Petkova et al. 2013, Petkova, Gasparrini, and Kinney 2014).

Heat-related risk might be expected to impact all citizens equally. However, heat-related risk is stratified across the population and is linked to both ‘intrinsic’ person-specific characteristics and ‘extrinsic’ socio-economic factors. Extrinsic factors refer to social, environmental and location-specific characteristics, such as socio-economic status, living and working conditions.

Intrinsic factors: Intrinsic factors include various physiological attributes, of which age, female sex, and pre-existing medical condition have been identified as main factors (Fernandez Milan and Creutzig 2015, Reckien et al. 2015) in a meta-analysis of 18 recent studies A study probing the age factors suggests that physical fitness is the underlying variable explaining the age effect. Women may be more heat intolerant than men due to potential physiological and thermoregulatory differences (referring to aspects of sex) (Druyan et al. 2012, Racine et al. 2012). However, women may also typically experience more exposure to heat than male residents, due to the time spent in interior spaces undertaking reproductive labors such as cooking in informal settlements, that do not have adequate air flow or air-conditioning (referring to aspects of gender) (Jabeen 2014). In terms of medical status, vulnerability to heat waves is higher in people who are less mobile and confined to bed (e.g., (Vandentorren et al. 2006)). People suffering from cardiovascular diseases are also at relatively higher risk (Tran et al. 2013, Nitschke et al. 2013).

For the extrinsic factors, lower socio-economic status (using a deprivation index based on a series of components, namely education, occupation, unemployment, number of household members, overcrowding and household ownership) and education levels increase relative vulnerability to heat stress. Heat also disproportionately impacts socio-economically disadvantaged households because of their residence in areas with less access to urban green infrastructure and their reduced ability to fund, maintain, and develop private green space. The existence of open spaces and waters are risk-reducing environments, as they cool their immediate surroundings. Unsurprisingly, people living in inner cities are therefore generally more at risk than those living in the suburbs.

Precipitation-related equity concerns

Precipitation-induced hazards may occur as a result of a surplus of rain in short timeframes, such as those connected to inland flooding and landslides, and to a lack of sufficient precipitation potentially causing drought. Inland flooding can occur on a massive scale, e.g. of watersheds—as in Pakistan in 2010 (Atta ur and Khan 2013), Australia in 2011 (Coumou and Rahmstorf 2012), and Thailand in 2011 (Komori et al. 2012)— but localized flash floods can also cause substantial damage and threaten health, lives, and livelihoods as the case in Kampala, Uganda (Sliuzas et al. 2013, Sliuzas, Flacke, and Jetten 2013). In many cities, informal settlements have been developed on flood plains that experience frequent flooding or on steep slopes affected by landslides (Dodman 2013, Carcellar, Co, and Hipolito 2011, Moser and Stein 2011, Hardoy and Pandiella 2009, Douglas et al. 2008, UNISDR 2009, 2011). Insufficient or delayed precipitation also severely impacts mostly low-income populations by way of water shortages, generating crop failures and subsequent food price increases.

Inland flood risk in cities of low- and middle-income countries stems from a number of factors: impermeable surfaces that lead to rapid run-off; the general scarcity of parks and other green spaces to absorb such flows; inadequate drainage systems that are quickly overwhelmed by storm water; and/ or the ill-advised development of housing on marshlands and other natural buffers (Jha, Bloch, and Lamond 2012, Revi et al. 2014). The urban poor are highly affected due to locating in these environmentally riskier areas and lack of risk reducing measures in the neighborhoods. The exposure to flood risks associated with living close to urban rivers and canals is in many instances a consequence of the on-going pressure for land in fast-growing cities and can be attributed to a lack of tenure security for the urban poor. Given the proximity to waterways, the urban poor risk the loss of their homes to flooding and are often displaced leading to disruption of livelihoods and social support networks (Hardoy and Pandiella 2009). Other indirect effects are related to unsanitary conditions and health risk, e.g. when hazardous materials contaminate flood waters and spill into open wells, elevating the risks of water-borne, respiratory, and skin diseases (Ahern et al. 2005, Kovats and Akhtar 2008, Haines et al. 2013). Outbreaks of cholera, dysentery and diarrheal diseases, Acute Respiratory Infections (ARI), dengue, and malaria are all reported to occur largely in cities with dense low-income neighborhoods (Akanda and Hossain 2012, Khan et al. 2011, Kovats and Akhtar 2008) following intense and excessive rainfall. In turn, diseases may increase the amount of care work and number of unpaid hours women have to spend taking care of sick children and elderly. In many occasions women have to quit their paid jobs to cope with these sanitary and health emergencies (GGCA 2009, Dankelman 2010, Tovar-Restrepo 2010).

The poor in Asian cities deserve particular attention, and if simply as a matter of scale: Asia is the most populated continent; and an estimated 28.6% or 506 million people in Asia live in sub-standard housing or slums (2010), which are often found along a city's rivers and canals (Taylor 2013). The percentage of urban residents living in sub-standard housing in Africa is higher (37.5%), but in total this affects smaller numbers (211 million people) (UN-Habitat 2010, p.32).

Excessive rainfall is a crucial risk factor and has been associated with triggering landslides, which have not yet received as much attention as flooding and coastal hazards, perhaps because these are highly localized events. Despite the recording of these events in international disaster databases, attention usually shifts away from extreme rainfall to geophysical causes of landslides as soon as response programs get underway and rescue efforts are called off. As noted by Cepeda et al. (Cepeda et al. 2010, p.2) "landslides are usually not separated from other natural hazard triggers, such as extreme precipitation, earthquakes or floods in the natural disaster databases. This underestimation contributes to reducing the awareness and concern of both authorities and general public about landslide risk". Yet in many countries and cities, landslides (individually and in combination) present significant threats to human well-being. In general, rainfall triggered landslide are the product of a combination of geo-hydrological and locational factors in mostly mountainous cities. Geo-hydrological factors include intensity of precipitation; locational factors include slope, rock strength, rock susceptibility to fracturing, soil moisture, and vegetation cover (Cepeda et al. 2010). However, whether landslide risk affects mostly low-income or other income groups strongly depends on a number of factors, as seen in El Salvador, Nepal and Sri Lanka (NGI 2012). After civil conflct in these countries rapid, uncontrolled migration from rural to urban centres led also well-off residents to move to hazardous (and non-occupied) urban areas, with entailing consequences for landslide impacts.

Men and women may experience migration and displacement in different ways. After periods of excessive rain and damages to house and property evidence suggests that women migrate to urban centers, starting a new life but also facing security risks, lack of skills to access the labor market or lack of linguistic skills related to the dominant language, e.g. in Colombia. After periods of drought men have been documented to leave in the quest to make money in urban or more prosperous areas, while women stay put to look after the property, facing challenges of food security and water scarcity (Tovar-Restrepo and Irazábal 2014).

Storm surge and coastal flooding related equity concerns

Storm-related hazards (hurricanes and storm surges) are associated with precipitation-related hazards and constitute a major risk to urban populations. (Tropical) storms often lead to excessive precipitation in addition to gusty winds. In affected coastal regions storms lead to inundation of low elevation coastal zones with differential impacts. The poor settlements are often impacted severely due to inadequate infrastructure protecting the neighborhoods. The impacts differ also among women and men. As women are present in greater numbers in the urban informal economic sector and home-based businesses, extreme weather may therefore impact their living space and income source at the same time. The loss of small productive assets such as sewing machines may permanently affect their livelihoods (GGCA 2009, Dankelman 2010). Coastal flooding can also be caused by excessive rainfall inlands with subsequent flooding in river deltas downstream due to heightened river levels. In Ganges-Brahmaputra and Zambezi deltas, multiple risks of storm surges and inland river flooding severely affect the cities and settlements within the deltas (Lwasa 2015).

Moreover, global warming induced sea level rise, combined in places with subsidence of coastal land, and increasing storm intensity have combined to put large and growing coastal populations at risk from the rise in sea levels as well as storm surges. Recent examples of coastal flood disasters include the flooding caused by Hurricane Katrina in 2005 in New Orleans, Cyclone Nargis in 2008 in southern Myanmar, Hurricane Sandy in 2012 in New York, and Super Typhoon Haiyan in 2013 in the Philippines (Temmerman et al. 2013). Wave heights reached up to 10 meters during Hurricane Katrina (Fritz et al. 2007) and to almost 4 meters above normal tide levels during Hurricane Sandy (Blake et al. 2013, McGranahan, Balk, and Anderson 2007).

Urban dwellers are highly exposed to the risks of cyclones and storm surges compared to rural villagers because urbanites are more likely to live on or near the coast. Cities and towns account for nearly two of every three residents of coastal areas world-wide (McGranahan et al. 2005, McGranahan, Balk, and Anderson 2007). In Asia, 18% of the population lives in the low elevation coastal zone—the highest percentage across all world regions; 12% of the urban land in Asia is at low elevation and near the coast (McGranahan, Balk, and Anderson 2007). Many of Asia's largest cities are located in coastal areas that are at risk of sea level rise, heavy rainfall (e.g. monsoon-related) or cyclones, leading to storm surge and flooding. Mumbai saw massive floods in 2005, as did Karachi in 2007 (World Bank 2008, Kovats and Akhtar 2008). Flooding and storm surges also threaten coastal African cities, such as Port Harcourt and Lagos in Nigeria (de Sherbinin et al. 2014, Güneralp, Güneralp, and Liu 2015). Similar vulnerabilities affect Mombasa in Kenya (Douglas et al. 2008, Awuor, Orindi, and Adwera 2008) and various cities in Latin America (Hardoy and Pandiella 2009, Revi et al. 2014).

4.2 Equity in urban climate change adaptation

Equity and environmental justice issues related to climate change adaptation include inequalities in the capacity to cope and adapt (Dodman 2013, Hardoy and Pandiella 2009), mainly arising from 1) failure to adapt (no adaptation) or 2) inadequate adaptation or 3) maladaptation to climate change among and within urban centers.

Differentials in the scale and nature of risks *among* settlements relate to the extent of infrastructure (piped water, sanitation, effective drains, all-weather roads and paths) and services provision (including health care and emergency services), as well as housing options available for low income groups (see for example, Krishna, Sriram, and Prakash 2014). The lack of risk-reducing infrastructure is often underpinned by a lack of capacity within urban governments to address the large infrastructure and service deficits (Parry et al. 2009). Figure 1 highlights the wide variation in urban areas' adaptive capacity (Revi et al. 2014), depicted by the proxy 'natioanl income'. In low-income and many middle-income nations, most urban authorities have very small budgets and even less investment capacity (UCLG 2014). At the other end of the spectrum are urban centers with universal provision for risk reducing infrastructure (such as piped treated water and adequate drainage) and services (like enforcement of buildings standards for structural safety) and active climate change adaptation policies, but these cover a very small proportion of the world's urban population. In these cities in high-income countries, development has greatly reduced risk from extreme weather—though, the infrastructure, services, important institutions and financial systems (Satterthwaite 2013) are not provided as a response to climate change and are therefore not 'adaptation' per se. This, however, is not to claim that all inequalities in risk are addressed–as work on environmental justice in high-income nations and their cities has shown (Schlosberg and Collins 2014).

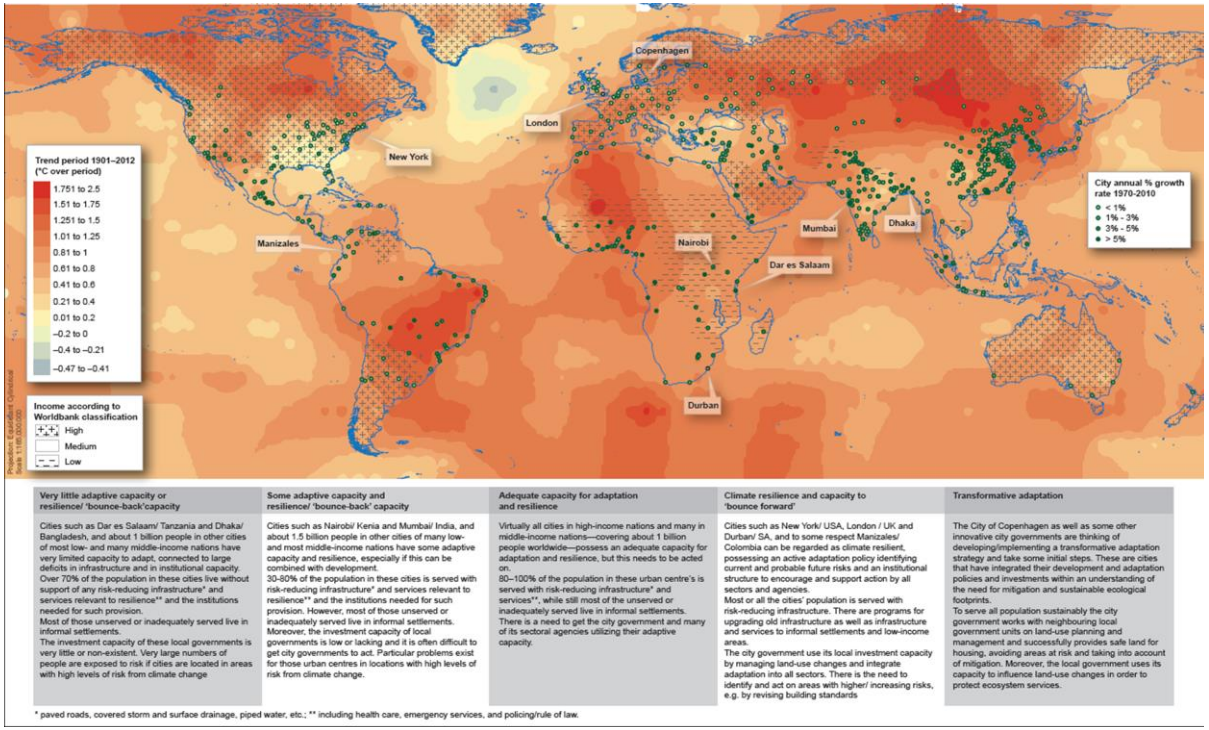

Figure 1: Location and annual growth rates (1970-2010) of large urban agglomerations in low-, medium- and high-income countries against the background of recently observed temperature change. Insets describe the spectrum of adaptive capacity in urban centers across the globe. Many cities with the highest population growth rates are located in low- and middle-income nations with generally low (national) adaptive capacity. This means that an increasing number of people are put at risk of future climate change with generally little structural or formal support to adapt. However, cities with the highest population growth rates are also located in areas of moderate recent temperature increase. Yet, under these conditions city authorities are struggling to provide basic infrastructure and institutional services of support during and after climate change impacts and weather extreme events to their residents. A projected increase in climate change impacts will very likely aggravate the situation. Source: own draft; Data: (Revi et al. 2014)

Within cities in low- and most middle-income countries, differentials in risk also arise from inadequate or no infrastructure and services in certain urban areas, mostly evident and documented in informal settlements (Revi et al. 2014, Dodman and Satterthwaite 2009, UN-Habitat 2013). Risks from extreme weather in many informal settlements are further magnified by their location on dangerous sites—especially in flood plains and alongside rivers, or on steep slopes (Hardoy, Mitlin, and Satterthwaite 2001, Hardoy and Pandiella 2009, Dodman 2013). Housing development on dangerous sites is nurtured by a range of factors, including inappropriate building regulations and land use/ zoning practices that increase the cost and restrict the supply of affordable housing plots (Aylett 2010, Lwasa and Kinuthia-Njenga 2012, Lwasa 2012). Unclear property rights and land tenure also contribute (Bartlett 2011, Busck et al. 2006), as documented in cities like Nairobi, Dar es Salaam, Dhaka, Dakar, Maputo, Manila and Kolkata (Jenkins 2000, Owens 2010, Rao 2013, Roy 2009).

Risk differentials within cities also emerge in relation to age, sex/ gender and health status (Bartlett 2008), which can be socially constructed as in the case of discrimination. For example, with regard to gender discrimination (Dankelman et al. 2008). an analysis of the impacts of floods in Lagos in 2011 revealed the differentials in vulnerability among low-income women created by the intersection of gender relations and gender roles in household structure, occupation, and access to health care (Ajibade, McBean, and Bezner-Kerr 2013). Focusing on process-oriented equity differentials in risk also arise from the lack of voice for particular groups (for instance those living in informal settlements) and the lack of accountability to them by government agencies (Bulkeley, Edwards, and Fuller 2014, Adger 2013). It is thus relevant to consider the extent to which adaptation measures acknowledge these differentials and take action to reduce them.

It is not only the lack of government capacity that underpins lack of attention to climate change adaptation but also deliberate choices by city or national governments (Bulkeley, Edwards, and Fuller 2014), as documented by Thailand's flood crisis in 2011. Mitigating flood damage in the central districts by diverting flood waters to other areas heightened the disproportionate impact on communities outside the defenses (Nabangchang et al. 2015). The refusal to address risks to poor and politically under-represented groups in urban areas is often also related to the low priority that national governments and international agencies have previously given to such equity issues.

Changes in land-use planning and regulatory frameworks are an important part of adaptation to climate change, as are fiscal incentives and infrastructure investments that respond to current and projected future climate risks. Land use planning and management should play critical roles in ensuring there is sufficient land for housing that avoids dangerous sites and in protecting key ecological services and systems.

There is also growing awareness of the need for gender-sensitive adaptation processes and intersectional analyses in order to develop inclusive, contextually-specific interventions and policies (Alston 2013, Sultana 2013, Kaijser and Kronsell 2014). Differentiated gender needs and roles are often missed out in displacement or re-location plans, usually lacking planning for the access to community services and child-care facilities. Another aspect relates to women's non-access to secure land tenure in many low- and medium-income countries. Secure land tenure determines the eligibility for financial credits or subsidies, which is needed to increase the adaptive capacity during post-disaster recovery stages. Moreover, in post-disaster camps and temporary accommodations women often face serious risks of sexual harassment and violence (Tovar-Restrepo and Irazábal 2014, Dankelman et al. 2008).

Those who live in settlements on dangerous sites without risk-reducing infrastructure and services often take measures to reduce risk to their household, homes and assets—especially in informal settlements or urban centers where there is no government interest or adaptive capacity (Revi et al. 2014). Such measures can make an important contribution towards reducing risk, but cannot provide the network infrastructure on which local adaptation measures depend (e.g., water abstraction and waste-water treatment plants, water, sewer, and drainage mains). However, an important lesson of these experiences is that the adaptive capacity, resilience and bounce-back capacity of communities can be sustainably increased by providing appropriate support for community-based initiatives. Support should preferably include economic incentives for residents—thereby framing adaptation measures as economic opportunities for low- and middle-income households. Women should be part of community efforts, since women are key agents of change (Dankelman 2010, GGCA 2009, UNDP 2009, UNISDR 2009).

Adaptation practices should also align with mitigation concerns to prevent maladaptation. For example, the choices made in the management of flood waters in and around Bangkok could be considered as an example of maladaptive practice as it protected the wealthy and placed an increasing burden on the more vulnerable in society (McEvoy et al. 2014). Other maladaptive practices relate to constraining land supplies, forcibly resettling people in areas far from their employment—or evicting people with no compensation—and pushing up land and housing costs. Forced evictions constitute gross violations of human rights as they indirectly and directly violate the full spectrum of civil, cultural, economic, political and social rights—and will not equally reduce vulnerabilities. Maladaptation leads to further impoverishment of vulnerable groups, often in the name of 'development', e.g. expansion of roads and highways and other measures to reduce infrastructure deficits.

4.3 Equity in urban climate change mitigation

We here focus on the sectors most relevant to urban mitigation, including spatial planning, accessibility and transport-related aspects, waste management and renewable energy. So far high-income countries led the urban mitigation agenda having emitted the largest share of urban emission on a per capita basis, and having more often the means to act. Cities in low- and middle-income countries face very different challenges to those in high-income ones; only a few cities include mitigation actions into city plans (Hardoy and Ruete 2013, Roberts 2010, Roberts and O'Donoghue 2013, Roberts et al. 2012, Seto et al. 2014). Spatial planning policies in cities of low- and middle-income countries are often outpaced by rapid population growth and constrained city budgets inadequate to meet the ensuing need for expanded infrastructure and service provision (Bartlett et al. 2009, UCLG 2014, Parry et al. 2009).

In cities of high-income countries, urban mitigation strategies are often based on anti-sprawl policies aiming at changing low-density development, the conservation of open spaces, the enhancement of mixed land use, walkable neighbourhoods, and low-carbon construction standards (Wilson, Hutson, and Mujahid 2008). These measures have been implemented to make public transportation and other services based on economy of scale profitable, thereby securing the services for all income households, and particularly the poor, while also reducing transport-related GHG emissions from transit. However, these principles can have negative side effects for low-income households if not properly designed. Anti-sprawl policies are criticized for pushing up housing prices with subsequent displacement of low-income residents (Addison, Zhang, and Coomes 2013, Burton 2000, Cox 2008, Ewing et al. 2014, Wendell 2011, Bradshaw et al. 2005, Golubchikov and Deda 2012), a process referred to as "environmental gentrification" (Checker 2011, Curran and Hamilton 2012, Jennings, Gaither, and Gragg 2012, Johnson-Gaither 2011, Todes 2012). Densification may curtail access to (well-maintained) public facilities, including transportation, or reduce open and green space. As access to green space often negatively correlates with racial/ ethnic and socio-economic characteristics, a reduction of green space may exacerbate existing inequalities (Burton 2000, Schindler and Caruso 2014, Dempsey, Brown, and Bramley 2012, Newman 1972, Dai 2011, Joassart-Marcelli 2010, Joassart-Marcelli, Wolch, and Salim 2011). There is no consensus on the burden shifts of fiscal anti-sprawl policies (Burton 2000, Sharpe 1982, Smyth 1996), but taxing new developments to cover infrastructure-related costs seem to imply a lower burden for low-income groups than other instruments that mandate which areas can be developed and under which conditions (Bento, Franco, and Kaffine 2011, 2006, Brueckner 1997).

The enhancement of public and private transportation is a frequent mitigation strategy in cities, which typically bring good to all and particularly the low-income households. To optimize the equity outcomes of such investments, special attention should be given to the changes on the affordability of housing and transportation for lower-income groups. Similarly, transit-oriented development (TOD), i.e. the improvement of access to public transportation, has positive socio-economic effects for the residents and communities, as it brings a larger area of land into the employment catchment area (Brand and Dávila 2011, Cerdá et al. 2012), but it can also have negative effects on low-income groups via decreased housing affordability (Deng and Nelson 2010, Deng and Nelson 2011, Zhang and Wang 2013, Smith and Gihring 2006). Low-income groups may be forced to migrate to other locations with limited access to transportation but more affordable housing (Boarnet 2007, World Bank 2012, Deng and Nelson 2011, Munoz-Raskin 2010, Zhang and Wang 2013). Another aspect relates to transportation fares, which usually require high up-front costs to access discounts, e.g. through the purchase of a periodic transit pass. This may oblige low-income households to purchase short-term passes, sometimes up to three times more expensive than longer-term ones (Nuworsoo, Golub, and Deakin 2009, Schweitzer 2011). Increases in the costs of transfers or the removal of unlimited-use passes also affects lower-income riders, women, youth, and minorities, as these groups generally make more trips and transfer more frequently than others (Chen et al. 2013, Nuworsoo, Golub, and Deakin 2009, Levy 2013). Gender-based violence, harassment, and crime in public transport are also sources of concern and should be addressed through gender-sensitive transportation-based mitigation actions—but not by reducing public transportation (Maffii, Malgieri, and Bartolo nY, Levy 2013, Clarke 2012). In cities like Vienna, Berlin and Malmo, transit-planning interventions are designed from a gender-sensitive perspective. General improvements on safety are achieved by participative planning with focus groups, wider pavements, pedestrian-friendly traffic lights, and safe crossings, among others (Maffii, Malgieri, and Bartolo nY).

Private transportation improvement actions show contradictory equity outcomes, mainly due to the range of policy options available (Schweitzer 2011). Registration fees based on emissions rates typically affect low-income drivers more than those based on distance travelled, because they drive vehicles that pollute more per mile than those owned by wealthier groups of the society (Dill, Goldman, and Wachs 1999, Walls and Hanson 1999, Fullerton, Devarajan, and Musgrave 1980, Bento et al. 2005). High Occupancy Toll (HOT) lanes tend to be progressive, especially when alleviating congestion on the unpriced lanes (Altshuler 2013), but they may also pose barriers to affordable mobility, depending on the transit provision (Schweitzer 2011). Area-based schemes tend to perform better in terms of equity effects than speed limit or cordon-based schemes (Bureau and Glachant 2011, Maruyama and Sumalee 2007, Eliasson and Mattsson 2006, Wang 2013, Schweitzer 2011). In middle- and low-income countries, congestion charges are mostly progressive, as car drivers tend to belong to the more affluent half of the population.

In many low- and middle-income countries waste picking constitutes the major re-use and recycling business, thereby helping to avoid substantial GHG emissions (King and Gutberlet 2013). Though being sustainable and inclusive, it may face strong opposition from authorities (Chen et al. 2013, Hayami, Dikshit, and Mishra

2006, Hunt 1996). When improved waste collection becomes a public priority, pickers are often displaced (Ahmad et al. 2006, Betancourt 2010, Medina 2008, Rouse and Ali 2001, Scheinberg and Anschütz 2006, Wilson, Velis, and Cheeseman 2006), regardless of their environmental contribution and the subsequent social impacts (Baud et al. 2001, Huysman 1994, Moreno-Sánchez and Maldonado 2006). However, some progressive cities have devised contractual arrangements for waste-pickers to support waste management services, such as in Kampala, Uganda (Fergutz, Dias, and Mitlin 2011, Kareem and Lwasa 2011, Vergara and Tchobanoglous 2012, Storey et al. 2013).

Finally, regarding broad-scale renewable energy schemes, these may also lead to unequal burden shifts when investments are put to the consumer, because low-income households often contribute a larger fraction of their disposable income to energy and other housing costs, compared to higher-income households (Earl and Wakeley 2009, Perry, Rosewarne, and White 2013). Renewable energy schemes should be implemented with caution of this effect.

5. Conclusions and policy recomendations

In this paper we reviewed the interactions of climate change with equity and equality in urban areas, drawing on the evidence base of how climate change impacts, adaptation and mitigation affect low-income residents and women. We argued that acting on climate change impacts in urban areas by way of poverty- and gender-sensitive adaptation and mitigation actions will be a promising pathway to simultaneously contribute to meeting multiple SDGs.

As we have seen, climate change interacts with differential exposure to risk, preparedness and coping capacities as well as recovery capabilities from climate change impacts. Low-income residents and women are often particularly affected by climate change, but also by adaptation and mitigation policies (Chen et al. 2005, UNIFEM 2008). Studies have impressively shown that poverty and gender are related (Brady and Kall 2008), not only in low- but also in high-income countries as, e.g., documented for affluent democracies since the mid of the last century (Brady and Kall 2008). It has further been shown that reducing the feminization of poverty will not naturally result from reducing overall poverty. Studies therefore suggest that extensive welfare measures, i.e. large social security transfers are needed in order to reduce female poverty (Brady and Kall 2008). In order for climate change impacts, adaptation and mitigation policies not to increase inequalities in urban areas, our study suggests focusing on the impact and needs of the most vulnerable and particularly on women and women living in poverty. Poor women in particular are dis-proportionately affected by climate change impacts, while too few adaptation measures are directly benefitting them and too few mitigation measures respect their concerns.

For adaptation this means foremost to address infrastructure and service insufficiencies in low-income neighborhoods and communities, to build up institutions and governance options including financing to do so. It also means to grant women full access to decision making processes, thereby making them active parts of climate change governance.

For mitigation, spatial planners should be aware of and attempt to lower possible negative side-effects of compact city spatial planning models on low-income neighborhoods and ethnic communities, e.g. by using social policy to cap accommodation prices and rents for households in need. Related to public transport, it seems important to reduce out-of-pocket fees, provide unlimited-use passes for public transportation, and prioritize women's perspectives in public transport schemes. Table 2 and 3 summarize our policy recommendations to foster poverty reduction and gender equality through climate change adaptation and mitigation actions in cities.

Table 2: How climate change in and across cities relates to poverty eradication/reduction. Note: We here refer only to outcome-based equity aspects, process-related and contextual aspect are omitted. LIC - Low-income countries; MIC - Middle-income countries; HIC - High-income countries.

Considering equity concerns for POVERTY ERADICATION	**SOLUTIONS**
Outcome/ distribution-related equity concerns	
Outcome-based equity concerns relate to an increase in climate risks and impacts of climate change in urban areas, as well as adaptation and mitigation measures that are dis-respective of their effects on the urban poor, e.g. via: Heat: mostly affecting elderly and women (LIC, MIC, HIC); Floods: mostly relating to poor and marginalized groups (in LIC & MIC) via high exposure and low coping; Landslides: impacting various income groups (MIC, LIC & MIC) via high exposure & low protection; Storm surge: affecting poor and marginalized group (HIC, LIC & MIC) via high exposure & low protection, but also better-off households in HIC. Within cities low-income neighborhoods and households often occupy high-risk areas at high densities.	**Adaptation:** Target protecting the most vulnerable of urban societies making it the primary goal of adaptation options; Provide sufficient infrastructure and services in all urban neighborhoods and work against the deliberate neglect of authorities to do so (mainly MIC and LIC); Align adaptation with adequate financial and institutional support, particularly in LIC and MIC. **Mitigation:** Prevent a disproportionate impact on the urban poor, e.g. by way of changes of housing affordability, costs and access to transportation; Exonerate or compensate low-income communities, cities or regions (across and within countries).
Process-related equity concerns	
Process-based equity concerns relate to the access, role and power of low-income households in formal and informal decision-making processes. Low-income households may not be familiar with formal decision making and power structures, which may translate into less access and understanding of risks and preparedness information. This may lead to informal structures that are misused, e.g. by slum lords—particularly for newly arrived migrants. Process-based equity concerns across countries and cities relate to the access, role and power of cities with large numbers of low-income residents within their countries (and low-income countries within international governance and policy structures), e.g. the access, role and power of low-income countries and cities within the UNFCCC decision making processes.	**Adaptation and mitigation:** Form supportive institutions and governance structures to cater for the urban poor and newly arrived migrants in cities, including the failure to address the malpractices of "slum lords". Foster accepting and hearing the voice of cities with large numbers of low-income population in national (and international) decision making processes.
Contextual equity concerns	
Contextual equity concerns relate to the locations, densities and problem-constellations of high-risk areas in cities, which may differ across geographies, culture and countries. Across cities, poverty and equity concerns relate to cities that are situated in risk zones, and the differentials in adaptation and mitigation capacity of cities in low- and middle-income countries. Climate change may affect these cities via: Increased average temperatures for continental cities; Increased sea level rise and storm surge for coastal cities; Higher risk levels for cities situated at large rivers (and deltas), Increased damage levels in cities where building regulations and standards are not implemented or enforced.	Support and increase enforcement of building standards (most in MIC and LIC); Adapt buildings standards to new threats, where needed; Exonerate or compensate low-income communities, cities or regions, to be able to meet their adaptation challenges; Support cities in LIC and MIC, in particular.

Table 3: How climate change in and across cities relates to gender equality.

Considering equity concerns for GENDER EQUALITY	SOLUTIONS
Outcome/ distribution-related equity concerns	
Outcome-based equity concerns regarding gender are shaped by direct and indirect impacts of climate change on women and girls, e.g. via: Heat: Heat stress affects women more than men; Floods/ Landslides/ Storm surge lead to reduced or no access to potable water, drainage and sanitation facilities in cities, women: Face loss of income from their home-based activities and often water-based economic activities like cleaning, washing clothes or cooking food products, particularly in informal settlements. Have to spend more hours fetching water from water trucks or tanks. Face malnutrition or low calorie intake especially in older women and young girls because gendered diet hierarchies and the reduction in food supply or increase in food prices. Face the risk of infections as they overwhelmingly take care of children, old and sick family and community members, who tend to suffer diarrheal, respiratory and other health problems. Are more vulnerable to losing their jobs given that they need to devote more time to non-paid care-work.	**Adaptation:** Reduce ex-ante vulnerabilities of women; Ease women's income opportunities and home-based businesses; Value and adequately pay care-work and female income options; Align measures with adequate financial and institutional support for women, particularly in LIC and MIC; **Mitigation:** Address gender-based violence, harassment, and crime through gender-sensitive mitigation actions, e.g. in transportation.
Process-related equity concerns	
Process-based equity concerns within cities relate to differentiated gender roles among women and men. Women who do not speak the dominant language have less access and understanding of risks and preparedness information. Process-based equity concerns across countries and cities relate to the discrimination of women with respect to access to technologies, education, and income opportunities, particularly in LIC and MIC. Also, because women in LIC and MIC have less access to secure land tenure, they lack access to financial credits or subsidies, important in climate change recovery stages.	**Adaptation and mitigation solutions:** Involve women in leadership roles in community processes and local climate change politics, as women are recognized as key agents of change. Increase women participation in (inter-)national political decision-making processes, including the UNFCCC.
Contextual equity concerns	
Contextual equity concerns in cities regarding gender mainly relate to strongly diverging roles of women and men in different cultures, and high-, medium or low-income nations. Women from low- and middle-income countries living in poverty are typically more vulnerable to climate change impacts than men because of the discrimination they face with respect to wealth and capital goods, health, access to technologies, education, services and information, and opportunities to generate financial and productive assets.	Take into account gender roles and women's needs Challenge traditional gender roles and recognize and balance care work between men and women; Value paid income options for women.

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Chapter 3

Beyond technology: demand-side solutions to climate change mitigation[1]

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Beyond technology: demand-side solutions to climate change mitigation

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Abstract

To date, the assessment literature on climate change solutions has emphasized technologies and options based on cost-effectiveness analysis. However, many solutions to climate change mitigation misfit such analytical frameworks. We here examine these less discussed mitigation options. To do, we synthesize demand-side mitigation options in cities, the building, transport, and agricultural sectors and highlights the specific nature of demand-side solutions in the development context. Then we discuss key analytical considerations to integrate demand-side mitigation options into overarching assessments on mitigation. Such a framework would include infrastructure solutions that interact with endogenous preference formation. Both 'hard' infrastructures, such as the built environment, and 'soft' infrastructures, such as habits and norms, shape behavior and, through that, offer significant potential for reducing overall energy demand and GHG emissions. Systemic infrastructural and behavioral change will likely be a necessary component of a transition to a low-carbon society.

Keywords: GHG emissions; Demand-side management; Climate-change mitigation; Urban infrastructure; Agriculture; Lifestyle.

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1. Motivation

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) leaves no doubt that humanity is on track to warm up the planet beyond 4°C by the end of this century (Stocker et al. 2014) and that the impacts of such changes in climate on human populations will be severe, especially for the most vulnerable populations and places (IPCC 2014). At the same time, AR5 shows that through vigorous actions by all nations, temperature increases could still be limited to approximately 2°C above pre-industrial levels (Edenhofer et al. 2014). Limiting climate change to ~2°C can only be achieved by staying within a global carbon budget of about 1000 $GtCO_2e$ through the end of this century. But current emissions rates exceed 50 $GtCO_2e$ per year. At these rates, the carbon budget to remain within the 2°C increase would be used up in only 20 years. Only drawing on the full set of available mitigation options would achieve the 2°C target. On a political level, the agreement achieved at the COP21 in Paris specifies the 2°C target and provides a tentative route for action with mitigation pledges and reviews of those pledges every 5 years.

The report from Working Group III of AR5, focuses on mitigation of climate change, and emphasizes technological options. Its key conclusions are that (i) immediate action would result in mitigation at low costs, while any delay would increase the costs of meeting a 2°C target; (ii) mitigation efforts involve a transition from fossil fuels to renewable energies and/or nuclear power; and (iii) so-called 'negative emissions' achieved either through bioenergy carbon capture and storage (BECCS) or afforestation would increase flexibility in reaching the 2°C target, reduce costs of meeting the target, and are likely to be a necessary component of any trajectory capable of limiting warming to ~2°C if stringent mitigation action is further delayed. Indeed, of the 400 scenarios that limit warming to 2°C, 344 (86%) rely on negative emission technologies, in particular on BECCS, and the remaining 56 scenarios indicate emission peaking around 2010 (Anderson 2015), in contrast to observed trajectories (Le Quéré et al. 2015). However, BECCS and other negative emission technologies remain mostly speculative and would require massive global-scale changes in land use (Creutzig 2014a; Fuss et al. 2014). Hence, even aggressive transformation of the supply side of the energy system could be insufficient to successfully mitigate climate change within the limits given by the international community. This poses the urgent question of how much the demand-side could contribute, and whether demand-side mitigation options could help fill the gap, thereby also reducing or perhaps even avoiding the need for technologies such as BECCS that are highly controversial (Stephens 2015).

Although demand-side solutions are promising, they are not given the same level of attention as technological supply-side solutions in the WGIII Summary for Policymakers, or in the popular media. This is possibly due to the dominance of some epistemic communities in AR5, and the relatively fewer scholars from the humanities and social sciences outside of economics (Corbera et al. 2016)[1] Yet, other reasons of this perceived bias are likely to be more important. First, technological solutions are often more accessible for quantitative investigation and are more straightforward to implement in models, where it often suffices to modify one or a few specific parameter(s), such as efficiency or CO_2-intensity. This focus on specific quantities has been referenced as 'golden numbers' (Socolow 1976). Demand-side solutions, however, are often embedded in a complex network of social institutions and practices (Spaargaren 2011), and thus less prone to quantitative analysis and clear-cut implementation. Second, they also often involve explicit normative positions, or values, making those solutions subject to value-laden discourses (Tribe, Schelling, and Voss 1976). In addition, as demand-side solutions presuppose modified behavior, they are less compatible with the revealed-preference framework prevalent in economics.

To substantiate these claims, we systematically investigate demand-side solutions that either influence direct emissions, e.g. in transportation, buildings, agriculture and cities, or that influence indirect emissions through their influence on consumption patterns. This review fills a surprisingly large gap in the climate-change mitigation literature, which has been dominated by studies of specific end-use sectors. An important exception is Roy et al. (Roy et al. 2012) who assessed the importance of lifestyle changes for energy choices. Here we report insights from AR5 WGIII and other literature to advance the comprehensive assessment of demand-side solutions to climate change. We conclude that demand-side solutions are a crucial component of climate change mitigation, and can slow the rate of or reduce emissions growth. But alone, they cannot halt climate change. Methodologically, we observe that cost-effectiveness analysis, while not always perfectly adequate, could be more systematically applied to investigate demand-side solution. Normative considerations and behavioral choice models, however, point to a more complex overall assessment framework. Altogether, demand-side solutions and lifestyle changes could trigger and co-evolve with systemic changes in law, values and lifestyles, to become a necessary component of a transition to a low-carbon society.

2. Demand-side solutions in end-use sectors

This section investigates demand-side solutions in transportation, buildings, cities and the agriculture/food sector. Several characteristics of urban areas are particularly salient in shaping emissions from the transport and buildings sectors within cities. Key among these is the spatial organization of urban areas, particularly the geometric characteristics established by the relationship between the configuration

[1] Carbon pricing, then, emerges as a main solution in AR5, and is proffered as the instrument most likely to induce technological and behavioral changes. However, while pricing GHG emissions is possibly the single most important policy instrument for climate change mitigation, and is likely to induce behavioral change, it is not the primary reason for the observed self-organized action and climate-friendly behavior by individuals, business and communities (Middlemiss and Parrish 2010).

of roads, buildings, the primary elements of public structure, including green spaces, the distribution and mix of land uses, and the relative location of activities and places of origins and destination. Often referred to as urban form and structure—although these terms are used by different disciplines in slightly different ways—it is well established that urban spatial characteristics such as connectivity, accessibility, land use mix and density strongly affect transport demand and building size. These can also involve direct behavioral action, for example, by advancing a low-carbon lifestyle that incentivizes modal shift from car transport to cycling. Here we review a significant range and potential of solutions, and reason for optimism for effective climate change solutions at local scales.

Throughout this section we emphasize the role of hard and soft infrastructures to foster demand-side solutions. Hard infrastructures refer to the physical built environments, such as walkable environments, public transit, and highways, but also buildings themselves; soft infrastructures and choice architectures comprise norms, habits, and behavioral framings, and also include nudges. We design a focal role to infrastructures because they pre-shape the available action space, and provide the opportunity for behavior that is associated with low greenhouse gas emissions. Or, more technically, infrastructure investments (capital costs) enable the reduction of marginal costs of low-carbon activities. Clearly enough, infrastructure investments become crucial part of the policy instrument set to realize climate mitigation solutions on the demand side.

We start by investigating the urban perspective (2.1), as they provide a bracket for more specific transport (2.2) and building (2.3) solutions. In fact, it will become clear that many demand-side solutions related to hard infrastructures have an explicit spatial dimension. We proceed with investigating solutions in the agriculture and food sector (2.4) and end this section with summarizing demand-side solutions in end-user sectors (2.5).

2.1 Urban Areas and Spatial Planning

WGIII of AR5 established that urban areas could achieve lower emissions if they had certain spatial characteristics: (1) high population and employment densities that are co-located; (2) compact and mixed land uses; (3) high degree of connectivity; and (4) high degree of accessibility (Seto et al. 2014) (Figure 1) .

The literature shows that there is a high degree of correlation between population and employment densities and transport modes. Lower population and employment densities entrench the use of the private motor vehicles. Longer distances between destination and origin make modes of transport such as walking and other forms of non-motorized transport less likely a viable transport option, while public transportation is only possible with minimum levels of either population or employment densities (Brownstone and Golob 2009; Chatman 2003; Creutzig 2014b). The relationship between relative location of residence and location of employment also affects modes of travel (e Silva, Golob, and Goulias 2006; Vega and Reynolds-Feighan 2009).

Urban settlements with fine-grained urban fabric with smaller city blocks, where buildings are close together, building size is small, block dimensions are small, and streets are narrow, promote walking and non-motorized travel. Moreover, a system of smaller city blocks enables pedestrians to change direction easily, a factor which promotes convenience and accessibility. In contrast, coarse-grained cities with large city blocks, where building size is large, block lengths are long, and streets are wide encourage fast-moving vehicular traffic. Another aspect of the built environment that affects the type of travel behavior is the quality of the urban spatial environment. Where urban space is pleasant and safe—characterized by pedestrian-friendly street and building design, vegetation, and a mix of interesting street life, it fosters walking, the use of non-motorized transport and public transport modes (Reid Ewing and Handy 2009).

A recent study found that lack of connectivity is a predictor of urban sprawl and vehicle ownership in the United States. During the 20th century, many communities, especially residential areas, were designed with dead-ends and low street connectivity. Destinations were rarely within reach of walking distance. Combined with the disconnected street design, it created urban environments that required private motorized transport. In recent years, there has been interest many countries are rethinking urban design towards developing “complete” neighborhoods with higher connectivity. Sometimes called, “Traditional Neighborhood Development”, the concept is to reverse the trend of low-density, auto-oriented, single-use developments that lack local character by creating vibrant mixed-use neighborhoods with higher residential and employment densities and complementary land uses (Khattak and Rodriguez 2005).

Another factor that is important for shaping urban, transport and building emissions is the land use mix, or the spatial distribution of economic activity. Strong coordination between land use and public transportation routes is essential for reducing private vehicle use. Intensification of mixed-use development along or around public transport routes and stops brings a number of benefits: it reduces aggregate amounts of movement; it encourages walking; and it improves the viability and efficiency of public transportation.

Urban design, therefore, is of utmost importance in shaping forms of transport, movement choice, as well as building size and use. For example, good urban design can reduce paved areas for parking, make use of shared walls to reduce embodied energy, promote smaller units, etc. Building height is an important dimension of urban form. The operational energy requirement of buildings is a function of climate, design, quality of the building stock, function and location, as well as of orientation, height and user behavior. Semi-detached and three story buildings have been shown to be significantly more efficient in terms of operational energy than single-story freestanding units.

Housing is a durable good and the quality of housing varies tremendously within cities. Thus, two kinds of path dependencies emerge from the spatial structure and history of cities. First, the street and transport network development closely develops together with buildings, inducing a spatial pattern of cities enduring for centuries. Crucially, if residential and employment locations are spatially dislocated, this spatial pattern induces substantial transport, often individual and motorized, and hence GHG emissions, that are difficult to change on short time scales, if at all. Second, buildings have a life-time of decades to centuries, and the turnover rates – often desirable to improve energy efficiency of buildings – are expensive to increase. These path dependencies are both central and pose tough challenges, but they also indicate where low-carbon cities are easiest to build: where they are newly created, especially in Asia, the Middle East, and Africa. A recent study analyzing driving factors of GHG emissions in urban settlements suggest that modifying the emerging urbanization in these continents alone could reduce future urban energy use by 20-25% until 2050 (Creutzig, Baiocchi, et al. 2015). However, as developed countries often also display highly inefficient built environment, there are many specific options to reduce emissions also here, as elaborated in section 3.

There is debate in the literature as to how much urban spatial structure is an outcome of individual choice. There is evidence that urban spatial structure is partly a result of individual choices and preferences. For example, individuals who like density tend to live in denser areas, whereas individuals who value accessibility and land use mix will also sort into those neighborhoods. Because individuals sort in space based on their preferences, many of traditional spatial planning strategies to alter urban form (and hence demand-side behavior) may have limited effectiveness, since individuals can easily counteract these policies through behavioral adjustments. A detailed analysis revealed that the contribution of self-selection to sustainable mobility component of denser urban development is about 50% (Reid Ewing and Cervero 2010). Other suggest that, for the US, self-selection is so strong that restrictive urban planning may improve local sustainability but is nearly fully compensated by sprawled development in other parts of the country (Glaeser and Kahn 2004).

Nonetheless, two arguments point to crucial role of urban planning in spite of the endogeneity of spatial choice. First, only if low-carbon sustainable quarters are built, can they be the choice of residents who prefer such environments. Second, preferences on location and transit mode are not exogenous but endogenous to social norms and upbringing. In other words, it is possible that over generations, more sustainable living will generate a greater demand for even more sustainable living.

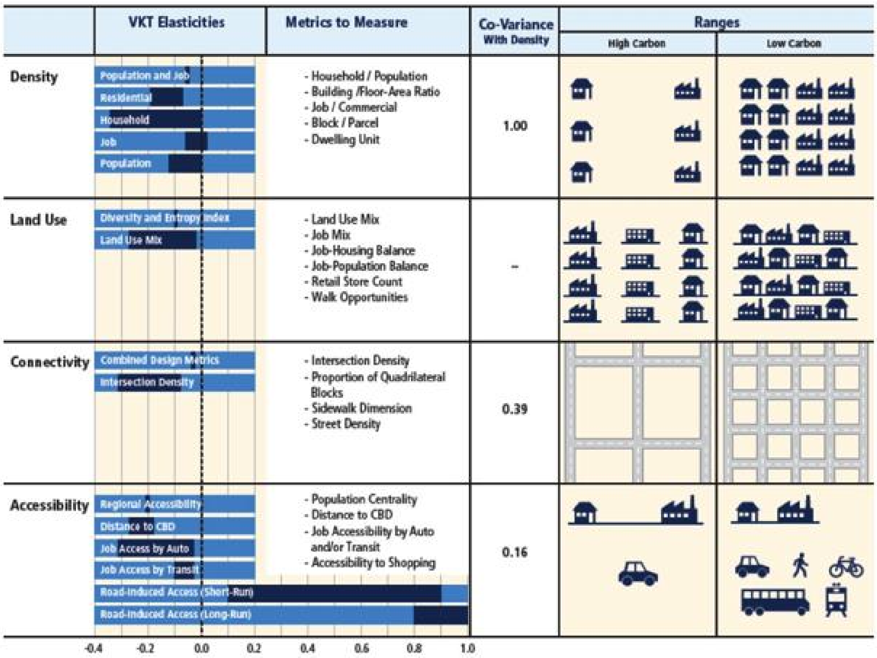

Figure 1. Four characteristics of urban form that affect transport emissions and associated elasticity in distance travelled, relevant measures, co-variance with density, and visualization of the ranges (Seto et al. 2014).

2.2 Transportation

Policy options aimed at reducing the need for transport emissions in general and land transportation in particular typically receive far less attention than do technological measures (Reid Ewing and Cervero 2001), but such demand avoidance options are likely essential to meeting mid-century GHG reduction goals (Grimes-Casey, Keoleian, and Willcox 2009; Hodges and Potter 2010). Demand reduction can on the one hand be induced by physical infrastructures and urban form that enable high accessibility and low-carbon modes (see preceding section). On the other hand, measures that directly incentivize different behavior can additionally reduce emissions.

Urban transportation solutions would add a small but significant component to halving transport emissions from 2010 to 2050, a requirement for ambitious climate mitigation targets (Creutzig, Jochem, et al. 2015). Overall, behavioral and infrastructural measures in cities can potentially reduce GHG emissions of urban passenger transport by 20-50% until 2050 (Creutzig 2015).

Giving sufficient attention to urban planning and alternative transport reduces trip distances and transport emissions. Compactification is seen as a main strategy for reducing emissions. Relatively compact cities (i.e. Hong Kong, Seville, Turin) show per capita LVT levels up to 7 times lower than sprawled cities (i.e. Chicago, Washington, Houston) (“2005 Mobility in Cities Database: Recommendations and Analysis,” n.d.). A meta-study concluded that compact versus sprawled development reduces GHG emissions by 20–40% (the precise magnitude depending on density, diversity, design, destination accessibility, and distance to transit, and the baseline scenario). Hence, compact development in the USA, compared to business-as-usual development, could enable, in total, 7–10% reduction in distance traveled and associated GHG emissions between 2007 and 2050 (R. Ewing et al. 2009). Similarly, a reasonable increase in population density in California would decrease fuel consumption by 5.5% (Brownstone and Golob 2009). For case studies in England a detailed land-use/transport model revealed about 5% reduction in distance traveled for compactification in 30 years compared to trend (Echenique et al. 2012).

‘Optimal’ pricing of motorized urban transport, in order to reduce air pollution and congestion, can reduce demand by up to 30%. Such pricing is often co-aligned with well-managed urban planning, a relatively dense development and a long-term increase in public and non-motorized transport. Current experience with pricing strategies in cities like London, Stockholm, and Singapore reveal reduction in automobile transport by 15-20% (Creutzig, Baiocchi, et al. 2015). For the US case, urban development policies could reduce transport emissions country-wide by an estimated 10% in a smart growth versus business-as-usual scenario (R. Ewing et al. 2009). Both pricing of private motorized transport and provision of alternative mode choice encourage modal shift. Parking prices can reduce distance traveled by 2–12% (Salon et al. 2012), and congestion charging can reduce distance traveled within the charging zone by 10–20% (Eliasson 2008; TFL 2007). In two cases studies of London and New Delhi — focusing on improving public health — a modal shift from car and motorcycle toward active travel (walking and cycling) would reduce GHG emissions by 38% and 47%, respectively, in 2030 (Woodcock et al. 2009). An evaluation of Beijing urban transport demonstrated that an economically optimal combination of congestion charging and investments into bus rapid transit would reduce distance traveled by up to 30% (Creutzig and He 2009). Combining pricing with bicycle infrastructures and public transport investment, and long-term land use planning (which is most relevant where populations are growing) could realize 50% reduction in urban transport GHG emissions from 2010 until 2040 in European cities (Creutzig, Mühlhoff, and Römer 2012). Combining subway line building with land-use planning and pricing instruments would reduce GHG emissions by 36% (versus trend in 20 years) in Bengaluru, India (Lefèvre 2009). For Paris, a mix of urban planning and public transport subsidies (excluding pricing of car transport) results in 36% reduced vehicle km compared to base- line in a model of 2030 (Viguié and Hallegatte 2012).

Behavioral options could be fostered by information campaigns, facilitating social learning, active choice and framing information. A recent review provides a summary of behavioral options with confirmed experimental effectiveness (Mattauch, Ridgway, and Creutzig 2015). The direct costs of many options are negligible. For example, providing free day or monthly public transport trial tickets, in particular to commuters or to households after they moved (Bamberg et al. 2003;

Pedersen, Friman, and Kristensson 2011) or redesigning information labels (Larrick and Soll 2008; Avineri and Waygood 2013) proved to be surprisingly effective in inducing changed travel patterns. Telecommuting is relevant on an individual level. Changes in car distance traveled for telecommuters are large (50 – 75%) but absolute city-wide average effects are unclear; employer-based trip reduction achieve car distance travel reduction of about 4 – 6% among participants, with region-wide effects of about 1%; voluntary travel behavior change programs achieve city-wide car distance travel reduction of up to 5–7% (Salon et al. 2012). In addition to directed information measures, social network and spillover effects can lead to nonlinear uptakes of low-carbon modes such as cycling (Goetzke and Rave 2011). Allover, behavioral measures, including marketing, information provision and tailored new service, may reduce transport demand by about 10% (Salon et al. 2012) (Cairns et al. 2008).

When considering the prospect of rapidly increasing carbon-intensive transportation in many countries with historically low emissions per capita due to i.e. their relatively low vehicle ownership, innovation in a single area such as fuel economy cannot guarantee the targets needed to achieve low-carbon mobility. The large differences in national per capita LDV emissions (range: ∼100–4000 kg CO_2-eq yr^{-1}) are principally explained by LDV use per capita (range: 300–13 000 VKT yr^{-1}), rather than to fleet average fuel efficiency and carbon intensity factors (Sager et al. 2011). Global growth of per capita LDV use to levels from contemporary high-income countries (~10 000 km yr^{-1}) would require vehicle technology options that far exceed optimistic technology scenarios for the year 2050. On the contrary if these levels converges at today´s typical middle-income countries (~3000 km yr^{-1}), 2050 targets could be met with medium-term technologies (Sager et al. 2011).

The tourism sector offers another instructive example of the interaction between technological and behavioral mitigation potential. In case of the 'business-as-usual' scenario CO_2 emissions in the global tourism sector may experience a growth of 160% from 2005 to 2035. If maximum assumed technological efficiencies were achieved for all transport modes, accommodations and activities, this may result in 38% lower emissions. On the demand side, reducing energy use by a combination of transport modal shifts and increasing average length of stay could result in emission reductions by 44%. Using a combination of both above measures, the 'business-as-usual' scenario emissions in 2035 could be reduced by 68%, thus achieving a 16% reduction of emissions with respect to the emissions in 2005 (UNWTO and UNEP 2008).

2.3 Buildings

Buildings represent one of the largest end-use sectors worldwide. In 2010 buildings accounted for 32% of total global final energy use and 19% of energy-related GHG emissions. This energy use and related emissions may double or potentially even triple by mid-century, particularly from substantial new construction in developing countries. Path dependency is a central issue as the long lifespans of buildings generates the risk of long-term carbon lock-in. The building sector is deeply embedded in urban form and spatial planning, both of which determine structural energy demand from buildings independent from technology (see section 2.1). More compact urban form tends to reduce building energy consumption due to lower per capita floor areas, reduced building surface to volume ratio, increased shading, and more opportunities for district heating and cooling systems and, by this, reduces overall GHG emissions (Ürge-Vorsatz et al. 2012).

Technological solutions to realize the energy efficiency potential from buildings are well demonstrated. However, in addition to technologies and architecture, behavior, lifestyle, and culture have a major effect on buildings' energy use; three- to five-fold differences in energy use has been shown for provision of similar building-related energy service levels (Herring 2006; Sanquist et al. 2012; Oikonomou et al. 2009).

This potential is more fully represented in sectorial models than integrated models, as the latter do not represent any or all of the building energy mitigation options and instead focus on the supply-side. More generally, too, the potential benefits from building measures beyond energy cost savings are rarely internalized by policies, especially if they are difficult to quantify and monetize for cost-effectiveness or cost-benefit analysis (Ürge-Vorsatz, Novikova, and Sharmina 2009; GEA 2012). Examples include measures that also provide ecological, social and other services.

Recent literature published after AR5 on the gap between building design and operational energy consumption finds that the consideration of occupant behavior in studies has often been overly simplistic. The discussion of behavior should be guided by the social context of habits, occupant motives and attitudes (Tetlow et al. 2015; Liu et al. 2015; Moezzi and Janda 2014). Measures aimed at habits, such as information disclosure and feedback of energy consumption (particularly through smart meters) can have substantial household energy savings (Simanaviciene et al. 2015; Ramos et al. 2015; D'Oca, Corgnati, and Buso 2014; Nachreiner et al. 2015). In addition, the framing of the problem affects the types policies proposed and there is an increasing need to integrate engineering, economic and behavioral perspectives for effective policy (Lopes, Antunes, and Martins 2015; Janda et al. 2015; Janda and Topouzi 2015).

There are substantial differences in building energy use driven largely by behavior and culture. Factors of 3 to 10 can be found worldwide in residential energy use for similar dwellings with same occupancy and comfort levels (Zhang et al. 2010), and up to 10 times more in office buildings with same climate and same building functions with similar comfort and health levels (Batty, Al-Hinai, and Probert 1991; Zhaojian and Qingpeng 2007; Zhang et al. 2010; Grinshpon 2011;

Xiao 2011). Therefore, buildings and their energy infrastructure need to be designed, built, and used taking into account culture, norms, and occupant behavior.

This is particularly true for developed countries where energy service levels are already high. Short term behavioral change potential is estimated to be at least 20% in the US (Dietz et al. 2009); over long periods of time, more substantial reductions (typically 50%) are possible (Fujino et al. 2008; Eyre et al. 2010). Similar absolute reductions are not possible in developing countries with development needs, though the rate of growth of energy service demands can be reduced (Wei et al. 2007; Sukla, Dhar, and Mahapatra 2008) (see also section 3).

There is a range in the savings achievable in buildings due to behavioral changes, depending on the type of end use. For example, savings from heating loads of 10–30% are possible for changes in thermostat setting. Similarly, cooling savings of 50–67% are recorded with measures such as substituting air conditioning with fans in moderately hot climates with tolerable brief heat exposures. In another example, increasing the thermostat setting from 24°C to 28°C reduces annual cooling energy use by more than a factor of three for a typical office building in Zurich and by more than a factor of two in Rome (Jaboyedoff et al. 2004), and by a factor of two to three if increased from 23°C to 27°C for the night-time in residential Hong Kong (Lin and Deng 2004). Since these settings are influenced by dress codes and cultural expectations towards attires, and major energy savings can be achieved through changes in cultural standards (GEA 2011).

Behavior and lifestyle are crucial drivers of building energy use in more complex ways, too. Electricity use for summer cooling in apartments of the same building with similar households in Beijing ranges from 0.5 to 14.2 kWh/m_2/yr (Zhaojian and Qingpeng 2007). The difference is explained by different operating hours of the split air-conditioner units. Buildings with high-performance centralized air-conditioning can use much more energy than decentralized split units that operate part time and for partial space cooling (Zhaojian and Qingpeng 2007; Murakami et al. 2009).

There are similar findings for other energy end-uses. The savings based on differing clothes drying behavior ranges from 10–100% (e.g., lower end by operation at full load vs. one-third to half load (C. B. Smith 2007). Other examples include hot water savings of 50% (e.g. by shorter showers, switch from bathing to showering); cooking savings of 50% (e.g., by using different cooking practices); lighting savings of 70% (e.g., by turning off not needed lights); refrigerator savings of 30-50% (e.g., by smaller fridge/fridge-freezer volumes and elimination of a second fridge); dishwashers savings of 75% (e.g., by fully loaded operation versus typical part-load operation); and clothes washers energy savings of 60–85% (e.g., with cold compared to hot water washing).

Policies to target such behavior change include progressive appliance standards and building codes, for example, with absolute consumption limits (kWh/person/year) rather than efficiency requirements (kWh/m^2/year) (Harris et al. 2008), and feed-in tariff incentives (Bertoldi et al. 2010; Bertoldi, Rezessy, and Oikonomou 2013).

2.4 Agriculture and other land use

The earth's productive lands provide humans with a large array of resources, including non-substitutable resources such as food, but also raw materials such as wood, fibers for clothing and other purposes, as well as energy (Haberl 2001). Most analysts expect that rising population numbers and affluence will result in increases in the demand for agricultural products of 70-100% until 2050 (FAO 2006). Many climate-change mitigation scenarios, e.g. all scenarios relying heavily on bioenergy with or without carbon capture and storage or options to sequester carbon through afforestation (P. Smith et al. 2014) would require substantial additional land areas. As three quarters of the earth's land (except Antarctica and Greenland) are already used by humans, substantial area demand for climate-change mitigation options is bound to intensify land-use competition, which could potentially result in a host of socioeconomic (loss of livelihoods, negative impacts on food security) and environmental (GHG emissions, degradation of ecosystems, biodiversity loss) issues (Haberl 2015). Changes in future food demand will have strong effects on GHG emissions, both directly, through agricultural GHG emissions from cropping and livestock, and indirectly by influencing the availability of areas for production of biogenic low GHG resources such as some forms of bioenergy, raw materials or timber, respectively for carbon sequestration through afforestation (Pete Smith et al. 2013; Stehfest et al. 2009).

Technical GHG reduction potentials related to behavioral changes (dietary change, waste reduction) for agricultural products strongly exceed the potentials of supply-side related mitigation options even at a carbon price of 100 US\$/tCO_{2eq} (P. Smith et al. 2014), as shown in Figure 2. Comparability between economic potentials (supply side) and technical potentials (demand side) is limited, which is also related to the fact that demand-side options are difficult or impossible to judge in terms of cost-benefit analyses (indicated by different colors). Indeed costs of buying healthier, plant-based food may be even lower than those of diets richer in animal-based products. For example, a study of environmental impacts and food expenditures related to the adoption of healthier diets showed that diets that helped to reduce environmental impacts were related with similar or even lower expenditures for food than those prevailing today (Tukker et al. 2011).

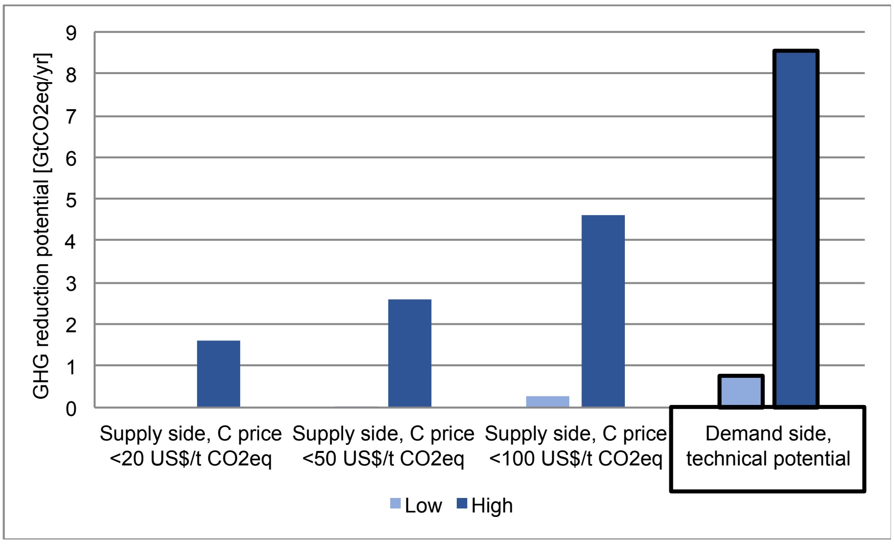

Figure 2: Economic potentials of supply-side options to reduce GHG emissions in agriculture depending on the carbon price for 2030, compared to the technical potential related to demand-side options for 2050 (P. Smith et al. 2014; Pete Smith et al. 2013); the demand-side potential is also described by a low and a high estimate.

Studies based on either Life-Cycle Assessment (LCA) or Integrated Modelling show that changes in diets strongly affect future GHG emissions from food production (Stehfest et al. 2009; Popp, Lotze-Campen, and Bodirsky 2010). Most plant-based food stuffs have substantially lower GHG emissions than animal products (P. Smith et al. 2014) although there are exceptions, e.g. vegetables grown in heated greenhouses or fruits transported by airfreight (89). GHG benefits of plant-based food over animal products also hold when compared per unit of protein (González, Frostell, and Carlsson-Kanyama 2011).

Agricultural non-CO_2 emissions (CH_4 and N_2O) would triple by 2055 to 15.3 Gt CO_2eq/yr if current dietary trends and population growth were to continue (Popp, Lotze-Campen, and Bodirsky 2010). The same study estimated that technical mitigation options on the supply side, such as improved cropland or livestock management, alone could reduce that value to 9.8 Gt CO_2eq/yr, whereas emissions were reduced to 4.3 Gt CO_2eq/yr in a 'decreased livestock product' scenario and to 2.5 Gt CO2eq/yr if both technical mitigation and dietary change were assumed. Along the same line, another study showed that large GHG savings (-36% compared to a business as usual scenario) could be achieved by adopting a healthy diet that includes a meat, fish and egg consumption of 90 g/cap/day (Stehfest et al. 2009).

2.5 Summary of end-user sectors

We reviewed the potential contribution to climate change mitigation from three sectors - building, transport and food - under two main perspectives – hard urban infrastructures and soft behavioral frameworks. We argue that the full potential of demand-side solution becomes visible in these two perspectives.

Overall, urban planning could reduce GHG emissions from urban transport by 5 – 10%, with significantly higher values expected in rapidly growing cities, by 10–30% by pricing measures and infrastructure provision for non-motorized and public transport, and by around 5–7% by information. A combination of these measures might achieve between 20% and 50% reduction in GHG emissions by activity reduction or shifted transport until 2050 relative to baseline growth, though the synergies and trade-offs between these measures deserve further research (section 2.2.) (Creutzig 2015).

The existing variation in per capita transport related energy consumption within high-income cities indicates that there are different infrastructure trajectories with different carbon intensities. Low and middle income countries can avoid locking-in high carbon modes and choose urban developments that enable cheaper future abatement (Sager et al. 2011). But urban infrastructures not only influence transport but also buildings in their GHG emissions (Reid Ewing and Rong 2008). Overall, urbanization choices in developing cities, especially in Asia and Africa, would make a difference of 190EJ in 2050 energy use (Figure 3) (Creutzig, Baiocchi, et al. 2015). Crucially, the cost structure of urban transport choices is a strong determinant of urban form and, hence, both transport and building emissions (Creutzig 2014b).

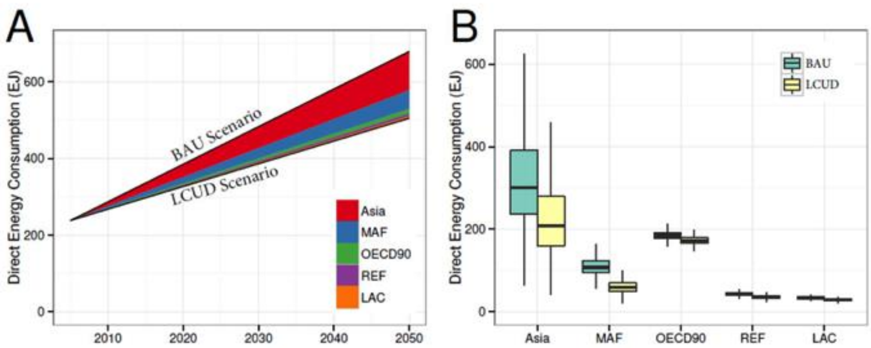

Figure 3: A low-carbon urban development scenario would save about 190EJ in annual energy demand compared to the BAU scenario (Creutzig, Baiocchi, et al. 2015).

Behavioral change provides additional demand-side potential for climate mitigation. Typically, behavioral change options are cost-effective, albeit their costs have not been systematically studied (Mullainathan and Allcott 2010). For building energy use, the behavioral change potential can be typically 50% over long periods of time (section 2.3). In the agricultural sector, diet shift towards more healthy nutrition would reduce mitigation more than what would be possible by technological options alone (section 2.4).

In many cases, behavioral and lifestyle issues are tightly entangled with hard infrastructures. A detailed typology of residential GHG emissions in the UK revealed tight correspondence between the built infrastructure and lifestyles (Baiocchi et al. 2015).

3. Demand-side solutions and development

This section investigates demand-side solutions in the context of development. Clearly, the solution space must apply to both developed as well as developing countries, albeit in a differentiated manner. We discuss how the solution space differs between countries with respect to their development stage, and how demand-side solutions are salient in developing countries where they can achieve multiple development objectives.

3.1 Aligning development and climate change objectives

The growing importance of developing countries is highlighted by the tripling of the emerging economic output since 1990, and its doubling in low-income countries (World Bank 2014). The net effect of the changes on livelihoods and well-being has been remarkable. In just the last decade, the number of poor fell by nearly 500 million in line with increased income and rises in access to basic infrastructure. However, against the background of this growth, a number of outstanding developmental challenges still remain. For a start, the benefits of growth are not equitably distributed between countries and within countries, particularly in fast-growing middle-income countries. There are still over 800 million Asians living on less than \$1.25 a day and 1.7 billion surviving on less than \$2 a day (ADB 2012). The proportion of people living in poverty in Sub-Saharan Africa is even more daunting with about half of the total population living on less than \$1.25 per day. And with about 70% of the population in Africa and 20% in Asia with no access to electricity, the demand for resources is expected to continue, threatening to erode the very ecosystems that sustain economies and livelihoods.

Along with high rates of poverty, other factors such as hunger and malnutrition, lack of access to education and basic services, and exclusion from civil, social and cultural life create structural impediments for transformation to a better quality of life in developing countries (Sen 2001). Moreover, climate change acts as a threat multiplier to these problems, adding to existing stresses and potentially exacerbating social tensions. Conventional models of development have usually focused on increased economic growth and mobilizing new technologies without considering the local and global environmental consequences and social (and distributional) costs associated with the growth pathways (Deaton 2013). However, in the context of a changing climate and carbon constrained global order, bold efforts are now needed to rethink the utility of conventional models in addressing pressing development goals – particularly for emerging economies.

The “co-benefits” framework is widely cited as a way forward to enable a sustainable energy transition and also meet climate goals (Stechow et al. 2015). Co-benefits offer developing countries with an approach to promote their prioritized development objectives such as energy for growth, energy security and access and healthy local environments, while also yielding benefits for addressing climate change effectively (Navroz et al. 2013). The increasing policy attention to linkages between sustainable development and climate considerations – expressed as co-benefits of multiple objectives – is also backed by a growing research base (Khosla et al. 2015). According to a recent World Bank report entitled “Decarbonizing Development” (Fay et al. 2015), a country’s low-carbon pathway and its achievement of socioeconomic development and prosperity can be strongly aligned. That is, the mission to move away from carbon-intensive production and consumption patterns need not supersede the efforts to reduce poverty and meet basic needs.

Developing countries are well positioned to reap the potential ‘win-win’ opportunities that can prevent carbon lock in and simultaneously stimulate development since much of their infrastructure in is yet to be built (Mulugetta and Urban 2010; Bowen and Fankhauser 2011). While supply-side options play a significant role in assembling the arsenal of options required for the pursuit of such a low carbon transition, demand-side options are potentially as crucial. We explore the salience of these developing country choices and their challenges across different demand side sectors in the next section.

3.2 Demand side options in development

An important objective for developing countries is to achieve their development goals, often in conjunction with climate related interventions. These goals can be articulated in the form of the newly agreed Sustainable Development Goals, or through nationally determined priorities. In this section, we discuss the role of demand side opportunities in helping developing countries meet their multiple development objectives, which include climate co-benefits. Hard infrastructure opportunities are described, followed by those in the form of soft infrastructures.

New construction in developing country regions represents one of the most significant opportunities (and risks) from a mitigation perspective. As real estate infrastructure is one of the longest-lived components of the economy, the sector is particularly prone to lock-in. Recent research finds that by 2050 the lock-in risk in South-East Asia (including India) is over 200% of 2005 final heating and cooling energy use (Ürge-Vorsatz et al. 2012). Countries and regions undergoing early stages of urbanization may therefore have a unique potential to reduce future emissions, particularly in cases where income levels, infrastructure, and motorization trends are rapidly changing (Kumar 2004; Chen, Jia, and Lau 2008; Perkins et al. 2009; Reilly, O’Mara, and Seto 2009; Zegras 2010; Hou and Li 2011; Adeyinka 2013). Energy efficiency and demand response measures also help reduce costs due to lowered overall demand with benefits in terms of balance of payments from avoided fossil fuel imports, improved levels of energy services and lower GHG emissions (Welsch et al. 2013).

The growth of building energy use, especially in developing countries, can be moderated through the provision of high levels of building services at much lower energy inputs, by incorporating elements of traditional lifestyles and architecture. One approach is to use vernacular designs to provide comfortable conditions; successful examples are found in Vietnam (Nguyen et al. 2011) and India (Dili, Naseer, and Zacharia Varghese 2010). Another is to allow natural ventilation, with the use of 'part-time' and 'part-space' indoor climate conditioning, using mechanical systems only for the remaining needs when passive approaches cannot meet comfort demands. Such pathways can enable energy use levels below 30 kWh/m^2/yr as a world average (TUBESRC 2009; Murakami et al. 2009), as opposed to the 30–50 kWh/m^2/yr when utilizing fully automatized full thermal conditioning (Murakami et al. 2009; Yoshino et al. 2013).

Developing countries also present opportunities for integrated infrastructure and energy planning to be most effective at shaping development and emissions trajectories. For instance, an estimated 3 billion people worldwide rely on highly polluting and unhealthy traditional solid fuels for household cooking and heating (Pachauri et al. 2012; IEA 2012) and shifting their energy sources to electricity and clean fuels could strongly influence building-related emissions reductions (Ahmad, Baiocchi, and Creutzig 2015).

Finally, as economies shift from agriculture to industry to service, there is increased demand for, and emissions from, motorized two-wheelers and expansion of bus and rail public transport systems (Cuenot, Fulton, and Staub 2010; Figueroa, Fulton, and Tiwari 2013). A major shift towards the use of mass public transport guided by sustainable transport principles, including the maintenance of adequate services and safe infrastructure for non-motorized transport, presents great mitigation potential (Bongardt, Breithaupt, and Creutzig 2010; Bongardt et al. 2013). For example, Bogota and Addis Ababa have demonstrated that city transformations mainly happen when transport challenges are addressed. And that local pollution problems and GHG emissions can be reduced as the benefit of traveling by public transport outweighs the cost of using private vehicles or local taxis. Analogously, in Delhi improved cycle lane infrastructure e led to greater uptake of cycling (Tiwari and Jain 2012). Supporting non-motorized travel thus often supports development more effectively, more equitably, and with fewer adverse side-effects to the environment and human health than if providing for motorized travel (Woodcock et al. 2009).

Along with the benefits of hard infrastructure mitigation options in developing countries, quantitative modelling of the impact of future lifestyle change on energy demand shows that the rate of growth of energy use can be reduced by lower consumption lifestyles in developing countries (as opposed to absolute reductions in energy use in developed countries) (Wei et al. 2007; Sukla, Dhar, and Mahapatra 2008).

For instance, agriculture and land-use account for a large proportion of the emissions from developing countries (P. Smith et al. 2014) and it is predicted that growing urban populations will demand more resource intensive foods such as meat, reflecting the strong relationship between higher income and consumption of livestock products (Satterthwaite, McGranahan, and Tacoli 2010). The link between increasing prosperity in developing countries and resource intensity also extends beyond food to other high-status goods and services, which require land, water and energy for their production. However, given that developing countries are in the early phases of the transition when animal and other product consumption per capita is very low, they can avail of a huge opportunity in choosing alternate consumption patterns that bring benefits to personal health and reduce GHG emissions (Strzepek and Boehlert 2010).

While developing countries have a unique set of opportunities that can bring both development and climate benefits, they are also often marked by poor governance and low institutional capacity which is an obstacle to building resilient urban, agricultural and land use management systems. Such obstacles can often stall the pace of policy uptake which is especially important because ongoing development efforts that do not consider co-benefits may lock in suboptimal technologies and infrastructure and result in high future costs (123).

Technical capacities to implement mitigation options and institutional frameworks and regulations are often limited in developing countries because they are motivated by short-term priorities, lack of resources and skills (124–128). An example is when sparing forest land competes with other development needs such as increasing land for agriculture or promoting mining (Forneri et al. 2006) or when large-scale bioenergy compromises food security (Nonhebel 2005). Or, as in the case of Indonesia, institutional shortcomings such as limited experience with urban planning and management, budgeting and accounting, and finance have thwarted the decentralization of infrastructure programs from the central to local governments over the past decade (Cervero 2013). Although lack of coordination among local land management and infrastructure agencies is also a common problem in industrialized countries (Kennedy et al. 2005), in developing cities institutional fragmentation undermines the ability to coordinate urban services within and across sectors (Dimitriou 2011), which often translates into uni-sectoral actions and missed opportunities, for example, the failure to site new housing projects near public transport stations. Limited capacities also result in little attention left to strategically plan. Water utilities in southeast Asian cities, for example, are so preoccupied with fixing leaks, removing illegal connections, and meeting water purity standards that there is little time to strategically plan ahead for expanding trunk-line capacities in line with urban population growth projections and other measurable objectives (Cervero 2013). This lack of local institutional capacity among developing cities highlights the urban institutional climate conundrum that rapidly urbanizing cities — cities with the greatest potential to reduce future GHG emissions — are the cities where the current lack of institutional capacity will most obstruct mitigation efforts (UN-HABITAT 2013).

Sustainability in developing countries as a pathway towards a healthy and fulfilling way of life offers a compelling alternative to the course Northern countries travelled, which has given rise to conspicuous consumption lifestyles. However, reversing this trend implies changing habits and social norms that underpin unsustainable lifestyles and practices. Behaviour change and lifestyle choices can influence the nature and evolution of infrastructures, which are still evolving in the emerging economies and/or yet to be built in the least developed countries. But bringing about changes in behavior through norms is also harder in a context with low institutional and technical capacity. This focus on social norms and habits is distinct from those of technological-economic assessment, and thus necessitates a closer look into the framework for assessing demand-side solutions, the topic of the next section.

4. Beyond technology: Framework for assessing demand-side solutions

We proceed in investigating analytical framework for assessing demand-side solutions. Center stage are lifestyle changes that are commonly much more explicit on the demand side than on the supply side. Hence lifestyle issues require a particular focus when assessing this solution space motivating a short summary of the important role of lifestyle changes (section 4.1), drawing on section 2. But lifestyle changes have overarching and important implications that change the way how such a solution space can be assessed. It requires an explicit reference to values and normative positions taken (section 4.2). It also often expands the tight boundaries of analytical analysis, requiring a delicate approach in quantitative assessments (section 4.3).

4.1 Lifestyle changes

Demand-side solutions involve end-users and, hence, often involve lifestyle and behavioral change. For example, individuals might switch from personal motorized transport to a flexible mode choice model, involving cycling and public transport for daily trips, and free-floating car-sharing for other purposes. It might also involve substituting a trip to remote islands by a trip to a local national park. In apartments, savings could accrue from adjusting the thermostat. And a diet shift would considerably reduce land demand, thereby helping to reduce GHG emissions. Altogether these options can significantly reduce emissions compared to baseline, and, we argue, are essential part of any realistic effort to achieve the highly ambitious 2°C target. Even more, many of these options can be achieved at low costs, or even reduce costs of consumers. Nonetheless, most options are not or only insignificantly implemented. This points to culturally-shaped preferences, the existence of strong default choices, but also to significant difficulties in modifying behavior. Humans act and decide within societal structures according to well-established practices that are difficult to change because they are stabilized through routines, incentives and institutions. Changes in practices are constrained by spatio-temporal and technological fixes (Harvey 1986; Jessop 2004), in which cultural patterns, social inequality and power relations are inscribed. These structures stimulate or underpin certain practices and discourage or prevent others. Political and economic institutions are key to explain the stabilization or transformation of practices (Ostrom 2009).

However, lifestyle changes have so far only received scarce attention in IPCC reports. The reason is two-fold. First, lifestyle changes are highly normatively charged, with some reacting strongly against the very notion of lifestyle changes, and others welcoming lifestyle changes as something desirable. In other words, the very notion of lifestyle changes opens the door for contentious value debates. Second, as costs are rarely the issue with lifestyle changes, it becomes a difficult to consistently evaluate and prioritize different options for lifestyle changes in terms of one consistent measure such as US\$/kgCO_2-eq. In a certain sense, cost-effectiveness studies of behavioral options and social norms are possible, as demonstrated for energy conversation by communicating the relative ranking in electricity bills (Allcott 2011; Mullainathan and Allcott 2010). More of these studies are required. Yet the overall welfare effects remain often elusive, as demand-side changes often have a normative touch, and also impact the supply side in general equilibrium frameworks. Lifestyle changes hence touch on the questions of the boundaries of analytical frameworks and the usefulness of quantitative analysis. We discuss both of these two points in turn.

4.2 Explicit normative frameworks

Technology-focused solutions assume that revealed preferences on issues like energy consumption are normatively applicable and will continue to exist in a manner similar to the current situation. In contrast, demand-side solutions to some degree assume a shift in preferences, underpinned by policies that encourage adoption of preferences compatible with broader welfare goals. This is apparently in contradiction with a naïve revealed-preference approach within economics. But this contradiction can partially be reconciled.

A revealed preference approach assumes that actors have fixed exogenous preferences, that they hold correct beliefs about their environments, and that they make decision by computing the maximal utility they can obtain. However, empiric literature in behavioral economics has demonstrated that this approach holds only under narrow conditions and cannot applied to conditions in complex social and environmental settings. Crucially, preferences have been shown to be endogenous to learning and the built environment, beliefs are often determined by cultural settings and more specific effects, like the availability bias, and decision making is subject to habitual effects and the social context (Bowles 1998; Kahneman 2003; Tversky and

Kahneman 1974). In other words, choices are socially, culturally, and environmentally contextualized. This is summarized in Figure 4, based on (Mattauch, Ridgway, and Creutzig 2015).

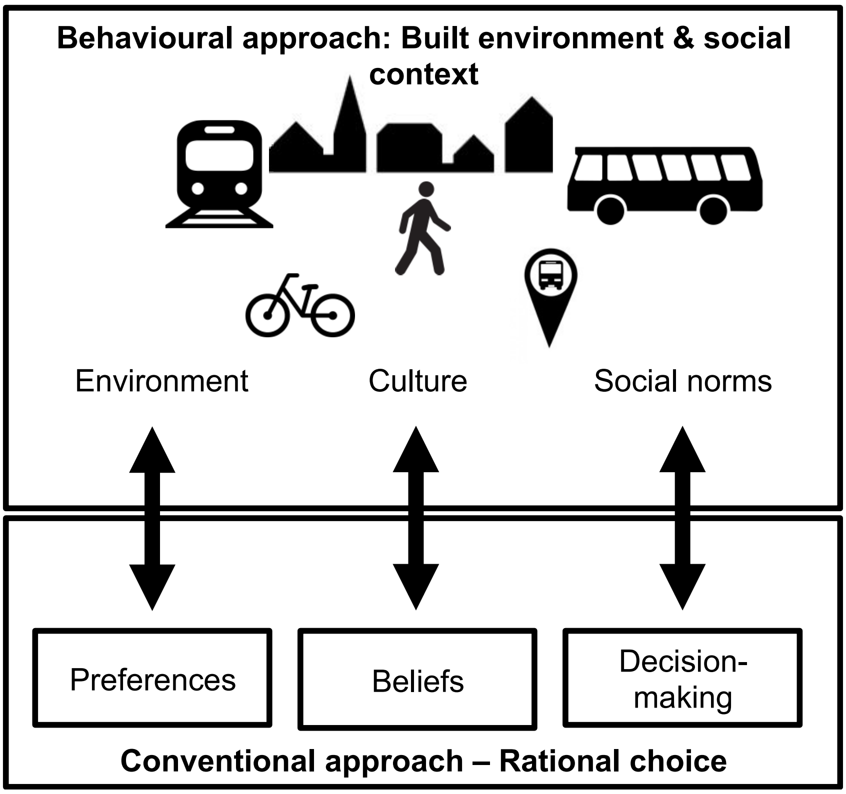

Figure 4. Comparing a behavioral and rational choice approach. Assessing mitigation solutions from a behavioral perspective implies taking a rich contextual perspective. Adapted from (Mattauch, Ridgway, and Creutzig 2015).

The challenge with this broad contextualization is that the liberal approach of maximizing what people want, or what they state they want, gets into conflict with a perspective that aims to maximize subjective well-being. One example: some may prefer to drive their car in car-oriented built environments, but would have higher health if using their bike in bike-oriented built environments. Under this circumstances the question of lifestyle changes, at least in some instances, becomes subjected to the specific normative position held. The consequences of a liberal perspective and a subjective well-being perspective for policies for mobility choices are summarized in Table 1.

Table 1. Normative positions and their influence on shaping policy decisions on transport-related choice situations. Reproduced from (Mattauch, Ridgway, and Creutzig 2015).

	Subjective well-being	Liberalism
Environmental Awareness	Rewards for individual altruistic behaviour	No particular rewards
Mode choice	Incentives for NMT, change in social norms and cues against biases	Degree of incentivizing NMT depends on type of liberalism
Safety	Disincentives for risky behaviour	No disincentives for risky behaviour (unless: others at risk or preferences about risk inconsistent)
Commuting	Disincentives	No disincentives
Car purchases	Vehicle tax according to car type	A 'status tax' (according to type of liberalism)
Infrastructure	Prioritization: NMT and short commuting distances	Not directly applicable, alternative: elicit preferences in simplest context

The lesson is that those taking a subjective well-being perspective, or those emphasizing public health, are more likely to embrace lifestyle changes than liberals. Liberals would typically aim to satisfy revealed preferences; this can be strongly defended, e.g., by specifying an equivalent-income approach that incorporates not-monetary dimension of well-being, such as health (Fleurbaey 2009). In contrast, a subjective well-being approach would further extend the picture by also investigating how infrastructure and social norms influence behavior. A subjective well-being approach would then consider, for example, to change the built environment such that welfare is improved. More generally, the most important policy space would relate to opportunity structures, - or infrastructures – that incentivize behavior that reduces energy demand. For assessments, however, it is practically and methodologically very difficult to evaluate such a change in welfare. That is what we discuss in the next section.

4.3 Quantification and the boundaries of analysis

Any comprehensive analysis is plagued by substantial evaluation uncertainties. Commonly, discount rates are contested, and distributional effects play a major role in sensitivity studies. But the question of the boundaries of analysis remains too often undiscussed (Socolow 1976). A cost-benefit analysis always needs to specify the boundary of its framework. Technology-focused solution can often work in a quantitative framework, specifying, for example, the amount of energy needed in any given year, under certain assumptions, underlying economic growth and demographic change, and the portfolio of evolving technological options and their cost profiles. Importantly, the underlying models implicitly assume constant preferences that are fulfilled by economic parameters. Demand-side solutions, in contrast, need often a more contextual specification in that it directly interacts with lifestyle questions. As discussed above, demand-side solutions often translate into changing the opportunity space by offering different infrastructures, and ultimately by dynamically interacting with the formation of endogenous preferences. Clearly, then, a comprehensive assessment of demand-side solutions requires a different boundary of analysis then. But the analytical framework for a changing infrastructure environment is hardly developed, and poses hard challenges especially when it comes to taking explicit normative position (see 4.2). In other words, existing analytical frameworks and their common boundaries pose a considerable barrier towards the exploration of demand-side solution spaces.

5. Conclusion: Ambitious climate change mitigation requires demand side solutions

This review synthesizes demand-side options for climate change mitigation. Two classes of demand-side options emerge. One the one hand hard infrastructures, epitomized by the urban built infrastructure, provide a physical setting for shaping preferences, practices and opportunity spaces. On the other hand, changing norms, practices and nudges modify the opportunity space and can induce direct behavioral change. Reshaping urban form and the urban environment provides ample opportunity to make car travel obsolete and save high amounts of energy in buildings. Both mobility and buildings also offer significant opportunities for reduced energy demand by providing information about different use and trigger new routine behaviors. In agriculture, demand-side action, in particular diet-shift, could reduce emissions compared to trend by more than 70% in 2055, and by this surpassing the potential of technological options.

Development provides both challenges and opportunities for demand-side solution. In many cases, demand-solutions will mitigate energy demand growth rather than reducing absolute energy use or GHG emissions. Demand solutions can be challenging to implement if capacities if administrative or institutional capacity is low. However, emerging economies offer also very high low-cost potential when building new infrastructures and cities, enshrining low-emission sustainable energy use patterns from the beginning.

The review also investigates the specific nature of assessing demand-side solutions. To date, demand-side solutions have been less systematically assessed than the technological supply-side solution space, especially as part of comprehensive cost-effectiveness analysis. However, in many cases, cost-effectiveness analysis is possible. The challenge is indeed one of the boundaries of analysis. When investigating supply-side solutions, a rational-choice model with given preferences can be safely assumed. Demand-side solutions instead often require the assumption that preferences are endogenously modified, for example by different infrastructure settings – as has been empirically substantiated. However, assessment then requires explicit normative assumptions and a different, contextually richer framework of analysis, which has not yet been firmly established.

Ambitious mitigation targets require making use of the complete option space. Only low-carbon energy technologies can reduce GHG emissions to zero. But demand-side solution would facilitate the task of technological solutions enormously, as highlighted in the AR5. The next IPCC assessment report should, in our view, assess demand-side solutions systematically. More systematic evaluation of demand-side mitigation options, both in cost-effectiveness frameworks and in broader frames of behavioral economics and explicit normative perspectives, are required to achieve this goal.

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Chapter 4

Reducing urban heat wave risk in the 21st century[1]

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Reducing urban heat wave risk in the 21st century

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Abstract

Global warming increases the frequency, intensity and duration of heat waves, particularly endangering urban populations. However, the health risks of heat waves are distributed unequally between people because of intrinsic person-specific characteristics and extrinsic factors. The confluence of forecasted urbanisation and projected heat wave increase necessitates the identification of strategies that both lower the overall health impact and narrow the gap in risk distribution within urban populations. Here, we review the literature on vulnerability to heat, highlighting the factors that affect such distribution. As a key lesson we find that the literature strands on public health, risk reduction and urban planning all contribute to the identification of alleviation options for urban heat wave health impacts, but that they are rarely jointly evaluated. On the basis of the literature review, we suggest a common framework. We also evaluate response measures in addressing total and distributed risks. We find that person- specific risk is effectively addressed by public health and risk reduction intervention, while intra-urban variations of extrinsic factors can be efficiently tackled with urban planning, both in scale and scope.

Keywords: urban heat island, health riks, equity, heath exposure.

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1. Introduction

Projected changes in heat waves and ongoing urbanisation provide the setting for a dramatic increase in heat-related morbidity and mortality in urban settings. Recent forecasts suggest that a robust, several-fold increase in the frequency, intensity and duration of observed global heat waves and warm spells will occur irrespective of the emission scenario (Perkins, Alexander, and Nairn 2012; Coumou and Robinson 2013; Dong et al. 2015). At the same time, more than two thirds of the population will live in cities by the 2050´s (UN 2014). Heat-related risk develops into one of the main climate-change related hazards in cities (Karen C Seto and Shepherd 2009). Two dynamics converge: the global increase in average temperature and the urban heat island (UHI), i.e. the temperature gradient between higher density human built environments and the non-built-up environment around the city (Karen C Seto and Shepherd 2009). Hence, the added heat stress in cities will be even higher than the sum of the background urban heat island effect and the heat wave effect (Li and Bou-Zeid 2013). A population faces particular risk situations during urban heat waves (UHW), which are elongated periods of excessive heat when urban temperature crosses a certain threshold, or peak events when urban temperature crosses a relative threshold (e.g. two standard deviations of yearly average urban temperature) (Harlan et al. 2006; Reid et al. 2009; Tian et al. 2013). Evidence points towards increasing health risks, especially in cities where the UHI intensifies extreme heat events (Dong et al. 2015; Luber and McGeehin 2008; Smargiassi et al. 2009), which will require economic and social resources, particularly in the areas most directly affected. It is therefore urgent that researchers and practitioners take appropriate measures in responding to this threat (IPCC 2014; Dong et al. 2015). Total health risks will increase with both increased vulnerability and the expected increase in hazard severity. These risks will develop differently for different world regions. Looking at future trends in urban population and number of heat waves, while the risk for North America, Europe and, to some extent, South America will increase due to changes in the hazard itself (number of heat wave days), Asia and Africa also show a significant increase in vulnerable population (urban population growth). On the other hand, individual susceptibility will increase vulnerability, especially in developed countries due to factors such as ageing population and cardiovascular diseases (UN 2012; Dong et al. 2015; UN 2014; Kovats and Hajat 2008) (Fig. 1).

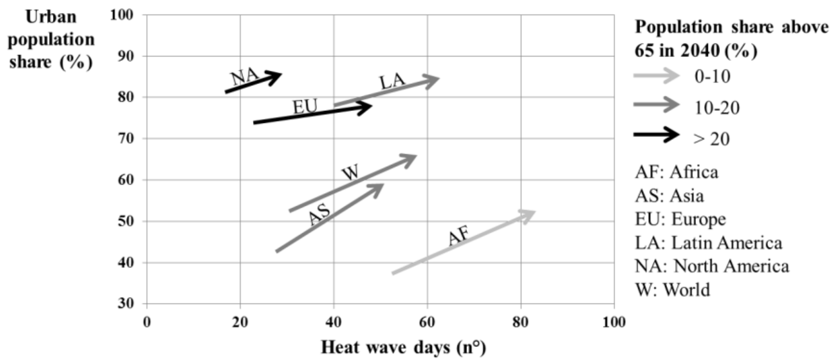

Figure 1 Future heat risk is likely to increase because of increases in hazard severity, urban population and ageing population. The figure is based on the following data: urban population rates, population share above 65 and number of annual heat wave days for the main five world regions in 2010 and 2040. The starting point of the arrow is based on 2010 values and the end on those projected for 2040. The colour coding of the arrow represents the population share above 65 in 2040. Data sources: UN (2014), UN (2012) and Dong et al. (2015).

These differences in risks are even more apparent within cities between distinct parts of urban populations. Specifically, an increasing number of studies show an unequal distribution of risks due to intrinsic person-specific characteristics and extrinsic factors within and across urban populations (Harlan and Ruddell 2011; Gronlund 2014; Uejio et al. 2011). Hence, response measures need to adjust to this stratification. Yet the range of responses to urban heat risk fail to systematically conceptualise approaches in a way that integrates knowledge across disciplines (Solecki, Leichenko, and O'Brien 2011; Jabareen 2013; Kovats and Hajat 2008; Kovats and Kristie 2006). Given the forecasts on urban population and heat waves, we need frameworks and tools that can compare and integrate findings across research fields (Harlan and Ruddell 2011; O'Neill et al. 2009; K.C. Seto et al. 2014). This paper merges the different strands of literature on combating urban heat risk. In order to do so, after presenting the methodology we review different literatures on the issue and suggest a framework for assessing implementation strategies, both individually and jointly. The paper concludes with a discussion of potential improvements to addressing forecasted risk factors.

2. Methodology

The objective of this paper is to critically review and compare current theoretical and practical approaches to heat-related risk reduction in cities. On this basis we attempt to answer the following research questions:

a. Which factors contribute to health impact and the existing differences in risk distribution from extreme heat events in cities (Section 3)?

b. Which interventions effectively reduce the different risk factors (Section 4)?

In order to address these questions we review the literature on urban heat risk, concentrating on peer-reviewed papers that have been published over the last five to ten years. We uncover health studies and research on disaster risk reduction, climate change, adaptability and resilience at the city level as well as reviews of current responses to heat, including public health and urban planning perspectives.

In the following paragraphs we introduce concepts from public policy and health literature and combine them with the body of literature on urban resilience in order to develop a framework for the evaluation of interventions. We will use this framework in section 4 to discuss the contributions and limitations of current intervention approaches and potential improvements for those to come.

Risk can be addressed at multiple levels: by avoiding and reducing exposure to hazards, lessening susceptibility and improving preparedness through response and recovery mechanisms (Wamsler, Brink, and Rivera 2013; Solecki, Leichenko, and O'Brien 2011; Jabareen 2013; Romero Lankao and Qin 2011). Each factor may be addressed either by different intervention strategies or a sum of them. In the literature on public policy analysis, and particularly that of public health intervention, effectiveness, efficiency and equity are commonly used evaluation criteria[3] (Tones and Tilford 2001; Andrews and Entwistle 2010; Davis et al. 2013; Haynes 1999). We adapt the definitions from the literature and include insights from urban resilience, adaptation and climate change risk reduction research (Solecki, Leichenko, and O'Brien 2011; Jabareen 2013; Wamsler, Brink, and Rivera 2013; Romero Lankao and Qin 2011) and specify the following criteria:

a. Effectiveness assesses the capability of the intervention to produce the desired effect under real life circumstances (does it work in practice?) (Haynes 1999). In the case of interventions aiming to reduce urban health impact from heat, this would be a measure of heat-related mortality and morbidity reduction taking into account the urban context. Public health studies often refer to the slope of the temperature-mortality/morbidity response (Kovats and Hajat 2008; Andrews and Entwistle 2010) (Fig. 2.a).

b. Efficiency refers to the ratio of output to the input; it measures the effect of an intervention in relation to the resources it consumes (is it worth it?) (Haynes 1999). Applied to our case, it is the lessened effect of urban heat on health in relation to the intervention costs. In climate change science, this is calculated by looking at the effects on government revenue and expenditure, paying particular attention to externalities: how much revenue and expenditure the government generates overall by implementing this policy (K.C. Seto et al. 2014; Harlan and

[3] In health care interventions the concept efficacy is also used. Efficacy refers to the extent to which an intervention does more good than harm under ideal circumstances (Haynes 1999). Given the urban complexities, we believe this term does not apply to the evaluation of health risk reduction in cities.

Ruddell 2011). Based on concepts from urban agglomeration economics (Fujita, Krugman, and Venables 2001; Simone Singh 2014), we include the following considerations, which are fundamental for future risk mitigation: forecasts on urban population size, the development of levels of susceptibility and hazard characteristics (frequency, intensity and duration). With regards to the first one, efficiency refers to the marginal intervention costs of an additional person that has to be covered in the intervention (economies of scale). Efficiency in addressing changes in susceptibility and hazard level is given by the marginal costs of including an additional level (greater scope). Susceptibility changes can be due to factors such as ageing population and cardiovascular diseases. Hazard severity may be given by changes in the frequency, intensity or duration (economies of scope). Fig. 2.b illustrates the different dimensions of efficiency that should be considered in the design of optimal public interventions for decreasing urban heat risk.

c. Equity: the extent to which the benefits of a policy and the costs are spread among those affected in such a way that no group or individual receives less than a minimum benefit level or more than a maximum cost level (Phelan et al. 2004; Tones and Tilford 2001; Kjellstrom, Mercado, et al. 2007). Typically, policymakers measure how fairly a service is distributed among various targeted groups by considering how much of a needed service the individuals in each recipient group receive. Because the needs and abilities of individuals and groups will differ, one could evaluate equity in two ways. Commutative justice is the equal provision of a good or service to each group or individual. Distributive justice considers that a fair amount should be provided according to the level of need (Childress 2013) (Fig. 2.c).

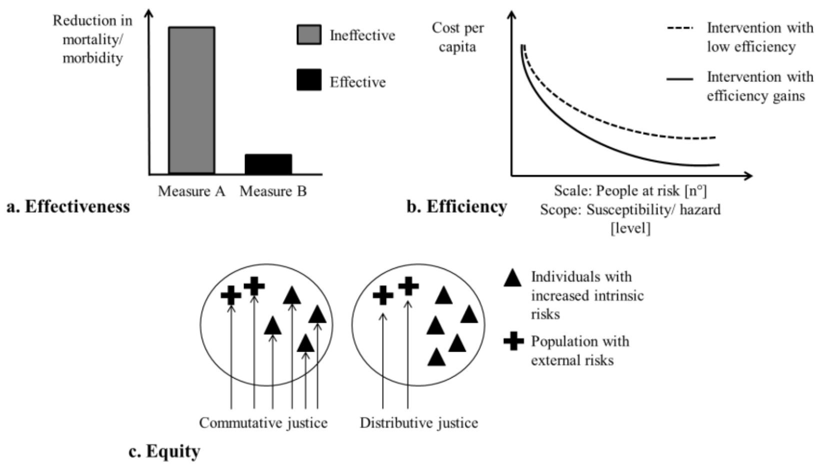

Figure 2 Evaluation criteria for urban heat risk reduction

3. UHW: Health risk factors

Risk from urban heat waves differs with so-called intrinsic and extrinsic factors. Intrinsic factors refer broadly to the physical condition of individuals (typically named susceptibility factors or sensitivity in public health literature), whereas extrinsic factors point to stratified levels of risk across socio-economic and spatial urban settings. We briefly review the literature on both sets of factors to clarify their importance.

3.1 Intrinsic factors

Among the susceptibility explanatory variables of risk unequal distribution, age is at the forefront (Baccini et al. 2008; Son et al. 2012; Sung et al. 2013; Yang et al. 2013; Zeng et al. 2014; Madrigano et al. 2013; Reid et al. 2009). Several studies suggest women are more heat sensitive than men due to gender-related physiological and thermoregulatory differences (Son et al. 2012; Yang et al. 2013; Druyan et al. 2012), but literature shows inconsistencies in this regard (Zanobetti et al. 2013; Robine, Michel, and Herrmann 2012). Alternatively, much of the excess mortality and morbidity is related to previous medical status. People with lower mobility and confinement to bed (Y. Zhang, Nitschke, and Bi 2013; Vandentorren et al. 2006), people suffering from cardiovascular diseases (Bouchama et al. 2007; Tian et al. 2013; Tran et al. 2013; Vandentorren et al. 2006; Klein Rosenthal, Kinney, and Metzger 2014; Hajat, O'Connor, and Kosatsky 2010) and those with pre-existing psychiatric and pulmonary illnesses and renal problems show higher susceptibility (Bouchama et al. 2007; Price, Perron, and King 2013; Zeng et al. 2014; Y. Zhang, Nitschke, and Bi 2013). Pregnant women may observe shorter lengths of pregnancy (Auger et al. 2014; Carolan-Olah and Frankowska 2014). Personality traits and behavioural characteristics may also influence susceptibility; those most commonly mentioned are isolation, high risk perception and low behaviour adjustment (Y. Zhang, Nitschke, and Bi 2013; Vandentorren et al. 2006; Baccini et al. 2008; Liu et al. 2013; Tran et al. 2013). Finally, drug consumption has also been said to influence physiological responses to heat (Sommet et al. 2012).

3.2 Extrinsic factors

Additional uneven distribution of risk among populations in suburban population groups can be explained through the interaction of social, economic, environmental and political characteristics. These characteristics influence heat exposure directly or individual susceptibility indirectly (Wamsler, Brink, and Rivera 2013; Gronlund 2014; Uejio et al. 2011; Reid et al. 2009).

On a macro scale, regional climates and geography modify heat wave hazards among cities in terms of intensity, frequency and duration (Baccini et al. 2008; Michelozzi et al. 2005; Bobb et al. 2014). At the city and neighbourhood levels, socio-economic factors of risk include deprivation, economic or income levels and isolated minorities, particularly in inner cities (Depietri, Welle, and Renaud 2013; Hattis, Ogneva-Himmelberger, and Ratick 2012; Y. Zhang, Nitschke, and Bi 2013; Klein Rosenthal, Kinney, and Metzger 2014; Kovats and Hajat 2008; Uejio et al. 2011; Madrigano et al. 2013; Bobb et al. 2014). Education level also influences risk; it is a sign of technological strength and an individual's resilience due to higher awareness and better knowledge of hazard prevention (Johnson, Wilson, and Luber 2009; Reid et al. 2009). Different working and living conditions change the risk too (Tran et al. 2013; Xu et al. 2013; Fleischer et al. 2013; Gubernot, Anderson, and Hunting 2014). Living under the roof or on the upper floor and in old structures was a risk factor during the 2003 heatwave in France and during the warm seasons of 1999-2000 in Barcelona (Spain) (Vandentorren et al. 2006; Xu et al. 2013).

The awareness of the role of environmental factors (also known as urban climate) and their interaction with the urban fabric in explaining different levels of risk within cities is explored by an increasing body of research on urban structures and their link to public health. The landscape of the urban periphery shapes the decreases in temperature as the airflow enters the leeward rural area (Hu et al. 2012; Smargiassi et al. 2009), and ecosystem conservation contributes to this effect (Depietri, Welle, and Renaud 2013). At the neighbourhood level, physical factors and processes (radiation, elevation, wind and land use) interact with urban structures (housing orientation, construction materials, ventilation and other heat protection measures) (Wolf and McGregor 2013; Stone 2012; Coseo and Larsen 2014; Harlan and Ruddell 2011) and create differences in surface temperatures of up to 10 °C between districts (Klok et al. 2012). Transport networks, industrial activities and corridors, air quality (Breitner et al. 2014; Harlan et al. 2013; Laaidi et al. 2012), built-up densities and sealed surfaces (Tomlinson et al. 2011) are some examples of the urban fabric that shape heat hazard severity (Aubrecht and Özceylan 2013; Depietri, Welle, and Renaud 2013; Fischer and Schär 2010; Gabriel and Endlicher 2011; Giannaros and Melas 2012; Merbitz et al. 2012; Reid et al. 2009; Wolf and McGregor 2013; Klein Rosenthal, Kinney, and Metzger 2014). Open spaces, tree canopy and water bodies have been shown to reduce risk in the areas surrounding them to a certain extent (Xu et al. 2013; Dugord et al. 2014), depending on the morphology of urban structures nearby (Armson, Stringer, and Ennos 2012; Feyisa, Dons, and Meilby 2014; Coseo and Larsen 2014). At a lower spatial level, street design and building materials also change risk levels through the radiation exchange between buildings, the air circulation and the anthropogenic heat released (Stone 2012; Coseo and Larsen 2014; Mills et al. 2010). All this taken together, the urban fabric represents a great influence firstly on the nature of UHW and urban heat risks (Smargiassi et al. 2009; Coseo and Larsen 2014; Memon, Leung, and Chunho 2008) and secondly on the performance of interventions (Wamsler, Brink, and Rivera 2013).

Finally, urban governance may also change risks and risk distribution among populations; this refers to how response and recovery mechanisms in place interact with all the previously described factors (Romero-Lankao and Dodman 2011; Wamsler, Brink, and Rivera 2013; Balbus and Malina 2009). For example, people living in cities with infrequent extremely hot weather are more at risk because of deficient response and recovery mechanisms (Anderson and Bell 2009; Baccini et al. 2008; Henderson, Wan, and Kosatsky 2013; Kovats and Kristie 2006; Medina-Ramón and Schwartz 2007; Reid et al. 2009). The burden of risk also increases for populations living in tropical cities of middle and low-income countries due to water scarcity issues (Vörösmarty et al. 2005; IPCC 2014).

4. Evaluation of responses to heatwaves

Research on strategies for coping with urban heat waves has grown considerably in the last decade, but interdisciplinary differences limit the overall understanding of how cities can respond to this ever increasing climate hazard. Health literature explores how and why particular populations are more at risk than others – intrinsic factors; climate change, risk reduction and urban planning research addresses extrinsic factors (Solecki, Leichenko, and O'Brien 2011; Pascal et al. 2012; Kinney et al. 2008; O'Neill et al. 2009). Disciplines have succeeded in evaluating the effectiveness of the isolated measures to a certain extent, but the gap between approaches hinders the discussion on the overall performance, which includes on the one hand scale efficiencies and on the other equity considerations (Romero Lankao and Qin 2011; Kovats and Hajat 2008; Kinney et al. 2008; O'Neill et al. 2009). Dichotomies between adaptation and mitigation literatures, and between health care and urban planning intervention approaches, hamper the emergence of inclusive approaches (Biesbroek, Swart, and van der Knaap 2009; Laukkonen et al. 2009; Romero-Lankao and Dodman 2011; Jabareen 2013; Hajat, O'Connor, and Kosatsky 2010; Sandink 2013; Soebarto and Bennetts 2014). We here highlight the main intervention approaches in the public health and urban planning literature, discuss how each of them can address some risk factors, and conclude that both approaches should be jointly planned to maximize synergies for public health outcomes. We focus on how they address distributive and commutative justice, meaning whether they prioritise their interventions in favour of individuals with increased intrinsic risks, or they cover the general population and their external risks.

4.1 Public Health interventions are effective and address intrinsic risk factors

Public health interventions have been proven effective. The collaboration between meteorological agencies and the public health sector has become practice worldwide, developing in the so-called Heat Health Warning Systems (HHWS) (Pascal et al. 2012). Australian and North American cities were the pioneers (Hajat et al. 2010; Price, Perron, and King 2013). Since the heat wave of 2003 the systems have spread all over Europe (Hajat et al. 2010; Kovats and Kristie 2006; K. Zhang et al. 2012). HHWS include interventions aimed at providing cool environments, enhancing public awareness through education plans and risk communication, and measures to produce behavioural change (Luber and McGeehin 2008). They focus on intrinsic factors (i.e. the elderly and medical statuses), which makes them highly efficient in reducing susceptibilities at the individual level (Daanen and Herweijer 2014; Ebi et al. 2004).

Although the population is continually adapting to heat (Bobb et al. 2014), the efficiency of HHWS has not yet been proven for future scenarios, where increasing heat-wave frequency, severity and duration is coupled with a rapidly growing at-risk population (Daanen and Herweijer 2014; Kenney, Craighead, and Alexander 2014; Koppe et al. 2009; Krau 2013; Patidar et al. 2014; Wu et al. 2014; Hajat, O'Connor, and Kosatsky 2010; IPCC and Ebi 2012; Bobb et al. 2014). These measures generally disregard the heterogeneous distribution of extrinsic factors such as hazard and exposure levels within urban populations (Sampson et al. 2013; Sandink 2013; Uejio et al. 2011; Smargiassi et al. 2009). For example, with regards to advice on heat avoidance, a typical measure is the use of air conditioning (Department of Health 2013; Koppe et al. 2009; Kovats and Kristie 2006; Barnett 2007; Sheridan, Kalkstein, and Kalkstein 2008). Air conditioning is extremely effective in reducing risks among vulnerable people facing continuous specific individual risks – enabling so-called distributive justice (Barnett 2007). However, its overall performance is questionable in the long term (Sheridan, Kalkstein, and Kalkstein 2008). First, disruptions to electricity supply during heat waves may hinder its effective performance (Sailor 2014). Second, the measure uses narrow perspective on equity. On the one hand, not only does it not include risk avoidance or reduction considerations, measures like air ventilation also further contributes to UHI, thus affecting those not addressed through the intervention (Tremeac et al. 2012; Memon, Leung, and Chunho 2008; Reid et al. 2009; Gronlund 2014; Bobb et al. 2014). On the other hand, access to air conditioning is highly stratified depending on poverty levels and racial and ethnic compositions (Klein Rosenthal, Kinney, and Metzger 2014; Sheridan 2007). Even if accessible, resorting to an air conditioner may not be the most preferred strategy for low-income groups due to the costs involved (Soebarto and Bennetts 2014; Sheridan 2007). Similarly hydration advice may not reach those most at risk; water availability and affordability does not distribute equally among population (Ruijs, Zimmermann, and van den Berg 2008). This is particularly true in regions where heat waves are accompanied by drought periods and water is scarce, thus being drought-sensitive (Vautard et al. 2013; Gershunov et al. 2013; Vörösmarty et al. 2005; Kjellstrom, Friel, et al. 2007; IPCC 2014).

Generally, public health interventions address those with higher intrinsic risks under a distributive justice perspective (i.e. prioritising the assistance of individuals at higher risk), but lack adequate measures to also intervene with commutative justice considerations (Romero Lankao and Qin 2011; Kovats and Hajat 2008). In addition, preventable causes of death show substantially larger socioeconomic inequalities because socioeconomic resources become more relevant for minimising risks (Phelan et al. 2004). Mechanisms allowing individuals and households to cope with the constant hazards encountered show high efficiencies at the individual level, yet it is difficult to up-scale these actions to the city level (Romero Lankao and Qin 2011). They forget key extrinsic aspects, and consequently measures do not necessarily reach the most at-risk populations (Soebarto and Bennetts 2014; Sampson et al. 2013). Although these public health measures play a key role in reducing individual susceptibility, they should not be overestimated by public authorities (Boumans et al. 2014; Hagerman 2007; Harlan and Ruddell 2011; Harlan et al. 2013; Harlan et al. 2006; Heaton et al. 2014; Kovats and Kristie 2006; Wolf and McGregor 2013).

4.2 Urban planning interventions become increasingly relevant but are rarely deployed

Urban heat has a strong interaction with built structures, ultimately shaping the frequency, intensity and duration of heat waves and further shaping exposure levels. Information on location specific thermal radiative power helps define the impact of urban structures at the community level (Wang and Akbari 2014). Spatial models of health–environment interactions include these figures, using information layers related to topography profiles, building densities, vegetation bodies, transport networks, night temperatures and socio-demographic data in order to build risk maps (Boumans et al. 2014; Laaidi et al. 2012; Merbitz et al. 2012; Xu et al. 2013; Johnson et al. 2012; Krüger et al. 2013). These exercises assist policy makers to identify spatial attributes from the built and natural environments that interfere with heat waves and the ensuing health effects.

Well-known strategies include the increase of albedo though the modification of urban building materials and colours and optimising the urban canopy layer (Sailor 2014; Ohashi et al. 2007). These alternatives are of particular importance from a cost-efficiency perspective at the household level; they are particularly recommended in housing for middle and low-income occupants, which also makes them vey inclusive from an equity point of view (Santamouris 2014; Susca and Creutzig 2013; Soebarto and Bennetts 2014; Claus and Rousseau 2012). In general, strategies that move away from electricity requirements perform better from a commutative justice perspective; effectiveness is not reduced when loss of power or electric system failures occur (Koppe et al. 2009; Sailor 2014).

At the street and neighbourhood level, one could also reduce exposure times through shadowing and enhancing urban connectivity (Wilhelmi and Hayden 2010; Armson, Stringer, and Ennos 2012). Other structural strategies aim to optimise long-wave radiation loses, favouring air circulation and avoiding waste heat related activities. To this end, changes in street configuration, wall surfaces and roofs are suggested (Memon, Leung, and Liu 2010; Allegrini, Dorer, and Carmeliet 2012; Susca and Creuztig 2013). For example, avoiding street canyons may reduce air conditioning demands by half (Allegrini, Dorer, and Carmeliet 2012). Air flow optimisation through non-blocked street intersections, wind corridors and usage of porous construction materials also has a prominent mitigation effect, especially for locations with low wind speed (Hu et al. 2012; Memon, Leung, and Liu 2010; Allegrini, Dorer, and Carmeliet 2012; Saneinejad et al. 2012). City-wide albedo increase also mitigates peak temperatures up to 1 °C, especially for locations with high population density (Akbari and Matthews 2012; Susca and Creuztig 2013; Santamouris 2014; Santamouris 2013; Mackey, Lee, and Smith 2012). The cooling effect of water bodies can be up to 2 °C, which may be propagated through the avoidance of physical barriers and dark materials (such as brick or tarmac) and the increase of vegetation cover nearby (Hathway and Sharples 2012; Chun and Guldmann 2014).

Recent case studies of Seoul and Berlin, lead by the department of landscape planning at the Technical University of Berlin suggest specific urban planning strategies to mitigate urban heat island effects and urban heat waves (Eum et al. 2013; Dugord et al. 2014). With detailed spatial information, urban planning can focus on those districts with highest heat-wave related mortality (Schuster, Burkart, and Lakes 2014).

All these measures perform very well for commutative justice; the effects are in principle equally distributed among the whole population because they help to decrease the overall UHI effect. Research tells us that most of these strategies reduce overall anthropogenic heat intensity, thus providing benefits to all (Shashua-Bar, Pearlmutter, and Erell 2009; Memon, Leung, and Chunho 2008; Jr 2005). Furthermore, measures of urban planning increase in effectiveness with scale, including that of higher levels of risk and vulnerabilities (Memon, Leung, and Chunho 2008). The efficiency of reducing risk through measures addressing extrinsic factors increases with the number of the population at risk and the severity of the hazard (Shashua-Bar, Pearlmutter, and Erell 2009). Weaknesses of urban planning come mainly from the fact that effectiveness at the individual level to cope with susceptibilities is rather low compared to public health measures, which lowers the equity outcomes of urban planning with regards to distributive justice. Unequal distributions of access to cooling and green spaces based on income, ethno-racial characteristics, age, gender, (dis)ability and other axes of difference may reduce the positive outcomes, but this can still be addressed directly with alternative planning strategies (Dai 2011; McConnachie and Shackleton 2010; Shawn M Landry 2009; Sister, Wolch, and Wilson 2010; Wolch, Byrne, and Newell 2014; Sampson et al. 2013; Klein Rosenthal, Kinney, and Metzger 2014; Friel et al. 2011; Kjellstrom, Friel, et al. 2007). However, urban planning interventions to reduce risk from heat waves have rarely been implemented, despite their ability to address extrinsic risk factors beyond the reach of public health measures.

4.3 Achievements, challenges and the way forward

While public health measures focus on individual susceptibilities and levels of exposure, urban planning succeeds in lessening UHW hazard severity as well as intra-city exposures. Public health responses perform very effectively under a distributive-justice approach, yet it is difficult to up-scale intervention actions to the city level from a cost-efficiency perspective. This fact makes prioritisation a design criteria, and health care interventions do not directly address options aimed at the total population and tend to be based on mainly short term interventions (Krau 2013; O'Neill et al. 2009; Kinney et al. 2008; Kravchenko et al. 2013). They cannot alter urban climates (Harlan and Ruddell 2011; Koppe et al. 2009). Yet these shortfalls may be offset with planning strategies acting at an upper spatial level (i.e. street, neighbourhood) that include more people with relatively low costs (Eum et al. 2013; Dugord et al. 2014). At the same time, the relative ineffectiveness of urban planning in addressing individual susceptibilities makes it inevitable and necessary to intervene through public health actions.

Currently, the majority of responses are based on susceptibility or individual exposure factors, but these do not reduce the population's exposure either on a larger scale or in the long term. Little has been done in regards to urban planning apart from isolated initiatives focussing on albedo modification (Santamouris 2013) and increase in vegetation cover (Armson, Stringer, and Ennos 2012; Feyisa, Dons, and Meilby 2014). Some are designed from a climate change mitigation perspective (greenhouse gas emissions reduction) rather than using an integrative mitigation-adaptation approach that also considers UHW (Harlan and Ruddell 2011; Biesbroek, Swart, and van der Knaap 2009; Laukkonen et al. 2009). In other words, urban planners' potential to address heat waves in the field remains largely untapped. Measures addressing urban microclimate interaction with social and environmental risks would assist in more effective long-term heat risk reduction strategies (Johnson et al. 2012; Wu et al. 2014). This is not counting the well-known co-benefits and synergies with other policy objectives that can be achieved through urban planning (i.e. enhanced entrainment of pollutant concentrations (Tong and Leung 2012; Harlan and Ruddell 2011). Growing awareness among scientists on the role of spatial planning in functioning as a switchboard for mitigation, adaptation and sustainable development objectives may assist practitioners in the future to implement changes in the traditional administrative structure that spatial planners are accustomed to (Biesbroek, Swart, and van der Knaap 2009). From a climate justice perspective it is extremely important that future interventions tackle commutative and distributive justice jointly (Soebarto and Bennetts 2014; Sampson et al. 2013; Hajat, O'Connor, and Kosatsky 2010; Klein Rosenthal, Kinney, and Metzger 2014).

The combination of actions addressing intrinsic and extrinsic factors at the same time could fill the gaps each approach has on its own. Fig. 3 below illustrates the potential contribution of each approach individually to motivate the idea that joint consideration, evaluation, design and implementation of the two currently existing approaches would better cover the spectrum of future risks related to urban heat waves. Strategies themselves could benefit from synergies through a multilevel governance context, including institutional arrangements, governance mechanisms and financial resources (Friel et al. 2011; Wolf and McGregor 2013; Pascal et al. 2012; IPCC 2012; K.C. Seto et al. 2014).

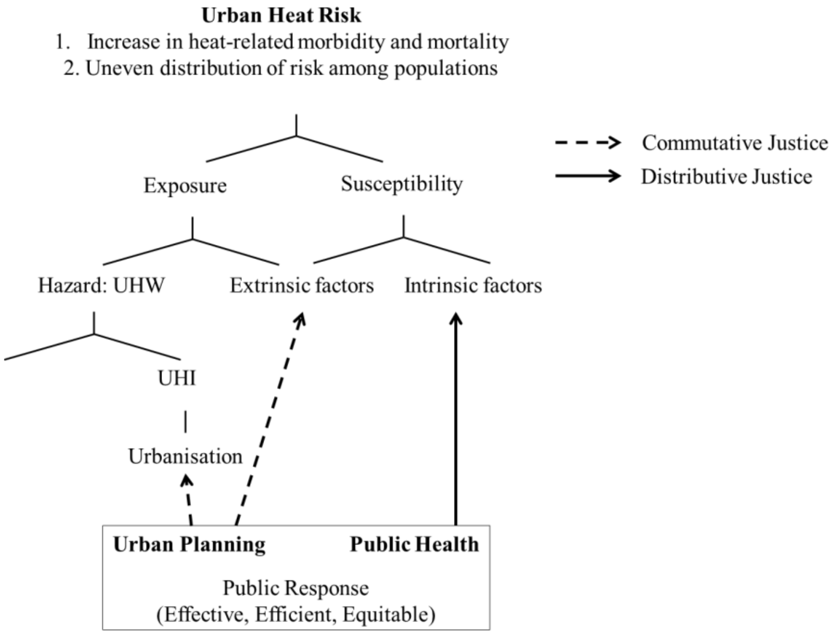

Figure 3 Person-specific risk is well addressed by public health interventions, while extrinsic factors can be tackled through urban planning considerations.

5. Conclusion

This review identifies intrinsic and extrinsic factors that contribute to stratified vulnerability to urban heat waves. We show that public health interventions are highly effective and can be used to address intrinsic risk factors. Urban planning measures show their efficiency on longer time scales but are rarely deployed. Crucially, urban planning measures would reduce exposure and through this help to mitigate extrinsic risk factors. We claim that this reduction of extrinsic risk factors becomes increasingly relevant due to the confluence of urbanisation and rising levels of urban heat hazards. We conclude that a coordinated effort between public health and urban planning departments would most effectively counter the threat of future heat waves worldwide, and specifically would help to address both individual susceptibility (intrinsic factors) and overall exposure (extrinsic factors).

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Chapter 5

Water security in an urbanized world: An equity perspective[1]

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Water security in an urbanized world: An equity perspective

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Abstract

Ensure access to water and sanitation for all is one of the Sustainable Development Goals (SDGs) recently recognized at the international community. The combination of natural constraints, population forecasts and climate change threat this and other SDGs closely related. In cities, inequalities in water security become more explicit as complexity in water management given by institutional and market barriers increases. This looks at the threats to ensuring access to water in cities for different world regions and reviews recent literature on water governance and sustainable water management to identify drivers and barriers to just burdens on urban water security. Intrinsic factors related to individual characteristics influence the distribution of water in cities to a certain extent. The relevance of extrinsic factors such as governance structures and pricing schemes will increase in parallel to the forecasted water scarcity. In the discussion we group different measures into three lines of action: efficiency improvement, water democratization and holistic approaches in water governance. We call for further interdisciplinary between the fields of urban water governance and urban hydrology to address the increasing challenges of domestic water allocation under stronger equity objectives.

Keywords: urban water; equity; Sustainable Development Goals; water governance.

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1. Introduction

The United Nations (UN) General Assembly formally adopted the Sustainable Development Goals (SDGs) to mark the path for a continued uniform development effort on a global level, leaving the Millennium Development Goals (MDG) behind. They consist on a set of 17 goals expected to shape political policy worldwide for next 15 years. The 6th SDG refers to clean, accessible water for all. The right to water security entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for domestic uses (United Nations 2015b). Although access to safe water was reduced in many countries, this was often at the extent of an increase in disparities (Lu, Ocampo-Raeder, and Crow 2014; Roth, Boelens, and Zwarteveen 2005; Soares et al. 2002; World Health Organization and UNICEF 2012). Besides, the MDG target to improve basic sanitation, such as access to latrines and hygienic waste collection is one of the MDGs that is most off-track (World Health Organization and UNICEF 2012). Responsibility is placed upon public authorities to ensure no discrimination among their citizens (Cook and Bakker 2012; UN Economic and Social Council 2003), but the practical implementation depends on multiple factors at different regional scales. Together, natural constraints, national laws and local customs define the reality of water security (Niemczynowicz 1999; Patrick, Syme, and Horwitz 2014; Roth, Boelens, and Zwarteveen 2005).

These observations yield to a stronger focus on justice and equity when it comes to water accessibility in the proposed 6th SDG. Moreover, it closely interacts with other SDGs, particularly in cities. Water scarcity, poor water quality and inadequate sanitation negatively impact food security (SDG 12), livelihood choices (SDG 11), water-dependent ecosystems (SDGs 14,15) and educational and gender opportunities for poor families across the world (SDGs 6,10&16) (Revi et al. 2014). Drought will afflict some of the world's poorest countries, worsening hunger and malnutrition (SDGs 1,2&3) (see Figure 1) (IPCC 2014).

SDG 6 Clean water and sanitation
Equity perspective

- SDG 11 Sustainable cities and communities
- SDG 16 Peace, Justice and Strong Institutions
- SDGs 1,2,3 No poverty, Zero Hunger, Good health & well-being
- SDGs 6,10 Gender Equality, Reduce Inequalities.
- SDGs 14,15 Life below water, Life on land
- SDG 12 Responsible Consumption and Production

Figure 1 Relationship between 6th SDG and other SDGs relating to equity in urban water.

At the same time, population prospects highlight the importance of urban contexts in the future, with more than 70% population living in cites by 2050 (United Nations 2015a). The 6th SDG will find enormous challenges in future urban developments, where physical and financial limitations to water resources are spatially explicit (Mehta 2014; Vairavamoorthy, Gorantiwar, and Pathirana 2008; Barbier and Chaudhry 2014). Drinking and sanitation water will compete with agricultural demands under circumstances of scarcity due to depleted aquifers and environmental pollution (Pahl-Wostl 2015; Revi et al. 2014). Consequently, new low-income suburbs, often second priority for local water management agencies, will struggle with water security, being both a cause and consequence of their socioeconomic level (Barbier and Chaudhry 2014). Managing water resources sustainably and ensuring human water security is one of the most pressing environmental challenges of the 21st century.

This paper provides valuable insights on the factors influencing equity in urban water security, with due attention to low income groups. First, we look at the upcoming challenges related to water security in cities for different world regions within the SDGs timeframe. We review literature on urban hydrology, water management and governance to identify influencing factors on water distribution among people in cities. We then discuss approaches in reducing water inequities and their efficiency, and finally suggest several key areas for action and research to ensure equalitarian domestic water provision in an urbanized world.

2. Urban water threats

We first look at figures on urban water accessibility and urbanization prospects to have an idea on future threats for different world regions. Urban population growth refers to the per cent change in the period 2015-2030 (United Nations 2015a). Access to an improved water source refers to the percentage of urban population using an improved drinking water source[3]. Access to improved sanitation facilities refers to the percentage of the urban population using improved sanitation facilities, which makes it likely to ensure hygienic separation of human excreta from human contact[4] (World Health Organization and UNICEF 2015). Domestic fresh water withdraw is the municipal water withdrawal as % of total withdrawal (%) (World Bank 2015). Data is from 2013.

We also compare blue domestic WF and water availability to look at future burdens on water ecosystems. Blue WF refers to the amount of surface water and

[3] Improved drinking water source includes piped water on premises (piped household water connection located inside the user's dwelling, plot or yard), and other improved drinking water sources (public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs, and rainwater collection) (World Health Organization and UNICEF 2015).

[4] Improved sanitation facilities include flush/pour flush (to piped sewer system, septic tank, pit latrine), ventilated improved pit (VIP) latrine, pit latrine with slab, and composting toilet (World Health Organization and UNICEF 2015).

groundwater required (evaporated or used directly) to make a product (Hoekstra and Mekonnen 2012; Mekonnen and Hoekstra 2011). Domestic water relates to the standard of living and lifestyle choices of the country's residents (Hoekstra and Mekonnen 2012; Mekonnen and Hoekstra 2011). We use the latest data available; an average of the period 1995-2006 suited to making regional comparisons. Water stress measures total annual water withdrawals from domestic use expressed as a percentage of the total annual available blue water. Higher values indicate more competition among users[5] (Luo, Young, and Reig 2015). We use figures on the projected future country-level water stress for 2030 under a middle optimistic scenario[6]. We also compare the blue WF with the World Health Organization (WHO) minimum of 7.5 litres per capita per day[7].

Figure 2 provides the following insights: higher increase in future domestic water demand due to urban population growth will happen in countries where:

a) They show today´s lower performance in the 6th SDG (both for clean water and sanitation) (see Figure 2a, b).

c) They have limited financial resources (low and middle income countries) (see Figure 2a,b).

b) Accessibility to domestic water drastically affects fresh water withdraw (see Figure 2c).

Countries from the Sub-Saharan Africa, Middle East and North Africa will face the greatest challenge on providing urban water facilities to more population. Cities from Europe, Central Asia and North America with high urban dynamics draw from better levels of accessibility to urban water facilities. Countries with strong link between accessibility to domestic water and freshwater withdraw will face competitiveness issues with other uses (e.g. agriculture).

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[5] Water stress scores and values: [0-1) Low (<10%); [1-2) Low to medium (10-20%); [2-3) Medium to high (20-40%); [3-4) High (40-80%); [4-5] Extremely high (>80%)(Luo, Young, and Reig 2015).

[6] Three possible scenarios: business-as-usual (BAU), pessimistic, and optimistic.

[7] 7,5 litres per person is the water needs that represents a tolerable level of risk. It does not account for health and well-being-related demands outside normal domestic use –e.g.- excluded: water use in health care facilities, food production, economic activity or amenity use- (Bartram and Howard 2003; UNESCO and WWAP 2012; WHO 2011).

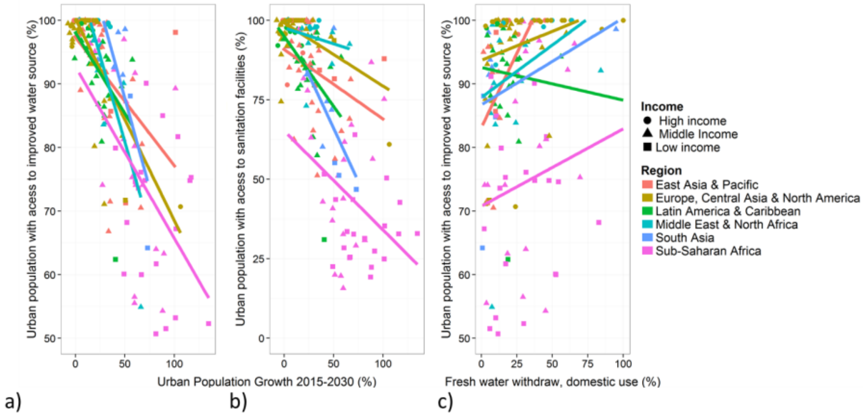

Figure 2 a) b) Urban population growth rates and access to improved water source and sanitation facilities; c) Fresh water withdraw due to domestic use and access to improved water (sample=182 countries; source: United Nations (2015); World Health Organization & UNICEF (2015)).

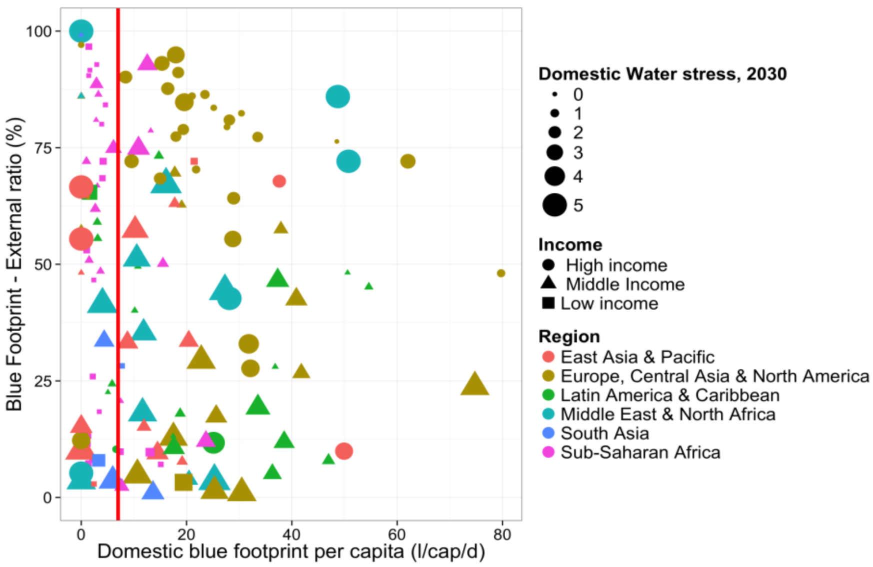

Figure 3 Threats on urban domestic water: water footprints, dependencies and forecasted water stress; red line represents WHO minimum (7,5 litre) (sample=154 countries; source: (Luo, Young, and Reig 2015; Mekonnen and Hoekstra 2011; World Bank 2015; World Health Organization and UNICEF 2015)).

Figure 3 shows that equity challenges in water security may be driven by different factors and thus influence countries differently. Countries with external water dependency in water scarce regions will face problems in keeping current water demands constant. But more challenges are ahead those countries that in addition will face an increase in water demand per capita. This could be due to a) increase in urban population and/or b) increase in per capita consumption following political mandates (e.g. the 6th SDG). More than one third of the total sample is still below the minimum water access stipulated by the WHO. From these, those from Sub-Saharan Africa are highly dependent on external sources of water, which increases their vulnerability to water stress. In other words, multitude factors will increase water scarcity in cities, which consequently will affect equity in water distribution –e.g. skyrocketed prices due to large demand increase-.

Urban water management will embrace enormous challenges driven by insurmountable competition among different water demands. Available water from natural ecosystems will be jeopardised by climate change and human overuse. On the one hand, population prospects augur not only an enormous increase in human demand for water, but also great changes on the distribution to different water uses. Water competitiveness between industry, agriculture and domestic use will increase, causing changes in municipal water resources. On the other, climate change will exacerbate water scarcity, especially in regions where this resource is already limited (Hoekstra et al. 2012). The combination of these dynamics will multiply the equity effects of domestic water management, especially considering that most population growth will occur in cities not yet built. Ensuring water security under these conditions will increase the dependency on external water sources and/or the water stress depending on the country.

The global dimension of water consumption and pollution is given by the fact that several countries heavily rely on foreign water resources and that many countries have significant impacts on water consumption and pollution elsewhere. Technological and infrastructure betterments enhance the efficiency of urban water management. But decisions at the managerial level will definitely be fundamental in in achieving the 6th SDG.

3. Inequalities in urban water security

Defining and ensuring water equity among populations is highly contested. First, ambiguities in the legal terms of equity and water security in international and national legal frameworks are compounded by the lack of enforcement mechanisms ensuring the existence of the principles agreed-upon (Sallam 2014; Barbier and Chaudhry 2014). Even the SGDs lack in regulatory specifications (United Nations 2015b). Second, different dynamics explain water inequalities at the global, regional and local level (Hoekstra and Mekonnen 2012; Lu, Ocampo-Raeder, and Crow 2014). We focus on local challenges but with the regional settings in mind. Thirdly, a wide variety of definitions and analytical approaches to water security across disciplines indicate its complexity (Cook and Bakker 2012). Data on drinking water and sanitation coverage may indicate distances to water sources, overlooking the reality given by affordability, reliability, quality and quantity (Smiley 2013; Euzen and Morehouse 2011).

Equity in water security is affected by climatic and hydrological conditions, population growth, urban migration, increased per-capita water use, pollution and over-abstraction of groundwater, among others (Kujinga et al. 2014). Urbanization itself deteriorates water shortage and increases water total and per capita water demand having direct equity implications (Chen and Yang 2009; Kujinga et al. 2014; Kiriscioglu, Hassenzahl, and Turan 2013). But inequities can sometimes attributed to failures in governance rather than the resource base itself (Pahl-Wostl 2015). Decisions lack in just and equalitarian approaches, especially in developing countries (Patrick, Syme, and Horwitz 2014; Sahin, Stewart, and Porter 2014). We review the issue of inequities in water security looking at intrinsic and extrinsic factors.

3.1 Intrinsic factors

Availability of potable and accessibility to water bodies stratifies among socioeconomic factors (Nogueira et al. 2005; Ruijs, Zimmermann, and van den Berg 2008; Sampson et al. 2013; Vörösmarty et al. 2005). Water accessibility, affordability, quality and quantity all vary greatly with income (Awad 2012; Ruijs, Zimmermann, and van den Berg 2008; Sampson et al. 2013)(Awad 2012). Water usage increases with income level especially in urban areas, as domestic use for food preparation, personal hygiene and household cleaning increases (Sallam 2014; Justes, Barberán, and Farizo 2014). Low incomers spend up to 4.7% of their income on water, whereas richer people typically pay no more than 0.5% (Ruijs, Zimmermann, and van den Berg 2008). Women, more vulnerable to water scarcity than men, are hindered by their social roles and position (Figueiredo and Perkins 2013) and have a secondary role in the participation of water governance and decision making, especially in settlements from developing countries (Das 2014). Ecosystem´s value perception and water conservation also varies between populations. Social, demographic and cultural factors influence attitudes and behaviours (Garcia et al. 2013; Justes, Barberán, and Farizo 2014). Some groups perceive ecological impacts to water bodies more intensely, but they care less about equity issues (Kiriscioglu, Hassenzahl, and Turan 2013). In water scarce communities urban bodies are extremely valuable (Abbott and Allen Klaiber 2013).

3.2 Extrinsic factors

3.2.1 Settlement characteristics and climate change

Population growth and rapid urbanization is a major challenge for the human right to water. Rapidly growing non-agricultural demands together with declining water quality and limited water quantity cannot be followed by basic water service provision in complex sub and peri-urban areas (Douglas et al. 2008; Hellberg 2014; Jimenez-Redal, Parker, and Jeffrey 2014; Jimenez-Redal, Parker, and Jeffrey 2014; Vörösmarty et al. 2005). Physical and environmental conditions such as urban form, climate, and hydrology also influence accessibility distributions. In sprawled settlements economies of density get lost and may provoke unequal distribution of water services (K. Bakker et al. 2008; Cook and Bakker 2012; García-Sánchez 2006). In highly dense ones, water pollution challenges clean access to water (Zgheib, Moilleron, and Chebbo 2012).

Climate change will threaten numerous SDG´s, and water in particular. Scenarios predict more frequent and severe heat waves in drought-sensitive locations that will be accompanied by long drought periods (IPCC 2014; Meehl and Tebaldi 2004; Vautard et al. 2013; Vörösmarty et al. 2005). World minorities and marginalized will be the most affected from new water distributions under different climate change scenarios (Figueiredo and Perkins 2013; IPCC 2014). Glacial retreat for example will increase competition between urban and rural water uses, affecting poor urban neighbourhoods the most (Lynch 2012).

3.2.2 Institutional failures

Governance structures play a key role in how water is distributed among population. Many problems and barriers are due to institutional failures rather than the resource base itself (Pahl-Wostl 2015; Rockstrom 2013; Sibly and Tooth 2014).

First, legal pluralism at different regulatory levels influence the effective implementation of water rights (Obani and Gupta 2014). The declining role of international water programs decreases awareness of low-income water issues and the financial resources reserved to these programs (Wescoat Jr, Headington, and Theobald 2007). Second, investments in water and sanitation infrastructure do not account for the total costs of the projects and avoid sustainability practices; very much relevant for lifestyles and regional social values (Ioris 2012; Wilder and Romero Lankao 2006). They tend to produce overexploitation and contamination, unequal access to water, and fragmented and weak institutional settings (K. Bakker et al. 2008; Herrera and Post 2014; Herrera and Post 2014; Romero Lankao 2011; Wilder and Romero Lankao 2006). These harmful practices have affected inequalities particularly in the African and Asian context (K. Bakker 2007; K. Bakker et al. 2008; Bowonder and Chettri 1984; Shah 1989; Smiley 2013; Truelove 2011).

The distribution and regulation of different water uses also contributes to water inequalities. In China and India, groundwater extraction from agricultural fields to be use in cities supply, de facto creates private property rights for the farmers who sell water and create imbalances in the distribution of the resource (Cai 2008; Ruet, Gambiez, and Lacour 2007). Low and mid-income countries show significantly higher water use for tourist than for local population compared to developed countries (Becken 2014). In Zanzibar, luxury resorts use up to 2000 litres of water per tourist per day, while local people use only 30 litres (Nunn 2007). Lack of managerial leadership –e.g. local governors give priority to the tourist faculties (Becken 2014; Cole 2012; Hazou, 2008; Tourism Concern 2009; Zagt 2014)-, and awareness both by local and tourist groups (Cole 2012; Page, Essex, and Causevic 2014) create inequalities and threaten local’s water supply (Goodwin 2007). In Kerala (India), the tourism industry buys or steals water from local communities and contaminates water with chemicals (Hickman 2007). -. Embodied water[8] also contributes to the imbalance between tourists and locals (Gössling 2015).

Dichotomies in land and water management also influences (Evans et al. 2003). Inexistent or poor environmental quality assessments and monitoring hampers transparency and creates inequalities specially in places where environmental damages abound (Lundin and Morrison 2002; Mehta 2014; Mehta et al. 2014). Public authorities strategically define different contamination levels for different locations to avoid such problems (Christenson et al. 2014; Smiley 2013). Lack of clear task assignment and unplanned intermittent water supply to face water scarcity creates chaos and water spatial inequalities (Lee 2000; Vairavamoorthy, Gorantiwar, and Pathirana 2008).

Finally, water pricing policies fail to accomplish their strategic objectives, especially in developing countries. They generate insufficient revenues to ensure that utilities can recover their financial costs. They cannot send the correct economic signals to households to include the long-term viability of the resource and fail to help poor households, many of whom are not connected to the piped distribution system (Abbott and Allen Klaiber 2013; Whittington 2003). Consultants, international organizations and investors continue to recommend increasing block and rate tariffs (IBT and IRTs), but these practices are neither fair nor efficient (Bithas 2008; Boland and Whittington 1998; Chen and Yang 2009; Dahan and Nisan 2007; Foster and Yepes 2006). They price commodities at a low initial rate up to a specified volume of use (Foster and Yepes 2006; Sibly and Tooth 2014). The rationale is that it results in higher marginal prices to the customer and thus higher average prices for higher-income households and subsidized services to the poor. But non distinction is made on household size and large households, also likely to be poor given the negative correlation between income and household size, are charged a relative higher price (Dahan and Nisan 2007; Liu, Savenije, and Xu 2003; Sibly and Tooth 2014). Under water shortages IBTs are not flexible in the face of changing availability of water (Sibly 2006), and fail to place the welfare burden of conservation on large water users and benefit low- income people (Griffin and Mjelde 2011; Ward and Pulido-Velázquez 2008). Overall, they introduce inefficiency, inequity, complexity, and lack of transparency for no apparent reason.

3.2.3 Water privatisation

The provision of water and sanitation services in the past decades has focused on private sector participation, mainly through Public Private Partnerships (PPPs) and subcontracting. Sufficient evidence demonstrates the failure of Private sector partnerships (PSPs) in supplying households equally. Although the positive record on service and efficiency improvements reaffirms the value of PPPs (Marin 2009), the equity outcomes of such structures are somehow unclear, depending on the stage

[8] Water used in the production of goods somewhere else but consumed in in resorts and other touristic facilities.

of market development (K. J. Bakker 2003; Castro 2007; Jepson 2014). Different prices of water services apply depending on the nature of the provider, lower in the case of town councils (García-Valiñas, González-Gómez, and Picazo-Tadeo 2013). Also unclear is the possibility to have equity under monopolistic markets, independently of their private or public nature (K. Bakker et al. 2008).

In developing countries, market-centred governance using a pro-poor rhetoric has driven water management since the 1980s. Reforms enhancing the role of corporations and private sectors swept through the water sector. But results are disappointing. They not only did not achieve their pro-poor intentions, but also increased water inequalities (Castro 2007; Herrera and Post 2014; Jepson 2014). Priorities to middle and high-income households (Awad 2012; K. Bakker 2007; Kujinga et al. 2014) together with short-term profit oriented approaches threat the long-term viability of water ecosystems and foster inequalities such as the ones emerging in Latin America, Africa and Asia (Aurélio Peres, Simara Fernandes, and Glazer Peres 2004; K. Bakker 2007; Castro 2007). Private water monopolies may weaken the role of public authorities and citizens and thus, the social and ecological aspects of water management.

4. Equitable water governance for the urban future

The concept of sustainable water management has increased its popularity in all regions and levels of governance. Complex links between poverty and water security challenge nations striving for universal access to water (Patrick, Syme, and Horwitz 2014; Wescoat Jr, Headington, and Theobald 2007). The underestimation of institutional barriers -including normative values, risk perception, lock-in effects of legal measures, stakeholder’s plurality of preferences, and investment requirements- hampers the process of transforming agendas (Marlow et al. 2013). This creates a rushing need to include justice in water allocation decision both at regional and local levels of governance (Patrick, Syme, and Horwitz 2014). We review the literature on water governance and sustainable water management focusing on cities and domestic water. We group different measures into three lines of action: efficiency improvement, water democratization and holistic approaches in water governance.

4.1 Increase efficiencies

4.1.1 The true costs of domestic water

First, governments should base their decisions on data that gives a true view of the situation. Local documentation (e.g. official documents, reports, neighbourhood white documents), and other secondary data (e.g. household’s questionnaires and interviews) help understand the actual circumstances (Cook and Bakker 2012; Mehta 2014; Kolokytha, Mylopoulos, and Mentes 2002). Water footprints (WF) are also useful to look at virtual water flows between production and consumption, and the water appropriation of different water uses (Dumont, Salmoral, and Llamas 2013; Sallam 2014). Quantitative indicators help evaluating the various aspects of social sustainability in water security (Popovic et al. 2014; Luh, Baum, and Bartram 2013; Davidson et al. 2013).

Second, the domestic use of water leads inevitably to pollution. Households must pay the process in which used water is brought again to the environment in the best conditions possible. That is, internalizing in the user prices the externalities (economic and ecological) to avoid overconsumption (Elton 2015). Public authorities should find ways to increase awareness of water scarcity and pollution, which leads to either higher willingness to pay (WTP) or lower consumption patterns. Enhancing the accountability and transparency of sustainability indicators for urban water systems is fundamental. Avoiding subsidies and including payment for environmental services (PES) will reduce water resource degradation rates, specially in medium to large cities (Lee 2000). Although the WTP heterogeneity among population calls for attention to the affordability and distribution issues of a water pricing reforms that includes externalities (Jiang, Jin, and Lin 2011), the full-cost price approach seems to be the most efficient instrument from a sustainable point of view, promoting both social equity and smaller water footprints (Chen and Yang 2009; Lundin and Morrison 2002; Lynch 2012).

Third, every claimed advantage of an IBT can be achieved with a simpler and more efficient tariff design that does not use blocking (Boland and Whittington 1998). For example, an increasing rate tariff based on water consumption per capita (IRT-cap), where the water price depends on two things: total household water consumption and the household size has better equity outcomes, but also simplicity and transparency and economic efficiency (achieve cost recovery) taking the ability to pay of water consumers into account. Water fee percentage -water fees calculated on a per year income- may be another alternative, however they do not account for the water consumption per connection (Liu, Savenije, and Xu 2003). A tariff in which a households' water bill is based on a volumetric charge set equal to marginal cost and a fixed monthly rebate (negative fixed charge), -uniform price with rebate (UPR) – also offers important advantages. It has a smaller probability of inducing economic inefficiency and is more effective at transferring income. It is simple, transparent, easy to implement, appears fair and equitable in most circumstances, and requires less data for design and revenue estimation (Whittington and Boland 2000).

Under water shortages conditions low-income households prefer scarcity-inclusive uniform rates or two-tiered pricing. Temporary drought pricing (TDG) regimes not only lower the frequency and severity of water insecurity events but also reduces the long-run marginal cost of water supply when compared to traditional reactive planning approaches that focus on restrictions to affect demand in scarcity periods (Sahin, Stewart, and Porter 2014). Seasonal water pricing (SWP) determine water prices on meteorological observations based on an ex-post price determination for diminishing excessive fresh water use purposes, thus serving as price signal to water users on resource scarcity. Not knowing ex ante how high their monthly bill is going to be, but aware of the price-setting rule makes consumers change their pattern of behaviour, pushing them towards rationality (Pesic, Jovanovic, and Jovanovic 2013). However SWP induces inequalities based on the WTP of different households. Two-part tariffs may be the better mix. On the one hand, an efficient volumetric rate accounts for the erratic rainfall patterns reflecting the expected availability of water. On the other, the fixed charge satisfies the residual revenue requirement and serves as a mechanism to address equity concerns (Sibly 2006). Regardless of the pricing type, metered connexions ensure the implementation of pricing policies (Whittington 2003).

Finally, it is also important to offer flexible payment options to the urban poor, especially in new urbanized areas. Even though residents perceive connection fees very expensive, their WTP increases if payments are spread in time. Subsidies to upfront connection costs, not volumetric water use can both bring utility services within reach of low-income households and expand the customer base for utility service providers (Jimenez-Redal, Parker, and Jeffrey 2014; Whittington 2003). In any case, governments should ensure all households having a water connection if they want it. For example, they could provide public taps as a water source of last resort for the very poor, legalizing water vending and selling by neighbours, and not giving private operators exclusive rights to provide water within a service area (Whittington 2003). A careful evaluation of the differences in the demand curve of the poor and rich consumers should be reflected it in the price policy; it is not enough to know the cost curve –e.g. private taps will improve the access to piped water and consequently increase the use of appliances for the poor consumer- (Moilanen and Schultz 2002).

4.1.2 Water use differentiation

Food preparation, personal hygiene and household cleaning require different water qualities. Understanding the heterogeneity among population on how direct users valuate these different uses helps pricing and managing water resources (Justes, Barberán, and Farizo 2014).

Also, social trust, risk perceptions and public acceptance of different water sources influence the sources used for water supply –e.g. recycled water, desalinated water, tap water and rainwater from tanks- (Justes, Barberán, and Farizo 2014). Policy interventions transfer economic value from one use to another and influence users perception of water value for different uses (Liu, Savenije, and Xu 2003). Higher levels of public trust lowers risk perceptions and enhances public acceptance of mix water sources supply schemes (Ross, Fielding, and Louis 2014). Water attributes and branding makes water more attractive to consumers (Dolnicar, Hurlimann, and Grün 2014). Preferences for the different domestic water uses should be used to price them differently for equity purposes.

4.1.3 Demand management

Shifts from traditional supply to demand management paradigms enhance the use of limited water supplies. Traditional approaches have no future in contexts with limited finance and water resources. Spatially explicit demand models help identifying efficient and equitable allocation strategies (Zeng et al. 2012). Rainwater tanks, infiltration trenches, grassed swales, central basins, and constructed wetlands can be used in housing allotments and subdivisions to reduce blue WFs (Coombes, Argue, and Kuczera 2000; Vairavamoorthy, Gorantiwar, and Pathirana 2008). These strategies depend on settlement characteristics (K. Bakker et al. 2008), and should be promoted with adequate information dissemination and training, and water supply infrastructure and institutional capacity (Manzungu and Machiridza 2005).

4.2 Water democratization

4.2.1 Governance structures

Clear task assignment to particular agents at all levels of responsibility helps institutional outcomes. Although defining a minimum water quantity has limited significance due to the great variations among regions and circumstances (Bartram and Howard 2003; WHO 2011), strong mutual support between different regulatory frameworks minimises dichotomies (Obani and Gupta 2014).

The main focus of urban water services should not be about attracting private investment, but use private operators to improve service quality and efficiency under strict parameters of social equity and ecosystem preservation. This approach fosters a virtuous circle whereby the utility improves its financial situation and gradually becomes able to finance a larger share of its investment needs (Marin 2009). Privatisation complicates the clear differentiation if the regulator and the operator are in the same institution. It is thus recommendable to have institutional and legal differentiation through decentralization to autonomous operators (Lee 2000).

In well-developed markets, partnerships between the public and the private sectors are a valid option to turn around poorly performing water utilities. Although concessions have worked in a few places, contractual arrangements that combine private operation with public financing of investment appear to be the most sustainable option. Including local investors reduces dependencies, risks and enhances social and ecological outcomes compared to international ones (Marin 2009). In any case, governments and donors need to remain heavily engaged in the water sector (Marin 2009).

In developing countries, governments should have various options to tackle the different challenges of water security. The rationale to decentralize and enhance the role of private sector as a tool to enhance equity is clearly contradictory (Castro 2007). Reforms in this direction intends to foster community's influence in decision making process, but the parallel corporatization and privatization process depoliticize the management and have contrary effects in terms of democratic governance (Herrera and Post 2014). Privatization is a legitimate tool for private capital accumulation and for public authorities to transfer the burden of water management to non-state institutions (Ruet, Gambiez, and Lacour 2007). Water cannot be addressed by merely passing over responsibilities along with their complex set of social and environmental problems (Romero Lankao 2011). Besides, resource transfer negotiations have limited transparency conditions. These should include governance mechanisms to promote trust, accountability, and consequently a more efficient and equitable water allocation (Pfaff and Vélez 2012).

Finally, municipalities should have defined and influencing roles, and foster strong and committed civic participation. Responsibilities transfer to local levels of governance may difficult the insulation of water systems in practice (Herrera and Post 2014), but democratization outcomes prevail on general basis. It enhances the discussion among shareholders in terms of priorities, needs etc. which helps establishing policy frameworks adequate for each settlement short and long term need (Lee 2000).

4.2.2 Transparency and public participation

Transparency increases social awareness, understanding of current and future water challenges, and helps gathering community-based knowledge (Smiley 2013). Policy makers should exploit these synergies. For example, users perceive scarcity of common water resources differently and tend to alter altruistic and selfish behaviours depending on the trade-offs between equity and efficiency (D'Exelle, Lecoutere, and Van Campenhout 2012). Communicating decisions of water reallocation to all community levels helps identifying critical barriers to smooth water redistribution, particularly under scarcity conditions (Cai 2008). Using guidelines and network analysis looking at the duration and timings of the supply, pressure at the outlet, and the type of connection required enhances intermittent water distribution systems (Vairavamoorthy, Gorantiwar, and Pathirana 2008). Environmental education and non-governmental organizations also expand the equitable involvement of citizens, raise consciousness and confidence (Figueiredo and Perkins 2013). The role of women is increasingly praise; they possess knowledge on effective social technologies for coping with and adapting to climate change (Figueiredo and Perkins 2013).

The SDG on clean water and sanitation requires a re-democratization of water management. Trade-offs between returns and social equity call for a process of re-regulation (K. J. Bakker 2003), overcoming mismatches between organizational scales, and including marginalized groups in water decision-making processes with new governance practices that strengthen trust among stakeholders and identify common preferences (Hu et al. 2013).

4.3 Holistic water management

The conventional water-resource planning and management focus is on liquid water, or blue water. It serves the needs of engineers involved in water supply and infrastructure projects quite well. However, it represents only one-third of the real freshwater resource (Falkenmark and Rockström 2006; Mekonnen and Hoekstra 2011)[9]. Considering future scarcities, it is necessary to incorporate the rainfall or green water, largely embedded in agricultural products (Falkenmark and Rockström 2006; Hoekstra and Mekonnen 2012). In this context, urban hydrology is gaining relevance (Niemczynowicz 1999; Barbier and Chaudhry 2014). Significant savings in water resources and infrastructure costs can be achieved when applying holistic water management. For example, it is important to use adequate sets of performance indicators suitable for different water uses, considering water availability, planning and operation, as well as complexities of direct versus indirect water consumption (Gössling 2015). Including them in modelling the effect of individual infrastructure projects on urban-peri-urban-rural (Zhang et al. 2014), and land use and land cover models to predicts water demand accounting for storm water runoff enhances efficiency and equity outcome (Evans et al. 2003; Willuweit and O'Sullivan 2013). Such models could also help to develop indexes to measure progressivity (Luh, Baum, and Bartram 2013), and the realization of the SDG.

Climate change will provoke extreme weather events and water-related challenges affecting the marginalized first and worst (Figueiredo and Perkins 2013; IPCC 2014). Traditional water infrastructures will face resilience issues that need to be addressed with decentralised systems enabling institutional, cognitive, normative and regulative dimensional shifts (Ferguson, Frantzeskaki, and Brown 2013). Water alternatives in different scenarios should be considered and consulted through social multi-criteria to all stakeholders (Domènech, March, and Saurí 2013), and path-dependencies in long-term urban infrastructure addressed with new normative transition scenarios through transformative changes in governance structures, a better understanding of system complexities and uncertainties (Ferguson, Frantzeskaki, and Brown 2013).

Equal access to clean drinking water and adequate sanitation and hygiene facilities closely interacts with many of the newly proposed 17 SDGs, and this link becomes starker in urban contexts. The right to water may itself reduce distinctions between different forms of life, and thus inequalities. As water is a finite resource, environmental injustices and rights violations often go hand in hand. It seems valid to apply the global environmental justice approach to the problem of universal access to safe and potable water, especially in rapidly expanding urban areas. The water sector has many features that set it apart from other infrastructure sectors. A careful consideration of these together with context-specific factors is important for

[9] Human water use for food varies from less than 700 m3/person/ year in Sub-Saharan Africa to 1800 m3/person/year in North America, expressed by the differences in calorie intake.

successfully reconcile ostensibly conflicting goals. Global frameworks provide moral imperatives, however it is difficult to bring them down to the practical side at the local level. City planners should aim at redistributing water resources, political power, and participation toward disadvantaged urban populations (Krumholz 2001). In situ applications of human development approaches to urban water challenges beyond utilitarianism (Mehta et al. 2014) based on principles for social and ecological system integrity and interconnectivity, resource efficiency and maintenance, civility and democratic governance, intra- and inter-generational equity, and adaptive capacity (K. Bakker et al. 2008; Larson, Wiek, and Withycombe Keeler 2013) will assist in overcoming future trade-offs. How urban resources, services and functions are governed strongly influence ex-urban, rural and natural areas; acquiring local, national and even global relevance.

5. Conclusion

Water resources for domestic use will face tremendous challenges, especially in the new settlements to come. Our ability to manage these trade-offs and encourage long-term viability will affect numerous SDGs. Demand outstripping supply, unplanned settlements, poor planning, financial mismanagement and lack of robust governance structures exacerbate inequalities in water security. Interconnections across natural and anthropogenic systems, the incorporation of justice, decentralized governance at all levels of decision-making processes, and integrative management approach promoting collaborations and social learning between stakeholders will be required to ensure water security to all. In doing so, urban water integrative approaches could foster good governance practices, and bring promising outcomes to urban sustainability as well as global water resources.

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Part II

Urban planning under sustainability objectives

Chapter 6

Municipal policies accelerated urban sprawl and public debts in Spain[1]

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Municipal policies accelerated urban sprawl and public debts in Spain

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Abstract

Urban form and resource consumption co-evolve dynamically with public finances. While in compact urban settlements public service is provided more efficiently, and in larger amounts per surface area, sprawled developments often translate into larger marginal infrastructure investments, and into higher rates of consumption of resources per capita: land, raw materials, and transport fuels. Yet the relationship between municipal tax policies, rapid urban land consumption and municipal debts is poorly understood. In this paper we first scrutinize the relationship between urban sprawl and municipal deficits in Spain, and contextualize this development in the European situation. We then investigate statistically how urban economic drivers and municipal policies influence sprawling patterns, municipal debt and location values, demonstrating that local interventions jointly influence all three variables and that location value taxes can reduce both sprawl and debts. The linkages between local decisions and global land markets deserve further scrutiny.

Keywords: urban sprawl, local finances, municipal land use planning, property tax.

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1. Introduction

Industrialized and urbanized nations face two grand challenges: an immediate shortage of public finances, and limiting environmental damage within local, regional and planetary boundaries. The more immediate one crystallizes in the aftermath of the financial crisis, which co-evolved with a real estate bubble in countries like the USA, Ireland and Spain. In austerity-marked politics public expenditures are crumbling and public entities, especially municipalities, are deeply indebted. The long-term challenge is to deal with limited resources, notably land, and climate change. Both challenges converge in the issue of urban sprawl and stable municipal finances, which themselves are required to implement low-carbon transport systems and infrastructures.

When the Wall Street engineered financing of housing in the USA imploded and the Great Recession hit major economies, Spanish budgets were stable, showing a relatively modest public debt of 36.2% of GDP in 2008 (European Commission 2014a). But revenues were fed by an unceasing stream of constructions; and worse, these constructions were financed by uncontrolled and unstable financial instruments. It came then not as a surprise when in 2012 Spain had to apply for a rescue package from the European Stability Mechanism to rescue its banks, which had emitted these financial instruments. Yet another part of the story turns out to impact Spanish citizens even more directly: municipalities had learned to live on a steadily rising revenue stream from real estate construction. When the Spanish real estate bubble burst, the revenue stream ceased from one day to the other, while large expenditures still needed to be paid. House prices imploded; newly constructed towns were born as ghost towns. While arguably the pervert financing mechanisms and greed of banks caused these disastrous dynamics, the specific sprawl dynamics of Spanish municipalities and its tax system exacerbated the crisis of municipal debts. This is the starting point of our analysis.

The main concern of our investigation entertains the nexus of urban sprawl and local public intervention. Recent literature agrees that sprawled development leads to greater provision costs of local public services based on economics of density or agglomeration economics (Carruthers and Úlfarsson 2008; Carruthers and Ulfarsson 2003; Gómez-Antonio, Hortas-Rico, and Li 2014; Hortas-Rico 2014; Hortas-Rico and Solé-Ollé 2010; Solé-Ollé and Viladecans-Marsal 2012). But interestingly enough, the work made by (Hortas-Rico 2014) for the Spanish case identifies additional dynamics in the public finance-sprawl relationship that may lead to short-term surpluses of local finances. Taking her work as a starting point, we go a step further and analyse the medium to long-term effects on municipal budgets for the Spanish case. Our analysis focuses on the period when the intergovernmental transfers stopped as a consequence of the financial crisis to better estimate the role of local fiscal and planning instruments.

We review literatures that provide insights on the nexus between urban sprawl, local debts, and location values (section 2). After explaining our methods (section 3), we investigate quantitatively how local land-use decisions shape municipal finances (section 4). We then discuss our results and conclude by suggesting that land use decisions at the local level influence both local financial sustainability and environmental change, and therefore should become focal points for municipalities that wish to tackle these two fronts to their own and the larger common benefit (sections 5 and 6). Our results reveal that municipal property tax level and design drives urban sprawl; and that short-sighted public finance strategies backlash upon the implosion of real estate bubbles. We point to the importance of recurrent location value taxes to stabilize municipal finances.

2. Literature review

2.1 Urban sprawl and municipal indebtedness in Spain exceeds EU levels

Although different definitions exist to measure urban sprawl, they have common features: low levels of population density, lack of mixed use and long commuting distances (Brueckner 2000; Galster et al. 2001). Since the mid-1990s, Southern European cities experienced rapid urban expansion with these characteristics (European Environment Agency 2006; Kasanko and Barredo 2006; Saliba 1990; Schwarz 2010). Historical data shows that European cities now cover a surface 75% larger than in the mid-1950s, whereas population has grown only by 35% (European Environment Agency 2006). In particular, recent data points to an alarming trend: almost 1000 km^2 per year were converted to urban land cover in the last decade, the majority of it turned into housing and recreation areas (European Commission 2013). But Spain is by far the largest contributor (25%), doubling its total amount since 2000[3]. This difference also holds when we normalize by population; the annual land converted to urban use was 70m^2 per capita between 2000 and 2012 in Spain, surpassed only by Ireland and Malta[4] (European Commission 2013).

[3] Share of built-up area for the years 2000, 2012: Spain (1.93%; 3.9%) EU27 (4.0%; 4.9%).

[4] Land converted to urban use per capita 2000-2012 for the EU27: 34 m^2.

Box 1. Desirability and Costs of Urban Sprawl

Although urban sprawl may have several desirable outcomes –e.g. household´s preferences for larger housing units-, the undesirability of sprawl has been widely justified in the literature through multiple arguments. Inefficient land consumption depletes natural resources, including land and soil (Cervero 2001; Duarte and Tornés Fernández 2014; European Environment Agency 2006; M. T. Fernández and Duarte 2012; M. T. Fernández and Duarte 2012; Marmolejo Duarte and Tornés Fernández 2012; Stellmes et al. 2013). Sprawl induces high operational energy consumption of households, mostly due to the large shares of motorized transport modes, and longer distances travelled, increasing transport emissions consequently (Bart 2010; Cervero 2001; National Research Council 2009; National Research Council 2002; Newman and Kenworthy 1989; Perkins et al. 2009; Rickwood, Glazebrook, and Searle 2008; Su 2011; Troy et al. 2003). Sprawl-related commuting patterns also cause significantly higher adverse health effects than transit-oriented modal shares (Berrigan et al. 2014; Bhatta and Drennan 2003; Creutzig, Mühlhoff, and Römer 2012; Creutzig and He 2009; Dulal and Akbar 2013; Echenique et al. 2012; Griffin et al. 2013; James et al. 2013; OECD 2013). In addition, urban sprawl contributes to socioeconomic segregation, income inequality and polarization, and drives urban decay in core areas (Brueckner and Helsley 2011; Mieszkowski and Mills 1993; Mills and Price 1984). Such a space-explicit environment makes households highly vulnerable to changes in fuel prices (Dodson and Sipe 2007; Ferdous et al. 2010; Sexton, Wu, and Zilberman 2012). Last but not least, urban sprawl makes financing of public infrastructures more difficult as economies of density get lost. In Southern Europe, the combination of sprawled development with local politics lead to an inefficient allocation of vast amounts of local investment (Couch, Leontidou, and Petschel-Held 2007; Díaz Orueta 2007; European Environment Agency 2006; García-Palomares 2010; Hawkins 2013).

Spanish regions located along the Mediterranean coast and the central region are at the forefront of sprawling patterns (Catalán, Saurí, and Serra 2008; Ortuño-Padilla and Fernández-Aracil 2013; Saliba 1990; Solé-Ollé and Viladecans-Marsal 2012; Stellmes et al. 2013). Recent development shows strong residential suburbanization, experiencing growth on the fringes of cities with low densities, large losses of non-urban land cover, depopulation of metropolitan inner cores, predominant construction of single-family houses, and great expansion of motorized transport networks (Catalán, Saurí, and Serra 2008; Garcia-López 2010; Garcia-López, Holl, and Viladecans-Marsal 2013; Puertas, Henríquez, and Meza 2014, 2010–2045). New development has low-density, spatially segregated land use, accompanied by massive road network development (Catalán, Saurí, and Serra 2008). Barcelona and Madrid metropolitan regions are typical examples of the overall loss of land-use efficiency in the country (European Environment Agency 2006; García-Palomares 2010; Marull and Pino 2010). In Barcelona, the historical polycentric urban form has been highly disturbed through large suburbanization trends at the central business district and the pre-existing sub centres (Garcia-López 2010). Likewise, Madrid is regarded as one of the EU hotspots in suburban development (European Environment Agency 2006), with 50% greater urbanization surface compared to 1990s (European Commission 2013).

The adverse effects of such sprawled developments become increasingly evident. Spanish transport emissions, by half coming from private vehicles, have increased by one third since 1990 (Creutzig, Mühlhoff, and Römer 2012; Navalpotro, Pérez, and Quiroga 2012). Commuting volumes, distances, and car use mode share have multiplied in metropolitan areas, decreasing the energy efficiency of transport networks (García-Palomares 2010). Artificial land in coastal areas has doubled and by this, increased the vulnerability of these ecosystems and affecting its biodiversity. Soil sealing has diminished extremely important soil functionalities like its water storage capacity (Duarte and Tornés Fernández 2014; European Environment Agency 2006; M. T. Fernández and Duarte 2012). The Barcelona metropolitan regions displayed a simultaneous loss of energy and land-use efficiency since the mid-19th century, as tracked by changes in the functional landscape structure (Duarte and Tornés Fernández 2014; Marull and Pino 2010).

But sprawl has also provoked socioeconomic consequences. The rocketing of single-family houses' development in Spanish suburban areas has been linked to household's indebtedness (European Environment Agency 2006; García-Palomares 2010). The most extreme case is Madrid, where urban planning was based on real estate suburban development and a decentralization process for all economic activities, favouring the construction of employment hubs and shopping and entertainment malls all over the region (Couch, Leontidou, and Petschel-Held 2007; European Environment Agency 2006; M. T. Fernández and Duarte 2012; García-Palomares 2010). People have been pushed out of the city, and commuting volumes, distances, and car use mode share have skyrocketed together with increase in social segregation and share of households with mortgages (Díaz Orueta 2007; García-Palomares 2010).

The public sector has not been spared, especially after the financial crisis in 2008. Evidence tell us that the costs of providing local public services in more sprawled urban settlements increases notably (Carruthers and Úlfarsson 2008; Carruthers and Ulfarsson 2003; Hortas-Rico and Solé-Ollé 2010). At the same time, municipal revenues have dropped in more than 15% since 2007 (European Commission 2014a). At first, intergovernmental transfers and short-term funding schemes were used to cushion the financial crisis, aiming at maintaining the economic activity in the construction sector. Urban plans were used as budget adjustment instruments. But after the bursting of the real estate bubble many private investment projects stopped (Torres-Machí et al. 2013). Real estate-based revenues declined drastically; sales, income and value added taxes reacted immediately, and entitlement programs costs started to increase (Council of Europe 2011; Ministerio de Hacienda y Administraciones Públicas 2014a; Pérez López et al. 2013). The increasing uncertainty made supranational bodies curtail their financial assistance to municipalities, causing reductions in loans and transfers from 2011 onwards. Alternatives used to offset budgetary constraints in previous times, such as Public Private Partnerships (PPP), were also notoriously hindered (Council of Europe 2011). The central government launched a municipal rescue plan between 2012 and 2013, which granted local government's financial help under strict restrictions. However, only one-third of the municipalities absorbed more than 80% of the state fund (Ministerio de Hacienda y Administraciones Públicas 2015; Ministerio de Hacienda y Administraciones Públicas 2014a). Altogether, local budgets have been most severely affected by the financial crisis; the gap between revenues and expenditures appears insurmountable when previous sources of revenues are not taken into account (Council of Europe 2011). Regardless of ambitious budget cuts since 2009, the gap still remains. Adjustments have caused multiple adverse effects: temporal school closures due to poor hygiene, gradual deterioration of public transport, late payroll payments, and mass dismissals through employment regulation plans and privatization of public services between 2008 and 2013. But the local debt distribution among the more than 8000 Spanish municipalities is highly unequal: roughly a hundred of them represent more than 50% of the total local debt (Ministerio de Hacienda y Administraciones Públicas 2014a).

But the imbalance between revenues and expenditures dates back some time and it is not solely related to the financial crisis. Annual differences at the local level have increased almost 75% since 1995. Cumulative imbalances have multiplied by a factor of 10. Tellingly, these figures are much greater at the local and regional government level (Fig. 1a). When comparing with other EU members, local per capita indebtedness in Spain is above 180 EUR, whereas in the EU27 is only 10 EUR (both values close to 0 in 2000 (European Commission 2014a) (Fig. 1b). Spanish local public debt is the largest among EU states; it has risen to more than 11 million EUR, 220% of local annual revenues and almost 4% of the national Gross Domestic Product (GPD) in 2010[5] (Council of Europe 2011; European Commission 2014a; Ministerio de Hacienda y Administraciones Públicas 2014a). Debt management has become the Alpha and Omega of Spanish municipalities.

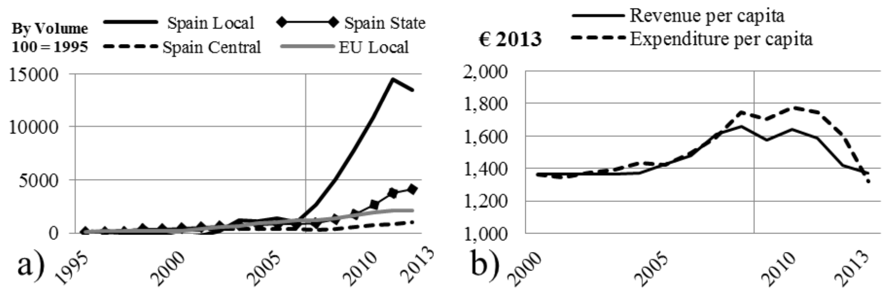

Fig. 1 Local Public Finances in Spain and the EU27. 1a: Cumulative difference between expenditures and revenues for the period 1995-2012 by level of Governance for Spain and EU27 (base year: 1995). 2b: Spanish average local

[5] National total debt has doubled in the same period up to 95% of GDP in 2013 (Ministerio de Hacienda y Administraciones Públicas 2014a).

revenue and expenditure per capita in adjusted 2013 € 1998-2012. Source: (European Commission 2014a).

2.2 Political particularities of Spanish municipalities

The Spanish municipal map (in terms of its high local political fragmentation) plays an important role in local dynamics. Land-use regulatory responsibilities are shared by different levels of government. The central government establishes the land-use regulation benchmark regarding protected areas, whereas local governments pass municipal land-use plans, which gives them freedom to define their land use management and urban planning strategy (Bilbao, García Valiñas, and Suárez Pandiello 2006; G. Fernández 2008; Hortas-Rico 2014). But municipalities also have the duty to provide a range of services according to their population, independently or in partnership with other municipalities. In order to exercise its powers, they have the power of regulation and self-fiscal organization, and tax and financial management, among others. Specific to real state taxation, municipalities may require non-recurrent taxes, recurrent taxes and development taxes. Non-recurrent taxes include: property transfer and certified legal documents tax, tax on inheritances and locations, special contributions. Recurrent taxes include: real estate tax, excises on real estate of non-resident organisations, tax on large commercial establishments, capital gain tax, and real estate tax for empty housing. Developing taxes include: urbanization fees, tax in the increase in value of urban land, fee on urban uses (Boletin Oficial del Estado 1985; Ministerio de Hacienda y Administraciones Públicas 2015; Velasco, Falcón y Tella, and Martínez Lago 2015). But the tax base is eroded in many ways. The real estate tax (IBI) for instance, excludes more than one third of the existing land uses. Reductions apply to properties with recent reassessments for the following 9 years. Deductions also apply to the tax bill, especially to new developments[6]. Regardless of the surcharges to metro areas and unused properties[7], they cannot offset the overall loses (Boletin Oficial del Estado 2004b; Boletin Oficial del Estado 2004a; Ministerio de Hacienda y Administraciones Públicas 2014b). In practice, Spanish municipalities enjoy a freedom to manage land use, which counteracts its relatively low fiscal responsibility.

2.3 The nexus between urban sprawl, municipal indebtedness and planning policies

To explore the link between urban sprawl, public indebtedness, and public intervention, we briefly point to important insights from the literature.

Conceptually, urbanization dynamics are described through changes in population, income, and transport costs, all of them linked through the price of

[6] Deductions: Regions of Ceuta and Melilla (-50%); new urban development (50-90%); social housing (50%).

[7] Surcharges for metro areas (0.2%); unoccupied residential buildings (0-50%).

housing (Alonso 1964; Mills 1967; Muth 1968). Fuel prices play a key causal role: they determine not only urban expansion and urban form but indirectly also the financial viability of public transit (Creutzig 2014). Urban sprawl is partially driven by cheap money fuelling new real estate development (Squires 2002) and by physical geography and local amenities (Burchfield et al. 2006; Saiz 2010). Sprawled development aligns with individual preferences for large affordable consumption of land (Fujita, 1989). Population growth, enhanced purchasing power and changes in transport infrastructure and expenditures explain sprawling patterns to a great extent (Baum-Snow 2007; de Bartolome and Ross 2007; Leroy and Sonstelie 1983; Molloy and Shan 2012; Rodriguez 2013; Small 1981). Urban form characteristics also influence land consumption and commuting patterns –e.g. fragmentation of urban fabrics and job ratio balance- (Duarte and Tornés Fernández 2014; M. T. Fernández and Duarte 2012). But fiscal policies and other public interventions are equally important in explaining recent developments. Literature highlights the role of market failures, fiscal distortions and similar government interventions (Brueckner 2000; Couch, Leontidou, and Petschel-Held 2007). For example, mortgage deductions and related housing policies encourage excessive land use conversion for residential use (Burchfield et al. 2006; Hamidi and Ewing 2014; Squires 2002). Excessive spatial growth of cities is also caused by under-pricing of infrastructures (Baum-Snow 2007; Brueckner 1997); absence of region-wide cooperation, territorial competitiveness, decentralized land use planning polices and permissive urban plans (Carruthers and Ulfarsson 2001; Chorianopoulos et al. 2014; Eicher 2008). Last but not least, property tax regimes are key in explaining urban development patterns (Anderson 1986; R. Arnott 2005; Brueckner and Kim 2003; Cocconcelli and Medda 2013; Groves 2009; Song and Zenou 2006).

Interestingly, in Europe fiscal and land-use policies are more important for urbanization dynamics than transport costs and income, especially compared to land-rich regions such as the US (Catalán, Saurí, and Serra 2008; Chorianopoulos et al. 2014; Couch, Leontidou, and Petschel-Held 2007; European Environment Agency 2010; European Environment Agency 2006). The work by (Couch, Leontidou, and Petschel-Held 2007) singles out political and social aspects as fundamental explaining factors of the recent urban growth patterns in Europe.

The Spanish case exemplifies this local political influence starkly. Here, income, transport costs, housing and the economic recession explain recent urban development only to a certain extent for suburbanized areas. While such variables explain up to 80% of the variation in the construction of highly dense centralized development, they can only explain 48% of suburban sprawled development (Ortuño-Padilla and Fernández-Aracil 2013). Also, although the relatively low fuel taxation in Spain in comparison to other EU countries makes it more susceptible to fuel price variations, no major changes on commuting patterns have been observed since the start of the crisis (Álvarez et al. 2011), possibly due to lock-in effects in land-use/commuting patterns. Social factors accelerated the sprawling development: Seasonal life-style patterns, fragmented work, and leisure time multiplied the demand for second homes and led to an oversupply of new dwellings unadjusted to population growth figures (Couch, Leontidou, and Petschel-Held 2007; European Environment Agency 2006; Hortas-Rico 2014). Crucially, suburbanization trends have gone hand in hand with planning decisions at the local level, such as the provision of public infrastructure, planning regulations and other public-related interventions (Couch, Leontidou, and Petschel-Held 2007; Jaraíz Cabanillas et al. 2013). In fact, local governments competed for the creation of new suburbs and increased the supply of land (Gómez-Antonio, Hortas-Rico, and Li 2014; Solé-Ollé and Viladecans-Marsal 2012). In this situation, household´s location preferences shifted towards segregated suburban communities (Díaz Orueta 2007; M. T. Fernández and Duarte 2012; García-Palomares 2010). In addition, national freeways and highways projects lacked planning restrictions, and lead to uncontrolled urban growth along transport corridors (Garcia-López, Holl, and Viladecans-Marsal 2013). In metro areas, motorway rings and duplications of pre-existing radial highways facilitated residential suburbanization even more (Díaz Orueta 2007). In Madrid for example, a decentralization process on all economic activities led to the development of employment hubs, shopping and entertainment malls throughout the region (Duarte and Tornés Fernández 2014; European Environment Agency 2006; M. T. Fernández and Duarte 2012). In Spain, urban sprawl was fed by municipal action.

But how does the above link with local indebtedness? Municipalities slipped into a vicious circle of mounting provision of public resources to attract external capital investment, mainly taking the form of real estate development. Urban surface per person has increased in more than 10% since 2000; importantly most of this increase is due to unused urban land (Ministerio de Hacienda y Administraciones Públicas 2014b). Consequently, there has been an overprovision of infrastructures and services for urbanization, financed through large public investments. One example is street light consumption. EU energy efficiency goals for 2012 limited the per capita average consumption at 75kWh/year. In Spain this number peaked at 113 kwh/year, the highest by far in the EU27[8]. The total cost of streetlight doubled between 2007 and 2012, from EUR 450 million to EUR 830 million (Sánchez de Miguel et al. 2010). Mammoth investment in transport infrastructure driven by political interests is another reason, where underestimation of investment and maintenance costs bankrupted municipalities in numerous occasions, especially for those municipalities higher degree of decentralization and inter-municipal cooperation (Pérez López et al. 2013).

Property taxation, often the most important source of local revenue, aims at recovering public expenditures in municipalities. When public investment – especially for new development- takes place, these fiscal instruments must ensure the raise of enough revenues to cover a share of the expenditures (Cho and Choi 2014; Medda 2012; Wang et al. 2015). In the case of new development, developers

[8] France: 90-77 kwh/year; Germany: 48-43 kwh/year (Sánchez de Miguel et al. 2010)

pay for the cost of new development (Almeida et al. 2013; Brueckner 1997; McFarlane 1999). Literature refer to as the so-called unearned value of locations, the share of property's worth which is not produced by landowner's labour, but from public intervention and to a certain extent from community actions and environmental quality (R. J. Arnott and Stiglitz 1979; Brandt 2014; Brueckner 2000; Fainstein 2012; Fernandez Milan, Kapfer, and Creutzig 2016; Mattauch et al. 2013; UN-HABITAT 1976). But Spanish municipalities have long counted on regional and national grants to balance their budgets. Additional infrastructure requirements associated with urban growth are mostly funded by upper tiers of government as some capital transfers are dependent on the municipalities' infrastructure deficit (Hortas-Rico 2014; Ministerio de Hacienda y Administraciones Públicas 2015). Literature has already pointed at the role of planning decisions on land values and, as a consequence, development patterns (Almeida et al. 2013; Altes 2009; Cocconcelli and Medda 2013; Rebelo 2009).

In Spain, land supply and the property tax design are particularly relevant. Land supply is considered to be one major contributor to sprawled development especially in the suburbs, making developable land cheap enough to attract investors (Gómez-Antonio, Hortas-Rico, and Li 2014; Solé-Ollé and Viladecans-Marsal 2012). But revenues of property taxes in Spain have been relatively instable since early 2000´s compared to EU27; temporal variability emerges especially when investigating recurrent and non-recurrent property taxes independently[9] (European Commission 2014b; European Commission 2012; European Environment Agency 2010). As property taxes are the most important source of revenue for municipalities, they are likely to play a crucial role in explaining debt levels.

We here look at all these views together and focus on exploring the link between urban developments, municipal finances and location values at the same time to see if local decision-making does have a say in the simultaneous sprawled settlements, location value increase and indebtedness. We use systematic statistical analysis to understand the role capitalization dynamics in real estate markets and the link with urban sprawl and debts in Spain. We explain our data and method in the next section.

3. Methods

3.1 Temporal development of urban location values and property taxes

To overview the development of real estate taxes and land supply with that of municipal indebtedness we first look at the behaviour of all real estate taxes and

[9] Recurrent taxes refer to those ones that are collected periodically, mostly on an annual basis. Non-recurrent taxes consist on transfer taxes, applicable only when a property changes its ownership.

compare them with location values for the period 2000-2013. We include values for developable land to tell us about land supply prices. We use data on market and cadastral location values from the Spanish Ministry of Public Works and the Ministry of Finance and Local Administration respectively (Ministerio de Fomento 2015; Ministerio de Hacienda y Administraciones Públicas 2014b). We also calculate the location share (the% of real estate values coming from location values) to indicate the capitalization dynamics of public intervention in the real estate market. Tax revenues come from the European Commission report "Taxation trends in the European Union (European Commission 2014b)" and the Tax Revenue Statistics Database (European Commission 2015). All prices are adjusted to 2013€.

3.2 The nexus between sprawl, indebtedness and location values

For analysis, we rely on the urban economic framework explained in section 2. Formally, the urban economic budget equation allocates income Y to spurious consumption c, transport costs T=tr (with t marginal transport costs and r the travel distance to the inner city), and land consumption S=sR (with R rental costs per unit land and s the amount of land consumed): Y=c+Tr+Rs. This framework clarifies that urban sprawl is driven by higher income and lower marginal transport costs, both of which enable an higher amout of land consumption. In contrast, a restriction of land available for residential purposes would increase R and by this limit land consumption. Municipal expenditures on road infrastructure would reduce marginal transport costs and increase urban sprawl. Everything else being equal, higher expenditures would also be related to higher debt levels. Also, a tax rate on property would reduce urban sprawl and the value of property compared to the untaxed case. We use this theoretical framework to motivate the statistical analysis.

We focus on the specific link between sprawl, indebtedness and location values and their relation with municipal intervention. We define four urban indicators to look at sprawl, indebtedness, and location values, five to look at municipal characteristics, and six indicators to evaluate municipal intervention (Table 1). In order to have a study period where intergovernmental transfers and short-term urban development revenues do not distort municipal budgets, we use data for the year 2013 for all variables except from sprawl.

The sprawl variable is defined as the difference in urban surface built per capita between 2006 and 2013. Among the multiple approaches to define sprawl, the per capita urbanised land has been recently used in the Spanish context by (Hortas-Rico and Solé-Ollé 2010) accompanied by other variables to increase preciseness. We take the urban surface built (following the sprawl definition used by (Hortas-Rico 2014) for two points in time -2006 and 2013- and calculate the percentage change for the period to better assess the development pattern. Looking only at urban surface built – not total urban surface- and having two points in time, together improve the sprawling indicator. Municipal indebtedness is defined as per urban surface to better account for the spatially explicit capitalization dynamics of public investment[10]. We only look at urban surface because the majority of the public services municipalities are responsible for are carried out in designed urban land (Boletin Oficial del Estado 2004a; Boletin Oficial del Estado 1985; Velasco, Falcón y Tella, and Martínez Lago 2015). For location values, the Spanish cadastre database distinguishes between location and structural value of properties. We use the location values as they are a closer indicator of the capitalization dynamics we here want to look at – property values includes structure values, which do not necessarily come from the capitalization of public investment (R. J. Arnott and Stiglitz 1979; Burge 2014; Fainstein 2012; Mattauch et al. 2013; UN-HABITAT 1976). We use per surface location value and residential property average value -the Spanish cadastre does not distinguish between structure and location values for different land uses-. Based on the insights from urban economic theory, we define the following municipal characteristics: share of urban surface – urbanity indicator-, population, total urban surface, and the distance to the nearest provincial capital – economics of density indicators- (Brueckner 2000; Brueckner and Fansler 1983; Burchfield et al. 2006; Fujita 1989; McDonald 2009). We include a dummy variable "Province"[11] to control for regional effects – notably income. For evaluating the public intervention, we focus on tax-induced distortions and land supply because they have been identified as major drivers of recent development in southern Europe (Couch, Leontidou, and Petschel-Held 2007; Gómez-Antonio, Hortas-Rico, and Li 2014). Tax-induced distortions are evaluated though the urban property tax rate, the frequency of assessment (last assessment year) and the erosion of the tax base –in% loss- due to exemptions, reductions and deductions. The amount of land classified as developable indicates the land supply (Gómez-Antonio, Hortas-Rico, and Li 2014; Solé-Ollé and Viladecans-Marsal 2012).

The data is from the Spanish cadastre (Ministerio de Hacienda y Administraciones Públicas 2014b) except from that of municipal debt, which belongs to the Ministry of Finances and Public Administrations (Ministerio de Hacienda y Administraciones Públicas 2014a). There were 8188 Spanish municipalities in 2013. The cadastral database does not provide data for municipalities in the Basque Country and Navarra (594) and we therefore exclude them from the study. Next, 9 municipalities changed their boundaries between 2006 and 2013, and we cannot calculate the sprawl variable. This said our initial sample consists of 7585 municipalities. The National Institute of Statistics defines a city one municipality with more than 10000 people (INE 2015). The vast majority of the Spanish municipalities correspond to rural areas; with very low number of people and little urbanised location (Fig. 2). We therefore fix the population limit to 13000 to raise the average urban share of the sample from 10 to 20%[12] (see Fig. A.1).

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[10] Typically, public investment variables are expressed in per capita (Bernardino Benito 2009; Garcia-Sanchez, Mordan, and Prado-Lorenzo 2012; Hortas-Rico 2014), but it does not reflect capitalization dynamics into location values.

[11] There is no data available for income at the municipal level for the year 2013.

[12] A Kernel density curve serves us to estimate the optimal population limit to increase the urban share in the sample. Municipalities with population between 10000 and

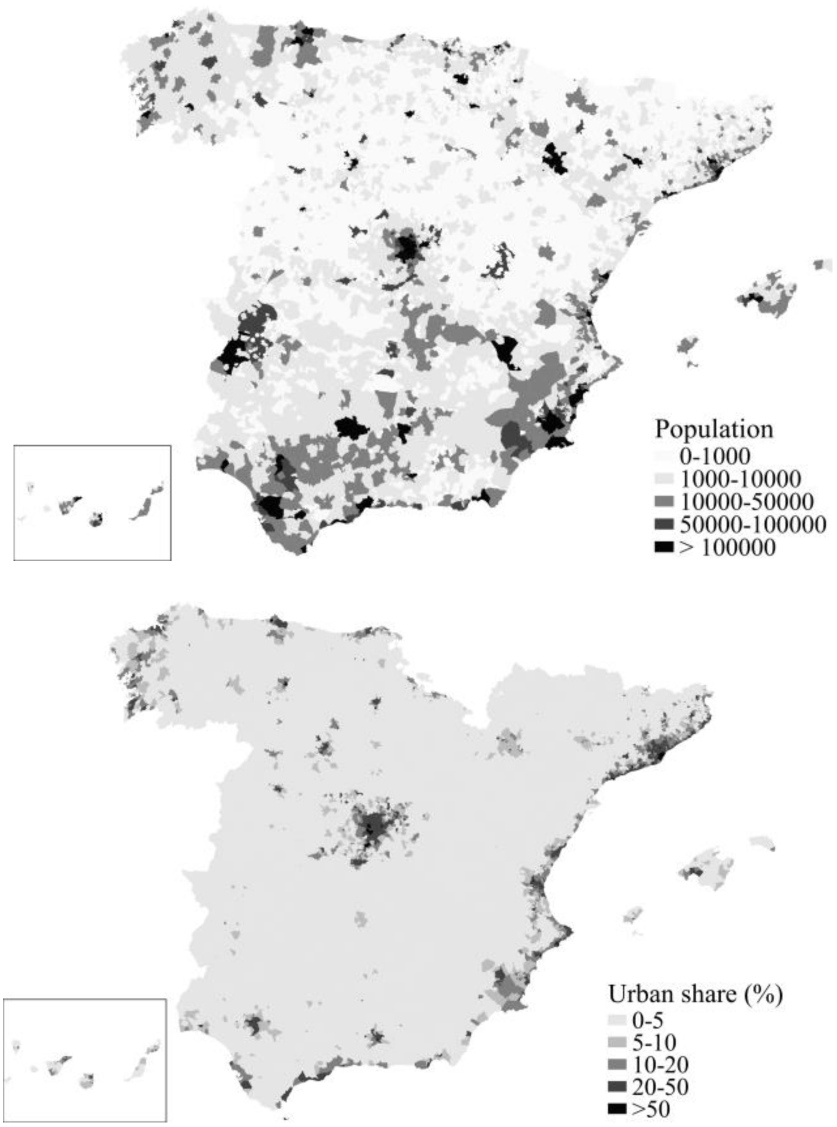


Fig. 2 Population and urban share of Spanish municipalities in 2013[13]

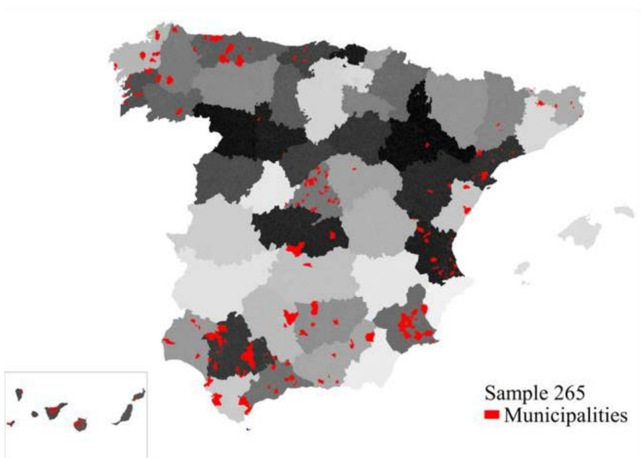
We also control for residential land share to exclude municipalities that did not base their development on residential sprawl. As there is no data on the location use surface of the municipalities, we take the share of total cadastral value corresponding to residential land share. The total sample shows a residential cadastral value share between 55 and 85 (see Fig. A.1), thus we exclude those municipalities with less than 55% of residential cadastral value. Finally, we control for the municipal distance to capital to focus on suburban sprawled development. We exclude metropolitan urban centres – province capital municipalities- and

13000 have relatively low urban share and would therefore not be representative if they were to be included.

[13] Data missing for Basque Country and Navarra for urban share as it is not available in the cadastre.

municipalities located within a ratio of 4.5[14] km as well as those municipalities that are no longer in the metropolitan areas of influence -45 km-[15]. Our statistical analysis is based on a sample of 265 municipalities, representing the 54% of the total Spanish population[16] and 63% of the province map[17] (Fig. 3).

We perform a statistical analysis by looking at how our selected municipal characteristics and the public intervention indicators have a relation with sprawl, surface indebtedness and location values. We use ordinary least squares models - multivariate regression analysis- to explain the external dimensions in the empirical data. We test several linear regression models according to the existing literature that substantiate our models, including both municipal characteristics and local intervention indicators as explanatory variables. We further contemplate the link between the three urban indicators – in case of endogeneity -, as we include the additional other two in the regressions, although they do not always have explanatory power (e.g. for sprawl, the regression model also includes surface debt and location value).



Province	N°	Province	N°
Albacete	1	Jaen	4
Alicante	16	Lleida	2
Almeria	4	Lugo	2
Asturias	9	Madrid	28
Badajoz	1	Malaga	11
Barcelona	45	Murcia	11
Cadiz	8	Ourense	1
Cantabria	4	Palmas, Las	7
Castellon	4	Pontevedra	10
Ciudad Real	2	S.C. Tenerife	9
Cordoba	2	Sevilla	16
A Coruna	6	Tarragona	7
Girona	6	Toledo	2
Granada	6	Valencia	24
Guadalajara	1	Valladolid	2
Huelva	5	Zaragoza	1
I. Baleares	8	**Total**	**265**

Fig. 3 Sample of 265 selected municipalities for the statistical analysis and their regional distribution according to provinces.

[14] Average ratio of regional capitals: 4.5 km (INE 2015).

[15] Recent case studies looking at commuting patterns in Spain report community distances typically varying between 0 and 45 km in metro areas (Creutzig, Mühlhoff, and Römer 2012; Muñiz and Galindo 2005; Romaní, Suriñach, and Artiís 2003; Royuela and Vargas 2009).

[16] Spanish population 44274277; sample population: 23838423.

[17] Spanish provinces: 52; sample provinces: 33.

Table 1. Definition of the variables and descriptive statistics for the sample of 265 municipalities (for the year 2013, except for the sprawl variable)

Indicator	Measure	Variable	Unit	Mean	Min	Max	S.D
Urban indictors	Sprawl	Δ Urban surface built per capita 2006-2013	m^2/pop	6.5	-164	179	33.8
	Debt	Surface debt: Municipal debt per surface	€/m2	3.7	0	33	4.4
	Location values	Location value	€/m^2	152	14	1086	151
		Residential property value (mean)	€	72529	16694	262797	45138
Municipal characteristics		Population	n°	43171	13068	296479	46955
		Share urban: Urban surface in% of total surface	%	22.2	0.5	76	17
		Urban Surface	ha	858	32	5546	842
		Distance to capital	km	22.9	4.6	45	11
		Province (dummy)	-	-	-	-	-
Local Intervent.	Tax induced distortion	Tax rate	%	0.6	0.2	1.2	0.2
		Exemptions	%	3.29	0	33.5	4.0
		Reductions	%	11.85	0	56.33	15.79
		Deductions	%	3.12	0	18.23	3.62
		Assessment year	year	2003	1986	2013	-
	Land supply	Share of urban surface not built	%	37.3	7.4	82.8	13

4. Results

First, we analyse how locations values and municipal tax revenue developed before and after the implosion of the real estate bubble in 2008. Motivated by the results, we then quantitatively assess, with regression analysis, how urban sprawl, debts, and location value depend on urban characteristics, and municipal tax design. The results demonstrate that sprawl, debt, and location value vary with location, and that municipal design of land taxation has a notable impact.

4.1 Disjoint development of location values and property tax revenues

With the financial crisis, the mean location value, as determined by the market, more than halved between its peak in 2007 and 2013, our last data point (Fig. 4a). Interestingly, the cadastral value increased slightly, reflecting a convergence of market and assessed value; in fact the share of location cadastral value increased by 2% between 2008 and 2010, indicating a higher assessed value of locations compared to structures in the property price. The price of land supplied by municipalities for further residential build-up only increased 10%. This suggests that, on the one hand, further residential build-up ceased or slowed down, while, on the other hand, municipalities still set land aside for further development.

The development of tax revenues before and after the financial crisis clarifies the dynamics. Revenues from development taxes decreased with the crises by 47% indicating continued development albeit at lower speed (Fig. 4b). However, the non-current taxes display a drastic dynamic. Non-recurrent taxes i.e. transfer taxes of properties at market value, more than doubled in the build-up of the real estate bubble between 2002 and 2007; and they dropped drastically when the market collapsed to below 2002 values (Fig 4a). In absolute terms, 2013 revenues were 15% less than those from 2000. At the same time recurrent taxes have increased more than 40%, uninterrupted by the real estate bubble. This reflects that recurrent taxes are levied against the cadastral value, not the market value (compare with Fig. 4a). Together, all taxes in place captured on average no more than 0.25% of the total annual cadastral value (see Fig. A.2 for disaggregated revenues from all types of property taxes), which is, in addition, far below market prices (on average urban market values are almost 65% higher than cadastral values in the period 2000-2013). This suggests that recurrent taxes prevent municipal budgets from the absolute worst, but that they could also play a larger role towards recovery.

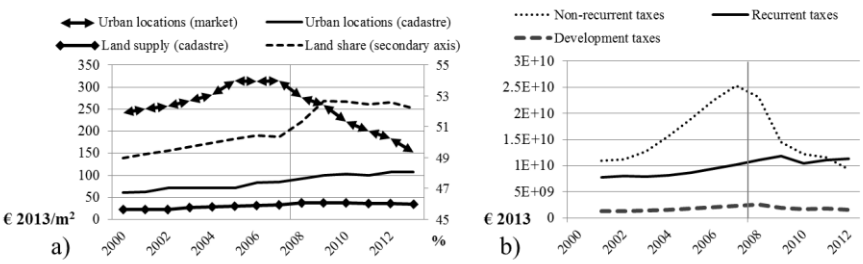


Fig. 4 a) Urban location values 2000-2013 (market and cadastral value) and land share (secondary axis); b) Revenue from fiscal instruments based on property in Spain, 2000-2013. Source: European Commission, 2014a, 2014b; Ministerio de Fomento, 2015; Ministerio de Hacienda y Administraciones Públicas, 2014.

We now proceed by investigating the independent variables influencing urban sprawl, municipal debt, and location value, revealing location-specific variation between municipalities.

4.2 Statistical analysis

We present the regression models on urban sprawl, surface debt and location value in Table 2. We run different test to check for collinearity, where none of the variables from the three reported regressions are worrisome. Our results show the following: urban sprawl can only be explained to a limited degree by our set of variables (R2: 0.22). Specifically, surface debt influences urban sprawl, albeit weakly: the higher the surface debt, the higher the sprawl. This result coincides with the hypothesis that public infrastructure investment for urbanization has been cost-free for developers (development taxes don’t work, or not enough). Possibly municipalities learnt to live on transfers, redesigning from rural and urban, a result that goes in line with the bubble dynamics (results substantiated by (Hortas-Rico

2014). As expected from urban economic theory, the results show that the lower the residential value the higher the sprawl, as sprawl occurs in "cheap land" or where developable land is subsidised. In the same line, lower population, higher urban surface and higher distance to metropolitan areas lead to higher sprawl. (Brueckner and Fansler 1983; Burchfield et al. 2006; Mieszkowski and Mills 1993; Saiz 2010). As expected, the lower tax rates of developed land, the higher sprawl: a low tax rate appears to incentivize development (Anderson 1986; Groves 2009). The assessment year is also related to sprawl: land for development is reassessed before and after development. Contra intuitively, land supply does not explain sprawl in our sample – although they correlate significantly, see Table A.1-. An explanation could be that our land supply variable is not well defined on a temporal scale. Development occurred already in the previous years and land reclassification for urban development is no longer occurring.

Surface debt can be partially explained by our set of variables (R2:0.44). Surface debt co-varies to considerable degree with location values. Higher location values produce higher debt when they are not captured by taxes. This confirms our hypothesis that public surface debt is privately capitalized by location values. In addition we observe that the more population and the lesser the urban surface, the higher the surface debt. Clearly, in areas with higher population density, the higher construction volume per surface leads to higher debts. Local intervention is also relevant. As expected, the more deductions the more surface debt, because, as noted above, new urban development benefits from deductions that go from 50 to 90% of the tax bill.

Finally, location value is surprisingly well explained through a larger set of variables (R2:0.67). Higher surface debt produces higher location values as public investment increases location values (see Fig. 5 for a spatial visualization). More population, share urban and less surface leads to higher values, a result that also complies with urban economics (Alonso 1964; Mills 1967; Muth 1968). Quite intuitive, the more recent the assessment of cadastral values the higher value, highlighting the importance of the frequency of assessment. The lesser the land supply, the higher the land scarcity and thus the higher the market competitiveness leading to higher location values. Finally, lower tax rates lead to higher location values. This result is coherent with the insights from land taxation theory, indicating that higher taxation leads to counterfactually lower location values (not increase location values but stabilize them) (Cocconcelli and Medda 2013; Dye and England 2009; Tideman 1982).

Table 2: Regression models of urban indicators, correlation coefficients and p-values from a statistical analysis of a dataset comprising 265 municipalities. Coefficients listed (adjuted R^2) are for the following models: a) *sprawl = surface debt + residential value + population + urban surface + distance to capital + tax rate + assessment year*; b) *surface debt = location value + population + urban surface + deductions;* c) *location value = surface debt + population + share urban + urban surface + tax rate + assessment year + land supply*. Ommited values ("-") denote variables that removing them from the model changed R^2 by less than 0.01 (the results presented therefore are refered to models that omit such variables in question). Statistical significance: * significant at $p < 0.05$ and ** $p \leq 0.01$ respectively.

		Dependent variable for the regression models analysed		
	Data units	**Sprawl** (Δ Urban surface built per capita 2006-2013)	**Surface debt** (Municipal debt per surface)	**Location value**
R^2 (adjusted)		0.22	0.44	0.67
Debt	€/pop	-	-	-
Surface debt	€/m2	0.82*	-	9.18**
Location value	€/m2	-	0.01**	-
Residential value	€	-0.0003**	-	-
Population	n°	-0.0001*	0.0005**	0.0006*
Share urban	%	-	-	1.59**
Urban surface	ha	0.02**	-0.002**	-0.03*
Distance	km	0.44**	-	-
Province	(dummy)	-	yes	yes
Tax rate	%	-20.37**	-	-316.35**
Exemptions	%	-	-	-
Reductions	%	-	-	-
Deductions	%	-	0.12*	-
Assessment year	%	1.17**	-	7.33**
Land supply	%	-	-	-2.61**

5. Discussion

The combination of financial crisis and real estate bubble caused high damages on the national economy and the overall welfare of the population through public budget cuts, high unemployment and mortgage rates. And land intensive urban development is deeply entangled with environmental consequences such as higher greenhouse gas emissions. The 20 years preceding the financial crisis have seen an explosion of land use for housing and transport, particularly during the last decade, with often-detrimental outcome for the environment and climate change. Our analysis reveals how municipal policies participated in the making of this disaster.

Our results need to be understood in the context of previous studies. Notably, empirical studies already demonstrated the downside of sprawling patterns for municipal budgets (Carruthers and Úlfarsson 2008; Carruthers and Ulfarsson 2003; Gómez-Antonio, Hortas-Rico, and Li 2014; Hortas-Rico 2014; Hortas-Rico and

Solé-Ollé 2010; Solé-Ollé and Viladecans-Marsal 2012). Specifically, (Hortas-Rico and Solé-Ollé 2010) indicate that sprawled development leads to greater provision costs of local public services. (García-Sánchez 2006) evaluated the efficiency of the water supply and found that population density has a statistically significant impact on the indexes of efficiency. But (Hortas-Rico 2014) also provided empirical evidence of the municipal interest of promotion urban development. Her results indicate that the increase in current revenues offsets the increase in current expenditures due to public service provision for new development. Although sprawl demands new infrastructures, the deficit generated by this new infrastructure is covered by intergovernmental transfers and, to a lesser extent, by revenues linked to the real estate cycle (including planning permissions, construction taxes, and taxes on land value improvements, revenues from sales of public land and asset revenues).

These findings suggest that municipalities may be interested in encouraging urban sprawl. But our research points at the pitfalls of such a rationale. The financial crisis stopped the upcoming revenues from grants from upper tiers of governments and evinced the inefficiencies of revenue associated with the real estate cycle itself.

In Spain – like most Southern European countries – municipal revenues system relied mainly on non-recurrent property taxation. But these fiscal packages were unable to recapture public urbanization investments –previously refer to as unearned values. Development taxes captured a very limited share of the public investment related to urban growth and non-recurrent taxes – taxes, stamps, duties, etc. – crashed with the financial crisis. Revenues from recurrent taxes remained stable or increased slightly but their magnitude was capturing only a small part of market values. The causes are many and varied. First, cadastral values remain below market values by a large margin. Second, the municipalities' right to adjust the tax rate within a certain range encourages them to fix it at maximums of around 0.5% due to fiscal competitiveness[18] (Boletin Oficial del Estado 2004b; Ministerio de Hacienda y Administraciones Públicas 2014b). But most important, third, are the uncountable number of exemptions, reductions and deductions of the property tax regime. Last but not least, municipal budgets have lacked in transparency and accountability around their urban development plans (Pérez López et al. 2013). As in many other countries, Spain lacks in adequate long-term fiscal instruments able to recover significant shares of public investments in the real estate market cycle, which has provoked exacerbated capitalization dynamics in the last decade (Dye and England 2009; European Environment Agency 2010; Gaffney 2009; Ingram and Hong 2012; Institute for Fiscal Studies and Mirrlees 2011; Raslanas, Zavadskas, and Kaklauskas 2010; UN-HABITAT 2011).

[18] Urban tax rate range: 0.4%-1.1%

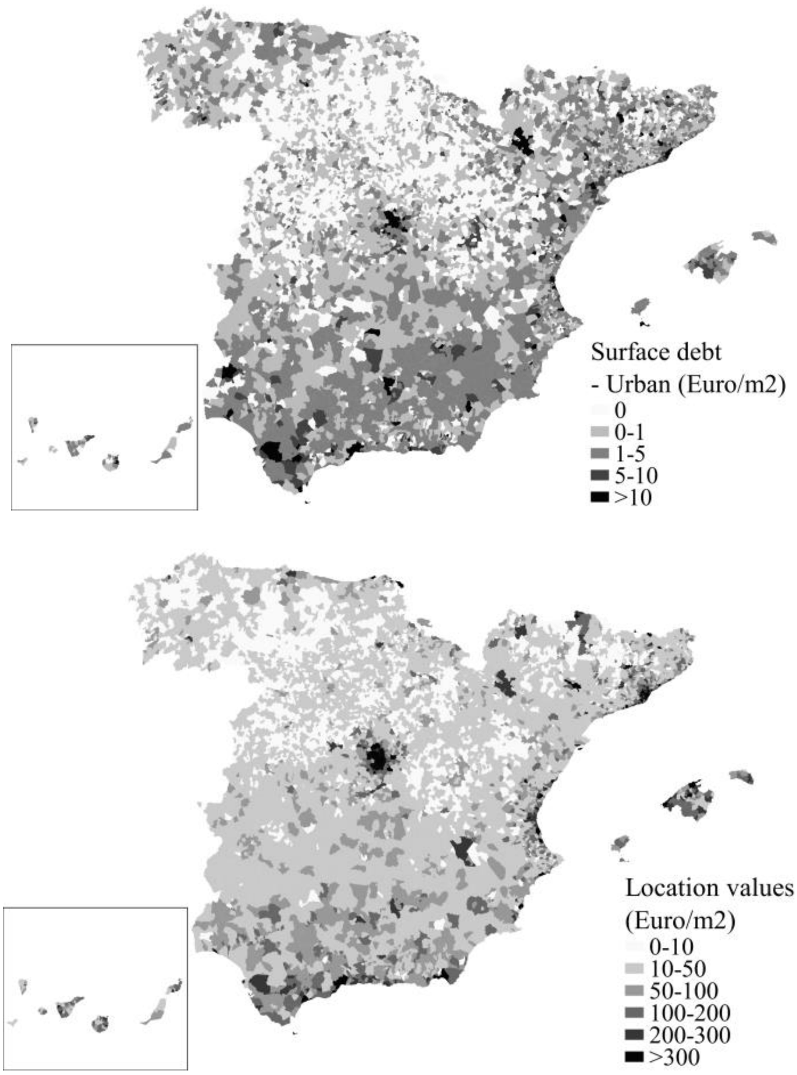


Fig. 5 Surface debt and location values are spatially joint. Source: (Ministerio de Hacienda y Administraciones Públicas 2014b).

The canonical variables from urban economics can hardly explain the difference that exists between Europe´s and Spanish recent urban land consumption and municipal indebtedness. In fact, local decision-making greatly influences the variables that shape the development of urban settlements. Notably, we find that surface debt contributes to explaining location value. Location values are higher where municipalities capture only a small fraction by taxes. This may indicate capitalization dynamics through real estate values. In fact, debt values in turn are higher were tax deductions are more common (but not were tax rates are lower). The role of tax deduction may appear somewhat surprising but, in fact, is in accordance with the literature, emphasizing that tax deduction became a major instrument in municipalities, systematically skewing the tax revenue statistics (Brueckner and Kim 2003; Groves 2009; McFarlane 1999).

Urban planning shapes land use mix, determines connectivity and accessibility to urban services, its attractiveness and, ultimately, their perceived value in the real estate market. Thus, household location preferences and private investor's decisions rely heavily on how municipal intervention is designed. Inversely, municipal decision-making for urban planning can create market distortions that - in a climate of propriety - inflict externalities. Often land will then be excessively developed. Our research combines the insights on urban sprawl from public finances, urban economics and environmental sciences and creates an explicit link between this type of development and municipal indebtedness. We argue that, if no capture of the value added by public intervention occurs, this value accumulates in real estate assets through location value increase. As municipal debts enlarge, strict budgetary constraints affect the provision of public services and investments. Our study also points towards a potential remedy: location value taxation has considerable to stabilize municipal budgets again, especially in those areas struggling the most (Cho and Choi 2014; McCluskey and Trinh 2013; Wang et al. 2015) and, at the same time, can help curve urban sprawl and its related CO_2 emissions (Almeida et al. 2013; Altes 2009; Bart 2010; Roakes 1996). Furthermore, location value taxes are also slightly more progressive than a property tax and stabilize real estate prices even under market bubbles conditions (Cocconcelli and Medda 2013; Haila 1985; Plummer 2010; Wang et al. 2015).

Clearly, both local policy instruments and national and global real estate markets and financial engineered contributed to the Spanish real estate bubble. We suggest that the joint analysis of local and global factors to the real estate crisis, both with statistical assessment, and with theoretical analysis, is a fruitful field. A more comprehensive analysis would also improve the resolution of urban economic variables, such as income on household level, and travel time costs, but also include a wider perspective on municipal budgets. Such studies would further contribute to help policy makers in preventing new outbreaks of real estate and banking crises.

6. Conclusion

In this paper, we investigated the joint development of rapid urban land consumption and municipal public finances in Spain. While shaped by global dynamics in financial markets, public intervention shapes sprawl and local debts through land values. The combination of permissive urban planning and tax-induced distortions exacerbated the housing bubble, and unsustainable urban expansion. To remedy this situation, we suggest that recurrent location values in real estate markets would reduce debt burdens and less permissive planning would alleviate sprawl in the long run. Crucially, these results demonstrate that municipal policies that seem adequate in times of expanding financial markets and associated liquidity can prove disastrous in the long-run. Instead prudent municipal policies disentangle public finances from temporary growth dynamics. Our analysis serves as a basis to investigate the entangled role of local decisions and global markets on land use, and its multi-scale effects.

Appendices

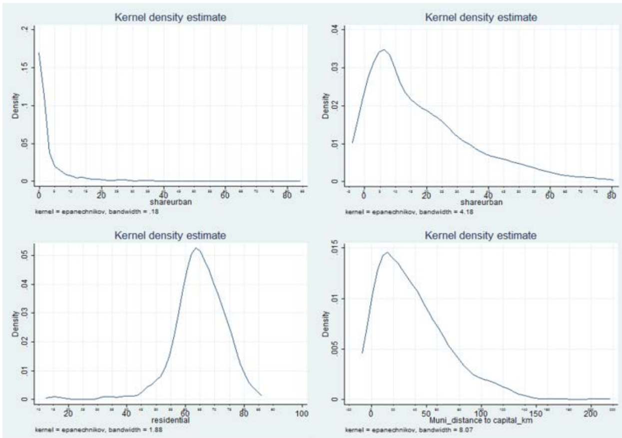


Fig. A1. Sample selection criteria for statistical analysis; a,b) Difference in the variable share urban for municipalities with a) below 13000 people and b) above 13000 people; c,d) density distribution of c) residential values and d) municipal distance to capital for the whole sample (7585 municipalities).

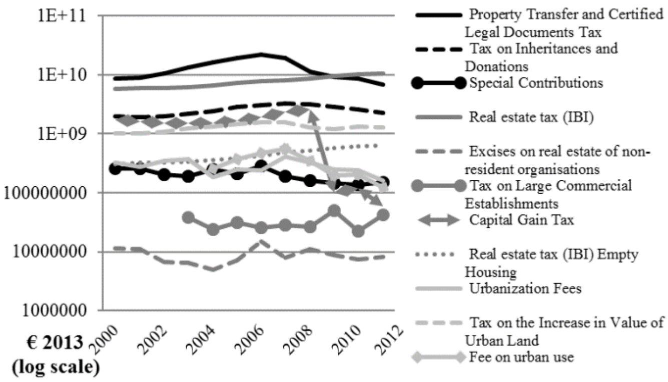


Fig. A.2. Disaggregated revenues from property taxes in Spain (2000-2013) Source (European Commission 2015; European Commission 2014b).

Table A.1. Relationship between urban indicators, municipal characteristics and local intervention. (Pearson's coefficient). Significant relationship if p < 0.01 (*), and strong relation if p < 0.001 (**).

	Sprawl	Surface debt	Land value	Residential mean	Population	Share urban	Urban surface	Distance to capital	Tax rate	Exemptions	Reductions	Deductions	Assessment year
Surface debt	0.0												
Land value	-0.1*	0.5**											
Residential mean	-0.3**	0.0	0.5**										
Population	0.1	0.4**	0.3**	0.1									
Share urban	-0.1*	0.2**	0.4**	0.3**	0.3**								
Urban surface	0.2**	0.0	0.0	0.2**	0.7**	0.1							
Distance to capital	0.2**	-0.1	-0.2**	0.01	-0.1	-0.4**	0.0						
Tax rate	0.0	0.2**	-0.2**	-0.4**	-0.1	0.0	-0.2*	0.1					
Exemptions	0.0	0.0	0.1	0.2*	0.0	0.1*	0.0	0.0	-0.1				
Reductions	0.0	0.1	0.3**	0.5**	0.1	0.1	0.1	0.0	-0.1	0.0			
Deductions	0.0	0.2*	0.0	0.0	0.2*	0.1	0.1*	0.0	0.0	0.0	0.0		
Assessment year	0.0	0.1	0.4**	0.6**	0.1	0.2*	0.1	-0.1	-0.2**	0.2*	0.8**	-0.1	
Land supply	0.2**	-0.3**	-0.3**	0.0	0.0	-0.1	0.3**	0.1*	-0.2**	0.1	0.0	0.0	0.1

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Chapter 7

A systematic framework of location value taxes reveals dismal policy design in most European countries[1]

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A systematic framework of location value taxes reveals dismal policy design in most European countries

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Abstract

Location values have long been recognized as an attractive instrument to raise municipal revenues. First, they increase fiscal efficiency and equability compared to traditional property taxes. Second, they can be used to enhance sustainable urban planning. The question of how to design a location value tax has long been discussed in various strands of literature, but there are few efforts to create multidisciplinary approaches. This lack of reconciliation hampers the discussion on optimal designs that includes all economic, social and environmental considerations. Here we combine literature on public finances, urban economics and value capture with that of sustainable urban planning to narrow this gap. We develop a framework to assess the design characteristics of location value taxes from a sustainability perspective, and apply this framework to assess current practices in Europe. The analysis reveals severe shortcoming in policy design in most European countries, although Denmark provides a more promising example. Nonetheless location value taxes have a high potential for improving sustainable urban planning.

Keywords: location value tax; urban sustainability; European property taxation.

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1. The rationale of a location value tax for urban sustainability

Cities constitute both sources and solutions to climate change and other sustainability challenges. While diverse disciplines address some aspects of urbanization, there is a need to integrate this knowledge in order to find optimal – or at least appropriate - pathways that could minimize the negative impacts as well as maximize the positive outcomes of the urbanization process (Rosenzweig et al. 2011; Seto et al. 2014). Solutions are strongly related to policy instruments that enhance synergies among multiple objectives, and well-designed urban plans exhibit great potential (Seto et al. 2014; Zanon and Verones 2013). On the one hand, they efficiently limit urban externalities (R. Arnott 2011; Brueckner and Kim 2003; Kaza and Knaap 2011). On the other hand, they may alleviate municipal budget constraints (especially in Europe) for low carbon urban infrastructure investment (Dexia and CEMR 2012; Mathur and Smith 2013; Rybeck 2004).

Location Value Tax (LVT), a tax that recovers the value of properties that has not been created by landowners, could explicitly support sustainable urban planning objectives (Batt 2011a; Brandt 2014; Panella, Zatti, and Carraro 2011; UN-HABITAT 1976; UN-HABITAT 2011b) (we argue in favour of using the concept LVT instead of the common term Land Value Tax based on a proposal to homogenise nomenclature; see Figure 1 in Section 3.1 for clarification). First, it increases fiscal efficiency. As the provision of land remains cost-free, taxing away urban location values (LV) does neither harm the economy nor does it distort markets (George 1879; Kunce and Shogren 2008; Mattauch et al. 2013). Revenues have been used to finance sustainable urban infrastructure in different contexts[3] (Ingram and Hong 2012b; Kitchen 2013; Medda 2012; UN-HABITAT 2011b; Zhao et al. 2012). Second, it is legitimate to tax away LV. The share of property's worth which is not produced by landowner's labour, but from public intervention, community actions and environmental quality, is an unfair burden on those whose activities had given it value (Albouy 2012; Albouy 2009; R. J. Arnott and Stiglitz 1979; Brandt 2014; Brueckner 2000; Fainstein 2012; Mattauch et al. 2013; UN-HABITAT 1976). These capitalization dynamics, exacerbated in the last decade, have provoked a strong call for reconsidering the property tax (PT) base and shift it from real estate towards LV for wealth distributional objectives (Seely 2013b; H. J. Brown and Smolka 1997; Terry Dwyer 2003; European Environment Agency 2010; F. E. Foldvary 2006; Gaffney 2009; Institute for Fiscal Studies and Mirrlees 2011; D. E. Mills 2001; Oates and Schwab 2009a; Raslanas 2013; UN-HABITAT 2011a). Third, a tax on LV fosters sustainable urban development in the following ways: (a) it reduces urban land conversion trends (Altes 2009; Banzhaf and Lavery 2010; Brueckner 2000), (b) it fosters mixed land use development and by this supports low-carbon transport modes (Altes 2009; Nuissl and Schroeter-Schlaack 2009), and

[3] (Cord 1985) found that an annual land rent tax would yield nearly two-thirds of all taxes in place for the U.S.

(c) it internalizes externalities, especially those related to environmental degradation (Brandt 2014; European Environment Agency 2010). The fact that more than 30 states use some form of LVT demonstrates that it is far from being a utopian concept (J. E. Anderson 2009; Richard M. Bird and Slack 2003; Bourassa 2009; Johannesson Lindén and Gayer 2012; McCluskey and Franzsen 2005).

While there seems to be a common consensus of the benefits from LVT, literature lacks in conclusive outcomes with regards to optimal designs, particularly for fairness and land consumption concerns (Brueckner and Kim 2003; Cho et al. 2008; Dye and England 2009b; Ingram 2008; Lim 1992; Luca 2011; Maxwell and Vigor 2005; Oates and Schwab 1997; Skaburskis 1995; Song and Zenou 2006; UN-HABITAT 2011a). Three important shortcomings appear in the literature. First, diverse disciplines investigate different aspects of LVTs, but vague terminology and inconsistencies disable useful comparisons between outcomes (Richard M. Bird and Slack 2003; Doerner and Ihlanfeldt 2011; Dye and England 2009b; England 2003; F. E. Foldvary 2006; Institute for Fiscal Studies and Mirrlees 2011; Lutz, Molloy, and Shan 2011; Raslanas 2013). Second, evaluation lacks a systemic holistic perspective that covers all potential benefits at the same time (Alterman 2011; Cocconcelli and Medda 2013; Riël C.D. Franzsen and William 2008; Luca 2011; Maxwell and Vigor 2005; McCluskey and Franzsen 2005; UN-HABITAT 2011a; UN-HABITAT 2011b). Finally, empirical studies deal with very specific set-ups where evidence comes only from observing the effect of changes in tax regimes, and remains incoherent as evaluation depends also on baseline conditions (initial tax regime), and institutional and macroeconomic contexts (J. E. Anderson 2009; Riel C. D. Franzsen 2009).

We seek to alleviate these shortcomings by critically reviewing and comparing current theoretical and practical approaches to LVT in cities under a sustainable perspective. Sustainability here indicates the set of effects in urban land (developed or developable) induced by shifting PT towards LVT on economic, social and environmental systems, by assembling those independently identified in the literature. On this basis, we answer the following research questions:

a. Which design characteristics of LVT are enhancers of urban sustainability?

b. Are current European practices of LVT properly designed according to what literature says?

Section 2 describes a framework to assess outcomes from different LVT design characteristics. We use this framework for the evaluation of current European practices in Section 4. Finally in Section 5 conclusions are drawn as to whether LVT may be a useful instrument to complement other planning measures. Our research indicates that LVT is a valid option for future fiscal reforms from an urban sustainability perspective, but outcomes strongly depend on the instrument design characteristics as well as on the urban context.

2. Design elements of LVT: A framework

This section reviews and synthetize the literature dealing with LVT to address the first question, combining findings from the fields from urban economics, public finances and property taxation, urban sustainability planning and value capture. We develop a framework that assists in the evaluation of a shift towards LVT from a holistic perspective, considering the potential effects different tax designs may have on different aspects of urban sustainability, understood as a term that embraces not only pure economic efficiency improvements in the fiscal system and revenue potential (Clark and Jamelske 2005; Cord 1985; England 2007; England 2003; Nechyba 1998), but also social and environmental ones. Social sustainability entails on the one hand the progressivity of the LVT (based on public economic literature) (George 1879; Musgrave 1974; Youngman 2002), and the equitable access to public intervention on the other (taken from sustainability and development literature) (N. Dempsey, Brown, and Bramley 2012; Nicola Dempsey et al. 2011; Fernandez Milan 2015). Environmental sustainability in cities may include multiple aspects. We focus on excessive urban land consumption (also known as urban sprawl) (see e.g. (Cho et al. 2008; England and Ravichandran 2010; Lim 1992), and environmental pollution to a lesser extent (often refer to as environmental externalities) (Alterman 2011; Batt 2011b). Our evaluation toolkit structures typically discussed issues on which policy-makers take decisions when developing and implementing a LVT into ten main design characteristics (Alterman 2011; Dye and England 2009a) (see Table 1 below).

Table 1. Design characteristics of LVT influencing sustainability effects. X indicates the most suggested option literature refers to when looking at the sustainability effects. Abbreviation characters explained in Table 2.

	Criterion Sub-criterion	**X**
1. Tax base	Natural resources (N)	
	Private improvements: investment nearby (T)	
	Environmental Externalities (Q)	
	I Public/ Community intervention (C)	
	II Public intervention: Urban infrastructure (E)	
	III Public intervention: Land-use regulations (O)	
	Private improvements-owner: non-structural (M)	
	Private improvements-owner: structural (G)	
	Site Value (S) (T+Q+C+E+O1+M)	
	Location Value (LV) (T+Q+C+E+O)	X
	Land Value (H) (T+Q+C+E+O+M+N)	
2. Tax subject - Ownership	All urban owners (AUO)	X
	Private ownership (PO): Private owner-occupied (POo) and Private owner non-occupied (POn)	
	Legal Entities (LE): Legal Enterprise (LEn), Public (P) and Institutional (I)	
	Tenants/ Users (U)	

Table 1 cont (1).

3. Tax subject - Location Use	All land uses (ALU) (under restrictive urban land use planning)		X
	All Economically Usable Activities (AEU): Residential (RES); Commercial (BUSS); Industrial (IND); Scientific Parks (SPK)		
	Non-Economically Usable (NEU): Non-profit (NP); Religious (R); Education (EDU); Health (HEA); Public (P); Infrastructure provision (IP); Natural reserves (NR)		
	Location beneath buildings (L1)		
	Location not beneath buildings (L2)		
	Vacant building ground (V)		
4. Valuation method	3.1 Basis of assessment	Market value (MV) [HBPU]	X
		Area based assessment (ABA)	
		Cadastral value (CV)	
		Flat base (FB)	
		Location gains (LG)	
		Annual rents (AR)	
		Appraisal: HBPU	X
		Appraisal: Current Use (CU)	
	3.2 How to appraise	Traditional techniques: Abstraction (AB), allocation (ALL), teardowns (TD); Contribution (CON).	
		Sales Comparison (SC)	
		Self-Assessment (SA)	
		Massive Econometric Appraisals (MA); Computer Assisted Mass Appraisals (CAMA)	
		CAMA + GIS (CAMA-GIS)	X
	3.3 Frequency of assessment	< 5 years	X
		≥ 5 years	
5. Elements of differential taxation	5.1 Liability base	Delays in assessment ratios adjustments under equity considerations	X
	5.2 Tax rate	≥ 2.5%	X
		Differential taxation according to land uses	
		Rate in relation to local year-to-year market value change/ CPI	X
	5.1 & 5.2 Tax liability	Enough to raise substantial revenues and change behaviours	X
	5.3 Exemptions and reliefs - Owner	No reliefs/exemptions (-)	X
		Assessment limits (AL)	
		General discretionary exemptions (GDE): Low Incomers (LI); Disabled (D); War Veterans (WV)	
		Mortgage interest deductibility (MID)	
		Tax deferral (TD)	
	5.4 Exemptions and reliefs - Land use	Exemptions based on area (ARE)	
		Conditional relief (CR): Relief if intended use is realized within a given period/ budgetary responsibilities	
		Pigouvian relief: site specific reasons (PR)	
		Exemptions based on Types of land use (see 2.2)	
	5.5 Temporality	Permanent (PER)	
		Temporary (TEMP)	

Table 1 cont (2).

6. Revenue raising	6.1 Tax liability	Minimum criteria: payment obligations cover administrative costs	X
	6.2 Collection [Normative]	$R_r \geq$ predefined value	X
		$R_i \geq$ predefined value	X
		$R_r(t)$ constant	X
7. Revenue recycling	[Normative] Locally - Benefit view (BV), Redistribution - New view (NV)		
8. Governance	8.1 Tax Base; 8.2 Tax Rate; 8.3 Reliefs; 8.4 Collection; 8.5 Revenues	Local Government (L)	X
		Regional or State (C)	
		State and Local (C/L)	
		Local within state set range (C(L))	
		Local within LUZ set range (LUZ(L))	X
9. Fiscal Environment	No taxes related to property (No)		X
	Additional taxes related to property (Yes)		
10. Implementation	10.1 Legal separation		X
	10.2 Taxpayer's right to require a revision of the valuation		X
	10.3 Explicit tax bills and revenue recycling		X
	10.4 Strong land use planning		X
	10.5 Coordination among tax offices		X
	10.6 Gradual introduction		X

2.1 Tax base

2.1.1. What can be taxed?

Terms like "site value"; "location value", and "value capture" are used interchangeably in the literatures creating inconsistencies (Franzsen and William 2008; Hubacek and van den Bergh 2006; Özdilek 2011; Park 2014). An established nomenclature would facilitate the discussion (Özdilek 2011; Hubacek and van den Bergh 2006; Park 2014). Two issues are crucial for this exercise: a) where does the value come from, and b) who creates the value (Huxley 2009; Rybeck 2004; Ingram and Hong 2012b; Zhao et al. 2012; Rao 2008; Grosskopf 1981; Brueckner 1986; Riël C.D. Franzsen and William 2008; Alterman 2011); both necessary for the applicability of political rationales. Few attempts on classifications and methodological guidelines exist (Alterman 2011; Ingram and Hong 2012a; Medda 2012), but none is exhaustive enough to cover all three sustainability criteria we here deal with.

In our attempt to bridge the gap between literatures, we identify the value elements that comprise property values and their value sources. Literatures also use terms that aggregate a number of value elements, but these are never appropriately clarified. We disentangle them and delineate them with their "element mix", to define them in a systematic way. Fig. 1 and Table 2 below show the different elements and aggregated value terms coming out of this exercise.

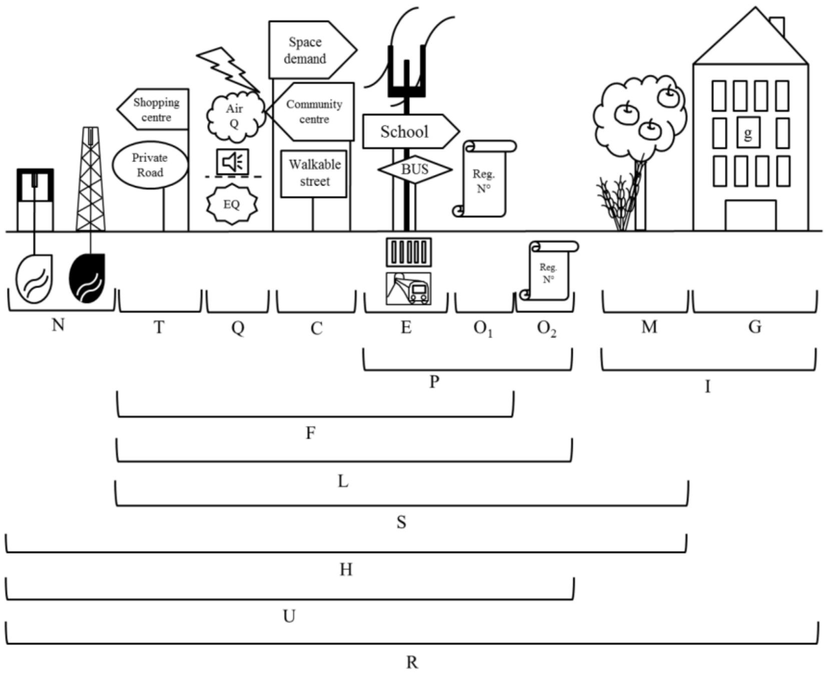

Figure 1 Nomenclature: Conceptual Diagram

Table 2 Nomenclature: Definitions

Sign	Nomenclature	Example/ Definition
	Element	
N	Natural resources (including land productivity)	Minerals, oil, water bodies, soil
T	Private improvements: investment nearby	Shopping centre, private road
Q	Environmental externalities	Air Q., noise, radiation.
C	I Public/ Community intervention	Space demand[4], community attractiveness.
E	II Public intervention: Urban infrastructure	Transport, sewage, electricity
O	III Public intervention: Land-use regulations	O1: Zoning; O2: use rights
M	Private improvements-owner: non-structural	Garden, irrigation system
G	Private improvements-owner: structural	House, dwellings
g	Private improvements-owner: structural	Apartment or part of building
	Aggregated Value	
P	Value from public intervention	E+O
I	Value from private improvements-owner	M+G
F	Location surface value	T+Q+C+E+O1
L	Location value	T+Q+C+E+O
S	Site value	T+Q+C+E+O+M
H	Land values	T+Q+C+E+O+M+N
U	Unearned value	C+E+O+Q+T+N
R	Real estate/ Property value	U+I
W	Immobile wealth	Depends on definition of wealth

[4] Space demand is what often is referring to as urban development macro-effects: population increase, economic development (income) Security, income, and agglomeration effects among others.

2.1.2 What should be taxed?

Defining which value should remain in which hands is a normative issue with philosophical implications. Some authors claim that land productivity should be added to that of private land improvements and remain in private hands because it is already paid for by the owner at the time of acquisition (Ingram and Hong 2012a). Others use the case of larger natural resources to make the case for taxing them (Alterman 2011)[5]. Significant differences between natural resources and the rest of value elements on how the value is created, capitalized and assessed, leads to different outcomes depending on whether they are included or not in the tax base. Taxing natural resources encourages over-exploitation, whereas a tax on extraction outputs -e.g. through a sufficiently high environmental consumption tax- discourages it and leaves the resources underground for future generations. Hence, natural resources should be addressed with an independent instrument which taxes the extraction rent, not the value element (Gaffney 2009).

A wide agreement exists on capturing value from infrastructure improvements and public services (UN-HABITAT 1976; L. W. Walters 2012). Although it raises political opposition (Dillman and Fisher 2009), the same occurs with the value from changes in land use regulations. Land use regulations create artificial land scarcity, and building regulation constraints supply through height and density constraints, both inflating location prices[6] (The Economist 2015; UN-HABITAT 1976; L. W. Walters 2012). Community-related value, forgotten in the value capture literature, it is included in the tax base under wealth redistribution arguments (UN-HABITAT 1976; L. W. Walters 2012). Finally, the value from environmental externalities, only mentioned in new development, should also be part of the LVT for environmental concerns (Pigouvian taxation) (Batt 2011a; European Environment Agency 2010; Kunce and Shogren 2008; Panella, Zatti, and Carraro 2011). This said, LV is the least economically distortive aggregated value (Recktenwald and Smith 1999; Mill 1985; George 1879; F. E. Foldvary 2006; F. E. Foldvary 2008; F. Foldvary 2010); one of the fairest tax base (Harrison 2014; F. E. Foldvary 2008; Gaffney 2009), and discourages extensive, space-consuming urbanization by fostering intensive use of urban land (F. E. Foldvary 2008). Weaknesses only appear when it comes to implementation (Ingram and Hong 2012a).

2.2 Ownership

Two types of individual entities constitute private property ownership: residential owners - owner that is registered at the location -, and non-residential owners - not registered at the location -. Tenants, users or renters also hold specific rights and duties. An increase in LV affects only tenants because they suffer a proportional

[5] An oil discovery near Gatwick (London, UK) has brought this issue to the front of the discussion (Barrett 2015).

[6] In West End London (UK) land-use regulations inflate LV by about 800 percent; in Milan and Paris by 300 percent approx. (The Economist 2015). The absolute liberalization of the real estate market in the US would yield about $1.5 trillion, rising GDP by between 6 and 13 percent (The Economist 2015).

increase in their rents, sometimes high enough to cause displacements. Non-residential owners see their revenues climbing with zero additional investment costs. Residential owners can either sell their property and capitalize the added value, or stay and pay unchanged mortgages. Hence, added values are captured by ownership, and it is thus acceptable to tax only owners, disabling them to pass the charge to renters (Dye and England 2009b; F. E. Foldvary 2008; Ingram and Hong 2012b; Mattauch et al. 2013; Mill 1985; UN-HABITAT 2011b). Next, three types of legal entities exist: Legal Enterprise, Public bodies, and Institutions. An optimal LVT should apply to all urban ownerships to avoid underuse and suboptimal allocation of untaxed land (Alterman 2011), especially in countries with a large share of public land (Waicho Tsui 2008).

2.3 Land-uses

The chargeable subject mostly varies depending on the type of human activity allowed. First, a LVT can be applied to all land uses or to all economically usable activities (European Commission 2015). One could exempt surface not covered by a dwelling and tax only location beneath buildings, but this leads to small dwellings and large surrounding plots, ultimately incites sprawling tendencies. An exemption on the surface covered by building, taxing only unconstructed land also encourages households to fill their location with structures (Dye and England 2009a; European Commission 2015; Zabulenas et al. 2010).

Urban economic activities generally entail residential, commercial, industrial, public, special uses (e.g. non-profit, social, religious, events and sports), and undeveloped urban land. Residential use is the most space-consuming use per capita in cities and suburbs with great infrastructure needs[7] (European Environment Agency 2013; European Environment Agency 2010; Couch, Leontidou, and Petschel-Held 2007). Taxing residential use would contribute reducing its excessive urban land consumption (Blum 2014; Bringezu 2014; L. E. Brown 2014; European Environment Agency 2010; Zabulenas et al. 2010), increase residential density and reduce transport emissions (Banzhaf and Lavery 2010; Creutzig et al. 2015).

Taxing commercial and industrial use is more controversial; two views coexist. On the one hand businesses are not end payers and LVT would hand additional wedges onto consumers (Richard M. Bird and Slack 2003; R.M. Bird and Slack 2013). But excluding them also subsidizes consumers, as the total costs of production – including business location – are not fully internalized. In practice, governments fear taxing businesses especially if the nearby jurisdictions do it too (Wassmer 2009). But net effects depend on mobility of the business, typically lower in practice than what businesses claim (Wassmer 2009). Besides, commercial activities represent a great share of the tax base in large urban zones

[7] In Europe, urban residential land consumption accounts for 20 percent of total land use change in the last decade (European Environment Agency 2013; European Environment Agency 2010; Couch, Leontidou, and Petschel-Held 2007).

(Gutachterausschuss für Grundstückswerte in Berlin 2014; Higgsmith 2013). From a social planer perspective, LVT on commercial use is of particular interest if the net social and environmental benefit of residential space exceeds that of commercial use (Glaeser 2013). In this regard, innovative alternatives suggest the idea of a “sustainable compensation” or “footprint charge” that fully includes production costs (Zwingler 2002; European Environment Agency 2010). With regards to special uses, preferential treatment provides direct community benefits, but also exempts local governments from fiscal responsibilities. It is thus preferable to implement direct subsidies available to all, not just to property owners (Cordes 2012). In practice, exemptions apply to those called non-economically usable, which include non-profit and public and institutional uses[8](European Commission 2015). One alternative could be that local governments assess the tax base erosion and perform a cost-benefit analysis (W. Bowman, Cordes, and Metcalf 2009; Cordes 2012). Finally, vacant land encourages development and deters land speculation (Brueckner and Kim 2003), but new development is not always desirable, leading to negative outcomes on society and ecosystems – e.g. withdrawal of land from agriculture may provoke unemployment and urban sprawl- (J. E. Anderson 1986; Douglas 1980; Roakes, Barrows, and Jacobs 1994). An adequate classification of natural and artificial land cover with specific regulation of developable land solves this issue[9]. Even in rapidly growing areas, although a burden on undeveloped land does not ensure contiguous development, it certainly shapes it towards more sustainable urban forms (Brandt 2014; Fainstein 2012; Seto et al. 2014). Based on these observations and for the sake of simplicity to further discuss the effects of a shift towards LVT, we assume relative inelasticity of land supply through the existence of restrictive land use planning.

2.4 Valuation method

Valuation methods aim at capturing the spatiotemporal property value change linked to location advantages and disadvantages, and incorporate it into the tax base to provide taxpayers with a sense of fairness (L. C. Walters and Rosengard 2012). Plot-specific appraisals are therefore the most equitable alternative but also administratively unfeasible (Alterman 2011). We focus on the adequacy of different bases of assessment, the technical approaches, and the importance of the frequency of assessments.

2.4.1 Basis of assessment

The basis of assessment is the indicator used to obtain a monetary value for the tax base (Johannesson Lindén and Gayer 2012). Market Value (MV) is “the estimated amount for which the property should exchange on the date of valuation between a willing buyer and a willing seller in an arm's length transaction after proper

[8] Exemptions in Europe include public infrastructure regardless of its owner (water, electricity, and sewage) (European Commission 2014).

[9] We exclude non-urban artificial land cover like agriculture and other natural land covers.

marketing wherein the parties had each acted knowledgeably, prudently and without being under compulsion" (EU 2013, sec. 56; TEGoVA 2015)[10]. It reflects the expectation of bidders for the most productive permitted use of the location, often referred to as ‘Highest and Best Permitted Use’ (HBPU). Assessed or cadastral value (CV) is a database with values based on the adjustment of historic MV using diverse factors – age, use, inflation factor, etc.-. Rent refers to inter-temporal value increase. On a general basis, it accounts for a life-time period – location gains (LG)-, but it can also be expressed as Annual Rental Value (AR). This is called recurrent income for non-residential owners and absent owners - the annual income that an owner can expect from renting out the chargeable subject- and imputed income for owner-occupied properties. Flat base appraisals (FB) group properties onto value bands. Lastly, if there is no market, tax agencies base their assessment on stock values and resort to surface areas, the so-called area based assessment (ABA).

FB cancel the need for reassessments, but assume zero relative value variations over time, which makes it regressive and an incentive for space consumption (Mirrlees et al. 2011). ABA is mostly applied in former communist regimes and countries where there is no real estate market (Almy 2013; Bell and Bowman 2009; Riël C.D. Franzsen and William 2008). Governments use it to increase PT yields in relatively short periods, its simplicity is appealing and administrable, and brings clarity and transparency for the first stage of a PT regime (Bell and Bowman 2009). But in the long run ABA undervalues locations and raises equity concerns (Rao 2008). To include scarce and new market information as the housing market develop one could first weigh the area by indicators of quality and location (Mikesell and Zorn 2008). AR and LG need continuous adjustment to inflation (Richard Miller Bird and Slack 2007). AR also requires substantial administrative undertaking to calculate the tax base, especially in the case of owner-occupied housing where no rents are available from the market, and provides highly volatile values compared to LG, where expectation of future value development are included (Richard M. Bird and Slack 2003). Also, the link between tax obligations and benefits is more explicitly spelt out under LG compared to AR (Kitchen, 2013). MV and CV – if up to date - are the most preferable assessment bases. They forecast value changes both for market agents and local planners (Raslanas et al., 2010). One could say that they discourage people from moving leading to inefficient household allocation and homeownership among infrequent movers at the expense of frequent (O’Sullivan, Sexton, and Sheffrin 1995; Wasi and White 2005). But empirics show that these dynamics benefit low-income homeowners because they move less frequently (O’Sullivan, Sexton, and Sheffrin 1995; Sjoquist and Pandey 2001; Wasi and White

[10] Market price is not the same as market value. In a competitive market, the buyer's willingness to pay (market value) might be higher than the market price due to personal preferences; the difference is the "consumer surplus".

References

2005). This said, MV performs best regarding the ability-to-pay principle and land use efficiency (Kitchen 2013; Raslanas 2013).

2.4.2 How to appraise

Appraisal agencies typically report location and improvement values separately, but their accuracy varies according to the technique used (Bell, Bowman, and German 2009; Bell and Bowman 2008; Bell and Bowman 2006; E. S. Mills 1998; Netzer 1998). In places with limited assessment capacities, self-assessments and pre-set charges dominate, but resulting inaccurate estimates erode the value capture justification (Alterman 2011; Richard Miller Bird and Slack 2007; Brzeski 2005). The straightest way forward is to assess undeveloped parcels and use the sales comparison approach, where market transactions are adjusted using different characteristics – size, corner influence location, topography, etc.-. But vacant plots are scarce in urban cores and appraisers use mainly four traditional techniques. First, the abstraction approach subtracts the depreciated costs of improvements to the property value. It is an attractive alternative when new development abounds, but as structures become older distortions on residual LV increase. Second, the land share allocates a percentage of the total parcel value to land derived from the market evidence. This comes from the abstraction method, historical sales data of a time where there were enough undeveloped plots, or by comparing data from a nearby jurisdiction. While the first source requires proper calibration of construction costs and depreciation percentages georeferenced, the second and third ones lack in accounting for timing and spatial related changes (Bell, Bowman, and German 2009). Third, the contribution value method calculates the sum of values of each property element and its characteristics – typically differing from total property value (Eckert 1990). Finally, sales data for teardowns discount the demolition costs to the property value (Dye and McMillen 2007b). All these methods use statistical models to calculate the urban property universe (Bell, Bowman, and German 2009; Eckert 1990). However, they show significant weaknesses (Bell, Bowman, and German 2009; E. S. Mills 1998), with the contribution approach providing most accurate results (Bell, Bowman, and German 2009; Bell and Bowman 2006). Either way, it is always better to combine these methods with vacant and improved sales data (Gloudemans, Handel, and Warwa 2002).

Today, appraisers use econometric regressions to develop modern mass appraisals. They estimate both vacant and improved LV with reasonable accuracy, even if few vacant plots data are available (Barker 2007; Case 2007; Davis and Heathcote 2007; Gloudemans 2000). Based on this methodology, Computer Assisted Mass Appraisals (CAMA) estimate hedonic price indexes from a representative sample of sales and apply it to the entire universe of unsold properties. Indexes relate sale prices to physical and location characteristics, where weights are estimated from marginal changes in the physical and location figures and then used to assess unsold properties. Finally, the most accurate methodology is the integration of CAMA into Geographic Information Systems (GIS) technology to develop spatially explicit datasets (Aleksiene and Bagdonavicious 2009; Bell, Bowman, and German 2009; Ward et al. 2002). Even with low level of satellite imagery, combining GIS with little on-ground data and international expert support is highly recommended in countries with no sale records or markets in transition (Aleksiene and Bagdonavicious 2009; Eckert 2008). Industrial and commercial inactive markets also benefit from CAMA-GIS because it replicates appraisal procedures more efficiently than traditional per-unit-breakdowns. Benchmarks or proxy sales are adjusted by property characteristics – e.g. size, zoning, retail, apartment, warehouse, motel, heavy manufacturing – and then interpolate between known points to finally obtain the value of unsold properties, including dummy variables to account for additional land use specifics – e.g. primary, unused or right-of-way-(Bell, Bowman, and German 2009).

To sum up, good appraisal practices require a combination of modelling specifications to enhance coefficients from regression models, data enhancement techniques –e.g. working with real estate companies-, GIS technologies, and regularly evaluated standards regardless of whether they are public or private contracted appraisal firms (Bell, Bowman, and German 2009). Also, legislation should specify how the technical approach can avoid variation among municipalities, although the assessment practice must take place at the lower spatial level (Bell, Bowman, and German 2009; Bell and Bowman 2006; Mattsson 2003).

2.4.3 Frequency

An updated base is crucial to keep the liability, accountability, transparency and rationale of the tax, but here is where most countries perform worse (Almy 2013; European Commission 2014; Mirrlees and Institute for Fiscal Studies 2011; Smith 2013; UN-HABITAT 2011a; UN-HABITAT 2011b). Governments believe that updating CV makes the PT more visible and creates social and political reluctance, which ultimately costs votes. But out-of-date tax bases lead to unfair fixes, unequal taxation and political disruption. It is thus better to have an annually updated inflation-adjusted ABA than a CV above three to five years of age, -depending on the market conditions- (Almy 2013; Cocconcelli and Medda 2013).

2.5 Elements of differential taxation

2.5.1 Liability base

Liability base, also known as assessment ratio value, is the part of the assessment base to which charge rates are applied (Dye and England 2009b). A split rate tax burdens a higher assessment ratio and/or tax rate to LV as compared to structures. The extreme case - a pure LVT - is when buildings are assessed with zero ratios (Brandt 2014). Assessment ratios adjustments may be delayed a period of time under equity considerations (Ayuntamiento de Madrid 2014; European Commission 2014; European Commission 2015).

2.5.2 Tax rate

There is no consensus on how high or low a tax rate should be; it is intrinsically dependent on the tax purposes – e.g. abatement of previous PT, raise additional revenue -. What does seem clear is that rates have to be sufficiently high to a) result in higher tax bill on the affected location, and b) raise enough revenue to cover the administrative costs of the tax (Alterman 2011; Cho et al. 2008; Mirrlees and Institute for Fiscal Studies 2011; Raslanas, Zavadskas, and Kaklauskas 2010; L. C. Walters and Rosengard 2012). Next, for LVT to be a planning instrument, under the condition of inelastic supply of land, as mentioned above, the rate should be high enough to raise enough revenues and change behaviours – the "super neutral" nature of LVT - (Alterman 2011; Calavita et al. 2010; Calavita and Mallach 2009; Terence Dwyer 2014). Looking at the revenue raising from LVT in Europe and other countries, tax rates below 2.5 percentages contribute in a lesser way to local revenues than what the LVT rationale suggests (major contributor of local revenues) (Cord 1985; European Commission 2014; European Commission 2015; F. E. Foldvary 2006). Finally, rates should be flexible to absorb shifts in the tax burdens, e.g. through housing Consumer Price Index (CPI) adjustments (Bourassa 2009).

Generally, municipalities define the tax rates freely or within a given rate, which creates heterogeneity between different locations. Additionally, it is often the case that different tax rates apply to different land uses (e.g. commercial, industrial, residential, etc.) (Richard Miller Bird and Slack 2007; Smolka and Biderman 2011; Waicho Tsui 2008). But discretionary tax rates create additional burdens, leading to unfair circumstances, lobbying, and suboptimal land use allocation, which ultimately hinders appropriate land use mix from an urban sustainability perspective (Alterman 2011; Augustine and Bell 2009) (although discretionary tax rates is less distortive than zoning (Augustine and Bell 2009)).

Together, the liability base and the tax rate should produce a tax liability (what remains when applying the tax rate to the tax base) high enough to foster the land regulation potential of LVT, and to raise enough revenues to cover administrative cost of the tax (Brandt 2014; Dye and England 2009a).

2.5.3 Exemptions and reliefs

Exemptions and reliefs are used for two things. First, they neutralize the regressive aspects of PT, especially with regards to low-incomers and elderly owners (Augustine and Bell 2009). Second, they subsidize owner-occupied residential housing, a practice massively applied throughout the 20th century for economic development reasons (Kortelainen and Saarimaa 2015; S. E. Sexton, Wu, and Zilberman 2012).

For the first objective, governments typically use assessment limits to stabilize tax liabilities when property values raise rapidly (T. A. Sexton 2009; Hamilton 2007). But these create unequal redistribution of burdens which undermines the fairness of the LVT (Minnesota Department of Revenue 2006; Dye and McMillen 2007a; Dye 2007; Dornfest 2005). Those, whose property values are increasing more rapidly, profit because effective tax rates decline more rapidly the faster the property appreciates at rates above the limit. Next, if assessment limits apply interchangeably to all uses, the burden will shift toward residential owners: their aggregate assessed value increases more rapidly due to turnover because they typically change ownership more frequently (Minnesota Department of Revenue 2006; Dye and McMillen 2007a; Dye 2007; Dornfest 2005). Finally, they erode the tax base and impact government revenues heavily (N. B. Anderson 2006; Minnesota Department of Revenue 2006; Moak 2004; O'Sullivan, Sexton, and Sheffrin 1995; T. A. Sexton 2009; Sjoquist and Pandey 2001). General discretionary exemptions apply according to property or owner characteristics – e.g. low income, disabled; war veterans, etc.-. They have direct social benefits, but these can be more efficiently provided through alternatives that do not discourage owners to seek for higher income or optimum use location (T. A. Sexton 2009).

To subsidise homeownership tax payments can be credited – tax deferrals - or exempted if the income is below a certain threshold. These practices however discourage owners seek for higher or more stable income. Tax deferrals also reduce the expectation value of inheritors, who often find alternative ways to avoid their tax bills. Similarly, mortgage interest deductibility enables taxpayers deduct their tax liability according to their level of indebtedness. This practice creates critical distortions by incentivising private households indebtedness and sprawl (Archer 2010; Couch, Leontidou, and Petschel-Held 2007; Diaz-Serrano and Raya 2014; Hanson, Brannon, and Hawley 2013; Johannesson Lindén and Gayer 2012; S. E. Sexton, Wu, and Zilberman 2012). It produces very low tax payments, while it does little to increase homeownership (Augustine and Bell 2009; Kortelainen and Saarimaa 2015). An increasing agreement exists on the idea that deductibility practices should be replaced by subsidies targeted at low-income first-home buying households instead of a general measure that in practice enables tax avoidance of high income residential owners (Augustine and Bell 2009; Bartlett 2013; Bell, Bowman, and German 2009; J. H. Bowman 2009; Stiglitz 2014).

Literature discussing the externalities of new development or already developed areas with a specific project or public intervention plan refers to a tax relief based on the consumption of new or old urban land to achieve lesser eat up land development (Panella, Zatti, and Carraro 2011). Value capture literature also identifies reliefs based on budgetary and/ or development responsibilities, the so-called conditional reliefs (Ingram and Hong 2012a; Peterson 2009). Finally, there is zoning specific reliefs based on noise, air pollution etc.; a kind of inverse Pigouvian tax (Batt 2011a; Brandt 2014; Kreiser et al. 2011; Panella, Zatti, and Carraro 2011).

All this said, reliefs or exemptions undermine the beneficial aspect of LVT, and limit local spending capacity (Augustine and Bell 2009; Richard M. Bird and Slack 2003). They function in the same way as regulation or an additional tax, but with more complex distortions (Barnett and Yandle 2004). Hence, lower and uniform rates are less likely to create distortions than higher and non-uniform rates (Augustine and Bell 2009; Buchanan 1987). Socially based exemptions may be considered in very specific cases by no means are permanent; they need to be constantly revised (Alterman 2011). But even then, direct expenditures are more efficient than tax reliefs (Augustine et al. 2009; Edel and Sclar 1974).

2.6 Tax liability and collection

2.6.1 Liability

Liability refers to the final payment obligation, often expressed as the effective rate - the ratio of the liability change to the market value change-. Effective rates vary due to different factors. Governments may intentionally set the tax liability significantly below market values for political reasons (Waicho Tsui 2008), but it is often the case that they are not aware of the factors behind (Barnett and Yandle 2004; Virtanen 2000). Bahl and Linn (1992) developed a methodology to decompose the tax revenues and identify factors affecting the level of LVT collection. First, the relative growth of property stocks may not follow the overall growth (macroeconomic factors). Policy choices influence the non-exemption ratio, the valuation or assessment ratio, and the tax rate. Lastly, the collection rate falls, to a major extent, under the tax administration authority (Gravelle and Wallace 2009). There is no harmonized suggestion on how high effective rates should be – besides that of uncover administrative costs-, but underrating location values weakens the redistributive effects and hinders significant net yields (Alterman 2011).

2.6.2 Collection

The value capture literature uses two criteria for evaluating the instrument that can be applied to a LVT: the percentage of LV captured (R_r), and the percentage of public infrastructures investment financed by the LVT (R_i) (Hong 2003; Hong 1996; L. C. Walters 2012). Deciding R_i and R_r has normative assumptions. Nonetheless the following criteria are strongly recommended: a) R_i should take into account investment, operation, and maintenance; b) R_r should be constant over time for equity reasons (Hong 2003; Hong 1996; L. C. Walters 2012).

2.7 Revenue Recycling

How to invest the revenues is a highly normative decision where two views compete. The “new view” says that revenue should be redistributed where most needed, regardless the revenue raising location. The “benefit view” suggests that LVT is a benefit tax, thus its benefits should be directly reinserted in the place where they were raised (Alterman 2011; Oates 1969; Oates and Schwab 2009b; Tiebout 1956).

2.8 Governance level

The main argument towards a decentralized LVT relies on the fundamental link between tax and expenditure decisions, assuming competing autonomous municipalities. If finance comes from elsewhere, this link is broken and the choice of programs are not based on true costs (McKinnon and Nechyba 1972; Oates 2001; Oates 1999; Oates 1993; Weingast 1995). To motivate municipalities they should keep full LVT revenues; otherwise collection is not robust enough (Alterman 2011; R.M. Bird and Slack 2013). In metropolitan areas, the local discretion on rates may cause tax competition and socio-economic segregation (Cutler and Glaeser 1997; Glaeser 2013). There is no clear cut solution to this problem but the subsidiarity principle or to a central planning approach may help, where total metropolitan revenues should be inter-municipality redistributed (Alterman 2011).

2.9 Fiscal Environment

The interaction of LVT with other forms of property charges varies the outcomes of the instrument. Typically, countries tax LV through non-recurrent instruments. Zoning, land-use charges, development taxes, or transaction taxes are some examples. We do not address these interactions because they are beyond the scope of this paper. Nevertheless, consensus exists on the idea that additional instruments may hinder the potential benefits of LVT (Batt 2011a; Dye and England 2009a; Panella, Zatti, and Carraro 2011; Powers 2009; Raslanas 2013; Zabulenas et al. 2010).

2.10 Implementation

LVT often faces political opposition; unpopularity of wealth taxation grows when this is based on unrealized capital gains rather than current cash flow (Bourassa 2009). This makes it a highly contested debate that intersects with political ideologies (Alterman 2011), and may even be perceived as a violation of the state´ constitutional principles of uniformity, equality and proportionality (Coe 2009). The philosophical and legal perspective on property rights and land ownership is a key element in the discussion of the viability of LVT. For example, the concept of property used by the European Court on Human Rights could be understood as that appropriation of some part of land value is permitted if it benefits public interest, but appropriation is not permitted to seize the LV produced by someone else but the owner (Carss-Frisk 2001; Council of Europe 1950). This view contrasts with "the unearned value" the UN-HABITAT refers to in the Vancouver Action Plan (UN-HABITAT 1976). These dichotomies appear not only at the institutional level, but also between parties from the same country (Alterman 2011). The concept of property changes over time and scale, and so does the legitimacy of taxing away LV. However, although fundamental, the normative discussions go far beyond the scope of this paper.

Assuming a legal framework that allows the taxation of LV and considering the above, the rationale behind a LVT is of extreme importance, where two main views coexist: the redistribution and justice argument -"capturing the unearned value"-, and the pragmatic view, which seeks to enforce developers pay their share and control development patterns (Alterman 2011; Balchin, Bull, and Kieve 1995; Booth and Albrechts 2012; UN-HABITAT 1976; L. C. Walters 2012). The first one faces administrative and regulatory-based feasibility challenges; the second one faces transparency issues because policies are jointly design by developers and government (Alterman 2011; Fainstein 2012; Meltsner 1971; Smolka and Biderman 2011). Clear rationales (what should be taxed, and why) and national legal frameworks alleviate these challenges. But designs should be flexible enough to accommodate to changing needs for public perceptions on what merit public financing (Alterman 2011; Bourassa 2009; Coe 2009). Predefined assessment standards must apply nationally (Bell, Bowman, and German 2009) and it has to be legally separated. Its revenue and revenue recycling should be reported separately from other taxes to increase awareness and acceptability (Alterman 2011; Bourassa 2009; Coe 2009; Oates 2001; Powers 2009). The other way around, unless taxpayers are ensured adequate level of public services, it will face opposition (Bourassa 2009; Rao 2008).

Next, every tax reform creates winners and losers, and so does LVT. Governments should acknowledge this and ensure that the tax bill is affordable by majority of tax payer (Powers 2009). Taxpayers should have the right to require a revision of the valuation (Aleksiene and Bagdonavicious 2009). To avoid drastic changes, the implementation of an LVT should be best done in combination with a tax shift. This could be gradually introduced through a split tax rate, where there is a simultaneous decrease on improvement rate with increases in rates on location values (Wallace Oates and Robert Schwab 2009). Next, never increase the LVT at the same time as assessments take place (Bourassa 2009). It is also important to minimise administrative costs in the long term - e.g. coordination on data collection and valuation - (Bourassa 2009; Powers 2009; Tiits 2009). Local governments should be aware of macroeconomic forces that may interfere and lead to an apparent failure (Bourassa 2009). Finally, the introduction of a LVT has to go hand in hand with appropriate land use planning that regulates and delimitates developable zones; otherwise overconsumption of land may take place (Bourassa 2009; Riel C. D. Franzsen 2009).

3. Assessing current practices in Europe

This section deals with the second question on whether current European practices of LVT are designed according to the criteria from the previous section. We select those European countries that have a kind of LVT. Two inclusion criteria apply: a) the tax base excludes structural private improvements (and thus focuses on some aspect of LV), and b) the tax ownership includes private owners. The evaluation material is based on databases and reports from the European Commission on property taxes (European Commission 2014; European Environment Agency 2010; European Commission 2015). We look at the “Grundskyld” in Denmark, the “maamaks” in Estonia, the “compensation for the use of building ground” in Slovenia; the “tax on land” in Slovakia, the “tax on land” in Romania, the tax on "aree edificabili" in Italy (IT), the “telekado” in Hungary, and the “land tax” in Lithuania. Data is from 2014, the latest fiscal year available for all countries. We compare the design characteristics available in the database with the findings of the previous section for each country. Each criterion (a total of 20) is weighted according to whether it fits or not with literature suggestions (no: 0, yes: 1) (see Table 3 below). Although it is challenging to evaluate normative criteria, we attempt to do it in the following way: To give an intuition on criterion revenue rising (6), although there are no LV databases available, we express the revenues from LVT as share of Gross Domestic Product (GDP), national and recurrent property tax revenues (see Figure 2). For the revenue recycling criterion (7), as there is also no data available on how revenues are allocated, we evaluate it negatively for all countries based on the transparency and accountability criteria (see 3.10 Implementation), same as we do when no data is available for any other criterion (“n.a.” entries in Table 3). Grey shadowed entries in Table 3 indicate that the design criteria are appropriate according to the revised literature.

Table 3. Evaluation of current European practices (DK: Denmark; SI: Slovenia; EE: Estonia; SK: Slovakia; RO: Romania; IT: Italy; HU: Hungary; LT: Lithuania; AU: Austria)

	DK	SI*	EE	SK	RO	IT	HU	LT	AT
1. Tax base	S [1]	S	H	LV	S	S	S	S	S
2. Owner	AUO [2]	AUO + US	AUO - P [3]	AUO + US	AUO + US	AUO	AUO	PO [2]	AUO
3. Land use	ALU	V + L1	ALU [4]	AEU	AEU - L1	V	L2 + V	ALU	V
4.1 Basis of assessment	MV	ABA	CV	CV	ABA	AR [5]	ABA/ MV [6]	CV	CV
4.2 Frequency (stipulated/ last year)	2	1	6 (2001)	(2004)	n.a.	(1988)	n.a.	5 (2013)	n.a.
4.3 How to appraise	SC	CON [7]	CON / SC [8]	CON	CON [9]	CON [7]	SA	CAMA	n.a.
5.1 Assessment ratio (%)	81	n.a.	66	72	n.a.	100	50 [10]	100	n.a.
5.2 Tax rate (%)	2.60 [11]	[12]	1.30 [13]	[14]	[15]	0.4 [16]	1.5 [17]	1.5 [18]	1
5.3 Exemptions and reliefs: ownership	NP; IP [19]	P [20]; LI [21]	D [19]; PO(RES) [22]	R; NP; EDU; HEA	R; NP; EDU; HEA; WV; D	R; NP; EDU; HEA	PO (RES) [27]	LI, D	-
5.4 Exemptions and reliefs: land use	I	I; L1[23]	N [24]	[25]	I; IND; SPK; N [26]	n.a.	n.a.	I; NR;	ZN [28]

Table 3 cont.

	DK	SI*	EE	SK	RO	IT	HU	LT	AT
5.5 Temporality	PER	PER	TEM	PER	PER	PER	PER	PER	TEMP
6. Revenue raising					See Fig. 2				
7. Revenue recycling					n.a				
8.1 Tax Base	C	L	C/L	L	C	C	L	C	C
8.2 Tax Rate	C(L)	L	C(L)	LUZ(L)	C	C/L	L	L	C
8.3 Reliefs	C/L	L	C/L	L	C/L	C/L	L	C/L	C
8.4 Collection	L	C	C	L	L	C	L	C	C
8.5 Revenues	L	L	L	L	L	C/L	L	L	C
9. Fiscal Environment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Buildings and apartments	X	X		X	X	LUX	X	BUSS, LUX	X
Capital gains	0.24	0.1	0.21	0.19	0	0	0.16	0.15	0.25
Land Use Change	X	X	-	-	-	X	-	-	-
Gift and inheritance	X	X	-	X		X	X	X	-
Transactions	X	X	-	X	X	X	X	-	X
Mortgage registration	-	-	-	-	-	X	-	-	-
Imputed rent of residential owners	-	n.a.	-	-	n.a.	n.a.	n.a.	-	n.a.
Luxury value criterion	X	n.a.	-	-	n.a.	X	-	X	no
10. Implement.					n.a				
Score (max. 20)	**11**	**3**	**5**	**7**	**3**	**4**	**5**	**8**	**5**

* Tax abolished in 2014.

[1] Until 2013, private non-structural improvements were excluded; [2] A separated LVT applies to Public ownership; [3] Excluded: municipal land and land in public use. Included: state land not in public use [4] Included: exploitation minerals; [5] From cadastre; [6] Municipalities choose either 50% of MV; or L2 + V; [7] Factors: plot size; municipality; location zone; land use coefficient; infrastructure availability; [8] Valuation authorities allowed to consider all available evidence: e.g. sales comparison, estimation of value for HBPU; [9] Factors: plot size; municipality; location; land use coefficient; [10] For MV basis; [11] 1.6-3.4%, average 2.6%; [12] Each parcel assessed in absolute amount; [13] 0.1-2.5%, average 1.3%; [14] Up to 5 times the lowest rate set by another municipality; [15] Lump sum per square meter; [16] 0.2 -0.4%; [17] 0- 3%;[18] 0.1- 4%, average 1.5%; [19] Optional; [20] Exemption; [21] Reduction; [22] Formerly repressed persons if not receiving rent for leasing out land; [23] During 5 years after construction; [24] RES: Area up to 0.15 ha exempted; NR: 50% reduced rate; [25] Exempt if NEU due to natural state or zoning; [26] Exemption: land for subsoil exploitation, water bodies; [27] 25m² per resident; 50% lower: land where building is not permitted; [28] Private ownership recovers tax payment if dwelling built within 5 years.

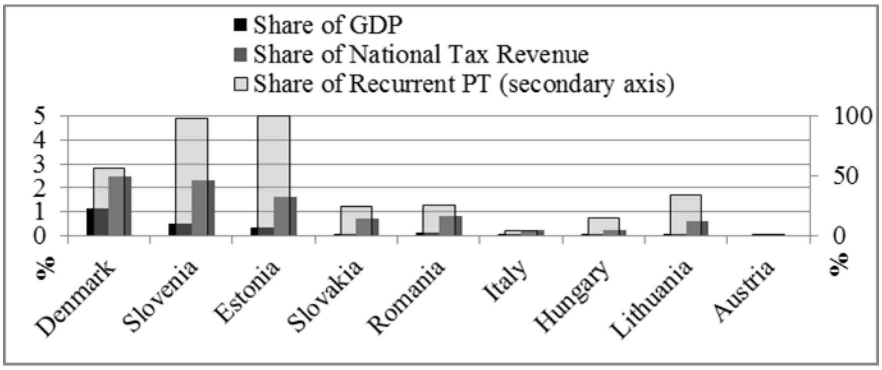

Figure 2. LVT revenues expressed in GDP, national and recurrent property taxes revenues (secondary axis).

This evaluation demonstrates that Denmark is the best practice in Europe, followed by Slovenia and Slovakia. Denmark also had a pure LVT until 2013, which has not been recorded in the evaluation, as we use data from 2014. Lithuania is currently developing a LVT with improved design; considerable effort is made in updating cadastral values (last update 2013). For Slovenia, although it also has a well-designed tax, it is worthwhile mentioning that the Constitutional Court recently abolished the tax. In Estonia, for every property there is an area up to 0.15 hectares exempted since 2013, which erodes the tax base enormously. Looking at the revenue raised expressed as share of GDP and share of national tax revenue, Denmark is followed by Slovenia and Estonia (Fig.2 most and second most dark grey in the graph). Interestingly, the latter two base their share of recurrent property taxes solely on the LVT (Fig.2 light grey, secondary axis).

4 Discussion and Conclusion

A vast amount of research from public economics to sustainability science indicates that a shift from traditional PT towards LVT improves specific sustainability metrics: it increases fiscal efficiencies and raises revenue to pay back low carbon infrastructure investment, it fosters denser development and decreases urban land consumption, and it redistributes wealth accumulated in real estate cycles given by LV and not by private investment". To understand how design characteristics enhance urban sustainability, we homogenise nomenclature and revise the normative statements behind LVT. We also present a framework that organizes alternative design decision, together with a discussion on the sustainability effects from each of them. Fields of urban economics and public finance address issues of equity, and efficiency (socio-economic outcomes). Value capture and sustainable transport literatures provide mixed insights on the sufficiency and equity arguments. Urban planning and sustainability sciences address the issue of land consumption and environmental effects. All together, they stress the following crucial elements in the design of a LVT for its outcomes: the importance of how the tax base is designed the valuation method that is used -especially the frequency of assessments-, the disturbances of exemptions and tax reliefs together with other property taxes in place. In addition, strong land use regulations is very much encouraged for dealing with environmental concerns, especially with regard to reducing land use consumption.

Overall, we find that location value tax is of relevance in the urban sustainability debate and, with adaptive policy instruments, should be considered in planning integrated strategies for sustainable cities. We also suggest that a quantitative assessment would be desirable, enabling the quantification of not only financial but also ecological and societal effects of the proposed tax reform. A shift towards LVT would enhance the overall sustainability outcome of the real estate taxation system.

In Europe, although there are good practices with regards to some criteria (e.g. assessment ratios, governance level, and tax subject definition), most countries fail our evaluation. In other words, there is considerable room for improvement in most countries, especially by improving the tax base, the frequency of assessment practices, and abolishing additional property taxes that distort the outcome of LVT. But countries like Slovenia illustrate the enormous legal difficulties a LVT has to overcome, not always successfully. As it prioritises urban planning objectives that interfere with incentives for economic development – e.g. profitability for developers-, supporters must be able to package a rationale that transcends party ideologies. In societies where private control of land is firmly embedded, resistance to limiting speculative profit is greater and will be opposed politically. Thus, many states prefer indirect instruments designed to collect contributions from developers to meet the infrastructure needs– e.g. betterment ad public ownership, agreements, to obligations and community infrastructure levies- (Alterman 2011). At the European level, the few research projects are quite disperse and either look at its potential for spatial planning and environmental policy (Altes 2009; European Environment Agency 2010) or on abstract economic rationales (Mattauch, Siegmeier, and Edenhofer 2013; Mattauch et al. 2013). Interestingly, there are a number of places where LVT is gaining attention (Alterman 2011; Brandt 2014; Terry Dwyer 2003; Dye and England 2010; European Commission 2012; Land Value Tax Working Party 2005; Panella, Zatti, and Carraro 2011; Tom and Kris 1999). In Europe, the UK (Mirrlees and Institute for Fiscal Studies 2011; Seely 2013a; Wightman 2013), Scotland (Wightman 2010), Ireland (Gurdgiev 2010; Gurdgiev 2009; Inter-Departamental Group 2012) and the Netherlands (Altes 2009) openly debate the issue. In particular, Greece would greatly benefit from implementing a land registry and a location value tax, obtaining stable tax revenue with less regressive effects compared to high levels of value added taxes. The European Statistical Office (EUROSTAT) and the Organisation for Economic Co-operation and Development (OECD) have a joint project to develop methodological guidelines for LV estimation that will be applied in future tax systems reviews at the EU level (European Commission 2012; Garnier et al. 2013). This initiative may indeed further stimulate the discussion on LVT. Neither urban sustainability nor location taxes are easy to impose. There are logistical and institutional hurdles, where politics is the hardest one. But the underlying rationale of a levy on locations for financing public expenses is compelling.

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Part III

Governance for urban sustainability

Chapter 8

How participatory planning processes for transit-oriented development contribute to social sustainability[1]

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How participatory planning processes for transit-oriented development contribute to social sustainability

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Abstract

Transit-oriented development (TOD) is a relatively recent neighbourhood development concept associated with the three dimensions of urban sustainability (environmental, economic and social). Traditionally, TOD has been associated with environmental and economic benefits. Recent research has shown evidence of positive social outcomes related to the spatial characteristics of TOD areas. But the social sustainability that can be drawn from TOD interventions may multiply when designed through participatory planning processes. Here I combine TOD literature with that of collaborative urban planning to highlight the potential of participatory TOD for urban social sustainability.

Keywords: Transit-oriented development, participatory planning, social sustaianbility.

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1. TOD and urban sustainability

Sustainable urban development goes hand in hand with the concept of transit-oriented development (TOD) (Belzer and Autler 2002; Curtis, Renne, and Bertolini 2009; Nahlik and Chester 2014; Newman and Kenworthy 1999; Renne 2008). TOD is a relatively recent neighbourhood development concept associated with the three dimensions of urban sustainability (environmental, economic and social). It aims at decreasing transport distances through diverse land use patterns, moderate to high residential and employment density, frequent and well connected public transport services (PT), and street network design that prioritizes pedestrian and transit users. This results in expanded use of non-motorized transport modes and a shift away from car ridership.

There is strong evidence ofglobal and local benefits on environmental and economic issues arising from TOD projects. Land use diversity and transit ridership shift transport modes from fossil fueled to low-carbon intensity ones and reduces transport distances. Consequently, emissions from green house gases and local air pollutants decrease together with traffic congestion. Such changes generate economic gains with regards to transport efficiencies and ecosystems quality (Nahlik and Chester 2014; Newman and Kenworthy 1999; Rahul and Verma 2013; Vickerman 2008; Belzer and Autler 2002). Next, households save on transport costs (Dubé et al. 2011; Nahlik and Chester 2014) and see an appreciation in home prices related to the increase in location attractiveness (Hasibuan et al. 2014; Nahlik and Chester 2014; Rahul and Verma 2013).[3] At the regional level, TOD projects often stimulates private investment, job creation, and overall competitiveness (Knowles 2012), which enhances socio-economic circumstances. Although there is less research evidence, TOD may also contribute to social sustainability (Kamruzzaman et al. 2014). Research to date has only looked at the link between the spatial characteristics of TOD neighbourhoods and social capital. In this article, I focus on the unexplored synergies that could take place when linking TOD projects with participatory planning processes. I first summarize the evidence related to TOD and social capital and identify important knowledge gaps. Next, I summarize the current evidence on the effects of transport and urban planning interventions on social sustainability. I then describe the concepts of participatory planning and the methodologies available that could be applied to TOD. I use these strands to argue that participatory planning would improve the social benefits of TOD.

2. TOD and social sustainability

Empirical evidence covers the relationship between specific built environment characteristics of TOD areas (i.e. density, planned mixed land uses, walkability and street design) and social capital (one aspect of social sustainability). Social capital

[3]Increase in location values may, however, decrease housing affordability if no parallel land policies occur.

comprises all institutions, relationships, and customs that shape the quality and quantity of social interactions in a community (The World Bank 2011). Findings suggest that the built environment influences social capital, but the empirical relationship remains unclear. For example, although TOD fosters dense development, denser neighbourhoods do not always provide higher social capital (Glaeser and Gottlieb 2006; Dempsey, Brown, and Bramley 2012). Mixed land uses, another intrinsic characteristic of TOD, has also shown divergent outcomes. In line with this argument, (Lund 2003) found a weak relationship between neighbourhood environment features and social interactions in Portland, Oregon (US). Counterarguments also exist: (Leyden 2003) Irish study showed that mixed-use neighbourhoods had higher levels of social capital.

Similarly, there is no clear evidence on the link between public transport accessibility levels (PTAL) and social capital, although most scholars agree that it positively affects social inclusion (Janet Stanley and Lucas 2008; Janet Stanley and Vella-Brodrick 2009; Janet Stanley et al. 2010; Currie and Stanley 2008; John Stanley, Stanley, and Hensher 2012). What is clear is that walkable neighbourhoods perform better in terms of social sustainability. Pedestrian-oriented neighbourhoods foster a sense of community (Lund 2002; Leyden 2003; Du Toit et al. 2007), trust, political participation, and social engagement (Leyden 2003; Wood, Giles-Corti, and Bulsara 2012; Mason 2010). There is only one study comparing TOD and non TOD areas for the case of Brisbane (Australia). Results showed that individuals living in TOD areas had a significantly higher level of trust and reciprocity and connexion with neighbourhood compared to non-TOD areas, which indicates that specific built environment characteristics of TOD areas may foster the development of social capital ((Kamruzzaman et al. 2014). Interestingly, however, the same study found negative relations between the indicators of social capital they used and the built environment characteristic when such relations were assessed individually. Still, the relationship between different built environments and other aspects of social capital (i.e. participation in networks, civic engagement, the existence of pooled community resources and social norms) remains understudied. Furthermore, a knowledge gap exists on the relationship between TOD intervention designs and social capital.

Altogether, it is reasonable to say that social capital is highly sensitive to changes in the built environment related to TOD. But the impacts of TOD on social sustainability depend to a great extent on the context. TOD projects create new public spaces and transform pre-existing ones, thus having an impact on communities that goes beyond individual transport or land use interventions. These projects thus have the capacity to foster eco-friendly behaviours (i.e. related to urban mobility) and shift social norms and perceptions related to active transport and lifestyles preferences (i.e. car dependency and preference to live in low-density suburban areas). Therefore, the design of appropriate interventions that takes the social context into account may further increase the overall sustainability outcomes of TOD interventions.

However, the ways and extent to which TOD could influence communities' social sustainability have not been fully realized. First, some TOD projects are merely "transit-related" interventions (Boarnet and Compin 1999). Second, many projects labelled as "transit-oriented" often entail local goals that go beyond those of TOD, such as fostering economic growth, building a location brand or satisfying political interests (Baumann and White 2012; Cervero, Ferell, and Murphy 2002; Dorsey and Mulder 2013). Hence, the process of planning and implementing TOD is not always aligned with social sustainability. There are competing interests that hamper adequate prioritization of social and cultural preferences (Dorsey and Mulder 2013; Cervero, Ferell, and Murphy 2002; Turner 2012). The traditionally narrow priorities based on utility-maximising rational present poor awareness of the nexus between TOD and place making (Ndebele and Ogra 2014) and little integration of environmental and social considerations (Baumann and White 2012) . TOD designs often focus predominantly on physical and functional requirements (Belzer and Autler 2002). One example of this is the development of large-scale TOD projects that do not necessarily increase equity nor welfare (Chiu, Huang, and Ma 2011; Winston and Maheshri 2007). Also, unsuccessful TOD projects have been related to lack of information on travel-related attitudes prior to the intervention (Bailey, Grossardt, and Pride-Wells 2007; De Vos, Van Acker, and Witlox 2014), a critical success factor for low-income neighbourhoods (Bailey, Grossardt, and Pride-Wells 2007). Ecosystem services and local values are not always integrated into urban and transport planning, mostly due to inefficient public participation processes and unstructured stakeholder involvement (Soria-Lara, Bertolini, and te Brömmelstroet 2015). Consequently, social unacceptability and designs at odds with the local needs occur (Assefa and Frostell 2007; Kathryn Scott 2000). The intransigence of the target community on changes in lifestyles may lead to unintended consequences. For example, the introduction of measures to avoid car usage (i.e. inner-city parking fees) may result in new suburban driving patterns, protests, and induced technological innovations that hamper social changes and, ultimately, sustainable development (i.e. the rebound effect) (Vallance, Perkins, and Dixon 2011; Clark 2005). In sum, TOD faces a wide nature of challenges and uncertainties, which frequently end up in underprioritization of community's interests (Belzer and Autler 2002; Dorsey and Mulder 2013) and suboptimal designs for social sustainability. The large-scale mass transit investment in Jakarta (Indonesia) is one example where social sustainability outcomes were affected. The differences across gender and other social groups with regards to safety and security were not addressed in the design of the projects resulting in gender gaps and other inequalities (Turner 2012). In Cali (Colombia) accessibility to the newly implemented Bus Rapid Transit (BRT) system varies in relation to neighbourhood socio-economic strata, greatest for middle-income groups and most limited for areas with population from the highest and lowest socio-economic strata (Delmelle and Casas 2012). Workplace relocation towards mixed-use transit-oriented development in a suburban area of Lisbon (Portugal) did not trigger the expected modal shifts, indicating a lack of understanding of citizen´s commuting preferences and inadequate measures to discourage workers from using their cars to commute (Vale

2013). In the wider European context, urban transport vision plans are still based on technological innovation, which devalues the importance of social innovation as a key factor for transformative changes towards sustainable urban transport, and further indicates that citizens' participation plays a secondary role in the design and decision-making process (Upham, Kivimaa, and Virkamäki 2013). Although notable progress has been made in terms of policy rhetoric in countries such as the UK and Finland, the link between participatory processes and policy outcomes remains unclear, partly because there are no explicit procedures to make it a deliberative process (Elvy 2014).

3. Participatory planning for TOD

As with urban sustainability, TOD governance offers great opportunities but also challenges, especially with regards to citizens, which can be resolved with stakeholder participation. While a great deal has been written about the role of participation on urban sustainability transitions and on transport planning (Proli 2011; Mahdavinejad and Amini 2011; Smedby and Neij 2013; Collier et al. 2013; Sagaris 2014), so far there has been no research on the effects of participatory planning processes for TOD on social sustainability. (Innes and Gruber 2005) identified the following planning styles in the transit development of the San Francisco Bay area: a) the technical/bureaucratic style, based upon neutrality, objectivity, and quantitative analysis; b) the political influence style, which pushes for a particular agenda influenced by politics and popularity; c) the social movement style, which reflects community activism and involvement in strategic planning decisions; and d) the collaborative style: the “coming together” of diverse stakeholders to reach a consensus. In their research, collaborative designs showed greater public satisfaction and cost efficiency in the design of the projects compared with other approaches. Two major reasons were identified. First, there was a strong incentive to reach agreements when involving stakeholders. Secondly, building networks created additional social, political and intellectual capital, which together is most likely to produce innovative outcomes that overcome controversies and minimise uncertainties. In relation to this argument, although new technologies (i.e. GPS data) can help obtain information on intra-personal day-to-day variability and flexibility of commuting behaviour (i.e. space, time, travel mode, and travel route) (Shen, Kwan, and Chai 2013), these patterns vary among communities, neighbourhoods and social and minority groups, and participatory processes capture better the diversity of preferences. More generally, there are new goals emerging in urban transport planning: while physical mobility is still an essential priority, the social and environmental performance of interventions is becoming more and more relevant for communities ((Bertolini, Clercq, and Straatemeier 2008).

Urban transitions towards sustainability also benefit from stakeholder participation: it enhances deliberation and collaboration between diverse stakeholders and among public agencies, particularly in contexts of social inequalities (Hamann and April 2013). The concept of neighbourhood planning also addresses the importance of community involvement to identify, negotiate, and reconcile strategic and community interests (Pinnegar 2012). Furthermore, true dialogue among stakeholders defuses adversarial processes and facilitates better and depoliticised policy choices (Faehnle and Tyrväinen 2013; Bertolini, Clercq, and Straatemeier 2008). Such planning approaches enhance the collaboration between governmental authorities, and their awareness and efficiency in addressing environmental and social externalities (Taylor and Schweitzer 2005). In the case of TOD, as they create tangible urban transformations, active inclusion of citizens' views could further reinforce transformation trends across diverse scales, not just through changes in the built environment. Participatory planning for TOD helps achieve lifestyles, social preferences and behaviours aligned with sustainability principles. In Medellin (Colombia) citizens' empowerment in the design, implementation, handing over mechanisms and evaluation of TOD plans strengthened democratic processes in the most conflict-prone neighbourhoods of the city (Dávila and Daste 2011; Rodriguez Herrera 2012; Brand and Dávila 2011). The participatory design of TOD in a low-income urban neighbourhood of Louisville, Kentucky (US) helped to integrate local preferences resulting in a positive response from the community which was willing to change its travel behaviour (Bailey, Grossardt, and Pride-Wells 2007). In Santiago (Chile), self-organized citizen participation generated transparent processes favouring sustainability and democratization and fostered innovation in urban and transport planning (Sagaris 2014).

The institutional feasibility of participatory planning through political and social frameworks and methodological practices has now reached maturity (Innes 1996; Innes 1995) and could easily be applied to the TOD case. Multiple-criteria decision analysis through analytical hierarchy process approaches serve, especially at the initial stage, to understand the biases between preferences, desires and expectations among groups (de Luca 2014). The development of local knowledge in practice-based training programmes can help construct local capacity for collaboration (Ataöv and Ezgi Haliloğlu Kahraman 2009). Visual and participatory workshops embedded into a structured public involvement (SPI) process help identify preferred planning combinations for citizens (Bailey, Grossardt, and Pride-Wells 2007). Computer support for collaborative planning also facilitates group interactions and decision-making processes. Visualization tools, from 2D Geographic Information Systems (GIS) (Coors, Jasnoch, and Jung 1999) to recently developed 3D visualization and modelling programs, help in managing complexity in communication (Neuenschwander, Wissen Hayek, and Grêt-Regamey 2014; Bailey, Grossardt, and Pride-Wells 2007). The design of participatory TOD planning processes can thus be achieved with relatively little effort.

4. Conclusion

Public interventions that change urban spaces like TOD also alter social sustainability. TOD improves the quality of public spaces and urban connectivity and accessibility, which enhances urban mobility and fosters social networks. Appropriate transit, land use mix, and public space design is fundamental to the social outcomes of TOD interventions. It would therefore be useful to use participatory planning processes to maximize the social outcomes of the interventions. But the potential of making citizens feel part of the projects that shape communities remains underdeveloped, even though the community's perception is key in optimizing public interventions. Participatory planning processes could multiply the social benefits related to TOD, such as increased transparency, trust, social inclusion, collective action and social networks, and further act as a catalyser of urban sustainability.

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Chapter 9

Participatory design in transit-oriented development uncovers social benefits[1]

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Participatory design in transit-oriented development uncovers social benefits

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Abstract

Transit-oriented development (TOD) tackles multiple challenges simultaneously and fosters sustainable urban development. Low-carbon intensity transport modes help mitigating climate change, enhance the quality of local ecosystems and offer monetary savings. While less well studied, TOD also positively affects citizen's social interactions. The social sustainability that can be drawn from TOD interventions may multiply when designed through participatory planning processes. To investigate this hypothesis, we evaluate TOD and participatory intervention for Medellin (Colombia). We find that designing TOD together with participatory measures results not only in the decrease of motorized transport modes, but also in positive changes in socioeconomic variables, people´s perception of public interventions and in social capital especially of disadvantaged groups. Making citizens feeling part of the projects that shape their communities fosters transparency, trust, social inclusion, collective action and social networks. Participatory measures can catalyse urban sustainability.

Keywords: Transit-oriented development, social capita, participatory planning, urban upgrading.

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1. Introduction

Motivated by climate change and urban sustainability challenges, municipalities show an increasing interest in transit-oriented development (TOD) because it provides economic, social, and environmental benefits (Belzer and Autler 2002; Bongardt, Breithaupt, and Creutzig 2010; Felix Creutzig and He 2009; Felix Creutzig, Mühlhoff, and Römer 2012; Curtis, Renne, and Bertolini 2009; Newman and Kenworthy 1999; Renne 2008). Low-carbon intensity transport modes bring economic benefits in addition to the reduction of GHG emissions and other local air pollutants (Belzer and Autler 2002; Curtis, Renne, and Bertolini 2009; Nahlik and Chester 2014; Newman and Kenworthy 1999; Renne 2008; Felix Creutzig, Mühlhoff, and Römer 2012; Rahul and Verma 2013; Vickerman 2008). First, they generate savings to the entire system because they reduce congestion and transport related accidents (Bongardt, Breithaupt, and Creutzig 2010; Nahlik and Chester 2014; Newman and Kenworthy 1999; Rahul and Verma 2013; Vickerman 2008). Second, cities that reduce their motorized vehicles reduce expenditures on passenger and goods transportation (Belzer and Autler 2002; Newman and Kenworthy 1999). The use of public transit to the detriment of fossil fuelled vehicles also decreases household transport expenses, and together with mixed land use they enhance the quality of ecosystems and increase location values (Dubé et al. 2011; Nahlik and Chester 2014; Hasibuan et al. 2014; Nahlik and Chester 2014; Rahul and Verma 2013). TOD projects also attract additional investment, create jobs, and expand the catchment urban area, in turn leading to enhanced competitiveness at the regional and other levels (Knowles 2012). While less well studied, TOD also positively affects citizen’s social interactions. But these outcomes seem to depend on how TOD interventions are designed and implemented (Glaeser and Gottlieb 2006; Dempsey, Brown, and Bramley 2012).

We use the case of Medellin (Colombia) to evaluate the social benefits of participatory TOD. Medellin has been widely used as a benchmark for its transit development in general and its participatory urban planning in marginalized areas in particular (Blanco and Kobayashi 2009; P. Brand 2010; Echeverri and Orsini 2011; Fukuyama and Colby 2011; Hylton 2007; J. Dávila 2014). Empirical evidence exist on the effects of its interventions on the reduction of violence and transport emissions (Cerda et al. 2012; J. Dávila 2012a), but lacks in systematic comparison on TOD modal shifts, on life quality in general and on social capita in particular. Our methods – based on data from the annual citizen survey - allow us to evaluate citizen´s changes on socioeconomic variables, their perception of public interventions, and their social capita for two comparison groups according to their changes in their use of TOD modes. Interestingly, positive changes in TOD modes coincide with the target population the participative TOD interventions wanted to address-. The structure of the paper is as follows: Section 2 reviews the literature on TOD and social capita, Section 3 introduces the case of Medellin; Section 4 explains the methods and data on which our research relies. Section 5 reports the main results, discussed in Section 6 and focusing on policy recommendations drawn by the case presented here. Section 7 concludes the paper.

2. TOD and social capital

Until now, empirical evidence has focused on the relationship between specific built environment characteristics of TOD areas (e.g. density, planned mixed land uses, walkability and street design) and social capital (one aspect of social sustainability). Social capital comprises all institutions, relationships, and customs that shape the quality and quantity of social interactions in a community (The World Bank 2011) (Figure 1). Findings suggest that the built environment influences social capital, but the empirical relationship remains unclear. For example, although TOD fosters dense development, denser neighbourhoods do not always provide higher social capital (Glaeser and Gottlieb 2006; Dempsey, Brown, and Bramley 2012). Mixed land uses, another intrinsic characteristic of TOD, also shows inconsistent outcomes (Leyden 2003; Lund 2003). Public transport accessibility levels typically fosters social inclusion, but its relationship with other social capital dimensions is still unknown (Janet Stanley and Lucas 2008; Janet Stanley and Vella-Brodrick 2009; Janet Stanley et al. 2010; Currie and Stanley 2008; John Stanley, Stanley, and Hensher 2012). What is clear is that walkable neighbourhoods perform better in terms of overall social sustainability. Specifically, pedestrian-oriented neighbourhoods foster a sense of community (Lund 2002; Leyden 2003; Du Toit et al. 2007), trust, political participation, and social engagement (Leyden 2003; Wood, Giles-Corti, and Bulsara 2012; Mason 2010). We identified only on case study – of Brisbane, Australia - comparing TOD and non-TOD areas. Results show that individuals living in TOD areas have a significantly higher level of trust and reciprocity and connexion with neighbourhood compared to non-TOD areas, which indicates that specific built environment characteristics of TOD areas may foster the development of social capital (Kamruzzaman et al. 2014). Still, the relationship between the design of TOD, the built environments and other aspects of social capital (i.e. participation in networks, civic engagement, the existence of pooled community resources and social norms) remains understudied.

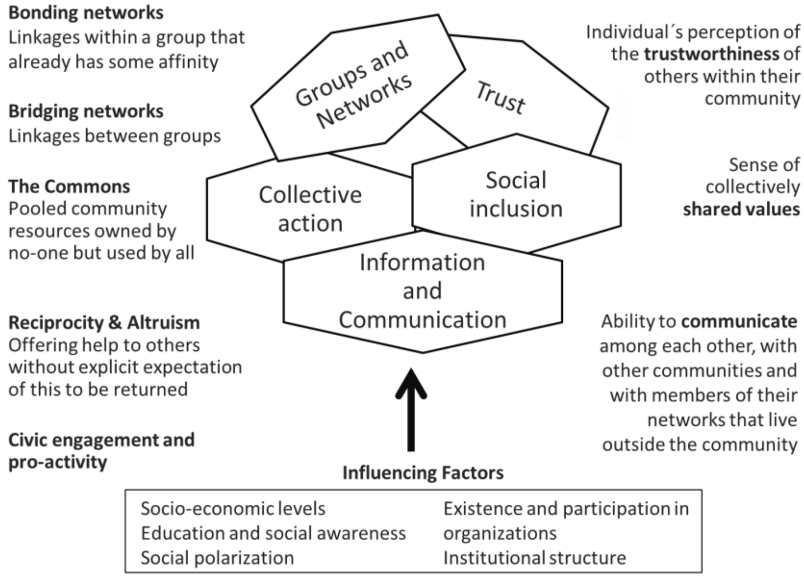

Figure 1 Social Capital: dimensions and influencing factors

TOD projects aim not only at reducing transport emissions, but also want to create public spaces and transform pre-existing ones, thus impacting communities beyond infrastructural changes. Public spaces are fundamental for the enhancement of social capital; they foster an atmosphere of trust and cooperation and develop links and mutual understanding among citizens and with government institutions. They also constitute a fundamental scenario for political and social engagement (Chen, Acey, and Lara 2015; Chen, Acey, and Lara 2014; Leyden 2003; The World Bank 2011). But the ways and extent to which TOD could influence communities' social sustainability have not been fully realized. Some projects have mixed goals that hamper adequate prioritization of social and cultural preferences (i.e. fostering economic growth, building a location brand or satisfying political interests) (Baumann and White 2012; Cervero, Ferell, and Murphy 2002; Dorsey and Mulder 2013; Boarnet and Compin 1999; Turner 2012). Traditionally narrow priorities based on utility-maximising rational and physical and functional requirements present poor awareness of the nexus between TOD and place making (Ndebele and Ogra 2014; Baumann and White 2012; Belzer and Autler 2002; Chiu, Huang, and Ma 2011; Winston and Maheshri 2007) and little integration of environmental values (Soria-Lara, Bertolini, and te Brömmelstroet 2015) and social considerations such as travel patterns (Bailey, Grossardt, and Pride-Wells 2007; De Vos, Van Acker, and Witlox 2014)). Intransigence of the target community on changes in lifestyles may also lead to unintended consequences. For example, the introduction of measures to avoid car usage (i.e. inner-city parking fees) may result in new suburban driving patterns, protests, and induced technological innovations that hamper social changes and, ultimately, sustainable development (Vallance, Perkins, and Dixon 2011; Clark 2005).

The design of appropriate interventions that take the social context into account increases the overall sustainability outcomes of TOD interventions. Specific to social capital, public participation in decision-making processes is commonly identified as a key factor of success (Bowling and Stafford 2007; Grootaert and Bastelaer 2001; Grootaert 1998; Kamruzzaman et al. 2014; Masoud, Rastbin, and Ardahaey 2011; Onyx and Bullen 2000; Roche 2004; The World Bank 2011). From the urban planner perspective, if wider sustainability objectives are to be achieved, transit infrastructure investment would benefit from parallel investments in housing, schools, the environment and public space (Peter Brand and Dávila 2011). These could generate synergies as the enhancement of social capital contributes to the development of sustainable development principles in the communities –e.g. fosters social equity and the preservation of natural ecosystems, among others- (Chen, Acey, and Lara 2015; Grootaert 1998; Grootaert and Bastelaer 2001; Putnam 1993; The World Bank 2011; Vallance, Perkins, and Dixon 2011). In the case of TOD project designs, participative interventions may foster eco-friendly behaviours related to urban mobility and shift social norms and perceptions related to active transport and lifestyles preferences (e.g. car dependency and preference to live in low-density suburban areas).

3. Medellin: Connecting TOD and place making

The construction of the mass transit system Metrocable and the works around stations through the participatory urban upgrading projects (Proyectos Urbanos Integrales, PUIs) transformed the public spaces in Medellin (P. Brand and Dávila 2011). Since mid-2000s, the development plans defined the territory as scenario targeting of public policies. They operate under the following principles: a) enhancing the natural environment; b) urban mobility; c) public space and housing conditions; d) and security and coexistence (Alcaldía de Medellin 2015; Alcaldía de Medellín 2004; Alcaldía de Medellín 2008; Alcaldía de Medellín 2012; P. Brand 2010).

The government first developed an exhaustive diagnosis of the city that served as a basis to the current monitoring program that includes a detailed annual citizen survey. Results showed that the lowest levels of quality of life and human development indices were concentrated in 20% of the total urban territory; including those areas (comunas) where Metrocable was planned (see Fig. 2). They were characterized by dramatic socioeconomic conditions, exposure to social exclusion and spatial segregation, and their predisposition to the occurrence of crimes and violence. Furthermore, terrains had high vulnerability levels to natural risk (due to e.g. topography), and high environmental degradation. They also showed typical peripheral location characteristics, with highly dense urban expansion and territorial disorder resulting from irregular development. They lacked in public infrastructure and insufficient government investment as well as private appropriation of public spaces. All this affected mobility and travel security, lengthening travel times within the neighborhood and transport systems connecting with the rest of the city. At institutional level, a history of inappropriate public interventions created dissatisfaction, and the existence of a widespread regulatory ignorance (Puerta Osorio 2011).

In the light of these results, the government decided to intervene through upgrading programs designed on a case-to-case (see Fig. 2). These interventions aimed at providing equal opportunities to all city residents, especially those traditionally excluded, and get both a territorial and social balance based on the following areas of action (Puerta Osorio 2011):

1) The improvement of the urban environment with a specific focus on mobility and accessibility, especially for pedestrians. These infrastructure interventions included the construction and improvement of collective facilities such as libraries, health centers, schools and urban parks, and transit infrastructures like bridges and walkways. Altogether, they generated new public spaces and social facilities, turning them into elements of social cohesion, promoting ownership, collectivism and carefulness. The insertion of population into the health care and education system became a number one priority (Blanco and Kobayashi 2009). Housing conditions were also improved through regularization, rehabilitation, and new development. In addition, the work created in the construction sector (a share of the workers had to be chosen from the local community) fostered the local economy

(Arenas Madrigal and Arenas Madrigal 2015; Bateman et al. 2011). Authorities also launched social programs: child protection, social reintegration, and support of victims of human rights violations, among others. Environmental care was also advanced through wildlife conservation, rehabilitation of degraded environmental spaces and improved water treatment (P. Brand and Dávila 2011; J. Dávila and Daste 2011; J. Dávila, Daste, and Millan 2015).

2) The strengthening of citizen involvement, key to the subsequent local appropriation of the services and equipment generated**.** Participatory planning processes legitimized actions on the territory through NGOs and Community Local Administrative Action Boards, creating spaces for discussion, exchange, and dissemination. Community involvement occurred before, during and after the infrastructure works, regardless of social roles. A wide variety of participation tools were used: tours, committee meetings and other public meetings, workshops and training processes, census, inter-institutional coordination activities, open calls, home visits, dissemination and promotion campaigns, free press (number of letters) and information booths, conferences and social events. Already at the diagnostic phase, citizens were involved to identify key areas together with technical teams. At the project design phase, they were involved in the decision-making of intervention projects looking both at social and economic feasibility. When projects were finalized, dissemination and appropriation was successfully done though different cultural activities where all Medellin citizens were invited to show the renovated image among all Medellin population, creating pride among locals (Farajado Valderrama, Cabral, and Tonkiss 2014).

3) The strengthening of institutions through transparency, communication, predefined management distribution, decentralization and empowerment of local entities. Transparent institutional coordination reversed the established culture of corruption, inefficiencies and illegality. Over 20 municipal departments participated in managerial assembles together with civil society and private organizations as well as international cooperation agencies. Financing was on the premise that the development of the neighbour could be self-financing at one stage, due to the proper management of public finances (Carvajal 2009; J. Dávila and Daste 2011). For this, the administration put in place strategies as permanent accountability worthy taxpayer assistance, publicity and responsibility of taxpayers, besides regular updates of cadastral values in the area (Echeverri and Orsini 2011).

Together, these measures increased the quality of life for Medellin population and minorities in particular. Urban upgrading projects achieved to work with and for the community on the different proposals and intervention designs. This may have led to synergies between participatory urban planning and the development of new public spaces and transport infrastructure, promoting ownership of the environment, and close bonds of trust within and between communities and authorities; thus making them feel taken into account regarding their views improving social interactions.

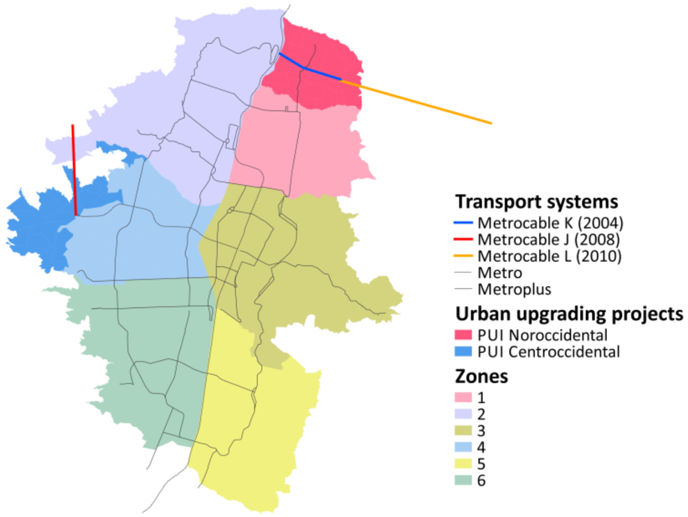

Figure 2 Medellin: Zones, TOD and urban upgrading projects distribution for the study period area.

The Medellin case has been studied already, but so far none has compared the effect of TOD changes on social sustainability in general and social capital in particular**.** (Cerda et al. 2012) showed that the enhancement of physical structures reduced violence in Medellin for their study period (2003-2008). However, with their study period they focused only on the Metrocable infrastructure, as it is the only one finished at that time, and results may be influenced by the relative violence reduction due to the peace process in the region[3] (Velásquez-Castañeda 2014). (Bocarejo Suescún and Velásquez Torres 2011) and (Agudelo Vélez et al. 2011) studied the neighbour impact of the first Metrocable line between 2000 and 2005. (Bocarejo Suescún and Velásquez Torres 2011) found an increase in the Hansen accessibility index in the neighbour and (Agudelo Vélez et al. 2011) also measured some social indicators but with inconclusive result. (Peter Brand and Dávila 2011) discuss the feeling of inclusion and integration among the citizens of the intervention areas, but they do not explicitly cover the issue of social capital. Other studies discuss in detail the so-called "PUI methodology" and highlight its transformative power, based not only on infrastructure and institutional change but also on the understanding of the socio-spatial fundamentals ant the community-oriented planning (Blanco and Kobayashi 2009; P. Brand 2010; J. Dávila 2014; Echeverri and Orsini 2011; Fukuyama and Colby 2011; Hylton 2007). Finally, others investigate microenterprise development to foster sustainable development (Bateman et al. 2011) and the impact of the participative budgets (Carvajal 2009) and the major´s perception (J. Dávila 2009) on governance transparency and consequently, institutional renewal.

The case study of (J. Dávila 2012a) is the only one that highlight the social and environmental synergies of the Medellin case. Although the original drive for transit infrastructure development hinged on social and mobility considerations, potential environmental effects were considered at some point (Alcaldía de Medellin 2015; Metro de Medellin 2015a; Metro de Medellin 2015b). According to this

[3] In fact, the homicide rate between 2008 and 2010 increased (Velásquez-Castañeda 2014).

baseline, the replacement of the fossil fuel operating vehicles by a system of hydroelectric-powered aerial cable cars was projected to contribute to a reduction of up to 121,000 tCO_2 between 2010 and 2016; a reduction of 62,4 % compared to the baseline emission scenario[4]. Additionally, the volumes of trans-boundary air pollutants (mainly carbon monoxide and sulphur dioxide) dropped as baseline modes of transport are replaced with a system relying on electricity generated, predominantly through the use of renewable resources (CDM Executive Board, Grütter Consulting, and TÜV SÜD Industrie Service GmbH 2009). However, the study does not measure the social and/or economic consequences of the Metrocables due to methodological difficulties, assuming it can be said to be largely positive.

None of the above studies quantify the effect of TOD increases in social capital systematically. We here fill the gap and evaluate the enhancement of the quality of life in general and social capital in particular, resulting from Medellin's TOD development and its participatory processes, by post/ante comparison of TOD and non-TOD communities.

4. Study design and methods

In order to evaluate the effect of changes on TOD modal shares and participatory planning interventions on citizen´s quality of life, social sustainability and inequalities reduction, we use the Medellin citizen survey "Medellin como vamos" (Medellin como vamos 2015). We compare the responses between the years 2009 and 2012 on different aspects, including social capita. The period selection is based on the following: according to the public evaluation reports more than 80% of the infrastructures related to participatory TOD planning were finished by 2012, enough to consider this year as a post-evaluation date. Although the lines K and J of Metrocable were opened before, the effect of the upgrading programs could only be observed after 2010 when the construction phase began to an end, hence 2009 could be considered a pre-intervention year (Alcaldía de Medellín 2004; Alcaldía de Medellín 2008; Alcaldía de Medellín 2012; Arenas Madrigal and Arenas Madrigal 2015; Puerta Osorio 2011). This said, the number of survey questions comparable is highest between 2012 and 2009 years. Finally, due to the success of the first two upgrading programs in zones 1 and 4, following interventions using the same design were implemented in other parts of the city, which effect –based again on the finalization of the construction phase -could alter the results.

We use the changes in TOD modal share as the dependent variable and compare the survey scores on issues that cover the socioeconomic status, the satisfaction with public intervention and the social capita of the respondents. The survey answers are

[4] Baseline emissions were defined as those that would have resulted from the use of other modes of transport to cover the required origin and destination distances. Medellin´s modes available were minibuses, taxis and jeeps using fossil fuels such as petrol and diesel (CDM Executive Board, Grütter Consulting, and TÜV SÜD Industrie Service GmbH 2009).

available for three comparison groups besides Medellin average: geographic zones, income levels, and gender; for our analysis we use all independently.

4.1 Grouping variable: changes in the use of TOD modes

For each comparison group, we first identify which group (e.g. for gender: male, female or both) show a change in commuting behaviour towards typical TOD modes (bus, metro, bike and walk) at the expense of non-TOD modes (private car, motorcycle and taxi). We look at the change in modal shares between 2009 and 2012 to select our case and control groups. For each comparison group, TOD groups include those where there has been a positive change in TOD modes (TOD), and non-TOD groups those groups where the use of TOD modes has remained stable or decreased (n-TOD).

4.2 Independent variables

In the survey, the questions are presented in 16 different topic categories. We regroup them into the following three: socioeconomic variables, perception of public intervention, and social capita. Each topic category consists of different variables (aspects) (Table 1). We use the literature review to define social capital and socioeconomic variables according to the dimensions and influencing factors identified.

For data preparation we use feature scaling, a method used to normalize from nominal and ordinal to scale values and further rescaling to the [0, 1] range, allowing us to use 187 questions of the survey. In addition, 12 questions were also reversed to have homogeneous scale direction.

Table 1 Study design: variables, survey questions, and groups in the study sample

N	**Topic category /** Variable name	**N° questions (187)**	**Groups**	**Group description**
	Socioeconomic variables	**8**	**Medellin**	Medellin average
1	Housing	3	**Income**	Low (L); Mean (M); High (H)
2	Education	3	**Zones**	1, 2, 3, 4, 5, 6
3	Income	2	**Gender**	Female (F); Male (M)
	Pub Intervention	**89**		
4	Education (satisfaction)	1		
5	Environment	16		
6	Health	3		
7	Public Infrastructure	26		
8	Public space	27		
9	Transit	16		
	Social capita	**90**		
10	Collective action	6		
11	Groups and Networks	16		
12	Information and communication	15		
13	Social inclusion	35		
14	Trust	18		

For the comparison analysis, we first calculate the % change between 2009 and 2012 for each variable and topic category (“Change”). We are also interested in the rate of homogenization between different groups, to evaluate if the interventions have not only been effective within the area, but also reduce inequalities, as it is read in the planning programs “for a just city” (Alcaldía de Medellin 2015; Alcaldía de Medellín 2004; Alcaldía de Medellín 2008; Alcaldía de Medellín 2012; P. Brand 2010). Hence, in order to evaluate the homogenizing effect –meaning, reducing inequalities between group scores- we compare the different groups with Medellin average. To do so, we calculate the deviation to Medellin average (“Deviation”) for 2009 and 2012 determined by the ratio between each group score and the Medellin average score. This gives a value below or above 1, where =1 tells that the value is equal to Medellin average, <1 means that it the group scores worse, and <1 means that it the group scores better than Medellin average. We then calculate “Change in deviation”, which is the % change of “Deviation” for each group.

Finally, we compare TOD and n-TOD groups for the % changes in “Change” and “Change in deviation” to see whether TOD changes influence the socioeconomic variables, perception of public intervention, and social capita. We use the Wilcoxon Mann-Whitney Rank Sum Test, a nonparametric test with the null hypothesis that two samples come from the same population against an alternative hypothesis, that a particular population tends to have larger values than the other. It is used when the dependent variable (in our case “Change” and “Change in deviation”) can be assumed that it is at least ordinal but cannot be assumed it has a normal distribution[5]. For each statistical test run we report the median (M) of each group, the z and p values.

5. Results

This section presents the main results, divided into two main parts. First we report the TOD-modal changes between 2009 and 2012 for all groups to identify TOD and n-TOD groups for the different zones, income levels and gender.

5.1 TOD-modes increased in 5 groups

TOD-modes changed in all groups between 2009 and 2012. TOD-modes increased in zones 1, 2, and 4, as well as in the low income and female group. On the contrary, zones 3, 5 and 6, middle and high income, and the male group show a decrease in TOD-modes (see Figure 3). Hence, in the urban upgrading intervention areas (1 and 4) there has been an increase in the use of TOD-modes, and presuming these are the areas with higher concentration of population with low incomes, the changes in the income comparison group is not surprising. Crucially, insecurity issues in mobility for women had also been a number one priority in the urban upgrading programs. Hence- and considering the high concentration of positive TOD-modes in lower areas- these variations may indeed indicate a great success of the intervention for low and mid income women previously reluctant to use transit modes for security issues.

[5] Different graphical and numerical methods were used to dismiss normal distribution in all variables included in the analysis for all groups.

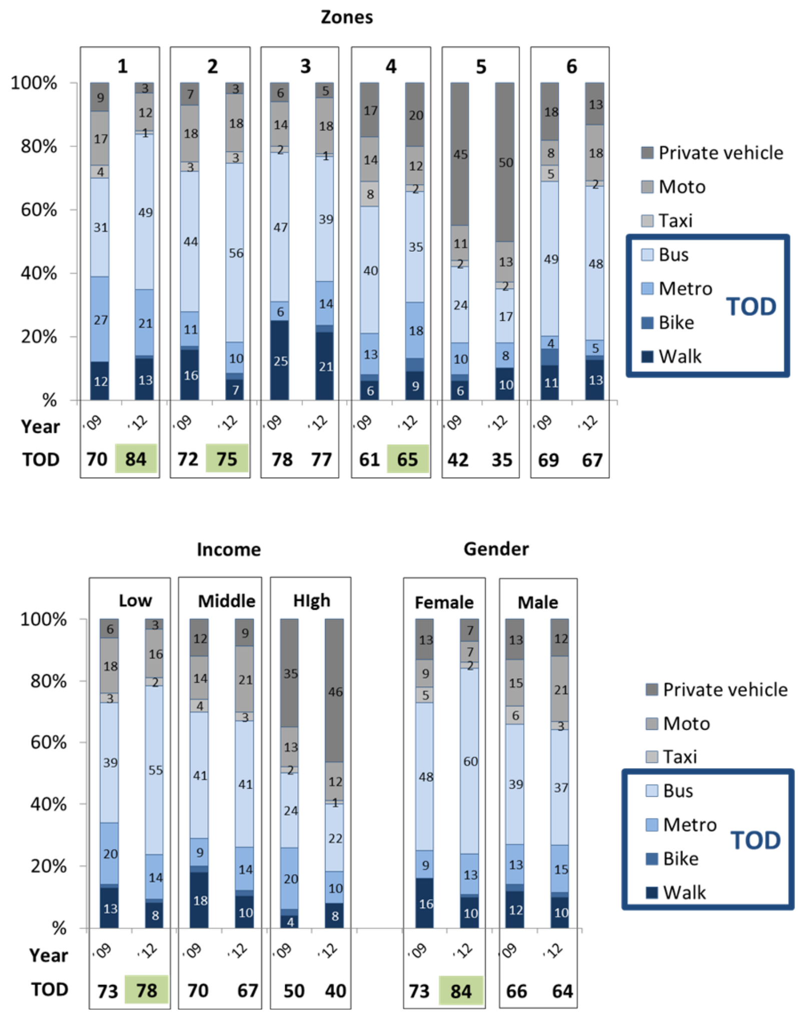

Figure 3 Modal shares changes between 2009 and 2012 for the study groups.

5.2 Variable scores, deviation to Medellin average and group comparison

Table 1 reports the score of the different variables and topic categories for all groups for both 2009 and 2012. Values range from 0 to 1, where 0 is the minimum and 1 the maximum. Overall, there is a general increase in the scores for all socioeconomic variables, perception of public intervention and social capital. However these changes are different for each topic category, variables and groups. For all the groups included, housing shows the lowest scores among the socioeconomic variables. Income improves; education deteriorated from 2009 until 2012 in all zones. Regarding citizen´s perception on public intervention and social capita satisfaction with education is the only one decreasing among all groups accordingly with education quality. Health and transit slightly decrease for Medellin average, but this tendency differs among groups. Satisfaction with policies aiming a enhancing the environment and public infrastructure increase while public infrastructure remains constant. Social capital variables also score very different depending on the dimension we look at. Whereas collective action and trust have rather high scores, groups and networks and information and communication scores are surprisingly low. Overall, although Medellin averages show minor changes, positive and negative changes are clustered according to different groups. We further analyse this variation by looking at “Change in deviation” and the results of the statistical analysis.

Table 2 Absolute scoring of the variables for the years 2009(I) and 2012 (II) (“Change”) (see Fig. A.1 for illustration).

Group			Medellin		Zone											
Subgroup			Average		1		2		3		4		5		6	
Year			I	II	I	II	I	II	I	II	I	II	I	II	I	II
Topic category		**Variable**														
Socioec. variables	1	Housing	0.35	0.38	0.26	0.26	0.31	0.35	0.31	0.36	0.38	0.48	0.50	0.54	0.37	0.28
	2	Education	0.70	0.66	0.73	0.70	0.71	0.64	0.71	0.68	0.73	0.67	0.67	0.64	0.67	0.64
	3	Income	0.81	0.87	0.72	0.79	0.81	0.86	0.80	0.86	0.83	0.89	0.91	0.96	0.81	0.84
Public Intervent.	4	Education (satisfaction)	0.84	0.79	0.81	0.77	0.85	0.80	0.86	0.76	0.83	0.85	0.87	0.82	0.81	0.73
	5	Environment	0.42	0.44	0.44	0.46	0.43	0.48	0.40	0.41	0.38	0.46	0.42	0.42	0.44	0.42
	6	Health	0.54	0.53	0.52	0.52	0.50	0.49	0.59	0.53	0.52	0.52	0.58	0.64	0.55	0.50
	7	Public Infrastructure	0.80	0.85	0.77	0.82	0.78	0.85	0.77	0.83	0.82	0.85	0.84	0.88	0.81	0.85
	8	Public space	0.55	0.55	0.54	0.57	0.56	0.52	0.55	0.53	0.55	0.57	0.57	0.54	0.54	0.57
	9	Transit	0.66	0.65	0.64	0.66	0.69	0.65	0.71	0.62	0.62	0.65	0.69	0.64	0.62	0.65
Social Capita	10	Collective action	0.74	0.72	0.73	0.78	0.71	0.69	0.79	0.62	0.69	0.77	0.80	0.75	0.69	0.69
	11	Groups and Networks	0.21	0.21	0.18	0.18	0.22	0.20	0.18	0.15	0.21	0.27	0.27	0.30	0.20	0.15
	12	Inf. & Commun.	0.42	0.43	0.37	0.42	0.44	0.43	0.42	0.43	0.44	0.45	0.47	0.48	0.38	0.40
	13	Social inclusion	0.49	0.50	0.46	0.52	0.49	0.53	0.51	0.49	0.48	0.49	0.52	0.50	0.46	0.48
	14	Trust	0.61	0.64	0.61	0.65	0.58	0.66	0.63	0.64	0.58	0.63	0.65	0.64	0.61	0.63
Socioeconomic variables			0.62	0.64	0.57	0.58	0.61	0.62	0.60	0.63	0.64	0.68	0.69	0.72	0.61	0.58
Pub. intervention			0.64	0.63	0.62	0.63	0.64	0.63	0.65	0.62	0.62	0.65	0.66	0.65	0.63	0.62
Social Capita			0.49	0.50	0.47	0.51	0.49	0.50	0.51	0.47	0.48	0.52	0.54	0.53	0.47	0.47
Total			0.58	0.59	0.55	0.58	0.58	0.58	0.59	0.57	0.58	0.62	0.63	0.64	0.57	0.56

Table 2 cont.

Group			Income						Gender			
Subgroup			**Low**		**Middle**		**High**		**Female**		**Male**	
Year			I	II	I	II	I	II	I	II	I	II
Topic category		**Variable**										
Socioec variable	1	Housing	0.26	0.37	0.36	0.33	0.47	0.31	0.29	0.55	0.36	0.34
	2	Education	0.71	0.68	0.71	0.65	0.63	0.58	0.71	0.71	0.72	0.65
	3	Income	0.74	0.80	0.82	0.87	0.90	0.95	0.80	0.85	0.77	0.84
Public Inter.	4	Education (satisfaction)	0.83	0.79	0.83	0.77	0.85	0.83	0.84	0.80	0.82	0.76
	5	Environment	0.44	0.46	0.41	0.44	0.39	0.44	0.42	0.46	0.42	0.45
	6	Health	0.53	0.52	0.53	0.51	0.52	0.55	0.53	0.52	0.53	0.51
	7	Public Infrastructure	0.76	0.83	0.80	0.85	0.85	0.87	0.79	0.85	0.80	0.85
	8	Public space	0.55	0.55	0.55	0.55	0.53	0.56	0.55	0.56	0.55	0.54
	9	Transit	0.65	0.66	0.66	0.64	0.67	0.64	0.63	0.61	0.65	0.64
Social Capita	10	Collective action	0.73	0.69	0.75	0.71	0.77	0.74	0.66	0.70	0.75	0.71
	11	Groups and Networks	0.16	0.21	0.19	0.19	0.25	0.31	0.18	0.19	0.21	0.19
	12	Inf. & Commun.	0.39	0.44	0.42	0.42	0.46	0.45	0.40	0.42	0.43	0.43
	13	Social inclusion	0.45	0.52	0.48	0.48	0.51	0.50	0.46	0.50	0.49	0.51
	14	Trust	0.60	0.66	0.60	0.63	0.64	0.63	0.61	0.65	0.60	0.64
Socioeconomic variables			0.57	0.62	0.63	0.62	0.67	0.62	0.60	0.70	0.62	0.61
Pub. intervention			0.63	0.63	0.63	0.63	0.64	0.65	0.63	0.63	0.63	0.63
Social Capita			0.46	0.50	0.49	0.48	0.52	0.53	0.46	0.49	0.50	0.50
Total			0.55	0.59	0.58	0.58	0.61	0.60	0.56	0.61	0.58	0.58

Displaying Medellin´s inequalities, Table 3 shows the percent change of the groups' deviation to Medellin averages between I and II ("Change in deviation"), including all socioeconomic, public intervention and social capita variables. Results show that most positive changes in scores happen in those groups where I values were below Medellin average (bold numbering), indicating a reduction in inequalities between high-scored and low-scored groups, and consequently, among the whole urban population. This effect is more observable for the TOD groups - zones 1, 2 and 4, low income and female group.

Table 3 Equity effect ("Change in deviation") (in %)

			TOD					n-TOD					
Topic category		**Variable**	**1**	**2**	**4**	**Low**	**Female**	**3**	**5**	**6**	**Middle**	**High**	**Male**
Socioeconomic variables	1	Housing	**-0,05**	**0,04**	0,19	**0,31**	**0,77**	**0,09**	0,01	-0,30	-0,12	-0,38	-0,12
	2	Education	0,01	-0,04	-0,02	0,02	0,05	0,03	**0,02**	**0,00**	-0,04	**-0,03**	-0,04
	3	Income	**0,03**	**-0,01**	0,01	**0,02**	**0,00**	**0,01**	0,00	**-0,03**	-0,01	-0,01	**0,02**
Public Intervention	4	Education (satisfaction)	**0,01**	0,01	**0,08**	**0,01**	0,01	-0,06	0,00	**-0,04**	**-0,02**	0,04	**-0,01**
	5	Environment	-0,01	0,06	**0,14**	-0,01	0,03	**-0,02**	-0,06	-0,10	**0,01**	**0,06**	0,00
	6	Health	**0,02**	**0,00**	**0,01**	**0,00**	**0,00**	-0,09	0,12	-0,07	**-0,03**	**0,08**	**-0,02**
	7	Public Infrastructure	**0,00**	**0,03**	-0,03	**0,02**	**0,01**	**0,03**	-0,01	-0,01	-0,01	-0,04	0,00
	8	Public space	**0,05**	-0,07	**0,04**	**0,00**	0,02	-0,04	-0,04	**0,06**	0,00	**0,05**	**0,00**
	9	Transit	**0,06**	-0,03	**0,07**	**0,05**	**-0,01**	-0,10	-0,05	**0,07**	-0,01	-0,02	**0,01**
Social Capita	10	Collective action	**0,10**	**-0,01**	**0,14**	**-0,03**	**0,08**	-0,20	-0,03	**0,02**	-0,03	-0,01	-0,03
	11	Groups and Networks	**0,04**	-0,08	0,30	**0,38**	**0,04**	**-0,15**	0,10	**-0,26**	**-0,02**	0,29	-0,09
	12	Inf. & Commun.	**0,11**	-0,07	-0,03	**0,09**	**0,01**	-0,01	-0,02	**0,04**	-0,05	-0,04	-0,03
	13	Social inclusion	**0,10**	0,05	**0,00**	**0,13**	**0,05**	-0,07	-0,07	**0,01**	**-0,03**	-0,06	0,01
	14	Trust	0,02	**0,08**	**0,03**	**0,04**	0,02	-0,03	-0,05	-0,03	**-0,01**	-0,06	**0,00**
Socioeconomic variables			**0,01**	**-0,01**	0,03	**0,06**	**0,15**	**0,03**	0,02	**-0,07**	-0,04	-0,10	**-0,03**
Public Intervention			**0,02**	0,00	**0,04**	**0,01**	**0,01**	-0,05	-0,01	**-0,01**	-0,01	0,02	**0,00**
Social Capita			**0,07**	**0,01**	**0,06**	**0,07**	**0,04**	-0,09	-0,03	**-0,01**	-0,03	-0,01	-0,02
Total			**0,03**	**0,00**	0,05	**0,04**	**0,07**	-0,03	-0,01	**-0,03**	-0,03	-0,03	-0,02

Note: bold format: 2009 values (I) below Medellin 2009(I) average.

Finally, Table 4 shows the results of the Wilcoxon-Mann-Whitney test between TOD and non-TOD groups for both the % change in score ("Change") and the % change in the deviation to Medellin mean ("Change in deviation") for the study period. Our results suggest that there is a statistically significant difference between the underlying distributions of the total "Change in deviation" and "Change" of TOD groups and non-TOD groups for all three comparison groups -geographic zones ("Change": $z= 6.93$, $p =0.00$; "Change in deviation": $z = 8.46$, $p =0.00$), income levels ("Change" : $z=4.71$, $p =0.00$; "Change in deviation": $z = 6.64$, $p =0.00$), and gender ("Change": $z = 2.82$, $p =0.00$; "Change in deviation": $z = 4.05$, p

=0.00)-. TOD groups show a higher rank sum than non-TOD, indicating that TOD may increase the quality of life besides reducing transport emissions.

There is no statistical difference for the socioeconomic and public intervention variables (except from geographic zones (“Change in deviation”: z = 4.22, p =0.00), and income level (“Change in deviation”: z = 3.37, p =0.00), with higher scores for the TOD groups in both cases. However, social capita has a statistically significant difference in both “Change” and “Change in deviation” between TOD and n-TOD for all three comparison groups -zones (“Change”: z = 7.13, p =0.00; “Change in deviation”: z = 7.50, p =0.00), income levels (“Change”: z=5.07, p =0.00; “Change in deviation”: z = 6.07, p =0.00), and gender (“Change”: z = 2.96, p =0.00; “Change in deviation”: z = 3.96, p =0.00). TOD groups have higher rank sum than non-TOD groups, indicating that positive changes in TOD use also increases social capita.

At the variable level, although housing, education and income typically show higher medians for TOD groups, particularly for housing, none of them are statistically significant. With regards to the variables looking at the perception of public intervention, only environmental and transit interventions show statistical differences for zones and income levels with TOD groups having higher scores.

Table 4 Statistical results for the comparative groups for all variables: median (M) z and p values (*significant at p < 0.01, grey coloured).

			Zones				Income				Gender			
			Change		Change in deviation		Change		Change in deviation		Change		Change in deviation	
Variables/ Topic category		Values	TOD	n-TOD	TOD	n-TOD	TOD	n-TOD	TOD	n-TOD	TOD	n-TOD	TOD	n-TOD
1	Housing	M	0.60	0.05	0.02	-0.03	0.35	-0.26	0.31	-0.25	0.91	-0.03	0.77	-0.12
		z; p	0.84; 0.40		1.01; 0.31		2.32; 0.02		2.32; 0.02		1.96; 0.05		1.96; 0.05	
2	Education	M	-0.05	-0.03	-0.01	-0.01	-0.04	-0.08	0.02	-0.02	-0.04	-0.07	0.02	-0.07
		z; p	-0.66; 0.51		-0.57; 0.57		1.03; 0.30		1.03; 0.30		1.09; 0.27		1.53; 0.13	
3	Income	M	0.02	0.00	0.00	-0.02	0.01	0.01	0.00	-0.01	0.01	0.03	0.00	0.01
		z; p	0.44; 0.66		1.06; 0.29		0.37; 0.71		0.98; 0.33		-0.31; 0.75		0.31; 0.75	
4	Education (satisfaction)	M	-0.05	-0.09	0.01	-0.04	-0.05	-0.05	0.01	0.01	-0.05	-0.06	0.01	-0.01
		z; p	1.96;0.05		1.94; 0.05		0.00; 1.00		0.00; 1.00		1.00; 0.32		1.00; 0.31	
5	Environment	M	0.10	-0.01	0.06	-0.03	0.01	0.05	-0.02	0.05	0.03	0.02	0.01	0.00
		z; p	3.33; 0.00*		3.61; 0.00*		-1.38; 0.17		-3.63; 0.00*		0.41; 0.68		1.17; 0.25	
6	Health	M	-0.08	-0.09	-0.03	-0.04	-0.05	-0.04	0.00	0.00	-0.06	-0.05	0.00	-0.02
		z; p	0.49; 0.63		0.84; 0.40		0.26; 0.79		0.26; 0.80		-0.22; 0.83		0.65; 0.51	
7	Public Infrastructure	M	0.04	0.02	0.00	0.00	0.06	0.01	0.01	-0.01	0.03	0.04	0.01	0.00
		z; p	0.18; 0.85		0.64; 0.52		1.62; 0.10		3.62; 0.00*		0.85; 0.40		1.56; 0.12	
8	Public space	M	0.00	-0.02	0.05	-0.01	0.01	0.02	0.03	-0.01	-0.02	-0.01	0.02	0.00
		z; p	-0.01; 0.99		1.53; 0.12		-0.13; 0.90		0.78;0.43		0.32; 0.75		0.99; 0.32	
9	Transit	M	0..02	-0.06	0.04	-0.03	0.02	-0.03	0.03	-0.01	-0.03	0.00	-0.01	0.01
		z; p	2.95; 0.00*		3.07; 0.00*		2.86; 0.00*		2.71; 0.00*		-1.47; 0.14		-2.83; 0.01	
10	Collective action	M	0.06	-0.08	0.09	-0.05	-0.04	-0.04	-0.02	-0.03	0.07	-0.06	0.06	-0.04
		z; p	2.75; 0.00*		3.04; 0.00*		0.00; 1.00		0.28; 0.78		1.92; 0.05		1.76; 0.07	

Table 4 cont.

11	Groups and Network	M	0.15	-0.12	0.15	-0.14	0.31	0.15	0.15	0.12	0.08	-0.03	0.05	-0.12
		z; p	4.05; 0.00*		4.33; 0.00*		1.11; 0.27		0.92; 0.36		1.85; 0.06		3.77; 0.00*	
12	Inf & Communication	M	0.07	-0.02	0.03	-0.02	0.06	-0.03	0.05	-0.03	0.03	-0.04	0.02	-0.03
		z; p	1.50; 0.13		0.95; 0.34		3.06; 0.00*		2.94; 0.00*		1.14; 0.25		1.80; 0.07	
13	Social Inclusion	M	0.09	-0.01	0.05	-0.04	0.12	0.00	0.07	-0.04	0.08	0.06	0.03	0.02
		z; p	4.73; 0.00*		5.60; 0.00*		3.94; 0.00*		5.74; 0.00*		1.49; 0.14		1.24; 0.22	
14	Trust	M	0.09	-0.01	0.03	-0.03	0.08	0.02	0.03	-0.01	0.08	0.07	0.01	0.01
		z; p	3.20; 0.00*		3.61; 0.00*		2.38; 0.01		3.27; 0.00*		0.28;0.77		0.41; 0.68	
Socioeconomic variables		**M**	0.17	0.01	0.01	-0.02	0.12	-0.04	0.05	-0.04	0.21	-0.04	0.15	-0.08
		z; p	0.74; 0.46		0.76; 0.45		2.39; 0.02		3.37; 0.00*		1.89; 0.06		2.42; 0.02	
Public Intervention		**M**	0.03	0.00	0.02	-0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.00	0.00
		z; p	2.53; 0.01		4.22; 0.00*		0.95; 0.34		1.77; 0.08		0.22; 0.83		0.8; 0.43	
Social Capita		**M**	0.09	-0.02	0.05	-0.04	0.11	0.00	0.06	-0.02	0.07	0.02	0.02	0.00
		z; p	7.13; 0.00*		7.50; 0.00*		5.07; 0.00*		6.07; 0.00*		2.96; 0.00*		3.98; 0.00*	
Total		**M**	0.05	-0.01	0.03	-0.02	0.07	0.00	0.04	-0.01	0.05	0.01	0.01	0.00
		z; p	6.93; 0.00*		8.46; 0.00*		4.71; 0.00*		6.64; 0.00*		2.82; 0.00*		4.05; 0.00*	

The variables measuring social capital are statistically significant, with the exception of information and communication, maybe because this dimension requires more time for changes to be observed. For the income levels however, information and communication is statistically significant together with social inclusion and trust. The comparison group gender only shows statistic significant results for groups and networks both at the variable and topic category level.

Overall, TOD groups show an increase not just in the quality of life, but also in social capital. At the outset, inequality dominated in TOD groups, an observation that legitimises the equity intention of the interventions. As a result of the TOD interventions, the previously disadvantaged parts of Medellin improved and became less disadvantaged. Pointedly, among TOD zones, zone 1 demonstrates better results than zone 4. Possibly this is due to the fact that the PUI Noroccidental (zone 1) started before the PUI Centroccidental (zone 4) and the works were more advanced (Puerta Osorio 2011).

6. Discussion

Urban planning in general and TOD in particular will be fundamental in tackling the social and environmental challenges to come in cities due to climate change (Fernandez Milan and Creutzig 2015). While TOD and participative urban planning emerges as an increasing popular urban measure, the potential of TOD interventions on social capital when citizen’s participation takes place in the process remains underexploited. TOD often faces challenges related to inefficient public participation processes and unstructured stakeholder involvement which may lead to project designs at odds with local needs and suboptimal outcomes in social sustainability (Assefa and Frostell 2007; Kathryn Scott 2000; Soria-Lara, Bertolini, and te Brömmelstroet 2015; Belzer and Autler 2002; Dorsey and Mulder 2013). Participatory TOD planning could avoid such undesired outcome and further increase social and environmental positive effects. Besides the well known TOD changes in transport emissions and land use mix, participatory approaches enhance the effects on social interactions in two ways. First, TOD itself improves the quality of public spaces and urban connectivity and accessibility. Diverse land use patterns, well-connected street networks and fast, frequent and well-connected TOD modes enhances citizen's urban mobility that in turn fosters social networks. Second, participation fosters transparency, trust, social inclusion, collective action and social networks. In addition, social capital itself leads to sustainable behaviours in the community. For example, the feeling of ownership of the TOD makes usage of TOD more likely. The strengthening of democratic processes; and the empowerment of citizens in the design, implementation, handing over mechanisms and evaluation of TOD plans increases the public welfare and associated social benefit. Numerous methods have proved to be effective in communicating complex matters to citizens –e.g. visual and participative workshops aiming at identifying preferred TOD combinations for citizens (Bailey, Grossardt, and Pride-Wells 2007; Fernandez Milan 2015)-. Hence, TOD and citizen's participation could be used as a catalyser for local sustainability.

Our results have to be understood in the larger context of Medellin´s transformation since the early 2000s until now. During the study period there were many interventions all around the city aiming at similar outcomes that certainly influenced all city areas. However, taking TOD modal changes as the grouping variable, we avoid looking at secondary effects (e.g. zone 2 is included in our TOD group regardless of the development of its upgrading program, not yet finished for the study period). In any case, despite the impressive positive effects of the PUIs, these cannot be considered as the only tool to enhance social and environmental objectives at the city level.

TOD is critical to the achievement of a wide range of social, economic and environmental objectives and, therefore, needs appropriate institutions to ensure its integration with the strategic management of the rest of urban development policy. In Medellin, local political leadership played a key role. An institutional strategy that comprises the processes of decision-making, design, construction and coordination of the multiple civil works, cable equipment procurement, installation and implementation, system operation, and financing of the whole package is fundamental for maximizing outcomes. This should be done by aligning the divergent interests of the greater city, the project municipality, the regional authority and the national government to avoid individual structural intervention from the public transport authorities (Acevedo II; Bahl II; J. Dávila 2014). In this way, the process also enhances local democracy, equality and social regulation and avoids confrontation with unaccepted structural interventions, ultimately maximizing the social results of the intervention (P. Brand 2005).

Medellin´s experience could be used in urban development contexts to come. In Medellin itself, different governments repeated this scheme in other marginalized areas. They have developed an intervention methodology that is showing applicable in other contexts, provided there is commitment from the government to carry out such innovative urban planning (Cárdenas 2008; J. Dávila IIb). In fact, this methodology has already been adapted to other cities in Colombia and Brazil, and is the bases for the development of the Growth Acceleration Program (J. D. Dávila 2013; Farajado Valderrama, Cabral, and Tonkiss 2014). This is slightly reminiscent of isomorphic development of urban administrations in China, coordinated partially be central governments, and by peer-based learning from frontrunners (F. Creutzig et al. II). Network and learning processes should be leveraged to further upscale the positive experiences with TOD.

7. Conclusion

The extraordinary outcomes of Medellin in the last years is not just a result of the massive public transport investment, but also on the synergies between transport infrastructural interventions and the urban upgrading integration programs in the form of participatory TOD. With this study, we provide new evidence that citizen participation increases the environmental benefits of TOD, and augment the social capital of its participants.

Appendix

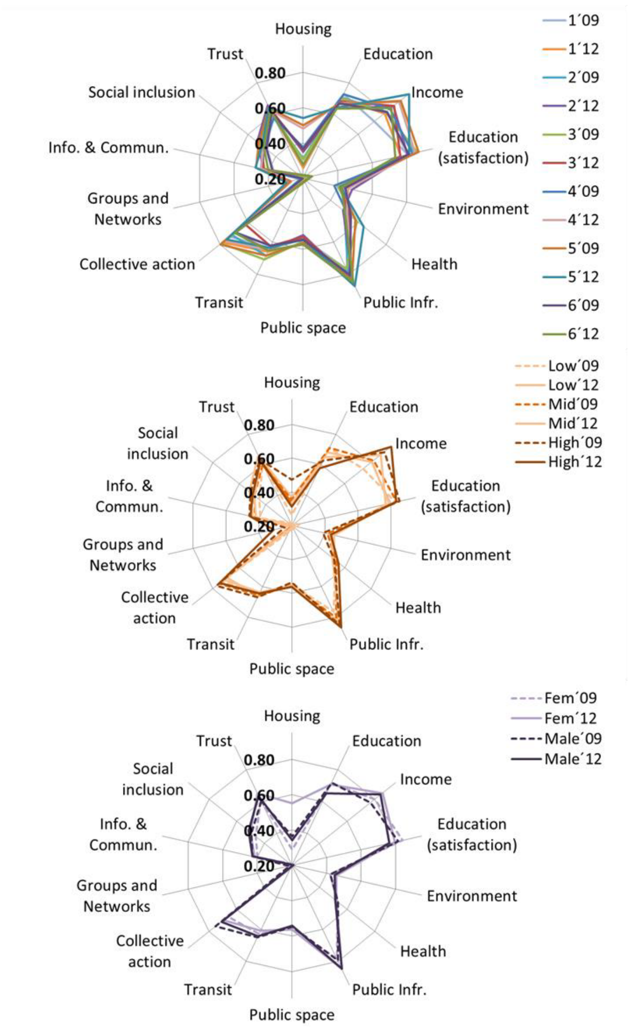

Fig. A.1 Scoring of the variables for the years I and II ("Change") for all three comparison groups: zones, income level and gender (based on the numbers reported in Table 2).

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Chapter 10

Stakeholder involvement in sustainability science A critical view[1]

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Stakeholder Involvement in Sustainability Science - A critical View

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Abstract

Discussions about the opening of science to society have led to several developments: New fields of sustainability science and transformative research have emerged and the "megatrend" of stakeholder participation has reached the academic world and thus research processes. This challenges the way science is conducted and the tools, methods and theories perceived appropriate. Although researchers integrate stakeholders, the scientific community still lacks comprehensive theoretical analysis of the practical processes behind it – for example what kind of perceptions scientists have about their role, their objectives, the knowledge to gather, the understanding of science or the science-policy interface. Our paper addresses this research gap by using the categories above to develop four ideal types of stakeholder involvement in science – the technocratic, functionalist, neoliberal, rational and democratic type. In applying the typology which is based on literature review, interviews and practical experience, we identify and discuss three major criticisms raised towards stakeholder involvement in science: the legitimacy of stakeholder claims, the question whether bargaining or deliberation are part of the stakeholder process and the question of the autonomy of science. Thus, the typology helps scientists to better understand the major critical questions that stakeholder involvement raises and enables them to position themselves.

Keywords: Stakeholder involvement, sustainability science, legitimacy of science, typology.

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1. Stakeholder involvement in Sustainability Science

The involvement of stakeholders into science is an expanding trend in an increasing number of research areas, especially in those that besides their technological dimension also touch societal, economic and political interests[8]. Due to the complexity of such fields like i.e. the energy transition[9], the scientific community felt the need to go beyond conventional scientific methods by incorporating non-academic actors´ views and knowledge in their research through stakeholder involvement[10]. The concept that is common in the economic realm (mainly to deal with Corporate Social Responsibility strategies) or the political realm (i.e. in decision-making processes) has thus been integrated into the broader science environment and especially into new scientific fields such as sustainability science (Kates et al. 2001; Clark and Dickson 2003; Komiyama and Takeuchi 2006; Jäger 2009; Ostrom 2009; Jerneck et al. 2011; Wiek et al. 2011), transformative research[11] (Schneidewind and Singer-Brodowski 2013; WBGU 2011; Dietz and Rogers 2012; Crocket et al. 2013) and transition research (e.g. Kemp and Rotmans 2009; Geels 2002, 2011; Loorbach 2007; Markard et al. 2012). These new fields incorporate a broad array of concepts like post-normal-science (Funtowicz and Ravetz 1993), mode-2 science (Gibbons et al. 1994), mode-3 science (Schneidewind and Singer-Brodowski 2013) or citizen science (Irwin 1995; Fischer 1996) as well as transdisciplinary (Hirsch Hadorn et al. 2006; Berger 2010; Daschkeit 1996; Scholz 2000; Bergmann and Schramm 2008; Jahn 2008; Nowotny 1997) and participatory research strategies (Kasemir et al. 2003a, 2003; Becker 2006; Robinson and Tansey 2006; Scholz et al. 2006; Glicken 2000; Renn et al. 1991)[12].

In this context, the main objective of stakeholder involvement is to tackle the "complexity, uncertainty, and multiplicity of values" and perceptions on controversial issues such as the energy transition, or mitigation and adaptation to climate change by combining "expert assessments with problem framings of the lay public" (Kasemir et al. 2000: 181). Lang et al. (2012) refer to objectives of stakeholder involvement by saying that sustainability issues need "the constructive input from various communities of knowledge" – here described as scientists from different disciplines and non-academic-actors – to include "essential knowledge from all relevant disciplines and actor groups related to the problem" as well as allowing for the incorporation of "goals, norms, and visions". Particularly the

[8] Schneidewind (2013: 83) defines the integration of the technological, cultural, economic and institutional dimension in transformative research as „transformative literacy".

[9] The energy transition refers to the task of decarbonizing the economy and shifting from fossil to renewable energy sources.

[10] There is a variety of terms used, ranging from stakeholder dialogues over stakeholder participation and stakeholder engagement to stakeholder involvement, depending on the scientific field and the research context.

[11] WBGU defines transformation research as the analysis of the transformation process and transformative research as the one supporting the transformation process (WBGU 2011: 23).

[12] The movement of action research also belongs to these new research strategies (Action Research Manifesto 2011).

involvement of citizens is linked to discussions on challenging existing epistemologies of science and assessment of knowledge production and knowledge validity (Tàbara 2013: 116). Welp et al. (2006) describe stakeholder involvement in science as the "structured communication processes linking scientists with societal actors such as representatives of companies, NGOs, governments and the wider public", called "science-based stakeholder dialogues" 13. A more pragmatic branch of stakeholder participation engages with the development and implementation of methods and participatory tools intended to support sustainability learning and the transformation of agents through "effective interfaces between knowledge and action" (Heras and Tàbara 2014: 379; Cornell et al.: 64).

This implies that transformative research does not focus on "intrinsic" scientific discussions, but on solving "extrinsic" societal problems (Strohschneider 2014: 180). Weingart and Maasen speak of a "democratisation of expertise" (2005) whereas Gibbons (2000: 162), Nowotny (2003) and Nowotny et al. (2001) call for the creation of "socially robust knowledge" through combining research capabilities with other institutions, actors and practices which are relevant for the transition to take place. Schneidewind et al. (2011: 134) add that to generate system, target and transformation knowledge in transformative science, the latter has to integrate "context- and experience knowledge of relevant actors". Hayn et al. (2003) organize stakeholder input on three different levels: on the analytical level, stakeholders bring in system knowledge through their practical experience; on a normative level they add orientation knowledge through their opinions; and at the operative level they incorporate target knowledge and transformation knowledge by working on solutions with their own set of resources and motivations. Glicken (1999) divides knowledge into three types: "cognitive, experiential, and value-based", where cognitive knowledge stems from technical experts, experiential knowledge comes from people sharing their personal experience and value-based knowledge is related to social interests and social values.

Academic literature describes a wide array of opportunities associated with stakeholder involvement – although mostly related to participatory and decision-making processes concerning for example the implementation of GHG mitigation measures (Kempton 1991; Löfstedt 1992), global processes of change (Shackley and Skodvin 1995) or environmental governance (Renn et al. 1991; Renn and Schweizer 2009; Bäckstrand 2006). Stakeholder involvement is said to increase relevance (Spangenberg 2011: 283; Hirsch Hadorn et al. 2006: 125; Baumgärtner et al. 2008: 387), legitimacy and credibility (Fiorino 1990: 228; Cash et al. 2003: 8087; Spangenberg 2011: 283), ownership (Lang et al. (2012); Spangenberg 2011: 283; Bäckstrand 2006: 472), effectiveness (Funtowicz and Ravetz 1993: 755) as well as the (social) accountability of research (Welp et al. 2006:171; Gibbons et al. 1994: 3; Bäckstrand 2006: 484ff; Lang et al.(2012); Kasemir et al. 2000: 182)

[13] A science-based stakeholder dialogue needs to be designed in an open manner such that stakeholders are able to communicate their values and the constraints and boundary conditions that they feel limit their freedom to act (Kasemir et al. 2000: 181).

However, criticism can also be found in the literature; mostly concerning the validity and credibility of scientific results established with stakeholder involvement (Yosie and Herbst 1998: 4). Concerns relate to co-design – the involvement of stakeholders in the definition of research questions and designs (Schneidewind and Singer-Brodowski 2013: 121ff) – and the co-generation or co-production of knowledge – i.e. the integration of societal actors' bodies of knowledge into the actual research process and related scientific findings – (Schneidewind and Singer-Brodowski 2013: 316; Pohl et al. 2010: 269). Pohl et al (2010: 271-272) identify three major challenges of this co-production of knowledge: the challenge of power, the challenge of integration and the challenge of sustainability. Related to this, some fear that certain kinds of stakeholder involvement might as well threaten the autonomy of science (Strohschneider 2014; Bosch et al. 2001: 201; Enserink et al. 2013: 14). Brandt et al. 2013: 7), who define five challenges[14] of transdisciplinary research projects, criticize that currently there is "no clear set of tools required for different process phases or integration of different types of knowledge" as well as little "practitioner empowerment".

Since participatory or decision-making processes – i.e. labelled as "policy dialogues" by Welp et al. 2006: 172f) – typically do not concentrate on the generation of knowledge, we explicitly do not follow these concepts in this article.[15] We instead follow the distinction between research processes that aim at improving knowledge and evidence and decision-making or management processes as proposed by Mackinson et al. (2011: 19). While we relate to the approach of Renn and Schweizer, who developed six concepts of stakeholder and public involvement in risk governance based on "philosophies of participation and collective decision making" (2009: 176ff), we in contrast look at the way stakeholder dialogues between science and society are understood by scientists. This perspective that we find important for carrying out scientific work with stakeholders is so far underrepresented in the peer-reviewed literature.

In this paper, we establish a typology of scientific perspectives on stakeholder involvement. Section 2 will briefly outline the methodology behind the typology and section 3 will describe the different ideal types we derive. Section 4 shows an example by applying the typology to the field of energy transition research. In section 5, we use our typology to analyze and systematize the critique with regards to stakeholder involvement by deriving three continua that enable scientists to position themselves (section 5). We conclude by pointing out the critical choices for scientists that arise from this analysis (section 6).

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[14] Three of the challenges that were evaluated via an analysis of case studies relate to the discussion in this paper: "research process and knowledge production; practitioner involvement; generating impact" (Brandt et al. 2013: 2ff).

[15] Welp et al (2006) differentiate policy dialogues, multi-stakeholder dialogues for governance, science-based stakeholder dialogues and corporate dialogues based on their objectives.

2. Methodology

Depending on the perspective one takes, stakeholder involvement practices and the difficulties and critical choices they entail, differ substantially. In order to show this, we establish a typology of ideal types of scientific perspectives on stakeholder involvement. Though in practice there might only be hybrid forms, the development of ideal types has a long tradition in sociological studies as a research heuristic that stresses and exaggerates distinctive characteristics of a group of cases to disentangle different categories from each other (Kelle and Kluge 2010: 83).

In order to develop our types of stakeholder involvement in science, we apply five criteria of differentiation:

1. Role of the scientist: The perception on which role the scientist should take (and in relation to that also the stakeholder) differs widely. This also relates to the question of the autonomy of science (see for example Welp 2006: 180).
2. Objectives: The reasons why a scientist would want to work with stakeholders are diverse – ranging from increasing impact on real world issues to getting insider information or increasing legitimacy (see for example Renn and Schweizer 2009: 176).
3. Kind of knowledge: Scientists seek to gather different kinds of knowledge when involving stakeholders. Based on other differentiations such as cognitive, experimental and political knowledge (Glicken 1999: 301f) or system, orientation as well as target and transformation knowledge (Schneidewind and Singer-Brodowski 2013: 42ff, 69ff), we structure the kinds of knowledge that scientists can integrate into their research along the range of pure data, information, assessments and normative values.
4. Understanding of science: Scientists have different understandings of good or appropriate science including not only tools and methods, but also epistemic and philosophical questions (Weingart 2003: 53ff). Is science a detached system dealing with self-referential questions or does science serve societal needs? Can science be neutral and objective or does it mirror societal developments and conflicts?
5. Science-policy interface: The role and impact scientists have or expect to have on political decision-making, and hence their perceptions of the societal responsibility of science, strongly imply the way stakeholders are involved in the research process.

On the basis of these criteria, we derive our typology from literature and own experiences working with stakeholder dialogues in climate and energy transition research. We complement both with empirical data generated in interviews with practitioners that involve stakeholders in their research projects , focusing on their perceptions of the science-stakeholder relation and practical experiences[16].

[16] All authors are active or have recently been active in projects involving stakeholders. The typology is based on experiences e.g. from the following projects: “Investment Impulse for the German Energy Transition in Times of Economic and Financial Crises”, funded by the Federal Ministry of Education and Research (BMBF),

3. A stakeholder involvement typology for scientists

Sections 3.1 to 3.4 describe the four ideal types – the technocratic, the functionalist, the neo-liberal and the democratic type – of stakeholder involvement in science. Section 4 makes use of a hypothetical scenario from the Energy Transition in Germany to illustratively discuss the different types that we here deal with.

3.1 Technocratic type

The technocratic type's main objective to get stakeholders involved is to improve the scientific research process by broadening the extent of available information through the engagement of what could be called 'expert-stakeholders' (Gupta et al. 2012; Whitmarsh et al. 2007: 5). The role of stakeholders is to provide issue-specific, objective and falsifiable information that fits into the classical way science is conducted according to philosophers of science such as Karl Popper (1957). Thus, the technocratic view shares certain important characteristics with the literature on expert interviews (Przyborski 2014: 118ff.). If lay people are involved in research processes it is only indirectly as a source of data (Fiorino 1989: 293f). They do not provide information themselves - e.g. the interpretation of these data - but lend it to scientists who use it to extract what they consider is relevant for their research (Fiorino 1989: 298f, 1990:227).

The impact of stakeholders on science is thus relatively limited in the sense that stakeholder involvement is expected to feed in additional data and information, but not to define or transform the research question or process. The ontological difference between scientists that play the active part in research, and relatively passive stakeholders involved directly, if experts, or indirectly if lay people, is greatest in this view. Scientists determine all the elements of the research process autonomously, including the ways in which stakeholders are involved. Consequently, the scientific sovereignty of interpretation, or primacy of science, is kept throughout the research process.

The kind of knowledge that is to be generated by stakeholder involvement is defined from a purely scientific angle and thus, research questions are derived from intra-scientific debates and controversies rather than societal needs. Consequently, research questions typically focus on the technological dimension of transformation processes rather than on cultural or institutional problems, which are more closely linked to research on implementation (Schneidewind 2013: 83ff). Stakeholders are involved only on an analytical level, providing data and information rather than assessments and normative evaluations. Moreover, since technocratic research is

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often based on a linear concept of knowledge transfer (Bergmann 2014), it tends to neglect questions of implementation and societal impact like the social robustness of the knowledge it generates. Such a relatively narrow concept of scientifically relevant knowledge is in part due to the understanding of the science–policy interface put forward by the technocratic type. In discussions on scientific consultation in policy or decision-making processes, it is often circumscribed by the idea of ‚speaking truth to power‘ (Pohl and Stoll-Kleemann 2007: 10f) and emphasizes ethical neutrality and technical advice. Science and policy-making are conceived of as separate fields that are not intertwined. Rather, scientific findings are expected to inform policy processes and provide the foundation for policy measures. How these findings can become relevant in the sphere of politics is, however, not discussed in this context. From a technocratic perspective, this is a question that is to be addressed by politicians or activists, but of no immediate interest to science.

3.2 Neoliberal type

The neoliberal type understands knowledge as “merely a ‘hook’ on which interests hang their case” (Radaelli 1995: 173). He acknowledges the existence of interest and power in the science society interfaces and understands stakeholder participation as a tool for both groups to impose their perceptions and interests, or parts of them, on the other group. Stakeholders are thus understood as lobby groups or individuals advocating for their specific organizational, individual or political interests and try to channel their views into the research process and thus indirectly into a public discourse or the political arena. Furthermore, stakeholders are interested to get legitimacy of certain positions by the “objectivity” often claimed by or attached to scientists (van den Daele 1996: 297ff). On the other hand, scientists are not understood as “naive”, but conscious about the differing interests and are able to only take out the knowledge/information they find valid or interesting (Hoppe 2005: 210). Following this understanding, stakeholder involvement would be a tool for scientists to efficiently obtain data or knowledge they need for further research. Stakeholders and scientists are both aware of these mechanisms and try to use them for their own purposes. Scientists might even want to use the process as a means to channel their research results into actual projects and decisions to ensure impact or application of the research. Another motivation for the neoliberal type of scientist to involve stakeholders is the perception of an increased chance of being funded by public authorities that support stakeholder involvement (Schneidewind 2013: 178).

The kind of knowledge scientists try to get from stakeholder involvement depends on the specific discipline, task and methods applied. Knowledge is not bound to pure data or information but can also include system, normative and creation knowledge. The phase where stakeholders are involved is not restricted. They might already be part of the negotiating phase between funding partner and scientists. The science policy interface is thus seen as a kind of “battlefield” where both groups follow their specific interests and bargain about all possible aspects, i.e defining the research question, methods, wording, boundary conditions for modelling exercises, scenarios, possible take-outs, messages and interpretation of the results and communication. The actual roles of scientists and stakeholders and their respective influence on the research process are not pre-defined in the neoliberal “bargaining” concept of stakeholder involvement. Although scientists are expected to have a slightly greater impact on the research process, no ontological difference between the two groups of actors is detected (each has their own interest and wants to succeed). In a sense, scientists are themselves stakeholders who have personal agendas (Brinkmann et al. 2015: 10). These ontological foundations relate to basic assumptions of game theory (Nash 1950: 155), where rational individuals seek to maximise their utility defined by individual preferences. The understanding of science in the neoliberal sense relates to more relativistic concepts of science such as i.e. Feyerabend (1986). As there are no general rules which scientific reasoning and methods are appropriate, there is no single “right” way to do science. It depends on the actors’ perceptions and constellations.

A characteristic framing of this neoliberal perspective is the notion of “win-win situations” which explicitly acknowledges the win-lose taxonomy in a positive way. In the neoliberal view this behaviour is not perceived normatively (good or bad) but as “natural” or “rational”, relating to the rational choice paradigm (Esser 1993; Coleman 1990) where individuals as well as organizations are understood as rational actors that have fixed preferences and strive for optimal choices with regards to these preferences (Geels 2010: 496; Braun 2013:xx). The group politics approach sees scientific controversies as the result of the pluralist bargaining on the political marketplace by different kinds of actors (Martin and Richards 1995). Following that perspective, stakeholder involvement is just another arena for different kinds of actors - such as governmental bodies, individual citizens, economic, social and environmental interest groups as well as different kinds of scientists - to carry out the battle of power and authority.

3.3 Functionalist type

The functionalist type is based on an understanding of society as consisting of autonomous social spheres, or systems as introduced by Niklas Luhmann (1984; Kneer 2000) and further developed by a number of scholars with regards to social coordination processes (Teubner and Willke 1984; Bora 2001; Fuchs 2013; Mölders 2013, 2014). It takes a social-constructivist perspective and presumes that modern society is predominantly differentiated into functional subsystems such as the economic, the political, the legal or the science system that are defined by the kind of relevance criteria – or codes – along which the world is observed.

From a functionalist perspective, stakeholder involvement has the objective to irritate the science system with other social perspectives and relevance criteria in order to trigger learning processes that can make science more sensitive for societal problems (Willke 1983: 25, 1987: 333). However, these self-reflective processes can only be induced, but never enforced. Hence, stakeholder involvement is perceived as an opportunity or random generator that may, by chance, change the research process. In order to generate occasions of irritation, functionalist scientists attempt to integrate 'representative stakeholders' of different societal logics, e.g. from the economic or political systems or civil society organizations. Stakeholders are typically involved in all stages of the research process in order to increase the probability that changes take place. However, this never guarantees that stakeholders' perspectives are well-reflected and adequately incorporated into the research process.

With regards to the understanding of science, this type suggests that the science system consists of all communication that observes the world through the lens of truth – e.g. if a certain observation can be regarded as true or false according to certain theories or methods, which in Luhmann's terms would form the contingent 'programme' of the science system. Compared to the other types, the functionalist has a completely different view on the pre-described roles of scientists and stakeholders since he emphasizes communication over actors. He does not care who observes the world, but only looks at how is it observed (whether their communication is considered scientific or not). The kind of knowledge that stakeholders provide is always related to their respective mode of observation, i.e. depending on the systemic relevance criteria the stakeholders use.

However, as stakeholders such as politicians, business men or civil society activists typically act as 'representatives' of certain social systems, they tend to observe events from a political (power/no power), economic (payments/no payments) or moral (just/unjust) rather than a scientific perspective (true/false). As such, these observations are merely 'noise' to science, unspecified communication that does not (yet) make sense in scientific terms. As science generates 'order' from stakeholders' 'noise' by transforming stakeholders' statements into a scientific kind of information, substantial characteristics of their original meaning might get lost. Consequently, a functionalist attaches relatively low legitimacy to the original stakeholder input. It is this tension between irritation potential and scientific re-interpretation that describes the opportunities and limitations that stakeholder involvement generates from a functionalist perspective. In the strict sense, the science-policy interface does not exist from this perspective since science and politics generate meaning in very different and incommensurable ways. There can be no easy, immediate and substantial exchange or coordination across these different systems, but coordination can be achieved indirectly and probabilistically. Stakeholder involvement is a tool to enhance the probability that self-reflective processes are triggered, especially if they follow a so-called 'irritation design' (Mölders 2013: 15-16 , 2014: 24) that takes into account the social, temporal and factual dimensions of system-specific meaning (Luhmann 2012, cited by Mölders 2014: 3-4). For stakeholder involvement, this means that scientists should first consider which kind of actors have the greatest impact on the focal system, be it the science or the political system (social dimension), for example because they provide relevant insider information or are especially affected by the research questions. Second, scientists should think about the way statements need to be framed in order to become relevant or 'readable' (Fuchs 2013 as cited by Mölders 2014: 4) in the focal system – for example by explicitly linking opinions to ethical debates that are well-anchored in scientific or political debates (factual dimension). Third, good timing is essential and needs to take into account the temporal structures of different systems (e.g. length of review processes in science, election periods in politics, quarterly statements in the economy or rapid changes in societies due to salient event).

3.4 Democratic type

For the democratic type, stakeholder dialogues have the objective to integrate actors in society that are touched by a (complex) transformation or sustainability matters (Ward and Dubos 1972: xx; Schneidewind and Singer-Brodowski 2013: 314ff) into the research process. Especially through the participation of lay people, science can create legitimacy for itself, thus allowing "for the development of a genuine and effective democratic element in the life of science" (Funtowicz and Ravetz 1993: 740f).

From a democratic viewpoint, extending stakeholder dialogues from experts and scientists to civil society can enhance the quality of the research results (Spangenberg 2011: 283). Concerning the kind of knowledge, instead of only taking data and scientific observations into account, subjective probabilities science- and knowledge-based opinions and ideas are integrated into the research process. Also, networks and relationships are of great importance. Wiek 2007: 55) defines this process as collaborative research, where "scientists and local experts not only exchange relevant information but jointly generate (new) knowledge on the basis of their scientific as well as local expertise (joint research)."

By opening all levels of the process to stakeholders, e.g. from the definition of the research questions („Co-Design ", Schneidewind and Singer-Brodowski 2013: 121ff., 182, 211, 314ff.) to answering them („Co-Production"), socially robust knowledge is created (Nowotny et al. 2001: 166) to achieve a "democratization of expertise" (Maasen and Weingart 2005: 53). Besides the impact on the way science as such is conducted, the democratic type also looks at the political implications of stakeholder involvement in science. It argues that stakeholder dialogues are used to improve scientist's policy recommendations and make them more relevant since they reflect a broader range of interests from different stakeholder groups in society. Hence, stakeholder involvement is seen as a means to improve the interconnection and exchange processes between science and politics, alas the science-policy interface. Through this transdisciplinary approach (Wiek 2007; Dressel et al. 2014; Lang et al. 2012_ENREF_43) stakeholder dialogues can help bridge the gap between science and society and allow science to adapt to modern complexity (Bergmann 2014).

To be able to fully make use of this instrument, scientists have to approach stakeholders at eye level (Spangenberg 2011: 283), fostering a dialogue reflecting on their own and on stakeholder's roles. In the sense of Habermas' theory of communicative action, the democratic type believes that a true and valid communication can be achieved if certain rules are adhered to. Thus, through this "ideal speech situation" (Habermas 1990: 122) where there is "power neutrality" and "transparence" (Habermas 1993: 31; 1990: 56f), the "force of the better argument" is the dominant one (Habermas 1990: 198).

The role of the scientist is to facilitate and moderate the dialogue, bringing together different stakeholders from politics, business, research and civil society in an open arena (relating to the concept of the transition arena of Rotmans 2003; Loorbach 2002). The scientists have to translate the belief systems and languages of the different 'systems' while at the same time creating trust and ownership for the research process. The sense of ownership can foster stakeholder's engagement in the process and increase the chance that research results are taken into account by policy-makers. The established cooperation of stakeholders and scientists enables the researcher to follow the implementation of the scientific results and at the same time strengthens the acceptance of political measures in society (Spangenberg 2011: 283). Through the active involvement of the stakeholders they are not merely seen as an object of science.

Stakeholders on the other hand can influence and shape the research process through their engagement (or through other forms of (non)-participation: manipulation, therapy, informing, consultation, placation, partnership, delegation, citizen control (see Arnsteins's Ladder: Arnstein 1969)). Consequently, they play an active role and are typically involved in all stages of the research process –from the definition of the research question to the actual implementation of the scientific findings and the derived policy recommendations. This underlines the idea that the democratic type understands science as a tool to support transformation in society and to ensure representation of all people touched by it.

4. Energy transition research through the lens of the typology

The European Union's research funding program Horizon 2020 provides a useful framework to explore the different types we here discuss, to understand their implications and to illustrate the main controversies arising from each of them when dealing with controversial issues such as the energy transition in Europe and elsewhere. The implementation of the societal or political goals to reduce GHG emissions and increase the share of renewables in energy production in the near future demands scientific research on a large number of technological – e.g. smart grids and energy storage, building energy efficiency among others – and 'sociological' issues such as behavioral changes in consumption, mobility, etc. that require social acceptance for their success. We briefly describe stakeholder involvement strategies in the required research for a transition towards renewable energy and the discontinuity of CO_2 intensive energies in Table 1.

The next section will present an outline of the major critical arguments concerning stakeholder involvement in scientific processes and apply the typology to these arguments.

Table 1: Stakeholder involvement in energy transition research

	Research questions	**Stakeholders**	**Research process**	**Kind of results**	**Kind of projects**
Technocratic type	Generation: Scientifically identified gaps in research Content: Technical questions of the energy transition (wind and solar power, transmission, financial products)	Technical experts (planners, engineers, other scientists)	Generation: Scientists collect and evaluate information without direct influence of stakeholders Content: empirical data and information	Generation: No support of implementation, solely scientific communication of results Content: market assessments, technical feasibility studies	Pathways, case studies, scenarios, technical projections
Neoliberal type	Generation: result of bargaining process of interest groups (including scientists) of the energy transition Content: questions concerning societal needs and particular interests, policy demands, opinions/values	All stakeholders with interest in energy transition (Corporations negatively/ positively affected, citizen initiatives, Policy makers, NGOs, Lobby organizations)	Generation: scientists interpret/evaluate stakeholders' positions during all steps of the research process Content: opinions, information, values, interests	Generation: support of implementation to bring results into the political or societal arena (incl. media) Content: policy recommendations, studies	Scenarios (decentralized/ centralized, role of efficiency, technology development, role of nuclear energy) opinion polls, events, studies
Functionalist type	Generation: Scientifically identified problems Content: questions integrating social dimension of energy transition into science system	Powerful (and thus vocal) stakeholders from all affected social sub-systems: politics, economy, science, civil society	Generation: scientists involve 'representative stakeholders in all stages of research process to irritate science system with other social perspectives (random generator) Content: system-specific knowledge	Generation: enhance probability of self-reflective processes in the science and implementing systems through 'readable' framing and good timing Content: translated knowledge such as science-based policy recommendations	Studies, events, workshops (Bayesian Risk assessments for investments in different forms of energy production; social acceptance of new technologies (demand-side management, electric cars)
Democratic type	Generation: socially relevant problems arising from dialogue process Content: problems that hinder the energy transition/ questions that integrate needs of all stakeholders supporting the energy transition	All stakeholders affected by energy transition (Corporations, citizen initiatives, Policy makers, NGOs, Lobby organizations, citizens)	Generation: scientists take into account stakeholders' positions during all steps of the research process Content: opinions, information, values, interests	Generation: support of implementation through dialogue with stakeholders Content: policy recommendations, studies, opinion polls, assessments	Scenarios (decentralized/ centralized, role of efficiency, technology development, role of nuclear energy) opinion polls, events, studies

5. Discussion

This paper aims at a better understanding of the critique raised against stakeholder involvement in science. Following debates in science and society, we identify three major critical topics: First, the question of the legitimacy of stakeholders' claims as input for scientific purposes. Second, there is the issue of communication process that can be perceived as ranging from pure bargaining to deliberation addressing the science-policy-interface. Related to this is the more encompassing question of the autonomy of science that scientists uphold when working with stakeholders. Using our typology as a heuristic tool, we systematize the critical arguments on three respective continua (Fig 1), showing the implications the different types have for stakeholder involvement.

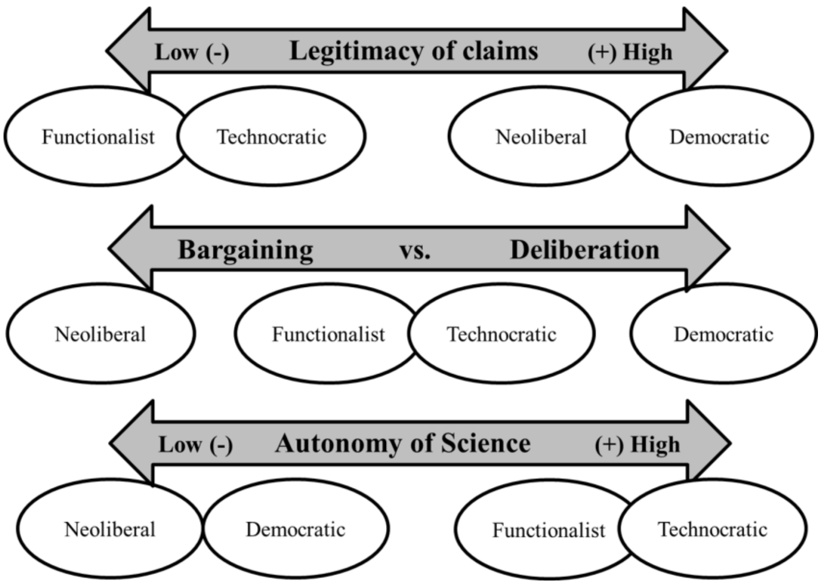

Figure 1: Critical continua of stakeholder involvement in science

The critique is most strongly directed against the types that are located at one of the ends of the respective continua and, accordingly, it is often issued from a perspective located at the opposite end of that continuum. The legitimacy of claims differs most strongly from the perspectives of the technocratic and the democratic type. When it comes to the question of bargaining vs. deliberation, the neoliberal and democratic types represent the most divergent perspectives. Concerning the autonomy of science, the critique stems from a rather technocratic or functionalist understanding of science and it is especially directed against the democratic and neoliberal type.

5.1 Legitimacy of claims

In literature and interviews, we find that one of the most contested problems is the scientific legitimacy of stakeholder input in the research process. Thus, the perception of the knowledge that is created through stakeholder involvement in scientific research processes is discussed. How much of the knowledge offered by the stakeholder is relevant and thus can be used by the scientist (to answer the research questions) – as data, as opinions, as information? How strong does the scientist distance himself or herself from the claims ranging from acknowledging all input as honest to looking through the “objective” lens of science?

On a practical level, the difficulty to differentiate between strategic communication and biased information by stakeholders is a main challenge for scientists. But not only stakeholders might use strategic communication. Funding organizations or researchers may also emphasize "win-win" situations when they want to persuade stakeholders to participate even if their main motivation the democratization of scientific processes. Another critical point discussed in literature is whether the opening of scientific processes to non-academic actors might threaten scientific sovereignty of interpretation by challenging intra-disciplinary criteria of knowledge production (Weingart 2011: 135).

On a theoretical level, criticism of the position that scientific knowledge can be described as ‘pure’ or objectively true has been formulated from different angles in the social sciences for a long time. To mention just a few examples, Michel Foucault retraces the co-constitutive relation between knowledge and power (Foucault 1995: 27). Paul Feyerabend argues that there can be no universal or definitive criteria for scientific methods or theories and that scientific claims are just as valid or invalid as claims from other spheres such as antique Mythology (Feyerabend 1986: 21, 55ff., 249ff.). Constructivist scholars highlight the social embeddedness and observer-dependency of all knowledge (Berger and Luckmann 1966; von Glaserfeld 1995). Consequently, the criteria, theories or methodologies which define “valid scientific knowledge” are dependent on the scientific sub-discipline (Strohschneider 2014: 184). Relating this to stakeholder involvement, the way claims are treated is dependent on the researcher’s understanding of science.

We refer to the critical trade-off that arises in such situations as “legitimacy of stakeholder claims/input”, describing the kind of stakeholder knowledge that the scientist uses in her research process and how she uses it. The continuum reaches from low legitimacy, seeing stakeholder claims as mere noise in the Luhmanian sense, to taking all claims as honest and true (high legitimacy). Adding to the kind of knowledge, the continuum thus also describes how strongly scientists distance themselves from the stakeholder input.

Applying the four different ideal types to this continuum can help to better understand the critique. The functionalist type stands on the far low end, seeing all claims as unspecified ‚noise‘ that is ‚senseless‘ unless transformed to the code of the science system. The technocratic scientist believes in the objectivity of science and thus expects stakeholders to provide only data (via lay-people) and technical information (via experts). The neo-liberal type is characterized by a high legitimacy of claims since following the logic of mathematicians like Nash, all players know the rules and act in their best interest. All statements are interest-driven and equally valid (or invalid) and thus interests are brought into the research process via inclusion of stakeholder knowledge. The democratic type sees all stakeholder claims or input as honest communication and takes them seriously in the research process. He thus takes into account data, information, science- and knowledge-based opinions, ideas, subjective probabilities, networks and values. Following Habermas' theory of communicative action (Habermas 1990), in a perfect speaking situation, there is no strategic communication.

Considering the critique that stakeholder involvement (or the opening of scientific processes to non-academic actors) might pose a threat to scientific sovereignty of interpretation by integrating 'un-scientific' kinds of knowledge and challenging intra-disciplinary criteria of knowledge production, the technocrat and the functionalist would agree, whereas the democratic and the neoliberal type believe that stakeholder involvement enhances scientific results. According to the democratic view, involving stakeholders into research processes can help to expand the perspective of "mainstream science" by incorporating the context-specific knowledge and value judgements of those affected by the research. Also, creating solution-oriented knowledge is considered a goal (Lang 2012: 29f). In the case of the neo-liberal, equally legitimate interest would contribute to the research.

5.2 Bargaining vs. deliberation

Another major criticism of stakeholder involvement in science relates to the question of interest-driven vs. deliberative stakeholder communication. How much convergence or divergence exits in regards to "operational codes of science and politics" (Hoppe 2005:207)? There is a mismatch between the positive notion of including the affected and concerned into the former "isolated" scientific research process and the perception of stakeholder involvement as another means to channel specific economic or political interests into research results. The latter is discussed as hampering the "neutrality" of research. Framed differently, this critique addresses the science-policy interface and thus the question whether stakeholder involvement supports a democratization process in science or allows for implicit or explicit lobbying of powerful actors in another societal area.

Even if scientists are perceived as conscious concerning the material interest stakeholders have, they have to rely on stakeholder's input into the research process (knowledge mismatch). Stakeholder dialogues mostly involve different kinds of actors – ranging from single affected citizens to politicians, administration, NGOs, companies, consultancies and lobby organizations. Actors need time and resources to participate, plus a strong motivation/interest. As Mancur Olson (1965) has shown, interest groups in democratic societies have very asymmetric chances of organizing themselves and voicing their values, interests and concerns. Especially large and dispersed groups such as citizens, tax payers or consumers are often unable to form interest groups that match the well-organized interests in society of i.e. economic branches (van de Kerkhof and Wieczorek 2005: 737ff). Generally, stakeholder dialogues in science do not involve political decision-making, thus we do not further elaborate on possible motives in that field, but make one point: influencing the public discourse by labelling and enriching and thus legitimizing specific interest-related positions with the "neutrality" and "objectivity" claim of science could be a motivation for stakeholders to participate.

All this said, the selection bias (who is able and who is willing to take part in a stakeholder dialogue and how do scientists chooses stakeholders) is a main criticism towards stakeholder involvement in science. On a more general level, this leads to the question whether stakeholder input is understood as a part of a deliberative democracy or as part of the bargaining power play of politics.

Depending on the type of stakeholder involvement in science, the views on this critique differ strongly. On the bargaining side, the neoliberal type sees the science-policy interface as a "battlefield" where all actors anyway bargain for their interest (Nash 1950). Stakeholders can be lobby groups/individuals who try to channel their interests into research process and indirectly into the political arena. On the other hand, the scientist tries to influence political decisions. Thus, although the neoliberal type understands the process as determined by interest and power, he does not perceive it as a threat or danger. The functionalist type though is indifferent to both bargaining and deliberation since he sees no overlap of the political and the science system especially when they communicate with each other. Scientific findings might become relevant for politicians if they trigger reflection in the political system through irritation, but that happens only by chance. The technocratic type is slightly closer to deliberation than the functionalist, believing that ‚explaining' the world instead of convincing political actors is the right way. This bears the underlying idea that science is objective: and scientists ‚speak truth to power' (Pohl and Stoll-Kleemann 2007: 10f.).

On the deliberation side of the continuum, following Meadowcroft's (2004) idea of group-based deliberation is the democratic type. Here, the scientist aims at the "democratization of science/expertise" and wants people/groups touched by transition (or energy transition) to be represented in the research process as well as science to support the (energy) transition. The involvement of citizen-stakeholders might remedy the influence on scientific results by powerful and well-organized interest groups in society. Another aim is to improve interconnection and exchange processes between science and politics. The democratic type understands stakeholder involvement as a way to increase relevance, legitimacy and fairness when certain standards are met. From a more pragmatic view, the so-called "democratization of research/science" may decrease the quality of research results. Following our typology, the technocratic and the functionalist type would argue that political goals (i.e. taking binding decisions according to opinions, preferences or value judgements based on voting) can not be transferred into the scientific realm without fundamentally changing the nature of science. The technocratic type would fear that scientific standards are softened, the functionalist would regard such a tendency as a creeping process of de-differentiation or re-programming by which non-scientific criteria such as social relevance substitute or modify the originally scientific criteria of true and false.

5.3 Autonomy of science

When designing stakeholder involvement, the question of the integration of stakeholders in the research process arises. On a meta-level, this can be summarized as a question of the autonomy or primacy of science . Should stakeholders already be included in the definition of the research questions and design process or is it enough to integrate their knowledge later? Literature on stakeholder engagement in science shows that important questions regarding this issue are still far from being answered (Niederberger and Wassermann 2015: 12; Hanson et al. 2006: 132; Lang 2012: 35ff). How can the relation of scientific and non-scientific knowledge be described? (Habermas 1990). By which scientific or democratic criteria can different kinds of stakeholder input in the research process be evaluated? Is this evaluation carried out by scientists alone or jointly with the stakeholders? What is the role of the stakeholders: are they supposed to provide insights and perspectives that can lighten up the blind spots of science, or are they actually doing science themselves?

In this context, stakeholder involvement concepts are criticized for their understanding of science and the science-society relationship it entails (Strohschneider 2014: 180; Weingart 2003: 99). With regards to 'transformative science' (Schneidewind and Singer-Brodowski 2013), Peter Strohschneider (2014: 184) identifies four central motives that might lead to the decline of scientific autonomy and pluralism. The most challenging ones are ‚solutionism' and ‚de-differentiation'. The term 'solutionism' describes the framing of research topics as practical problems that scientists try to solve. Strohschneider argues that a solutionist concept of science, which privileges directly relevant findings over more indirect effects of science (such as basic/ foundational research) and questions on design and societal impact over understanding, is reductionist. De-differentiation means that the sphere of science is no longer regarded as an autonomous societal arena that defines its own standards and categories such as the constitution of scientific knowledge or the choice of research topics. Rather, there is a tendency to equate scientific problems with problems of immediate social relevance. According to Strohschneider, this solutionist understanding of science in which epistemic problems are only considered scientifically legitimate if they can be labelled as societal problems (Strohschneider 2014: 183) poses a threat to the autonomy of science.

The typology shows that this critique applies above all to the neoliberal and democratic type that show a low differentiation between scientists and stakeholders (left end of the continuum) and thus low autonomy of science. In the tradition of Feyerabend (1986), the understanding of science as a separate arena of society with distinct and clear criteria of valid knowledge production, as defended by Strohschneider, is no longer taken for granted. Consequently, the roles of scientists and stakeholders barely differ, and stakeholders have a much higher impact on research. The neoliberal type which relates to the ontological foundation of game theory (Nash 1950) sees no divergence between stakeholder and scientist since they both act as rational utility-maximizers. The posed research questions thus do not only depend on epistemic interest, but also on the possibility to get research funding or to further one‘s material interests through the research. Though on different, more morally oriented grounds, the democratic type rejects a differentiation between stakeholders and scientists and opts for integrating everyone affected as extensively as possible – from the definition of the research question to the structuring of the research (Hirsch Hadorn et al. 2006: 125; Spangenberg 2011: 283). The research questions are not limited to epistemic interest but aim at offering solutions for socially relevant problems.

In contrast, both in terms of the involvement of stakeholders in the research process and the underlying understanding of science, the technocratic type seems to be closest to a classic understanding of science in the tradition of Karl Popper (1957) that sees a strong qualitative difference between trained scholars and lay stakeholders. The scientist is in charge of the research design and merely consults stakeholders if he or she feels they can provide useful data or information. The research questions typically deal with intra-scientific debates rather than societal needs. The functionalist type also perceives science as an autonomous arena with distinct relevance criteria that differ substantially from those of the economic or the political system. As in these more classic perspectives on the science-society relationship the motives of ‘solutionism’ and ‘de-differentiation’ are rejected, Strohschneider’s critique does not apply to them.

6. Conclusion

There is an increasing trend of including stakeholders in research concerning sustainability or transformations like the energy transition. Though frequently used, little theoretical reflection on the underlying concepts of stakeholder involvement in science by the practitioners themselves exists so far. With the typology described here, this paper tries to fill this research gap by offering a heuristic, self-positioning and decision-making tool for stakeholder involvement in scientific research processes. The differentiation of four different ideal types linked to the critique that has been voiced among practitioners and in the academic literature can help scientists to better understand the different concepts of stakeholder involvement and potential pitfalls in designing it. By identifying and analysing three major critical topics with our typology –the legitimacy of claims, the idea of bargaining versus deliberation and the autonomy of science – we reveal critical choices that every scientist involving stakeholders should be aware of, thus giving an impulse for further discussion in this field. Our analysis also shows that – even though in literature it is often framed in the notion of the "democratic type" – there is no singular concept of stakeholder involvement. With the application of our typology to the energy transition, we emphasize one of the major fields where stakeholder involvement is currently strongly used and at the same time link practical and theoretical level in the discussion.

The tool presented here can only be an aid of orientation concerning the three major critical points of stakeholder involvement as addressed in this paper. The challenges of societal transitions will keep challenging science – especially the question of its autonomy among claims of democratization and vested interests and its input between scientific and non-scientific knowledge.

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Chapter 11

Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition[1]

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Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition

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Abstract

The threat of climate change and other risks for ecosystems and human health require a transition of the energy system from fossil fuels towards renewable energies and higher efficiency. The European geographical periphery, and specifically Southern Europe, has considerable potential for renewable energies. At the same time it is also stricken by high levels of public debt and unemployment, and struggles with austerity policies as consequences of the Eurozone crisis. Modelling studies find a broad optimum when searching for a cost-optimal deployment of renewable energy installations. This allows for the consideration of additional policy objectives. Simultaneously, economists argue for an increase in public expenditure to compensate for the slump in private investments and to provide economic stimulus. This paper combines these two perspectives. We assess the potential for renewable energies in the European periphery, and highlight relevant costs and barriers for a large-scale transition to a renewable energy system. We find that a European energy transition with a high-level of renewable energy installations in the periphery could act as an economic stimulus, decrease trade deficits, and possibly have positive employment effects. Our analysis also suggests that country- specific conditions and policy frameworks require member state policies to play a leading role in fostering an energy transition. This notwithstanding, a stronger European-wide coordination of regulatory frameworks and supportive funding schemes would leverage country-specific action. Renewed solidarity could be the most valuable outcome of a commonly designed and implemented European energy transition.

Keywords: Energy transition, renewable energies, Europe, multiple-objective policy framework.

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1. Introduction

Avoiding anthropogenic climate change and risks for ecosystems and human health call for a thorough transformation of the global energy system from fossil fuels towards a more sustainable pathway (Graßl et al. 2003; Schubert et al. 2008; IPCC 2011; IPCC 2007; Johansson et al. 2012)[9]. Sustainability criteria translate into multiple policy targets for the energy sector, such as climate change mitigation, reduction of local environmental damages, energy security, phase-out of nuclear power plants, "green" economic growth associated with green jobs and poverty reduction, as well as maintaining or achieving a sufficient food supply. A meaningful policy analysis requires a multiple-objective, multiple-externality framework that explicitly accounts for the dynamic interdependencies (Edenhofer, Hirth, et al. 2013; Edenhofer, Seyboth, et al. 2013) and that acknowledges potentially considerable uncertainties and the consideration of impacts that are not well quantifiable (Heazle 2010; Sarewitz 2004; Tribe, Schelling, and Voss 1976).

The European Union's (EU) climate and energy strategy rests on explicit targets for reducing greenhouse gas emission, promoting renewable energy sources and increasing energy efficiency (the so-called 20-20-20 targets). These targets have been underpinned by a variety of EU and Member State policy instruments, most notably the EU Emission Trading Scheme (EU-ETS) in the utility sector and country-specific support schemes for renewable energies. Primary measures to address these policy targets include the massive deployment of renewable energy sources, an increase in energy efficiency, and the associated changes in distribution, storage and usage patterns, shortly also referred to as energy transition (IPCC 2011). These efforts notwithstanding, the political reality places the long-term challenge of climate change mitigation on the back burner. The Eurozone crisis, which involves a sovereign debt crisis, a banking crisis and a severe and enduring recession, dominates the European discourse (Panico and Purificato 2013). The crisis has affected all EU Member States but particularly those in the geographical periphery. Energy transition modeling suggests that a cost-effective decarbonization of the European electricity production and distribution system can be achieved by transitioning on different pathways in terms of technology choice, spatial distribution of production capacity and the degree of connectivity between different Member States (European Commission 2012b; Knopf, Bakken, et al. 2013; Schmid and Knopf 2013). It is the central argument of this paper that this degree of freedom in designing an energy transition offers significant leeway to maximize welfare from co-effects of renewable deployment, thus simultaneously addressing other public policy targets than climate change mitigation. Hence, depending on its design, a

[9] RE: Renewable Energies; PV: Photovoltaic; BOS: Balance of System Costs; LCOE: Levelized Cost of Electricity; EMF: Energy Modeling Forum; TFEU: Treaty on the Functioning of the European Union; NREAPs: National Renewable Energy Action Plans; EU ETS: EU Emissions Trading Scheme; ACER: Agency for the Cooperation of Energy Regulators; ENTSO-E: European Network of Transmission System Operators for Electricity

European energy transition may also help European economies to recover by fostering economic growth, creating jobs, providing energy security, and building trust.

We argue that European renewable policy should be designed such that the respective co-benefits are realized predominantly in peripheral countries. This argument rests on three rationales. 1) An argument of economic efficiency: A crash of economies in the periphery will also affect those countries that are currently well off. If the use of direct means of economic policy, such as fiscal and monetary instruments, is limited (e.g. for political reasons), the promotion of renewable energy investments in the periphery may be understood as a surrogate for such policy (Gillingham and Sweeney 2010; Lehmann and Gawel 2013). 2) An argument of justice and fairness: A joint European effort to promote renewable energy investments in the periphery may provide a fairer distribution of wealth within Europe. This is especially relevant in a unified European economy where central regions such as the Benelux countries, Germany and Northern Italy profit from agglomeration dynamics and without the periphery the center would not boast such impressive agglomeration dynamics. 3) An argument of political feasibility: Co-benefits in terms of economic development or trust building may be a precondition for governments to be willing to support a European energy transition (Edenhofer, Knopf, and Luderer 2013).

To date, the questions of how to design a European energy transition and how to help the European periphery overcome the debt crisis have been analyzed in entirely separated strands of literature. The New Economic Geography points out that in a unified economic zone, the geographical core profits at the expense of the geographical periphery due to agglomeration economics (Fujita, Krugman, and Venables 1999; Krugman 1991). On the debt crisis, one strand of literature argues that deep recessions, accompanied with the bursting of property bubbles, require increased government investments to compensate for the saving demands on business (Eggertsson and Krugman 2012; Koo 2011). Lending and investments into those countries that suffer most from the debt crisis are seen as most promising to elicit growth and employment effects (Griffith-Jones et al. 2012). In a very different strand of literature, the prospective of a European energy transition as driven by climate change mitigation has been explored in a recent special issue (Knopf, Bakken, et al. 2013; Knopf, Chen, et al. 2013). The technical and sustainable potential and options had already been comprehensively explored by Graßl et al. (Graßl et al. 2003). The policy status and further options were also subject to scrutiny in recent analyses (Neuhoff, Boyd, and Glachant 2012; Lehmann and Gawel 2013). Special emphasis has been given to the European ETS (Verbruggen, Moomaw, and Nyboer 2011; Chesney and Taschini 2012; Neuhoff et al. 2012; Schäfer and Creutzig 2008). In a first, more holistic approach an edited volume studied the German energy transition from a behavioral economic, engineering, legal, philosophical, and political perspectives (Felix Creutzig and Goldschmidt 2008). Nevertheless, a common denominator of these analyses is that they implicitly consider climate change mitigation as the predominant public policy challenge. This paper, in contrast, contextualizes a European transition of the energy system – driven by climate change mitigation concerns – in the broader framework of European challenges, notably the deep recession and debt crisis in the European periphery and its lack of solidarity. Similar to Leggewie (Leggewie 2012), we see an opportunity in fostering renewable energies in the European periphery, an argument that we substantiate with quantitative analysis.

The scope of this paper is restricted to the analysis of electricity generation and distribution as this sector of the energy system is currently the most dynamic one in terms of decarbonization. The outline is as follows. Section 2 investigates the technical and economic potential for renewable electricity generation across Europe, and particularly in peripheral Member States. Section 3 evaluates the potential co-effects of a European energy transition, with a special focus on which additional co-benefits could be realized by a transition that specifically targets co-benefits in the periphery. Section 4 turns to analyzing the different barriers to a (periphery-focused) European energy transition, describes measures of how these barriers could be overcome and the policies needed, and evaluates the options in regard to feasibility and accordance to different welfare perspectives. Finally, Section 5 concludes in positioning the issue of a European energy transition in the periphery into the larger context of a common project for Europe. To substantiate our analysis, we explore the specific cases of Greece, Spain, Italy, Ireland and Poland in detail, representing countries that are hit by the debt crisis and where renewable deployment would make a difference, but have quite different patterns in terms of economic activity, renewable energy resources and conducted energy transitions.

2. Potential for renewable electricity generation in Europe

As a basis for the analysis of a European energy transition, it is important to know what is the potential for electricity generation from renewable energy (RE) across Europe, and particularly in its periphery? Potential estimates need to be differentiated between the technical, economic and market potential (Verbruggen, Moomaw, and Nyboer 2011): The technical potential refers to the theoretical amount of renewable electricity generation that could be obtained with the best available techniques under given natural conditions and using the maximum available land area, irrespective of cost considerations. The economic potential is defined as the socially optimal benchmark deployment level of renewable technologies when all corresponding social costs and benefits, including negative externalities and co-benefits, are taken into account. The market potential is the amount of renewable energy use that market participants pursue as investments under given market conditions.

The following elaborates on the underlying argument why the deployment of RE technologies in the European periphery can be a cost-effective and -efficient solution to decarbonizing the European electricity system. Section 2.1 elaborates on the abundant technical potential of wind and solar energy in Europe and discusses prospects of technology development. Section 2.2 explores model-based estimates of the economic potential of RE and discusses issues that are not, or cannot be represented in the models but may be highly relevant for assessing the effects of a European energy transition.

2.1 Technical potential and technology costs

The most important RE electricity generation technologies in Europe are based on solar irradiation (i.e. solar photovoltaic and solar thermal power plants), and wind energy, both onshore and offshore. Biomass, hydro power and geothermal energy also play a role, however, their potential is regionally limited and in the case of biomass also subject to land competition with food production and biodiversity. From a resources point of view, a fully renewable electricity system in Europe is possible, as the technical potential of RE is abundant (Sachverständigenrat für Umweltfragen (SRU) 2011). In order to visualize the regional distribution of solar irradiation and wind energy, Figure 1 illustrates annual full load hours of wind turbines and solar photovoltaic (PV) modules based on meteorological data and specific technology assumptions. Even though full load hours may be higher in the future due to technology advancements, a distinct pattern emerges: Wind potentials are the highest in the northern periphery and solar potentials are particularly high on the Iberian Peninsula, Italy and south-eastern Europe.

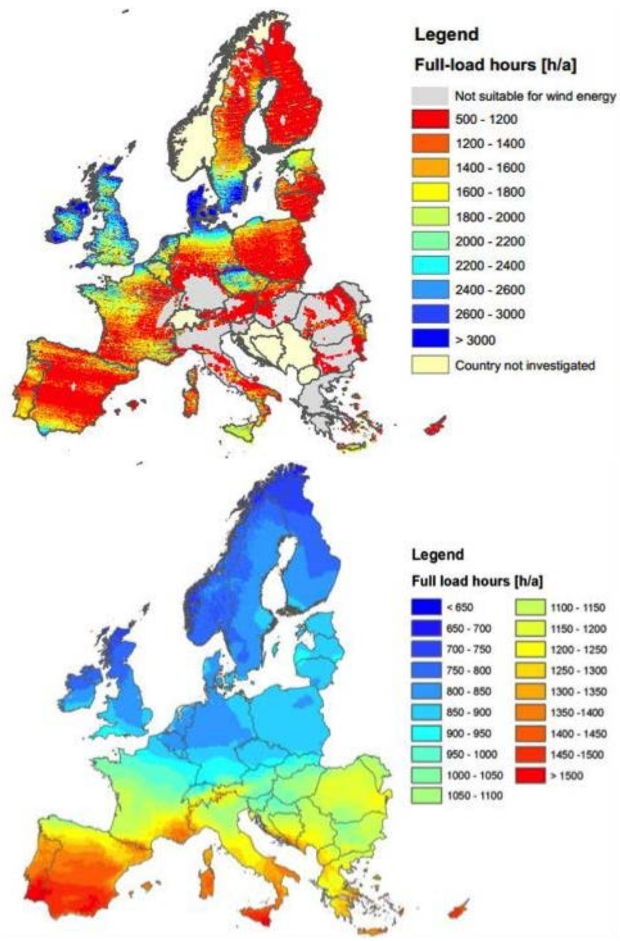

Figure 1. Annual full load hours of wind turbines (left) and optimally inclined PV modules (right). Source: Figures 4-5 and 4-10 in Held (Held 2010) and reproduced in Hoefnagels et al. (Hoefnagels et al. 2011). Some of the area judged to be not suitable for wind energy might still show substantial potential (Hoefnagels et al. 2011; Rathmann et al. 2011).

Table 1. Electricity from Renewables and Potentials in six EU member states. The electricity consumption of six EU member states and their year 2011 electricity trade balance is shown in the top two rows. The following three blocks describe in three rows each the countries' current electricity production per renewable energy source, its technical potential and the current production as the percentage of potential. (a) The final electricity consumption defined by the IEA excludes energy industry's own use. (b) The 2012 Wind Power Share denotes the electric energy that the wind power installations by 2012 would produce in a meteorologically normal wind year ("Wind in Power, 2012 European Statistics" 2013) .(c) The estimation of technical potential for electricity from wind is based on seven different land covers and their respective suitability for wind power installations, and average wind speed distributions. Environmental factors and social preferences are not taken into account. When accounted for designated nature areas, the technical potential reported would decrease by 14% on an European average (EEA 2009). (d) The bioenergy potentials are based on (de Wit and Faaij 2010). A conversion factor of

1/3 from biomass to electricity is assumed. (e) The 2012 Technical PV potential is calculated based on Braun et al. (2012), using population and infrastructure-based estimations of PV capacities. These are applied to country-specific solar PV yield data of Breyer and Schmid (2010). The technical potential for PV reported here only assumes use of readily available surfaces, such as on roofs or closely along motorways. This estimation is much more conservative than the one used for wind energy.

			Greece	Ireland	Italy	Poland	Spain
Wind	2011 Final Electricity Consumption	*TWh yr^{-1} (IEA 2011) (a)*	52	25	302	122	234
	2011 Electricity Trade Balance	*As share of final consumption (IEA 2011)*	- 6	- 2	- 15	4	2,6
	2012 Wind Power Penetration	*Final consumption (EWEA 2012) (b)*	6	13	5	3	16
	2030 Technical Wind Electricity Potential	*TWh yr^{-1} (EEA 2009)(c)*	1430	2350	2150	4000	3150
	Technical Potential used in 2012	*Share of 2030 potential*	0.22	0.14	0.70	0.09	1.19
Biomass	2011 Electricity from Biomass	*TWh yr^{-1} (IEA 2011)*	0.21	0.34	8.63	7.60	3.81
	2030 Technical Potential	*TWh yr^{-1} (d)*	13	6	44	132	68
	2030 Technical Potential used in 2011	*Share of 2030 potential*	1.6	6.1	19.8	5.8	5.6
Solar PV	2011 Electricity Production from Solar	*TWh yr^{-1} (IEA 2011)*	0.6	0.0	10.8	0.0	8.7
	2012 PV Technical Potential	*TWh yr^{-1} (e)*	119	35	429	241	516
	Technical Solar Potential used in 2011	*Share of 2012 potential*	0.5	0.0	2.5	0.0	1.7

Wind is in many situations, but depending on the remaining availability of hydro, currently the most cost competitive renewable energy technology in the electricity market. The levelized costs of electricity from wind energy are between 4-8€c/kWh in many locations (Lantz, Wiser, and Hand 2012; EEA 2009). Offshore wind installations are currently more expensive, but are experiencing a steep learning curve (EEA 2009). The total cost of onshore installations is mostly determined by the turbine price itself (ca. 80 of total costs), while operations and maintenance account for about 1.2-1.5 €c/kWh. Hence, the profitability of wind energy mainly depends on the availability of wind. The profitability threshold is usually assumed to be around 2300 full load hours (EEA 2009) (cf. Figure 1). At high penetration levels of wind power of 40 or higher, costs for grid expansion and reserve capacity become important, but are not well estimated (EEA 2009). EEA (EEA 2009) summarises grid extension costs to be anywhere between 0-10€c/kWh, and costs for reserve capacity at 2-4€c/kWh. Overall, wind energy is often cost-competitive without subsidies. The technical potential would allow for an increase of about 2 orders of magnitude compared to current deployment levels, theoretically satisfying current electricity demand (Table 1). In practice, local environmental impact due to the installation of operation of wind turbines, however, cannot be ignored (Leung and Yang 2012), leading together with local protests and economic consideration to considerably lower projected deployment rates (see 2.2).

The technical potential for bioenergy in Europe is significantly below that of wind energy but potentially highly relevant for future bioenergy supply (Table 1, (de Wit and Faaij 2010)). Within Europe, Romania, Bulgaria, Ukraine, the Baltic States and Poland might have the highest potential at low costs (de Wit and Faaij 2010). Costs of biomass vary between European countries, with feedstock, climatic and geographic conditions, and the state of supply chain logistics: 5–15 €/GJ for current food-based biofuels with possibly lower costs for residues and dedicated bioenergy crops (de Wit and Faaij 2010). Under ideal circumstances, electricity from biomass is cost competitive with electricity from fossil sources, but prices remained above 20€c/kWh in 2012 (European Commission 2012d). Its most significant role is as a flexible fuel counterbalancing intermittency from other renewables. In many cases biomass still builds on mandates or monetary incentive to be supplied in energy systems. As land availability is a limiting factor, higher demand results in higher prices on feedstock, while supply chain logistics experience notable learning curves, i.e. reduce prices.

The global warming impact of bioenergy remains uncertain with inductive studies pointing to relevant life-cycle emissions in the short run, whereas global integrated assessment models indicate the potential for bioenergy for climate change mitigation (F. Creutzig et al. 2012). Life-cycle emissions and climate change mitigation effects are highly variable, and depend on fertilizer application, land use change effects, yields, and market-mediated effects. Guaranteeing food security and the protection of biodiversity can constitute additional constraints on bioenergy deployment.

The technical potential of solar energy based electricity generation appears to be no practical limitation to a European energy transition. In the EU, on average a photovoltaic module area being equivalent to 0.6 of a country's surface area is sufficient to deliver the country's complete electricity consumption (Šúri et al. 2007). This potential shrinks if only rooftop installations and installations near or on sealed land are considered as indicated in Table 1. The dominating technology to harvest this huge potential will be photovoltaics. The costs of electricity from solar photovoltaics vary strongly depending on the used technology, system size and country of deployment. As a global trend, however, electricity from photovoltaics has become continuously cheaper over the last decades. The costs can be split into two major cost components: the costs for PV modules on the one hand, and on the other hand the additional costs to plan, market, and construct a complete system comprising photovoltaic modules, inverters and other components all summarized as balance of system costs (BOS). PV modules are traded on a more or less global market. Since 1979, global average module prices decreased with a learning rate of 22 (22 price reduction for each doubling of cumulative volume) for the dominating crystalline silicon technology (IRENA 2013), with current (September 2013) average prices on the European spot market between 0.58 €/Wp - 0.74 €/Wp[10], even below that historic trend. In contrast learning rates for BOS differ by country being about 15 in Germany and 7 in the United States (Seel, Barbose, and Wiser 2012), reflecting among other reasons different administrative conditions for the deployment of photovoltaic systems. Together with different market maturity (cumulative installed photovoltaic capacity), this results in a wide range of BOS with the global average of 1.19 €/Wp being nearly double as high as best cases in the range of 0.6 €/Wp, which are realized with utility scale ground mounted systems in Germany (IRENA 2013). The resulting levelized cost of electricity (LCOE) in turn depend on the cost for capital reflected in the calculatory interest rate and the specific yield, which is the amount of generated electricity for one year divided by the system's capacity. This results into a situation in which LCOE in mature markets like Germany can be comparable to LCOE in southern Europe, where higher specific yields (more sun) are offset by higher BOS and higher capital costs (Kost et al. 2013).

2.2 Economic potential estimates

It is clear that the full technical potential of any renewable energy source can hardly be used under realistic circumstances, that is, when economic and sustainability constraints are accounted for. Economic potential estimates are usually pursued by means of large-scale models of the European energy system and macro economy. In the 28th round of the model intercomparison exercise Energy Modeling Forum (EMF28), thirteen different models have been employed to calculate scenarios that lead to an 80 greenhouse gas emission reduction in 2050 relative to 1990. A robust conclusion across all models is that the variable renewable energy sources wind and solar will both have a substantially larger role to play, with a median share of 27 in the European electricity sector for the year 2050 (Knopf, Bakken, et al. 2013). This share even increases up to 37 if CCS is not available and up to about 50 if in addition no new nuclear power plants are being built. A more detailed analysis of individual countries technology mixes in the electricity sector reveals that they differ significantly across countries and largely depend on the type of renewable potential that each country is endowed with (Knopf, Chen, et al. 2013). However, a common denominator of the energy system models employed in the EMF28 model comparison exercise is that they do not explicitly consider infrastructure requirements (Knopf, Chen, et al. 2013; Knopf, Bakken, et al. 2013). The EMF28 scenarios have also been analyzed with dedicated infrastructure models (Holz and von Hirschhausen 2013). In this context Egerer et al. (Egerer, Gerbaulet, and Lorenz 2013) find with a line-sharp model of the European transmission grid that more that around 50,000km of pan-European transmission lines need to be built or upgraded for achieving a cost-efficient system.

[10] Wp (Watt Peak) is commonly used in the PV field to describe the size of PV systems. A module with 1Wp would deliver 1 W power output under standard test conditions.

A particularly important driver for transmission infrastructure expansion is the location of renewable electricity generation capacities. Schmid and Knopf (Schmid and Knopf 2013) show that different assumptions on the development of specific investment costs for wind and solar technologies lead to substantially different configurations of a cost-optimal decarbonized European electricity system in the long-term future. Figure 2 illustrates average annual power flows in 2050 in two scenarios that allow for a high expansion of transmission capacities between ENTSO-E regions but with differing assumptions for the investment costs of wind and solar technologies: once with values set to the middle of the range reported in literature, and once with optimistic cost development assumptions for solar technologies (which appears to be plausible given the discussion in 2.1), and pessimistic ones for wind technologies. In the first case it is particularly the wind resources in the north-western, northern and eastern European periphery that generate a surplus of electricity that is imported to central Europe. In the second case the pattern changes significantly – here it is particularly the solar resources of the Iberian Peninsula and South-Eastern Europe that are exploited and transported to central Europe.

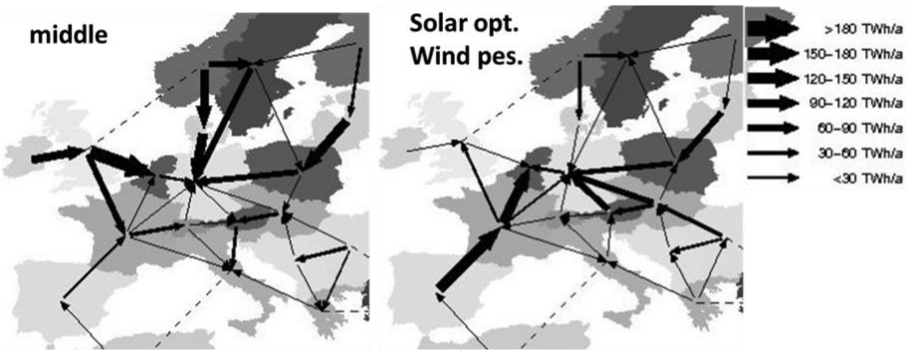

Figure 2. Average annual net electricity flows between ENTSO-E regions in the year 2050 for two scenarios with high transmission capacity expansion between regions and different assumptions on the development of investment costs for wind and solar technologies, i.e. middle of the range in the literature (left) and solar optimistic /wind pessimistic values from the range in the literature (right). Source: Figure 5 in Schmid and Knopf (Schmid and Knopf 2013).

Schmid and Knopf (Schmid and Knopf 2013) find for a set of scenarios that the increasing integration of the European electricity system by means of transmission capacity expansion leads to a reduction of total system costs of 2-3.5 over the period 2010-2050, confirming earlier results that grid integration is a no-regret option for Europe as a whole. This finding is robust across scenarios that are based on different assumptions on the development of investment costs for wind and solar technologies. The basic logic is that, once pan-European transmission capacities are expanded, the cost-optimal location of wind and solar capacities shifts to comparatively more favorable resources in the European periphery. Whether the "Northern solution" based on wind energy or the "Southern solution" based on solar energy is more cost-optimal will depend on the comparative development of their investment costs. The implications of different pathways for individual countries would be substantial. This includes issues such as 1) dependence on other countries (e.g., in the transmission expansion scenario some countries turn into net importers); 2) change in domestic technology mixes; and 3) modified capital requirements of individual countries for renewable investments. From a global perspective, however, the costs are not overly sensitive with respect to the design of the European electricity system in terms of transmission corridors and the choice of which renewables potential to tap into. Considering that the illustrated pathways are designed to be primarily optimal with respect to the policy objective of climate change mitigation, it seems therefore worthwhile to explore further what the externalities of increasing RE deployment are with respect to other public policy objectives related to sustainability. Such an analysis would allow exploiting the broad optimum to simultaneously achieve such other objectives.

However, quantitative energy system models are bound to simplify the energy system in order to remain numerically tractable and are only able to consider effects that are quantifiable after all, and thus do not consider most of these externalities. Furthermore, estimates of the economic potential of RE are strongly dependent on underlying assumptions. While there is a multitude of issues, the following discussion concentrates on specific quantifiable and non-quantifiable effects that are of particular interest for a European energy transition.

The most important aspect that is either neglected or represented in very simplified terms is the variability of wind and solar both on the temporal and geographical scale (Edenhofer, Hirth, et al. 2013). Time scales are mostly coarsely specified. Many energy system models possess limited means to deal with fluctuations. Instead these fluctuations are usually represented by characteristic days or comparable concepts (e.g. a fixed share of flexible gas power plants per RE capacity). The geographical resolution is usually confined to model regions in the size of countries that exhibit significant intra-regional variability, with beneficial or detrimental correlations in terms of balancing requirements. Other options to balance production and demand than grid interconnections are usually neglected (e.g. special configuration of solar modules, virtual power plants of decentralized dispersed combined heat and power plants and especially demand side management). The major reason for their omission is most likely the crude geographical scale and the lack of explicit consideration of individual actors. New electricity planning models, however, allow fine-grained considerations of both temporal intermittency and spatial variation (Fripp 2012; Mileva et al. 2013), pointing tentatively to higher renewable-share potentials, though these models have not been validated for Europe.

A range of issues that are not directly quantifiable may remain beyond modeling exercises. The non-quantifiability arises on the one hand due to a lack of theoretical concepts to describe the effects in stylized models, and on the other hand due to non-observability of the data. Three issues seem particularly important: a) the wider macro-economic impact of RE deployment, b) employment effects and c) energy security. Due to their focus on the energy system, such models represent macroeconomic processes only very crudely, if at all. But the renewables industry does not act in isolation; especially on a regional or local level the public policy objective of climate change mitigation often has lower priority than employment, energy security or direct environmental effects.

3. Evaluating welfare increase induced by co-effects of an European energy transition

If an energy transition focuses RE deployment in the periphery, particularly in southern European countries, the benefit and cost distribution could be such that the economic debt crises could be effectively mediated. In the following, we analyze this argument in more detail.

3.1 Stimulus effect of RE deployment in the periphery

Besides positive environmental effects related to reductions in GHG emissions, increased spending on RE infrastructure could potentially have the effect of an economic stimulus. The idea that economic slumps can to at least some extent be remedied by fiscal policies is a cornerstone of Keynesian macro-economics and has regained prominence in the recent financial and economic crisis, in which the world's major economies have enacted stimulus packages to revive their economies. The basic premise of this theory is that an economic downturn is first and foremost a consequence of a shortfall in demand, and that it can be tackled by reviving demand through either lowering taxes or increasing public spending. It has been suggested that it would be advantageous to target activities that not only have a stimulus effect, but also yield environmental benefits (Edenhofer et al. 2009; Goulder 1995; Manresa and Sancho 2005). Related literature suggests that a deep recession, characterized by a debt crisis, triggers saving efforts in the private sector (Demetriades and Mamuneas 2000; Koo 2011; Lin and Doemeland 2012). An expansion of the public sector can then prevent the long continuation of the recession. Understanding infrastructures as the template and basis for economic activities, targeted public investments in infrastructure construction and maintenance can be most productive (Demetriades and Mamuneas 2000; Lin and Doemeland 2012; Munnell 1992).

The respective literature identifies several criteria for stimulus spending to have a positive effect on growth. First, they exhibit their most pronounced positive effect when the economy is in a slump, while they are less effective in a growing economy (Auerbach and Gorodnichenko 2012; Baum, Poplawski-Ribeiro, and Weber 2012; Blanchard and Leigh 2013). Second, the associated fiscal multipliers – i.e. the expansion of output as a reaction to an increase in demand (either through tax cuts or additional government spending) – are largest if interest rates are (very) low (Christiano, Eichenbaum, and Rebelo 2011) and in the presence of a financial crisis

(Corsetti, Meier, and Müller 2012). Third, stimulus measures are found to be more effective if they rely on additional spending instead of tax cuts (Baunsgaard et al. 2012). More pronounced positive effects of stimulus measures should be expected if the additional spending keeps government debt within certain boundaries. Otherwise, high debts might undermine investment incentives due to expectations of a deteriorating business environment (Alesina and Ardagna 2010; Nickel and Tudyka 2013).

Arguably, all the above conditions hold for the case of increased investment in RE in the EU periphery. The corresponding countries are by 2013 still experiencing economic recessions. Interest rates remain low, while the banking system is severely weakened. The discussed infrastructure investments would hence boost public spending, and – if their costs were covered by countries from the core (for financing see section 4.2.2) – would not increase government debt. Reviewing a total of 37 empirical studies, Baunsgaard et al. (Baunsgaard et al. 2012) find that under such conditions, observed fiscal multipliers range between 0 and 2.1, with a mean of 0.8. Of course, the described effects are not uniform across countries, and detailed country-specific studies would be required in order to understand the conditions that have to put into place to achieve the most in terms of stimulus (Baum, Poplawski-Ribeiro, and Weber 2012).

In terms of volume, RE investment could be of an order of magnitude that yields noticeable effects on economic activity. For instance, spending on FiTs for RE in Germany in 2012 amounted to about 0.6 of GDP[11]. This figure is comparable to the 0.5 of GDP targeted at infrastructure investment in order to kick-start growth in the EU proposed in a recent proposal by Griffith-Jones et al. (Griffith-Jones et al. 2012) whereas the stimulus packages enacted in the EU during the period 2008-2010 amount to about 2 of GDP (Spencer, Lucas, and Emmanuel 2012).

Perhaps the most substantial concern regarding the stimulus effects of increased spending on RE concerns the timeframe in which they can be carried out: as few RE projects are ‘shovel ready’, they might require several years of planning and investment. Hence, policies aiming to achieve short-run should focus on projects that can be put into practice relatively quickly (solar PV, for example, can be built relatively fast). However, also projects with a longer ramp-up phase could help to overcome the recession, as the latter is not merely a short-term fluctuation of the business cycle, but rather a structural crisis that can be expected to last for several years. Hence, increased spending on RE could contribute towards improving long-term growth prospects in the periphery.

[11] As part of the Energy Roadmap 2050, the EU Commission has assessed that a shift from reference scenarios with existing policy measures to low-carbon scenarios would require €260 billion in annual average incremental investments over 2010 – 2050, which is equivalent to 2.1% of 2008 EU GDP (however, it should be noted that the largest part of these investments are projected for energy efficiency measures).

3.2 Employment effects

Evaluating the labour market effects of renewable energy policies in detail is a challenging task that requires an assessment of how value chains and production patterns adjust in the mid-term and how structural adjustment and innovative activity respond in the long term. Results depend on (a) the assessment of positive employment effects (consideration of the electricity sector only or the renewable energy sector in general including also heat systems and biofuels; assumptions about foreign trade effects), (b) the assessment of negative employment effects (crowding-out effects only or budget effects as well), and (c) the time horizon of the assessments in general. A comprehensive assessment of these effects is missing so far and numbers from different studies are often not comparable with each other as they consider different aspects. Nonetheless, we summarize here some studies that refer to the employment effect of RE.

One study finds that under the 'Energy(R)evolution' scenario developed by Greenpeace, which sets a target of reducing global GHG emissions by 50 below their 1990 level by 2050, 500'000 additional workers will be employed in the energy sector of the EU27 compared to the business-as-usual case (Rutovitz and Atherton 2009). A very similar figure is obtained by Ragwitz et al. (Ragwitz et al. 2009), who assume a 20 share of renewable energy in the EU's final energy as stated in the Renewable Energy Directive for 2020. Under this scenario, Greece is projected to have an employment gain of roughly 1 and Spain of 0.6, while Ireland only sees a negligibly small but still positive impact on employment. Most additional jobs are created in industrial manufacturing sectors. These numbers also agree well with the order of magnitude found in analysis of current employment on national levels and globally (Aretz et al. 2013; Räuber, Warmuth, and Farian 2013; Sawin et al. 2013). For example, a typical number of 11 thousand employees per installed GW of PV electricity is found in Germany in several studies in a very rough analysis, simply dividing the number of full-time equivalent jobs associated with the complete German PV sector by the number of GW installed in the same year (2012) (Aretz et al. 2013; Räuber, Warmuth, and Farian 2013; Sawin et al. 2013). On a global scale the same indicator is even four times higher (Sawin et al. 2013).

As policies that increase the share of renewables may lead to rising electricity prices, job gains in the energy sector have to be weighed against potential job losses in other sectors. For instance, while energy-intensive industries are mostly exempted, and actually benefit from lower electricity prices, household electricity prices in Germany had already risen by 5 in 2009, which can be partly attributed to the Renewable Energy Law ("Electricity from Renewable Energy Sources. What Does It Cost Us?" 2009) and have since increased markedly for several reasons, including the increasing share of renewable energies and increasing numbers of exemptions from the support payments for industries. Ragwitz et al. (Ragwitz et al. 2009) estimate that reaching the EU's 2020 goals might entail electricity price increases of on average 2.2, concluding that these increases should not have substantial negative effects on the EU's industrial structure. These costs could further be lowered if EU member states harmonized their support of renewables in order to exploit potentials cost effectively (the total annual costs of renewable energy deployment could be lowered by about €10 billion if member states traded energy as a good in a single European market instead of national markets (European Commission 2011)).

These considerations notwithstanding, the empirical evidence on net employment effects is mixed. Some confirm a significant increase in employment (Lehr et al. 2008; Wei, Patadia, and Kammen 2010), while others find zero or negative effects (EWI, IE, and RWI 2004; Hillebrand et al. 2006). Crucially, equilibrium effects on employment depend on the revenue source and/or the counterfactual spending (see also section 4.2). For example, if financed by labour taxes, economic models suggest that RE subsidies decrease employment and welfare (Böhringer, Keller, and van der Werf 2013). Overall, a comprehensive assessment of the net effects of RE deployment is lacking; arguments for RE policies based on employment effects are subjects to considerable uncertainty and ignorance. Hence, RE policies as such should not be regarded as an appropriate means to remedy underlying distortions in the labour market. Yet, if conducted as part of a stimulus measure, it makes good economic sense to consider employment effects of such policies, as the unemployment can be attributed to a shortfall in demand rather than labour market frictions. In such a situation, measures to boost employment can improve an economy's long-term growth potential, as they e.g. reduce the depreciation of human capital occurring under long-term unemployment (which could lead to 'hysteresis', i.e. the economy not returning to its previous potential output after a crisis) (Blanchard and Summers 1989).

3.3 Energy security

Covering a higher share of domestic energy consumption can also have bearing on a country's energy security. In its broadest sense, energy security refers to the uninterrupted provision of vital energy services (Johansson et al. 2012), or from a system perspective to robustness against sudden disruptions of energy supply (Arvizu et al. 2011). Building on these concepts, three particular dimensions of energy security have been identified: A) depletion of exhaustible resources; B) import dependence; and C) variability and reliability of energy supply at affordable costs (IPCC 2011). In turn, these dimensions are influenced by a number of factors, in particular the portfolio of power plants (fuels, capacity), transmission lines, storage and demand.

We discuss each of three dimensions of energy security in turn. Any policy to increase the share of RE will reduce the depletion rate of exhaustible resources, especially in the presence of a carbon tax or a tightened ETS. In other words, RE deployment in peripheral countries will contribute to prolonging the life-time of existing deposits of exhaustible resources and dampen the rise of extraction costs by avoiding the need to tap low-grade, high cost reserves of coal and gas.

Addressing the import dependence, some periphery countries are net importers of about 2-15 of their electricity consumption (especially Italy, and to lesser degree Greece and Ireland see Table 1). RES support may help to increase the share of domestic generation in these countries - and even convert them into net exporters of electricity. This would support lowering current account deficits, which for Greece and Portugal amounted to more than 6 in 2012 (European Commission 2012c). In addition, an increase in RES generation typically crowds out natural gas and oil-fired power plants, the fuels for which are often imported from outside the EU [79,80].

Third, due to their fluctuating time profiles, higher reliance on RE could negatively affect grid stability, especially if large shares of total electricity are met by RE. This is a very relevant risk and applicable for RE deployment without a comprehensive system transition. Complementary and necessary system measures would include investments in storage and back-up capacities, which, however, would involve additional costs during the transition. In fact, a detailed study demonstrated that energy security is possible with 100 RE if well integrated with storage units and energy-savings measures even on the national level (Henning and Palzer 2014; Palzer and Henning 2014). Moreover, this transition, once completed, would deliver electricity at similar costs as the existing energy supply [81]. On the other hand, closer integration of the European electricity grid would not only lower costs by means of reaping gains from trade, but would also increase reliability of electricity supply, as – at least on average – regional fluctuations would cancel out on a larger scale. Increasing transmission capacity is particularly important for the peripheral countries investigated (especially for Poland, Ireland and Spain, and to lesser degree for Greece, Italy), which display the lowest ration of interconnection capacity over peak load (Fig. 4 in E3G (E3G 2013)).

For the EU, the perceived dependence on Russian gas might increase the desirability of RE if integrated with the heating sector. But generally, while RE can contribute to energy security, depending on the overall system design, the comparative advantage of RE lies in its environmental benefits rather than in its potential to increase energy security (Borenstein 2011).

4. How to promote an energy transition in the European periphery?

4.1 Barriers to renewable deployment

In principle, support schemes have been implemented in virtually all countries in the periphery to address barriers to RE deployment. The EU also provided an option for bilateral agreements between Member States spur RE deployment (see Section 4.2). These efforts notwithstanding, significant barriers remain.

The cooperative mechanisms established by the EU have hardly been made use of - either because Member States are unlikely to be sanctioned if their RE targets are not met, or because their targets are not very ambitious and can be easily attained by domestic measures (Battaglini et al. 2012; European Commission 2007).

More importantly, important barriers still prevail at the Member State level. To evaluate barriers to RE deployment, we report and categorize these barriers in selected recession countries (Table 2). We find that economic and administrative barriers are the dominant obstacles for RE deployment. In the economic domain, the financial crisis exacerbated financing challenges as governments reduced support policies. For instance, in Spain and Italy, the crisis intensified the slowing down of the RES development. In Spain, poorly designed policies based on subsidizing programs through high feed-in tariffs have increased the difference between utility payments to renewable power producers and revenues utilities collect from customers annually (Gobierno de España 2013; Rathmann et al. 2011). In consequence, the national government restricted incentives. In 2013, Spain and Italy eliminated subsides to renewable production (Autorita´ per l´energia elettrica e il gas 2013; Gobierno de España 2013). Legal uncertainty has also influenced ratings agency to downgrade tariff deficit securitizations. Consequently, the current lack of predictability has been translated to market instability. Often the high initial capital investments are discouraging for investors. In addition, in some countries (e.g., Poland and Spain) taxation regimes further disincentive investments into renewables (Ecorys 2010).

Administrative obstacles constitute the second important category of barriers (Table 2). Many projects suffer delays due to lack of harmonization in legal frameworks, trading schemes and administrative procedures; regulatory and administrative issues impair the RE development. In many countries of the European periphery the lack in the national regulatory framework provokes an asynchrony in receiving authorizations. The high number of administrative bodies involved in the approval procedures for the installation also lengthens the process (Assosolare 2011; Ecorys 2010; Rathmann et al. 2011). By the same token, the complexity and lack of standardization of environmental procedures also limits RE projects (e.g., Italy and Poland). Such administrative hurdles contribute to deterring investors (Ecorys 2010). The spread of PV deployment costs between Germany and some Southern Europe countries, such as Greece, is most likely due to the difference in bureaucratic costs and other soft costs.

Important barriers are also related to infrastructural limits. In some cases, lack of transmission capacity hinders installation of RE (e.g., Italy, Ireland and Greece). In other cases, the transmission lines need to be extended or modernized. In addition, political and social conflicts (e.g.; the not-in-my-backyard (NIMBY) syndrome) prevent the development of RE. Finally, policies for RE deployment often compete rather than co-operate with environmental protection and land use and face community acceptance (Ecorys 2010; Rathmann et al. 2011).

Table 2. Country-specific barriers for the RE development in European periphery. Full circle: the issue is crucial for the country. Empty circle: the issue is relevant for the country. Dash: the issue has no relevance for the country.

Country	Issue	Economic constraints	Infrastructural constraints	Regulatory & administrative framework	Community acceptance	Incompatibility with other policies
Italy	Regional inhomogeneity in the procedures, especially in environmental ones, high capital costs related to landscape policies and administration fees (8-12% of the total costs) and high number of administrative bodies involved – that provoke long authorization processes and asynchrony in receiving authorizations – discourage investors (Assosolare 2011; Ecorys 2010). Environmental groups and Regions oppose to the installation of onshore wind turbines to not alter the natural landscape. For offshore wind turbines, constraints come from the depth of the coastal water (World Energy Council 2007).	●	○	●	○	●
Poland	Often large initial capital requirements prevent the development of RES. The installation of photovoltaic panels is limited to special purposes and in most cases these are not connected to the grid (Ecorys 2010; Minister of Economy 2011). For RES in buildings, low financial support available for individuals and lack of information lead to low RES installation. Historical and public buildings do not often include RES technology, showing a lack of exemplary action (Ecorys 2010). Transmission lines are often obsolete and insufficient. The Energy Law is not clear about the sharing between investors and TSO for their modernization. Operators are not obliged by any legal regulations and nor stimulated by any financial incentive to invest in the modernization and expansion of the grid. Landowners are not willing to permit the lines to be built up on their properties (Ecorys 2010). The procedural, administrative and regulatory frameworks are fragmented, since the RES sector is regulated by numerous executive supplements to the Energy Law. This provokes asynchrony in receiving authorizations, lengthens processes and discourages investors, e.g. when hydropower, biomass and small power plants are evaluated. The procedures for small power plants are as complex as those for large plants. Environmental procedures are complicated and non-standardized. RES compete with environmental protection and land use policies. Resistance of local authorities to RES results in a lack of regional planning and public support (Ecorys 2010).	●	●	●	○	○

Table 2 cont.

Spain	Legal framework shift from subsidising to restrictive oriented leads to market instability (Gobierno de España 2013). Infrastructure development – mainly distribution network and grid connexion – is affected by regional inhomogeneity and inefficiency in administrative procedures, and the large number of administrative bodies involved. This lengthens the authorization process and subsequently discourages investors (Ecorys 2010; Rathmann et al. 2011).	●	○	●	–	–
Ireland	Feed-in tariffs have an upper capacity limit, which is far exceeded by the number of applications for grid connections. The number of subsidized filed projects is uncertain (Ecorys 2010; Rathmann et al. 2011). Important infrastructural barriers, mainly concerning transportation grids, limit the RES development. Additionally, Ireland and the European Continent are not directly connected (Ecorys 2010).	●	●	–	–	–
Greece	Grid congestion problems exist in locations with high RES potential. Greek islands are excluded from any RES project because they are not connected to the main grid due to capital constraints and the great depth of the Aegean Sea. Complicated administrative procedures and multiple authorities involved – interpreting law in different ways – cause authorization delays. A national lack of communication and awareness provokes local opposition (Ecorys 2010). Lack of experience (procedural expertise) in obtaining financial support from the EU community is perceived as a barrier to RES development (personal communication Argyropoulos, D., 2013).	●	●	●	○	–

4.2 A Multi-Level implementation strategy with a stronger role for the EU

A European energy transition would profit, if Member States in the periphery implemented national measures to address the barriers outlined above more properly. Exemplarily for the large body of literature, Lehmann et al. (Lehmann et al. 2012) provide an overview of instruments, which could be employed to spur an energy transition. Policies can address three categories: RE generation, grid, and storage and demand response. A coordination of these different categories is crucial as energy investments are strongly path-dependent, sub-optimal investment decisions taken today are perpetuated over a long period of time (Kalkuhl, Edenhofer, and Lessmann 2012; Lehmann and Gawel 2013; Unruh 2000). Country-specific options are briefly summarized in the right column of Table 3.

In the light of the Eurozone crisis and the associated budgetary limits – but also due to institutional constraints – it is highly unlikely that most Member States in the periphery will be able to overcome the barriers in the short term by themselves. As a consequence, a strong(er) enabling policy framework at the EU level could support an energy transition. For example, a uniform European feed-in tariff including an EU-wide compensation scheme could be proposed. However, such schemes would need to be adapted to and coordinated with local and national circumstances and policies. Well-intentioned top-down schemes are bound to fail if opposing local civil society is ignored (Scott 1998) (Felix Creutzig and Goldschmidt 2008); an exclusively top-down European approach for energy policy is neither economically justifiable nor legally and politically feasible.

The analysis in 4.1 suggests that ‘soft’ bureaucratic costs of RE deployment may explain the relatively high costs in some Southern European countries. Providing funds for overcoming this cost barrier (e.g., human capacity building; designing streamlined bureaucratic procedures) could make RE deployment more cost competitive and bring LCOEs down to those in front-runner countries.

From an economic perspective, the following arguments can be put forward in favor of a certain degree of decentralization in energy policy. First, the theory of fiscal federalism (e.g., Oates; Shobe and Burtraw (Oates 1999; Oates 1972; Shobe and Burtraw 2012)) suggests that co-benefits (and co-costs) of RE deployment that are realized at the local or regional scale are more likely to be addressed properly by policy approaches taken at the same scale, such as regionally differentiated RE schemes (Siler-Evans et al. 2013). Second, technology preferences and geographical conditions – and accordingly the assessment of related costs and benefits of different options – may vary across regions, and may explain the heterogeneity of technology choices observed across Europe (Knopf, Bakken, et al. 2013; Knopf, Chen, et al. 2013). Third, if the actual performance of policy approaches is subject to uncertainty, regulatory diversity and competition may promote institutional and policy innovation and diffusion (Ania and Wagener 2012; Oates 1999; Shobe and Burtraw 2012), and even lead to bottom-up policy convergence over time as observed in the EU (Jacobs 2012; Kitzing, Mitchell, and Morthorst 2012).

From a legal perspective, it has to be pointed out that the current European legal framework impairs a full harmonization of energy policies across Member States (see, e.g., Callies and Hey (Callies and Hey 2013)). On the one hand, Article 194 of the Treaty on the Functioning of the European Union (TFEU) mentions energy policy as a field of European responsibility, following inter alia the principles of environmental conservation and solidarity across Member States. On the other hand, however, the same Article also clearly emphasizes that the competences regarding the exploitation of energy sources and the choice and use of energy technologies reside with Member States. It will need strong political will to strengthen EU competencies in the short- or mid-term as Member States usually have a strong interest in maintaining their energy policy sovereignty to protect their national energy technology mixes and energy security at the national level.

Consequently, a pragmatic strategy to promote RE deployment and generate related benefits particularly in the periphery has to rest jointly on European as well as Member State activities. Against this background, we see two particular avenues for the EU to promote an energy transition in the periphery: Strengthening the regulatory framework for Member State policies and providing funds. These avenues are briefly outlined in the following and also summarized in Table 3.

Table 3 Policy instruments at EU and Member State level to address barriers to RE generation, grid extension and storage and demand response.

	EU policies		
	Strengthening the regulatory framework	**Financing**	**Member State policies**
Generation	• Setting a separate RE target for 2030 • Promoting the use of cooperation mechanisms for renewable energy policy • Employing the open method of coordination for RE policies • Strengthening the EU Emissions Trading Scheme by setting ambitious GHG reduction targets for 2030 • Increasing minimum tax rates for non-renewable fuels Promoting the internal energy market • Transfer of administrative procedures, skills and arrangement of financing schemes	• Allocating a higher share of EU ETS auctioning revenues to Member States in the periphery • Targeting loans of the European Investment Bank (EIB) more strongly to renewable energy investments • Targeting loans under the European Investment Fund (EIF) more strongly to small and medium-size enterprises in the field of renewable energy • Targeting the European Regional Development Fund (ERDF) and the Cohesion Fund more strongly to renewable energy investments	• Governments endorsing explicit deployment scenarios • Providing and modifying support policies for RE deployment, e.g. low interest rates for investments, and generation subsidies • Phasing-out adverse subsidies/increasing taxes for fossil and nuclear fuels • Implementing transparent and participatory planning processes, e.g., including zoning of priority areas • Standardizing binding permitting procedures for renewable energy investments with one-stop contact points for investors • Waiving administrative fees for permitting renewable energy investments • Compensation schemes for local external costs of RE investments
Grids	• Ensuring network interoperability by common guidelines • Harmonizing Member States' diverse technical standards • Strengthening the competencies of the Agency for the Cooperation of Energy Regulators (ACER) • More transparent planning process for grid development	• Providing financial support via the Cohesion Fund	• Shallow connection charges plus differentiated network use of system charges to provide locational signals • Stronger regulatory incentives for investment and innovation
Storage and Demand response	• Common EU-wide standards for smart meters		• Dynamic electricity pricing for customers • Time-variant grid fees and taxes • Lower entrance barriers to ancilliary markets, e.g., smaller bid size in balancing markets • Large-scale support for infrastructure development (smart meters and grids)

4.2.1 Strengthening the regulatory framework for an European Energy Transition

Measures to *strengthen the regulatory framework* refer, in the first place, to the limited array of energy policy means – as specified in the Renewables Directive 2009/28/EC (European Parliament 2009). First of all, a separate target for RE (next to a greenhouse gas reduction target) for 2030 would address the additional market failures that are associated with the deployment of RE. This should again be translated into National Renewable Energy Action Plans (NREAPs), which provide a clear guideline for Member State policies. In addition, the cooperation mechanisms established by the Directive – statistical transfers, joint projects and joint support schemes – would spur EU-wide RE deployment. So far, these mechanisms have only rarely been used for a variety of reasons (Battaglini et al. 2012; European Commission 2013; Klessmann et al. 2010; Klinge Jacobsen et al. 2014). Notable exceptions include the North Sea electricity grid founded in 2010 by nine EU States and Norway and the collaborative plans between Germany, Poland, the Czech Republic and the Netherlands to commonly manage fluctuating wind power (EEX Transparency Platform 2013). Finally, the European Commission can make active use of the open method of coordination to promote voluntary convergence of Member State policies (Ania and Wagener 2012; Borrás and Jacobsson 2004; Kerber and Eckardt 2007). This method supports the exchange on experiences with and the performance of RE schemes across the EU – and may thereby stimulate regulatory competition and learning.

Beyond energy policy, the EU may also strengthen the regulatory framework in other policy fields for which it holds stronger competencies and which may have direct and indirect impacts on RE investment decisions (see, e.g., Callies and Hey (Callies and Hey 2013)). First of all, this applies to the EU Emissions Trading Scheme (EU ETS, in line with Article 192 TFEU (European Parliament 2008)), which, if tightened, could provide stronger incentives to switch to RE technologies. Second, minimum tax rates for fossil fuels and energy (European Parliament 2003) could be increased to promote fuel switching. Third, the integration of the internal energy market (in line with Article 114 TFEU (European Parliament 2008)) may be further promoted. Fourth, the EU could adopt more effective measures to support trans-European electricity grids (Article 172 TFEU (European Parliament 2008)). In fact, Article 170 TFEU (European Parliament 2008) emphasizes that such measures should pay particular consideration to connecting peripheral regions. Eligible measures include common guidelines to ensure network interoperability, a harmonization of Member States' diverse technical standards as well as the provision of financial support via the Cohesion Fund (Article 171 TFEU (European Parliament 2008)). In this context, a strengthening of the competencies of the Agency for the Cooperation of Energy Regulators (ACER) as well as a stronger engagement of the European Network of Transmission System Operators for Electricity (ENTSO-E) may be desirable, particularly to allow for a more target-oriented planning of trans-European networks. A more transparent planning process could promote public acceptance of grid development.

4.2.2 Financing an European Energy transition

Financing a European energy transition cannot be treated as an independent challenge to that of the political design of the energy transition. The counterfactual effects of not raising revenues can be substantial. In fact, Böhringer et al. (Böhringer, Keller, and van der Werf 2013) demonstrated that the overall employment and welfare effects are negative when an energy transition is financed by taxes on labor (or, to lesser degree, on electricity). This needs to be seen against a background of economic analysis that suggests that a shift from labor taxation to natural resource taxation could produce a double dividend by decreasing distortions in the labor market and making workers and employees better off, while at the same time incentivizing more efficient resource use (Bovenberg 1999; Goulder 2013). This result co-aligns with more theoretical results pointing to the potential of rent taxation (e.g. land rent) to finance public goods without reducing market efficiency (Mattauch et al. 2013). Specifically, taxing GHG emissions could generate a climate rent that outperforms the counterfactual fossil fuel rent, generating a trillion $ revenue stream globally (Bauer et al. 2013). Hence, a primary source of funding of a European energy transition could come from within the climate change mitigation system, from taxing or pricing CO_2.

Within the European Union, the framework for generating a climate rent has been already established. Revenues are generated by auctioning ETS allowances. Resulting revenues are already used to redistribute funds to those Member States, which are least wealthy (10 of total revenues) or have realized most GHG emissions reductions (2 of total revenues). Both characteristics apply to many Member States in the south and east, and could be further extended to promote RE deployment in the periphery. For comparison, a hypothetical price increase of 20€/tCO2 for emissions in the European energy industries would bring an additional revenue of about 30 billion € per year at 2012 levels of consumption. A fraction of about 1-3 billion € annually could help to reduce the barriers (soft costs in RE deployment; see 4.1 and 4.2.1) and incentivize renewable deployment of a higher order of magnitude.

Other modes of financing could also be considered. Several European programs of financial assistance are already targeted to less wealthy regions in the periphery and/or the development of environmentally friendly energy technologies – including loans of the European Investment Bank and the European Investment Fund and means of the European Regional Development Fund and the Cohesion Fund. Specifically, the proposed expansion of loans from the European Investment Bank to leverage investments in recession countries (Griffith-Jones et al. 2012) could be specifically directed towards RE deployment and similar investments to decrease energy dependence and mitigate climate change.

5. Conclusion

Our analysis substantiates Leggewie's claim (Leggewie 2012) that an energy transition towards renewables in the Mediterranean region constitutes an important element towards a successful continuation of the European peace project and integration. Starting with climate change mitigation as a key objective, this paper argues that a European energy transition towards renewable energies is not only possible from a renewable resources point of view (Section 2), but could also help stabilizing national economies in the European South and other periphery countries (between 0.5-1 GDP increase possible), improve energy security (especially for Greece, Ireland and Italy), and possibly improve employment opportunities - depending on the assumed baseline macro-economic policy (Section 3). Economic justice considerations foster the understanding that a considerable part of required investments should be financed by economic-core European countries, which have benefited from the agglomeration dynamics of a unified European economic zone. While the overall evaluation is grounded in a broad cost-benefit analysis, a reduction in well-quantifiable outcome metrics would be misleading. In fact, if a European energy transition would show results, a renewed solidarity between European citizens could be the most valuable result even if hard to quantify in monetary or other economic units.

In the second part of this paper (Section 4), we analyze barriers and policy options towards realizing the benefits of a European energy transition. A key result is that barriers in many countries are combinations of economic and administrative obstacles: deployment costs, e.g. of photovoltaic systems, are often considerably higher than those in central European countries. Technology prices are dominated by world markets and do not cause this divergence. Rather, our analysis suggests that administrative procedures, often lengthy and complicated, but also lack of skilled labor capacity, and missing straight-forward financing schemes are at the center of the prohibitively high costs. Hence, a transfer of streamlined administrative procedures, labor skills, and financing schemes could support a country-specific acceleration of the learning curve, decreasing prices for renewables but especially solar. Overall, the policy analysis suggests that the country and even locality specific circumstances require member-state policies. European regulation and financing could then play an important supporting and coordination role. Crucially, a tighter cap of the European ETS would not only incentivize a faster transition to renewables, but could also serve as an important source of financing renewable deployment for cash-starved recession countries. Direct financial support could be focused on decreasing the soft costs of renewables, by streamlining administrative procedures and building up deployment capacity (training programs, financing schemes). Loans with low-interests rates from the EIB could leverage additional investments.

In summary, the analysis of this paper suggests that a climate-mitigation motivated European energy transition can also be understood as part of a strategy that counteracts the European recession and tentatively balances out its structural problems. The success of such a strategy must be seen with caution and depends on crucial implementation details. The advantage of providing a common rather than a fragmented European agenda, however, provides reason for optimism – a European energy transition could catch two European birds (climate change mitigation and relieving the deep recession) by one renewable stone.

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Chapter 12

Synthesis and outlook

Overview

The starting point for this thesis was the hypothesis that ensuring not only the short-term wellbeing of urban citizens, but also the long-term intergenerational welfare of the generations to come require policy instruments that achieve fiscal stability, social equity and low carbon-intense urban forms. In particular, the thesis contributes to answering the questions formulated in the introduction:

1. What is the solution portfolio for achieving long-term urban sustainability? What interdependencies exist between different sustainability policy agendas? Which strategies better achieve different objectives simultaneously?

2. How can urban planning and fiscal policies influence long-term urban sustainability? Which local revenue instruments can positively contribute to the stabilization of local budgets, the enhancement of fiscal equity and the reduction of urban land consumption?

3. Which governance structures enhance the success of public interventions in achieving long-term urban sustainability particularly in the context of urban planning? How can the effect of these practices be evaluated? Are these structures also desired to explore the solution portfolio for achieving long-term urban sustainability in science?

Long-term urban sustainability requires a policy portfolio that, on the one hand, explores the whole solution space and, on the other hand, is able to combine different urban agendas simultaneously. Urban planning stands out as one strategy with great potential to contribute achieving this endeavour. In particular, location value taxes and adequate land use regulations could enhance fiscal stability and equity and foster low carbon-intense urban forms simultaneously. Maximising the potential of such interventions requires, however, renovated institutional approaches that guarantee the legitimacy of the decision-making process and foster synergies between different objectives. Local public participation and coordinated multi-level governance could assist in this respect.

This Chapter synthesizes the findings from the ten core Chapters on how these instruments may look like and reviews the results of the previous chapters in the light of these three set of questions. An outlook on future research and a comment on the policy-relevance of this thesis conclude.

1. Effective combination of multiple urban agendas

The first set of questions concerns the policy portfolio of urban policies and their interactions:

- What is the solution portfolio for achieving long-term urban sustainability? What interdependencies exist between different sustainability policy agendas? Which strategies better achieve different objectives simultaneously?

To answer these questions, Chapters 2 to 5 explore, evaluate and identify effective combinations of urban strategies by integrating different strands of literature related to sustainability issues.

1.1 Aligning climate and social agendas

Chapter 2 synthetises results from different fields to come up with policy recommendations for urban climate action that also address equity concerns. On the one hand, climate change literature focuses progressively on cities: they enter the spotlight as places at the same time combatting and mitigating climate change in an age of rapid urban expansion. This literature assumes different mitigation scenarios and identifies best strategies to reduce climate risks, increase mitigation and adaptation in cities. On the other hand, the recently adopted Sustainable Development Goals (SDGs) expand the traditional climate-based framework of analysis by integrating climate objectives with additional socioeconomic and ecological goals. This has led to a new political and scientific field in which Chapter 2 is a pioneer.

In particular, the Chapter takes the equity and climate objectives to exemplify the interdependencies existing between urban agendas and further identify strategies that perform better for both[1]. The equity variable is defined by a number of SDGs, including poverty eradication (SDG#1), equality within and among countries (SDG#10), inclusive, safe and resilient cities (SDG#11), reduce climate change and its impacts (SDG#15), justice for all (SDG#16), and gender equality (SDG#5).

Two main interactions between climate change and equity in cities are identified. First, risks related to climate change hazards are heterogeneously distributed among urban population based on the combination of risk exposure, preparedness, coping and recovery capabilities. Second, adaptation and mitigation interventions further affect positively, negatively or neutrally this distribution. In both cases, socioeconomic variables explain equity outcomes to a great extent, with gender and poverty identified as risk factors. Low-income residents and women are often particularly affected by both climate change and climate action. Although poor women are dis-proportionately affected by climate change impacts, few adaptation measures benefit them directly and few mitigation measures respect their concerns.

The Chapter also identifies urban strategies that achieve climate and equity objectives simultaneously. Risk reduction and adaptation strategies must address

[1] The SDG agenda consist of a broader (17) set of goals; however for research feasibility reasons, Chapter2 focuses on those that are related to social equity.

infrastructure and service insufficiencies by building up institutions that explicitly focus on this issue and providing financial and governance strategies that assist vulnerable communities. In particular, interventions should target population coping with repeated ‘risk accumulation processes’ in order to maintain their adaptive capacities over time and avoid knock-on effects for chronic poverty. Decision making processes should be gender-sensitive, encouraging the participation of women. Equity-sensitive mitigation strategies can only be accomplished by holistic urban planning approaches and specific actions on minority-populated neighbourhoods. Social and fiscal policies have to be designed in a way that they are able to cap accommodation prices and rents, thus avoiding gentrification effects. For the specific case of low-carbon transit interventions, it is important to reduce out-of-pocket fees, provide unlimited-use passes for public transportation, and include the women’s perspective.

1.2 Expanding the policy portfolio through demand-side solutions

The solution portfolio for achieving long-term urban sustainability has not yet been fully grasped. Chapter 3 takes the climate mitigation objective to exemplify how the solution space can be expanded. For the particular case of climate mitigation, there has been a tendency to attach much more emphasis to intervention strategies shaping the supply of goods and services. But achieving the 2 °C target requires the exploration of all existing options, including the very promising one of changing demands towards less carbon-intense consumption patterns. Chapter 3 explains why a preference towards technological supply-side solutions exists and further explores the demand-side mitigation space, thus contributing to close the gap in the mitigation literature.

The analytical challenge of demand-side solution resides in the assumption of endogenous preferences within a cost-effectiveness approach, which requires explicit normative assumptions and a different, contextually richer framework of analysis that has not yet been firmly established. Still, Chapter 3 sheds light on the demand-side mitigation spectrum, thus expanding the policy portfolio for achieving long-term sustainability. Regardless of the methodological challenges that hinder the evaluation of absolute figures; transport, building and agricultural sectors show high mitigation potential. For agriculture, dietary changes, towards less carbon-intensity diets could even surpass the technological mitigation potentials. The Chapter also stresses the importance of developing economies for demand-solutions: they represent the hub where most future infrastructure is to be built, and thus it is crucial to enshrine low-emission sustainable energy use patterns from the beginning to avoid lock-in effects.

Finally, the Chapter identifies urban areas as consumption hubs that offer enormous mitigation potentials in general and for the transport and the residential sector in particular. Two types of demand-side strategies can be deployed at the city level. First, through the design of urban built infrastructure; a physical setting that shapes preferences, practices and opportunity spaces for decades. For example, spatial planning could kick out motorized transport modes and further contribute to energy savings in buildings. Second, changing norms, practices and nudges modify the opportunity space and, ultimately, induce direct behavioural change. This could be done by information and educational campaigns on products and services that trigger new routine behaviours.

1.3 Two *sine qua non* conditions: sustainable planning and governance practices

While the previous Chapters explore the solution space, Chapters 4 and 5 focus on specific sustainability challenges in cites to give exemplary answers on which interventions better achieve different objectives simultaneously.

Chapter 4 takes the issue of heat risk and its heterogeneous distribution among urban population. Heat risk reduction in cities is becoming more urgently required: the combination of increase in hazard severity and exposed population – both for absolute and vulnerable population[2] figures- forecasts high future heat risks in cities. But this risk distributes differently among citizens shaped by the effect of intrinsic and extrinsic factors. Intrinsic factors refer to person-specific variables –e.g. age, gender, and health conditions, among others-. Extrinsic factors include all variables that shape exposure and adaptive capacity. Given these factors, heat risk reduction should aim at reducing exposure levels and susceptibility as well as improving preparedness through response and recovery mechanisms.

Crucially, the effectiveness, efficiency and equity performance of strategies addressing intrinsic and extrinsic factors varies widely. Based on public health literature, Chapter 4 defines these indicators in the following way: a) effectiveness assesses the capability of the intervention to produce the desired effect under real life circumstances; b) efficiency measures the effect of an intervention in relation to the resources it consumes; and c) equity evaluates the extent to which the benefits of a policy and the costs are spread. Importantly, two views exist on the equity outcome of a public intervention: while commutative justice seeks for the equal provision of a good or service to each group or individual, distributive justice considers that a fair amount should be provided according to the level of need.

In order to answer the overarching research of this thesis, Chapter 4 identifies the interdependencies between public health and urban planning agendas for the specific case of urban heat risk reduction. In particular, it explores how these strategies could be combined to achieve both commutative and distributive justice. Whereas public health interventions perform effectively in addressing intrinsic risk

[2] Urban heat vulnerability is highly influenced by age, among other factors (see Chapter 4 for extensive list). World population in general, and in some regions in particular, is steeply increasing in average age.

factors – distributive justice-, urban planning measures perform very efficiently in reducing extrinsic risk factors – commutative justice -, particularly on the long-term because they reduce exposure levels. Although the confluence of urbanisation and rising hazard levels makes the reduction of extrinsic risk factors increasingly relevant, planning interventions are rarely deployed. These results point to the relevance of coordination efforts between public health and urban planning departments to efficiently, effectively and equitably counter the threat of urban heat risk.

Chapter 5 uses the case of urban water to identify institutional strategies that reduce inequalities and enhance the management of natural resources simultaneously. The challenge of providing enough domestic water will not only threaten many urban populations, but also affect numerous SDGs because demand is increasingly outstripping supply in a growing number of regions. On the one hand, population prospects forecast a tremendous increase in urban population, while current trends in per capita consumption show a general increase[3]-. On the other hand, the combination of a fiercer competition between water uses plus weather dynamics related to climate change constrains water supply. Crucially, not only the absolute water insecurity increases, but also does the differences between how people are affected. Inequalities are driven by intrinsic factors only to a certain extent; institutional failures are great contributors. The unequal distribution of infrastructure, financial mismanagement, sub-prioritization of unplanned settlements and poor planning are some examples of poor or unsustainable governance practices. In particular, local governors in developing countries often prioritize other water uses –e.g. supply within the tourism sector- ahead of ensuring water security to the local population. Also, the way in which water privatization has been done in certain countries has raised distributional issues.

The reduction of water inequalities in cities and a simultaneous sustainable management of water resources require two things: first, a better understanding of the interconnections between water natural and anthropogenic systems in their specific context; second, incorporating the concept of justice in the decision-making processes. Decentralized governance at all levels of decision-making processes, and integrative management approaches promoting collaborations and social learning between stakeholders could contribute to this endeavour. Ultimately, sustainable water governance could bring promising outcomes to not only to long-term sustainability in cities but also for global water resources.

Altogether, Chapters 2 to 5 highlight the fundamental role of urban planning and sustainable governance practices for the achievement of long-term urban sustainability.

[3] It is although important to say that this figure still does not meet the World Health Organisation threshold in many countries.

2. Sustainable urban planning and fiscal policy

The second set of research questions of this thesis concerns the architecture needed for urban planning interventions to foster low-carbon urban form, stabilize local budgets and enhance social equity:

- How can urban planning and fiscal policies influence long-term urban sustainability?
- Which local revenue instruments can positively contribute to the stabilization of local budgets, the enhancement of fiscal equity and the reduction of urban land consumption?

2.1 Effects on urban form, local budgets stability and fiscal equity

Chapter 6 uses the Spanish case to provide empirical evidence on the effects of urban planning and fiscal policies on the long-term urban sustainability. Chapter 7 builds on the conclusions and policy recommendations of the previous one to thoroughly investigate the sustainability potential of a type of property tax and further looks at current European practices in this regard.

The recent suburbanization trends in Spain have had dramatic consequences for municipal budgets, urban land consumption, climate change and the welfare of its population. Chapter 6 particularly looks at the role of political decisions at the municipal level on such devastating outcomes.

On a first step, the Chapter arguments why urban compact development is more sustainable than sprawled development. First, it facilitates investments in low-carbon infrastructure and, if coupled with balanced jobs-housing mix, greatly reduces transport emissions- reduction of vehicle miles travelled and increases in non-motorized modes-. Consequently, this reduces traffic congestion and air pollution, thus enhancing local environmental quality. Both higher air quality and lesser motorized modes have direct effects on health. Lastly, compact development contributes to fiscal efficiency through a better spatial allocation of the provision of public goods and services.

Second, the Chapter develops an empirical analysis to demonstrate that urban sprawl of Spanish municipalities in the last decade was not solely driven by population and economic growth. The combination of massive investment in road infrastructure, permissive urban planning regulations and tax-induced distortions on properties had a strong influence. The results also show that sprawl has led to an inefficient allocation of local investment, which was never recovered through the property taxes in place. Location values accumulated the vast amount of public investments in urban infrastructure contributing to the bubble dynamics of the housing market.

Crucially, these results demonstrate that municipal policies that seem adequate in times of expanding financial markets and associated liquidity can prove disastrous in the long-run. In view of the Spanish experience, it seems crucial for local decision-makers to disentangle public finances from temporary growth dynamics. Based on the capitalization dynamics observed in the location values, the Chapter further suggests a reform in the property tax system towards location value taxes (LVT) to reduce distortive effects and raise enough revenues to bring fiscal stability again. Simultaneously, less permissive planning alleviates sprawl in the long run.

2.2 Location value taxes: sustainability potential

The results and conclusions that arise from Chapter 6 motivate a thorough investigation of adequate property tax (PT) designs that enhance urban sustainability. Following the suggestions from the previous Chapter, Chapter 7 looks at LVT as a local revenue instrument that could positively contribute to the stabilization of local budgets, the enhancement of fiscal equity and the reduction of urban land consumption.

A vast amount of research from public economics to sustainability science indicates that a shift from traditional PT towards LVT improves specific sustainability metrics: it increases fiscal efficiencies and equitably raises revenue to pay back public infrastructure investment; it fosters denser development and decreases urban land consumption; and it redistributes wealth accumulated in real estate cycles through publicly-driven location values (LV). Still, no consensus exists on how this tax should look like to ensure all the listed benefits. Chapter 7 addresses this gap.

The Chapter synthetises and harmonizes diverse strands of literature dealing with LVT. Urban economics and public finance typically address issues of equity and efficiency. Value capture and sustainable transport literatures provide insights on the local revenue sufficiency. Urban planning and sustainability sciences look at the LVT effects on land consumption and other environmental impacts. In order to systematically review all effects accounted in the different research fields, a framework that takes into account the broad portfolio of design alternatives is presented. With this assessment tool at hand, the Chapter then identifies the LVT designs that better preform in shaping urban form, stabilizing local budgets and enhancing equity simultaneously. The framework shows that the definition of the tax base, the tax base valuation method used- frequency of assessments, exemptions and tax reliefs- , and the fiscal and land use regulations environment are critical for the sustainability outcome of LVT. Overall, the theoretical findings suggest that LVT perform better than traditional PT. First, LVT could deliver revenues above current unsatisfactory levels from PT in place[4]. Second, it corrects PT distortions

[4] The contribution of PT to local revenues either remains stable or decreases, while housing rents increase worldwide (see Chapter 7).

such as wealth accumulation, fiscal inequalities, and excessive land consumption. These results evidence the potential of the LVT in enhancing sustainability.

The Chapter also applies the assessment tool to evaluate current LVT practices in Europe with disappointing results as most countries fail the evaluation - with the exception of some criteria (e.g. assessment ratios, governance level, and tax subject definition)-. These findings evidence the considerable room for improvement in policy-making. Improvements could be easily achieved through a better definition of the tax base, increase in the frequency of assessment processes, and the abolishment of additional property taxes that distort the outcomes of LVT. The analysis also shows the enormous legal difficulties a LVT has to overcome. The long-term prioritization approach interferes with short-term incentives for economic development and policymakers face tremendous barriers from different stakeholder groups. This implies that practitioners prefer the use of indirect instruments to collect contributions from developers and meet infrastructure financial needs –e.g. betterment taxes and obligations and community infrastructure levies-. While the article identifies major issues involved in a shift towards LVT, the sustainability rationale of a levy on LV for financing public expenses is compelling.

3. Governance structures for sustainability

The combination of different urban agendas, and most important, the deployment of long-term, intergenerational policy designs carries logistical and institutional hurdles. The last set of research questions concerns the institutional structures that better assist in triggering long-term sustainability in cities:

- Which governance structures enhance the success of public interventions in achieving long-term urban sustainability particularly in the context of urban planning?
- How can the effect of these practices be evaluated?
- Are these structures also desired to explore the solution portfolio for achieving long-term urban sustainability in science?

Chapters 8 to Chapter 10 analyse public participation as a governance structure that enhances long-term sustainability in science and policy. Chapter 11 focuses on the role of multi-level governance for the successful deployment of sustainability structures.

3.1 Participatory processes uncover social benefits

Chapters 8 and 9 use the case of public participation on urban planning to investigate the benefits that accrue in terms of social and environmental objectives. Chapter 9 further uses empirical data to evaluate these effects. The research hypothesis is the following: given that the modifications of public spaces carried out by public intervention alter social structures, which intervention designs uncover social benefits?

Chapter 8 reviews the literature on Transit Oriented Development (TOD)[5] to identify participatory processes as an intervention design highly performing with regards to social objectives. The enhancement of urban mobility shapes common and public spaces and ultimately influences social networks. Thus, public participation in TOD could increase its social benefits by enhancing transparency, trust, social inclusion, collective action and social networks. However, literature shows that this potential remains untapped and TOD interventions often appear at odds with local needs, which suggests the suboptimal design of the governance structures for this particular planning strategy.

In order to have empirical evidence of the social benefits –in addition to the environmental ones- arising from public participation in TOD, Chapter 9 takes one of the few cases existing where structured stakeholder involvement was implemented. In Medellin (Colombia) the combination of a mix of participatory planning methods helped in the interactions between the city and local authorities around complex matters. Thanks largely to these governance practices; the city is now known for its great social transformation since the early 2000s, with highest increase in wellbeing on the most disadvantaged communities. Another important influence has been the local political leadership with a solid institutional strategy behind that coordinated all public and private actors involved, avoiding confrontation between different stakeholder groups and governance levels. The Chapter uses a methodological approach based on the comparative evaluation of the performance of TOD interventions with and without public participation. To ensure the environmental objective is met, changes in transit modal shares are used as the grouping variable. A citizen survey is used to assess the social changes of different variables including socioeconomic variables, the perception of public interventions in the neighbourhood, and different dimensions of social capita. Results show a general increase in social capita for those groups where transit modal share increased. Tellingly, these groups were also the ones where TOD interventions were designed with a participatory approach. Thus, participatory TOD increases the positive environmental and social effects simultaneously.

The positive results of public participation in policy making raises the question of whether this governance approach may also be beneficial in sustainability science. Following this reasoning, Chapter 10 looks at the same governance tool applied to the scientific world in general, and to sustainability science in particular, an increasing trend in this field. But these practices are rather new and there is still little theoretical reflection on the underlying concepts of stakeholder involvement in science and the different consequences and issues derived from it. As a pioneer

[5] TOD is a neighbourhood concept that seeks to improve the quality of public spaces, urban connectivity and accessibility (see Chapter 8).

experiment with this regard, the German energy transition is used in the testing and development of a typology of stakeholder involvement approaches in science – the technocratic, neoliberal, functionalist and democratic type. The Chapter identifies three critical points from stakeholder involvement in science: the legitimacy of claims; the idea of bargaining versus deliberation; and the autonomy of science. Together with the typology, it offers a heuristic, self-positioning and decision-making tool for scientific research processes. Every scientist that involves stakeholders should be aware of these critical choices when deciding how to involve stakeholders in the process of exploring the solution portfolio for achieving long-term sustainability in science.

3.2 The deployment of sustainable strategies requires multi-level governance

Aside from technological difficulties, sustainability strategies may also face political, administrative and legal barriers that hamper their depletion. Chapter 11 takes the European energy transition as an example where governance structures at the local, national and supranational levels hinder policies that are proven to reach different sustainability objectives simultaneously. An energy transition towards renewable energy in Europe could bring multiple benefits for climate change mitigation, economic stabilization and political integration. In particular, it could help stabilizing national economies in the European South and other periphery countries, improve energy security, and possibly improve employment opportunities. All these benefits arise from the agglomeration dynamics of enhancing the concept of a unified European economic zone through an integrated energy transition.

However, the combination of economic and, more importantly, administrative obstacles prevent these sustainable outcomes take place. Administrative procedures often lengthy and complicated, lack of skilled labour capacity, and missing straightforward financing schemes represent the greatest barriers. Given the results of the policy analysis from Chapter 11, a transfer of streamlined administrative procedures, labour skills, and financing schemes through multi-level governance practices is suggested in assisting a country-specific acceleration of the learning curve, ultimately enabling the achievement of the above mentioned benefits. First, the European regulation and financing mechanisms should play an important support and coordination role focused on decreasing the soft costs of renewables. This could be done by streamlining administrative procedures and building up deployment capacity (training programs, financing schemes) together with financing support in the form of loans with low-interests rates that leverage additional investments. Second, the country and even locality specific circumstances require member-state policies that account for regional dynamics and considerations. Success in this endeavour requires multi-level governance structures to ensure overcoming current institutional barriers.

4. Outlook and further research

The research presented in this thesis shows that a multi-objective strategy in cities is of eminent importance, in particular for the wellbeing of future urban populations. It further identifies, evaluates and provides policy recommendations for the tools that perform successfully in this endeavour. Here I present the main conclusions of the thesis and use them to motivate a number of questions that arise for future research.

1. Social commitments in cities seem to be abandoned not just in periods of austerity like Europe, but also during prosperity phases like Spain in the early 2000s or China in the late 2000s. Financial and economic preferences prevail particularly in places where weak governance structures predominate. But these views reshape the understanding of sustainability towards market and technology driven discourses, where fundamental concepts of justice, equity and global responsibility are sidelined.

The dominant discourse on sustainable cities, with a commitment to intergenerational equity, social justice and global responsibility, should be the focus of research and policy recommendations. Crucially, issues of local challenges and global environmental change become increasingly prevalent and call for new interdisciplinary approaches that are able to investigate these interactions and the assessment of policy alternatives from a multidimensional perspective. Future research should extent current system boundaries and establish indicators that evaluate integrated policies tackling multiple urban objectives simultaneously. Research on integrated model inter-comparison could assist in the difficult endeavour.

2. The here discussed potential of urban planning and fiscal policies in achieving multiple objectives simultaneously calls for a new research field that includes different sustainability outcomes simultaneously and provides guidance on how these instruments could be integrated into national economic development strategies.

With regards to the LVT, there is still so much to know from an empirical point of view. The few research projects existing are quite disperse and either look at its potential for spatial planning and environmental policy (Altes 2009; European Environment Agency 2010) or theoretical economic rationales (Mattauch, Siegmeier, and Edenhofer 2013; Mattauch et al. 2013). However, it is important to develop robust evidence on the social, fiscal and environmental effects of a shift towards LVT. In addition, a wide variety of value capture mechanisms are being designed providing a detailed portrait of the research agenda required to explore best practices for different urban environments.

As discussed above, LVT has the merit of taxing an inelastic good, and by this, avoid so-called market distortions. However, LVT actually may induce behavioural change, and some of this change might be beneficial. Further research should consider the environmental effects of a LVT, in particular by investigating whether the tax incentivizes sustainable urban form by denser urban settlements. If a tax explicitly internalizes externalities, changing behaviour to some assumed optimal or more appropriate direction, it is commonly referred to as Pigouvian taxation[6]. Currently, instruments aiming at raising revenue from new land development are also seen as efficient anti-sprawling instruments (Banzhaf and Lavery 2010; Bento, Franco, and Kaffine 2006, 2011; Brueckner 2000; Brunner 2013; Cho et al. 2008; Cox 2006; Ewing et al. 2014; McFarlane 1999; Squires 2002; Turner 2007; Anas 2012; Brueckner 2001; Brueckner and Kim 2003); in other words their Pigouvian character is acknowledged. Hence, what are the observable environmental effects of LVT?

Also, the equity effects of LVT are still somehow unclear. It is important to evaluate how LVTs influence the ability-to-pay of dwellers, and more generally, horizontal and vertical equity in comparison to a traditional PT. Intuitively, the shift of burden when transitioning from PT to LVT will fall most heavily on land of high value but few improvements (Plummer 2009). But the effect of LVT on housing affordability is highly context dependent (Alterman 2012; Evans-Cowle and Lawhon 2003; Skaburskis 1995; Skaburskis and Qadeer 1992). To determine the absolute burden shift, two variables are important: the concentration of land ownership among income profiles, and the share of net wealth coming from LV. For the US and UK, Plummer (2009) finds that although wealthiest households accumulate more absolute LV wealth, the share to total net wealth derived from land value decreases with wealth. Unfortunately, there are few studies looking at the change of distributional burden.

Furthermore, two views coexist on how the tax should be design from an equity perspective: the benefit proportionality and the distributional one. The first one argues that beneficiaries should pay their increased wealth, but also keep their revenues at the community level. Under this view public intervention in low income neighbours should be paid by themselves, conflicting with a progressivity intuition and overall distributional fairness (Alterman 2012). A distributive view instead, argues that revenues should be reallocated onto localities that have low income dwellers. Typically, the more developed the jurisdiction is, the higher land intensity and wealth concentration among higher income groups, and the more progressive a LVT becomes (Netzer, 1998; Plummer, 2009; The Economist, 2015), but empirical evidence is needed to support either view.

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[6] In this case, the policy maker imposes a corrective fiscal instrument, which equals the marginal externality associated with the economic activity or good that is intended to be remediated (Baumol and Oates 1988; Kreiser et al. 2011; Goulder 1995).

Finally, it is worthwhile exploring the applicability of Medellin´s experience in other urban development contexts aside from Latin America.

5. Policy-relevance of this thesis

The adoption in 2015 of the Paris Agreement (UNFCCC 2015) and the Sustainable Development Goals (United Nations 2015) opens a new era of consensus between climate and other policy agendas. How to combine such a broad portfolio of policy goals calls for multidisciplinary research, integrated assessments and legitimate process to assist in the selection of value laden policy alternatives. For example, the particular experience of public participation and urban planning in Medellin has been repeated in other cities in Colombia and Brazil (Dávila 2013; Farajado Valderrama, Cabral, and Tonkiss 2014). Developing methodologies that can provide empirical evidence of the positive effects would foster and optimize these practices in other rapidly growing urban context such as Asia and Africa.

The policy-relevance of LVT is long-standing. Already in 1976 at the first Habitat Conference in Vancouver (Canada), land and property taxation were specifically recommended, and the following remark was made on unearned increases in land values:

"Taxation should not be seen only as a source of revenue for the community but also as a powerful tool to encourage development of desirable locations, to exercise a controlling effect on the land market and to redistribute to the public at large the benefits of the unearned increase in land values" (UN-HABITAT 1976).

Along the same lines, UN-HABITAT has recently published a report called "Innovative Land and Property Taxation", in which land and property taxation is described as an effective mechanism for urban sustainability worldwide. An adequate design could have multiple beneficial outcomes: shaping the urban form of cities efficiently while raising targeted revenue for low-carbon infrastructures, such as public transit lines (UN-HABITAT 2011).

At the same time, the observed increase in mostly urban location values and the capitalization by land lords accelerated in the last decade have provoked economists from different disciplines to advocate for a single tax on land and the abolishment of all other distortive fiscal instruments (UN-HABITAT 2011; Gaffney 2009; Wightman 2013; European Environment Agency 2010; Adam 2012; Seely 2013; Mills 2001; Oates and Schwab 2009; Raslanas 2013; Terry Dwyer 2003; Foldvary 2006; Brown and Smolka 1997; Terence Dwyer 2014). Also, it has been recently suggested that rent taxation in general, and location taxes in particular, could stabilize public revenues under the effects of an economic downtown (Cocconcelli and Medda 2013; Constantin 2010; Löhr and Harrison 2013; Wightman 2013; Wightman 2010; Green 2012).

Interestingly, there are a number of places where LVT is gaining attention (Alterman 2012; Brandt 2014; Terry Dwyer 2003; Dye and England 2010; European Commission 2012; Land Value Tax Working Party 2005; Panella, Zatti, and Carraro 2011; Tom and Kris 1999). In Europe, the UK (Mirrlees and Institute for Fiscal Studies 2011; Seely 2013; Wightman 2013), Scotland (Wightman 2010), Ireland (Gurdgiev 2010; Gurdgiev 2009; Inter-Departamental Group 2012) and the Netherlands (Altes 2009) are in an ongoing debate since a couple of years. The European Statistical Office (EUROSTAT) and the Organisation for Economic Co-operation and Development (OECD) have a joint project to develop methodological guidelines for LV estimation that will be applied in future tax systems reviews at the EU level (European Commission 2012; Garnier et al. 2013). This initiative may indeed further stimulate the discussion on LVT.

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Statement of contributions

Chapter 2: Diana Reckien initiatied, conceptualised and led the project, wrote the background section, the methodological section, and the summary as well as parts of the introduction, conclusion and policy recommendations. Felix Creutzig supported the conceptualisation, contributed to the introduction and background section, wrote the review on heat-related equity concerns and contributed to the conclusion and policy recommendations. The author of this thesis contributed the findings related to equity and climate change mitigation, including its respective literature review, and contributed to the policy recommendations. Shuaib Lwasa wrote the findings on common equity concerns as well as the sections on equity concerns related to precipitation and storm surge and coastal flooding. He also contributed to section on equity and climate change adaptation, to the conclusion and policy recommendations. Marcela Tovar-Restropo developed the gender equity argument for the whole text, added respective evidence, and contributed Box 1 on gender related terms. Darryn McEvoy contributed to the background section. David Satterthwaite contributed to the conceptualisation and wrote the section on equity and climate change adaptation. All authors contributed to editing and revising of the manuscript.

Chapter 3: Felix Creutzig was responsible for the conceptual design and overall handling of the article, with refinements from all authors. Karen C. Seto contributed to the motivation section. Helmut Haberl developed the entire section on demand-side solutions in agriculture and Radhika Khosla the one dealing with the building sector. Karen C. Seto and Felix Creutzig contributed to the urban areas and spatial planning section, with minor literature review from the author. The author contributed to the literature review and text of the transportation section and the summary of end-users. Demand-side solutions and development was developed by Yacob Mulugetta and Radhika Khosla. The author also substantially contributed to the section presenting the framework for assessing demand-side solutions. Felix Ceutzig developed the conclusion.

Chapter 4: The author was responsible for the conceptual design and writing of the article. Felix Creutzig contributed in extensive discussions and by editing the manuscript.

Chapter 5: Developed and written only by the author.

Chapter 6: The author was responsible for the conceptual design and writing of the article. Felix Creutzig contributed in extensive discussions and by editing the manuscript.

Chapter 7: The author of this thesis was responsible for the conceptual design and writing of the article. Felix Creutzig contributed in extensive discussions and by editing the manuscript. David Kapfer contributed in discussions to the methodological approach of the article; furthermore he contributed to data collection and evaluation.

Chapter 8: Developed and written only by the author.

Chapter 9: The author was responsible for the conceptual design and writing of the article. Felix Creutzig contributed in discussions and by editing the manuscript.

Chapter 10: Jahel Mielke initiated the idea for the paper. All authors contributed to the conceptual design, framing of the research question and specifying the typologies. Jahel Mielke wrote the introduction and literature review, the cases for the energy transition section, part of the typology, part of the discussion and the conclusion. Hannah Vermaßen wrote part of the typology and part of the discussion. Saskia Ellenbeck wrote the methods section, part of the typology and part of the discussion. The author of this thesis wrote part of the typology and developed Figure 1. Carlo Jaeger supported the design and framing of the manuscript through many discussions. All authors contributed in editing and discussing the manuscript.

Chapter 11: Felix Creutzig leaded the project. He defined the structure of the paper with refinements from all authors. Specifically, Eva Schmid and Christian Breyer developed the argument on technical potential with empirical support from Steffen Lohrey. Brigitte Knopf also collaborated on this argument, especially on the evaluation of costs of deployment. Paul Lehmann developed the argument on the political framework. Jan Christoph Goldschmidt developed the argument that the different possible technological pathways for a cost-effective decarbonization of the European electricity production and distribution system offer significant leeway to consider additional aspects beyond technology and economic concerns. In the discussion, this argument was further extended by the collaboration of Jan Christoph Goldschmidt, Eva Schmid and Michael Jakob to include the concept of a welfare increase induced by co-effects. Paul Lehmann developed the argument on multilevel implementation strategy, with inputs from Michael Jakob to refine the financial argument. The author of this thesis and Tiziana Susca developed the section on barriers to renewable deployment. Their contributions included data collection, data analysis and synthesis of results. Konstantin Wiegandt, Felix von Blücher, Christian Breyer and Brigitte Knopf contributed with discussion and edits.

Tools and resources

All chapters of this thesis were written with Microsoft Office Word 2010. References were added using the reference manager Zotero for Firefox and Zotero Standalone[1] as well as the plug-in for Microsoft Office Word. This document was prepared using LATEX[2], particularly Texniccenter[3] and the pdfpages package[4] to ensemble all chapters in their given layouts. In some chapters, additional resources have been used for data analysis and generating graphical output, as indicated:

Chapter 3: Figure 3 was generated with Microsoft Excel 2010 (Version 14.0). Figure 4 was drawn with Microsoft PowerPoint 2010 (Version 14.0). Figure 2 and Figure 3 were drawn with Microsoft PowerPoint 2010 (Version 14.0).

Chapter 4: Figure 1 was generated with Microsoft Excel 2010 (Version 14.0).

Chapter 5: Figure 1 was generated with Microsoft PowerPoint 2010 (Version 14.0). Figure 2 and Figure 3 were generated with R Version 3.1.1[5], particularly with RStudio[6].

Chapter 6: Figure 1, Figure 4 and Figure A.2 were generated with Microsoft Excel 2010 (Version 14.0). Figure 2, Figure 3 and Figure 5 were generated with QGIS[7], a geographic information system . Data analysis and Fig A.1 were conducted with StataSE 10[8], a statistical software.

Chapter 7: Figure 1 was drawn with Microsoft PowerPoint 2010 (Version 14.0). Figure 2 was generated with Microsoft Excel 2010 (Version 14.0).

Chapter 9: Figure 1 was drawn with Microsoft PowerPoint 2010 (Version 14.0). Figure 2 was generated with QGIS. Figure 3 and Figure A.1 were generated with Microsoft Excel 2010 (Version 14.0).

Chapter 10: Figure 1 was drawn with Microsoft PowerPoint 2010 (Version 14.0).

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Chapter 11: Data analysis was conducted with Microsoft Excel 2010 (Version 14.0).

Publication list

Chapters 2 to 11 of this thesis correspond to articles that have been submitted, and accepted or published in a revised version in different journals. They are listed here in order of appearance:

Chapter 2: Submitted in March 2016 to *Environment and Urbanization* as Reckien, D., Creutzig, F., Fernandez, B., Lwasa, S., Tovar-Restrepo, M., McEvoy, D., Sattherthwaite, D. Climate Change, Equity and Sustainable Development Goals: An Urban Perspective.

Chapter 3: Submitted in February 2016 to *Annual Review of Environment and Resources* as Creutzig, F., Fernandez, B., Haberl, H., Khosia, R., Mulugetta, Y., Seto, K.C. Beyond Technology. Demand-Side Solutions to Climate Change Mitigation. A revised version (submitted in July 2016) has been published according to journal format requirements as Creutzig, F., Fernandez, B., Haberl, H., Khosla, R., Mulugetta, Y., Seto, K.C. (2016): Beyond technology: demand-side solutions for climate change mitigation. *Annual Review of Environment and Resources* 41, 21.1-21.26. DOI: 10.1146/annurev-environ-110615-085428.

Chapter 4: A version has been published according to journal format requirements as Fernandez Milan, B., and Creutzig, F. (2015): Reducing urban heat wave risk in the 21st century. *Current Opinion in Environmental Sustainability* 14, 221-231. DOI: 10.1016/j.cosust.2015.08.002.

Chapter 5: Submitted in February 2016 to *Habitat International* as Fernandez Milan, B. Water security in an urbanized world: An equity perspective.

Chapter 6: A version has been published according to journal format requirements as Fernandez Milan, B., Creutzig, F. (2016): Municipal policies accelerated urban sprawl and public debts in Spain. *Land Use Policy* 54, 103-115. DOI: 10.1016/j.landusepol.2016.01.009.

Chapter 7: A version has been published according to journal format requirements as Fernandez Milan, B., Kapfer, D., Creutzig, F. (2016): A systematic framework of location value taxes reveals dismal policy design in most European countries. *Land Use Policy* 51, 335-349. DOI: 10.1016/j.landusepol.2015.11.022.

Chapter 8: The final publication is available at Springer via DOI: 10.1007/s13412-014-0217-5 as Fernandez Milan, B. (2015): How participatory planning processes for transit-oriented development contribute to social sustainability. *Journal of Environmental Studies and Sciences* 2015, 1-15.

Chapter 9: Submitted in January 2016 to *Cities* as Fernandez Milan, B., Creutzig, F. Participatory design in transit-oriented development uncovers social benefits.

Chapter 10: A version has been published according to journal format requirements as Mielke, J., Vermaßen, H., Ellenbeck, S., Fernandez Milan, B., Jaeger, C. (2016). Stakeholder involvement in sustainability science. A critical view. *Energy Research and Social Science* 17, 71-81. DOI: 10.1016/j.erss.2016.04.001.

Chapter 11: A version has been published according to journal format requirements as Creutzig, F., Goldschmidt, J.C., Lehman, P., Schmid, E., von Blücher, F., Breyer, C., Fernandez, B., Jakob, M., Knopf, B., Lohrey, S., Susca, T., Wiegandt, K. (2014): Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition. *Renewable and Sustainable Energy Reviews* 38, 1015-1028. DOI: 10.1016/j.rser.2014.07.028.