IMPEDIMENTS, INCENTIVES AND INTERRELATIONS WITH OTHER OBJECTIVES – ON THE INTRICACY OF CLIMATE POLICY IMPLEMENTATION

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Abstract

The Paris Agreement on climate change mitigation – celebrated as a historic breakthrough – relies on the voluntary implementation of adequate climate policy measures on the national and sub-national levels. The compliance with mitigation pledges will crucially depend on the interplay of different incentives and political realities in the emitting countries. It is therefore of fundamental importance to gain a better understanding of what determines national policy making, how incentives can be fostered and how obstacles for policy implementation can be identified and overcome. This thesis is dedicated to the challenges of national climate policy implementation, the politics of climate change and the role of non-climate incentives.

When putting climate policy into practice policy makers are confronted with a variety of real-world imperfections that complicate the implementation of policies. Economic models providing advice for climate policy makers, in contrast, tend to assume idealized conditions and often center their analysis on the climate externality only. Developing a typology, three different categories of real-world impediments are identified and discussed. First, barriers that impede the formulation and implementation of optimal climate policies on the level of governments and institutions. Second, obstacles impacting the behavior of households and firms when responding to implemented policies. And third, market imperfections and distortions affecting both policy implementation and responses of economic agents. The applicability of the typology is illustrated in a case study on China. Moreover, common assumptions of (climate-) energy-economy models are contrasted with the identified impediments and implications with respect to the interpretation of model results are discussed.

To gain more insights into the challenges of climate policy formulation and implementation, a case study on Vietnam analyzes the drivers of climate-related policies in a Non-Annex-I country. In the absence of a binding international agreement, such voluntary mitigation efforts seem to contradict conventional collective action theory that predicts free-riding. Based on qualitative interviews with Vietnamese policy makers and development agencies a policy analysis is conducted investigating the factors that motivated Vietnam to strive for a low-carbon economy. It is found that, while Vietnam's high vulnerability to climate impacts has contributed to put climate change on the political agenda, the recent climate policies were mainly driven by non-climate objectives such as restructuring of the economy, addressing energy security concerns and gaining access to finance and technology.

The effectiveness of climate policies with respect to yielding emission reductions will depend on the response of consumers to these policies. Focusing on road transport in Europe, an econometric analysis of the fuel consumption response to pricing policies is conducted. The dynamic panel data analysis provides robust estimates for petrol and diesel price elasticities, accounting for underlying dynamics, dieselization, and fuel price endogeneity. Based on these estimates, the potential of fuel tax reforms to address the two objectives of curbing harmful air pollutants from road transport as well as contributing to climate change mitigation is assessed. It is shown that both (i) a repeal of the preferential tax treatment for diesel and (ii) an introduction of a carbon content-based tax, could contribute substantially to achieving the EU climate policy goals for 2020 while at the same time avoiding considerable amounts of health damaging air pollutant exhaust.

Zusammenfassung

Das Pariser Klimaabkommen - als historischer Durchbruch gefeiert - setzt auf die freiwillige Umsetzung der notwendigen Maßnahmen auf der nationalen und sub-nationalen Ebene. Doch die Einhaltung der nationalen Vermeidungszusagen (INDC) wird maßgeblich vom Zusammenspiel verschiedener Anreize und den politischen Gegebenheiten in den emittierenden Ländern abhängen. Für eine erfolgreiche Umsetzung des Pariser Abkommens ist es demnach von essentieller Bedeutung, ein besseres Verständnis davon zu bekommen, welche Faktoren den nationalen politischen Entscheidungsprozess beeinflussen, wie gewünschte Anreize gefördert werden können und wie Hindernisse für die Politikimplementierung von Klimaschutzmaßnahmen erkannt und beseitigt werden können. Diese Dissertationsschrift widmet sich den Herausforderungen bei der Umsetzung von Klimaschutzmaßnahmen, den politischen Realitäten und den Interaktionen mit anderen Politikzielen.

Bei der Umsetzung von Klimaschutzmaßnahmen sind Politiker mit einer Vielzahl von Schwierigkeiten konfrontiert, welche die Implementierung verkomplizieren. Für die Politikberatung entwickelte ökonomische Modelle nehmen hingegen zumeist idealisierte Zusammenhänge an, wobei sich die Analyse weitestgehend auf die Externalität des Klimawandels beschränkt. Anhand einer Typologie werden drei Arten von Hindernissen für Klimaschutzpolitik identifiziert und diskutiert. Die erste Kategorie umfasst Hindernisse, welche die Formulierung und Implementierung von optimalen Klimaschutzmaßnahmen auf der Ebene der Regierung und der Institutionen beinträchtigen. In der zweiten Kategorie werden Hürden zusammengefasst, die das Verhalten von Haushalten und Unternehmen betreffen, welche auf die Politiken reagieren. Als dritte Kategorie werden Marktunvollkommenheiten und –verzerrungen identifiziert, welche sowohl Einfluss auf die Politikimplementierung als auch auf das Konsumenten- bzw. Produzentenverhalten haben. Die Anwendbarkeit der Typologie ist in einer Fallstudie zu China veranschaulicht. Außerdem werden die gängigen Annahmen von (Klima-)Energie-Ökonomie Modellen den identifizierten Hindernissen gegenübergestellt und Folgerungen für die Interpretation von Modell-Ergebnissen diskutiert.

Um bessere Einblicke in die Herausforderungen der Formulierung und Implementierung von Klimaschutzpolitik gewinnen zu können, analysiert die Fallstudie zu Vietnam die zu Grunde liegenden Antriebsfaktoren, die zur Implementierung von klima-relevanten Politiken in einem Nicht-Annex-I-Land geführt haben. Ohne verpflichtendes internationales Klimaabkommen scheinen solche freiwilligen Vorstöße im Widerspruch zur Theorie des kollektiven Handelns zu stehen, nach welcher vollständiges Trittbrettfahrerverhalten zu erwarten wäre. Basierend auf qualitativen Interviews mit vietnamesischen politischen Entscheidungsträgern und Mitarbeitern der Entwicklungszusammenarbeit wurde eine Politikanalyse durchgeführt. Diese untersucht Faktoren, die Vietnam dazu bewegt haben, ein kohlenstoffarmes Wachstum anzustreben. Während Vietnams starke Anfälligkeit gegenüber hohen Klimaschäden ein Grund war, dass das Thema Klimaschutz auf die politische Agenda in Vietnam gesetzt wurde, so scheinen die kürzlich verabschiedeten Klimaschutzpolitiken größtenteils durch Faktoren getrieben worden zu sein, welche nicht in direktem Zusammenhang mit Klimaschutzzielen stehen. Diese umfassen die notwendige Umstrukturierung der Wirtschaft, die Sicherung der Energieversorgung und Zugang zu finanziellen Mitteln und Technologie.

Die Wirksamkeit von Klimapolitikmaßnahmen zur Erzielung von tatsächlichen Emissionsreduktionen ist stark davon abhängig, wie Konsumenten auf die jeweiligen Politikinstrumente reagieren. Anhand des Straßenverkehrssektors in Europa wird eine ökonometrische Analyse durchgeführt, welche die Nachfragereaktion auf Preispolitiken für Treibstoffe untersucht. In einer dynamischen Analyse eines Paneldatensatzes werden robuste Schätzergebnisse für die Preiselastizität der Nachfrage nach Benzin und Diesel ermittelt, welche dynamische Zusammenhänge, den steigenden Anteil von Dieselfahrzeugen sowie Preis-Endogenität berücksichtigen. Basierend auf diesen Schätzergebnissen wird untersucht, wieviel Potenzial Reformen der Treibstoffbepreisung bieten würden, sowohl schädliche Abgase im Straßenverkehr zu reduzieren als auch einen Beitrag zum Klimaschutz zu leisten. Es wird gezeigt, dass sowohl i) die Abschaffung des Steuervorteils für Dieseltreibstoff als auch ii) die Einführung einer CO_2*-Steuer erheblich dazu beitragen könnten, die EU Klimaschutzziele für das Jahr 2020 bezüglich des Transportsektors zu erfüllen und den sonstigen Schadstoffausstoß beträchtlich zu reduzieren.*

Chapter 1

INTRODUCTION

CHAPTER 1 - INTRODUCTION

Economic theory suggests that a global carbon price would serve as an efficient measure to internalize the negative externality of climate change. However, efforts to agree on a global carbon price have failed to receive the necessary global support, despite the largely acknowledged need for climate stabilization. Pursuing a different approach based on national pledges, the Paris Agreement from the 21st Conference of the Parties (COP) in December 2015 has been celebrated as a historic success by most leading politicians and the majority of climate scientists (see e.g. Schellnhuber, Rahmstorf, and Winkelmann 2016; UNFCCC 2015). Yet, the signing of the Paris Agreement can only be seen as a necessary first step which, however, will by far not be sufficient. In the absence of a globally acknowledged central sovereign authority and a credible enforcement mechanism, the success of national climate policy implementation as well as the level of ambition of each member will largely depend on the national incentives to comply with pledges and even intensify ambitions in line with the stated 'well below 2°C' target (UNFCCC 2015, article 2). However, putting pledges into practice will affect a variety of policy areas and will require fundamental policy changes in most countries. Consequently, climate considerations will inevitably interact with many other policy objectives. For the success of the Paris Agreement it is therefore of fundamental importance to gain a better understanding of what determines national policy making, how incentives can be fostered and how obstacles for policy implementation can be identified and overcome. This thesis is dedicated to the challenges of national climate policy implementation, the politics of climate change and the role of non-climate incentives.

The remainder of this first introductory chapter gives an overview of the problem of climate change (section 1.1), the economic perspective on optimal climate policy (section 1.2) and the political challenges of climate policy implementation in the presence of other policy objectives (section 1.3). In the Chapters 2 to 4, this thesis compiles three analyses on the challenges of national climate policy implementation, and the potential of non-climate policy objectives to incentivize climate policy implementation. Chapter 5 synthesizes and discusses the insights of this thesis and concludes.

1.1. The problem of climate change

1.1.1. Insights from natural science on the danger of climate change

Many anthropogenic activities such as energy-related processes, agriculture and land use cause greenhouse gases (GHG) to be released. The flow of greenhouse gases by far exceeds the absorptive capacity of natural carbon sinks like the oceans and forests, so that GHG accumulate in the atmosphere where they trap heat, increasing global mean temperatures – a process known as greenhouse effect. Representing about 76% of total annual anthropogenic GHG emissions in 2010, CO_2 constitutes the most significant contributor to climate change (IPCC 2014). Due to its long atmospheric lifetime of 100 years and more (Archer et al. 2009), CO_2 can be characterized as a stock pollutant[1] that will persist long after flows of emissions have decreased or even ceased (IPCC 2014).

Climate Impacts

The reports of the Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC) provide a comprehensive assessment of the current scientific consensus on the physics of climate change and the risks caused by the human impact on the climate, investigating on the severity of impacts, the associated uncertainty and time horizon in which these impacts are to be expected (Stocker et al. 2013; Field et al. 2014). The heat that has been trapped by high GHG concentrations in the atmosphere has already led to an increase in global mean temperatures (combing land and ocean surface temperature) of approximately 0.85°C over the period from 1880 to 2012 (Stocker et al. 2013). The gathered results also imply that the frequency of extreme weather events such as heat or cold waves, severe droughts and floods has already increased in more areas than it has decreased in others and is expected to further increase in many regions (Field et al. 2014). The rising temperatures and ocean surface warming cause ice sheets and glaciers to melt globally, leading sea levels to rise slowly but inexorably. Ocean acidification and ocean warming threaten marine and costal ecosystems (Field et al. 2014). Moreover, scientific evidence suggests that there may be certain tipping points in the global climate system, i.e. thresholds for abrupt and irreversible change, which could entail catastrophic consequences (Lenton et al. 2008; Y. Cai, Lenton, and Lontzek 2016; Nepstad et al. 2008; McNeil and Matear 2008).

Apart from environmental and economic damages, climate change may also increase other social risks. Desertification, droughts and floods are likely to negatively affect people's livelihoods, push people into poverty and could trigger large waves of migration flows (Hallegatte et al. 2016; Reuveny 2007). Impacts on agricultural production of food, decreasing fish stocks and water scarcity bear the risk of famines and regional conflicts over scarce resources or even civil wars (Barnett and Adger 2007; Reuveny 2007). Even in the absence of direct climate shocks, climate change can add indirectly to risks of violent conflicts by aggravating the vulnerability to economic shocks (Field et al. 2014).

Preventing 'dangerous interference' with the climate system

The scientific finding that current GHG concentrations considerably exceed the highest concentrations recorded in ice cores over the past 800,000 years (Stocker et al. 2013) indicates that the consequences are unprecedented in human history and that – while impossible to predict with certainty – the extent and likelihood of hazard could be immense. As Stern formulates it: "These are not tiny probabilities of inconveniences but substantial probabilities of catastrophes" (Stern 2014, p.403). The inertia in the climate system additionally adds to the danger of a misperception of actual risks. Thus, when the uncertainty about damages caused by past emissions resolves as impacts are observed, it might be too late to reverse decisions as the impact of past accumulated emissions will only take effect with a certain time lag.

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[1] CO_2 accounts for around 85–90% of the current atmospheric GHG concentration measured in CO_2 equivalents (CO_2e) (Stern 2014).

Acknowledging that climate change poses a severe global threat, the United Framework Convention on Climate Change (UNFCCC) was established in Rio de Janeiro in 1992, meanwhile signed and ratified by 197 parties[2]. The convention defines a long-term objective of stabilizing greenhouse gas concentrations in the atmosphere "at a level that would prevent dangerous anthropogenic interference with the climate system" (United Nations 1992, article 2). However, it avoids the definition of an exact threshold. In 1996, supported by some scientists and environmentalists, the Council of Environment Ministers of the European Union (EU) was the first to formally support the target of limiting global mean temperature increase maximally 2°C above pre-industrial levels. In 2010, at the Conference of the Parties (COP) in Cancun, the UNFCCC negotiations first agreed upon limiting global mean temperature increase to at most 2°C (Schellnhuber, Rahmstorf, and Winkelmann 2016). The Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) have contributed to consolidating the scientific knowledge on linking atmospheric concentration levels to temperature increase and expected climate risks. The latest IPCC report states that an atmospheric concentration level of 500 ppm CO_2eq[3] in 2100 would correspond to a >50% likelihood of staying below 2°C mean temperature increase (relative to 1850 – 1900) without allowing for a temporary emission overshoot (Edenhofer et al. 2014,table TS.1).

Though the 2°C target has dominated the debate (see, e.g., Randalls 2010), it remains contested in the scientific community until now what characterizes 'dangerous interference' and which level of atmospheric concentration would be acceptable. There is scientific evidence that already with lower concentration levels and temperature increases, some tipping points[4] may be reached and some regions may face severe impacts. Tipping elements include for example the Greenland Ice sheet or West Antarctic Ice Sheet, the Amazon rain forest and the Indian Summer Monsoon (Lenton et al. 2008). Moreover, considering a time horizon *beyond* 2100, many negative impacts associated with climate change will continue for centuries after GHG emissions have seized (IPCC 2014). During the climate negotiations in Paris in 2015, several vulnerable countries have therefore pushed for a more ambitious climate stabilization target. This is reflected in Article 2 of the Paris Agreement stating the objective of limiting temperature increase to "well below 2°C above pre-industrial levels" and additionally calling for "efforts to limit the temperature increase to 1.5°C" (UNFCCC 2015). However, even limiting atmospheric concentration levels to below 450 ppm CO_2eq would make it more unlikely than likely[5] that a 1.5°C temperature increase is not exceeded by the end of the century (Edenhofer et al. 2014, table TS.1).

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[2] 196 nations and 1 regional economic integration organization (the EU) are party to the convention (see UNFCCC 2016).

[3] This corresponds to the uncertainty range of 480-530 ppm CO_2eq. The abbreviation ppm refers to parts per million.

[4] The term ''tipping point'' as defined e.g. by Lenton et al. (2008, p.1786) refers to "a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system". A "tipping element" is a major component of the earth system that threatens to pass such a tipping point (Lenton et al. 2008).

[5] The formulation "more unlikely than likely" corresponds to a likelihood range of 0 to < 50 % (Edenhofer et al. 2014, p. 38).

1.1.2. The carbon budget and actual trends in emissions

Back in 2015, the atmospheric global mean CO_2 concentration level has crossed the 400 ppm mark, reaching 404 ppm CO_2 in April 2016 (NOAA 2016). Given the stock pollutant characteristics of CO_2, any concentration target entails that the world is subject to a finite carbon budget which is maximally allowed to be emitted globally. The IPCC has estimated that complying with a 2°C stabilization target (with a probability of >66%) would require that cumulative anthropogenic CO_2 emissions (since 1870) stay below about 2900 $GtCO_2$ when accounting for other non-CO_2 forcings. Considering that around 1900 $GtCO_2$ have already been emitted by 2011, the remaining carbon budget from 2011 onwards amounted to only about 1000 $GtCO_2$ (IPCC 2014), while around 160$GtCO_2$[6] have meanwhile been additionally emitted. Model results suggest that already by 2050 this would necessitate reductions in global GHG emissions of 40 to 70% relative to 2010 levels, and near-zero or net negative emission levels[7] by the end of the century (IPCC 2014). In contrast, the estimates on available fossil carbon reserves by far outweigh the remaining carbon budget (IPCC 2014). McGlade and Ekins (2015) estimate that in order to not exceed the 2°C target about one third of global oil reserves, half of gas reserves and over 80 % of known coal reserves world-wide that would be used under business-as-usual assumptions need to stay in the ground from 2010 to 2050 without allowing for carbon capture and sequestration technologies.

Despite large agreement for decades about the need for climate stabilization, global trends in emissions continue to show a different picture. In 2014, CO_2 emissions from fossil fuel combustion and cement production were the highest in human history amounting to around 35.9 $GtCO_2$, thereby being 60% higher than emission levels in 1990, i.e. the reference year for the mitigation efforts under the Kyoto Protocol (Global Carbon Project 2016). Between 1970 and 2010 total anthropogenic GHG emissions have increased by 80%, with cumulative fossil CO_2 emissions more than tripling (Blanco et al. 2014). Total annual anthropogenic GHG emissions have been rising on average by about 1 $GtCO_2eq$[8] (2.2%) each year between 2000 and 2010 (Blanco et al. 2014). The increases have majorly been driven by growth in per capita consumption and production. Regional differences in population growth and economic growth have contributed to differences in regional patterns with respect to emissions growth (Blanco et al. 2014). Global carbon emissions stemming from industrial processes and fossil fuel combustion accounted for about 78% of the increase in total GHG emissions between 1970 and 2010. In the same time, primary energy consumption per capita increased by 30%, while total energy use rose by 130% driven by population growth (Blanco et al. 2014). These increases largely outpaced the past progresses made in energy efficiency and carbon intensity of energy production, i.e. the average emission rate of CO_2 released per unit of energy generated. The recent 'renaissance of coal', i.e. the trend of increasingly relying on coal for energy production, has even led to an increase in carbon intensity, contributing to the surge in overall carbon emissions (Edenhofer 2015). Given the continuing

[6] Assuming a continuation of the trend as reported by the IPCC, stating that annual CO_2 emissions in 2010 have amounted to 38 (± 3.8) $GtCO_2$/yr (O. Edenhofer et al. 2014).

[7] For an overview on different technologies to achieve net negative emissions see McLaren (2012).

[8] The concept of carbon dioxide equivalents (CO_2eq) is used to compare the radiative forcing of different GHGs based on their Global Warming Potential. The IPCC AR5 WGI Glossary defines it as "the amount of carbon dioxide emission that would cause the same integrated radiative forcing, over a given time horizon, as an emitted amount of a greenhouse gas or a mixture of greenhouse gases" (IPCC 2013, p.1453).

growth in total global energy demand and the longevity of energy infrastructure, a large scale restructuring of global energy production will be necessary already in the near future. The currently existing global energy infrastructure alone already entails a commitment of about 729 $GtCO_2$ future cumulative emissions which will accrue over its lifetime, thereby already depleting most of the remaining carbon budget (Ottmar Edenhofer 2015). Adding expected lifetime emissions of the fossil-based energy infrastructure already planned or under construction today, the 2°C target would become largely infeasible without strongly relying on carbon sequestration technologies.

Driven by increasing energy demand, especially developing countries undertake huge investments in building up energy infrastructure. In January 2016, China alone had over 200,000 MW of coal fired power plants under construction and another 500,000 MW in the pipeline, and Vietnam had a coal power capacity of 12,000 MW already under construction and more than 40,000 MW additionally planned (Endcoal.org 2016). China, India, Indonesia and Vietnam - taken together - are responsible for around three-quarters of coal-fired power plants expected to be newly built globally in the next 5 years (Goldenberg 2016). These observed trends of continuing large scale investments in fossil fuel based infrastructure – especially but not exclusively in developing countries and emerging economies - are not only likely to render a 2°C stabilization target largely infeasible, they could also result in a dangerous lock-in in carbon-intense power generation technologies for decades (Jakob et al. 2012).

Also the transport sector bears the risk of dangerous lock-ins. Accounting for about 14% of global GHG emissions and 24% of energy-related GHG emissions in 2010, the transport sector is expected to exhibit higher emission growth than any other energy end-use sector reaching annual emissions of around 12 Gt CO_2eq by 2050 according to estimates[9] (Sims et al. 2014). In 2010, over 70% of direct global transport GHG emissions stemmed from road transportation (Sims et al. 2014). Decarbonizing the transport sector has been described as challenging (Creutzig et al. 2015), and mitigation effort have been largely offset by the ongoing increase in passenger and freight activity due to increasing incomes (Sims et al. 2014). Though per capita transport demand is currently much lower in developing countries and emerging economies than in OECD countries, income growth and infrastructure development are expected to boost transport demand in these countries. If mitigation policies fail to at least partially decouple GHG emissions from the demand for mobility, transport emissions will claim a substantial share of the already overstrained carbon budget. Similar to the danger of a carbon-intensive lock-in regarding energy infrastructure, current investments in transportation infrastructure are decisive for determining future GHG emissions from transport. This affects among other aspects urban planning, public transportation systems, the type of technology used and the composition and size of the vehicle fleet. However, transport emissions are not only an important issue in developing countries and emerging economies. In both the US and the EU, the transport sector is responsible for about one quarter of GHG emissions, rendering it the second largest emitting sector (EPA 2016; EEA 2015). Since 1990, GHG emissions in the transport sector have increased by 17% in the US (in 2014) and by about 19% in the EU (in 2013). In the EU, road transportation alone already accounts for around 20% of total CO_2 emissions. This illustrates that emission trends in many sectors even in industrialized countries have not peaked yet and that the

[9] This assumes that no new strong mitigation policies are implemented.

decarbonization of major sectors such as the transport sector poses a major challenge to all countries irrespective of development status.

With respect to cumulative CO_2 emissions, the OECD-1990 countries have been responsible for a major share, amounting to around 42% of global cumulative emissions from 1750 to 2010 (Blanco et al. 2014). Acknowledging the differences in historic responsibility and mitigation capacities, the principle of 'common but differentiated responsibilities' evolved in international negotiations, being first mentioned in the Rio Declaration 1992 (Pauw et al. 2014). With listing mostly industrialized countries in the Annex I[10] of the United Framework convention on Climate Change (UNFCCC) (United Nations 1992) and Annex B of the Kyoto Protocol, the dichotomy between Annex I countries and Non-Annex I countries was created. Annex I countries have committed to the objective of returning to their 1990 GHG levels by the year 2000 as stated in Article 4.2 (a, b) of the convention, while Non-Annex I countries were thereby basically exempted from mitigation obligations for the past two decades (Pauw et al. 2014). However, by 2010 the group of developing countries has overtaken developed countries with respect to annual CO_2 emissions from industrial processes and fossil fuel combustion (Blanco et al. 2014). While median per capita emissions in high-income countries still exceeded that of low-income countries by a factor of 10 in 2010 (Blanco et al. 2014), over the last four decades, GHG emissions in Asia increased by 330%, while emissions in OECD-1990 countries rose by 22% (Blanco et al. 2014). This further illustrates the prevailing gap in living standards and the resulting challenge of reconciling poverty reduction, growing energy demand and climate change mitigation. And it furthermore shows that climate change mitigation efforts can only be successful if *both* industrialized and developing countries engage in ambitious mitigation efforts.

The following section provides an introduction to the insights from economic theory on how optimal climate policy should be designed. Section 1.3 provides an introduction to the challenges related to the political dimension of climate policy implementation and the related incentives and disincentives for climate change mitigation.

1.2. Economic theory on addressing the climate change problem

1.2.1. Determining the desired level of ambition

In view of the severe expected damages, GHG emissions constitute a negative externality to society, i.e. an uncompensated negative impact of the action of one agent on the utility of other agents (Perman et al. 2003). Nicholas Stern has repeatedly called climate change the "greatest market failure the world has ever seen" (Stern 2007,p.viii) due to the extent of people affected and the severity of risks associated (Stern 2007; Stern 2014). In the presence of a market failure, the unregulated market solution based on the utility and profit maximization of agents does not yield the socially optimal outcome as private costs do not reflect social costs. As the costs associated with the negative externality of climate change are not captured in the market prices, producers do not account for them in their production decision

[10] Annex I (UN 1992, amended in 1998) lists OECD countries and economies in transition to a market economy. Annex B of the Kyoto Protocol comprises all Annex I countries (1998) except for Turkey and Belarus.

(profit maximization) nor do consumers in their consumption decision (utility maximization). Economic theory on externalities suggests that in presence of such market failures, policy intervention can be welfare enhancing.

Choosing a target for climate stabilization involves balancing the trade-off between the benefits of reducing the risk of climate damages and bearing higher mitigation costs (Edenhofer et al. 2013). While science provides insights in the physical consequences of climate change or mitigation costs, the social valuation of these costs and benefits involves value judgements. Several studies have attempted to estimate the Social Costs of Carbon (SCC), i.e. the marginal economic damage from the change in climate that results from a marginal increase in CO_2 emissions[11] (Tol 2008; Anthoff and Tol 2013; Howarth, Gerst, and Borsuk 2014; van den Bijgaart, Gerlagh, and Liski 2016; IAWG 2015). Estimates for the SCC vary widely, depending on underlying model assumptions including social discount rates for future costs or benefits and valuation of non-monetary impacts. The Fifth Assessment Report (AR5) of the IPCC provides an overview on different estimates, stating that the average estimate for SCC for studies published between the AR4[12] and AR5 was around 241 USD per ton of carbon, i.e. around 65 USD per ton of CO_2 (Arent et al. 2014). However, other studies argue that the SCC have largely been underestimated in previous studies, proposing substantially higher SCC if tipping elements are taken into consideration (Lontzek et al. 2015; Cai, Lenton, and Lontzek 2016) and higher risk aversion is assumed (Howarth, Gerst, and Borsuk 2014). The valuation of costs and benefits crucially depend on social preferences (see Kolstad et al. (2014) for an extensive discussion on social welfare functions (SWF)[13]). Such normative decisions are important for economic analysis; however they need to be determined subject to ethical debates.

In determining the optimal level[14] of ambition for climate change mitigation, economic welfare analysis applying cost-benefit analysis can be a useful tool for decision making. This involves weighing the value of the expected costs of mitigation and the value of the benefits from avoided climate damages, then comparing mitigation options. However, cost-benefit analysis may be perceived as inappropriate if costs and benefits are hard to monetarize or to compare in a common unit due to ethical concerns (Wegner and Pascual 2011). Similarly, applying cost-benefit analysis is at its limits with regard to catastrophic risks

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[11] The SCC usually refer to the discounted economic damage from a change in CO_2 of one metric ton, in a given year. Some studies refer to a change in carbon instead.

[12] Fourth Assessment Report of the IPCC published in 2007.

[13] The construction of a SWF requires the aggregation and inter-personal comparison of individual utility. This rests on strong assumptions such as cardinal measurability and an additive nature of utility, as well as normative assumptions about weighting factors.

[14] To avoid the problems of defining a SWF, Pareto has proposed an alternative concept of optimality that allows detaching welfare economics from the inter-personal comparisons of utilities (Perman et al. 2003). A Pareto optimum is achieved if no one can be made better off without rending another person worse off. However, this entails that while a welfare optimum is generally Pareto optimal (provided that the SWF increases in the utility of all individuals), not all Pareto-optimal outcomes coincide with the welfare optimum. Moreover, the original Pareto-criterion is limited in its applicability as it does not allow for any losers of a policy, thus inhibiting wealth redistribution. A more flexible extension proposed by Kaldor as well as Hicks introduces (hypothetical) transfers from winners compensating losers (Perman et al. 2003). Note that for a Pareto-improvement after Kaldor and Hicks it is not necessary that losers are *actually* compensated, it is sufficient that total gains outweigh losses.

that society wants to avoid by all means (Cai et al. 2015). The potential existence of tipping elements (see section 1.1.1) in the climate system may entail such catastrophic risks speaking in favor of a cost-effectiveness approach, i.e. setting a specific mitigation target that coincides with not passing the defined dangerous threshold, while aiming at minimizing costs in achieving this objective identified by society.[15] Again, determining the threshold that is considered to reflect dangerous levels as discussed in section 1.1.1 is a normative choice.

As CO_2 is a stock pollutant, the optimization is furthermore complicated by the dynamic nature of the problem. This results in various possible mitigation pathways for a given concentration stabilization target, where less stringent mitigation efforts today require more stringent future policies and vice versa. Early action will decrease the risks of damages from climate change or at least delay them. In contrast, delayed mitigation action increases the risk of shifting damages towards the present and additionally adds to the danger of a lock-in in carbon intensive long-lasting infrastructure which again raises costs for mitigation in the future. In analyzing the long-term implications of policy options and emission scenarios Integrated Assessment Models (IAMs) may serve as a useful tool to provide insights for decision making (Metcalf and Stock 2015). IAMs are a (heterogeneous) class of models that aim to integrate different disciplines by linking models on for example energy systems, climate and other natural systems, and economic systems (US Department of Energy 2009). Comparing different emissions pathways with respect to timing, technology mix and ambition levels, IAMs can provide valuable insights on e.g. the associated mitigation costs of policy options and inform policy makers about implications of technology choices and timing. However, when interpreting IAM results it is important to keep the underlying assumptions in mind, which may be challenging due to the high complexity and heterogeneity of the models often resulting in a lack of transparency (Schwanitz 2013). It is therefore informative to recall the underlying assumptions and evaluate the sensitivity of model results to normative assumptions and model structures by intra-model assessments and model inter-comparison exercises (Kriegler et al. 2015). Chapter 3 of this thesis will elaborate more on contrasting reality with underlying model assumptions, discussing the possible insights from and limits of IAMs and the implications for decision making.

1.2.2. Optimal climate policy and instruments choice

Given a desired mitigation target and pathway has been defined, policy makers can make use of different policy instruments which can be broadly categorized in direct regulatory measures (also called command-and-control) and incentive-based measures (also called economic instruments) (Hepburn 2006; Goulder and Parry 2008). Direct regulatory measures comprise for example technology mandates and performance standards which directly prescribe legally binding standards and maximally allowed thresholds. Incentive-based instruments in contrast regulate by setting a price signal to firms and individuals. This can either be achieved by setting a direct price, for example in form of a tax or subsidy, or by defining a quantity restriction and then trade emission allowances resulting in a market price.

[15] Given existing uncertainties, more ambitious targets may be interpreted as reducing the likelihood of impacts including catastrophic events (Edenhofer et al. 2013).

Moreover, hybrid approaches combining tradable permits with floor prices or ceiling prices are also possible (Hepburn 2006).

The performance of these policy instruments in achieving the desired target can be compared along different evaluation criteria. The first best solution where a benevolent, omnipotent and omniscient social planner chooses the mitigation effort of each agent serves as a benchmark for comparison of policy options.[16] With respect to minimizing costs, a given mitigation target is reached in a cost-effective way if marginal abatement costs are equalized over all available options and agents involved (Goulder and Parry 2008). As governments are often subject to information asymmetries, imposing command-and-control measures on heterogeneous firms likely leads to higher costs. In contrast, economic instruments can take advantage of markets' capabilities to exploit information on heterogeneous market participants on e.g. firm specific abatement costs (Hepburn 2006). Due to the pricing the externality, producers and consumers would internalize the external cost caused by the pollution in their production or consumption decision. This would serve to achieve a given mitigation target at least costs. For the optimal level of mitigation, the economist Arthur C. Pigou proposed to impose a fee on polluters per unit of pollution that would be equal to the aggregate marginal damages caused by the externality at the efficient level of pollution (Pigou 1920). Economic theory would therefore recommend imposing a globally uniform price[17] equal to the expected marginal damages caused by climate change at the efficient level. Moreover, apart from the instrument choice, policy makers need to make decisions on the design features of a policy instruments which also crucially impacts the outcome (Bechtel and Scheve 2013; Böhringer, Carbone, and Rutherford 2012).

1.2.3. Theory on second best

The theoretical considerations above refer to an ideal world facing only one market failure: the climate externality. Under these conditions the first-best solution would be the internalization of the climate externality as described above. However, reality is much more complex and characterized by the interplay of many more prevailing imperfections such as market power, information asymmetries, and other externalities, e.g. learning spillovers. If these other market failures again can be addressed directly, additional targeted policy instruments may be recommended tailored to address each specific market failure (Tinbergen 1952). However, many of these imperfections are irremovable. In their article on "The General Theory of Second Best" Lipsey and Lancester conclude that if one or more criteria for Pareto-optimality cannot be fulfilled as the source of divergence is irremovable, a second-best optimum can be achieved "only by departing from all the other Paretian conditions" (Lipsey and Lancaster 1956, p. 11). Given the complexity of multiple constraints, identifying and attaining an economy-wide second-best optimum is even more challenging than the first-best. More importantly, this implies that the removal of one market failure – like the climate externality – in the presence of other irremovable

[16] In contrast to the theoretical social planner, existing regulatory authorities such as governments face informational constraints as well as objective functions than differ from (largely unknown) social preferences.

[17] While in the deterministic case imposing a tax, i.e. a price instrument, is formally equivalent to applying a quantity-based instrument, such as trading emission permits, both policy approaches have different implications with respect to cost-effectiveness in the presence of uncertainty and incomplete information (for an overview see Goulder and Parry 2008; Hepburn 2006).

market failures does not necessarily improve welfare or efficiency, but could even reduce it (Lipsey and Lancaster 1956).

The theory of the second best tells us that for implementing climate policy one needs to gain a profound understanding of not only the climate externality but also of all other prevailing conditions and real world imperfections. Moreover, it tells us that considering only one part of the economy in welfare analysis can yield negative impacts on overall welfare with respect to the general equilibrium. Any policy imposed may entail unexpected consequences on other seemingly unrelated parts of the economy (Lipsey 2007). An improved understanding of the surrounding conditions and interrelations may help to inform policy makers for policy design in attenuating potential undesired consequences (Lipsey 2007). Chapter 2 of this thesis discusses factors that seem most relevant for climate policy in rendering the first-best unachievable.

1.2.4. Aspects beyond efficiency

While economics tends to emphasize efficiency or - for a given target cost-effectiveness advantages - there are also other potential evaluation criteria for policies such as environmental effectiveness, distributional considerations and political feasibility (Kolstad et al. 2014). Both, climate change mitigation as well as inaction entail distributional consequences as climate damages are not equally distributed over space and time and mitigation cost will also affect different actors differently. Distributional issues include the redistribution of scarcity and climate rents, redistribution within countries and between countries as well as intergenerational redistribution. Furthermore, these aspects may also be interrelated and mutually reinforcing.

Rent redistribution

As the carbon content of the available fossil fuel resources by far outweighs the remaining carbon budget, setting a binding ambitious climate stabilization target means that a large part of the remaining fossil fuel resources, especially coal, need to stay in the ground (Jakob and Hilaire 2015) (see section 1.1.2). Fossil fuel resource owner are thus requested to renounce on profits from selling these resources. At the same time a novel scarcity rent, the climate rent, is created. This raises ethical questions such as how the newly created climate rent should be distributed and whether resource owners should be compensated for their losses (see Edenhofer et al. (2013) for a discussion).

Redistribution within countries

Moreover, implementing effective climate change mitigation policies will affect carbon-intensive sectors disproportionately, leading to negative employment effects in these sectors while low carbon sectors may gain. Likewise, climate policy raises the prices of carbon intensive goods which may affect households differently depending on the share of their budget spend on carbon intensive goods. The recycling of revenues from carbon taxation or permit auctioning may be used to mitigate undesired distributional consequences by compensating losers. However, powerful interest groups or a lack of perceived distributional fairness may trigger resistance against certain policy options negatively impacting political feasibility despite cost-efficiency arguments.

Redistribution between countries

Due to the global nature of the problem, distributional considerations go far beyond country borders. While historically industrialized countries have caused most of the accumulated stock of GHGs, it is mostly developing countries that are expected to be disproportionally affected by climate damages (see e.g. Althor, Watson, and Fuller, 2016). Meanwhile, however, fast growing developing countries also contribute substantially to increasing emissions (see section 1.1.2). Pointing to historic responsibility and current emission shares of the other respectively, China and the USA have justified lacking mitigation measures until recently. Given the unequal distribution of mitigation costs and benefits from avoided damages, attaining general agreement on whether mitigation effort of oneself and others are perceived as appropriate and fair will likely remain a highly contentious issue.

Intergenerational Redistribution

Finally, the climate problem also poses questions of intergenerational justice. As CO_2 is a stock pollutant, past and current consumption decisions affect future consumption possibilities going far beyond the time horizon of current generations. With severe climate damages expected to mostly occur in the future of about 50 or more years from now, actors may therefore not adequately (or not at all) account for these future damages in their current decision making. The valuation of the wellbeing of future generations not yet born – and thus not yet able to represent themselves in democratic decision making processes - is therefore a contentious ethical question. However, defining the optimal climate policy in a dynamic problem necessitates the aggregation (and comparison) of uncertain costs and benefits over time, involving the normative choice of an appropriate discount rate for decision making (Heal and Millner 2014, see also Kolstad et al. 2014, p.230, on a discussion and overview on ranges for applied discount rates).

All these aspects involve a range of ethical questions with regard to justice and fairness as well as values. Social preferences and moral values will differ from region to region, further complicating the choice of an optimal *global* climate policy. Again, political feasibility will largely depend on perceived justice and the political power of winners and loser of distributional effects. As pricing policies often face strong opposition, a lack of political feasibility may lead to inaction or the implementation of suboptimal carbon pricing. As a consequence, the environmental effectiveness of implemented pricing policies may be compromised. Despite cost-effectiveness disadvantages, direct regulatory measures may then provide a more environmentally effective alternative, as costs are often less visible to voters. However, also direct regulatory measures have faced resistance from powerful interest groups and have shown to lack environmental effectiveness if not adequately enforced (see Chapter 4 of this thesis). Deciding on the 'optimal' level of ambition for climate change mitigation and the preferred policy instrument goes far beyond the question which climate policy would yield the lowest mitigation costs. Especially due to the global dimension of the problem, effective climate policy implementation and compliance will largely depend on "finding an approach widely understood as equitable" (Stern 2007, p.472).

1.3. Climate policy implementation - A multi-level and multi-objective problem

1.3.1. Governing the global commons - A multi-level collective action problem

Given the limited remaining carbon budget, every ton of GHG emitted by one actor may not be emitted by another actor if atmospheric concentrations are not supposed to exceed dangerous levels. At the same time, as the atmosphere is globally shared, excluding someone from using it as a disposal space for GHGs is difficult and costly to enforce. These characteristics of non-excludability as well as rivalry of usage qualify the atmosphere to be called a 'global common-pool resource' or open-access resource. On the other hand climate protection in the form of emissions abatement becomes a global public good as it is non-rivalrous (Edenhofer et al. 2013). The non-excludability from using the atmosphere for GHG emissions entails strong free-riding incentives for individual actors. While costs for mitigation would be borne by the individual, other actors that are unwilling to contribute to mitigation efforts cannot be excluded from benefiting from avoided damages. This induces a collective action problem, leading to the overuse of the common-pool resource atmosphere in the absence of regulation, a phenomenon that has been referred to as 'tragedy of the commons' (Hardin 1968).Without adequate regulation, the public good emissions abatement will be underprovided and the common-pool resource atmosphere will be overused, leading to dangerous impacts on the global climate. Though challenged by certain complexities such as information constraints, uncertainty and value judgements, economic theory tells us that, in principle, a regulating authority could implement and enforce policies to correct the mismatch of private incentives and public welfare thereby averting climate change. However, facing a collective-action problem of a global dimension, the lack of a global authority that could implement and enforce such a regulation entails that global cooperation is needed to address the climate problem. For a global agreement to take effect, ratification by national governments is required followed by the implementation of policies. Though at the national level, governments would have the authority to impose adequate regulation, also these governments are subject to strong free-riding incentives in the absense of a global enforcement mechanism. Likewise at the subnational level, regional and local policy making face similar incentives to shift the burden of mitigation towards others. The involvement of multiple levels of policy making with mutual interaction, combined with the absence of a global regulatory authority or enforcement mechanism and incentives to freeride on each level, renders achieving collective action in tackling the climate change problem particularly challenging.

Game theory has made various attempts to describe international negotiations on climate change and to explain strategic behavior and incentive structures (see e.g. DeCanio and Fremstad 2013; Mason, Polasky, and Tarui 2016; Barrett and Dannenberg 2014). Though simple game theoretical models such as the standard prisoners' dilemma or the chicken game are too simple to adequately reflect the complexity of international negotiations (Pittel and Rübbelke 2012; DeCanio and Fremstad 2013), these games can provide some insights to understand the incentives of players and to find enabling conditions and strategies for cooperation (Madani 2013). Though cooperation would be better for all players - every player has an incentive to deviate provided that the other player cooperates, resulting in the Pareto-inferior Nash-equilibrium of non-cooperation. So with respect to the Paris Agreement - having achieved agreement on global cooperation - the question arises, how participation (i.e. ratification of the treaty) and finally compliance with pledges can be attained. In the absence of a credible global enforcement mechanism, a successful agreement would need to be self-enforcing, i.e. provide sufficient incentives for each player in the coalition to comply without external enforcement (Barrett 2008; Mason, Polasky, and Tarui 2016). Adding the complexity of a multi-level game, with international agreements needing to be ratified at the national level, exacerbates the difficulties of ensuring credible commitment for participation and compliance. Putnam has analyzed a two-level game accounting for interdependencies between international negotiations and domestic politics, arguing that expectations about the domestic level politics are likely to influence the international level and vice versa (Putnam 1988). Chapman, Urpelainen, and Wolford (2012) moreover argue that national politics may deliberately create constraints to strengthen their bargaining power in international negotiations. Agreeing on a global climate policy has therefore proven especially challenging, often being described as a gridlock-situation (Victor 2011).

1.3.2. Polycentric climate policy

Despite strong free-riding incentives and a gridlock situation in international climate negotiations, several unilateral climate policies have been implemented on the regional, national and local levels in the past decade. According to the World Bank, in August 2015, 39 national and 23 subnational jurisdictions have been pricing carbon emissions by taxation or emissions trading (Kossoy et al. 2015). Since 2005, the EU has set up the world's first and until today largest Emissions Trading Scheme (ETS) for carbon emissions (European Commission 2016). On the subnational level, British Columbia implemented a carbon tax in 2008 that by 2012 had reached C$30/t$CO_2$ (Murray and Rivers 2015). A cooperation of several US states have launched the Regional Greenhouse Gas Initiative (RGGI) starting the first commitment period of their CO_2-ETS in 2009. In 2013, also California and Quebec started to price carbon emissions by setting up local ETS and linking them in 2014 (Carbon Market Data 2016). In 2013, China has launched several pilot ETS and plans to launch a nation-wide ETS in 2017 (GIZ 2016). Mexico has introduced a carbon tax in 2014 and South Korea launched an ETS in 2015. Similarly, other developing countries like Vietnam and India – which had historically emphasized their status as Non-Annex-I countries in international climate negotiations - have recently decided to change their position towards pursuing voluntary mitigation efforts[18] (Betz 2012, Chapter 3 of this thesis). These national and local initiatives are in contrast to predictions from conventional collective action theory, predicting inaction and free-riding behavior in the absence of an external regulation. Especially in developing countries, which could refer to having been exempted from mitigation obligations due to their status as Non-Annex-I countries, unilateral climate change mitigation policies may seem puzzling.

Ostrom (2010) affirms that the findings of conventional collective action theory are not necessarily supported by empirical findings on collective action problems. She argues that while climate change has a global dimension, the actions causing climate change are taken by actors at smaller scales in

[18] Both, India and Vietnam have introduced taxes on several carbon-intensive goods such as coal, gasoline and diesel. However, these taxes cannot be considered direct carbon pricing policies as tax rates are not set according to carbon content.

polycentric structures[19]. Conventional collective action theory lacks explanation for these unilateral, smaller scale or local initiatives as it often disregards several aspects. First, behavioral theory shows that altruistic preferences, trust, reputation, reciprocity and the perception of moral responsibility and social norms can influence individual behavior in favor of cooperation. Local knowledge and personal interrelations help to foster willingness of individuals to contribute voluntarily, and strengthen compliance with imposed regulations thus lowering policy costs (Ostrom 2010). Also in the international context, countries are interested in sending signals that they are a reliable partner fostering trust and reciprocity for bilateral or multilateral relations. Second, conventional collective action theory often disregards the existence of multiple policy objectives. This aspect is discussed in more detail in section 1.3.3.

Clearly, relying on uncoordinated voluntary unilateral efforts at the local level or even at the national or regional level has so far proven to be insufficient. Though in 2012 almost 70% of global GHG emissions where subject to national legislation or strategies (IPCC 2014), global emissions have continued to rise steadily. Without global cooperation unilateral efforts combined with the risk of carbon leakage to other regions or sectors are unlikely to achieve climate stabilization at a level preventing dangerous climate change. Yet, the “exclusive reliance on proposing global solutions” (Ostrom 2010, p.551) has been criticized to reinforce the tendency of the gridlock in global negotiations, thereby discouraging smaller-scale local actions (Victor 2011; Ostrom 2010). The local knowledge on the context and local preferences and concerns with respect to other policy objectives as well as mutual trust can provide an advantage of polycentric decision making over a global ‘top-down’ solution (Ostrom 2010). Though the international climate agreement attained in Paris is an important step, fostering the implementation (and enforcement) of policies at smaller scales is vital for avoiding dangerous climate change. With her work on polycentric management of common pool resources and global environmental change, Elinor Ostrom has encouraged researchers to dedicate more attention to examining the factors influencing local actions and initiatives. Subsequent research has strengthened the position that voluntary climate change mitigation actions in a polycentric approach could provide valuable stepping stones for promoting cooperation on the international level (Cole 2015; Edenhofer et al. 2015a). In absence of a global enforcement mechanism, important lessons can be learnt from analyzing the factors fostering and impeding policy implementation and behavioral change at the national and local level. Chapter 2 addresses the factors affecting decision making relevant to climate change mitigation at different levels. Chapter 3 scrutinizes the drivers of unilateral climate policy formulation in a developing country for the case of Vietnam.

1.3.3. Multiple policy objectives

The concept of polycentric climate policy does not only highlight the role of different levels of policy making and trust or reciprocity, it also emphasizes the existence and importance of multiple policy objectives in decision making. To reduce complexity, many conventional analyses have focused on finding solutions for the climate change problem in isolation, disregarding other objectives such as

[19] Polycentric structures are characterized by multiple formally independent authorities governing at different levels in contrast to a centralized system of one governing authority (see Ostrom 2010).

poverty eradication, energy security and access, and employment. However, the interplay of policy objectives has important implications for the incentives to implement climate policy and comply with regulations. Multiple benefits (or costs) may accrue at different levels, from the international to the household level. Climate change mitigation therefore needs to be discussed in a multi-objective context, taking the interplay with other societal objectives and different national circumstances into account. The interrelations of different objectives may carry incentives for voluntary climate policy, but also trade-offs disincentivizing actions which need to be taken into consideration in designing climate policy.

Co-benefits and adverse side effects

The existence of multiple societal and political objectives bears potential for both synergies and trade-offs with respect to climate policy. These are often referred to by using terms like 'co-benefit' or 'ancillary benefits' while a negative co-benefit is often called 'adverse side effect' (Mayrhofer and Gupta 2016). Co-benefits of climate policy may emerge for example through enhancing energy security and energy access, improving air quality, reducing water consumption, and protection of ecosystems. Potential adverse side effects of climate policy include for example impacts on food security, regressive effects for income distribution, and a slow-down of economic growth. These adverse side effects may be mitigated by complementary policies.

It is important to distinguish between the co-benefit (or adverse side effect) itself and the associated welfare effect caused by the co-benefit. For example, while a reduction in air pollution caused by a climate policy is a co-benefit of that policy, the question whether this leads to an improvement of welfare depends on the pre-existing level of regulation of air pollution. Equation (1) illustrates the differences in a conceptual welfare theoretical framework proposed by von Stechow et al. (2015). Assume social welfare W is a function of a range $i = 1, \dots, m$ of different objectives z_i. The success in achieving these objectives is impacted by a set of technological or other measures m_k $(k = 1, \dots, n)$ which on their side are again impacted by the implementation of a number of policy instruments p_l $(l = 1, \dots, o)$. Omitting the complexity of adding the spatial, temporal and distributional dimension, the net effect on social welfare dW of a marginal change dp_l in one or more policies is then given by

$$dW = \sum_{i=1}^{m} \sum_{k=1}^{n} \sum_{l=1}^{o} \frac{\partial W}{\partial z_i} \frac{\partial z_i}{\partial m_k} \frac{\partial m_k}{\partial p_l} dp_l \tag{1}$$

Each policy instrument p_l is aimed directly at achieving one or more objectives z_i with $l = i$, yielding the direct benefit of the respective policy. The use of the term co-benefit (or adverse side effect) for this thesis refers to the positive (or negative) effect of a policy p_l on *other* objectives not targeted directly, determined by $\frac{\partial z_i}{\partial m_k} \frac{\partial m_k}{\partial p_l}$ for $l \neq i$, *without* assessing the effect on social welfare (i.e. without multiplying by $\frac{\partial W}{\partial z_i}$). Analyzing the final welfare effect is beyond the scope of this thesis as assumptions on the form of the welfare function need to be made and multiple aspects of welfare beyond climate change need to be evaluated. This may need to involve the consideration of several second best conditions such as market distortions, pre-existing policies and other externalities. These real-world complexities are identified and discussed in more detail in Chapter 2 of this thesis. In practice, moreover, drawing the line between a direct benefit and a co-benefit may also be challenging as the expectation about potential side effects may already influence the choice and design of policies. Direct objectives of a policy as compared to co-benefits may therefore not be easily distinguishable in reality. Chapter 3 discusses the interplay of different explicit and implicit objectives shaping climate policy in Vietnam.

Several studies suggest that co-benefits of climate policies may partially offset or even outweigh marginal abatement costs (Rafaj et al. 2013,Bollen 2015; B. Cai et al. 2016; Pathak and Shukla 2016). Groosman, Muller, and O'Neill-Toy (2011) estimate that in the US health-related co-benefits per avoided ton of CO_2 range between 1- 77US$. West et al. (2013) estimate that global average marginal co-benefits stemming from avoided mortality amount to 50-380US$/t$CO_2$, thereby outweighing marginal abatement costs. Especially for Asia large potentials for co-benefits in terms of health or reduced energy imports have been identified (Dowling and Russ 2012; Aunan et al. 2007; Rafaj et al. 2013). For East-Asia, West et al. (2013) find that co-benefits would even exceed marginal costs by a factor of 10-70 in 2030. These situations, in which co-benefits alone would outweigh the cost of a climate change mitigation measure even disregarding direct benefits from reduced climate damages, are often referred to using the terms 'no regret' or 'negative cost' options (IPCC 2014). These prevail also at smaller scales like household or firm levels (Bréchet and Jouvet 2009). Energy efficiency gains outweighing costs are a prominent example. While economic theory predicts that negative cost potentials would eventually vanish due to arbitrage behavior, informational constraints and behavioral or market barriers may impede the exploitation of such seemingly "free lunches" (see Chapter 2).

The potential for co-benefits mainly arises from the existence of other additional externalities or market failures such as health-damaging air pollution, water contamination, congestion and traffic accidents. While in the presence of multiple externalities, economic theory would propose the use of separate policy instruments to address each respectively (Tinbergen 1952), several studies have argued in favor of applying integrated policies, for example targeting climate change and air pollution in a common policy. Bollen, Hers, and van der Zwaan (2010) conclude that addressing climate change, energy security and air pollution with one integrated policy could yield substantial benefits by exploiting synergies; they find that, for Europe, carbon emissions, oil dependency and premature deaths from air pollution would be reduced considerably compared to policies omitting one of the three policy objectives. McCollum, Krey, and Riahi (2011) moreover find that the optimal integrated policy addressing all three policy objectives would be less costly than added policy costs addressing each objective separately. One major argument for combining objectives to be addressed by one integrated policy is creating leverage for a policy objective that would have otherwise been likely neglected by policy makers. The global nature of climate change mitigation – entailing locally borne immediate costs but only globally-shared future and largely intangible benefits in form of avoided damages - renders stand-alone mitigation policies relatively unattractive to policy makers and voters. In contrast, most co-benefits are of a very local nature often showing immediate and visible impact. Coupling climate change mitigation with other policy objectives can therefore foster local incentives for implementation and thereby help overcoming the freeriding problem and facilitating global cooperation (Ottmar Edenhofer et al. 2015). Bollen and Brink (2014) find that more stringent air pollution policies can substantially reduce necessary carbon prices. Franks, Edenhofer, and Lessmann (2015) argue that - even disregarding reduced climate damages - taxing carbon is superior to taxing capital for resource-importing countries, as fossil-resource ownership creates scarcity rents that can be captured by taxation and reinvested. This may provide incentives to restructure tax systems even in the absence of climate considerations. However, so far little research has been conducted on the politics and institutional aspects of co-benefits (Mayrhofer and Gupta 2016). Chapter 3 of this thesis analysis sheds light on the role of co-benefits in motivating climate policy in Vietnam. Chapter 4 analyzes the potential of fuel taxation to curb CO_2 emissions from road transportation in Europe while at the same time substantially reducing health damaging air pollutants and raising fiscal revenues for e.g. investment in green infrastructure.

Climate Change and the Sustainable Development Goals (SDG)

In September 2015, shortly before the Paris Agreement, a new development agenda comprising 17 Sustainable Development Goals (SDG) was adopted at the United Nations (UN) (United Nations 2016). Climate change and the SDGs are highly interconnected; not only is climate change mitigation explicitly stated as SDG #13, progress in socio-economic development may have strong implications for the prospect to mitigate climate change and vice versa, as discussed below.

Many sustainable development goals are directly related to economic development, like promoting sustainable economic growth and full employment (SDG #8), ensuring access to energy for all (SDG #7) and building up infrastructure and promoting industrialization (SDG #9). While the SDGs highlight that all this is supposed to be achieved in a *sustainable* manner, past experiences have shown that economic development has been closely linked to a surge in energy use (Schäfer 2005; Medlock III and Soligo 2001). Energy use, again, has historically been strongly correlated with carbon emission increases, as fossil fuel based energy carriers have served as affordable and abundant energy inputs (see, e.g., Richmond and Kaufmann 2006). In China as well as in other emerging economies economic growth has been the main driver for surging carbon emissions (Steckel et al. 2011). Pursuing both, the SDGs related to economic development as well as the SDG for climate change mitigation, will thus require a strong and soon-to-come break with historically observed relationships between economic development and energy use as well as energy use and GHG emissions. However, there seems little evidence that such a decoupling of economic growth from energy consumption and GHG emissions is likely in the near term (Ang 2008; Andreoni and Galmarini 2012). In contrast, while there may be a partial decoupling of economic growth and energy consumption for industrialized countries, most developing countries seem to follow the carbon- and energy-intensive path that developed countries have taken before (Jakob, Haller, and Marschinski 2012; Jakob et al. 2014). Progress in poverty reduction and rising income levels show high correlations with increases in GHG emissions, on the macro level as well as on the micro level (Seriño and Klasen 2015; Jakob et al. 2014). Moreover, research suggests that there may also be a certain trade-off between reducing inequality and decreasing GHG emissions (Ravallion, Heil, and Jalan 2000; Grunewald et al. 2011; Irfany and Klasen 2015). Climate change mitigation policies, increasing energy prices or restricting the use of cheap fossil fuels, may therefore be perceived as being in stark contrast to economic development and poverty reduction objectives. At the same time, economic development successes likely have adverse side effects on climate change mitigation. For reconciling development objectives and climate change mitigation, a profound transformation of energy systems towards low-carbon energy technologies would be necessary, requiring enormous investments in low-carbon energy infrastructure that developing countries are unlikely to be able to bear by themselves (Jakob et al. 2014). Moreover, a profound global rethinking in lifestyles and consumption patterns would be necessary to allow for increasing wealth levels without compromising climate goals.

While climate mitigation policies may negatively affect economic development prospects, unmitigated climate change will also have detrimental effects on livelihoods. Especially for developing countries, the impacts from climate change pose a severe threat as poor people are often more exposed to climate risks and more vulnerable, i.e. less capable of coping with impacts (Hallegatte et al. 2016). Moreover, climate change threatens past successes already achieved with respect to other major policy goals such as poverty reduction and sustainable development. Thus, a failure in mitigating severe climate impacts will also have strong implications on the prospects of achieving many other SDGs (von Stechow et al. 2016). The IPCC finds that climate change impacts will slow down economic growth, exacerbate poverty traps, negatively affect food security and create new hotspots of indigence (Field et al. 2014).

Also the choice of mitigation strategies and technologies will have different implications with respect to other SDGs (von Stechow et al. 2016). An analysis of von Stechow et al. (2016) finds that weak short-term efforts with respect to climate change mitigation lead to a low level of synergies that could be exploited while the danger of a lock-in of considerable trade-offs across environmental and socioeconomic SDGs is increasing significantly. Climate policy cannot be successful if interrelations with other policy objectives and sustainable development implications are not taken into account when designing climate mitigation measures (Fay et al. 2015). Treating the different dimensions of the SDGs in isolation will miss making use of potential synergies and likely fail in attenuating negative side effects. Considering the climate change problem in the broader context of other policy objectives is therefore not only about exploiting co-benefits to motivate individual climate change mitigation policies but also about becoming aware of and avoiding adverse side effects from insufficient climate action and mitigation policy choices. This needs to include considerations of potential constraints – low institutional quality, capacity constraints and financial constraints – that may prevail in developing countries, potentially rendering some policy options less feasible subject to the country context (Jakob et al. 2014).

1.3.4. The approach of the Paris Agreement

Despite general agreement on the urgent need for climate stabilization, achieving collective action has proven challenging. Confronted with the impossibility of agreeing on a global common climate change mitigation policy and the distribution of the remaining carbon budget among countries, the global community has agreed on paving the way for a new strategy based on a more decentralized approach: Intended Nationally Determined Contributions (INDCs)[20]. For the 21st Conference of the Parties (COP) in Paris in December 2015 160 INDCs had been submitted, representing the pledges for their contribution

[20] In preparation of the international climate negotiations in Paris in December 2015, countries have agreed to publicly determine national intended targets for GHG mitigation and describe the post-2020 climate actions they are willing to take under a new international climate agreement (World Resource Institute 2016b). After the Paris agreement enters into force, these INDCs may be referred to as NDCs (Nationally Determined Contributions) (Climate Policy Observer 2016).

towards climate change mitigation of 187 countries (including European Union member states).[21] In this respect, the Paris agreement is a hybrid approach combining bottom-up elements in form of the INDCs with top-down elements in forms of international coordination and stock-taking. Constituting a framework for very heterogeneous national pledges, the Paris Agreement thereby chooses a polycentric approach in contrast to a global approach. It also explicitly acknowledges the role of cities and subnational level initiatives, as well as other policy objectives (UNFCCC 2015). Moreover, the Paris Agreement has achieved to overcome the divide between Annex I and Non-Annex I countries. With 195 countries adopting the first universal agreement on climate change mitigation, the Paris Agreement has been called a historic milestone in climate diplomacy (Schellnhuber, Rahmstorf, and Winkelmann 2016). However, the most crucial steps for the Paris Agreement to be successful are still to come. It now has to be followed by the ratification through national governments and the implementation of national climate change mitigation policies. Moreover, current pledges probably fall short of the stated goal of 'well below 2°C'.

Already beforehand, the political challenge of ratification on the national level was manifest and strongly shaped the Paris negotiations. The legal status of the agreement and termini used where intensely debated to circumvent an expected blockage by the US senate. To enter into force the Paris Agreement requires the ratification or approval of at least 55 parties representing at least 55% of estimated global GHG emissions (UNFCCC 2015, article 21). Even after this critical threshold of ratification is reached and the agreement enters into effect, compliance with pledges is not per se guaranteed as freeriding incentives persist and international law lacks strong enforcement mechanisms. Though the Paris Agreement defines a periodical review and global stock-taking of the progress with respect to the implementation every five years, there are no measures foreseen in case of non-compliance (UNFCCC 2015). This means that the success of the Paris Agreement will crucially depend on national and subnational politics and incentives to comply voluntarily. Finally, though the global community has formally agreed on a climate stabilization target of even 'well below 2°C' in the Paris Agreement (UNFCCC 2015), this is not reflected by the sum of current pledges (Jeffery et al. 2015). Achieving the proclaimed target will thus necessitate not only compliance with current INDCs but also an intensification of efforts far beyond current pledges. Aligning the global goal with national willingness to contribute will also strongly depend on national incentives and politics. Experiences on barriers for climate policy implementation as well as determinants for unilateral climate policy can provide valuable insights for identifying potential trade-offs and synergies in national policy making with respect to putting pledges into action.

1.3.5. Politics matter - Understanding policy making and policy change

As policies need to be implemented on the national (and sub-national) level, the political decision making process within countries will be crucial for the success of the Paris Agreement. This section provides an overview on political theories for the policy making process and policy change.

[21] Assessment as of Dec 15, 2015 by Climate Action Tracker (2015). Meanwhile, in July 2016, 162 INDCs were submitted representing 189 countries (World Resource Institute 2016a).

Political decision making

Simplifying the essence of the very complex process, policy making can be described as a policy cycle with different stages, often referred to as 'Stages Heuristic', comprising Agenda Setting, Policy Formulation and Legitimation, Implementation and Evaluation (Sabatier 2007). This is again followed by a decision whether the policy should be maintained, modified or abandoned. In each stage a large variety of different actors influence the policy process within a country; Interest groups from industry or NGOs, legal institutions, governmental agencies at different levels, researcher, journalists, each potentially pursuing different interests and policy preferences. Though the process is in reality much more complex and less clear cut, with interactions of different policies and different stages at different levels of policy making, the Policy Cycle illustrates that many steps have to be taken on the national level to achieve a successful implementation of a policy, even after the problem has been identified to be urgent and important. For a global problem like climate change, the interaction of local level, national level and international level policy making further complicates the process. Gaining a better understanding of the policy making process may help to identify and prevent potential impediments or conflicts.

Several political theories and frameworks have attempted to understand and describe the determining factors and causal drivers of policy making (see e.g. Ostrom 2011; Sabatier 2007). Whether a topic manages to mobilize sufficient political resources to be pushed to the policy formulation and implementation stage depends on a variety of factors from voting cycles, to media coverage and information policy as well as the general structure and power of institutions and actors (Sabatier 2007).

Understanding policy change

Effectively mitigating dangerous climate change, however, would not only require incremental adjustments to the business-as-usual situation but rather a strong shift away from the status quo policy making in most countries, especially if pledges were intensified sufficiently to aim for the 'well below 2°C' target. This would necessitate fundamental policy changes touching upon many different policy areas. A number of different theoretical frameworks deal with describing how *policy change* can occur, especially which factors foster and which hamper policy change under given circumstances. In the following a selection of relevant frameworks are briefly presented. A more in-depth description can be found in e.g. Sabatier (2007).

The *"Advocacy Coalitions Framework"* (ACF) developed by Sabatier and Jenkins-Smith identifies policy subsystems consisting of actors from different public and private organizations sharing the active concern about a specific policy issue (Sabatier and Jenkins-Smith 2007). In these subsystems, actors form coalitions based on shared core beliefs - e.g. about the causes of the problem, ideas for solutions and fundamental socio-cultural values - coordinating activities in order to advocate their ideas. Policy change then happens through the coordinated activities by these 'advocacy coalitions' competing for attention and influence. Policy brokers trying to mediate the conflicts arising from different advocacy coalitions propose compromises, resulting in governmental programs and policy outputs. While the core beliefs uniting a coalition are relatively resistant to change, external events such as changes in socio-economic conditions, changes in the governing coalition or changes in other subsystems may induce coalitions to revise their beliefs and/or alter their strategy leading to policy change. Moreover, policy oriented learning by cognitive processing of experience over time or new information may lead to the revision of policy objectives and trigger minor policy change, i.e. confined to secondary aspects. However, major policy changes, i.e. changes in policy *core* aspects, mostly require perturbations external to the subsystem such as changes in socio-economic conditions or personal changes in the system-wide governing coalition according to the ACF theory (Sabatier and Jenkins-Smith 2007). As the ACF does not provide many insights on the conditions under which these external events finally lead to policy change, the ACF can be seen as rather describing the policy process than explaining policy change (John 2015).

The "*Punctuated Equilibrium Theory"* developed by Baumgartner & Jones focuses on large scale policy shifts (True, Jones, and Baumgartner 2007). According to the Punctuated Equilibrium Theory policy making is characterized by stability over long periods with only incremental changes to existing policies, as governing institutions have a tendency to maintain the status quo with conservative courts, resistance to new ideas and influential policy groups countering radical changes. However, occasionally, the system is interrupted by major alterations in form of external shocks (such as accidents, crises or elections) bringing about a short period of disruptive, drastic policy change. The Punctuated Equilibrium Theory assumes that policy makers are subject to bounded rationality being limited in time and resources and thus large scale change which would necessitate dedicating a certain amount of attention to a topic is hampered unless external events raise this attention. However, similar to the AFC, it remains unclear in this theory how and when these punctuations can occur and change can be triggered (Cerna 2013).

The *"Multiple Streams Framework"* by Kingdon (1995) examines policy choice in the presence of ambiguity, i.e. situations of ambivalence where circumstances can be perceived and interpreted differently, viewing the collective output as a result of the push and pull of several factors (Zahariadis 2007). Kingdon's approach describes policy choice based on the 'garbage can model' (Cohen, March, and Olsen 1972) where due to time and resource constraints preferences and knowledge of individual actors remain vague and decisions are taken subject to bounded rationality and opaqueness rather than rational arguments or optimization considerations. Kingdon identifies three streams that coexist in a system: problems, policies and politics. The problems stream contains conditions that have been identified as problems by policy makers. It relates to the question why the policy makers pays attention to specific issues while disregarding others. This may be due to routine monitoring reports or caused by dramatic events like crises, natural disasters or accidents. Not all conditions raising policy makers' attention are valued as problems by policy makers and not all actual problems receive political attention. Moreover, attention can shift away easily towards other issues as problems are competing for attracting interest. The policies stream contains different ideas for solutions that may have been proposed e.g. by researchers or ministry staff. Many of these ideas may be applicable to different problems and may have been combined or modified to new proposals while other proposals never receive serious consideration by policy makers. The politics stream reflects the national mood, lobbying campaigns and legislative or administrative turn over. Changes in public opinion or support as well as opposition from important interest groups can influence policy makers in their views. Turnover in important positions can strongly impact attention for and attitudes towards certain issues. Kingdon highlights that these three streams act more or less independently from each other. However, new attention to problems from the problems stream or specific events in the politics stream may open a "policy window" or "window of opportunity" that provides the opportunity for policy entrepreneurs to couple the streams and advocate for their preferred problem to be addressed or for their preferred policy to be adopted. These policy windows are usually of short duration and policy advocates - willing to invest time and effort - need to be persistent and skilled at coupling the streams by finding suitable problems to their preferred policy or suitable solutions to their problem and gaining support by others. These policy windows allow policy change to occur if either the triggering problem is matched to a feasible idea developed in the policy stream or a policy idea pushed forward by e.g. the newly elected government is matched to address a problem. If all three streams are coupled conditions for change are most favorable. Although Kingdon has proposed this framework primarily to explain agenda setting, Zahariadis extended it to explain policy formulation as well (Zahariadis 2007). The multiple streams framework is of particular interest for situations when policy making is characterized by high complexity, ambiguity and limited capacities for political attention.

Implications for climate policy

Each of the different frameworks may exhibit different strengths and weaknesses in explaining observed policy change in different country contexts and in providing insights on how policy change can be fostered. For decision making in complex democracies, which are characterized by open debates and transparency, the Advocacy Coalition Framework is a valuable tool to analyze the interactions of groups and actors involved in the process. In more authoritarian and less transparent regimes, often characterized by a smaller variety of actors and groups, potential coalitions and underlying motivations are less visible and the inclusion of non-political stakeholders in the decision making process might be rather limited. Decision making and policy making might be more determined by individual perspectives of the political elite acting as policy entrepreneurs pushing for specific problems to be addressed and specific solutions to be favored. Moreover, identifying advocating or opposing internal coalitions is more challenging if the variety of political parties is limited and transparency of decision making processes is low. For the case study on Vietnam (Chapter 3) we therefore decided that the Multiple Stream Framework seems most appropriate in reflecting the Vietnamese political context.

As a common feature all discussed policy change frameworks acknowledge that policy makers are subject to bounded rationality due informational and time constraints and limited resources. This implies that policies may often be chosen *not* because they are the most suitable or optimal (e.g. least-cost or most effective solution) to a specific problem from economic perspective, but because they benefited from the right mix of enabling conditions and had talented advocates to push for it. It also implies that policy makers may not be well aware of potential co-benefits or adverse side effects on other policy areas as they tend to focus on their area of expertise. Research can help to identify climate policy barriers, potential co-benefits and adverse side effects and inform policy making. This thesis attempts to shed light on the intricacy of climate policy making, bringing together economic aspects and political aspects of the different dimensions of climate policy. Moreover it aims to contribute to improving the understanding of challenges with respect to putting climate policy into practice, as well as identifying opportunities for fostering national incentives for action.

1.4. Objective and outline of the thesis

As discussed above, the Paris Agreement can only be seen as a very first step which needs to be followed by the approval by national governments and the implementation of suitable climate policies. The compliance with national pledges - and all the more the required strengthening of efforts that would be necessary for the stated 'well below 2°C' objective (UNFCCC 2015) – will crucially depend on national incentives and national policy making processes. Ambitious climate change mitigation will require strong shifts in current policy making and profound rethinking, affecting many policy areas and many other policy objectives. This thesis is dedicated to the challenges of national climate policy formulation and implementation, the politics of climate change and the role of non-climate objectives in incentivizing climate policy. Applying a variety of empirical methods, this thesis aims to contrast the theoretical perspective with observed empirical findings. In this respect, this thesis pursues two major objectives: First, to provide insights that contribute to our understanding of the real-world complexities of climate policy making and the associated interrelations with other objectives. And second, to draw implications from these empirical findings on how incentives for climate policy implementation may be fostered in the light of the Paris Agreement. The research of this thesis has been motivated by the following questions:

- How do real-world conditions affect the implementation of climate policy? Which factors hamper the implementation of climate policy, rendering mitigation more costly or less effective? Which impediments prevail at the different levels of decision making: at the level of governments, households and firms and at the market level?
- Which factors determine climate policy making? Which role do national politics and non-climate policy objectives play for the implementation of climate change mitigation policies?
- How can the necessary profound change in policy making be fostered? How can synergies between climate change mitigation and non-climate objectives be taken advantage of in order to incentivize climate policy implementation?

To answer these questions the thesis regards the climate change problem from different perspectives, viewing the issue through economic and political science lenses as well as from the perspective of both developing countries and industrialized countries. The analyses build on a variety of different (empirical) methodologies; conducting a conceptual review (Chapter 2), a policy analysis based on qualitative interviews with policy makers and other stakeholders (Chapter 3), and applying econometrics methods for dynamic panel data estimation (Chapter 4). A brief overview on the different chapters is provided in the following.

Chapter 2: Climate Policy in Practice: A Typology of Obstacles and Implications for Integrated Assessment Modeling [22]

The second chapter discusses in detail the different impediments to climate policy implementation that can render policies more costly or even ineffective. It proposes a typology for the analysis that differentiates between factors on the political level in setting the right incentives and choosing optimal policies, on the level of the households and firms in their response to the policies when putting emission reductions into action as well as on the level of markets distorted by several market failures and imperfections. This typology may serve well for policy makers in identifying potential impediments and considering them for policy formulation and implementation, as illustrated by a brief application to the case of China. In this light, the chapter reviews common model assumptions and assesses the capability of Integrated Assessment Models (IAMs) to reflect these real-world impediments. Finally, it discusses implications with respect to policy making and the interpretation of model results.

Chapter 3: What motivates Vietnam to strive for a low-carbon economy? - On the drivers of climate policy in a developing country [23]

The third chapter identifies and analyzes the different factors that have shaped the formulation of the Vietnam Green Growth Strategy and other climate-related strategies and policies recently launched in Vietnam. Historically strongly emphasizing its status as a Non-Annex I country exempted from international emission obligations, this represents a shift in Vietnam's positioning from an adaptation focus towards voluntary mitigation action. Based on qualitative interviews with a variety of different Vietnamese policy makers, staff from development agencies active in Vietnam and other stakeholders, we conduct a policy analysis discussing the factors that determined this policy change in Vietnam and the role of other policy objectives in motivating and shaping Vietnam's national and international climate policy.

Chapter 4: Fuel consumption dynamics in Europe -Implications of fuel tax reforms for air pollution and carbon emissions from road transport [24]

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[22] This chapter (postprint version) has been published in a Special Issue of *Climate Change Economics:* Staub-Kaminski, I., Zimmer, A., Jakob, M. & R. Marschinski (2014): Climate Policy in Practice: A Typology of Obstacles and Implications for Integrated Assessment Modelling. *Climate Change Economics*, Vol. 5, No. 1, DOI https://doi.org/10.1142/S2010007814400041.

[23] This chapter (postprint version) has been published in *Energy for Sustainable Development*: Zimmer, A., Jakob, M. & J. Steckel (2015): What motivates Vietnam to strive for a low-carbon economy? - On the drivers of climate policy in a developing country. *Energy for Sustainable Development*, Vol 24, pp.19–32. DOI https://doi.org/10.1016/j.esd.2014.10.003. Moreover, the article has been awarded with the *Amulya K.N. Reddy Prize - Best Paper Award 2014*.

[24] A revised version of this chapter has been published in *Transportation Research Part A*: *Policy and Practice* as Zimmer, A. & N. Koch (2017): Fuel Consumption Dynamics in Europe - Tax Reform Implications for Air Pollution and Carbon Emissions. *Transportation Research Part A: Policy and Practice,* Vol 106, pp. 22-50, DOI https://doi.org/10.1016/j.tra.2017.08.006. The chapter included in this thesis is the preprint Working Paper, downloadable at https://ssrn.com/abstract=2813534.

The fourth chapter focuses on the role of the road transportation sector in Europe and the potential of fuel taxation policies in reducing negative externalities from fuel consumption. Using a panel of 16 European countries, we conduct an econometric analysis of fuel consumption behavior by applying a variety of different dynamic panel data estimators. Accounting for the dieselization observed in Europe, hitherto hidden dynamics in fuel consumption and potential price endogeneity, we estimate the fuel consumption elasticity of both petrol and diesel consumption with respect to pricing policies. Based on these econometric results, we assess the potential for curbing carbon emissions and health damaging air pollutants of two policy scenarios: i) ending diesel tax breaks and ii) introducing a carbon tax of 50€/tCO_2. We moreover assess how these fuel taxation reforms could contribute to achieving EU climate policy targets.

Chapter 5 summarizes and discusses the insights from this thesis.

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Chapter 2

CLIMATE POLICY IN PRACTICE: A TYPOLOGY OF OBSTACLES AND IMPLICATIONS FOR INTEGRATED ASSESSMENT MODELING[1]

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CLIMATE POLICY IN PRACTICE: A TYPOLOGY OF OBSTACLES AND IMPLICATIONS FOR INTEGRATED ASSESSMENT MODELING

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Abstract:

The implementation of mitigation policies will be complicated by several real-world imperfections ("second-best conditions") and constraints typically not included in the more idealized economies assumed in Integrated Assessment Models (IAMs), based on which such policies are derived. But which of these numerous imperfections found in real economies are actually relevant in this context? And how could they —in principle —be taken into account by IAMs? Based on a literature review, we propose a typology of three categories of obstacles inhibiting "first-best" conditions and outcomes: first, obstacles impeding the setting of least-cost abatement incentives; second, obstacles limiting the supply and exploitation of abatement options; and, third, obstacles creating distortions between the price and marginal costs of abatement. By reviewing the implementation of energy policy in China, we put our typology into practice and identify specific empirical evidence for each category. IAMs in principle can (and in practice often do) incorporate several relevant obstacles by means of additional cost or quantity constraints. However, the nature of some obstacles relating to strategic interactions between economic agents appears to be incompatible with the standard representative agent social-planner framework often employed in IAMs, suggesting a need for complementary analysis with decentralized "Integrated Policy Assessment Models".

Keywords: Climate policy; barriers; second-best; climate change mitigation; Integrated Assessment Models.

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2.1. Introduction

Scenarios play a central role in the current discussion on the design of climate policies. These scenarios depict possible future developments, e.g., the transformation of the global energy system or changes in land use patterns, under different assumptions, such as future rates of population and economic growth, or availability of fossil fuels and technologies (van Vuuren et al. 2011). As far as the implementation of policies to reduce greenhouse gas (GHG) emissions is concerned, it is frequently assumed that there is only one market failure – namely the environmental externality – that is internalized by an optimal policy. An example is a universal emission price covering all countries and economic sectors, set to its welfare maximizing value at each point in time. Hence, these scenarios usually – at least implicitly – consider the problem of climate change within a so-called "first-best" economy where frictionless markets produce an outcome identical to the social optimum that would be achieved by a fully informed benevolent social planner.

However, economic theory has shown that in order for an economy to behave in such an ideal way, a number of formal prerequisites must be met (e.g. Arrow and Debreu 1954). They are closely linked to those stated in the fundamental welfare theorems, which describe how and when a socially optimal state of the economy can be reached by means of a competitive equilibrium. These conditions, along with some of their implications, are listed in Table 1.

Assumptions	Implications
Consumers with standard utility functions	*Homo oeconomicus* paradigm: rationality, time-consistency, no social interaction. Consumers can be modeled as one representative agent
Complete markets	Fully defined property rights (i.e. no externalities); prices for all goods including forward-looking prices (i.e. perfect financial markets)
"Free" markets	No distortionary taxes or subsidies: all regulation only to protect property rights and ensure functioning of markets; costless lump-sum transfers of tax revenues; no public cost of finance
Complete information	Information on all prices and all technologies is available to all actors, no actor with informational 'advantage'
No transaction costs	Actors can freely exchange all goods and services, markets perform without costs
Competitive (price-taking) behavior of all firms and consumers	No strategic behavior; producers equate marginal costs to market price
Full mobility and flexibility of production factors	Always full employment of all production factors
Perfect foresight[2]	No uncertainty, e.g. learning curves of all low-carbon technologies known
Convex production technologies	Unique economic equilibrium, ruling out e.g. carbon lock-in

Table 1: Conditions characterizing first-best economies and their implications

[2] It should be noted that "perfect foresight" does not constitute a first-best requirement in the strict sense, as agents with rational expectations operating in complete future markets can still reach the efficient social planner outcome. However, in a broader sense the lack of foresight can still be considered a real-world imperfection, as it necessarily increases costs vis-à-vis the idealized deterministic case, e.g., when future learning rates of different mitigation technologies are not known today.

These strong conditions are generally judged to be in poor correspondence with reality (Stiglitz 1996). That is, distortions such as external effects (Pigou 1920), imperfect competition (Robinson 1961[1933], Chamberlin 1933), and missing markets and transaction costs (Coase 1960) have long been identified as reasons for why markets may fail to deliver a socially optimal outcome. More recently, issues such as asymmetric information (see Stiglitz 2000 for an overview) or seemingly "irrational" individual behavior (Simon 1955, Kahneman 2012) have been recognized to further undermine their efficiency. As a consequence, the term "second-best setting" is used whenever a given economy does not satisfy one or more of the conditions from Table 1, as opposed to the idealized first-best case.[3]

In a second-best setting, markets will lead to suboptimal outcomes and thus cannot be characterized by standard social-planner solutions. More importantly, second-best economies cannot be expected to adjust *optimally* to an exogenously imposed emission or temperature constraint, since this would require, amongst other things, well-functioning innovation markets (for low-carbon technology[4]), and perfect competition in energy markets. In other words, relative to a first-best analysis the actual economic costs for implementing a given climate policy will likely be higher.[5]

For assessing climate policies, therefore, a second-best setting explicitly taking into account additional obstacles that might make climate policy more costly or more difficult to be achieved can be regarded as an appropriate framework, as emphasized by Kriegler et al. (2012, p. 816): "[a]nalyses of climate policy need to take into account existing market failures in the economic system and cannot assume an ideal world in which markets would be complete and perfect".

Following up on this, the present study aims to make a contribution by establishing a typology of obstacles to climate change mitigation found in the literature and discuss its relationship to integrated assessment models (IAMs) used to generate climate policy scenarios. By doing so, we seek to combine two existing strands of research: literature on observed real-world obstacles to least-cost emission reduction and studies on the empirical and conceptual limitations of IAMs.

Research of the first area has mostly focused on barriers to energy efficiency (Hirst and Brown 1990, DeCanio 1993, Jaffe and Stavins 1994, Weber 1997, Sorrell et al. 2000, Sorrell et al. 2011) and diffusion of renewable energy (Reddy and Painuly 2004, Owen 2006, Sovacool 2009). Hirst and Brown (1990) divide barriers into structural barriers, beyond the control of the individual end-user, and behavioral barriers, that influence the decision making of the end-user. DeCanio (1993) highlights bounded rationality, principal-agent problems, and moral hazard as major reasons explaining the divide between theoretical and actual energy use. Jaffe and Stavins (1994) distinguish between market failure explanations, which could justify a government intervention, and non-market failure explanations, which depict the observed behavior as optimal from energy users' point of view. Weber (1997) groups barriers into institutional, economic, organizational, and behavior barriers, while Sorrell et al. (2000) categorize them as market, organizational, and rational behavior

[3] In reference to the seminal work by Lipsey and Lancaster (1956).
[4] Note, e.g., the telling title "A tale of two market failures: technology and environmental policy" chosen by Jaffe et al. (2005).
[5] In theory it is also possible that the implementation costs of climate policy are reduced by the presence of certain imperfections, namely when climate policy implementation allows for (partial) removal of these imperfections. This 'double dividend' effect might occur, e.g. when carbon tax revenues are used to lower distortionary labour market taxes (see, e.g., Goulder 1995).

barriers. Sorrell et al. (2011) provide a taxonomy of barriers and explain them from orthodox economics and transaction cost/behavioral economics perspectives. Reddy and Painuly (2004) differentiate between lack of awareness and information, economic and financial constraints, technical risks, institutional and regulatory barriers, market failures/barriers, and behavioral barriers. Owen (2006) focuses on market barriers that are either intrinsic features of markets or arise because of market failures. Sovacool (2009) divides obstacles to energy efficiency and renewable power in financial and market impediments, political and regulatory obstacles, cultural and behavior barriers, and aesthetic and environmental challenges. Finally, Finally, literature describing how technical innovations come about and are incorporated into society has assessed drivers and barriers of past technology transitions and possible shapes of future decarbonization pathways (see i.e., Anderson et al. 2005, Geels 2012, Ulmanen et al. 2009). As one example, Unruh (2000) widens the scope of previous studies, which are mainly focused on obstacles at the micro level, by exploring larger macro-level forces that can lead to a “carbon lock-in” of the economy into fossil-fuel based energy systems.

Various studies on the limited ability of IAMs to reflect above-mentioned real-world characteristics in their estimates of mitigation costs have been carried out (Ackerman et al. 2012, Ackerman et al. 2009, Stanton et al. 2008, van der Zwaan and Seebregts 2004). However, they tend to be mostly model-specific or only focus on specific aspects (e.g. Ackerman et al. 2012, Ferioli et al. 2009, van der Zwaan and Seebregts 2004). However, relatively few discuss limitations of IAMs from a broader perspective. Among those is Ackerman et al. (2009), who critically explore the use of IAMs in cost-benefit analysis. Stanton et al. (2008) analyze 30 existing IAMs and highlight several key shortcomings found in many of them, mostly regarding their representation of uncertainty about technological change and climate outcomes, as well as equity across time and space.

In this contribution we go beyond the existing literature by describing various types of obstacles and their modeling implications within one consistent framework. We also extend the scope of analysis from ‘pure’ second-best conditions (in the strict economic sense) to include all relevant obstacles and constraints undermining least-cost implementation of climate policy, like, e.g., the potential difficulties of some countries to establish and enforce a unique price on GHG emissions throughout all sectors of their economy. Our study will be of special importance for large emerging economies, such as China and India, where obstacles to least-cost climate policies can be expected to be prevalent. At the same time, due to their large populations and rapid economic growth, these countries play a central role in reducing (or slowing the growth of) global emissions.

The remainder of this paper proceeds as follows: Section 2 discusses potential obstacles to least-cost climate change mitigation and proposes a typology that classifies them as (i) impediments to formally establish least-cost climate policy, (ii) obstacles to the availability and efficient utilization of abatement options, and (iii) imperfections in markets for abatement, technology, and capital. Section 3 illustrates the empirical relevance of these obstacles for the case of China, currently the world’s top emitter of CO_2. Section 4 discusses the relationship of these obstacles to IAMs and whether (and how) they could be incorporated in future modeling work. Section 5 concludes.

2.2. Real-World Obstacles to Mitigation Policy: Theoretical View and Typology

Based on a literature review, this section proposes a typology of real-world obstacles to climate policy. We define an obstacle (or barrier) to climate policy as any circumstance that makes a given economy-wide emission target more costly to achieve than would be expected in a full information and frictionless first-best economy. The latter serves as a benchmark setting that is characterized by policy designs reflecting all relevant costs, policies being perfectly implemented and enforced, and all actors responding to these policies in a way that collectively leads to the socially optimal outcome. In what follows, we discuss 'real-world' barriers within a typology that categorizes obstacles as being related to the demand- or supply-side of abatement, or to market distortions. Its design was guided by the objective to accommodate all obstacles in a plausible manner, and to provide a useful structure in the context of economic modeling.

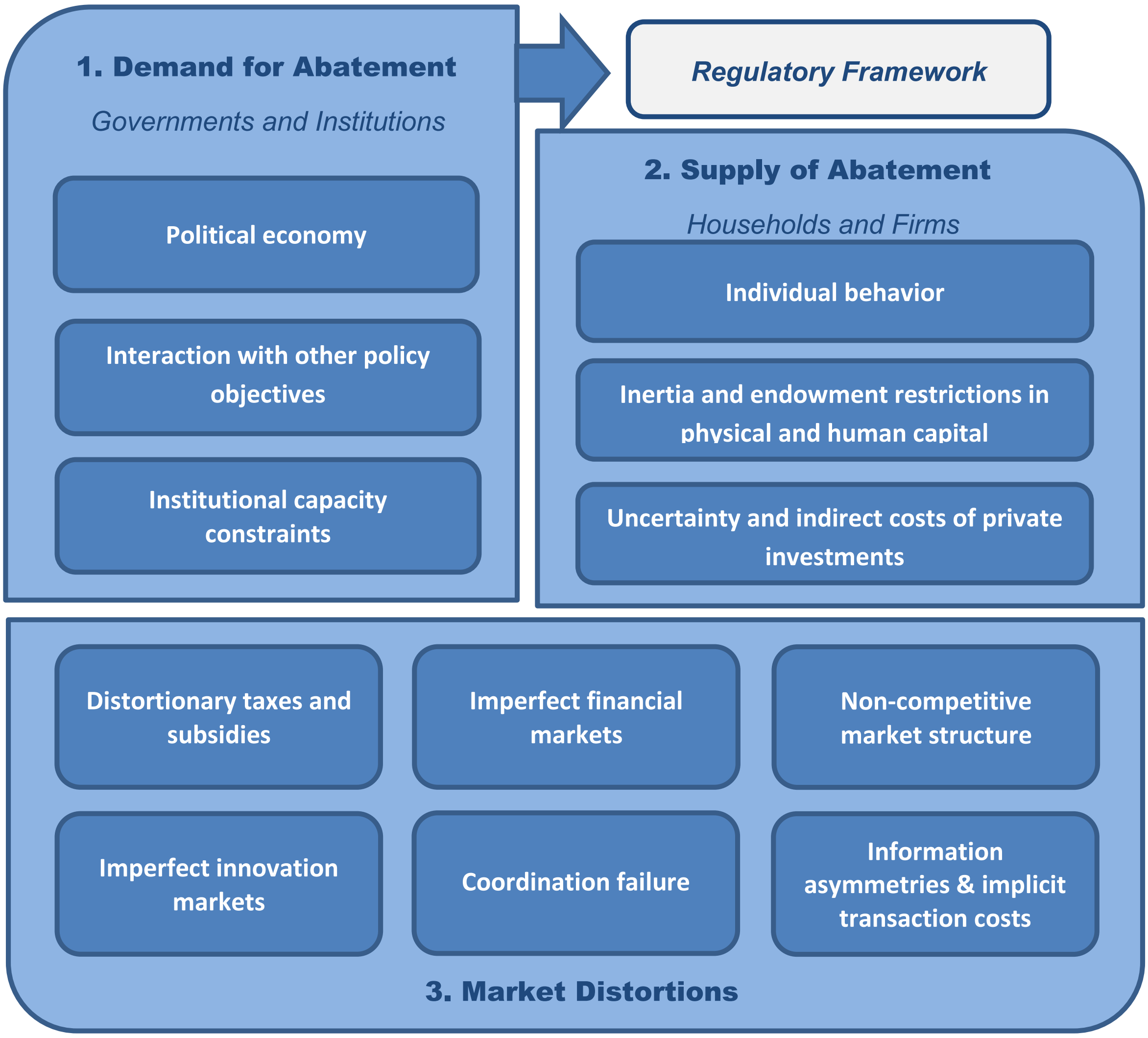

Figure 1: Overview of typology of obstacles to least-cost climate policy

This categorization necessarily exhibits ambiguities, as different obstacles may be interrelated and hence mutually affect each other. Moreover, as for the sake of comprehensiveness we discuss a large number of heterogeneous obstacles at a highly aggregated level (in line with the high level of aggregation typically found in IAMs), we must neglect details such as technology or actor-specific manifestations of different barriers, or idiosyncratic social processes such as collective-learning. Though it is impossible to claim completeness, we believe that our typology is capable to accommodate a broad range of different obstacles found in the literature (or potentially identified in the future), thanks to its quite general demand-supply-market framework. Figure 1 illustrates the three main categories of our typology and the specific obstacles discussed below.

2.2.1. Obstacles on the demand side for abatement: Impediments to implementing least-cost climate policy (Category 1)

Idealized economies in which markets produce socially optimal outcomes typically consist only of exchanges between consumers and producers, assuming that all externalities are internalized by appropriate policies. In reality, however, the implementation of emission targets requires a national government and institutions that must first design, pass, and enforce appropriate climate policy measures, like emission pricing or mandatory standards, in order to signal demand for abatement to households and firms. Furthermore, theory mostly assumes welfare maximizing governments that represent social demand for abatement adequately in their policies.

In view of this, our first category covers obstacles rooted in institutional or political circumstances that explain why policy makers might fail to establish an efficient GHG pricing (or shadow pricing by means of other forms of policy) over all sectors of the economy and over time.

Political economy

Contrary to what is implicitly assumed in a first-best world, governments or other regulating entities may not pursue social welfare as their primary objective (Grossman and Helpman 2001). Indeed, policy-makers and officials can be expected to work towards their own personal objectives, such as re-election, or increasing personal income. This may well have an impact on the design of emission policies, causing them to be more costly than would be expected under first-best conditions.

First of all, politicians facing re-election might be unwilling to implement policies that would be optimal from a social point of view, but are unpopular within important voter groups (Cremer et al. 2008). In the case of climate change, pricing emissions means that overall costs for producers and consumers rise, thereby reducing their perceived income. As a consequence, policy makers confronted with voters' potential resistance against higher energy and fuel prices may be hesitant to implement policies in an efficient way, and will perhaps rather resort to policies with higher costs, like renewable subsidies or energy efficiency standards. Furthermore, there might be a tendency to shift unpopular policy measures into the future, e.g. by taking on laxer reduction targets now but promising stronger ones for the next legislative period, which means that future prices will have to be higher than their inter-temporally efficient level.

Moreover, lobbying from minority coalitions, that bear a large share of the costs of a policy, can influence the policy outcome at the disadvantage of the general public interest (Olson 1982). Lobbying from coalitions of key industries has often been found to block necessary regulations or influence them in inefficient ways: e.g. the German car producers lobbied successfully against efficiency standards by depicting them as threats to German jobs (Greenpeace 2011); similarly, it is generally assumed that the first phase of the European Union (EU) Emissions Trading Scheme (ETS) suffered from an inefficient sharing of the overall reduction burden between ETS and non-ETS sectors, arguably due to successful lobbying efforts by industries included in the EU ETS (Ellerman et al. 2010).

Finally, the inability of most political systems to credibly commit to a long term policy that cannot be reversed by successors, e.g. due to electoral cycles or general political instability, leads to a lack of planning security (see also section 2.2) from the private investors' point of view (Brunner at al. 2012).

Interaction with other policy objectives

Analyzing climate change within a first-best context means that the only problem under scrutiny is the emission externality. In reality, the compliance with emission targets will be only one among a range of social objectives of public policy. Poverty reduction, economic growth, and energy security constitute important goals of their own right, which are usually not reflected by market prices in the second-best setting. Hence, they can alter the optimal mitigation policy and increase mitigation costs.

For example, striving for poverty reduction and economic growth often leads governments to keep energy prices artificially low, which raises market entry barriers for low-carbon technologies and slows down their diffusion (Schmidt and Marschinski 2009). In the same vein, several studies have emphasized the potentially adverse effects of increasing energy prices on the poorest segments of the population (Rao 2012). If financial redistribution to compensate this effect is not feasible ("lump-sum recycling"), e.g. in developing countries with weak institutions, policy makers might resort to more costly indirect policies, like energy efficiency standards or intensity targets.[6]

Pointing in the opposite direction, the decentralized, low-scale, and off-grid nature of most renewable energy technologies that eases energy access in remote areas can make their deployment politically more attractive, especially in developing countries. The same argument holds if energy security is a national concern and countries want to reduce their dependence on imported fossil fuels. However, a potentially high share of renewables in the overall mitigation portfolio may actually lead to additional monetary costs vis-à-vis the least-cost mitigation strategy derived from first-best analysis even though it may increase welfare.

Finally, some low-cost abatement options might not be used due to their lack of social acceptance. Examples include controversial high-risk technologies like Carbon Capture and Storage (CCS) and nuclear power, but also biofuels, which have been criticized for their impact on food prices (Mitchell 2008), or large hydropower projects due their perceived negative impacts on ecosystems (Zoellner et al. 2008).

[6] E.g. China has adopted a voluntary intensity target in 2009 (Stern and Jotzo 2010), arguably as a means to pursue an emissions reduction policy without endangering economic growth. The efficiency of intensity targets, however, is contested (Marschinski and Edenhofer 2010).

Institutional capacity constraints

Regulation incurs no costs and compliance is taken for granted under first-best conditions, assuming enforcement and its implied institutional prerequisites and costs are not an issue. But the successful implementation of any policy crucially depends on the capacity of institutions. Lack of financial means, insufficient number, or inadequately trained staff can be major obstacles to the successful establishment of climate policy (Willems and Baumert 2003).

For example, securing the financial and human capital for adequate monitoring is a great challenge for institutions in developing countries. Weak economic conditions may also increase the incidence of corruption, which is a significant problem especially in developing countries (see ,e.g., Olken and Pande 2012, or Transparency International 2012). Sometimes institutions are expected to fulfill duties they were not originally designed for, e.g., the monitoring of renewable energy policies (GNESD 2007). Moreover, regulators may also suffer from constraints in time and skills as well as uncertainty, making it unlikely that regulation dealing with a highly complex issue like GHG emissions is always designed efficiently (Goulder and Parry 2008).[7]

Finally, for some sectors or particular GHGs the transaction costs associated with their regulation (e.g. monitoring) may be prohibitively high, justifying the use of simplified and less cost-effective policies (e.g. fuel efficiency standards instead of emission-measurement for cars) or even their complete exemption from regulation (Goulder and Parry 2008). This will generally be ignored in first-best contexts, where administration costs are assumed to be negligible.

2.2.2. Obstacles on the supply side of abatement: Limited provision and exploitation of mitigation options (Category 2)

In a first-best setting, it is assumed that firms and consumers respond to the price signal of a given climate policy by optimal technology adoption and cost-minimizing changes in consumption patterns. However, several mitigation options have remained unused although they would be cost-effective even in the absence of climate policy (e.g. McKinsey 2009, Jaffe and Stavins 1994, Hirst and Brown 1990, Backlund et al. 2012). These unexploited “no regret” options clearly contradict the cost-minimization objective of a stylized rational agent (see, e.g., Maréchal 2007). In light of this, the present category collects reasons why households and firms might not react to a price signal as anticipated, i.e. why the supply of abatement falls short of what would be expected in a first-best world.

Individual behavior

The model of perfectly rational economic actors outlined in the introduction assumes an optimization process behind every decision. But in reality, actors are limited in their capacity to grasp the complexity of every decision, i.e. they are subject to bounded rationality (see, e.g., Kahneman 2003). Especially day-to-day decisions are highly routinized and rather based on

[7] Inadequate institutional coordination might also lead to inefficiencies, which is a relevant issue for many developing countries, where policy initiatives are often driven by development aid, but without proper coordination between different donor-backed projects (see, e.g., WGBU 2012).

heuristics than on complex optimization assessing all options (Gigerenzer 2008). This frequently results in irrational decision-making, e.g. a 'status-quo bias' by which individuals resist change even if it would leave them better off (Kahneman 2012).

In a similar vein, accustomed consumption patterns or a negative societal attitude against specific technologies might counteract seemingly economically rational behavior[8]. A perception of new technologies as inferior to conventional ones for reasons other than efficiency or costs induces indirect costs due to which low-cost abatement potentials might not be exploited. For instance, a high valuation of convenient, low-effort solutions, or the perceived costs for overcoming settled habits influence individuals' motivation to act. This is, e.g., confirmed by a study concluding that the main challenge for renewable energy technologies consists in "changing attitudes" (GNESD 2007, p. 20).

Finally, decision-making is not simply an individual choice, but also guided by the social environment and cultural influence (see, e.g., Maréchal 2007). In this context, status consumption – i.e. evaluating personal consumption against the consumption of others – can be expected to be relevant (Howarth 2000). That is, even if lowering consumption in favor of increased leisure or higher environmental quality would be collectively rational, each individual has an incentive to strive for higher levels of consumption in order to improve his or her relative position in society (Hirsch 1977, Frank 2005).

Inertia and endowment restrictions in physical and human capital

Idealized economic models often assume that production factors are perfectly mobile across sectors such that they can easily be redeployed in reaction to a changing policy environment. Some capital stocks, however, exhibit considerable inertia when old capital stock needs to be retired, which leads to delay or additional costs. Empirical evidence suggests that especially companies in developing countries often have low turn-over rates so that a replacement of existing equipment will take very long (UN-Energy 2009).

Significant investments in human capital will likely be needed in many countries in order to provide the skills necessary to develop, adopt, run, and maintain certain abatement technologies. Consequently, a lack of specialized workforce constitutes a serious obstacle, especially in developing countries (UNIDO 2011, Beck and Martinot 2004). The lack of commercial or marketing skills is likely to further obstruct the dissemination of low-carbon technologies (GNESD 2007), which can result in delayed response or additional costs.

Finally, the endowment with natural resources can have a considerable influence on countries' development patterns. While in theory such endowments should not matter (i.e. assuming that they can be traded at market prices), trade frictions and political economy motives often favor their domestic use over export. A salient example is the combination of coal abundance and energy-intensive industries in South Africa, sometimes described as a 'minerals-energy complex' (Fine and Rustomjee 1996). Consequently, a development model centered on energy-intensive industries can give rise to a 'carbon lock-in' (Unruh 2000) that would require a shift in the structure of industrial

[8] Utility is typically assumed to be derived only from consumption of goods, while in reality many other factors such as health, political stability, or time spent with family also contribute to household utility and therefore influence consumption patterns.

activity in addition to a transformation of the energy system to achieve GHG mitigation at least costs.

Uncertainty and indirect costs of private investments

Cost-efficient abatement requires substantial long-term investments in low-carbon technologies as well as R&D (see Bowen et al., this issue). Uncertainty about future prices of fossil fuels or electricity as well as future climate regulations represent a risk for the profitability of investments with a long time-horizon, which may be further exacerbated by the immaturity of new technologies (WGBU 2012). Regular changes of political power and programs due to, e.g., electoral cycles or general political instability, imply a need for costly flexibility in order to deal with potential adjustments in emission policies. I.e., firms incur additional costs and will defer some low-carbon investments because policy makers cannot credibly commit to a long-term emission price trajectory (see Section 2.1). In developing countries high exchange rate volatility, fluctuations in inflation rates as well as political instability can additionally boost investment risks significantly (UNIDO 2011). As a consequence, individual investors may require a risk-premium above the one that would be socially optimal, potentially resulting in significant underinvestment, as seen, e.g., in the case of industrial energy efficiency measures (UNIDO 2011).

High up-front investment costs can further discourage cost-effective investment decisions (Beck and Martinot 2004), especially in combination with imperfect financial markets (see Section 2.3), e.g. if credits have to be repaid before initial costs have been fully amortized (WBGU 2012). Moreover, investment can be accompanied by indirect costs that investors will likely price in, such as disruptions in production process or reduction of quality or productivity due to new equipment (Hirst and Brown 1990). In some cases this is even observed to be resulting in investments in inefficient and costly stand-by power systems that favor reliable power supply over reduced production costs (UNIDO 2011, Mathy and Guivarch 2010). Perfectly functioning insurance markets (see Section 2.3) could attenuate these problems, but additional costs for the insurance against the risk would arise.

Finally, investment decision may be negatively affected by the complex web of regulations investors are confronted with, such as restrictions on the siting and construction of renewable energy parks which have been imposed for other motivations, e.g, nature conservation or security (Beck and Martinot 2004). Similarly, local initiatives opposing the construction of, e.g., a wind park or a nuclear power plant in their region (‘NIMBY’) can provide disincentives for investors (van der Horst 2007).

2.2.3. Market distortions: Wedge between emission price and marginal abatement costs (Category 3)

In a first-best world the marginal costs of abatement are equal across all sectors of the economy (also across all GHGs) and correspond exactly to the permit price that would emerge in a decentralized cap-and-trade scheme. But this is true only if prices correctly reflect costs. Real economies exhibit distortions that drive a wedge between the two, implying that in some sectors costs will be above and in others below the efficient level. Hence, our third category captures market imperfections that put a wedge between marginal abatement costs on the supply side and the price for emissions set by the policy (demand) side.

Distortionary taxes and subsidies

The efficiency of markets may be undermined by distorting policies, like subsidies or price regulation. Estimated global fossil fuel subsidies amounted to USD 409 billion in 2010, of which a large share was granted in emerging and developing countries (IEA 2011). Fossil fuel subsidies put low-carbon technologies at a competitive disadvantage, and encourage inefficient use of resources. As a consequence, the lack of financial incentives given by governments constitutes a major barrier to efficiency improvements, as confirmed, e.g., by surveys in Asia (UNEP 2006). In terms of climate policy, fossil fuel subsidies imply that a higher emission price is needed to reach a given target and that, in addition, the relative abatement shares of fuel-switching, energy efficiency, and non-CO_2 options become distorted.

Although fossil fuel subsidies constitute the best known example, they are not the only relevant pre-existing price distortion. For instance, Goulder et al. (1997) identify 'tax interaction effects' of emission pricing that may exacerbate negative welfare effects from pre-existing distortionary taxes on production factors, e.g. labor taxes, and thereby significantly raise the costs of environmental policy compared to the first-best case.

Imperfect innovation markets

Innovation, especially in low-carbon technologies, is a necessary precondition for cost-effective climate policy. However, it is well known that the private sector suffers from the imperfect appropriability of innovation efforts (externality in the form of 'knowledge spillovers'), leading to a general underinvestment in R&D (Jaffe 1986; Jaffe et al. 2005). To some extent this adverse effect may be ameliorated by temporarily protecting 'intellectual property', i.e. by costly patent systems. However, for developing countries adjustment of existing technology to country specific conditions may actually be the more relevant aspect, a costly process that typically cannot be protected by patents. Imitators will diminish the return on investment of a successful domestic first-mover. Consequently, the laissez-faire situation will be characterized by under-investment in technology adoption and development (Hausmann and Rodrik 2003).

Imperfect financial markets

A least-cost implementation of climate policy implies that all investments that are profitable under a given emission price will be undertaken. The lack of access to capital hence becomes an important second-best condition (Ekholm et al. 2013). For example, companies often report problems in obtaining credit for energy efficiency measures (UNIDO 2011). But also households and small businesses – especially in developing countries – can face credit constraints and may hence be unable to finance improvements with a positive payoff because of their lack of collaterals and savings (GNESD 2007). Additionally, financial institutions may be reluctant to finance renewable energy projects due to the lack of experience and specific historical data needed to estimate the involved risks (WGBU 2012). As a consequence, it becomes difficult for project developers to obtain funding on the private capital market at reasonable interest rates, implying a suboptimal low level of such investments under a given emission price.

This is further exacerbated if insurance markets[9] are under-developed and lack suitable financing tools that would allow investors to hedge against the market risk associated with relatively immature low-carbon technologies. If this risk has to be fully borne by the individual investor, it will further discourage socially desirable investments.

Coordination failure

The diffusion of certain new technologies may depend on the simultaneous action of several different market participants, i.e. it requires coordination. This is the case, e.g., for the switch to alternative fuel vehicles: as long as the density of stations providing alternative fuels is low, consumers will be hesitant to purchase such cars. But if the demand for alternative fuels stays low, the economic incentives to expand coverage of such fuelling stations is also low (Corts 2010). This obstacle is known in different variations as ‘chicken-and-egg-problem’ (Corts 2011), path dependency, or lock-in phenomenon (Unruh 2000, Acemoglu et al. 2012).

A related inefficiency arises when the agent that bears the costs of an investment does not also reap in the economic benefits of it. E.g. a landlord has low incentives to insulate an apartment building as it is mainly the tenants who profit from lower heating cost (Jaffe and Stavins 1994, WGBU 2012). Finally, also firms may suffer from coordination failures if split responsibilities between departments prevent the implementation of energy efficiency measures (Backlund et al. 2012, UNIDO 2011).

Non-competitive market structure

Competitive behavior of firms and free entry to markets should in theory ensure that prices reflect production costs, a prerequisite for the efficiency of markets. In a first-best setting firms are atomistic, and hence cannot exert any influence on prices or other firms, but under more realistic assumptions the existence of large firms able to act strategically must be acknowledged, and the ensuing loss of efficiency be taken into account.[10]

Due to their particular characteristics (high upfront infrastructure costs, grid-based distribution), markets for final energy, especially electricity and gas, exhibit a natural monopoly structure. For instance, even in Europe where considerable efforts to liberalize markets have been made in the past, all except seven countries out of the EU27 have highly concentrated electricity markets (EC 2010).

As a consequence, market entry barriers for competitors might be significant. For example, grid-owning companies may not grant grid-access to suppliers of renewable energy (Beck and Martinot 2004). Furthermore, there may be a lack of incentives for investing in the modernization of grids needed to accommodate high shares of intermittent renewable sources, or to expand the grid, e.g., to areas of elevated solar radiation (see, e.g., Pegels 2010).

Information asymmetries and implicit transaction costs

The first-best assumption of complete and costless information has repeatedly been criticized in the economic literature (e.g. Grossman and Stiglitz 1980).

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[9] see, e.g., chapter 5 in Dlugolecki et al. (2009) for an analysis on insurance market failures.
[10] See, e.g., Hahn (1984) or Requate (1993).

The interaction between government and firms constitutes an example where asymmetric information undermines efficiency. As governments or other regulating entities may not have sufficient information about mitigation potentials and costs of firms (e.g. in different sectors), they may fail to implement the optimal least-costs policy (Laffont and Tirole 1993). For example, firms may use their informational advantage by overstating their true abatement costs in order to trigger regulatory adjustments (Harstad and Eskeland 2010).

Low awareness of saving potentials can also be a significant barrier to energy efficiency measures (see, e.g., UNIDO 2011 or Jaffe and Stavins 1994) and the deployment of low-carbon technologies (see, e.g., GNESD 2007). Individuals usually do not have sufficient information to attribute expenditure shares to each single device used (Hirst and Brown 1990). Similarly, firms are often not aware of technical possibilities and saving potentials (WGBU 2012). Therefore, high transaction costs for obtaining and evaluating relevant information may render seemingly cost-effective investments – expected to occur under first-best conditions – unprofitable.

2.2.4. Applicability of typology

An economic categorization that relates climate mitigation obstacles to the demand- or supply-side, or to market distortions has in our view three advantages: First, it covers a broad range of different obstacles, integrating them in a comprehensive framework and highlighting interrelations between the different impediments. Second, the concept can be applied to country cases – as will be demonstrated in the next section – systematically identifying possible challenges to national climate policy. Third, the market-inspired perspective reflects the basic structure of most numerical models assessing mitigation potentials and costs. Thus, this typology can directly be related to the design of IAMs as it allows mapping obstacles identified in the literature onto the assumptions made in the computations of an IAM mitigation scenario.

2.3. Real-World Obstacles to Mitigation Policy: The Case of China

Based on the typology established in the previous section, this section reviews existing literature to identify obstacles relevant for China's implementation of costs-effective mitigation policies. Energy security, environmental impacts, and socio-economic development are important drivers behind recent climate policy measures (Song and Zheng 2012, Wang et al. 2011a, García 2011), such as the *Renewable Energy Law* and the various energy and carbon intensity targets in the 11th (2006-2010) and 12th (2011-2015) *Five Year Plans* (FYP). The aim of this section is to highlight the difficulties encountered in the implementation of these policies for the current world's top CO_2 emitter, and relate them to our typology. China is an interesting case study because of its decisive role in combatting global climate change and therefore been studied intensively.

Perhaps the foremost obstacle on the demand side for abatement (Category 1) in China is the *interaction with other policy objectives*. As China is still a developing country, the Chinese government seems to set its priority on economic growth and social stability, which from a pure climate perspective has impeded, e.g., electricity pricing reforms (Ma 2011). The government guided price structure hampers the transformation of the energy system (Kahrl et al. 2011) as the low energy prices do not fully reflect environmental costs, resource scarcity, and the large supply-demand mismatch (Chai et al. 2009) suggesting that China might be inclined to sacrifice cost-effectiveness in order to avoid conflicts with other policy objectives.

Establishing least-cost climate policy can be further complicated by *political economy* obstacles, i.e. in form of opposition from the general public when hit hard with adverse impacts from regressive policies. Command and control measures, such as closing of inefficient power facilities, to reach some of the intensity targets of the 11th FYP generated negative attitude among the public and jeopardized social stability (Li and Wang 2012). In this context, it seems likely that China's future policies need to include appropriate instruments that dampen potential regressive impacts of measures for low-carbon development in order to be politically feasible (Li and Wang 2012). Concerning local implementation of policies, the strong resistance from provincial and municipal leaders is another structural obstacle, as their performance is mainly measured in terms of reaching targets related to economic growth within their region (Lo 2012). Finally, *institutional capacity constraints* are likely to undermine the effectiveness of China's planned nationwide emission trading scheme[11]. Past experience from previous pilot projects in China indicates that lack of administrative capacity, poor legal framework, and inadequate emission measurement systems will remain as key barriers (Chang and Wang 2010). The high administrative costs to measure and monitor sectors such as agriculture, transport, and other non-point emission sources is a further obstacle to the implementation of an economy wide emission cap (Li and Wang 2012).

Obstacles on the supply side of abatement (Category 2) can undermine the response to the price signal and result in under-provision of abatement compared to a first-best setting. Due to *inertia in the labor market*, the lack of qualified researchers and engineers is already perceived as an important obstacle to China's renewable energy technology development (Zhang et al. 2010). Grid infrastructure has significantly lagged behind the fast wind power development, resulting in a considerable bottleneck for renewable energy integration in the national grid (Li and Wang 2012). *Individual behavior* can further undermine the effects of a carbon price: Based on a study on household electricity saving in Beijing, inconvenience and discomfort has a significant adverse effect on consumer's disposition for electricity saving (Wang et al. 2011b). The willingness to save electricity was also lower among wealthier consumers because of higher perceived opportunity cost due to greater time constrains (Wang et al. 2011b). *Uncertainty* about future technological change and fossil fuel availability is another important obstacle *for private investments*. Most renewable energy technologies in China are still in early development stages and only few have been fully commercialized (Zhang et al. 2010). The high risk and the low economic return associated with those technologies serves as a barrier for private companies who often are hesitant to invest (Zhang et al. 2010).

Second-best characteristics in the form of market distortions (Category 3) impede the alignment of the emission price and marginal abatement costs. The Chinese government has apparently identified fossil fuel subsidies as a barrier, given that it has made considerable efforts towards their reduction (Boselli 2011). Though the estimated absolute amount of $21 billion in 2010 is still high, the corresponding relative level is in fact already comparably low in China (IEA 2011). The *non-competitive market structure* in the power sector, which is dominated by five large state-owned

[11] The Government of China plans to establish a nationwide emission trading scheme by the end of the decade (Wang 2013).

power generators and two state-owned grid enterprises with considerable market power (Wang et al. 2010, Wang and Chen 2012), is one of the main obstacles to renewable energy development in China (Jiang et al. 2010). The state-owned power generators often bid a low winning price for wind and photovoltaic concession projects. As they can afford losses, they drive prices below the profit margin, resulting in a significant investment barrier for both private and foreign investors (Wang and Chen 2012). The *imperfect financial market* allows for these low productive state firms to enjoy privileged access to capital, while more productive firms can find it hard to obtain financing (Li and Wang 2012). As the Chinese economy evidently represents a mixture of planned and market based economy, including large share of state owned enterprises, heavy governmental control, imperfect financial markets, and general lack of trust in business it is uncertain how well market based mechanisms, such as carbon trading, will function (Wang 2013, SEI 2012).

Control and monitoring of these sometimes large firms may not be very tight, leading to *information asymmetries* between firms and regulator (e.g. national government) and other *implicit transaction costs*, which can be expected to severely undermine efficiency. For instance, the weak control and the lack of transparent performance data in the wind power equipment industry have created significant information asymmetries between foreign investors and domestic firms, hampering innovation in the wind power sector (Wang et al. 2012). Likewise, the substantial discrepancy between emission statistics from regional and national level sources demonstrates the need for adequate and consistent information (Marland 2012).

In terms of *innovation market failures*, protectionist policies and legal obstacles constituting entry barriers for foreign investors were identified as hindering technology transfer for wind power (Klagge et al. 2012). Policies to encourage joint ventures between domestic firms and foreign technology leaders have had limited success because of concerns about intellectual property right violations (Klagge et al. 2012). Finally, one of the main barriers to China's wind power development has been attributed to the lack of coordination between wind farm development (local government) and grid development (national government) (Kang et al. 2012). The lack of incentives for energy managers in large commercial buildings to advise occupants, who pay the energy bills, on energy saving strategies is another form of a *coordination failure* which was evident in all commercial buildings studied by Jiang and Tovey (2009).

In sum, those and potentially more real-world obstacles observed in China's current efforts towards energy efficiency improvements and renewable energy expansion will very likely lead to a fragmented policy approach, price distortions, and added costs to the supply side of abatement, and thus ultimately to higher mitigation costs than would be expected from first-best considerations.

2.4. Mitigation Policy and Abatement in Numerical Assessment Models

The costs of different mitigation strategies are commonly studied by using Integrated Assessment Models (IAMs) that combine long-term macroeconomic modeling with a technologically detailed description of the energy sector and – in some cases – a representation of the climate system. IAMs, such as the ones contributing to this special issue like AIM, GCAM, IMAGE, MESSAGE, ReMIND, TIAM-ECN, WITCH (reference: this issue), therefore constitute a framework to generate selfconsistent long-term climate policy scenarios based on explicit assumptions on energy technologies, the climate system, and economic mechanisms. The modeling of the latter, i.e. the economic equilibrium and its response to emission constraints, usually relies on the validity of at least some of the stylized first-best properties outlined in Table 1, e.g. to justify the computation of (regional) market equilibria by means of the social planner approach.

However, in light of the climate-policy-relevant imperfections discussed in the previous sections of this study, real-world economies are more appropriately described as second-best systems exhibiting market failures and other economic inefficiencies and frictions. The need to include such 'implementation limits and obstacles' in IAMs has been recognized in the literature, stating, for instance, that "2nd best analysis of climate policy will give a more robust picture of feasibility and costs" (Kriegler et al. 2012, p. 821). Leaving them unconsidered means that currently employed climate scenarios may turn out to be overly optimistic with regard to abatement potentials and the overall costs of climate change mitigation.

To date, IAMs often include some relevant obstacles in order to capture some second-best elements. These are typically 'hard' technological and macro-economic constraints such as restrictions on the deployment of renewables or CCS, delays in the setup of an international climate policy regime (Luderer et al. 2012, van Sluisveld et al. this issue), or particular market failures such as imperfect financial markets (Ekholm et al. 2013). However, several other obstacles, especially those discussed in the previous sections rooted in institutional and political factors, as well as those related to individual behavior, have so far not been explored systematically. This is illustrated in Table 2, which relates our categories of obstacles to standard modeling assumptions. Therefore, the aim of the remaining part of this section is to discuss how real-world obstacles to efficient climate change mitigation are currently represented in IAMs and how these models could be improved further by a more comprehensive inclusion of obstacles.

As captured by our first category, efficient climate policies might not be in place due to political economy reasons, lack of institutional capacity necessary for their implementation, or interaction with other policy objectives. These obstacles are generally not included in numerical models that assume that the optimal emission price is levied on all economic sectors. As recent experience has shown, such an idealized setting is unlikely to emerge: e.g., the EU ETS only covers about 40% of total EU emissions, mainly from the power sector and industry, while the remainder is addressed by complementary policies, such as fuel taxes, which has been criticized for leading to an inefficient internal burden sharing (Böhringer et al. 2009b). Even though the ETS proposed under the US Waxman-Markey bill envisaged a considerably broader coverage (despite its political infeasibility), it also only included about 85% of national emissions (Larsen and Heilmayr 2009). These issues might be of special importance for developing countries, which – in addition to political economy considerations – can be expected to dispose of relatively low levels of institutional capacity, such that the implementation of climate polices might prove challenging. Furthermore, other policy objectives can be expected to play crucial roles. These include, e.g. policies designed to promote industrial development that include targeted support for energy intensive industries, poverty reduction measures, and energy security considerations (see, e.g., Jewell et al., this issue).

	Obstacle	Relationship to IAMs
Obstacles on the demand side for abatement	Political economy	Economy frequently modeled as representative agent that implicitly implements the cost-efficient climate policy without political interactions. Some scenarios take into account the exclusion of certain sectors or regions, or delay in climate policy.
	Interaction with other policy objectives	Additional policy objectives not taken into account as a policy target. Some scenarios estimate co-benefits of e.g. energy access and local air pollution, or restrict certain technology options (e.g. CCS or nuclear power).
	Institutional capacity constraints	Costless implementation of climate measures is assumed. Institutional capacity constraints and costs for administration are not included.
Obstacles on the supply side of abatement	Individual behavior	Most IAMs either explicitly (optimization models) or implicitly (via market clearing) assume utility maximizing individuals (only based on consumption of goods), behavioral economics or non-monetary costs are not taken into account.
	Inertia and endowment restrictions in physical and human capital	Inertia in transformation of energy system included via technologically explicit modeling of vintage capital stock; human capital constraints usually not taken into account.
	Uncertainty and indirect costs of private investments	Uncertainty or other indirect costs usually not modeled. Hence, risk premia etc. that could act as impediment to investment are not included in IAMs.
Market distortions	Distortionary taxes and subsidies	Prices of fossil fuels and mitigation technologies often determined by techno-economic characteristics, without considering taxes and subsidies. Other distortions, e.g., labor tax, not included.
	Imperfect innovation markets	Technology often assumed to be available to all actors, transfer via spill-overs in e.g. a global learning curve.
	Imperfect financial markets	Usually perfect capital markets, with agents able to borrow at risk-free rate of interest. As uncertainty is not part of regular IAM structure, no need for insurance markets.
	Coordination failure	Interactions between consumers, firms, and government not explicitly represented in IAMs.
	Non-competitive market structure	Perfect competition in all markets is assumed in most models. Market power in the electricity sector is accounted for in only some models.
	Information asymmetries and implicit transaction costs	IAMs commonly built around models of perfect information and costless transactions.

Table 2: Major obstacles to climate change mitigation and their relationship to IAMs

There are several possibilities how these obstacles could be represented in IAM scenarios: First, certain sectors, such as transport, residential, or agriculture, could be excluded from emission pricing or an emission constraint, or different emissions prices in different sectors can be allowed (cf. Edmonds et al. 2006; Wise et al. 2009). Second, the use of certain technologies that may be politically contentious or face significant opposition from interest groups, such as CCS or nuclear power, could be restricted (as already done for computing 'technology option values', see, e.g., Luderer et al. 2012). Third, 'hard' constraints on GHG emissions, which correspond to an emission cap, could be substituted by alternative policies frequently observed in the real world. These include intensity targets[12], renewable energy policies[13], or a portfolio of policies differentiated by sector and technology. Fourth, while the effect of climate policy on other policy objectives (such as ambient air pollution, energy access and energy security) has been examined (i.e. van Vliet et al. 2012 and van Ruijven et al. 2012), in-depth analysis of synergies and trade-offs between climate and energy policies would require the inclusion of multiple policy objectives as emphasized by van Vliet et al. (2012). Additional constraints, e.g. on the price increase of final energy occurring between two points in time (to reflect concerns related to poverty alleviation), or on the share of imports of a certain energy carrier in a region's total energy consumption (to take into account energy security) could be introduced for this purpose.

As elaborated before, several factors will raise abatement costs compared to what would be expected in a first-best world, e.g. individual behavior, inertia and human capital constraints, or obstacles for private investments. These obstacles of our second category do not feature prominently in IAMs for two reasons: First, there is a need to keep the models' complexity at a manageable level by e.g. analyzing deterministic scenarios without taking into account uncertainty. So far, full-fledged scenarios that include uncertainty only do so by Monte-Carlo-simulations (i.e. stochastic ensembles of deterministic scenarios; e.g. Pycroft et al. 2011), while approaches featuring a more detailed treatment of decision-making under uncertainty abstract from other relevant factors by, e.g., including only a highly simplified description of the energy system (Lorenz et al. 2012, Hassler and Krusell 2012). The second reason is the limited understanding of the involved economic mechanisms. Arguably, the latter point is of special relevance for obstacles rooted in individual behavior, which are only imperfectly understood (e.g. Kahneman 2012) and hard to quantify.

Possible ways to include these obstacles in IAMs could include the following: First, the models could be extended by including additional features, such as human capital or behavioral factors. In this case, the derived projections should acknowledge the implied uncertainties and knowledge gaps, i.e. they must probably be regarded as qualitative descriptions providing 'insights, not numbers' rather than quantitative assessments. Second, cost mark-ups on technology investments whose return depends on uncertain technology parameters or future emission prices could be introduced in order to capture the risk-premiums demanded by private investors when adopting such technologies. Third, additional constraints could be imposed, e.g. on the speed of penetration for certain energy technologies in order to account for inertias that cannot be appropriately modeled through detailed micro-foundations. Of course, this point might be rendered difficult by the fact that it is hard to (a) come up with reasonable numbers for these constraints, and (b) develop scenarios concerning their future development, such that extensive sensitivity analyses would be required.

With regard to category 3, several second-best conditions can create a wedge between the emissions price and abatement costs, including imperfect innovation markets, imperfect capital markets, asymmetric information, distortive taxes or subsidies, coordination failures, and non-competitive market structure. As most IAMs incorporate some sort of representative agent structure

[12] E.g. China has adopted a voluntary intensity target (Stern and Jotzo 2010).

[13] Currently more than 100 countries, many of which do not have emission targets, have adopted renewable energy targets (REN21 2012).

equivalent to a social planner on a regional or country level, they implicitly assume that optimal policies to address these category 3 obstacles are in place.[14] Yet, in reality it seems likely that a multitude of distortions that are not appropriately addressed prevail across the economy, especially in developing countries. As the discussion of the Chinese case in Section 3 has highlighted, these are indeed of empirical relevance. In theory, externalities as well as distortionary taxes and subsidies could be mimicked in IAMs by suitably adjusting the social planner problem (Kehoe et al. 1992). However, this would require a significant computational effort and would only be valid for relatively small deviations from the first-best setting.

Hence, more direct (but also less rigorous) approaches to incorporate these obstacles in IAMs include the following: First, one could assume costs for adopting technologies invented in other regions (in models that feature endogenous technological change), or partial instead of full technology spill-overs (in models with learning curves) to account for imperfections in innovation markets. Second, constraints to the expansion rate of novel energy technologies could act as a proxy for delayed market entry by new firms in a non-competitive market structure. Third, region- as well as technology-specific cost mark-ups or constraints on total capital supply (as already explored by Ekholm et al. 2013) could be included to account for imperfect financial markets.

Finally, it seems unlikely that more complex strategic interactions, such as principal-agent problems, or coordination failures, can easily be represented in a typical IAM framework, in which regions are depicted as representative agents. Improved understanding of these issues would rather require a shift towards a model structure with multiple actors that can be targeted individually with appropriate policy instruments. The PRIDE model (Kalkuhl et al. 2012) which explicitly represents utility and profit-maximizing economic agents (i.e. households, production, fossil and renewable energy firms, and fossil resource owners) as well as a government setting policy instruments is a salient example of such an 'integrated policy assessment model' (IPAM). Furthermore, combining more stylized models which capture specific imperfections with IAMs in order to estimate the impact of specific barriers on model results, or using adjustment factors to modify results from IAMs ex-post could be considered.

In summary, whether a certain obstacle can be represented in IAMs crucially depends on its specific characteristics. The most straightforward modification of existing models would very likely consist of (i) excluding certain sectors from carbon pricing or restricting the use of certain abatement technologies, (ii), replacing hard 'emission pricing' policies by 'softer' but generally less efficient indirect policies, (iii) introducing additional constraints, and (iv) imposing cost mark-ups. By contrast, a more ambitious way forward would be to develop a novel model structure allowing for explicit strategic interactions between decentralized agents.

2.5 Conclusion

The present study combines two strands of previous research by analyzing real-world obstacles and the limitations of IAMs to take them into account. 'Obstacles', as we have defined them, make the

[14] Exceptions include the modeling of knowledge spillovers e.g. in the ReMIND (Leimbach and Baumstark 2010) and WITCH (Bosetti et al. 2008) model.

achievement of emission targets more costly than in a first-best setting. This allows us to relate the obstacles identified within our typology to first-best assumptions typically made for numerical IAM computations of a mitigation scenario. Including those real-world obstacles in IAMs would very likely not only lead to rise of overall costs, but also have an impact on the composition of the least-cost mitigation portfolio.

Taking into account real-world obstacles is crucial for assessing mitigation costs, as emphasized by Böhringer et al (2009a, p. S295), who "highlight the importance of initial market distortions and imperfections [...] for the appropriate assessment of EU compliance cost". For example, inefficiencies in policy – for the case of the EU's 2020 policy – was found to result in 100%-125% higher costs than the theoretical least-cost estimate (Böhringer et al. 2009b).

From a general point of view, our analysis suggests that, despite inclusion of detailed description of technological developments, IAMs mis- and more likely under-estimate the costs of an economy to adjust to a carbon constraint because of three general types of simplifications, which could be called *aggregation*, *global optimization*, and *determinism*.

First, as any model can only represent some features of reality with some limited degree of accuracy, simplification and aggregation (see, e.g., Schwanitz submitted), particularly of the macro-economy (see Bowen et al., this issue), are inevitable. Yet, ambitious mitigation policy might also have an impact on areas of the economy that are not explicitly modeled. Aggregation is thus very likely to play down the role of economic frictions and costly adjustment processes and heterogeneity of regions and players. In response to this shortcoming, model design has become increasingly comprehensive, in particular in the energy sector, which can easily be seen when comparing, e.g., the structure of the DICE model (Nordhaus 1992) with the IAMs employed in this Special Issue.

Second, numerical models typically employ a global social planner optimization ('global' in the sense of covering the entire economy and all time-steps) that maximizes a given region's intertemporal social welfare resulting in an overall coherent, optimal response to the emission constraint. This assumption abstracts from the decentralized nature of real economies, and hence ignores many potential inefficiencies stemming from human interactions, including several of those listed in category 3 and also category 1. The already high computational burden does not seem to allow for the explicit modeling of different independent agents with their own objective function within existing IAMs; hence, the long-term strategic interactions between different agents has so far only been analyzed in considerably more stylized models (e.g. Kalkuhl et al. 2012).

Third, determinism in form of perfect foresight, such as on future learning rates of renewables or availability and prices of fossil fuel resources, is often assumed by IAMs and abstracts from irreducible real-world uncertainty that would even lead a social planner to choose costly 'hedging' strategies. Hence, assuming perfect foresight avoids the ex-post inefficiency that is inevitable under uncertainty, and will therefore lead to an under-estimation of abatement costs. A recent tendency in model development to take up this aspect can be seen in the use of Dynamic Stochastic Equilibrium Models (DSGEs), e.g. Hassler and Krusell (2012), or Golosov et al. (2011). However, this approach can only account for stochastic uncertainty, and qualitative methods are perhaps better suited to understand the non-deterministic nature of complex socio-technical transitions, as, e.g., exemplified by the literature on system innovations (Geels 2002; Kemp 2011; Schott and Geels 2007).

In light of our arguments, it will be important to conduct more extensive sensitivity analysis[15] as well as model inter-comparison projects on second-best scenarios to provide better estimates for the impacts of different obstacles on mitigation costs and derive suggestions for policy makers on how to address these obstacles. Finally, it seems unlikely that more complex strategic interactions, such as coordination failures, can easily be represented in a typical IAM framework, in which regions are depicted as representative agents. Improved understanding of these issues would rather require a shift towards a model structure with multiple actors that can be targeted with appropriate policy instruments, such as the aforementioned 'Integrated Policy Assessment Model'.

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[15]Such as Kober et al., this issue, who conduct a sensitivity analysis of the carbon allowances trade to analyze the effect of imperfect trade of emission allowances among world regions.

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Chapter 3

What Motivates Vietnam to Strive for a Low-Carbon Economy? On the Drivers of Climate Policy in a Developing Country[1]

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WHAT MOTIVATES VIETNAM TO STRIVE FOR A LOW-CARBON ECONOMY? – ON THE DRIVERS OF CLIMATE POLICY IN A DEVELOPING COUNTRY

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Abstract:

Though climate change is an urgent problem especially for vulnerable developing countries, international negotiations are in a gridlock. Standard game-theoretic models that describe climate change mitigation as a public good problem predict few incentives for individual countries to act. Nevertheless - despite the absence of a globally binding agreement - we can observe some developing countries launching unilateral climate policies. Being one of those, Vietnam has recently announced to strive for a low-carbon economy. Based on interviews with Vietnamese policy makers and other stakeholders, this explorative case study examines Vietnam's motivation for a policy change that has shifted from emphasizing the responsibilities of developed countries for climate change towards accepting responsibility of developing countries to also reduce their emissions. While Vietnam's high vulnerability has contributed to put climate on the political agenda, the policy shift from a pure adaptation towards a mitigation focus was mainly driven by expected multiple climate policy benefits other than climate change abatement (so-called co-benefits). These include restructuring of the economy, addressing energy security concerns and accessing international finance to counteract a phase-out of conventional development assistance. Air quality considerations, by contrast, do not seem to play a major role for Vietnam's shift in climate policy.

Keywords: climate policy, mitigation, co-benefits, Vietnam, policy change, window of opportunity

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3.1. Introduction

In recent years high rates of economic growth in developing countries have resulted in a rapid increase of greenhouse gas (GHG) emissions (see e.g. Raupach et al. 2007; Steckel et al. 2011). As a consequence, stronger involvement of developing countries – which currently do not face binding emission reduction targets under the United Nations Framework Convention for Climate Change (UNFCCC)[1] – is regarded as essential in order to achieve ambitious climate stabilization goals (see e.g. UNFCCC 2011).

However, from the view of standard economic theory, climate policies appear particularly unlikely to be implemented in developing countries for two reasons: first, even though there is no direct one-to-one relationship between energy use and socio-economic development, in the past it could be observed that high levels of human development were only attained for countries that have crossed a certain minimum threshold of per-capita energy use (Steckel et al. 2013). For low income countries economic development has been closely related to successful industrialization based on fossil fuel resource use and thus rising GHG emissions (Jakob et al. 2012). Despite the deficiency of GDP and energy growth in reflecting improvements in human development (see e.g. Rao et al. 2014), many countries suspect that climate change mitigation could adversely affect development objectives (Jakob and Steckel 2014) thereby providing a clear disincentive for developing countries to reduce their emissions. Second, mitigating global climate change is generally perceived to raise a collective action problem that requires a global solution. Conventional collective action theory usually regards climate change mitigation as a global public good. In the respective models a country's benefits from avoiding one's own climate damages do not suffice to incentivize this country to bear the costs related to climate change mitigation efforts as damages suffered by the rest of the world are not internalized in its decision on how much to emit. Consequently, such models predict a pronounced incentive to free-ride on others' abatement without reducing one's own emissions (Carraro and Siniscalco 1993, Barrett 1994). Hence, in such a setting, individual countries will not voluntarily engage in reducing GHG emissions without a globally binding and externally enforced regulation (Brennan 2009, Ostrom 2010).

Yet, in contrast to those theoretical considerations that view mitigating climate change as the sole benefit of emission reductions, some developing countries have recently announced unilateral emissions abatement policies (see Townshend et al. 2013). Ostrom (2010) argues that this observation can be explained by benefits other than the global benefit of mitigating climate change ('co-benefits', such as energy security or reduced local air pollution) that are usually ignored by conventional game theoretic approaches to model international climate change negotiations. Policy makers will usually pursue multiple objectives, among which climate change mitigation is only one. From a climate change perspective, a co-benefit is the indirect effect of climate policy on a non-climate objective (see e.g. IPCC 2014, WGIII, Ch.3, p.36). As a consequence, climate policy might yield benefits of a more local nature – such as increased energy security or improved air quality - that incentivize countries to engage in climate policy even without a global climate agreement. As pledges made on the international level will first need to be discussed and finally implemented and enforced on the national policy level, a better understanding of individual countries' reasons to voluntarily engage in mitigation policy would also generate important insights on how to improve global cooperation on climate change mitigation.

This study examines the underlying motivations for unilateral climate measures adopted in Vietnam. From our perspective, Vietnam constitutes a very interesting example. While it has exhibited high growth rates in both economic terms as well as with respect to GHG emissions in the last decades (see Section 2) it is also highly vulnerable to climate change. At the same time, it has not yet attained the same political as well as scientific attention as bigger developing countries such as China or India.

Despite the important role of developing countries for achieving a low climate stabilization target, studies examining the motivations of national climate policy making in developing countries – especially on smaller countries - are relatively scarce. Atteridge et al. (2012) examine drivers for climate policy in India on the international, national and state levels, highlighting how climate considerations are embedded in broader concerns related to national and sub-national development interests as well as foreign relations. Dubash (2013) provides an assessment of the role played by co-benefits and equity considerations in India's climate discourse and points out that energy security is a crucial driving factor behind efforts to introduce policies to reduce emissions. Escribano (2013) analyzes the interplay of divergent political, economic, social, and environmental factors driving the formulation of energy policy in Ecuador. One of the key results of this study is that Ecuador's energy policy is severely constrained by other policy objectives related to financing as well as distributional concerns. Quitzow et al. (2011) compare environmental governance (including climate issues) in India, China, Vietnam and Indonesia. They identify ambitious policy initiatives in all four countries that are, however, hampered by a lack of capacity. Recently, a selection of case studies has been conducted, summarized in Garibaldi et al. (2014), comparing and assessing mitigation action concepts of Brazil, Peru, Chile, South Africa, and Colombia. This analysis reveals how mitigation measures crucially depend on the country-specific context, such as the level of institutional capacity.

Existing studies on Vietnam have mostly focused on specific aspects. Fortier (2010) provides a procedural critique of political processes in the run-up to Vietnam's National Target Program to Respond to Climate Change (NTP-RCC). Also mainly focusing on the NTP-RCC, Zink (2013) comprehensively discusses the political and societal dimensions of climate change policy and donor involvement in Vietnam. Rodi et al. (2012) carry out a policy analysis regarding the implementation of the Environmental Protection Tax, and Coxhead and Chan (2011) as well as Willenbockel (2011) examine its expected macroeconomic and distributional implications with numerical models. Toan et al. (2011) give an overview of Vietnam's energy system, provide forecasts on supply and demand, and review recent energy policies. Do and Sharma (2011) likewise review Vietnam's recent energy policy and discuss challenges faced by its energy sector. Nguyen and Ha-Duong (2009) assess the potential of Renewable Energy in Vietnam and discuss barriers to their diffusion, while Nguyen (2007) focuses on wind energy potentials and discusses policies to promote their uptake.

To our knowledge, there is no comprehensive assessment of recent climate policies and their underlying motivations in Vietnam to date. This is where this paper aims to make a contribution to the literature. Our policy analysis builds on 23 semi-structured qualitative interviews with Vietnamese policy makers and other stakeholders involved in the policy making process in Vietnam conducted early 2013 as well as available literature. Our interviewees include leading staff of the key Vietnamese ministries involved in the policies under consideration, i.e. the Ministries of Finance (MOF), Planning and Investment (MPI), Industry and Trade (MOIT), Natural Resources and Environment (MoNRE) and Agriculture and Rural Development (MARD), as well as associated advisory units such as the Institute of Strategy and Policy on Natural Resources and Environment (ISPONRE) and the Central Institute for Economic Management (CIEM). Furthermore, we conducted interviews with partners from development cooperation agencies from bilateral donors (Germany's GIZ, UK's DFID, South Korea's KOICA, Japan's JICA) and multilateral donors (UNDP, World Bank, ADB) as well as with experts from the policy foundation Friedrich-Ebert-Stiftung and from one of the few existing local NGOs Climate Change Resilience Center. A list of all interview partners can be found in the appendix. We concentrate on policies that (at least indirectly) aim to put a price on carbon or internalize technology spillovers (i.e. cost reductions due to increased uptake of a certain technology, e.g. by means of 'learning-by-doing'), as these policies are generally regarded to be essential in order to achieve significant emission reductions (Jaffe et al. 2005). These policies mainly affect the power and industry sectors, which are hence the focus of this study.[2]

This paper is structured as follows: First, we provide some general information about Vietnam's development, including an in-depth analysis of energy related emission drivers. Second, we introduce climate and energy related policies in Vietnam. Third, using an inductive approach, we identify and evaluate the different motivating factors to engage in climate measures mentioned in the interviews divided into domestic (e.g. vulnerability to climate change, energy security, economic growth) and external factors (e.g. donors, international setting). We continue with discussing how the observed policy change in Vietnam can be explained from the perspective of Kingdon's (1995) 'multiple streams framework' and finally conclude.

3.2. Vietnam's economic development and energy system

Since its reunification in 1976, the Socialist Republic of Vietnam is a one-party state ruled by the Communist Party of Vietnam (CPV). In the mid-1980s, the CPV launched a socio-economic reform process ("Doi Moi", literally meaning "renovation"), which allowed private entrepreneurs to participate in the market. It is usually perceived that the set-up of the "Doi Moi" process gave impetus to subsequent rapid economic growth, with GDP per capita more than tripling between 1990 and 2010, lifting a large part of the Vietnamese population out of (absolute) poverty. This was accompanied by an outstanding social transformation significantly improving important developing indicators such as life expectancy and the Human Development Index (HDI) (see Table 1). Around 2009 Vietnam has crossed the GDP threshold to be listed as a Low Middle Income country by the World Bank. At the same time, in the last two decades, inflows from net official development assistance (ODA) have played a major role for Vietnam amounting to approximately 3.5 billion US$ in 2011 of which 61% stems from bilateral donors (source OECD 2013).

Table 1: Selected socio-economic and development indicators for Vietnam for the years 1990, 2000 and 2010

	1990	2000	2010
Population [million]	66.02	77.63	86.93
GDP per capita, Purchasing Power Parity (PPP) [constant 2005 international $]	905	1597	2875
Poverty headcount ratio at $1.25 a day (PPP) [% of population]	63.7*	40.1**	16.9***
Urban population [% of total]	20.3	24.4	30.4
Life expectancy [years]	65.5	71.9	74.8
Human Development Index (HDI)	0.439	0.534	0.611
Net Official Development Assistance (ODA) received [constant 2010 million US$]	254	2212	2940

Sources: World Bank 2013, UNDP 2013. Note that for selected data points available data differ from indicated years marked by symbols: * 1993, ** 2002, * 2008**

Social changes shown by Table 1 are mirrored in changes in Vietnam's economy. Once being dominated by the agricultural sector it is today built on a solid industry base, with the industrial sector having grown at more than 10% per annum in the 2000s. In 2006, it became the largest sector in Vietnam's GDP (see Toan et al. 2011 for a detailed description). While in 2000 GHG emissions from the energy sector accounted for only about one third of the overall GHG emissions in Vietnam (see latest official data available), the World Bank (2011, p. 33) projects the share of the energy sector to account for three-quarters with respect to Vietnam's total emissions in 2030. In view of this it is not surprising that the World Bank study also sees the highest mitigation potential in the energy sector (World Bank 2011).

Even though private entrepreneurship is basically allowed in Vietnam, most key industries (and in particular heavy industry) are controlled by the state. Those State-Owned Enterprises (SOE) generally play an important role in the Vietnamese political process, as leading figures in these enterprises usually have strong links to the Communist Party (see e.g. Hayton 2010 for a detailed discussion).

However, recently economic growth in Vietnam has slowed down. While the global economic crisis has impacted Vietnam's economy by decreased exports and reduced foreign direct investment (FDI) (World Bank 2012a), the country also has to deal with an increasingly inflexible economy (due to the high share of State Owned Enterprises), and a banking crisis, impeding new investments as reported by several interviewees. Additionally, Vietnam is ranked rather low on institutional quality including relatively high indices for corruption and a low ranking for rule of law (World Bank 2012b).

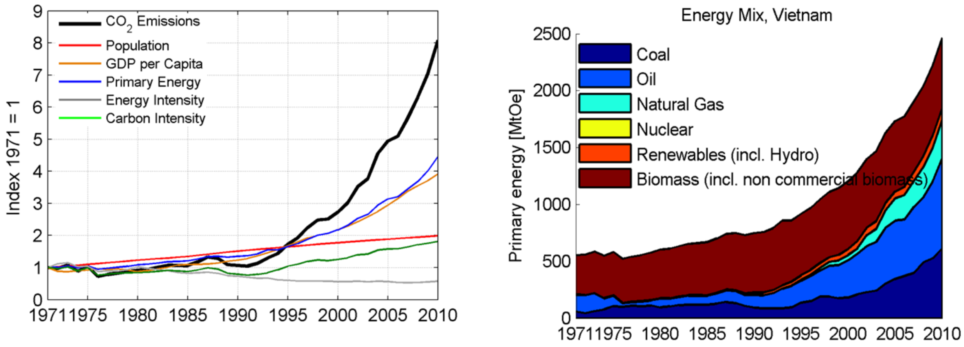

Figure 1: Development of Kaya indicators (left) and Vietnamese primary energy mix (right)
Note: For details on Kaya indicators see Appendix. 1 Mtoe = 41.868 PJ. Data Source: IEA (2012).

Energy demand, until the year 1990 to a large extent covered by renewable sources, mostly by traditional biomass and some hydropower, is now majorly covered by fossil fuels (particularly oil and coal) and has increased by nearly factor five since 1971. In the electricity sector the state owned utility Electricity Vietnam (EVN) controls the lion's share of transmission, distribution and generation; in 2010 EVN accounted for about 60% of electricity generation (Do and Sharma 2011, UNDP 2012). Most households (>97% according to World Bank (2013) statistics) have access to electricity, and electricity prices are regulated by the national government at a level below the total costs of production (with average retail prices being at approximately .07 US$ per kWh at the time of the interviews). Electricity prices are hence indirectly subsidized with the total amount of consumption subsidies in the electricity sector estimated to be US$ 2.92 B or 2% of GDP and US$ 4.12 B and 3.3% of GDP in the energy sector in 2011 (IEA 2013, World Bank 2013), though a UNDP study suggests that those figures might even underestimate the true value (see UNDP 2012). Vietnam's CO_2 emissions in the energy-related sectors have increased about eight-fold between 1971 and 2010 (see Figure 1: Development of Kaya indicators (left) and Vietnamese primary energy mix (right)), resulting in per capita emissions of 1.5 t (130 Mt CO_2 in absolute terms) in 2010.

Though there are other, non-CO_2 GHGs, especially in the waste and land-use and forestry sectors, our analysis focuses on energy-related CO_2 emissions, as it mainly addresses mitigation policies in the energy and industry sectors and CO_2 constituted 87% of energy-related GHG emissions (Socialist Republic of Vietnam – MoNRE 2010, p.42). We believe that this approach is reasonable, as these emissions account for the largest and fastest growing share of Vietnam's total GHG emissions and offer the highest potential for low-cost mitigation (World Bank 2011). In order to understand the drivers of Vietnam's CO_2 emissions in the energy-related sectors we present an analysis along the lines of the Kaya identity (Kaya 1990), which decomposes CO_2 emission changes into population, GDP per capita, energy intensity of GDP (i.e. primary energy per unit of GDP), and carbon intensity of energy (i.e. CO_2 per unit of primary energy), building on IEA (2012) data. Following Steckel et al. (2011) and Hübler and Steckel (2012) we also decompose changes in carbon intensity into contributions of different energy carriers (see Appendix for methodological details). It is first useful to look at the development of key Kaya factors in Vietnam compared to other countries. Figure 2 illustrates the development of CO_2 per capita emissions (in tCO_2), GDP per capita (in US$), energy intensity (in MJ per US$) and carbon intensity (in $kgCO_2$ per GJ) for Vietnam in comparison to China, the global average and an aggregate of other newly industrializing countries (NICs), including Brazil, India, Indonesia, Mexico and South Africa.

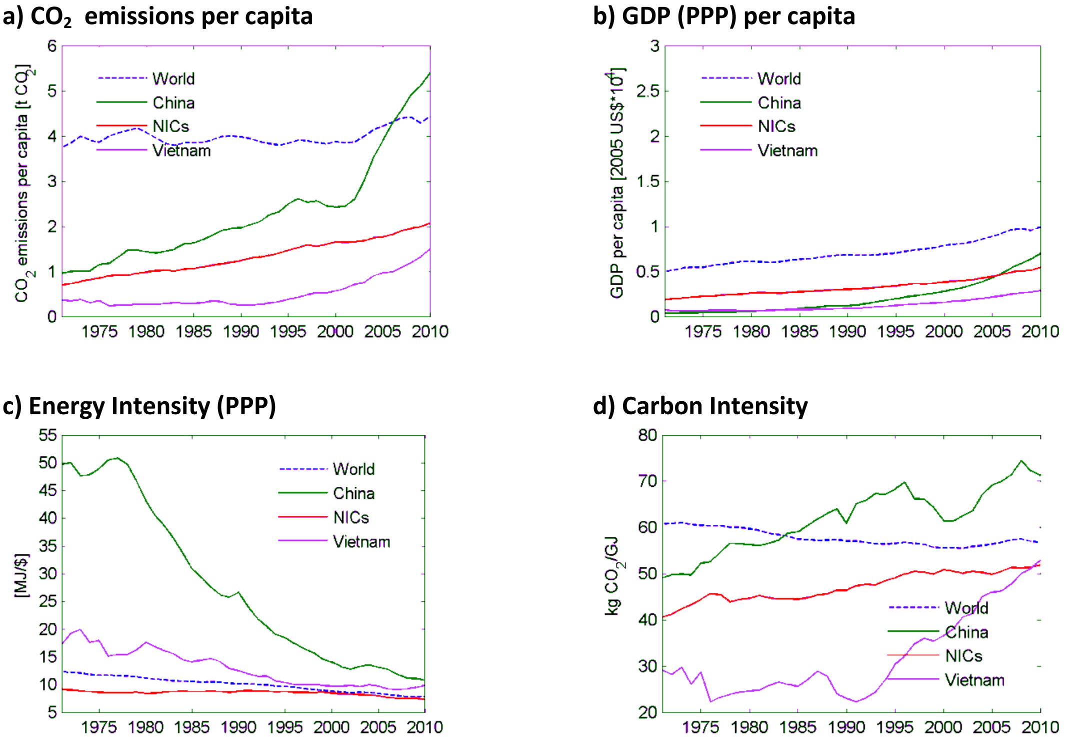

Figure 2: CO_2 emissions per capita and factors of the Kaya identity over time for Vietnam, China, Newly Industrialized Countries (including Brazil, India, Indonesia, Mexico and South Africa) and the global average. Data source: IEA (2012).

Per capita CO_2 emissions in the energy-sector in Vietnam, despite their dramatic growth in the last two decades, still remain far below the global average and also below the average value of other NICs (Figure 2a). However, Vietnam's carbon intensity has increased significantly in the last decades, now having crossed average levels of other NICs. Vietnam's energy system has carbonized even faster than China's, particularly in the last two decades (see Figure 2d). In addition to that, Vietnam's energy intensity has increased slightly in the last decade and is - comparable to China's - higher than the global average. Note that we show GDP measured in PPP; when using market exchange rates (not shown) Vietnam's level of energy intensity is nearly twice the global average and significantly higher than values given for China.

Vietnam's carbon emissions have grown by more than 10% in most years after 1990 (Figure 3a). While before 1990 a clear singular driver of emissions cannot be identified, after 1990 economic growth and carbon intensity have driven the increase of emissions to approximately equal extents. Energy intensity and population growth have not played a continuous role for emissions growth (with energy intensity however remaining at high levels, see Figure 3).

a) Decomposition along Kaya factors **b) Decomposition of Carbon intensity**

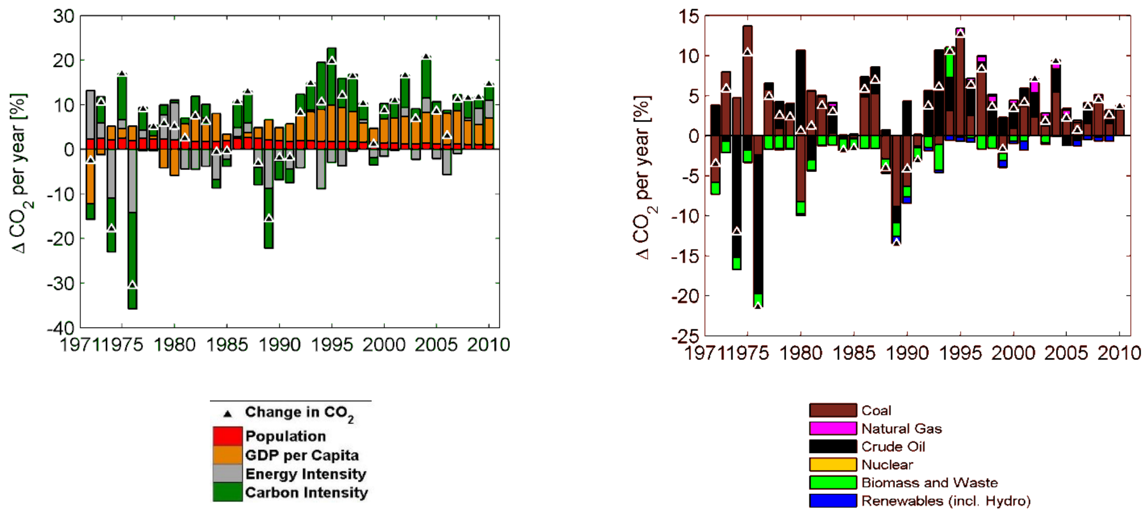

Figure 3: Decomposition of changes in CO_2 emissions in the energy system along a) Kaya factors (left) and b) a decomposition of the carbon intensity (right).
Data source: IEA (2012). See appendix for methodological details.

Large increases of carbon intensity after 1990 (see Figure 3b) can majorly be attributed to an increased use of oil, but coal has also played a significant role. In the last decade (2000 – 2010) coal is the main driver of a carbonizing Vietnamese energy system, with annual increases ranging from two to 5% per year. Even though carbonization of the energy system has slowed down, it is still very high compared to other NICs (see e.g. Steckel et al. 2011).

Available scenario analyses for Vietnam (e.g. Toan et al. 2011, Do 2011) predict a continuation of the observed trend in the future, with energy demand increasing substantially in the upcoming decades. Total end-use energy demand is projected to rise from below 44 Mtoe (1.8 EJ) in 2010 to about 74 Mtoe (3.1 EJ) in 2020 and about 126 Mtoe (5.3 EJ) in 2030 (Socialist Republic of Vietnam – MoNRE 2010, p.54), mainly driven by industrialization and rising household incomes. All studies expect a huge part of the demand to be covered by (carbon-intensive) coal. Even though Vietnam aims to cover some of its future electricity demand by nuclear power, emissions from its energy sector are expected to roughly double until 2020 (251 Mt CO_2e) and quadruple by 2030 (471 Mt CO_2e) (Socialist Republic of Vietnam – MoNRE 2010, p.56).

3.3. Energy and climate policies in Vietnam

This section first provides a detailed overview of domestic climate change mitigation related policies in Vietnam, focusing on policies that either (directly or indirectly) put a price on CO_2 or support new and renewable energy policies, as these policies are generally regarded to be essential in order to achieve significant emission reductions in the long term. Second, we sketch Vietnam's position in the international context, especially its positions in the UNFCCC process. On both levels – domestic and international - we can identify a shift in how climate and energy policy are perceived and framed by Vietnam's policy makers, changing from a position emphasizing industrialized countries' responsibility for climate change to a position acknowledging Vietnam's own contribution to a changing climate, also signaling the willingness to take responsibility.

3.3.1. Domestic policies

'Direct' climate policies

Even though Vietnam has already been involved in international climate negotiations since the 1990s and climate change issues have been discussed nationally since the beginning of the 2000s, climate change only explicitly entered the national policy making agenda with the *National Target Program to Respond to Climate Change* (NTP-RCC) approved in 2008 (see Zink 2013 for more details). Despite containing a long term component that identifies the need to develop towards a low carbon economy (NTP-RCC 2008), the allocation of funds granted for the NTP-RCC clearly reflects its focus on adaptation by attributing only about 2% of the overall resources to mitigation activities (see Fortier 2010). Moreover, the NTP-RCC (2008) emphasizes that mitigation actions will need to be financed externally by industrialized countries or international funds (see also Zink 2013).

In December 2011, the Prime Minister approved the *National Climate Change Strategy* (NCCS). In contrast to the NTP-RCC, which defined climate change response mostly in terms of adaptation measures, the NCCS states that climate change adaptation and mitigation actions should be carried out in parallel. The NCCS defines ten strategic tasks, inter alia outlining approaches for emission reduction, in particular renewable energy and energy efficiency improvements, though not yet defining emission reduction targets for the energy and industry sector.[3] However, the NCCS has confirmed and partially broadened targets from the *National Energy Development Strategy* of 2007 to increase the share of new and renewable energy (excluding large hydro > 30 MW) in total commercial primary energy to 5% in 2020 and 11% in 2050.[4] Additionally, a National Climate Change Committee has been established. In the NCCS, Vietnam (for the first time) signals its willingness to take responsibility for climate change caused by its own development pathway indicated by formulations such as *"the global trend […] demands every country, developed or developing, to reduce greenhouse gas emissions"* (NCCS 2011, p.2), thereby clearly marking the policy shift towards climate change mitigation.

Beyond this, in early 2012 and soon after the approval of the NCCS, the *Vietnam National Green Growth Strategy (VGGS)* was drafted and approved by the Prime Minister in September 2012 (Nguyen 2012). The VGGS - combining energy-, economic-, and climate policy (compare Table 2) - aims to "achieve a low carbon economy" (VGGS 2012, p.2) by restructuring the economy and reducing GHG emissions. In contrast to the NCCS, the VGGS defines explicit emission reduction targets for the energy sector. While in the NTP-RCC Vietnam had conditioned any mitigation action on the financial support from abroad, it now unconditionally commits itself to reduce its GHG intensity per unit of GDP by 8 to 10% by 2020 compared to 2010 levels and to reduce GHG emissions from energy activities by 10% (additional 10%

conditional on international support) below business as usual by 2020 and 20% (additional 10% with international support) in 2030 (VGGS 2012, p.2). Importantly, "adequate funding from the state and local budgets" (VGGS 2012, p.12) to finance the VGGS' implementation is promised. Finally, all line ministries, state agencies and regional authorities are requested to revise their strategies according to the VGGS and to develop Action Plans for its effective implementation. The Green Growth Strategy moreover announced a gradual phase out of fossil fuel subsidies (these are often imposed indirectly, e.g. by regulating end-user prices for electricity below power producers' total generation costs). UNDP (2012) provides a detailed overview on the different forms of subsidies for electricity (p.22) and refined petroleum products in Vietnam (p.24). As a first step, EVN has been granted the government's permission since 2011 to adjust electricity prices quarter-annually by a maximum of 20% per year (see also UNDP 2012). However, first price increases realized by EVN have been only 17% on average in 2011 remaining below inflation rates and leading to decreasing real prices (see UNDP 2012), and amounted to only about 10% in 2012. Although rates for poor households protected by a block tariff (VND 993 per kWh for the first 50kWh, about 4.72 UScents/kWh at the time of the interviews) have not been raised those price hikes have evoked public resentment (see e.g. Ngan Anh 2013, Tuoi Tre News 2013, Van Nam 2013) also due to impacts of electricity price increases on inflation (see Nguyen 2008).

In its Green Growth Strategy Vietnam also announced plans to move towards "trading of certified greenhouse gas emissions, carbon tax and fees and levies" (VGGS 2012, p.12). In this context, a World Bank project ("Partnership for Market-Readiness") assesses the feasibility of several pricing instruments such as a carbon tax, sectoral crediting[5] or an emissions trading scheme. Vietnam's interest in market-based instruments is underlined by Prime Minister Nguyen Tan Dung`s approval of a plan to implement an emissions trading scheme by the year 2020 (see e.g., Cheeseman 2012). However, an important prerequisite for pricing emissions is a functioning monitoring, verifying and reporting (MRV) scheme which is currently lacking. In cooperation with the Japan International Cooperation Agency (JICA) Vietnam is currently working on establishing a regular GHG emission inventory, which had already been announced in the NCCS in 2011.

Vietnam's strategy for promoting Renewable Energy (RE) or other low carbon technologies is not concentrated in one single policy document, but has been part of several direct and indirect climate policies. So far, private investment in renewable energy has remained low as stated by several interviewees, despite the implementation of economic incentives such as a feed-in tariff for wind energy of one US cent/kWh additional to the standard electricity price for households[6] (Socialist Republic of Vietnam 2011b) as well as tax exemptions and preferential loans. RE lacks competitiveness inter alia due to very low prices for conventional energy and market power of SOEs. Reforms in electricity pricing and steps towards market liberalization are envisaged, which might facilitate private investments and the diffusion of renewable energy technologies (see also Nguyen and Ha-Duong 2009 for the case of wind energy). Finally, the first nuclear power plant in Vietnam is supposed to enter into operation in 2020. In 2030, 10% of electricity production is planned to be covered by nuclear power (Power Master Plan VII 2011). The construction of several nuclear power plants is currently prepared in cooperation with Japan and Russia[7].

'Indirect' climate policies

Before the NCCS was approved Vietnam had already launched several 'indirect' climate policies dealing with energy use and natural resources, though not mentioning climate change mitigation explicitly as an objective. Single environmental policies in Vietnam could be observed since the beginning of the *Doi Moi* process in the 1980s. Inspired by the 1992 Earth Summit on sustainability, the Vietnamese government initiated the Vietnam Agenda 21 "Strategic Orientation for Sustainable Development" in 2001, which was finalized in 2004 (see Nguyen 2012). However, this was not seen as a major step by a number of our interviewees.

Discussed for the first time in 2004 (Nguyen 2012), the *Environmental Protection Tax Law* was passed by the end of 2010 with the tax coming into effect in January 2012. The *Environmental Protection Tax* (EPT) is levied on a broad range of fossil fuels including oil products and coal (EPT 2010). Though the EPT is also imposed on some other environmentally harmful substances such as plastic bags and pesticides it can be considered as a comprehensive energy tax (see Rodi et al. 2012). However, currently, the EPT cannot be called a climate policy instrument as tax rates disregard carbon content of taxable objects, thus potentially even leading to a shift to more carbon-intensive fuels like coal (see e.g. Willenbockel 2011). Moreover, tax rates are currently set very low and partially substitute preexisting fees, thus the EPT is not likely to have resulted in additional incentives to reduce emissions at the current state.

In parallel, the Vietnamese government made efforts to reform the power sector by launching the *Law on Economical and Efficient Use of Energy* in June 2010 and the *National Master Plan for Power Development* (Power Master Plan VII) in July 2011. The Master Plan for Power Development of 2011 adds explicit targets for electricity production by envisaging a share of renewable energy sources (excluding large hydro) in total electricity production of 4.5% in 2020 and 6% in 2030, and several specific targets of capacity increases for different types of renewable energy technologies and large hydro (Power Master Plan VII 2011).

Efforts to reform state-owned enterprises have been present before the Green Growth Strategy, independent from climate policy considerations. But, as the energy sector and in particular power generation are strongly characterized by market dominating SOEs as well as by significant subsidies for fossil fuels - mainly via government compensations for SOEs' losses due to regulated energy prices - the SOE reform is seen to play an important role for climate policy efforts. Several policy documents and strategies envisage to gradually restructure the power market, which includes transforming state-owned enterprises into shareholding companies and to eventually adapt electricity prices to long-term marginal costs (Power Master Plan VII 2011, NCCS 2011). This has been taken up by the Green Growth Strategy announcing a gradual phase out of (indirect) fossil fuel subsidies (VGGS 2012).

Table 2 gives an overview of important climate-related policies that have been passed from 2008 to 2012, indicating the ministries in charge and sketching the policy fields they mainly address. For a more detailed overview on energy policies in Vietnam see Do and Sharma (2011). For a more general overview on Vietnamese policies on environment and climate change see ADB (2013, Table 3, pp.13).

Table 2: Overview on selected recent climate and energy related policies in Vietnam indicating addressed policy fields

Policy documents	Year of approval	Ministry in charge	Fiscal Policy	Environ. Policy	Climate Policy		Energy Policy	Econom Policy
					Adap-tation	Miti-gation		
National Target Program to Respond to CC	Dec 2008	MoNRE (Nat. Res. & Environ)			● (light)			
Law on econ. & efficient use of energy	June 2010	MOIT (Industry & Trade)					● (dark)	● (dark)
Environmental Protection Tax Law	Nov 2010 (tax: Jan 2012)	MOF (Finance)	● (dark)	● (dark)				
Master Plan for Power Develop. (VII)	July 2011	MOIT (Industry & Trade)					● (light)	● (light)
National Climate Change Strategy	Dec 2011	MoNRE (Nat. Res. & Environ)		● (light)	● (light)	● (light)	● (light)	
Vietnam Green Growth Strategy	Sept 2012	MPI (Planning & Investm.)	● (light)	● (light)	● (light)	● (light)	● (light)	● (light)

Note: dark-blue dots mark laws, lighter dots mark strategies and plans that require further implementation.

Table 3 in the Appendix provides an overview on the status of measures with regard to renewable energy and pricing of emissions or fossil fuels.

3.3.2. International positioning

Vietnam ratified the UNFCCC in 1994 and the Kyoto Protocol in 2002 as a Non-Annex-B country, thus not facing obligations to reduce emissions under the Kyoto Protocol. In its two communications to the UNFCCC Secretariat (2003, 2010) (Socialist Republic of Vietnam – MoNRE 2003 and 2010) Vietnam has been continuously emphasizing the UNFCCC's principle of 'common but differentiated responsibilities' stating that mainly the developed countries should take the lead in climate change mitigation efforts. In this respect, at COP 16 (2010, Cancún) the Vietnamese Delegation urged industrialized countries to make more ambitious commitments and support developing countries with climate finance and technology transfer, particularly highlighting Vietnam's high vulnerability to climate change (Socialist Republic of Vietnam 2010).

One year later in Durban, the head of the Vietnamese delegation, Dr. Tran Hong Ha, decided to revise his COP 17 speech in short notice; while still stressing the 'principle of common but differentiated responsibilities', Dr. Ha stated that "*Vietnam […] believes that both developed and developing countries must take further actions*" (Socialist Republic of Vietnam, 2011a, p.1). Furthermore, he announced that Vietnam takes it as its responsibility to develop a low carbon economy and has started to do so with own national resources (pointing at the NCCS approved shortly before), though hoping for further support by developed countries. This shift in discourse towards a stronger focus on emission reductions on the international level of climate policy making came as a surprise to many international donors according to some interviewees.

Vietnam's domestic policies are thus reflected in the international arena, with the National Climate Change Strategy obviously marking a turning point in the discussion. In the following section, we aim to analyze the underlying motivations for Vietnam to formulate climate policies dealing with mitigation.

3.4. Motivations for Vietnam to voluntarily adopt climate change mitigation measures

This section outlines motivations for Vietnamese policy makers to introduce policies discussed in the previous section on the basis of the conducted interviews. The identified drivers can be differentiated in 'domestic factors' occurring *inside* Vietnam and falling into the responsibility of domestic policy, and 'external factors' being determined outside the country but relevant for Vietnam. Domestic factors include Vietnam's vulnerability to climate change, promoting economic growth and restructuring the economy, energy security issues and local air pollution. External factors include the role of other countries and donors as well as the international policy environment, i.e. international climate negotiations. Finally, using Kingdon's (1995) 'Multiple Streams Framework', we explain how a combination of changes occurring for each of these underlying motivational factors resulted in the observed policy shift towards GHG emissions mitigation plans.

3.4.1. Domestic factors

Vulnerability

Characterized by a long coastline where the majority of the population is located, Vietnam is particularly sensitive to climate changes that lead to intensified tropical storms and sea-level rise. These environmental changes endanger agricultural production, particularly in the Mekong delta, which is the heart of Vietnam's rice production (MoNRE 2009, Wassmann et al. 2004). A widely cited report by the World Bank identified Vietnam as one of the most adversely affected countries for different scenarios of sea-level rise looking at a subsample of 84 developing countries and specific indicators (Dasgupta et al. 2007, 2009).[8] Additionally, climate-change induced droughts already constitute a recognizable impact for Vietnam (Cruz et al. 2007).

It is thus not surprising that climate change has received considerable attention in the media and has resulted in the formulation of policies to respond to it such as the NTP-RCC on adaptation. However, it is less clear why vulnerability to climate change should provide an incentive for Vietnam to reduce emissions. As the country's emissions only accounted for about 0.4% of global emissions in 2011 (EDGAR 2013), any reduction would have a rather small effect on the change in global temperature and hence on the impacts of climate change borne by Vietnam. Yet, in the interviews conducted, the majority of respondents mentioned Vietnam's vulnerability as one of the main reasons for adopting policies targeted at climate change mitigation, such as the Green Growth Strategy discussed in Section 3. One possible explanation – which eludes empirical testing – is that policy makers have adopted mitigation measures as a kind of 'symbolic policy', in order to convey the impression that public concerns are being addressed, even if resulting policies might remain ineffective with respect to reduction of emissions and climate change impacts.

In any case it seems plausible that the country's vulnerability has played an important role in raising awareness and putting climate change on the political agenda though it seems to have not been sufficient to already trigger mitigation actions when passing the NTP-RCC at a time where most of the other factors described below have not yet constituted a major concern for Vietnamese policy makers.

Promoting economic growth and restructuring the economy

After a period of spectacular economic growth with GDP growth rates of more than 9% in some years (resulting in Vietnam's ascension to lower middle income country status in 2009, according to World Bank classifications), growth rates have decreased with the global economic crises to between 5 and 6% since 2008 (see World Bank 2014, World Bank 2012a). Consequently, policy makers fear that the country could run into a 'middle-income trap' marked by economic stagnation after an extensive period of rapid growth, obstructing the official goal of becoming a modern industrialized country by 2020 (SEDS 2011). In our interviews, we found a broad agreement among respondents that maintaining economic growth is the prime objective of the Communist Party. Some interviewees also indicated that failure to achieve this aim might create public unrest, which could eventually jeopardize the Party's rule.

We also encountered a wide-spread perception that the green policies under study could actually be an important ingredient of a new 'development model' that fosters economic growth by increasing productivity through more efficient use of natural resources and the adoption of modern technologies (see Hallegatte et al. 2012). Given the considerable inefficiencies that prevail throughout Vietnam's economy – with sizable (indirect) energy subsidies handed out through state-owned enterprises by fixed prices for electricity and fossil fuels being probably the most salient examples (UNDP 2012) – it seems plausible that a range of 'no-regret' mitigation options exist that pay off financially (at least in the long term) even if environmental benefits are not included in the calculation. This is confirmed by a recent World Bank study, which identifies a theoretical potential of reducing national overall GHG emissions referring to the reference year 2015 by up to 133 Mt CO_2-eq. below the business-as-usual projection[9] at negative or zero costs. Of these 133 Mt CO_2-eq., 55 Mt CO_2-eq. are in the power sector, 13 Mt CO_2-eq. in industry, and 18 Mt CO_2-eq. in transportation (World Bank 2011). In the power sector, accepting that new coal-fired power plants will be built and ensuring that these will be at least as efficient as possible is regarded as the most attractive negative cost abatement option, with some importance for new hydro power. For industry and transport, energy efficiency improvements are regarded as promising options, together with electric transport.

From these considerations the question emerges why no steps to exploit these efficiency gains, which would have saved costs and boosted economic performance, have been undertaken previously. Our interview partners repeatedly emphasized important obstacles hindering the implementation of policies to tackle no-regret options (see e.g. Staub-Kaminski et al. (2014) for a typology and discussion of such obstacles to climate policy). According to our interviews important obstacles are: first, lack of appropriate information on saving potentials and the required technologies and volumes of investment. Second, institutional and political obstacles, such as resistance by powerful interest groups. For example energy-intensive industries would face higher costs and hence lower profits if electricity were priced at its true economic cost and recent efforts to increase electricity prices have led to public opposition (see e.g. Ngan Anh 2013, Tuoi Tre News 2013, Van Nam 2013). Third, lack of up-front finance to meet initial investments that would pay off over a longer time-horizon (which is especially pronounced in the current situation of high budget deficits and a looming banking crisis); fourth, a lack of capacity to draft the legal documents and administer their implementation. Moreover, at times of high growth rates and (comparably) low state budget deficits the urgency to address these barriers seemed to be less pronounced before the economic crises.

Energy security

Until today, Vietnam has covered its fossil energy demand primarily from domestic sources. But in recent years export rates have decreased (for coal and oil) or have ceased entirely (for natural gas) (see IEA 2012). Depletion of domestic resources in combination with the projected rapid increase in energy demand is expected to turn the country into a net importer of both in the near future (Toan et al. 2011, Nguyen and Ha-Duong 2009) and a net energy importer by around 2015 (Do and Sharma 2011). This anticipated development raises significant concerns with regard to energy security (see IPCC 2011 for different dimensions of energy security). First, several interview partners mentioned that policy makers see import dependence as exposing the country to volatility of world market prices and make it prone to disruptions of energy supply. Second, as the domestic price for fossil fuels is set below the world market price, for imports this price difference would have to be met by public sources. This would put additional pressure on an already strained government budget (in 2012, the budget deficit amounted to 3.9% of GDP, and public debt to 48.2% of GDP, CIA Factbook 2013) and – in addition to the distortionary effects of subsidies – would redistribute money away from the Vietnamese economy to fossil fuel exporters. Hence, as repeatedly stated by our interview partners, a shift of economic activity towards less intensive energy use or substitution of fossil fuels with alternative sources of energy – such as renewables – is regarded as highly desirable from the perspective of increased energy security.

Local air pollution

The co-benefits of improved ambient air quality resulting from climate change mitigation measures have received considerable attention outside of Vietnam in the international discussion (GEA 2012) and it is sometimes argued that these benefits could be important for deciding whether to reduce the use of fossil fuels (Nemet et al. 2010). On the Environmental Performance Index, which provides a comparison of environmental quality across countries, Vietnam ranks among the lowest ten nations in the world with regard to health-related air quality (EPI 2012) and indeed, local air pollution was seen as a major public health problem by practically all our interview partners. Against this background, it is quite surprising that according to our interviews it did not have a major influence on the formulation and adoption of emission reduction policies outlined in Section 3, and we did not encounter a convincing explanation why reduction of local air pollution has not received more emphasis as a reason in favor of measures to abate GHG emissions but is rather seen as an unrelated problem. Though not all climate change mitigation measures necessarily have a positive effect on air quality and not all air pollution policies necessarily lead to lower GHG emissions, several studies argue that addressing climate change and air pollution jointly by means of integrated policies results in lower overall costs than addressing both separately (see e.g.McCollum et al. 2011). Interviewees stated that the role of benefits from reduced air pollution should be discussed more prominently in debates on climate change abatement in Vietnam as this co-benefit could also bear potentially high incentives for additional emission reductions.

3.4.2. External drivers

The role of other countries and donors

Arguably, policy formulation in one country can be influenced by policies that have previously been adopted in other countries by what Steinberg (2003) describes as policy transmission or translation. Several interviewees highlighted South Korea, a country pursuing sustainable socio-economic development within its National Strategy for Green Growth (see e.g. OECD 2010), to serve as a role model for Vietnam with respect to becoming an industrialized country by 2020 (SEDS 2011). Yet, it should be noted that at the time of adopting its Green Growth Strategy, South Korea had already achieved high-income status. Even though these experiences cannot be directly transferred to Vietnam and might not even have been decisive for Vietnam's decision to pursue unilateral climate measures, our interview partners repeatedly mentioned that policies in other countries had an influence on the choice of specific policy instruments (e.g. a pollution tax, or feed-in tariffs for renewable energy). This is corroborated by the fact that prior to implementation Vietnamese officials embarked on extensive fact-finding missions to learn from other countries' experiences (Interviews). According to one high-ranking Vietnamese official, "Vietnam tries to learn from other countries but does not copy anyone".

Further, as mentioned in most interviews, Vietnam's economy is to a certain degree dependent on official development assistance (ODA) from bi- and multilateral donors. In recent years, ODA accounted for up to 15% of the government budget (Interviews) and about 3% of GDP (World Bank 2013). With Vietnam having achieved low-middle income status in 2009, some donors have announced their intent to reduce their activities in or completely withdraw from Vietnam in all but few selected areas (e.g. the UK's Department for International Development (DFID) will exit Vietnam in 2016; see DFID, undated). In parallel, several interview partners emphasized that donors' aid portfolios have increasingly shifted their focus stronger towards sustainable development and green growth, so that Green Growth has become more attractive for Vietnam as a new opportunity to preserve access to international financial support as well as technical assistance.

Cooperation with donors seems to be perceived as a means to tackle some of the obstacles to reaping negative-cost options, e.g. by providing access to new technologies for power production or advising in the implementation of energy efficiency measures. That is, by carrying out workshops and background studies, donors helped to put climate change on the political agenda and assisted in building capacities required for formulating strategies and objectives as well as designing policy instruments. For instance, the United Nations Development Program (UNDP) has supported Vietnam with detailed studies identifying the structure and amount of fossil fuel subsides as well as potentials to reduce them and also provided advice in drafting the VGGS. Further, Germany's agency for international cooperation ("Gesellschaft für Internationale Zusammenarbeit", GIZ) provided advice on the Environmental Protection Tax as well as on feed-in tariffs for renewable energy (see GIZ, undated). Finally, cooperation with donors is also regarded as a potential means to spur technology transfer and thus to help modernizing the economy (Interviews). As a consequence, cooperation with donors on Green Growth policies is often evaluated to provide significant benefits with little or no associated costs or risks. Several interviewees saw an important role for development assistance in further identifying co-benefits and removing barriers for specific policies.

The international policy environment

Regarding global climate negotiations, several Vietnamese policy makers interviewed mentioned "to take responsibility" and "to contribute to global efforts against climate change" as enshrined in the VGGS and the NCCS as a motivation for climate policy. Some interviewees pointed out that by being a front-runner Vietnam might also motivate other countries to follow its example and pledge to reduce emissions. However, they also stated that this was not a major motivation for Vietnam to put forth green policies as it perceives itself as a too small player to influence others' behavior.

It seems more plausible that, as stated by several of our interlocutors, a strong impression of a 'first mover advantage' in attracting climate finance prevails among Vietnamese policy makers. That is, it is widely presumed that countries that are first to put climate polices on the table will attract a more than proportional share of the financial resources available for climate change mitigation. In particular, Indonesia, the Philippines, and Thailand were frequently mentioned to compete with Vietnam for climate finance. Not surprisingly, climate finance plays a central role and policy makers are exploring means to mobilize resources via several avenues, or, as one official put it: “Vietnam is trying to keep all options open”. The Green Climate Fund seems to be regarded as the most promising source, and first steps to develop frameworks for ‘nationally appropriate mitigation actions’ (NAMAs) have been undertaken. As stated in the Copenhagen Accord, NAMAs require the government of the recipient country to assess financing needs, possible barriers, and policy measures towards a low-carbon growth strategy that is in line with overall development objectives (see UNFCCC 2009). The Prime Minister’s announcement to implement an emissions trading scheme by 2020 suggests that Vietnam takes preparatory steps to obtain finance from selling emission permits on either a global carbon market or by linking its emission trading system to other countries’ domestic markets. The fact that climate finance from international sources is predominantly geared towards mitigation yields some explanatory power for the recent shift from adaptation to a strategy including mitigation and adaptation mentioned above.

Finally, some interviewees highlighted that constructive engagement in the arena of international climate change mitigation is seen to contribute towards establishing a good international reputation for Vietnam as a ‘reliable partner’ in the region, which could then have positive spillovers to other policy arenas, such as trade negotiations or investment treaties (See Rose and Spiegel 2009 for a theoretical model). According to our interviewee Koos Neefjes from UNDP, this is in line with Vietnam’s aim to be perceived as showing commitment and contributing to global efforts to tackle climate change. From this perspective, it also seems likely that efforts to address energy subsidies in Vietnam (see Section 3) have been strengthened by the renewed interest on energy subsidy reform on the international level (e.g. G20 2010, IEA 2011)

3.4.3. Understanding the policy change

Many of the negative-cost options seem to have been prevailing already some time before Vietnam decided to engage in climate change mitigation. So the question arises what were the reasons for the sudden shift in Vietnam’s national climate policy as well as international positioning concerning the willingness to take over responsibility in climate change mitigation efforts. This sub-section analyzes changes in underlying motivational factors along the lines of Kingdon’s (1995) ‘Multiple Streams Framework’ that in combination serve to explain the shift in Vietnam’s climate policy towards engaging in emissions abatement.

Kingdon (1995) identifies three streams - ’problems’, ’policies’, and ’politics’ - that in combination determine policy formation. Problems are conditions identified by policy makers or the public as issues that need to be addressed. Policies are political ideas that could serve as potential solutions that need to be tested for feasibility in the national context. Politics describe factors as party ideology or the national mood. To explain policy change one needs to understand developments in each single stream as well as their interplay.

The problem stream predominantly contains factors that according to our definition are labeled as domestic. In response to a number of international reports (Stern 2007, IPCC 2007, Dasgupta et al. 2007), climate change impacts, in particular sea-level rise, have been lifted high on the Vietnamese political agenda. The adoption of the NTP-RCC (2008) as well as a MoNRE (2009) report on vulnerability to sea-level rise can be seen as a direct reaction to them. In parallel, economic growth slowed down significantly as a result to the global economic crisis (from around 8% per pre 2007 to 5% in 2009, World Bank 2013) and structural deficits of the Vietnamese economy (including inefficiencies of domestic industrial production, price controls, and a high share of SOEs) were increasingly recognized as obstacles to economic development, however difficult to overcome due to political economy reasons. With domestic fossil energy resources becoming increasingly scarce and estimates predicting that Vietnam will turn into a net-importer of fossil energy carriers in the near future, additional concerns arose with respect to energy security especially in view of the expected increase in energy demand. At the same time, increasing budget deficits of up to 8% of Vietnam's GDP in 2010 (see ADB 2011) put additional pressure on the high subsidies on fossil fuels and decreased the tolerance for loss-making SOEs. Finally, with Vietnam achieving lower middle income status in 2009 while still being highly dependent on ODA, policy makers needed to deal with a gradual phase out of 'conventional' ODA.

Given these pressing problems, Vietnamese policy makers were searching the policy stream for potential solutions, which are mainly related to factors that we label as external. Donors supporting the policy process in Vietnam have proposed different ideas, which were then examined for their feasibility in the national context. Furthermore, Vietnamese policy makers have observed Green Growth implemented in some neighboring countries (particularly South Korea) as a reaction to the global economic crisis. So-called 'policy entrepreneurs' (Kingdon 1995) from important donors like UNDP and World Bank revealing existing 'no-regret' mitigation potentials while offering support to overcome barriers have potentially stimulated the adoption of the Green Growth Strategy in Vietnam (interviews). Against this background, the Vietnamese government identified Green Growth as a new potential policy to address several problems at once while – at least at first glance - dissolving the trade-off between economic development and environmental protection. As some important donors had furthermore announced to restructure their aid portfolios towards mainstreaming environmental and climate change issues, the available choice set has further shifted towards greener solutions. Finally, realizing that focusing on adaptation in international negotiations has not attracted significant funding from international sources, Vietnamese policy makers seem to perceive mitigation actions to be more promising in that respect, i.e. "the money does not lie in adaptation but in mitigation", as one interviewee put it. Arguably, this shift has been accelerated by a perceived first mover advantage for potential recipients of climate finance.

The adoption of climate change mitigation policies was furthermore supported by favorable conditions in the politics stream. Policy makers (including the government and the CPV) seem to have become apprehensive of people becoming increasingly discontent due to the economic situation but also to increasing environmental degradation and exposure to climate change impacts. Interviewees also mentioned an increasingly negative attitude of the people towards badly managed state-owned enterprises and corruption.

The considerations above suggest that Vietnam's policy change cannot be explained by a change of any single motivational factor; rather, it seems likely that their interaction has opened a 'window of opportunity' - a 'problem-window' in the words of Kingdon (1995) - for policy change. Being increasingly concerned of being stuck in a middle-income trap, a high budget deficit, fundamental structural problems of its economy, its high dependence on ODA as well as increased awareness of climate issues, Vietnamese policy makers seem to have been exposed to increasing pressure to find policies as potential solutions. Therefore, it seems likely that they have perceived green growth and climate change mitigation policies as a way to modernize the economy and to gain access to funding, technology and capacity building from donors. That is, the impression conveyed in the interviews strongly points in the direction that the main benefit expected to result from green policies is not seen in improved environmental quality or avoided climate change, but rather in an improved growth performance; thus, emission reductions are seen to be a co-benefit of these policies instead of the other way around. Given the sizable potential for efficiency improvements in the industry and power sector, it seems plausible that at least some negative-cost mitigation options exist that would indeed decrease emissions while at the same time raising economic output.

3.5. Discussion and Conclusions

Vietnam has recently announced and partially implemented a variety of policies relevant to climate change mitigation. If avoided climate damages were the only benefit of these policies, as it is frequently assumed in game-theoretic models analyzing incentives for collective action to contribute to a public good, this observation would come as a surprise. Though Vietnam's stake in mitigating climate change is high due to its considerable vulnerability, standard collective action theory predicts that without a globally binding and externally enforced regulation Vietnam has few incentives to engage in climate policy, as unilateral emission reductions would have only little effect in reducing climate change impacts due to its relatively small share in current global emissions.

Yet, as pointed out by Ostrom (2010), unilateral climate polices, such as those recently adopted or announced in Vietnam, can be understood by taking multiple levels of policy making and additional benefits of emission reductions into account. From this perspective Green Growth is regarded as a means to address issues such as declining rates of economic growth, restructuring the economy, addressing energy security concerns and accessing international finance at the same time. Emission reductions *per se* do not seem to be a major goal of the policies but rather a co-benefit of policies aiming to promote other goals in the first place, as it has also been done by some industrialized countries before (see Rabe et al.2006).

From a pure climate perspective the important question is not only *why* emission reductions are decided on by policy makers, but also *whether* they will actually be realized. Though it is too early to evaluate the effectiveness of the discussed policies, some remarks on this can already be made. First, targets for energy sector emissions are either formulated in relative terms in the form of emission intensity targets or in absolute terms compared to a business-as-usual (BAU) scenario based on projections of (growing) emissions. Second, the majority of the policies under consideration are so far only strategies or envisaged measures whose realization yet remains to be seen. The few climate relevant policy instruments that are already implemented, like the environmental protection tax and the feed-in tariff for wind power, can currently be expected to result in relatively small emission reductions compared to the BAU if any. Therefore, the question whether Vietnam has serious ambitions to reduce its emissions by implementing the announced more ambitious climate policy targets and instruments in the near future will be decisive.

Given that emissions from energy activities are expected to roughly double by 2020 and quadruple by 2030 compared to 2010 levels (see Socialist Republic of Vietnam – MoNRE 2010) it is obvious that even if the higher-bound reduction targets of 20% in 2020 and 30% in 2030 compared to BAU will be achieved, the result will still be a substantial increase in overall emissions compared to today's level. Yet, even though they may be considered to be of a limited extent, they very likely represent real reductions compared to BAU that contribute towards climate change mitigation and that would likely not be realized without the corresponding policies in place. Especially in view of the considerable negative-cost or low-cost mitigation options identified by the World Bank (2011), the potential for emission reductions seems to be significant and yet mostly untapped. Additionally, while most measures have been formulated as abstract strategies whose translation in concrete policies is still underway, they have established legal and institutional structures such as the Committee on Climate Change that can serve as foundations for further efforts and enhance coordination between ministries. The same holds for the EPT that had originally been formulated to mainly address the waste of resources and local environmental degradation. Resistance from industry and general concerns that the tax would further burden the already ailing economy and spur inflation led Vietnamese policy makers to finally decide on low tax rates when the tax entered into effect in January 2012. Yet, the EPT and Power Sector Reform plans can be seen as a basis for the future implementation of the VGGS. However, as Vietnam's main motivation seems to be reaping ancillary benefits not directly related to climate change mitigation, it is unlikely that it will go beyond those 'low hanging fruits' in its emission reduction efforts. Consequently, from a global perspective Vietnam's ambitions are clearly insufficient to prevent dangerous climate change. Yet, as stated above, it should not be taken for granted that the stated low or negative cost mitigation options will be exploited automatically, as this has not been happening in the past in the absence of those policies.

Eventually, there are numerous factors that will be crucial for the success of these policies. First, profound reforms announced in the electricity market, particularly with respect to pricing structures, are at the heart of a potential success. It is difficult to judge from the outside how different forces in Vietnam and its Communist Party will react to electricity price increases and resulting cuts in (indirect) subsidies. The fact that EVN does not take full advantage of the maximum price increases for electricity permitted by the government may be regarded as an indicator for increasing internal debates and fear of spurring inflation. Second, the reform of SOEs might raise distributional conflicts. Whether party cadres that profit from the current system will follow the party leadership, which seems to be committed, remains to be seen. Even though the balance of power between different coalitions of interest groups within the Communist Party is hard to assess from the outside, major reforms have proven possible in the past (cp. Hayton, 2010). It remains to be seen, whether the pressure on Vietnamese policy makers facing the high budget deficit, a banking crisis and stagnating growth rates will be sufficient to push through the necessary reforms despite the resistance of powerful interest groups.

Given the opportunity to exploit negative cost options, address multiple goals, and realize potential co-benefits, Vietnam seems to have a serious interest in putting its announced climate policies successfully into practice. This is for example indicated by the regular meetings of the newly established Committee for Climate Change, which consists of high ranking representatives of all involved ministries. Furthermore, the party resolution on climate change (Central Committee of CPV 2013) approved in April 2013 signals that the Communist Party has codified the importance of climate change and environmental policy. In a newspaper interview the Director General of ISPONRE, Nguyen Van Tai, states that the “resolution is among the highest-level political documents in Viet Nam in the way that it sets out the direction that all the relevant laws and policies have to abide” (Viet Nam News 2013). Moreover, first steps concerning the implementation of the Green Growth Strategy have recently been made by the approval of the National Action Plan on Green Growth in March 2014, confirming among other things that state budget will be allocated to most of the planned activities.

There are reasons to believe that there is a serious interest by Vietnam’s policy makers to transform their announced strategies into binding national laws even if this is mainly motivated by non-climate objectives such as access to finance and economic restructuring. Even though we argue in this paper that it has been the combination of country specific conditions leading to the adoption of climate change mitigation policies in Vietnam, some general insights could still be applicable to other developing countries facing similar issues. Taking multiple objectives and potential co-benefits into account could increase the willingness of other developing countries to voluntarily engage in mitigation actions even without a global agreement to be in place. As a consequence, a major task for international climate policy will be to identify how climate policies would affect different countries’ objectives and their motivations to adopt climate measures. In particular, international donors could strengthen voluntary climate policies in developing countries by supporting them to overcome barriers for exploiting negative cost options and raising awareness for potential co-benefits. Such measures could in the short- and medium-term help to dampen the expected steep increase in these countries’ emissions, while in the long-term they could provide a basis to establish more wide-ranging global cooperation in order to achieve a comprehensive climate agreement.

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3.7. Appendix

A. List of Abbreviations

ADB	Asian Development Bank
BAU	business-as-usual - scenario
CIA	Central Intelligence Agency
CIEM	Central Institute for Economic Management
CO_2 eq	CO_2 equivalents
COP	Conference of the Parties
CPV	Communist Party of Vietnam
DFID	UK's Department for International Development
EDGAR	Emission Database for Global Research
EJ	Exajoule
EPI	Environmental Performance Index
EPT	Environmental Protection Tax (see EPT 2010)
Eq.	equation
ESMAP	Energy Sector Management Assistance Program
EVN	Electricity Viet Nam
FDI	Foreign direct investment
GDP	Gross Domestic Product
GEA	Global Energy Assessment
GHG	greenhouse gas(es)
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German International Co-operation Agency)
IEA	International Energy Agency
IMHEN	Vietnam Institute of Meteorology, Hydrology and Environment
IPCC	Intergovernmental Panel on Climate Change
ISPONRE	Institute of Strategy and Policy on Natural Resources and Environment
JICA	Japan International Cooperation Agency
KOICA	Korean International Cooperation Agency
MARD	Ministry of Agriculture and Rural Development
MCC	Mercator Research Institute on Global Commons and Climate Change
MOF	Ministry of Finance
MOIT	Ministry of Industry and Trade
MoNRE	Ministry of Natural Resources and Environment
MPI	Ministry of Planning and Investment
MRV	monitoring, verifying and reporting

Mtoe	million tons of oil equivalent
NAMA	nationally appropriate mitigation actions
NCCS	National Climate Change Strategy (see NCCS 2011)
NEDS	National Energy Development Strategy (see NEDS 2007)
NIC	newly industrializing countries
NTP-RCC	National Target Program to Respond to Climate Change
ODA	official development assistance
OECD	Organization for Economic Co-operation and Development
PIK	Potsdam-Institut für Klimafolgenforschung (Potsdam Institute for Climate Impact Research)
PJ	Petajoule
Power Master Plan VII	Master Plan for Power Development VII (see Power Master Plan VII 2011)
PPP	Purchasing Power Parity
RE	Renewable energy
SEDS	Vietnam's Socio-Economic Development Strategy for the Period of 2011-2020 (see SEDS 2011)
SOE	State-owned enterprises
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
VGGS	Vietnam National Green Growth Strategy (see VGGS 2012)

B. List of interview partners

Institution and Position of Interviewee	Date of Interview
Policy Advisor Climate Change UNDP Vietnam	26/02/2013 and 12/03/2013
Advisor Sustainability Program Friedrich-Ebert-Stiftung in Vietnam	27/02/2013
Vice-President Central Institute for Economic Management (CIEM), associated with MPI	28/02/2013
Director of Environment Tax and Charge, Fee Policy Division Ministry of Finance	04/03/2013
Director Climate Change Resilience Center	04/03/2013
Chief Technical Advisor of Macroeconomic Reform Program Gesellschaft für Internationale Zusammenarbeit (GIZ) [German International Cooperation]	04/03/2013
Deputy Resident Representative Korean International Cooperation Agency (KOICA)	05/03/2013
Director General Ministry of Planning and Investment (MPI), Department of Science, Education, Natural Resources and Environment	06/03/2013
Technical Specialist on Climate Change and Sustainable Development UNDP, MPI/UNDP Sustainable Development and Climate Change project	06/03/2013
First Secretary, German Development Cooperation Embassy of the Federal Republic of Germany, Hanoi	06/03/2013
Deputy General Director Institute of Strategy and Policy on Natural Resources and Environment (ISPONRE) / Ministry of Natural Resources and Environment (MoNRE)	07/03/2013
Head International Cooperation Division Institute of Strategy and Policy on Natural Resources and Environment (ISPONRE) / Ministry of Natural Resources and Environment (MoNRE)	07/03/2013
Vietnam Institute of Meteorology, Hydrology and Environment (IHMEN)/ Ministry of Natural Resources and Environment (MoNRE)	07/03/2013
Country Director GIZ Office Hanoi Gesellschaft für Internationale Zusammenarbeit (GIZ) [German International Cooperation]	07/03/2013

Director of Department for new and renewable energy General Directorate of Energy Ministry of Industry and Trade (MOIT)	08/03/2013
Chief Technical Advisor of Wind Energy Project Gesellschaft für Internationale Zusammenarbeit (GIZ) [German International Cooperation]	08/03/2013
Environment and Climate Change Advisor Department for International Development (DFID), UK aid	11/03/2013
Environment and Climate Change Specialist Vietnam Resident Mission, South East Asia Department Asian Development Bank (ADB)	11/03/2013
Former MARD Vice-Minister and *Vice-Chairman of National Committee on Climate Change*	12/03/2013
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C. Kaya Decomposition

This appendix aims to explain the underlying calculations that lead to results presented in Figure 3. The text is heavily based on Steckel et al. (2011, pp. 3446). In order to come up with a detailed analysis of Vietnam's energy related carbon emissions, we break up emissions-growth along the factors of the Kaya identity (Kaya 1990), which expresses carbon emissions *F* as a product of the underlying factors GDP *G*, primary energy *E*, and population *P*:

$$F = P\left(\frac{G}{P}\right)\left(\frac{E}{G}\right)\left(\frac{F}{E}\right) =: P\,a\,e\,k\,, \qquad \text{(C.1)}$$

The right-hand-side refers to the relative variables per-capita GDP (affluence) $a = G/P$, energy intensity $e = E/G$, and carbon intensity of energy $k = F/E$. Using the Laspeyres index method[10] (Sun and Ang 2000), a change over time in emissions ΔF can be expressed as the joint contribution of the four underlying effects (indicated by subscript *f*),

$$F(t+\Delta t) - F(t) = \Delta F = P_f + a_f + e_f + k_f\,, \qquad \text{(C.2)}$$

where each effect can be derived from multiplication, as done here exemplarily for population,

$$P_f = \Delta P \cdot a_t \cdot e_t \cdot c_t + \Delta P \cdot \cdot \begin{bmatrix} +\frac{1}{2}\cdot\left[(\Delta a)\cdot e_t \cdot c_t + a_t \cdot (\Delta e)\cdot c_t + a_t \cdot e_t \cdot (\Delta c)\right] \\ +\frac{1}{3}\cdot\left[(\Delta a)\cdot(\Delta e)\cdot c_t + (\Delta a)\cdot e_t \cdot (\Delta c) + a_t \cdot (\Delta e)\cdot(\Delta c)\right] \\ +\frac{1}{4}\cdot(\Delta a)\cdot(\Delta e)\cdot(\Delta c) \end{bmatrix}. \qquad \text{(C.3)}$$

The first part of Eq (C.3) ($\Delta P \cdot a_t \cdot e_t \cdot c_t$) can be interpreted as the partial effect of the population component on the change of CO_2 emissions between time step *t'* and the preceding step *t*. The following parts capture interactions between the remaining variables and form the so called residual term.

In order to get a better understanding of the specific dynamics of the carbon intensity, we subject its time-series to an extended decomposition that allows expressing the change in carbon-intensity as a sum of changes in the supply from specific energy carriers. Namely, carbon intensity $k_{t'}$ at time *t'* can be expressed relative to a preceding time step *t* as

$$k_{t'} = k_t \frac{E_t}{E_{t'}} + \sum_j \left(\frac{k_{jt'}\,E_{jt'} - k_{jt}\,E_{jt}}{E_{t'}}\right), \qquad \text{(C.4)}$$

where j indexes the different energy carriers, e.g. natural gas, coal etc., and k_{jt} represents the specific carbon intensity of energy carrier *j* at time *t*, which supplies carrier-specific energy E_{jt}. Changing specific carbon intensity over time might be confusing at first sight. However, the composition of energy carriers, e.g. coal, changes over time, as for example lignite is replaced by hard coal or vice-versa. Given that by definition we have

$$E_t = E_{t'} - \sum_j \left(\Delta E_j\right), \tag{C.5}$$

where ΔE_j denotes the change between *t* and *t'* in energy supply E_j, one can write

$$k_{t'} = k_t \frac{E_{t'} - \sum_j \left(\Delta E_j\right)}{E_{t'}} + \sum_j \left(\frac{k_{jt'} E_{jt'} - k_{jt} E_{jt}}{E_{t'}} \right).. \tag{C.6}$$

The first part of the expression can be interpreted as the energy carrier's changing contribution to the overall energy mix, while the second term of the expression indicates the change of the energy carriers' specific carbon intensity. This can be reformulated to express the change Δk in carbon intensity between t and t' as a sum over contributions from all energy carriers:

$$\Delta k = \frac{1}{E_{t'}} \sum_j \left(k_{jt'} \cdot E_{jt'} - k_{jt} \cdot E_{jt} - \Delta E_j k_t \right) \tag{C.7}$$

Δk so far only captures the partial effect. In a complete Laspeyres decomposition, all residuals are taken into account, implying that the effect of carbon intensity k_f can be written as $k_f = \Delta k \cdot R$, where *R* represents the residual (compare also Eq C.3). *R* can then be written as:

$$\begin{aligned} \mathrm{R} &= (\mathrm{P_t} \cdot \mathrm{a_t} \cdot \mathrm{e_t}) + \frac{1}{2} \cdot (\Delta\mathrm{P} \cdot \mathrm{a_t} \cdot \mathrm{e_t} + \Delta\mathrm{a} \cdot \mathrm{P_t} \cdot \mathrm{e_t} + \Delta\mathrm{e} \cdot \mathrm{P_t} \cdot \mathrm{a_t}) \\ &+ \frac{1}{3} (\Delta\mathrm{P} \cdot \Delta\mathrm{a} \cdot \mathrm{e_t} + \Delta\mathrm{P} \cdot \Delta\mathrm{e} \cdot \mathrm{a_t} + \Delta\mathrm{e} \cdot \Delta\mathrm{a} \cdot \mathrm{P_t}) + \frac{1}{4} \cdot \Delta\mathrm{P} \cdot \Delta\mathrm{a} \cdot \Delta\mathrm{e}) \end{aligned} \tag{C.8}.$$

In order to adapt the decomposition of carbon intensity, i.e. the effect k_f of carbon intensity on the change of emissions, we need to multiply Δk (Eq. C.7) by R on both sides. This leads to the graphs shown in Figure 3, which allow to directly observe the influence of specific changes in the energy mix on emissions.

D. Renewable energy policies and fossil fuel pricing in Vietnam

Table 3: Overview of new and renewable energy policies as well as fossil fuel and emission pricing policies in Vietnam

<table>
<tr><th></th><th>New and Renewable Energy (RE) Policy</th><th>Fossil Fuel and Carbon Pricing Policy</th></tr>
<tr><td>Targets defined</td><td>• Increase share of RE from 3.5% of total electricity production in 2010 up to 4.5% in 2020 and 6.0% in 2030 (total power plant capacity RE share of 9.4% in 2030)
• Specific targets for different technologies</td><td>• Decrease GHG intensity by 8 – 10% (compared to 2010)
• Reduce GHG emissions from energy activities (VGGS 2012) :
- 2020: 10% below BAU (20% with international cooperation)
- 2030: 20% below BAU (30% with international cooperation)</td></tr>
<tr><td rowspan="2">Measures already implemented</td><td>• Feed-in tariff for wind energy of one UScent/kWh financed by an Environmental Protection Fund
• Economic incentives (e.g. tax exemptions, preferential loans)</td><td>• Environmental Protection Tax on several fossil fuels (among other substances)</td></tr>
<tr><td colspan="2">• First steps concerning phase out of fossil fuel subsidies: government permission to adjust electricity prices in quarterly steps by a maximum of 20% per year</td></tr>
<tr><td rowspan="2">Work “in progress”</td><td>• 2 nuclear power plants in preparation</td><td>• Partnership for Market-Readiness with World Bank to assesses the feasibility of several policy instruments
• Establishing a regular GHG emission inventory</td></tr>
<tr><td colspan="2">• Gradual phase out of indirect fossil fuel subsidies
• State Owned Enterprises (SOE) Reform</td></tr>
<tr><td rowspan="2">Envisaged measures/ objectives</td><td colspan="2">• Competitive power sector
• Equitization of SOEs (i.e. transformation of state-owned enterprises into shareholding companies, see Do and Sharma 2011 on details)
• Establishment of an ‘appropriate’ pricing system of energy by the year 2015 (prices equal marginal costs of production)</td></tr>
<tr><td>• technology transfer for particularly advanced technologies</td><td>• “trading of certified greenhouse gas emissions, carbon tax and fees and levies” (VGGS 2012, p.12)
• Domestic Emission Trading scheme plans for 2020 announced</td></tr>
</table>

[1] According to the UNFCCC's principle of 'common but differentiated responsibilities', which acknowledges that industrialized countries are responsible for the largest share of past GHG emissions, while developing countries are expected to be affected the most by the impacts of climate change (IPCC 2007) and have the least capabilities to adapt to them, binding emission reduction targets under the Kyoto Protocol only apply for industrialized countries and economies in transition (listed in the Protocol's Annex B).

[2] Though the agricultural sector in Vietnam does also play a role concerning climate change considerations, it cannot be covered in the scope of this study.

[3] However, in parallel, the Ministry of Agriculture and Rural Development (MARD) decided on a reduction target of 20% of total GHG emissions for the agriculture and rural development sector by 2020 (18.87 Mt CO_2e, see MARD 2011), which was also confirmed in the NCCS (NCCS 2011, p.11).

[4] Note that use of biomass predominantly takes places in non-commercial applications, e.g. as fuel wood (Victor and Victor 2003).

[5] Sectoral crediting refers to a dual mechanism where developing countries adopt emission reduction targets for entire sectors and can then sell the acquired permits for those reductions to industrialized countries on carbon markets. This is in contrast to project-by-project crediting as used for the Clean Development Mechanism or other sector-specific emission reduction targets that are not related to market mechanisms.

[6] Technically, Vietnam's feed-in tariff is in fact a feed-in premium. It is paid from the Environmental Protection Fund, financed by fees on waste water and fines for non-compliance with environmental regulations (Interviews).

[7] The construction work for the first nuclear power plants was originally planned to start in late 2014 with the first reactor coming online in 2020. However, in January 2014 a delay of about 4 years was announced, due to ongoing negotiations on financing and technology (see e.g. World Nuclear Association, undated)

[8] Indicators include the percentage of land area, population, GDP, urban area, agricultural area, and wetlands affected. Note that this sample excludes most small island states, which would arguably be most severely affected by sea-level rise.

[9] Note that this number includes CO_2 emissions unrelated to energy use (such as industrial processes and land use) and other GHGs (such as methane and NO_2). Nevertheless, as it corresponds to about 50% of Vietnam's emission projected for2015 (compare Fig.2 ibid.), this estimate should be regarded as rather optimistic.

[10] Different methods can be used to decompose the Kaya identity into additive effects, see, e.g. Ang (2004) for a review of different approaches.

Chapter 4

FUEL CONSUMPTION DYNAMICS IN EUROPE - IMPLICATIONS OF FUEL TAX REFORMS FOR AIR POLLUTION AND CARBON EMISSIONS FROM ROAD TRANSPORT[1,2]

Anne Zimmer
Nicolas Koch

[1]This chapter is a preprint version of the article published in *Tranportation Research Part A: Policy and Practice* as Zimmer, A. and N. Koch (2017) “Fuel Consumption Dynamics in Europe: Tax Reform Implications for Air Pollution and Carbon Emissions”, *Tranportation Research Part A: Policy and Practice*, Vol 106, pp. 22-50.

[2]Chapter written using British English due to the European context.

FUEL CONSUMPTION DYNAMICS IN EUROPE - IMPLICATIONS OF FUEL TAX REFORMS FOR AIR POLLUTION AND CARBON EMISSIONS FROM ROAD TRANSPORT

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Abstract:

This paper estimates the potential of fuel tax reforms to curb harmful air pollutants and carbon emissions from road transport in Europe. We provide robust estimates for the responsiveness of fuel consumption to changes in prices, which constitute a key determinant for emissions pathways in response to policy interventions. We show that accounting for the manifest shift to diesel in the European vehicle fleet, as well as hitherto restricted dynamics of the fuel consumption response over time yield strong evidence that petrol and diesel demand are more price elastic already in the short run than previous studies suggest. In particular, we present evidence that diesel demand in Europe tends to be more price elastic than petrol demand, when instrumenting prices with excise taxes to account for endogeneity. Inspired by recent fuel tax reform proposals, we then show that both (i) a repeal of the preferential tax treatment for diesel and (ii) an introduction of a carbon content-based tax, could avoid considerable amounts of health damaging air pollutant exhaust while at the same time contributing substantially to achieving the EU climate policy goals for 2020. In many countries, abandoning the diesel tax advantage has nearly as strong an effect as a 50€/tCO_2 tax on fuel. Both reforms have significant revenue potential.

Keywords: fuel price elasticity; diesel; gasoline; climate policy; air pollution; dynamic panel;

JEL codes:

H23 Externalities; Redistributive Effects; Environmental Taxes and Subsidies

R480 Transportation Economics: Government Pricing and Policy

Q410 Energy: Demand and Supply; Prices

Q480 Energy: Government Policy

Q530 Air Pollution; Water Pollution; Noise; Hazardous Waste; Solid Waste; Recycling

Q540 Climate; Natural Disasters and Their Management; Global Warming

Highlights

- Fuel price elasticities in Europe accounting for dieselization, endogeneity, dynamics
- Fuel demand is more price elastic in the short run than previous studies suggest
- Diesel is more price elastic than petrol both in the short and long run
- End of diesel tax break can have as strong an effect on CO_2, NO_x & PM as 50€ CO_2 tax
- Fuel tax reforms can contribute substantially to achieving EU climate targets

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Abbreviations

AB	Arellano-Bond
ADL	Autoregressive Distributed Lag
CO_2	carbon dioxide
EC	European Commission
ECM	Error Correction Model
ESD	Effort Sharing Decision
FE	Fixed Effects
GHG	greenhouse gases
GMM	Generalized Method of Moments
IV	instrument variable
LRM	long run multiplier
LSDV	Least Squares Dummy Variable
LSDVc	bias corrected Least Squares Dummy Variable
NO_x	nitrogen oxides
OLS	Ordinary Least Squares
PAM	Partial Adjustment Model
PM	particulate matter
$PM_{2.5}$	particulate matter with an aerodynamic diameter of up to 2.5 µm
SCC	Social Cost of Carbon
WP	White Paper

4.1. Introduction

Road transport was responsible for around 20% of total greenhouse gas (GHG) emissions in the EU-28 in 2013 (EEA 2015b). In fact, the transport sector is the only major sector which has exhibited an increase in GHG emissions since 1990 making it the second largest GHG emitter in the EU after the energy sector (EEA 2015b). Moreover, the World Health Organization (WHO) estimates that approximately 600,000 premature deaths in the European region in 2010 were due to health damaging air pollution (WHO Regional Office for Europe and OECD 2015). Road transport is responsible for around 40% of Nitrogen Oxides (NO_x) emissions in Europe (EEA 2015a). In 2013, around 61% of the urban population in the EU-28 was exposed to fine particulate matter ($PM_{2.5}$) concentration levels exceeding the WHO Air Quality Guidelines (EEA 2015). While most existing road transport policies, such as fuel efficiency standards, have failed to set consistent incentives across all fuels, technologies and other abatement options, price-based policies such as carbon content-based fuel taxes, could minimize perverse incentives (Creutzig et al. 2011). Indeed, several studies have demonstrated that emissions pricing can lead to notable emissions reductions (Fowlie, Holland, and Mansur 2012) and that the policy-induced improvements in ambient air quality and health benefits can be substantial (Malina and Scheffler 2015; Chay and Greenstone 2003; Currie and Neidell 2005). Moreover, studies have revealed strong potential synergies between climate policies and air pollution policies (Bollen and Brink 2014; Nam et al. 2014).

The European Commission (EC) and the European Environment Agency (EEA) have in this light both called for a reform of fuel pricing policies to correct the undesired externalities[1] from road transport (EEA 2015b; European Commission 2011b). The EC had withdrawn its proposal for a carbon and energy content-based fuel tax reform in 2015 due to a lack of agreement among EU member states, but two recent events have revived the policy debate on the current fuel pricing policy design. First, in the autumn of 2015, the fraud scandal of a major car producer using illegal software to pass approval tests, revealed that emissions limits were being substantially exceeded in diesel cars under real driving conditions (ICCT 2014; ICCT 2015c; New York Times 2016). This has provoked criticism into the political support for the dieselization of the car fleet in Europe and has refueled the debate on the effectiveness of emissions standards (Frondel, Schmidt, and Vance 2011) and the prevailing preferential tax treatment for diesel fuel (Harding 2014; ICCT 2015b; Schipper and Fulton 2013; Burguillo-Cuesta, García-Inés, and Romero-Jordan 2011). Second, the Paris Agreement on Climate Change of December 2015 - largely celebrated as a historic breakthrough in international climate negotiations - will need to be followed by ambitious climate change mitigation policies in order to be successful. Compliance with the pledges made by European countries will require the transport sector to make a large contribution towards mitigation efforts, given its share in total GHG emissions. In order to achieve the 2°C target, the European Commission estimates that GHG emissions from EU-transport will need to be reduced by 70% below 2008 levels by 2050 (European Commission 2011b).

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[1] A study suggests that aggregated social costs of noise, congestion, traffic accidents, oil dependence and infrastructure – which are not considered in this study – even surpass costs from climate change and air pollution (Parry 2009).

For the design of appropriate fuel pricing policies, policy makers need evidence about the consumer's response to fuel price changes and the distribution of the consumption changes over time. Despite the fact that fuel consumption price elasticity is a widely researched topic, reliable empirical estimates on recent European data, particularly for diesel, remain limited. While the proportion of diesel passenger cars is negligible in Northern America and many other countries, a substantial increase in the share of diesel vehicles since the 1990s is a distinguishing feature of European road transport. Yet, only very few empirical studies estimating petrol[2] price elasticities account for the increasing proportion of diesel vehicles (see Pock, 2010). Previous studies on Europe also do not consider that an increase in fuel demand can cause the price of fuel to increase, which can result in the endogeneity of the price as highlighted by Burke & Nishitateno (2013), Davis & Kilian (2011) and Kim, Han, & Moon (2011). Moreover, important questions on dynamics have remained unanswered; when designing pricing policies, policy makers might also be interested in "when" and especially "how fast" the consumption responds to shifts in fuel prices.

In this study we focus on the potential of fuel pricing policies in the European road transport sector in addressing climate change and air pollution. We contribute to the literature in two different ways. First, using a panel of 16 European countries from 1990 to 2012, we present estimates on the diesel and petrol price elasticity that are free of potential biases from diesel stock shift effects or price endogeneity. In particular, we provide a comprehensive analysis of the dynamics of fuel demand, which reveals important insights into the hitherto hidden adjustment behavior and the distribution of the demand response over time. In a comparison of a range of fuel demand equations, including a flexible error correction specification, we show that ignoring dynamics – for instance by imposing the widely-used partial adjustment model specification – masks consumers' responses to fuel price changes.

Second, equipped with robust estimates of the price induced fuel consumption reduction, we assess the potential of two fuel pricing policy scenarios to reduce emissions of CO_2, $PM_{2.5}$ and NO_x. These scenarios are inspired by specific policy proposals in the recent political debate. In a first scenario we explore the expected effects of adjusting diesel excise tax levels to petrol taxation levels as proposed in the wake of the 2015 diesel car scandal (Reuters, 2015; Umweltbundesamt, 2015). Our second policy scenario relates to the implementation of more ambitious climate policies in order to achieve the Intended Nationally Determined Contributions (INDCs) under the Paris agreement. More specifically, we explore the potential effects of introducing – in addition to the pre-existing taxes – a carbon content-based tax of 50€/tCO_2 on both diesel and petrol. We conclude with an assessment of how much these two policies would contribute to achieving the existing EU climate policy targets for the transport sector in 2020.

The remainder of the paper is structured as follows. Section II provides an overview of the related empirical literature. Section III introduces the empirical model framework, followed by the data and variable definition in Section IV and a discussion of estimators in Section V. Section VI presents the estimation results for the diesel and petrol price elasticity. Section VII assesses the expected impact on CO_2 emissions, as well as NO_X and $PM_{2.5}$ exhaust, for the two policy scenarios. We discuss policy implications and conclude in Section VIII.

[2] The terms petrol and gasoline are used interchangeably for this study.

4.2. Empirical literature

Motivated by concerns over future scarcities, triggered by oil crises rather than by environmental concerns, fuel consumption behavior was studied intensely in the 1980s and 1990s (see the reviews or meta-analyses of Espey, 1998; Basso & Oum, 2007; Brons, Nijkamp, Pels, & Rietveld, 2008; C. A. Dahl, 2012; C. Dahl & Sterner, 1991; Graham & Glaister, 2002; Havranek, Irsova, & Janda, 2012). Study design and methodologies, as well as estimation results, vary widely (see Basso & Oum, 2007, for a comprehensive assessment of different empirical methodologies). Price elasticity estimates also vary widely; the meta-analyses by Brons et al. (2008) finds mean short-run and long-run petrol price elasticities of −0.34 and −0.84, while Havranek et al. (2012) find petrol demand to be more price inelastic with on average only −0.09 (short-run) and −0.31 (long-run). Using IV-estimation techniques, a recent study of Burke & Nishitateno (2013) documents a quasi-global long-run petrol price elasticity of between -0.2 and -0.5.

While there is a large body of literature dealing with fuel demand in Northern America, Europe has been studied less intensely. However, the meta-analysis of Brons et al. (2008) provides evidence that petrol demand response in Europe might differ from Northern American estimates. Baltagi & Griffin (1997), using a panel mostly comprising European OECD countries, ascertain a range of -0.07 to -0.29 for the short-run petrol price elasticity while their long-run estimates vary widely between -0.24 and -1.42.[3] Liddle (2012) finds a petrol price elasticity of -0.16 (short-run) and between -0.19 and -0.43 (long-run) for a panel of 14 OECD countries with low diesel shares. This deliberately avoids the dieselization issue. Highlighting the importance of accounting for the rising proportion of diesel cars in Europe, Pock (2010) finds a petrol price elasticity range of between -0.03 and -0.19 in the short-run and between -0.32 and -0.84 in the long-run. However, Pock's results suffer from the very small panel size (14 countries over 15 years) yielding large differences between different dynamic estimators.

Moreover, though emphasizing the increasing importance of diesel use in Europe, Pock (2010) focuses on petrol demand in common with the vast majority of existing literature on fuel price elasticities. Only a few notable exceptions provide estimates for diesel price elasticities in Europe (Ramli and Graham 2014; Bonilla 2009; Burguillo-Cuesta, García-Inés, and Romero-Jordan 2011). In a meta-analysis, Dahl (2012) finds diesel price elasticity estimates to range between -0.13 and +0.38, strongly encouraging more research on diesel demand. Analyzing diesel vehicle demand and fuel demand jointly for a panel of EU-15 countries, Burguillo-Cuesta et al. (2011) estimate an elasticity of -0.27 with respect to diesel excise taxes.

While environmental impacts from transportation have gained more attention, comparably few studies combine their empirical estimates of price elasticities with an investigation of the effect of fuel pricing on emissions. Davis & Kilian (2011) provide one of the first studies to investigate the effect of fuel pricing on CO_2 emissions from road transport in the United States. Based on estimates for the petrol price elasticity, they calculate that a tax of US$10 per ton of carbon dioxide, translated into a 10 US cents tax (per gallon) on petrol, would decrease US carbon emissions from the transport sector by about

[3] Range for homogenous estimators.

1.5%. Overall carbon emissions of the United States would also fall by about 0.5%. Kim et al. (2011) follow a similar approach to Davis and Kilian and provide comparable evidence for South Korean data. However, neither Davis and Kilian nor Kim et al. (2011) investigate the dynamics of fuel consumption or implications for air pollution. Melo and Ramli (2014) estimate fuel[4] price elasticities for the Lisbon Metropolitan Area applying dynamic panel data methods, using these estimates to then predict road transportation CO_2 emissions.

Given the scattered empirical evidence based on recent European data, we seek to provide robust estimates for *both* petrol and diesel price elasticities for a panel of 16 European countries (1990-2012) accounting for dieselization stock shift effects, price endogeneity and dynamics. In addition, we seek to contribute to the still scarce strand of literature that assesses the potential of fuel pricing policies to reduce CO_2 and air pollution emissions, with a particular focus on recently discussed policy proposals in Europe.

4.3. Dynamic models of fuel demand

Empirical model specifications

In road transportation, overall fuel demand can be assumed to be largely driven by the aggregate of individual households' and firms' demand for fuel, maximizing their utility or profit. Given the costs of fuel and their budget constraints, households and firms will choose their fuel consumption according to their stock of vehicles. The key factors determining fuel consumption are thus the price of the fuel and the spending capacity of the households or level of economic activity of firms both of which are reflected in the level of income. A higher fuel price is expected to lead to a decrease in consumption, while a higher income is expected to increase demand for fuel. Moreover, we expect a certain stock effect for a given population; if a household has a second car, it will not normally be used as much as the main car. Similarly, for firms the mileage of each single vehicle is likely to decrease with an increase in stock of vehicles for a given level of economic activity. Thus, the fuel demand per vehicle is expected to decrease with an increasing vehicle stock.

The general relationship between fuel consumption per vehicle and its determinants can be written in the form of a log linear demand equation (see also Baltagi et al. 2003, Pock, 2010),

$$c_{i,t} = \alpha + \beta\, price_{i,t} + \gamma\, income_{i,t} + \delta\, stock_{i,t} \quad (1)$$

where $c_{i,t}$, $price_{i,t}$, $income_{i,t}$ and $stock_{i,t}$ denote the log of fuel consumption, fuel price, income level and vehicle stock of country $i = 1, \ldots, N$ in period $t = 1, \ldots, T$, respectively.

This demand equation is based on the assumption that adjustments to changes in prices, income or stock have taken full effect. While this relationship serves well to describe the long-run, in the short run, immediate adjustment to changes in the fuel price or in the income level are hampered for a number of reasons. To begin with, there is convincing evidence that consumers are subject to habit persistence in

[4] Melo and Ramli do not differentiate between diesel and petrol use in their estimation.

their behavior (see e.g. Ravina, 2005; Scott, 2012) and, therefore, changes in consumption behavior will occur only slowly. In addition, consumers are constrained by the technical features of the vehicles that are at their disposal. Given that the stock of vehicles, and consequently also the fuel efficiency of the stock, is fixed in the short term, consumers can only react by changing how they use their vehicle, i.e. by avoiding trips or switching to other modes of transport like cycling, or public transport. Only in the long run might drivers decide to change to more efficient vehicles or sell their car in reaction to changes in prices or income levels. Taken together, these factors lead to a slow and rather complex adjustment process over time. Consequently, fuel demand should not be modeled in a static framework but in a dynamic model allowing for adjustments over time, disentangling short and long-run effects as well as adjustment processes.

To account for dynamic adjustment mechanisms between consumption and price, we nest expression (1) for the long-run fuel consumption, within a general autoregressive-distributed lag (ADL) model. A specification search suggests that for the sample data at hand the following first-order ADL provides a parsimonious specification of the relevant dynamics:[5]

$$\begin{aligned} c_{i,t} = \alpha_0 + \alpha_1 c_{i,t-1} + \beta_0 price_{i,t} + \beta_1 price_{i,t-1} + \gamma_0 income_{i,t} + \gamma_1 income_{i,t-1} \\ + \delta_0 stock_{i,t} + \delta_1 stock_{i,t-1} + \mu_i + \epsilon_t + \varepsilon_{i,t} \end{aligned} \tag{2}$$

where μ_i is a country-specific effect reflecting unobserved time-invariant heterogeneity between countries, ϵ_t is a year-specific effect that captures the impact of common shocks, and $\varepsilon_{i,t}$ is the error term. In the ADL model, the short-run fuel price elasticities are given by the respective coefficients of the price variables β_0 and β_1. The long-run elasticity, or the long-run multiplier (LRM), is given by $(\beta_0 + \beta_1)/(1 - \alpha_1)$. It reflects the total effect of fuel price changes on fuel consumption distributed over future time periods.

Apart from short-run elasticities, interesting information about the adjustment process remains hidden in the ADL representation of the model. Policy makers are likely to be interested in learning how long it takes for fuel consumption to adjust to price changes and how much of the adjustment happens in early periods. This would help improve the planning of policy reforms. To gain better access to information about the adjustment process we transform the ADL model to its error correction form. This yields the following Error Correction Model (ECM) for fuel demand

$$\begin{aligned} \Delta c_{i,t} = \alpha_0 + \alpha_1^{ECM} c_{i,t-1} + \beta_0^{ECM} \Delta\, price_{i,t} + \beta_1^{ECM} price_{i,t-1} + \gamma_0^{ECM} \Delta income_{i,t} \\ + \gamma_1^{ECM} income_{i,t-1} + \delta_0^{ECM} \Delta\, stock_{i,t} + \delta_1^{ECM} stock_{i,t-1} \\ + \mu_i + \epsilon_t + \varepsilon_{i,t} \end{aligned} \tag{3}$$

[5] Subject to data limitations, we consider various ADL specifications up to a lag order of two for explanatory and lagged dependent variables. Models are compared using a specific-to-general approach based on F-tests and Arellano-Bond tests for first and second order autocorrelation.

with $\alpha_1^{ECM} = (\alpha_1 - 1)$, $\beta_0^{ECM} = \beta_0$ and $\beta_1^{ECM} = \beta_0 + \beta_1$, which applies equivalently to γ_0^{ECM}, γ_1^{ECM} and δ_0^{ECM}, δ_1^{ECM}. In this ECM the short-term price elasticities are given by $\beta_0^{ECM}$and $\beta_1^{ECM} - \beta_0^{ECM}$. The long-run multiplier is more readily available as $-(\frac{\beta_1^{ECM}}{\alpha_1^{ECM}})$.

The ECM representation provides important additional information about the adjustment speed at which the dependent variable – fuel consumption – returns to its long-run relationship after a change in an independent variable, i.e. price, income and stock. The adjustment speed is reflected in the error correction rate which is estimated by the coefficient of the lagged dependent variable α_1^{ECM}. It tells us how much of the adjustment, to the long-run state, takes place each period after a deviation has occurred. The rate has to be negative and in the range of $-1 < \alpha_1^{ECM} < 0$ for the process to converge to the long-run relationship with non-immediate adjustment. It is important to note that the error correction specification does not require co-integration but can also be estimated based on stationary data (Wickens and Breusch 1988; De Boef and Keele 2008). In particular, the inclusion of first differences - in addition to levels - mitigates the danger of spurious regression. With the notable exception of Liddle (2012), the ECM framework for panel data has not been applied in prior analyses of fuel price elasticities.[6]

Finally, it is also noteworthy that previous studies estimating dynamic fuel demand models have commonly relied on a restrictive form of the ADL, the Partial Adjustment Model (PAM), as given by:

$$c_{i,t} = \alpha_0 + \alpha_1 c_{i,t-1} + \beta_0 price_{i,t} + \gamma_0 income_{i,t} + \delta_0 stock_{i,t} + \mu_i + \epsilon_t + \varepsilon_{i,t} \qquad (4)$$

The PAM restricts the lagged coefficients of the explanatory variables to zero. If these imposed restrictions are invalid, the coefficient estimates of interest will be biased. The PAM can lead to serious bias of both the coefficients of the lagged dependent variable as well as the estimated coefficients of the explanatory variables. This particularly happens when the explanatory variables are subject to high autocorrelation and can thus influence both short and long-run elasticity estimates (De Boef and Keele 2008). To facilitate comparability with price elasticity estimates from previous studies we contrast the results from our preferred specification with those based on the PAM.

Distribution of adjustment dynamics

We might not only be interested in "how much" but also "when" and especially "how fast" consumption changes. Beyond disentangling short-run and long-run effects, the dynamic models can reveal other interesting patterns about the underlying dynamics that have mostly been disregarded in the current literature on fuel demand. Although the long-run multiplier (LRM) signals the total effect of a price change on fuel demand, it provides little information on when this effect has fully materialized. With the transformation to an ECM we could gain insights on the speed of adjustment. However, policy makers might also be interested in the distribution of the price effects over time to better anticipate implications on, for example, tax revenues, environmental effectiveness and climate targets.

[6] By restricting the sample to OECD countries with low or constant diesel car share, Liddle focuses on petrol demand for a panel of 14 OECD countries (1978-2005).

First, we can determine the cumulative effect over a certain period of time. Its calculation can easily be illustrated in the framework of the ADL in equation (2). Assume a permanent price shock of 1 in period r=0. In period r=0, the immediate response ω_0 to the shock will be a change in fuel demand by β_o, the short-run effect. In period r=1, this change in r=0 will be carried further by the direct effect of the lagged price variable β_1 as well as indirectly by the lagged dependent variable, i.e. the additional change in demand is $\omega_1 = \alpha\omega_0 + \beta_1$. From r=2 onwards, the shock is passed on only through the lagged dependent variable, so that $\omega_r = \alpha\omega_{r-1} = \alpha^{r-1}\omega_1$ for r>2. Thus, the cumulative effect of the shock realized in period R, φ_R, is obtained by

$$\varphi_R = \sum_{r=0}^{R} \omega_r \tag{5}$$

Second, based on the cumulative effect, we can obtain the median lag length. This provides information on the period in which at least half of the effect has occurred. It is obtained by normalizing the cumulative effect φ_R by the LRM (De Boef and Keele 2008).

$$m_{ADL} = \frac{\sum_{r=0}^{R} \omega_r}{\sum_{r=0}^{\infty} \omega_r} = \frac{\varphi_R}{LRM} \tag{6}$$

The period R in which the normalized cumulated price effect m, i.e. the share of the cumulative effect in the total long-run effect, exceeds 0.5, constitutes the median lag length.

Endogeneity of the price

So far, we have assumed that households and firms are price takers, i.e. that the fuel price is exogenous. While most studies estimating the fuel price elasticity build on this assumption, Davis and Kilian (2011) argue that feedback effects from fuel demand peaks to fuel prices could result in endogenous prices. Elasticity estimates would then be subject to a bias towards zero, understating the true effect. Davis and Kilian propose to use fuel taxes as instruments to address the potential endogeneity. The reasoning is that taxes are correlated with the contemporaneous price level, but can be assumed not to be impacted by contemporaneous fuel demand as politicians can implement taxes only with a certain time lag.

Choosing an appropriate instrument is generally challenging, and alternative instruments have been discussed in the literature[7]. Davis and Kilian (2011) provide another relevant argument in favor of using excise taxes: instrumenting prices with taxes has the advantage of demonstrating the demand response to a pricing policy, i.e. imposing a *tax* increase, rather than market price changes. As taxes are perceived as permanent price changes, often accompanied by media coverage raising awareness for the price increase, consumers might react more strongly to the introduction or increase of fuel taxes than to other price fluctuations. Evidence by Scott (2012) corroborates this, showing that changes in fuel

[7] Burke & Nishitateno (2013) instead propose to use a country's in-ground oil reserves as well as a measure for the international mean import price for crude oil as instruments. Given that domestic oil reserves play a minor role for most European countries, we do not follow this approach.

taxation result in greater demand responses than changes in total retail prices. As we have a particular interest in the excise tax effect, we argue that the instrumented estimation results - as highlighted by Davis and Kilian - reflect the effect of a change in the tax rate rather than general market price volatility effects. Following this reasoning, we will also address endogeneity concerns by applying European data on fuel excise taxes for instrumentation.

4.4. Data and variable definition

The estimation of the elasticity of fuel consumption with respect to fuel price changes is conducted on an annual panel of 16 European countries[8] for the years 1990 to 2012. As not all information was fully available for all countries or years, our panel is strongly unbalanced. More detailed information on the data can be found in the Appendix.

4.4.1. Dependent variables – Accounting for dieselization and non-passenger vehicle stocks

The two main types of road transport fuel used in Europe are petrol and automotive diesel. Data on automotive diesel and petrol consumption for road transport have been taken from EUROSTAT[9]. For Switzerland the respective data was not available in EUROSTAT, therefore data on road sector automotive diesel and petrol fuel consumption in kilotons of oil equivalent (ktoe) was taken from the World Bank - World Development Indicators[10].

While petrol has traditionally been the main fuel for European passenger cars, we observe a strong increase in the proportion of diesel cars since the 1990s. Figure 1 shows the development of per capita diesel and petrol consumption over time, revealing that total diesel consumption has increased in all sample countries while total petrol consumption has largely declined. Estimating the effect of price changes on per capita fuel consumption without accounting for dieselization would thus yield very misleading results for Europe, overestimating the petrol price elasticity and potentially yielding positive diesel price elasticities. We therefore normalize the diesel and petrol consumption by the stock of vehicles driven by the respective fuel type as has been proposed by Pock (2010). We will then estimate the respective fuel price elasticity for diesel and petrol vehicles separately.

Moreover, we account for the fact that road transport fuel consumption data, as reported by EUROSTAT or the World Bank, not only covers passenger cars but also other vehicle types. Disregarding changes in the stock of non-passenger vehicles could cause a bias in the elasticity estimates if the stocks of other vehicles do not develop parallel to the stock of passenger cars; this source of bias is neglected in most

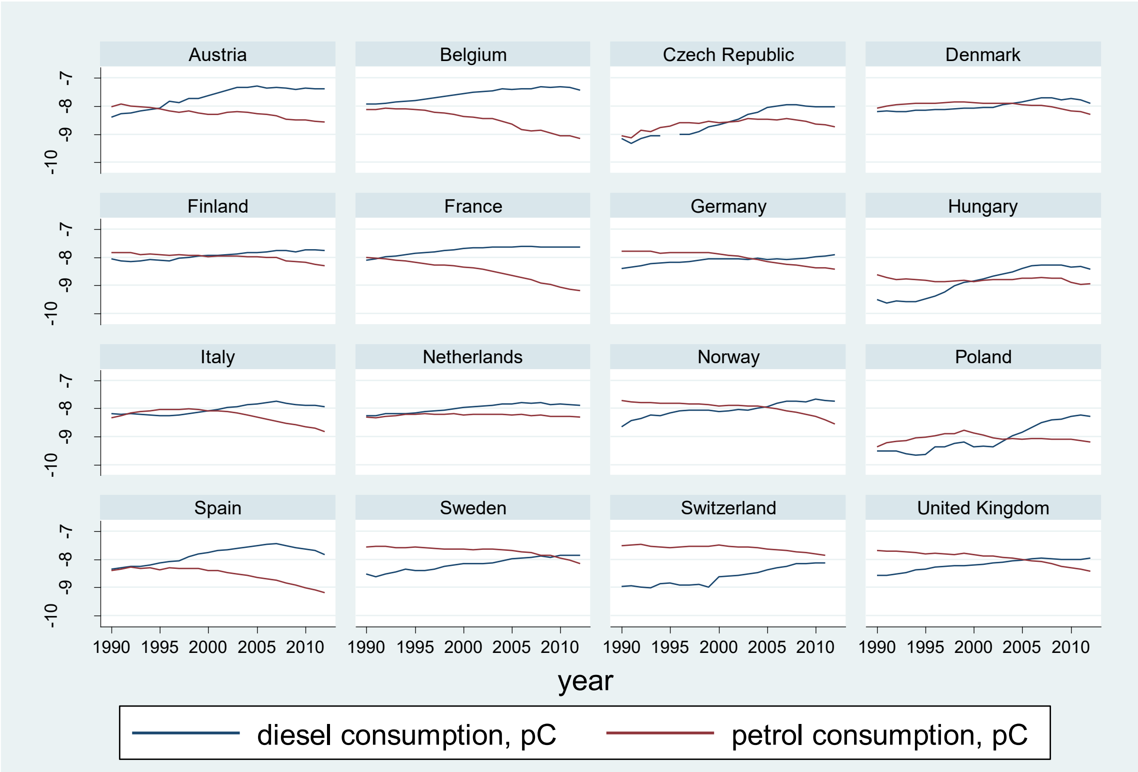
[8]The sample countries were selected based on data availability for European countries. For Ireland and Luxembourg the time series exhibit patterns of rising consumption despite increasing fuel prices presumably caused by fuel tourism from neighboring countries. We therefore exclude Ireland and Luxembourg from the sample.

[9] We use data on gasoline without bio components and gas/diesel oil without bio components for Road available at http://ec.europa.eu/eurostat/data/database (nrg_102a). Estimations accounting for bio-diesel and bio-gasoline consumption yield very similar results.

[10] http://data.worldbank.org/indicator/IS.ROD.DESL.KT and http://data.worldbank.org/indicator/IS.ROD.SGAS.KT.

previous studies. We therefore additionally compiled data on stocks of non-passenger road transport vehicles from EUROSTAT[11].

Figure 1: Road transportation fuel consumption per capita

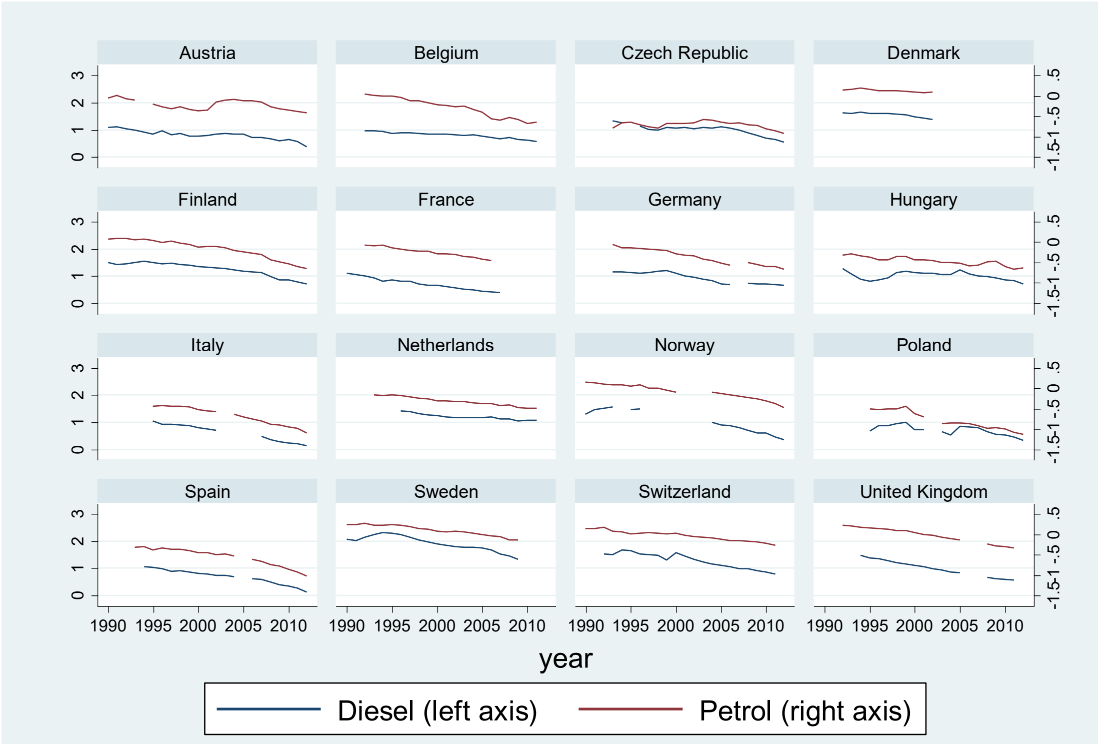


Data source: EUROSTAT and WDI World Bank (for Switzerland)

Figure 2 highlights that – after the normalization with respective vehicle stocks – both petrol and diesel demand show patterns in line with theoretical expectations, i.e. decreasing fuel consumption with increasing fuel prices (see A-1 in the Appendix on fuel price development). Most importantly, the figure documents that fuel consumption is highly persistent. This is also consistent with the theory of slow adjustment over time leading to differing long and short-run responses. Not accounting for this persistence in the data can lead to spurious regression results. It is consequently important to apply dynamic estimation techniques (see Section 4.5).

[11] We compiled data from EUROSTAT (road_eqs) on different vehicle types for which sufficient data was available (see Appendix A on details). Our estimation results are consequently based on the stock of petrol passenger cars plus motorcycles for petrol and on the stock of passenger cars and lorries for diesel.

Figure 2: Diesel and petrol consumption normalized with the respective vehicle stock



Note: Petrol consumption per petrol driven passenger car or motorcycles, diesel consumption per diesel driven passenger car or lorry. Data source: EUROSTAT for vehicle stocks and fuel consumption data, World Bank WDI for fuel consumption data for Switzerland.

4.4.2. Explanatory variables

Fuel price

Data on the price for automotive diesel and various petrol type prices, as well as taxes on diesel and petrol per liter, have been taken from the International Energy Agency (IEA 2014). For the petrol price, we use the price of the most common petrol fuel in Europe, i.e. premium unleaded RON95. Prices in national currencies have been converted to international Dollars[12]. The development of diesel and petrol prices over time for all sample countries is shown in Figure A-1 (Appendix).

We decided against the inclusion of cross-price elasticities or price differences between petrol and diesel for three reasons. First, collinearity arises due to similar price developments (see Figure A-1 in the Appendix). Second, as the motor type of a car determines the type of fuel that can be used, substitution between diesel and petrol can only occur in the long run by switching to a car with a different motor type. We indirectly capture this effect by including the total vehicle stock comprising all motor types. Third, Burguillo et al. (2011) show that the decision of which motor type of car to purchase, is

[12] We use the Purchasing Power Parity (PPP) conversion factor for private consumption (LCU per international $) from the World Bank database http://data.worldbank.org/indicator.

dominated by factors other than the fuel price, such as the purchase price and technological characteristics.

Vehicle stock

The stock of vehicles is included to account for the “second car effect” as in Pock (2010) and Baltagi and Griffin (1983). Following Pock (2010), we do not measure the stock of cars *per capita* but rather *per driver* to avoid potential demographical effects. We approximate the number of drivers by data on population and the share of the population aged between 15 and 64 years, both retrieved from the World Bank[13]. We use the aggregate of the total vehicle stock comprising all fuel types (in accordance with the definition of the respective dependent variable) to reduce the number of parameters estimated and to account for the small share of alternative motor types. This total vehicle stock divided by the population aged 15-64 yields our variable vehicle stock per driver.

Income

Income is proxied by data on GDP of the respective country reflecting the spending capacity of the inhabitants as well as the economic activity. Data on GDP per capita has been taken from the World Bank.[14]

4.5. Dynamic panel data estimators

To estimate the parameters of the dynamic models specified in equations (2) and (3), we apply several homogenous dynamic panel estimators.[15] The choice of drawing on a selection of different estimation procedures is motivated by the specificities of our panel data containing a relatively small number of 16 countries over a moderate number of up to 22 time periods. Given this panel structure, there is no single estimator that is particularly well suited to our data, and estimation performance remains an empirical issue. Subsequently, we briefly discuss the features of each estimation technique with regard to our data characteristics.

Pooled OLS and Fixed Effects

In panel estimation, simple pooled OLS estimation will be biased in the presence of time-invariant unobserved heterogeneity between countries. The Fixed Effects (FE) estimator eliminates the time-invariant country-specific fixed effects μ_i through within-transformation (demeaning). However, in a dynamic specification with lagged dependent variable the assumption that the regressors are not correlated with the error term ε_{it} is additionally violated (see Baltagi, 2013). As a consequence, the FE

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[13] http://data.worldbank.org/indicator/SP.POP.1564.TO.ZS and http://data.worldbank.org/indicator/SP.POP.TOTL.

[14] GDP per capita, PPP (constant 2011 international $), http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD

[15] Single country time series analysis or heterogeneous panel estimators could also be applied allowing for heterogeneity between elasticity parameters of countries (Pesaran and Smith 1995; Pesaran, Shin, and Smith 1999). However, Baltagi and Griffin (1997) as well as Baltagi et al. (2003) show that homogenous estimators taking full advantage of the panel structure outperform heterogeneous estimators which largely suffer from unstable region-specific parameters, even for time dimensions as long as 31 years.

estimator, as well as the equivalent Least Squares Dummy Variable (LSDV) estimator, suffer from a simultaneity bias (*Nickel bias*) that only vanishes with an increasing time dimension, as described by Nickel (1981). Though both pooled OLS and FE are biased in a dynamic panel specification, it is still interesting to apply them. Given that the OLS estimate of the lagged dependent variable coefficient is biased upwards, while the FE estimate of the same coefficient is biased downwards, the two estimators provide a range for the true coefficient, which can serve to validate other estimators (Bond, 2002).

GMM-IV estimators

Several instrumental variable (IV) estimators based on generalized method-of-moments (GMM) estimation (Hansen 1982) have been proposed to address the problem of simultaneity that causes the Nickel bias (see, e.g., Baltagi, 2013 for an overview).[16]

Anderson & Hsiao (1982) proposed using first-difference transformation (instead of demeaning) in combination with internal instruments (i.e. lagged values of the instrumented variable). Following this idea, Arellano & Bond (1991) proved that efficiency can be substantially improved by additionally exploiting the orthogonality condition between the lags of the dependent variable and the error term $\varepsilon_{i,t}$ under the assumption of no serial correlation. Applying GMM estimation, the *Arellano-Bond estimator*, also called difference GMM, uses the levels of additional lags of the dependent variable as instruments for the differenced lagged dependent variable. Using levels as instruments for first differenced variables can, however, lead to weak instruments if the variables are highly persistent, and thus correlation between levels and differences is low. To overcome this problem, Blundell and Bond (1998) additionally suggest making use of the original level equation yielding a system of two equations—the level equation and the differenced one. Based on an additional mild stationarity condition, this estimator, called *System GMM,* uses lagged differences as instruments for the lagged dependent variable in the level equation, in addition to the lagged levels of the dependent variable instrumenting the differenced equation.

Though in practice GMM-IV type estimators are often applied to macro panels (see e.g. Baltagi et al., 2003; Pock, 2010), both Arellano-Bond GMM and System GMM have originally been developed for micro-panels with a large N and small T dimension. With growing T, however, the number of instruments can become large relative to sample size. This may render some asymptotic properties of the GMM-IV estimators invalid and weakens related specification tests, such as the Hansen test, on over-identifying restrictions. The overfitting bias (Roodman 2009b) is aggravated by the introduction of explanatory variables, as the number of moment conditions increases further (see this Baltagi, 2013 on the bias–efficiency trade-off).

For our estimation, we present results from the Arellano-Bond estimator and the System GMM estimator, both using the one step procedure[17]. We also apply forward orthogonal deviations

[16] Alternatively, a bias correction for the Least Square Dummy Variable estimator has been proposed for simple dynamic models (see Appendix B).

transformation[18], instead of first differencing, to make best use of our unbalanced panel. To limit instrument count, we restrict the lag length used for instrumentation[19] and collapse the instrument matrix[20] to mitigate instrument proliferation as proposed by Roodman (2009b). The Arellano-Bond test is used to test for first and second order autocorrelation. The Sargan test is used to test over-identifying restrictions, as this test is not weakened by high instrument count (assuming homoscedasticity). For System GMM, the standard instruments are restricted to be applied to the level equation. The validity of additional instruments for System GMM is tested by the Difference-in-Sargan Test.

4.6. Elasticity estimation results

As discussed above, we compare a selection of different estimators and discuss their performance in estimating fuel price elasticities for the data at hand. Recall that the coefficient of the lagged dependent variable, estimated by OLS (upward bias) and FE (downward bias), serves as a range for the true coefficient.

4.6.1. Price elasticity of petrol demand

Table 1 shows the results for petrol demand for the first-order Autoregressive Distributed Lag model as well as its Error Correction form comparing different dynamic estimators. The signs of the estimated effects are in line with expectations, yielding negative price elasticities, positive income elasticities of fuel demand and a negative "second car" effect reflected by the vehicle stock in the short run as well as in the long run (see Table C-5 in the Appendix for long-run elasticity estimates with respect to income and vehicle stock).

With respect to the price, all estimators yield very similar estimates for the short-run elasticity as well as in the long run (LRM). The immediate effect of a one percent price increase in period t yields a reduction between 0.24% and 0.28% in the petrol consumption in the same period. However, this immediate negative effect is attenuated in the second period by a positive lagged price effect. Before discussing the short-run and long-run price elasticities with other dynamics in more detail below, we will first discuss the performance of the different estimators.

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[17] In small samples the estimation of the weighing matrix for the two step procedure can be very imprecise. Moreover, efficiency gains from the two step procedure applying the small sample correction proposed by Windmeijer (2005) have been shown to be rather small (Baltagi 2013).

[18] This alternative transformation to eliminate μ_i is proposed in Arellano and Bover (1995) to limit data loss caused by first differencing. It subtracts the average of all available future periods instead of subtracting the potentially missing previous observation only (Roodman 2009a).

[19] We selected the restriction of the lag length used for instrumentation based on test results for the Arellano-Bond test of autocorrelation, and the Sargan Test of over-identifying restrictions.

[20] This means combining instruments through aggregation into smaller sets thus collapsing the instrument matrix to be linear in T instead of quadratic.

Table 1: Estimation results for petrol consumption

PETROL	*Autoregressive Distributed Lag Model*				*Error Correction Model*		
	OLS	Fixed Effects	Arellano-Bond GMM	System GMM	Fixed Effects	Arellano-Bond GMM	System GMM
L.consumption per	0.951***	0.820***	0.732***	0.913***	-0.180**	-0.268^{+}	-0.087
vehicle	(0.016)	(0.048)	(0.131)	(0.079)	(0.048)	(0.131)	(0.079)
petrol price	-0.277***	-0.248**	-0.239*	-0.276***			
	(0.070)	(0.079)	(0.083)	(0.059)			
L.petrol price	0.249***	0.144*	0.087	0.228**	-0.105**	-0.152*	-0.048
	(0.072)	(0.067)	(0.106)	(0.069)	(0.032)	(0.065)	(0.040)
D.petrol price					-0.248**	-0.239*	-0.276***
					(0.079)	(0.083)	(0.059)
GDP	0.582***	0.622***	0.695**	0.622**			
	(0.141)	(0.129)	(0.213)	(0.181)			
L.GDP	-0.573***	-0.455**	-0.471*	-0.594**	0.167*	0.225^{+}	0.027
	(0.139)	(0.137)	(0.172)	(0.151)	(0.064)	(0.111)	(0.045)
D.GDP					0.622***	0.695**	0.622**
					(0.129)	(0.213)	(0.181)
total vehicle stock	-0.974***	-1.042***	-1.051***	-1.015***			
	(0.163)	(0.140)	(0.145)	(0.134)			
L. total vehicle	0.940***	0.894***	0.848***	0.958***	-0.147**	-0.203^{+}	-0.057
stock	(0.163)	(0.146)	(0.168)	(0.125)	(0.045)	(0.098)	(0.050)
D. total vehicle					-1.042***	-1.051***	-1.015***
stock					(0.140)	(0.145)	(0.134)
Constant	0.145	-0.838		0.048	-0.810		0.094
	(0.122)	(0.503)		(0.228)	(0.489)		(0.199)
Petrol price shock dynamics							
LRM	-0.572	-0.580	-0.565	-0.554	-0.580	-0.565	-0.554
period 5 effect φ_5	-0.34	-0.46	-0.50	-0.38	-0.46	-0.50	-0.38
median lag length	1	1	1	1	1	1	1
# observations	270	270	254	270	270	254	270
# instruments			35	37		35	37
max IV lag			9	9		9	9
AB-test (AR1)			0.0020	0.0016		0.0020	0.0016
AB-test (AR2)			0.8470	0.8803		0.8470	0.8803
Sargan Test			0.3350	0.1781		0.3350	0.1781
Diff-in-Sargan Test				0.3800			

Notes: Robust standard errors in parentheses. All specifications include year dummies. All variables in logs. Dependent variable: petrol consumption per petrol driven passenger car or motorcycle. Total vehicle stock refers to the sum of all fuel type passenger cars and motorcycles per driver (population age 15-64). L. denotes first lags, D. denotes first differences. For Arellano-Bond and System GMM: one step estimators, Forward Orthogonal Deviations Transformation as well as collapse and small sample option applied, internal instruments restricted from t-2 to maximum lag indicated. In System GMM the standard instruments are used for the levels equation only. Arellano-Bond-Test for first and second order serial correlation in transformed errors, H_0: no serial correlation of respective order. Sargan Test on over-identifying restrictions, H_0: instruments used are not correlated with the residuals. Difference-in-Sargan Test on the validity of additional instruments in System GMM. P-values reported for specification tests.
Significance level for parameters: $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Both Arellano-Bond GMM and System GMM pass the tests for autocorrelation (rejecting the null of no first-order autocorrelation, but not for second-order autocorrelation) as well as the Sargan test on instrument validity. The System GMM also passes the Difference-in-Sargan test on the validity of additional instruments. Yet, both may suffer from a large instrument count compared to the number of groups, i.e. countries, in the sample, though the instrument set has already been restricted by limiting lag length and collapsing the instrument matrix.

The coefficient of the lagged dependent variable shows that petrol consumption behavior is highly persistent, with the true persistence coefficient lying between 0.95 (OLS) and 0.82 (FE). The estimated coefficient for the Arellano-Bond estimator falls outside this range, indicating that this estimation procedure is not well suited for the given highly persistent data, as lagged first differences may provide low power for instrumentation. The System GMM estimator, benefiting from additional information included in the level equation, yields a parameter for the lagged dependent variables that falls inside the OLS-FE coefficient range. Interestingly, the point estimates of the other coefficients, as well as the LRM for both Arellano-Bond and System GMM, are similar to those obtained with the FE model, indicating that the estimation results for petrol are not very sensitive to the estimator choice. This finding suggests that our time dimension is sufficiently large to attenuate the Nickel bias of the FE estimation. Further scrutinizing the dynamics, we find that all estimators clearly suggest that half of the total effect occurs already in period one after the shock, as indicated by the median lag length. The effect in period five ranges between -0.38 and -0.5. The Error Correction form of the model reveals additional information about the existence of a long-run relationship and the adjustment speed towards this long-run relationship reflected by the coefficient of the lagged consumption in the ECM. As expected, this Error Correction Rate is negative for all three estimators shown, and significant for FE and Arellano-Bond. This indicates that we indeed observe an adjustment behavior back to the long-run relationship. For instance, the Fixed Effects estimator implies that consumption – in response to a 1% fuel price increase – will decline in the long run by 0.58% (LRM) and, more precisely, at a rate of 18% per year (error correction rate). Thus, the speed of adjustment tells us that consumption will decrease by 0.10% in t+1, by 0.09% in t+2, by 0.07% in t+3, and so forth until consumption will have returned to the long-run state after the price shock. The explicit inclusion of first differences in the ECM provides further evidence that the estimated price elasticity does not stem from spurious correlation.

As most of the previous literature estimating petrol price elasticities has relied on the more restrictive Partial Adjustment Model (PAM), in Table 2 we contrast our estimates that allow for first-order dynamics with those from the widely applied PAM (see Table C-1 in the Appendix for point estimates). The short-run effect in the PAM is indeed much lower due to the exclusion of the lagged price variable. As described above, the first-order dynamics ADL model reveals a strong immediate price response which is then attenuated in the following period. While the PAM seems to *under*estimate the short-run effect, it seems to slightly *over*estimate the long-run effect compared to the results based on the first-order dynamics ADL model. This shows that imposing invalid restrictions on dynamics causes a bias in the estimated fuel price elasticities, both in the short and the long run.

Table 2: Comparing dynamics for petrol price elasticity estimates of first-order ADL and PAM

PETROL	*ADL with first-order dynamics*			*Partial Adjustment Model*		
	Fixed Effects	Arellano-Bond GMM	System GMM	Fixed Effects	Arellano-Bond GMM	System GMM
Short-run	-0.248**	-0.239*	-0.276***	-0.140**	-0.125+	-0.075+
	(0.079)	(0.083)	(0.059)	(0.041)	(0.065)	(0.036)
Long-run (LRM)	-0.580*	-0.565**	-0.554*	-0.629*	-0.645*	-0.568*
	(0.221)	(0.141)	(0.236)	(0.215)	(0.261)	(0.203)
Error Correction Rate	-0.180**	-0.268+	-0.087			
	(0.048)	(0.131)	(0.079)			

Results for the short-run and long-run price elasticity, based on the Autoregressive Distributed Lag (ADL) Model with first-order dynamic (Table 1) the Partial Adjustment Model (Table C-1 in the Appendix, including additional estimation results for the bias corrected Least Square Dummy Variable Estimator). Standard errors in parentheses.
Significance levels: + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.6.2. Price elasticity of diesel demand

Table 3 shows the results for the diesel price elasticity, using again both the first-order ADL specification as well as the corresponding Error Correction form. As for petrol, the coefficient of lagged diesel consumption estimated by Arellano-Bond falls outside the range defined by FE and OLS. The System GMM estimate, however, remains inside the range although it is very close to the upper bound, indicating a very high persistence. Across estimation procedures, the point estimates for contemporaneous and lagged price effects are again close to each other with Arellano-Bond and System GMM being closer to OLS than to FE. The immediate effect of a one percent price increase for diesel in period t yields a reduction between 0.17% and 0.21% in the diesel consumption in the same period. The effect is again partially offset in the second period through the positive effect of the lagged price. However, the long-run price elasticity (LRM) estimate differs strongly between estimators. This finding is due to the high persistence in the lagged dependent variable, which results in very high long-run effects. For instance, the System GMM estimate amounts to -175%. The large estimated median lag lengths for both GMM IV estimators reveals that these suffer from weak instruments, due to very high persistence, leading to implausibly long-lasting adjustment processes. Calculating the effect in period five shows that the range between estimators then narrows down considerably to between –0.44 and –0.55. We discuss underlying reasons and potential methodological issues in more detail in the next section.

For diesel, the Error Correction term, as expected, is also negative, indicating an adjustment process back to the long-run relation. However, the EC-term is only statistically significant for FE and is very close to zero for Arellano-Bond and System GMM due to the high persistence. While the estimated effects for the vehicle stock are again in line with expectation, only the Fixed Effects estimator yields the expected positive long-run income effect (see Table C-5 in the Appendix for long-run elasticity estimates of income and vehicle stock). Though both Arellano-Bond and System GMM pass the tests for autocorrelation and over-identifying restrictions, the counterintuitive results for the income elasticity in combination with implausibly high long-run diesel price elasticities, indicate that there might be deeper methodological issues when estimating diesel demand. We will address these in the next section.

Table 3: Estimation results for diesel consumption

DIESEL	*Autoregressive Distributed Lag Model*				*Error Correction Model*		
	OLS	Fixed Effects	Arellano-Bond GMM	System GMM	Fixed Effects	Arellano-Bond GMM	System GMM
L. consumption	0.970***	0.811***	0.977***	0.966***	-0.189**	-0.023	-0.034
per vehicle	(0.013)	(0.051)	(0.094)	(0.128)	(0.051)	(0.094)	(0.128)
diesel price	-0.197	-0.169*	-0.206*	-0.195*			
	(0.143)	(0.076)	(0.088)	(0.088)			
L.diesel price	0.138	0.044	0.130	0.136	-0.124*	-0.076*	-0.059*
	(0.135)	(0.092)	(0.107)	(0.092)	(0.054)	(0.029)	(0.025)
D.diesel price					-0.169*	-0.206*	-0.195*
					(0.076)	(0.088)	(0.088)
GDP	0.885***	1.058***	0.799***	0.893*			
	(0.243)	(0.184)	(0.182)	(0.392)			
L.GDP	-0.919***	-0.921**	-0.819***	-0.926*	0.136	-0.020	-0.033
	(0.242)	(0.255)	(0.184)	(0.317)	(0.190)	(0.162)	(0.086)
D.GDP					1.058***	0.799***	0.893*
					(0.184)	(0.182)	(0.392)
total vehicle	-1.357***	-1.294***	-1.433***	-1.356***			
stock	(0.255)	(0.229)	(0.290)	(0.285)			
L. total vehicle	1.313***	1.230***	1.420***	1.311***	-0.065	-0.013	-0.046
stock	(0.261)	(0.232)	(0.271)	(0.216)	(0.148)	(0.119)	(0.113)
D. total vehicle					-1.294***	-1.433***	-1.356***
stock					(0.229)	(0.290)	(0.285)
Constant	0.688*	-0.743		0.691**	-0.864		0.691**
	(0.294)	(1.194)		(0.225)	(1.239)		(0.225)
price shock dynamics							
LRM	-1.933	-0.659	-3.251	-1.753	-0.659	-3.251	-1.753
period 5 effect φ_5	-0.45	-0.49	-0.55	-0.44	-0.49	-0.55	-0.44
median lag length	20	2	27	17	2	27	17
# observations	253	253	237	253	253	237	253
# instruments			35	38		35	38
max IV lag			9	10		9	10
AB-test (AR1)			0.0125	0.0059		0.0125	0.0059
AB-test (AR2)			0.1403	0.1439		0.1403	0.1439
Sargan Test			0.2760	0.2135		0.2760	0.2135
Diff-in-Sargan Test				0.3878			

Notes: Robust standard errors in parentheses. All specifications include year dummies. All variables in logs. Dependent variable: log diesel consumption per diesel driven passenger car or lorry. Total vehicle stock refers to the sum of all fuel type passenger cars, motorcycles and lorries per driver (population age 15-64). L. denotes first lags, D. denotes first differences. For Arellano-Bond and System GMM: one step estimators, Forward Orthogonal Deviations Transformation as well as collapse and small sample option applied, internal instruments restricted from t-2 to maximum lag indicated. In System GMM the standard instruments are used for the levels equation only. Arellano-Bond-Test for first and second order serial correlation in transformed errors, H_0: no serial correlation of respective order. Sargan Test on over-identifying restrictions, H_0: instruments used are not correlated with the residuals. Difference-in-Sargan Test on the validity of additional instruments in System GMM. P-values reported for specification tests.

Significance level for parameters: $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.6.3. Accounting for potential endogeneity of the fuel price

As discussed in Section III, more recent research has raised concerns that the assumption of exogenous fuel prices might be violated due to feedback effects triggered by demand peaks causing price elasticity estimates to be biased towards zero (Davis and Kilian 2011; Burke and Nishitateno 2013; Kim, Han, and Moon 2011). With this in mind, in Table 4 and Table 5 we contrast the price elasticities estimated above, assuming exogenous prices, with estimates that instrument fuel prices with taxes to account for the potential endogeneity of the contemporaneous price for petrol and diesel, respectively. In the FE estimation, the contemporaneous price is instrumented by the contemporaneous fuel excise tax rate. In the Arellano-Bond and System GMM the structure of the estimators allowing for internal as well as external instruments is exploited by using lagged prices (lag t-2) and the fuel tax rate as instruments (see Appendix Tables C-3 and C-4 for the complete regression results accounting for endogeneity).

Table 4: Comparing dynamics for petrol price elasticity estimates for ADL assuming exogenous prices with ADL accounting for endogeneity of prices

Petrol price elasticity	*exogenous price*			*price instrumented with tax*		
	Fixed Effects	Arellano-Bond GMM	System GMM	FE-IV	Arellano-Bond GMM	System GMM
Short-run	-0.248**	-0.239*	-0.276***	-0.391***	-0.252	-0.066
	(0.079)	(0.083)	(0.059)	(0.114)	(0.201)	(0.209)
Long run (LRM)	-0.580*	-0.565**	-0.554*	-0.742***	-0.572**	-0.460*
	(0.221)	(0.141)	(0.236)	(0.204)	(0.178)	(0.201)
Median lag length	1	1	1	0	1	3
Effect in period 5	-0.46	-0.50	-0.38	-0.61	-0.52	-0.32

Results for the short-run and long-run price elasticity, based on the Autoregressive distributed Lag Model with first-order dynamic assuming exogenous prices (Table 1) and instrumenting price endogeneity by petrol excise taxes (Table C-3 in the Appendix). Standard errors in parentheses.
Significance levels: $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

For petrol consumption (Table 4), the short-run and long-run petrol price elasticity, as well as the 5 year effect, are higher in absolute value if endogeneity is accounted for in the Fixed Effects-IV estimation. While for Arellano-Bond, the results differ only slightly, the System GMM estimates are lower if endogeneity is accounted for. Overall, the results with and without instrumentation of fuel prices do not seem to show consistent indications that petrol price endogeneity is indeed an issue for our data. Likewise, households' responses to a change in the petrol excise tax rate do not seem to differ substantially from the response to overall price changes for petrol. This is probably due to the fact that our results are based on yearly data. Petrol is primarily consumed by private households and demand peaks are therefore most likely caused by public holidays. Davis and Kilian (2011) indeed use monthly petrol consumption data for a panel of U.S states, which is more likely to reflect short-run seasonal price hikes. In annual data the feedback effect of these annually recurring holiday price hikes are mitigated through aggregation over the year. Thus price endogeneity seems less of a concern for petrol demand.

For diesel consumption, the price elasticity estimates, with and without diesel tax instrumentation, differ more strongly than those for petrol (see Table 5). The diesel price elasticity estimates for all estimators in the short run are much higher in absolute terms for the models accounting for endogeneity. The estimates for the long-run multiplier, which exhibited a wide spread without instrumentation, lie in a more plausible range, and are much closer together when controlling for endogeneity. The point estimates for the lagged dependent variable (see Table C-4 in the Appendix) show that the very high persistence found in the exogenous model, which had a large impact on the LRM magnitude, is reduced when controlling for endogeneity. The calculated expected effect after 5 years corroborates that the large LRMs are mostly caused by the very high persistence estimate. In fact, the 5-year effect almost doubles in magnitude if endogeneity is accounted for, indicating that the estimated effect is likely to be biased towards zero in estimations that assume exogenous diesel prices.

Table 5: Comparing dynamics for diesel price elasticity estimates for ADL assuming exogenous prices, with ADL accounting for endogeneity of prices

Diesel price elasticity	*exogenous price*			*price instrumented with tax*		
	Fixed Effects	Arellano-Bond GMM	System GMM	FE-IV	Arellano-Bond GMM	System GMM
Short-run	-0.169*	-0.206*	-0.195*	-0.654**	-0.616***	-0.720**
	(0.076)	(0.088)	(0.088)	(0.234)	(0.138)	(0.220)
Long-run (LRM)	-0.659	-3.251	-1.753	-1.131*	-1.290	-1.037
	(0.403)	(12.944)	(6.236)	(0.457)	(0.924)	(1.059)
Median lag length	2	27	17	0	1	0
Effect in period 5	-0.49	-0.55	-0.44	-0.94	-0.97	-0.86

Results for the short-run and long-run price elasticity, based on the Autoregressive distributed Lag Model with first order dynamic assuming exogenous prices (Table 3) and instrumenting price endogeneity by diesel excise taxes (Table C-4 in the Appendix). Standard errors in parentheses.
Significance levels: $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

What implications do these results have? Our finding of the importance of allowing for first-order dynamics indicates that the potential of fuel tax reforms in influencing short-run fuel demand has been underestimated in most prior studies. Moreover, our findings provide evidence that endogeneity concerns might be of more relevance for diesel than for petrol demand. While petrol vehicles are dominated by passenger cars and thus by the consumption patterns of private households, the share of lorries in the diesel vehicle fleet is much more substantial, for example with temporarily up to 65% in Denmark, and it seems fair to argue that these lorries are mostly used by businesses. Moreover, many companies prefer to use diesel passenger cars, as their fuel efficiency is favorable for long distances. In contrast to petrol, the diesel demand might therefore be affected by economic factors that we do not consider directly in the model, causing feedback effects on the diesel price. Accounting for this feedback effect, we find that diesel consumption is more price elastic (both in the short and long run as measured by the impact in period 5) than petrol consumption. One explanation, apart from the endogeneity bias, is that instrumenting with diesel excise taxes yields elasticity estimates that reflect the demand response to a tax increase as opposed to general price fluctuations. As tax changes are often (i) accompanied by high media coverage raising awareness and (ii) perceived to be of higher persistence, it seems reasonable that consumers may react more strongly to tax increases than to market price volatility (Scott 2012). Owners of commercial vehicles, which constitute a large proportion of diesel vehicles, probably account for fuel tax increases in their cost calculations and may consider changing to other modes of transport. Private households - which dominate petrol demand – may, in contrast, be more bound by habit persistence in their price response.

Note, however, that our data does not allow the fuel consumption of passenger cars to be distinguished from consumption by commercial vehicles. As the petrol vehicle stock is dominated by passenger cars, the petrol price elasticity is likely to primarily reflect the behavior of private car users, i.e. households. In contrast, the share of commercial vehicles – company cars or lorries – is much more substantial for diesel. Our estimates for diesel, therefore, reflect the average response of a diesel-driven vehicle, while private drivers and commercial drivers will likely differ in their response. Moreover, we assume symmetry in responses to price increases and decreases as well as parameter homogeneity as discussed in section 4.5. Due to data constraints, we also do not account for potential spillover effects between countries as suggested by Bond & Eberhardt (2013). However, we partially account for cross-sectional dependence by capturing common shocks in the year-specific time dummies.

4.7. Emission impacts of fuel tax reform scenarios

Two recent events – the Paris Agreement on Climate Change and the diesel emission scandal - motivate us to exploit the obtained information on fuel price elasticities in order to evaluate the effect on CO_2 and air pollution emissions of two hypothetical fuel pricing policy scenarios.

First, at the climate negotiations in Paris in December 2015, the EU and Norway[21] submitted Intended Nationally Determined Contributions (INDCs) committing to an economy wide reduction in total domestic GHG emissions of at least 40% by 2030 compared to 1990 (European Union 2015, Norway 2015). Although the sectoral distribution of mitigation efforts, as well as the effort sharing between countries, remain to be discussed in the EU, it is clear that the transport sector will need to make a major contribution given its large share in total emissions. The EEA TERM report concludes that decarbonizing the transport sector will require complementary pricing policies stimulating behavioral changes (EEA, 2015b, p.59).

Second, the fraud scandal in diesel car test cycles, followed by the discovery that the majority of diesel vehicles on the road fail to meet air pollution emission standards, has relaunched a political and public debate about environmental and health concerns with respect to diesel vehicles (New York Times, 2016, Reuters, n.d., EEA 2015b). Historically - arguing that the higher fuel efficiency of diesel cars would be beneficial for efforts combating climate change - many countries in Europe have supported the dieselization process by granting favorable tax treatments to diesel in recent decades. Yet, in fact, the carbon content of one liter of diesel is higher than that of petrol, rendering tax breaks *per liter* diesel highly questionable from a climate perspective (Harding 2014).[22] Moreover, despite improvements in

[21] Norway states that it will achieve its INDC either jointly with the EU or separately.
[22] Table D-1 (Appendix) shows that the CO_2 content per liter of fuel is actually higher for diesel compared to petrol. Yet, due to their higher fuel efficiency, diesel vehicles tend to emit less CO_2 *per kilometer* driven compared to a

technology and catalytic converters, diesel cars emit more NO_x and $PM_{2.5}$ per liter combusted than petrol vehicles (see Table D-2 in the Appendix). The EU has so far mostly relied on emissions standards to address air pollution from road transport. Efforts have shown limited success in staying below concentration limits in many cities, and discrepancies between exhaust measured in real driving conditions against that of approval test cycles have even increased (ICCT 2014; ICCT 2015c; Carslaw et al. 2011).

While the recent public debate on the diesel scandal was dominated by air pollution concerns (despite the finding that CO_2 emission levels are also often higher than car producers claim (ICCT 2015a)), the debate around the Paris Agreement mainly concerns CO_2 emissions. However, reforms in the transport sector, targeting either externality, will obviously have implications also for the other externality, yielding potential for synergies.

4.7.1. The policy scenarios

This section presents two policy scenarios of two distinct hypothetical fuel tax reforms in more detail, with scenario A focusing on diesel taxation and scenario B focusing on the carbon content of the fuels.

Policy Scenario A: Abandoning tax advantages for diesel

As a reaction to the diesel emission scandal, several authorities have called to abandon the favorable tax treatment of diesel. In line with this, the French government has recently announced plans to phase out tax breaks for diesel within the next 5 years (Reuters 2015). Similarly, the German Umweltbundesamt (UBA) has proposed an adjustment of the diesel excise tax level to that for petrol (Umweltbundesamt 2015). Inspired by such proposals, we assess a tax reform scenario of abandoning the diesel tax advantage in 2015.

Figure 3a) shows that in most sample countries excise tax levels are lower for diesel than for petrol. Only in the UK and Switzerland is diesel taxed equally or more than petrol. Figure 3b) depicts the associated diesel price increases given an adjustment of the excise tax level for diesel to that of petrol in the respective country, accounting for national value added taxes (VAT). Due to its high tax differential, the highest diesel price increase would take place in the Netherlands, amounting to over 25% of the 2013 diesel price while most East European countries exhibit much lower tax differentials. Diesel taxes for Switzerland and the UK remain unchanged in our scenario.

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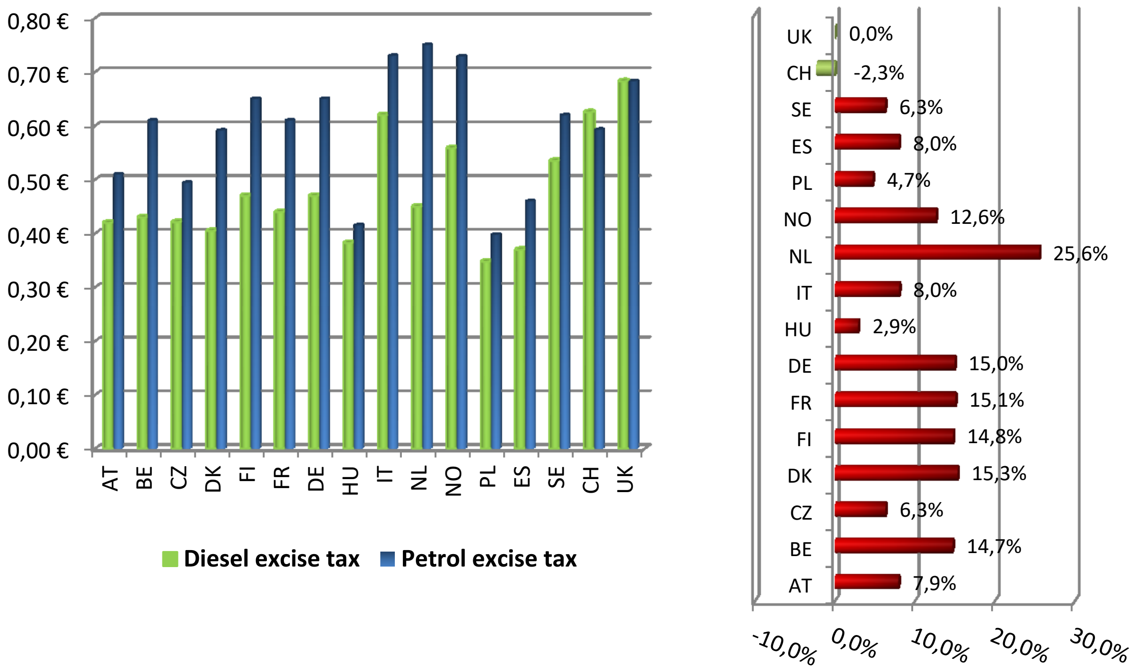
petrol vehicle of similar size and weight. However, diesel vehicles tend to be bigger, heavier and driven longer distances, which almost outweighs efficiency advantages per kilometer (Schipper and Fulton 2013).

Figure 3: POLICY SCENARIO adjust diesel excise tax. Current excise tax levels on diesel and petrol (2013) and resulting price change if excise taxes for diesel were adjusted to petrol taxation levels

a) Diesel and petrol excise tax levels in € per liter in 2013

b) Change in diesel price if taxation level was adjusted to petrol excise tax



Note: Price changes include the increase in the absolute Value Added Tax (VAT) due to the increase in the excise tax level accounting for country-specific VAT tax rates. Data source: (IEA 2014)

Policy Scenario B: Introducing a CO_2 –content based tax

In our second policy scenario, we assume that each EU sample country and Norway introduce a carbon content based tax per liter of diesel and petrol of 50€/tCO2 in addition to the pre-existing tax level. [23] Considering the different carbon content of diesel and petrol this would correspond to a CO_2 tax of 0.12€/liter for petrol and 0.13€/liter for diesel. While the appropriate magnitude of such corrective CO_2 taxes remains disputed, our assumed CO_2 tax lies well within the range of estimates on the Social Costs of Carbon (SCC), i.e. the welfare loss associated with an additional ton of CO_2 emitted, as analyzed in various studies and meta-analyses (Pearce 2003; Anthoff and Tol 2013; Tol 2011; Tol 2008). The Fifth Assessment Report (AR5) of the IPCC documents average SCC estimates of around 241 USD per ton of carbon for studies published after 2007 (post-AR4) (Arent et al. 2014)(IPCC 2014). This corresponds to around 65 USD/tCO_2 or 50€/tCO_2 (2013). The resulting price changes for each country are shown in the Table D-5 (Appendix).

[23] For the analysis we assume that pre-existing excise taxes are prompted by reasons other than climate change considerations. However, some countries may already partly capture the climate externality in their tax rates.

4.7.2. Assessment approach

For both scenarios, we calculate the effect on emissions of fine particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x) and carbon dioxide (CO_2). Moreover we discuss how the two policy reforms would contribute to achieving the EU's climate policy goals in 2020. For this analysis we proceed in two steps that are subsequently explained in more detail.

Step 1: Fuel tax-induced price changes and associated demand responses

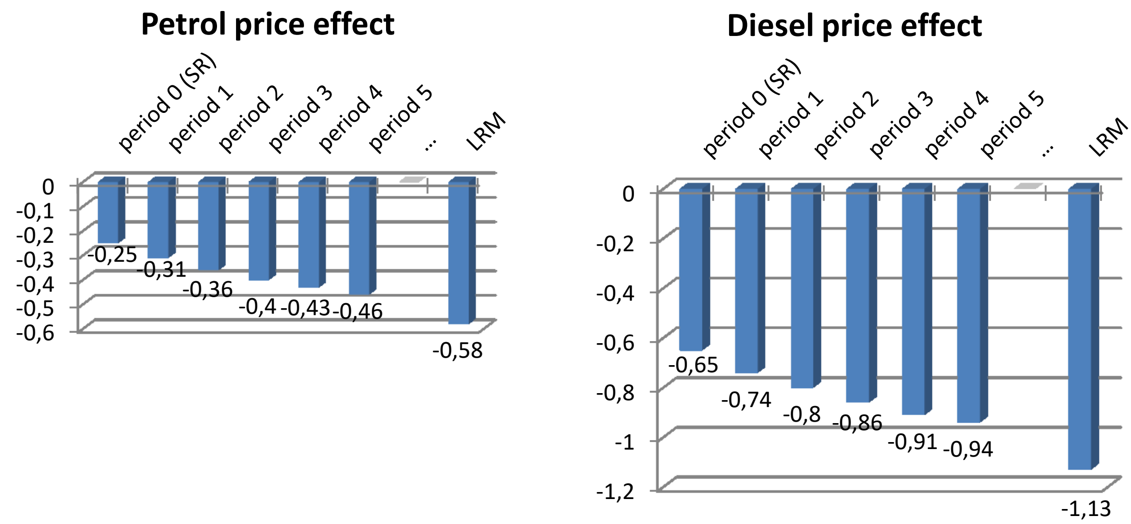
First, we exploit our estimation results on petrol and diesel price elasticities from section 4.6 to assess the relative change in diesel and petrol demand in response to hypothetical price changes, both in the short-run and in the year 2020.

In each policy scenario, we introduce fuel pricing policies which lead to hypothetical country-specific price changes compared to the current (2013) fuel price levels. Our estimates for the fuel price elasticity give us empirically grounded information about the typical response and dynamics of fuel demand to petrol and diesel price changes, for our sample-countries in Europe. The short-run effect reflects the immediate response to the pricing policies. The cumulative effect φ_R allows us – in contrast with the LRM - to calculate the demand response for a *specific* longer term period of interest. Assuming that the fuel pricing policies were introduced in 2015, we use the five-year effect to anticipate the demand response for the year 2020. Note that the policy Scenario A entails strong price adjustments to level the large tax differential between diesel and petrol excise taxes in several countries. This may interfere with the applicability of our elasticity estimates, which reflect the response for *marginal* changes in prices. However, we believe that presenting results for all countries can provide illustrative information about the potential impact of fuel tax adjustments. Generally, the projections presented should not be seen as an exact prediction but rather as an indication of the expected effect.

To reduce complexity, we choose to present scenario results based on a single estimator, which we perceive as the most representative for diesel and petrol, respectively. The elasticity estimates based on the Fixed Effects estimator for both petrol and diesel mostly fall in the middle of Arellano-Bond GMM and System GMM, i.e. they provide a moderate estimate of the fuel demand sensitivity. Moreover, the range of results indicates that the Nickel bias in the Fixed Effects estimator is not severe due to the relatively large time dimension. In addition, we have shown that endogeneity may be more of a concern for diesel than for petrol demand. We therefore base our policy scenarios on the Fixed Effects estimations, for petrol assuming exogenous prices, while for diesel we account for potential price endogeneity.

Figure 4 illustrates the dynamic (cumulative) fuel demand response over time for petrol and diesel respectively for a 1% increase in the respective fuel price based on the selected estimators.

Figure 4: Petrol and diesel price elasticity dynamics for different periods after the price change (based on FE results for petrol and FE-IV for diesel)



Based on these relative demand changes, we calculate the absolute changes in diesel and petrol consumption for the sample countries. Our data provides information on the total amount of diesel and petrol that has been consumed in the sample countries up to the year 2013. Based on the price-induced relative changes in consumption in the short-run and 2020, obtained in step one, we calculate the corresponding reduction in consumption of diesel and petrol in each sample country for the policy scenarios. Note that the results assume that income, as well as vehicle stocks, remain unchanged. In the light of this, the results can be interpreted as changes compared to a business-as-usual scenario, i.e. without tax reform. Moreover, we assume that fuel substitution effects are negligible for the time scale under consideration. Tables describing the demand changes due to the hypothetical tax reforms are presented in the appendix. [24]

Step 2: Impact on carbon emissions, air pollution exhaust and tax revenues

Second, using the obtained information on reduced absolute fuel consumption, we calculate the expected impact of the fuel tax reform scenarios on carbon emissions, air pollution, and tax revenues.

For carbon emissions, we apply the emission factors shown in Table D-1 in the appendix. Due to the chemical process of burning fossil fuel, the carbon content of a liter of diesel and petrol reduces to a constant. The amount of CO_2 emitted per liter of fuel, assuming complete combustion, thus only depends on the type of fuel, and not on other external factors such as vehicle type or temperature. We concentrate on CO_2, since other GHGs play only a minor role with respect to road transport. We assess the expected change in CO_2 emissions from road transport compared to the emission level resulting

[24] Table D-4 shows the relative and absolute changes in diesel consumption for scenario A. Table D-5 shows the CO_2 tax induced fuel price changes (accounting for VAT adjustments) and the expected impact on fuel consumption for Scenario B.

from the reported fuel consumption for 2013 (‘status quo’). Moreover, we assess how the policy scenario would contribute to achieving the EU’s 2020 climate policy targets.

For air pollution, we concentrate on avoided exhaust emissions for fine particulate matter ($PM_{2.5}$) and nitrogen oxides (NO_x). In contrast to CO_2 emissions, the calculation of expected exhaust emissions for the air pollutants of interest – NO_x and $PM_{2.5}$ – is less straight forward, as the emission factors depend on various factors such as combustion technology, motor temperature, driving behavior and the use and quality of catalytic converters. However, using data-based model estimates, the EEA-EMEP provides average vehicle type emission factors based on the country specific vehicle fleet composition for each European country (Ntziachristos and Samaras 2014). We use this information to calculate the country-specific exhaust emission factors for diesel and petrol based on our data of the vehicle stock composition from EUROSTAT[25]. The resulting emissions factors per kg of fuel can be found in Table D-2 (Appendix). We focus on exhaust-emissions as the in-depth investigation of non-exhaust emissions from road abrasion, dust or tire wear as well as secondary PM - though appealing - is beyond the scope of our analysis.

4.7.3. Implications for CO_2 emissions and EU climate policy targets

Changes compared to status quo (2013) CO_2 emission levels from road transportation

The first column of Figure 5 shows the expected reductions in CO_2 emissions for Scenario A (diesel excise tax adjustment) and B (50€/tCO2 carbon tax) relative to the CO_2 emission levels in 2013 from diesel and petrol use. In Scenario A, countries with the highest price differential between diesel and petrol excise taxation (most notably, the Netherlands) would experience the highest reduction in carbon emissions, of up to -14.7%, in 2020. Belgium and France could also reduce CO_2 emissions considerably due to their large share of diesel consumption in total fuel consumption[26]. As diesel tax breaks are much less pronounced in the Eastern-European sample countries, emissions reduction would remain limited in these countries. In contrast, in Scenario B, the expected CO_2 emissions reductions would be distributed more evenly, ranging between -7.2% in Sweden and around -10% in France, Spain and Poland. In this policy scenario the Eastern-European countries would also face significant CO_2 reductions. The latter finding highlights that a diesel tax reform (Scenario A) would shift the burden away from these economically weaker countries in the sample. Another interesting finding emerging from the comparison of Scenarios A and B is that in many countries the phase out of diesel tax breaks can have as strong an effect on CO_2 as the 50€/tCO_2 carbon tax.

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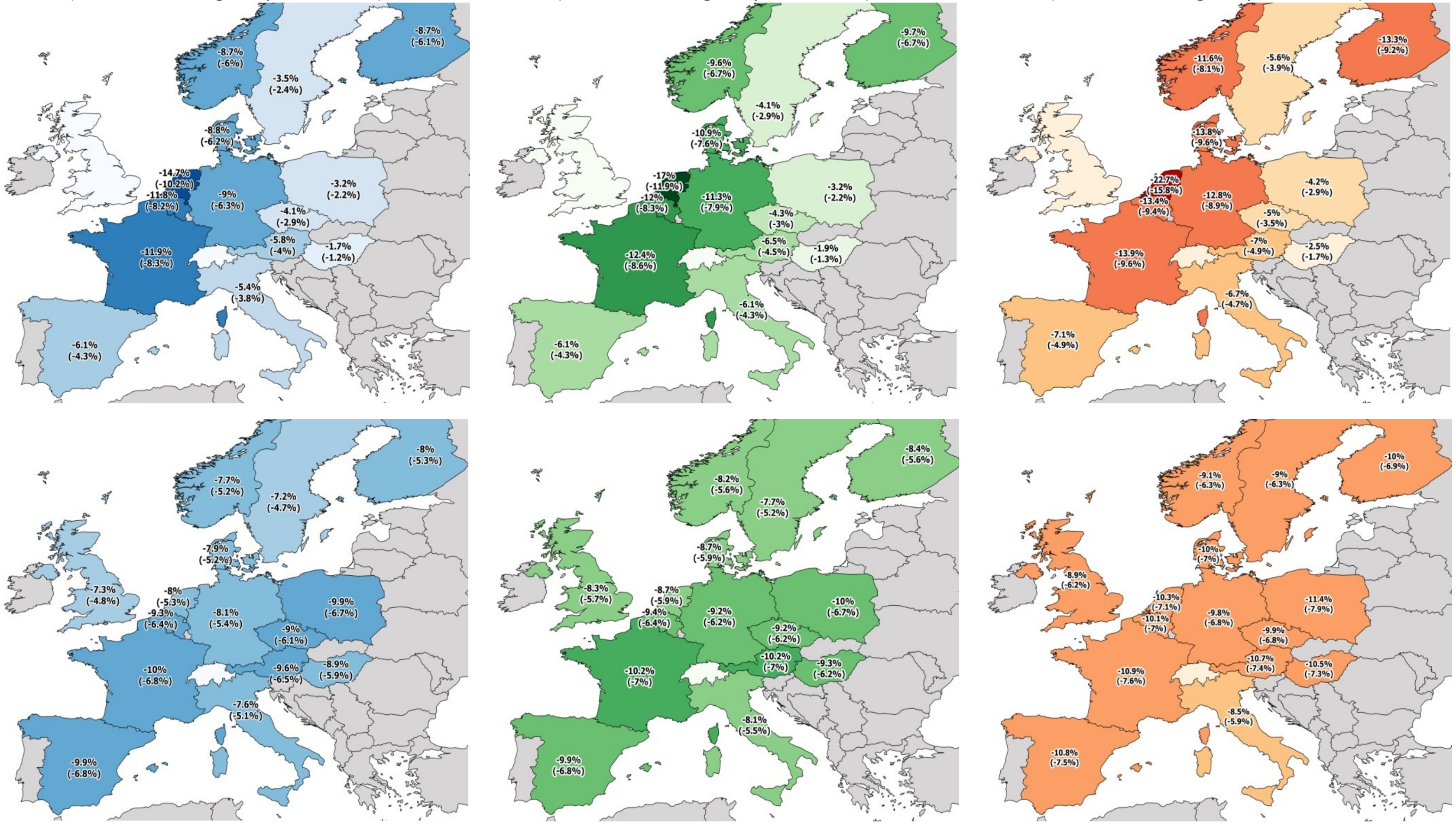
[25] We assume that shares of vehicle types (passenger cars, motorcycles, lorries, buses and heavy duty vehicles) reflect fuel consumption shares. This assumption is a necessary simplification which may underestimate the true emission factors, as larger (mostly commercial) vehicles are likely to be covering more kilometers and consuming more fuel per kilometer; but at the same time they exhibit higher emission factors per kg of fuel. Moreover, note that the EMEP-EEA emission factors are based on 2005 vehicle fleet composition (Ntziachristos and Samaras 2014) while we apply most recent available data (mostly 2011) for vehicle shares.

[26] See Table D-3 on shares of diesel and petrol use in aggregated fuel consumption.

Figure 5: Relative changes in 2020 compared to status quo (2013) emission levels for CO_2, NO_x and $PM_{2.5}$ for each policy scenario respectively

	ΔCO_2 in 2020 **% change compared to 2013** (short run change in parenthesis)	**ΔNO_x in 2020** **% change compared to 2013** (short run change in parenthesis)	**$\Delta PM_{2.5}$ in 2020** **% change compared to 2013** (short run change in parenthesis)
POLICY SCENARIO A (adjusting diesel excise taxes)			
POLICY SCENARIO B (carbon tax of 50€/tCO_2)			



Note: Results refer to calculated emissions from diesel and petrol consumption for road transport based on EUROSTAT fuel consumption data for 2013, own elasticity estimates and emission factors per liter (see Appendix). Reported changes assume that GDP per capita and vehicle stocks per driver remain unchanged.

Note that similar findings emerge if we compare the impacts on CO_2 emissions in absolute terms – as reductions in tCO_2 per capita (see Figure D-1 and Table D-6, Appendix). A notable difference is, however, that the highest absolute emissions reduction for Scenario B would stem from Austria (-0.25tCO2/capita in 2020); this is mainly due to the country's relatively high per capita fuel consumption. In Scenario A, the Netherlands would still exhibit the highest absolute reductions with -0.27tCO_2/capita due to its large price change for diesel. Belgium and France would also exhibit relatively high reductions in their absolute CO_2 emissions per capita, amounting to -0.25tCO_2 (BE) and -0.21tCO_2 (FR), which can largely be attributed to their large share of diesel use (see Table D-3 in the appendix).

Note that the indicated changes in emissions refer to annual emissions, i.e. *in* 2020 and not to accumulated emission reductions *up to* 2020. Due to the strong expected immediate impact, as reflected by the short-run effect (in parenthesis), the cumulative avoided emissions up to 2020 could be substantial.

Contribution of fuel tax reforms to EU climate policy targets

So far we have focused on assessing CO_2 emission reductions compared to the status quo (2013). In the following we analyze how the policy scenarios perform with respect to the EU's climate change mitigation targets for the year 2020. To this end, we discuss two different climate change mitigation targets of the EU that have specific relevance to the transport sector.

First, the 2020 EU climate and energy package defines GHG emission reduction targets for the year 2020 compared to 2005 emissions, defining a specific target for sectors not covered by the EU ETS which is relevant for road transport. In its Effort Sharing Decision (ESD) the EU member states have agreed on country specific emission targets varying between -20% and +20% based, inter alia, on relative GDP per capita; the EU-28 wide target is $ESD_{2005}^{2020} = -10\%$ (EU Parliament and EU Council 2009).

Second, in its 2011 White Paper (WP) for the Transport Sector (European Commission 2011b) the European Commission states that, in order to achieve the EU's 2°C long-term target of 80-95% below 1990 levels by 2050 for GHG emissions (European Commission 2011a), the transport sector must reduce GHG emissions by at least 60% by 2050 compared to 1990 ($WP_{1990}^{2050} = -60\%$) (European Commission 2011b). Assuming equal absolute emission reductions per year (from 2015 onwards) until 2050, we calculate that the corresponding transportation emission targets for 2020 for different baselines would be $WP_{2013}^{2020} = -9.3\%$, $WP_{2005}^{2020} = -17.8\%$ and $WP_{1990}^{2020} = +3.7\%$. Comparing the more recent $WP_{2005}^{2020} = -17.8\%$ to the corresponding 2009 $ESD_{2005}^{2020} = -10\%$, it is obvious that the ESD targets for 2020 are not likely to be sufficient in order to limit temperature increase to well below 2°C as agreed in the Paris Accord.

A comparison of 2013 emissions and ESD_{2005}^{2020} targets in Table 6 shows that the majority of EU countries in the sample would currently not fulfill their targets. Only the Czech Republic, Hungary, Italy and Spain can already over-fulfill their targets; these countries have been strongly affected by the recent economic crisis and have not yet fully recovered. Adjusting diesel excise tax levels to petrol taxation (PS A) would bring most countries that are currently falling short of ESD goals much closer to their targets. The Netherlands, France, Denmark and Belgium could then over-fulfill their targets and only Poland would still significantly miss its emission goal. In contrast, introducing a CO_2 tax of 50€/tCO_2 (PS B) would help to bring Poland much closer to fulfilling its ESD_{2005}^{2020} target. The UK and Sweden would also meet their ESD_{2005}^{2020} targets in Scenario B. Interestingly, the 50€/tCO_2 tax would not be sufficient in Finland, Germany and the Netherlands to enable them to meet their targets even in the absence of economic growth and vehicle stock effects. Assuming that most countries in the sample will exhibit GDP growth in the years to 2020, and experience rising vehicle stocks, meeting the ESD_{2005}^{2020} targets will likely require stronger policies for most countries.

While the ESD_{2005}^{2020} targets are measured against a 2005 baseline – i.e. a period before the economic crisis with GHG emissions at high levels – the White Paper (as well as the EU's INDC and 2050 roadmap) refers to 1990 as baseline. Although no country-specific reduction targets for achieving the proposed $WP_{1990}^{2050} = -60\%$ have yet been decided, the last three columns of Table 6 illustrate the development of emissions for each country in recent decades. While Germany seems to underperform compared to the 2005 baseline, it is one of the only countries in our sample, together with the UK, that exhibits an actual decrease in emissions in 2013 compared to 1990 levels. For the Czech Republic and Poland, CO_2 emission levels have more than doubled since 1990, although from a comparably low level. Adjusting diesel excise taxes (PS A) would help Finland, France, and Italy to reduce emissions relative to 1990 levels. The tax of 50€/tCO_2 (PS B) would additionally push Sweden below its 1990 levels.

Table 6: Change in CO_2 emissions from petrol and diesel combustion compared to the respective baseline

	Baseline 2005 CO_2 emissions				**Baseline 1990 CO_2 emissions**		
	in 2013	**in 2020**			**in 2013**	**in 2020**	
	Status Quo	***ESD targets***	**PS A) equal diesel tax**	**PS B) CO_2 tax of 50€/tCO_2**	**Status Quo**	**PS A) equal Diesel tax**	**PS B) CO_2 tax of 50€/tCO_2**
Austria	-8.21%	*-16%*	-13.52%	-17.04%	64.75%	55.22%	48.91%
Belgium	-5.66%	*-15%*	-16.77%	-14.44%	20.51%	6.31%	9.29%
Czech Republic	-7.36%	*9%*	-11.20%	-15.71%	118.49%	109.43%	98.78%
Denmark	-15.55%	*-20%*	-23.02%	-22.20%	11.81%	1.92%	3.01%
Finland	-4.48%	*-16%*	-12.82%	-12.12%	3.11%	-5.90%	-5.14%
France	-7.84%	*-14%*	-18.77%	-17.03%	5.49%	-7.02%	-5.03%
Germany	-2.20%	*-14%*	-10.99%	-10.14%	-3.80%	-12.46%	-11.61%
Hungary	-16.55%	*10%*	-18.01%	-23.95%	24.08%	21.92%	13.08%
Italy	-21.30%	*-13%*	-25.57%	-27.30%	0.12%	-5.32%	-7.52%
Netherlands	-7.03%	*-16%*	-20.65%	-14.45%	34.28%	14.61%	23.56%
Poland	28.41%	*14%*	24.33%	15.68%	106.71%	100.15%	86.22%
Spain	-22.60%	*-10%*	-27.36%	-30.29%	37.72%	29.26%	24.04%
Sweden	-10.94%	*-17%*	-14.06%	-17.35%	4.72%	1.05%	-2.81%
United Kingdom	-9.83%	*-16%*	-9.83%	-16.41%	-1.56%	-1.56%	-8.74%
All EU countries in sample	**-9.63%**	***-10%****	**-15.89%**	**-17.40%**	**11.08%**	**3.39%**	**1.53%**

Note: *ESD target for EU-28. Effort Sharing Decision (EU Parliament and EU Council 2009).

4.7.4. Implications for air pollution

The second and third column of Figure 5 illustrate the expected impacts of both fuel tax reform scenarios on exhaust emissions of NO_x and fine particulate matter, relative to the status quo.[27] By ending diesel tax breaks (scenario A), the Netherlands could benefit from 17% lower NO_x and over 22% lower $PM_{2.5}$ exhaust emissions in 2020. France, Germany, Belgium, Finland, Norway and Denmark could also achieve considerable emission reductions for both air pollutants of around -10% in 2020. For Finland this is mainly driven by comparably high emission factors for both NO_x and $PM_{2.5}$. In Belgium and France, the high share of diesel in fuel use substantially contributes to the considerable reductions of -12% in NO_x and over -13% for $PM_{2.5}$. Again countries with low diesel tax breaks would benefit least in terms of reduced air pollution, despite relatively high emission factors in Eastern-European countries. In contrast, with the introduction of a carbon tax (Scenario B) all countries would benefit more evenly from considerable exhaust reductions ranging from -7.7% for NO_x in Sweden up to -11.4% for $PM_{2.5}$ in Poland in 2020.

When comparing changes in air pollutant emissions in *absolute* terms per capita (see Figure D-1 Appendix), differences in country characteristics become more visible. In Scenario A, despite lower diesel tax breaks, Finland joins the Netherlands in benefiting from very high absolute reductions as Finland exhibits very high emission factors especially for $PM_{2.5}$. When introducing a carbon tax (Scenario B), Austria stands out regarding NO_x, exhibiting the highest absolute emission reductions per capita driven mostly by its high share of diesel use and its high per capita fuel consumption. Denmark and Finland would yield large NO_x reductions as they both exhibit relatively high NO_x emission factors for diesel due to their car fleet composition. For $PM_{2.5}$ (in Scenario B), the Czech Republic would exhibit the highest absolute reduction in fine particulate matter exhaust per capita due to its very high emission factor for $PM_{2.5.}$ For Scenario A, this effect is masked by the comparably low diesel price differential. While Hungary and Poland also exhibit high emission factors for both pollutants, these do not translate into over-proportionately high emission reductions due to the relatively low per capita fuel consumption in these countries.

The results also illustrate that fuel pricing reforms could considerably reduce air pollution exhaust already in the short term. While the estimates presented only relate to the direct exhaust of $PM_{2.5}$ stemming from fuel combustion of vehicles, tax-induced behavioral changes may additionally lead to a reduction in distances driven, thereby also reducing the non-exhaust emissions of PM stemming from, for example, dust swirl, road abrasion and wear of brakes and tires. Moreover, the formation of secondary PM is impacted by the concentration of precursor gases like NO_2, which is part of the family of Nitrogen Oxides (NO_x).

4.7.5 Implications for tax revenues

Implementing fuel tax reforms would also have an impact on tax revenues from fuel taxation. Table 7 shows estimates of additional tax revenues in excise taxes in the short term. We estimate that by ending

[27] Table D-7 and D-8 in the appendix compile all numbers on absolute and relative changes for NOx and $PM_{2.5}$.

diesel tax breaks, Germany and France could gain as much as €4 billion in the year of the tax reform. Italy, Spain and the Netherlands could raise their budgets by more than €1 billion. The introduction of a carbon tax of 50€/tCO_2 would yield more than €5 billion for Germany, €4 billion for France and €3.8 billion for the UK. In the carbon tax case, Poland could also earn €1.4 billion in tax revenues.

These additional tax revenues, especially in the short term, could contribute substantially to financing infrastructure for cleaner transport such as bike lanes, public transport or charging stations for electric cars. Likewise revenues could be invested in research and development or the health system.

Table 7: Additional excise tax revenues for tax reform scenarios (short run effect)

	PS A: adjusting diesel taxes in Mio €	PS B: carbon tax of 50€/tCO2 in Mio €
Austria	409	799
Belgium	918	857
Czech Republic	212	573
Denmark	305	403
Finland	314	421
France	4,046	4,089
Germany	4,131	5,470
Hungary	58	373
Italy	1,735	3,143
Netherlands	1,218	1,133
Norway	312	371
Poland	383	1,424
Spain	1,510	2,760
Sweden	255	727
United Kingdom	0	3,800

Note: Estimates refer to excise tax revenues only, additional revenues due to value added taxation (VAT) are not included here.

4.8. Concluding remarks and policy implications

Given the multiple negative externalities caused by road transportation, it is in the public interest to address fuel consumption behavior by setting corrective economic incentives. However, tangible research on the demand response of petrol and diesel consumption to pricing policies in Europe, accounting for the observed dieselization process, has so far been limited. Our analysis closes this gap; it not only accounts for the increasing share of diesel passenger cars but also includes non-passenger vehicles that have been overlooked in many previous studies.

We show that it is important and insightful to consider consumption dynamics beyond the standard Partial Adjustment Model and the Long-run Multiplier. Our analysis flexibly accommodates a first-order dynamic specification of fuel demand that allows us to scrutinize adjustment behaviors and the distribution of effects over time. We find that ignoring endogeneity may mask diesel elasticity estimates, while petrol estimates by and large remain unchanged if we instrument prices by excise taxes. Our results indicate that diesel and petrol demand - when first-order dynamics, potential endogeneity and dieselization are accounted for - are more price elastic in the short run than previous estimates for Europe based on Partial Adjustment Models imply. We provide first evidence that the diesel demand in Europe tends to be more price elastic than petrol demand, both in the long and the short run.

In contrast to most previous estimates - which imply low environmental effectiveness of fuel taxes due to inelastic demand responses - our finding of relatively price elastic short-run fuel consumption implies that complementary fuel taxes are a promising instrument to decrease fuel consumption and emissions. So far, emission and efficiency standards introduced in Europe have shown only limited success in reducing air pollution and CO_2 in the short-run, due to slow turn-over rates of vehicle fleets (Kageson 2005), limited compliance under real-driving conditions, a lack of incentives to reduce trips and distances driven and potential rebound effects. Introducing complementary fuel tax reforms would in contrast already yield significant effects in the short-run by incentivizing behavioral change in terms of reduced kilometers driven. Effects are even more pronounced in the long term with the provision of incentives for technological progress and innovation for alternative transportation types. Findings from Bonilla (2009) confirm such advantages of taxes over standards, showing that for the UK fuel economy is more responsive to fuel price changes than to imposed standards; in the long term, fuel economy is mostly driven by price induced technological progress and not by consumer preferences for more efficient cars. Reduced distances also mitigate non-exhaust emissions from, for example, dust swirl, road abrasion and tire or break wear.

Our evaluation of the impacts of fuel pricing policies on CO_2, $PM_{2.5}$ and NO_x emissions from road transport illustrates that complementary fuel taxes could make a significant contribution to reducing exhaust emissions of health damaging air pollutants while at the same time contributing substantially to achieving climate change mitigation goals. We investigate two hypothetical policy scenarios: a) the removal of the preferential tax treatment for diesel and b) the introduction of a carbon content based tax of 50€/tCO_2 per liter of fuel. We find that in both policy scenarios the EU climate policy goals for 2020 would be achieved for the current level of income and vehicle stock. However, the estimated positive income elasticity as well as observed trends of steeply increasing vehicle stocks in some countries suggest that fuel taxation policies would probably need to be more ambitious to outweigh future GDP growth and car purchases if climate targets are to be met.

As there are pre-existing fuel taxes in all sample countries, which at least partially aim to internalize negative externalities, national governments will have to decide on how best to restructure fuel taxation based on more detailed research on country specific circumstances. In contrast with standards, the revenues raised through taxation can be earmarked for reinvestment into public transport, clean transport infrastructure (e.g. bike lanes, e-mobility), the health system, research and development for clean technologies or to mitigate potential regressive effects of fuel taxation. Though taxation is finally decided by national governments, to avoid competitive disadvantages and “leakage” of fuel purchase to neighboring countries, the coordination of fuel pricing policies within Europe seems to be the preferable option (Frondel, Schmidt, and Vance 2011). The EU could build on its European Energy Tax Directive (Energy Tax Directive 2003/96/EC) to adjust minimum taxation requirements for fuel, especially for diesel. As taxation is imposed *per liter*, the fuel efficiency advantage of diesel cars per km driven is fully appropriated by the vehicle user, rendering additional tax advantages for diesel unjustified both from an air pollution as well as from a climate perspective (Harding 2014). If policy makers aim to mitigate the environmental and social costs associated with fuel consumption, tax reforms to (i) phase out diesel tax breaks and/or (ii) introduce taxes that reflect the carbon content per liter seem recommended policy options that may also be combined. The withdrawal of the European Commission's proposal to reform the 2003 European Energy Tax Directive through motor fuel taxation based on carbon and energy content, however, indicates that there may be considerable political barriers in achieving an agreement between EU member states. Nonetheless, new negotiations on such reform proposals seem to be necessary in view of the recent Paris Agreement and the diesel emissions scandal.

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4.10. Appendix

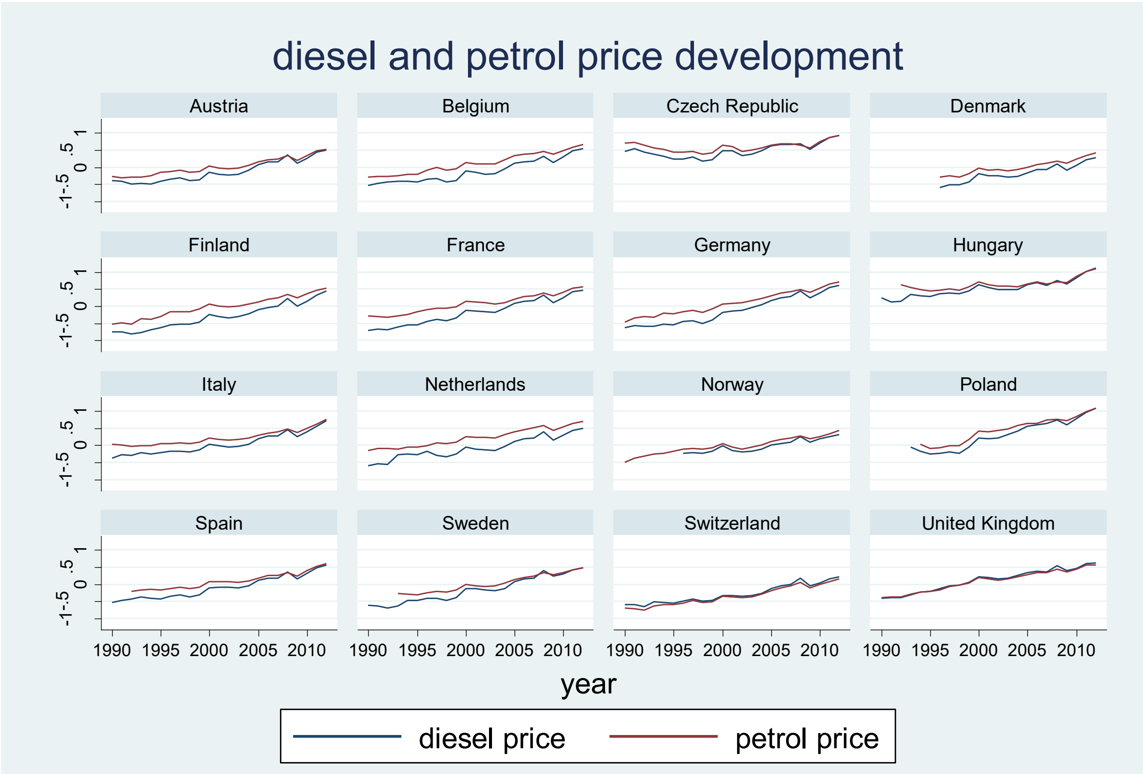
A. Data

We compiled data on passenger cars, motorcycles, lorries, busses and motor coaches as well as road tractors differentiated by motor energy type based on the information in EUROSTAT (road_eqs). Data on special purpose vehicles is only available from 2008 onwards and is therefore not included. For motorcycles, no information is available on motor energy type. As petrol is the dominant fuel for motorcycles, we assume that all motorcycles are petrol driven. For road tractors, busses and motor coaches the amount of missing values is considerable. As the share of road tractors and busses/motor coaches in total stocks is very low and mostly develops in parallel to other stocks, we decided to exclude these data in order to minimize the amount of data loss due to missing values. Our estimation results are consequently based on the stock of petrol passenger cars plus motorcycles for petrol and on the stock of passenger cars and lorries for diesel.

Missing values in the vehicle stock data have been filled only if other available information allowed a reasonable assumption. For example if the total stock and the number of diesel passenger cars was available, however, the stock of petrol passenger cars exhibited a missing, this has been filled by calculating the difference in total and diesel stock. Moreover, obvious data errors such as decimal point faults have been corrected.

A few data points constituting extreme outliers have been set to missing values to not distort overall estimation results by potential errors in the data. This affects the diesel consumption of the Czech Republic for the year 1995, the motorcycle stock in Austria in 1994, and the stock of lorries in the Netherlands for the years 1993, 1994 and 1995.

Figure A-1: Development of petrol and diesel prices (in logs)



Note: Petrol price is the premium unleaded RON95. Data source: IEA (2014).

B. Bias Corrected Least Square Dummy Variable estimator (LSDVc)

A bias corrected Least Squares Dummy Variable estimator (LSDVc) has been proposed for macro panels with medium N and large time dimensions to address the Nickel bias (see Bun & Kiviet, 2003; Judson & Owen, 1999; and Bruno, 2005a for an extension). The LSDVc estimator is based on Monte Carlo simulation results assessing the magnitude of the Nickel bias for simple dynamic Partial Adjustment models. Based on derived bias approximation formulas[1] the estimator has been frequently applied in previous studies using Partial Adjustment models. However, the reliability of the bias approximation of the LSDVc estimator in more complex dynamics models including lagged explanatory variables or in the presence of high persistence has not yet been explored sufficiently to our knowledge. We therefore present results for the LSDVc estimator only for robustness analysis as additional results and only for the partial adjustment model (see Table C-1) as this has been the focus of bias correction simulation studies.

[1] The formula has been derived for three different levels of accuracy of bias-approximation (Bruno 2005b).

C. Additional Tables on Regression Results

Table C-1: Partial Adjustment Model estimates for petrol consumption per passenger car or motorcycles

PETROL	(1) OLS	(2) Fixed-Effects	(3) Arellano-Bond GMM	(4) System GMM	(5) LSDVc
L.consumption per	0.953^{***}	0.778^{***}	0.806^{***}	0.868^{***}	0.836^{***}
vehicle	(0.017)	(0.051)	(0.110)	(0.074)	(0.058)
petrol price	-0.027	-0.140^{**}	-0.125^{+}	-0.075^{+}	-0.099^{+}
	(0.018)	(0.041)	(0.065)	(0.036)	(0.054)
GDP	0.023^{+}	0.196^{*}	0.177	0.063	0.162^{+}
	(0.014)	(0.089)	(0.111)	(0.052)	(0.086)
total vehicle stock	-0.055^{***}	-0.255^{***}	-0.238^{*}	-0.106^{+}	-0.214^{**}
	(0.016)	(0.062)	(0.096)	(0.055)	(0.083)
Constant	0.051	-0.463		0.005	
	(0.162)	(0.879)		(0.281)	
year dummies	Yes	Yes	Yes	Yes	Yes
LRM	-0.581	-0.629	-0.645	-0.568	-0.607
# observations	273	273	257	273	273
# instruments			29	31	
max IV lag			6	6	
AB-test (AR1)			0.0052	0.0021	
AB-test (AR2)			0.7561	0.6845	
Sargan Test			0.4530	0.2160	
Diff-in-Sargan Test				0.2847	

Standard errors in parentheses

Estimation results for petrol consumption per passenger car or motorcycle, robust standard errors in all specifications except LSDVc. All variables in logs. For Arellano-Bond and System GMM: one step estimators, Forward Orthogonal Deviations Transformation as well as collapse and small sample option applied, internal instruments restricted from t-2 to maximum lag indicated. In System GMM the standard instruments are used for the levels equation only. Difference-in-Sargan Test on the validity of additional instruments in System GMM, p-values reported. For LSDVc: Bias correction up to order O(1/NT) based on Arellano-Bond estimator, standard errors bootstrapped with 100 repetitions (based a method proposed by Kiviet and Bun (2001).

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C-2: Petrol estimation results accounting for price endogeneity – petrol excise taxes used as instruments.

PETROL	*exogenous price* Fixed Effects	*endogenous price* Fixed-Effects IV	*exogenous price* Arellano-Bond GMM	*endogenous price* Arellano-Bond GMM	*exogenous price* System GMM	*endogenous price* System GMM
L.consumption	0.820***	0.824***	0.732***	0.693***	0.913***	0.810***
per vehicle	(0.048)	(0.035)	(0.131)	(0.124)	(0.079)	(0.099)
petrol price	-0.248**	-0.391***	-0.239*	-0.252	-0.276***	-0.066
	(0.079)	(0.114)	(0.083)	(0.201)	(0.059)	(0.209)
L.petrol price	0.144*	0.260**	0.087	0.076	0.228**	-0.022
	(0.067)	(0.099)	(0.106)	(0.209)	(0.069)	(0.195)
GDP	0.622***	0.650***	0.695**	0.732**	0.622**	0.679*
	(0.129)	(0.156)	(0.213)	(0.183)	(0.181)	(0.273)
L.GDP	-0.455**	-0.492**	-0.471*	-0.482*	-0.594**	-0.594*
	(0.137)	(0.159)	(0.172)	(0.180)	(0.151)	(0.239)
total vehicle	-1.042***	-1.067***	-1.051***	-1.058***	-1.015***	-1.084***
stock	(0.140)	(0.117)	(0.145)	(0.149)	(0.134)	(0.203)
L. total vehicle	0.894***	0.929***	0.848***	0.831***	0.958***	0.966***
stock	(0.146)	(0.117)	(0.168)	(0.171)	(0.125)	(0.184)
Constant	-0.838	-0.785+			0.048	-0.205
	(0.503)	(0.441)			(0.228)	(0.401)
year dummies	Yes	Yes	Yes	Yes	Yes	Yes
LRM	-0.580	-0.742	-0.565	-0.572	-0.554	-0.460
# observations	270	270	254	254	270	270
# instruments			35	43	37	46
max IV lag			9	9	9	9
AB-test (AR1)			0.0020	0.0025	0.0016	0.0013
AB-test (AR2)			0.8470	0.8581	0.8803	0.7445
Sargan Test			0.3350	0.2162	0.1781	0.0157
Diff-in-Sargan Test					0.3800	

Notes: Robust standard errors in parentheses. All specifications include year dummies. All variables in logs. Dependent variable: petrol consumption per petrol driven passenger car or motorcycle. Total vehicle stock refers to the sum of all fuel type passenger cars and motorcycles per driver (population age 15-64). L. denotes first lags, D. denotes first differences. The “exogenous price”-columns refer to estimation results assuming prices to be exogenous without instrumentation, while “endogenous price”-columns assume prices to endogenous if not instrumented. Petrol excise tax used as external instrument for the endogenous contemporaneous price variable. For Arellano-Bond and System GMM: one step estimators, Forward Orthogonal Deviations Transformation as well as collapse and small sample option applied, internal instruments for L.consumption and endogenous price restricted from t-2 to maximum lag indicated. In System GMM the standard instruments are used for the levels equation only. Arellano-Bond-Test for first and second order serial correlation in transformed errors, H_0: no serial correlation of respective order. Sargan Test on over-identifying restrictions, H_0: instruments used are not correlated with the residuals. Difference-in-Sargan Test on the validity of additional instruments in System GMM. P-values reported for specification tests.
Significance level for parameters: $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C-3: Diesel estimation results accounting for price endogeneity - diesel excise taxes used as instruments.

DIESEL	*exogenous price* Fixed Effects	*endogenous price* Fixed-Effects IV	*exogenous price* Arellano-Bond GMM	*endogenous price* Arellano-Bond GMM	*exogenous price* System GMM	*endogenous price* System GMM
L.consumption	0.811***	0.828***	0.977***	0.863***	0.966***	0.894***
per vehicle	(0.051)	(0.045)	(0.094)	(0.086)	(0.128)	(0.108)
diesel price	-0.169*	-0.654**	-0.206*	-0.616***	-0.195*	-0.720**
	(0.076)	(0.234)	(0.088)	(0.138)	(0.088)	(0.220)
L.diesel price	0.044	0.460*	0.130	0.439**	0.136	0.611*
	(0.092)	(0.208)	(0.107)	(0.146)	(0.092)	(0.213)
GDP	1.058***	1.071**	0.799***	1.013***	0.893*	1.112***
	(0.184)	(0.327)	(0.182)	(0.191)	(0.392)	(0.255)
L.GDP	-0.921**	-0.974**	-0.819***	-0.946***	-0.926*	-1.134***
	(0.255)	(0.344)	(0.184)	(0.233)	(0.317)	(0.200)
total vehicle	-1.294***	-1.364***	-1.433***	-1.387***	-1.356***	-1.550***
stock	(0.229)	(0.264)	(0.290)	(0.290)	(0.285)	(0.291)
L. total vehicle	1.230***	1.336***	1.420***	1.368***	1.311***	1.449***
stock	(0.232)	(0.264)	(0.271)	(0.300)	(0.216)	(0.334)
Constant	-0.743	-0.640			0.691**	0.982***
	(1.194)	(0.940)			(0.225)	(0.215)
year dummies	Yes	Yes	Yes	Yes	Yes	Yes
LRM	-0.659	-1.131	-3.251	-1.290	-1.753	-1.037
# observations	253	253	237	237	253	253
# instruments			35	43	38	48
max IV lag			9	9	10	10
AB-test (AR1)			0.0125	0.0085	0.0059	0.0054
AB-test (AR2)			0.1403	0.2449	0.1439	0.3469
Sargan Test			0.2760	0.1708	0.2135	0.1636
Diff-in-Sargan Test					0.3878	

Notes: Robust standard errors in parentheses. All specifications include year dummies. All variables in logs. Dependent variable: log diesel consumption per diesel driven passenger car or lorry. Total vehicle stock refers to the sum of all fuel type passenger cars, motorcycles and lorries per driver (population age 15-64). L. denotes first lags, D. denotes first differences. The "exogenous price"-columns refer to estimation results assuming prices to be exogenous without instrumentation, while "endogenous price"-columns assume prices to endogenous if not instrumented. Diesel excise tax used as external instrument for the endogenous contemporaneous price variable. For Arellano-Bond and System GMM: one step estimators, Forward Orthogonal Deviations Transformation as well as collapse and small sample option applied, internal instruments for L.consumption and endogenous price restricted from t-2 to maximum lag indicated. In System GMM the standard instruments are used for the levels equation only. Arellano-Bond-Test for first and second order serial correlation in transformed errors, H_0: no serial correlation of respective order. Sargan Test on over-identifying restrictions, H_0: instruments used are not correlated with the residuals. Difference-in-Sargan Test on the validity of additional instruments in System GMM. P-values reported for specification tests.

Significance level for parameters: $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C-4: Short and long run (LRM) elasticities for income and vehicle stock per driver for diesel and petrol

	exogenous prices			*price instrumented with tax*		
	Fixed Effects	Arellano-Bond	System GMM	Fixed Effects- IV	Arellano-Bond	System GMM
Petrol						
Income (SR)	0.622***	0.695**	0.622**	0.650***	0.732**	0.679*
	(0.129)	(0.213)	(0.181)	(0.156)	(0.183)	(0.273)
Income (LRM)	0.923**	0.838**	0.314	0.899**	0.814**	0.446*
	(0.313)	(0.264)	(0.282)	(0.304)	(0.236)	(0.204)
vehicle stock (SR)	-1.042***	-1.051***	-1.015***	-1.067***	-1.058***	-1.084***
	(0.140)	(0.145)	(0.134)	(0.117)	(0.149)	(0.203)
vehicle stock (LRM)	-0.817**	-0.757**	-0.651***	-0.783**	-0.739**	-0.623***
	(0.236)	(0.212)	(0.155)	(0.277)	(0.206)	(0.129)
Diesel						
Income (SR)	1.058***	0.799***	0.893*	1.071**	1.013***	1.112***
	(0.184)	(0.182)	(0.392)	(0.327)	(0.191)	(0.255)
Income (LRM)	0.723	-0.848	-0.989	0.568	0.489	-0.205
	(0.897)	(9.239)	(6.266)	(0.685)	(1.172)	(0.972)
vehicle stock (SR)	-1.294***	-1.433***	-1.356***	-1.364***	-1.387***	-1.550***
	(0.229)	(0.290)	(0.285)	(0.264)	(0.290)	(0.291)
vehicle stock (LRM)	-0.344	-0.554	-1.359	-0.160	-0.143	-0.954*
	(0.744)	(4.838)	(1.955)	(0.610)	(0.944)	(0.340)

Robust standard errors in parentheses.
Estimation results for petrol consumption per passenger car or motorcycle and for diesel consumption per passenger car or lorry. For Arellano-Bond and System GMM: one step estimators, Forward Orthogonal Deviations Transformation as well as collapse and small sample option applied, internal instruments (for L.consumption and price if endogenous) restricted. In System GMM the standard instruments are used for the levels equation only.
External instrumentation with fuel excise tax levels in the models assuming endogenous prices.
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

D. Emission reduction calculation

Table D-1: Emission Factors and conversion rates for CO_2 from fuel combustion exhaust

	CO_2 emission factors		conversion of metrics
fuel type	*kg CO_2/ kg fuel* [a)]	*kg CO_2 /liter fuel*	*liter fuel/ kg fuel* [b)]
petrol	3.16	2.37	1.33
diesel	3.17	2.66	1.19

Note: a) Emission Factors in EMEP/EEA emission inventory guidebook 2013 update Sept 2014, Appendix 1 in chapter 1A3b (Ntziachristos and Samaras 2014) **b) http://www.bdbe.de/daten/Umrechnung_und_Formeln**

Table D-2: Country specific emission factors for air pollutant exhaust per kg fuel

	Country specific emission factors weighted by country vehicle fleet shares (g/kg fuel)									
	CO		NOx		NMVOC		CH_4		PM ($PM_{2.5}$)	
	petrol	diesel	petrol	diesel	petrol	diesel	petrol	diesel	petrol	diesel
Austria	129.24	3.62	7.10	13.70	17.62	0.74	1.30	0.07	0.22	1.05
Belgium	169.44	3.36	12.27	13.75	20.79	0.80	1.65	0.06	0.18	1.11
Czech Republic	239.28	8.68	12.27	14.54	88.52	1.87	2.52	0.24	1.10	2.66
Denmark	104.54	5.95	8.87	17.03	13.26	1.45	1.03	0.13	0.08	1.26
Finland	138.88	6.50	11.24	15.14	18.91	1.48	1.31	0.13	0.14	1.76
France	110.32	4.56	10.39	13.94	16.69	0.97	1.20	0.10	0.13	1.20
Germany	101.01	3.27	5.83	13.46	16.15	0.81	1.09	0.06	0.18	0.99
Hungary	129.32	7.66	12.07	16.13	31.46	1.65	1.59	0.21	0.33	1.96
Italy	193.15	4.13	8.47	14.44	31.57	0.84	2.04	0.08	0.40	1.23
Netherlands	102.45	4.44	9.51	14.90	14.24	1.00	1.03	0.07	0.11	1.26
Norway	111.78	4.78	8.86	14.21	11.56	1.06	1.09	0.07	0.08	1.25
Poland	208.51	6.27	15.22	15.76	29.31	1.31	1.78	0.16	0.19	1.31
Spain	177.13	4.85	14.31	14.40	26.27	0.85	1.61	0.09	0.29	1.11
Sweden	96.08	5.08	8.56	13.65	11.46	1.26	1.09	0.13	0.10	1.33
Switzerland	123.32	3.32	6.91	13.64	14.88	0.73	1.22	0.06	0.26	0.85
United Kingdom	89.94	3.44	4.75	14.27	7.18	0.73	0.82	0.07	0.07	0.99

Note: calculations based on Emission Factors in EMEP/EEA (2013) emission inventory guidebook 2013 update Sept 2014[2] and EUROSTAT vehicle stock data assuming that shares in stocks reflect shares in fuel consumption. Bulk emission factors refer to 2005.

[2] http://www.eea.europa.eu/publications/emep-eea-guidebook-2013. (Ntziachristos and Samaras 2014) Appendix 1 in Chapter 1 A3b.

Table D-3: Share of diesel and petrol use in aggregated fuel consumption and fuel consumption per capita

	share in total consumption (2013): petrol share	diesel share	fuel consumption per capita (diesel and petrol) in ktons per 1000 inhabitants
Austria	22.59%	77.41%	0.82
Belgium	14.88%	85.12%	0.67
Czech Republic	30.39%	69.61%	0.47
Denmark	38.74%	61.26%	0.59
Finland	37.21%	62.79%	0.66
France	16.26%	83.74%	0.56
Germany	36.18%	63.82%	0.58
Hungary	36.12%	63.88%	0.31
Italy	28.20%	71.80%	0.47
Netherlands	39.11%	60.89%	0.57
Norway	27.22%	72.78%	0.64
Poland	28.52%	71.48%	0.31
Spain	18.42%	81.58%	0.51
Sweden	40.61%	59.39%	0.64
Switzerland	.	.	.
United Kingdom	36.57%	63.43%	0.54

Table D-4: POLICY SCENARIO A adjusting diesel excise taxes to petrol taxation level: Changes in diesel consumption

	change in diesel consumption			
	Short Run		in 2020	
	in %	in Mt	in %	in Mt
Austria	-5.19%	-0.28	-7.46%	-0.40
Belgium	-9.62%	-0.61	-13.83%	-0.88
Czech Republic	-4.14%	-0.14	-5.95%	-0.20
Denmark	-10.04%	-0.20	-14.43%	-0.29
Finland	-9.67%	-0.22	-13.89%	-0.31
France	-9.85%	-3.05	-14.16%	-4.38
Germany	-9.80%	-2.92	-14.08%	-4.20
Hungary	-1.90%	-0.04	-2.73%	-0.05
Italy	-5.25%	-1.07	-7.55%	-1.54
Netherlands	-16.72%	-0.98	-24.03%	-1.41
Norway	-8.26%	-0.20	-11.88%	-0.28
Poland	-3.09%	-0.26	-4.44%	-0.38
Spain	-5.24%	-1.01	-7.53%	-1.45
Sweden	-4.10%	-0.15	-5.90%	-0.21

Note: All changes compared to 2013 levels, ceteris paribus. Potential impacts of GDP or vehicle stock changes are not accounted for. Based on elasticity estimates from FE-IV estimation for diesel. For Switzerland and the UK, taxes have remained unchanged for the policy scenario.

Table D-5: POLICY SCENARIO tax of 50€/tCO2: Price changes and resulting changes in petrol and diesel consumption

	Petrol					Diesel				
	change in price	change in consumption due to price change				change in price	change in consumption due to price change			
		Short Run		2020			Short Run		2020	
	in %	in %	in kt	in %	in kt	in %	in %	in kt	in %	in kt
Austria	10.23%	-2.54%	-40	-4.71%	-74	11.75%	-7.68%	-415	-11.04%	-597
Belgium	8.69%	-2.16%	-24	-4.00%	-44	10.89%	-7.12%	-453	-10.23%	-651
Czech Republic	10.30%	-2.55%	-38	-4.74%	-70	11.58%	-7.57%	-258	-10.89%	-371
Denmark	8.74%	-2.17%	-28	-4.02%	-51	10.96%	-7.17%	-145	-10.31%	-208
Finland	9.01%	-2.24%	-30	-4.15%	-55	10.93%	-7.15%	-161	-10.28%	-231
France	9.20%	-2.28%	-137	-4.23%	-254	11.80%	-7.71%	-2,385	-11.09%	-3,429
Germany	8.81%	-2.19%	-370	-4.05%	-686	11.08%	-7.25%	-2,161	-10.41%	-3,107
Hungary	10.71%	-2.66%	-30	-4.93%	-55	11.79%	-7.71%	-152	-11.08%	-218
Italy	8.21%	-2.04%	-163	-3.78%	-302	9.72%	-6.36%	-1,294	-9.14%	-1,860
Netherlands	8.24%	-2.04%	-77	-3.79%	-143	11.35%	-7.42%	-435	-10.66%	-625
Norway	7.86%	-1.95%	-17	-3.61%	-32	9.87%	-6.46%	-153	-9.28%	-221
Poland	11.16%	-2.77%	-94	-5.14%	-175	12.57%	-8.22%	-701	-11.81%	-1,008
Spain	10.03%	-2.49%	-108	-4.61%	-200	11.85%	-7.75%	-1,491	-11.13%	-2,142
Sweden	8.92%	-2.21%	-55	-4.11%	-102	9.90%	-6.47%	-235	-9.30%	-338
United Kingdom	9.01%	-2.24%	-281	-4.15%	-521	9.69%	-6.34%	-1,382	-9.11%	-1,987

Note: change refer to reference year 2013, price change including adjustment in value added tax (VAT) due to excise tax increase.

Table D-6: Absolute and relative changes in CO_2 emissions compared to the status quo (2013) for both policy scenarios

	ΔCO2 short run						ΔCO2 in 2020					
	MtCO2		*tCO2/capita*		*in % (to 2013)*		*MtCO2*		*tCO2/capita*		*in % (to 2013)*	
	PS A	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*
Austria	-0.9	-1.4	-0.10	-0.17	-4.0%	-6.5%	-1.3	-2.1	-0.15	-0.25	-5.8%	-9.6%
Belgium	-1.9	-1.5	-0.17	-0.14	-8.2%	-6.4%	-2.8	-2.2	-0.25	-0.20	-11.8%	-9.3%
Czech Republic	-0.4	-0.9	-0.04	-0.09	-2.9%	-6.1%	-0.6	-1.4	-0.06	-0.13	-4.1%	-9.0%
Denmark	-0.6	-0.5	-0.11	-0.10	-6.2%	-5.2%	-0.9	-0.8	-0.16	-0.15	-8.8%	-7.9%
Finland	-0.7	-0.6	-0.13	-0.11	-6.1%	-5.3%	-1.0	-0.9	-0.18	-0.17	-8.7%	-8.0%
France	-9.7	-8.0	-0.15	-0.12	-8.3%	-6.8%	-13.9	-11.7	-0.21	-0.18	-11.9%	-10.0%
Germany	-9.3	-8.0	-0.11	-0.10	-6.3%	-5.4%	-13.3	-12.0	-0.17	-0.15	-9.0%	-8.1%
Hungary	-0.1	-0.6	-0.01	-0.06	-1.2%	-5.9%	-0.2	-0.9	-0.02	-0.09	-1.7%	-8.9%
Italy	-3.4	-4.6	-0.06	-0.08	-3.8%	-5.1%	-4.9	-6.8	-0.08	-0.11	-5.4%	-7.6%
Netherlands	-3.1	-1.6	-0.18	-0.10	-10.2%	-5.3%	-4.5	-2.4	-0.27	-0.14	-14.7%	-8.0%
Norway	-0.6	-0.5	-0.12	-0.11	-6.0%	-5.2%	-0.9	-0.8	-0.18	-0.16	-8.7%	-7.7%
Poland	-0.8	-2.5	-0.02	-0.07	-2.2%	-6.7%	-1.2	-3.7	-0.03	-0.10	-3.2%	-9.9%
Spain	-3.2	-5.1	-0.07	-0.11	-4.3%	-6.8%	-4.6	-7.4	-0.10	-0.16	-6.1%	-9.9%
Sweden	-0.5	-0.9	-0.05	-0.10	-2.4%	-4.7%	-0.7	-1.4	-0.07	-0.15	-3.5%	-7.2%
Switzerland	0.0	.	0.00	.	0.0%	.	0.0	.	0.00	.	0.0%	.
United Kingdom	0.0	-5.3	0.00	-0.08	0.0%	-4.8%	0.0	-7.9	0.00	-0.12	0.0%	-7.3%

Note: PS A denotes policy scenario A (adjusting diesel excise taxes to petrol taxation levels) and PS B refers to policy scenario B (introducing a carbon-content based tax of 50€/tCO2 per liter of fuel). Emissions refer to calculated emissions from diesel and petrol consumption for road transportation based on elasticity estimates and emission factors per liter. Reported changes assume that GDP per capita and vehicle stocks per driver remain unchanged

Table D-7: Absolute and relative changes in NOx emissions compared to the status quo (2013) for both policy scenarios

	ΔNOx Short run						ΔNOx in 2020					
	in tons NOx		*gr/capita*		*in % (to 2013)*		*in tons NOx*		*gr/capita*		*in % (to 2013)*	
	PS A	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*
Austria	-3,847	-5,975	-454	-705	-4.5%	-7.0%	-5,529	-8,707	-652	-1,027	-6.5%	-10.2%
Belgium	-8,415	-6,518	-752	-583	-8.3%	-6.4%	-12,095	-9,492	-1,082	-849	-12.0%	-9.4%
Czech Republic	-2,049	-4,216	-195	-401	-3.0%	-6.2%	-2,945	-6,254	-280	-595	-4.3%	-9.2%
Denmark	-3,451	-2,711	-615	-483	-7.6%	-5.9%	-4,960	-3,998	-883	-712	-10.9%	-8.7%
Finland	-3,290	-2,768	-605	-509	-6.7%	-5.6%	-4,729	-4,118	-869	-757	-9.7%	-8.4%
France	-42,449	-34,668	-644	-526	-8.6%	-7.0%	-61,012	-50,424	-925	-765	-12.4%	-10.2%
Germany	-39,330	-31,245	-488	-387	-7.9%	-6.2%	-56,529	-45,809	-701	-568	-11.3%	-9.2%
Hungary	-603	-2,803	-61	-283	-1.3%	-6.2%	-866	-4,178	-88	-422	-1.9%	-9.3%
Italy	-15,439	-20,065	-256	-333	-4.3%	-5.5%	-22,190	-29,416	-368	-488	-6.1%	-8.1%
Netherlands	-14,600	-7,211	-869	-429	-11.9%	-5.9%	-20,984	-10,670	-1,249	-635	-17.0%	-8.7%
Norway	-2,791	-2,335	-550	-460	-6.7%	-5.6%	-4,012	-3,420	-790	-673	-9.6%	-8.2%
Poland	-4,154	-12,489	-109	-328	-2.2%	-6.7%	-5,970	-18,550	-157	-488	-3.2%	-10.0%
Spain	-14,510	-23,011	-311	-494	-4.3%	-6.8%	-20,856	-33,719	-447	-723	-6.1%	-9.9%
Sweden	-2,033	-3,678	-212	-383	-2.9%	-5.2%	-2,921	-5,482	-304	-571	-4.1%	-7.7%
Switzerland	0	.	0	.	0.0%	.	0	.	0	.	0.0%	.
United Kingdom	0	-21,069	0	-329	0.0%	-5.7%	0	-30,840	0	-481	0.0%	-8.3%

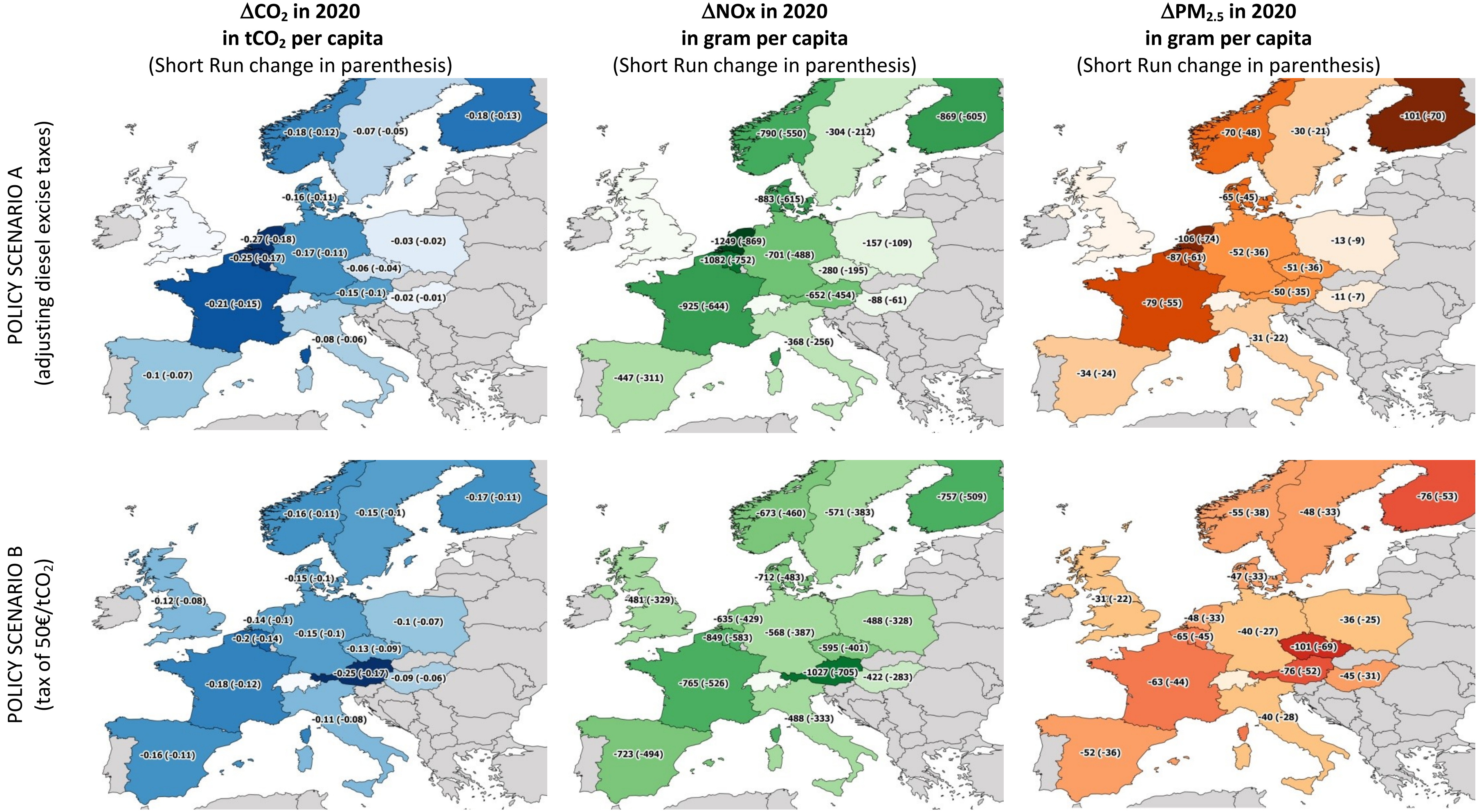
Note: PS A denotes policy scenario A (adjusting diesel excise taxes to petrol taxation levels) and PS B refers to policy scenario B (introducing a carbon-content based tax of 50€/tCO2 per liter of fuel). Emissions refer to calculated emissions from diesel and petrol consumption for road transportation based on elasticity estimates and emission factors per liter. Reported changes assume that GDP per capita and vehicle stocks per driver remain unchanged.….

Table D-8: Absolute and relative changes in PM2.5 emissions compared to the status quo (2013) for both policy scenarios

	Δ PM2.5 Short run						Δ PM2.5 in 2020					
	in tons PM 2.5		*gr/capita*		*in % (to 2013)*		*in tons PM 2.5*		*gr/capita*		*in % (to 2013)*	
	PS A	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*	*PS A*	*PS B*
Austria	-294	-444	-35	-52	-4.9%	-7.4%	-423	-642	-50	-76	-7.0%	-10.7%
Belgium	-679	-506	-61	-45	-9.4%	-7.0%	-975	-730	-87	-65	-13.4%	-10.1%
Czech Republic	-375	-727	-36	-69	-3.5%	-6.8%	-538	-1,063	-51	-101	-5.0%	-9.9%
Denmark	-254	-184	-45	-33	-9.6%	-7.0%	-366	-266	-65	-47	-13.8%	-10.0%
Finland	-382	-286	-70	-53	-9.2%	-6.9%	-548	-413	-101	-76	-13.3%	-10.0%
France	-3,643	-2,872	-55	-44	-9.6%	-7.6%	-5,237	-4,135	-79	-63	-13.9%	-10.9%
Germany	-2,901	-2,211	-36	-27	-8.9%	-6.8%	-4,170	-3,205	-52	-40	-12.8%	-9.8%
Hungary	-73	-308	-7	-31	-1.7%	-7.3%	-105	-446	-11	-45	-2.5%	-10.5%
Italy	-1,318	-1,659	-22	-28	-4.7%	-5.9%	-1,894	-2,412	-31	-40	-6.7%	-8.5%
Netherlands	-1,236	-557	-74	-33	-15.8%	-7.1%	-1,776	-804	-106	-48	-22.7%	-10.3%
Norway	-246	-193	-48	-38	-8.1%	-6.3%	-353	-279	-70	-55	-11.6%	-9.1%
Poland	-345	-938	-9	-25	-2.9%	-7.9%	-497	-1,355	-13	-36	-4.2%	-11.4%
Spain	-1,117	-1,683	-24	-36	-4.9%	-7.5%	-1,605	-2,433	-34	-52	-7.1%	-10.8%
Sweden	-198	-318	-21	-33	-3.9%	-6.3%	-285	-460	-30	-48	-5.6%	-9.0%
Switzerland	0	.	0	.	0.0%	.	0	.	0	.	0.0%	.
United Kingdom	0	-1,385	0	-22	0.0%	-6.2%	0	-1,998	0	-31	0.0%	-8.9%

Note: PS A denotes policy scenario A (adjusting diesel excise taxes to petrol taxation levels) and PS B refers to policy scenario B (introducing a carbon-content based tax of 50€/tCO2 per liter of fuel). Emissions refer to calculated emissions from diesel and petrol consumption for road transportation based on elasticity estimates and emission factors per liter. Reported changes assume that GDP per capita and vehicle stocks per driver remain unchanged

Figure D-1: Changes in CO_2, NO_x and $PM_{2.5}$ in absolute terms (per capita) compared to the status quo (2013)



Note: Emissions refer to calculated emissions from diesel and petrol consumption for road transportation based on EUROSTAT fuel consumption data for 2013, own elasticity estimates and emission factors per liter. Reported changes assume that GDP per capita and vehicle stocks per driver remain unchanged.

E. Appendix References

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Chapter 5

SYNTHESIS AND DISCUSSION

CHAPTER 5 - SYNTHESIS AND DISCUSSION

This thesis argues that successful climate change mitigation will crucially depend on national level policy making and individual incentives. In the absence of a global enforcement mechanism, this remains true even though the Paris Agreement has been termed a historic breakthrough in international climate diplomacy. Building on a patchwork of heterogeneous (and insufficiently ambitious) national pledges, the success of the Paris Agreement in preventing dangerous climate change will be determined by national level and local level policy making as well as the behavior of actors responding to the policies. These actors are subject to prevailing market imperfections. While economic theory can provide some guidance to policy makers on which emission trajectory or policy instrument may be recommended from an economic perspective, we economists need to acknowledge that a) our analyses are usually subject to a range of simplifying and highly normative assumptions which in many ways fail to adequately reflect the complexity and heterogeneity of real-world conditions and that b) policy outcomes are determined by a range of factors *other* than economic cost-efficiency considerations. Applying a range of empirical methods, this thesis confronted the theoretical perspective with observed findings. In this light, this thesis pursued two major motivations: First, to contribute to our understanding of the real-world context of climate policy making and the associated interrelations with other policy objectives. And second, to draw implications and lessons learnt from these empirical observations on how future incentives for climate policy implementation may be fostered.

5.1. Better understanding the real-world context of climate policy and underlying conflicting incentives

This section summarizes and discusses the main insights of this dissertation in the light of the broader research questions highlighted in the introduction and along the typology developed in Chapter 2. Section 5.2 discusses the implications of these findings with respect to translating the Paris Agreement into action.

5.1.1. Climate policy in an imperfect world

For tractability, economic models assume an idealized world that abstracts from most real world complexities. Chapter 2 of this thesis critically reviewed the underlying assumptions that are commonly used in Integrated Assessment Models (IAM), and contrasted them with real-world barriers and 'second-best' conditions encountered when putting climate policy into practice. It has thereby addressed the following questions:

- Which factors hamper the implementation of climate policy in practice, rendering mitigation more costly or less effective compared to commonly adopted first-best assumptions?

- Which specific impediments prevail at the different levels of decision making: at the level of governments, households and firms and at the market level?
- How well do economic models capture these real-world complexities and what does this mean for the interpretation of model results?

Starting from the perspective of IAMs and the assumption of a uniform global carbon price being the least-cost climate policy for tackling the climate change problem, Chapter 2 scrutinized the different levels of actors and decision makers involved, and identified a range of different real-world conditions that may in practice render climate policy more costly or environmentally ineffective. The typology differentiated between factors that influence the efficiency and effectiveness of climate policy at the level of i) policy formulation and implementation by institutions and governments, ii) the actors addressed by the implemented policies, responding by changing their behavior and related emissions and iii) the underlying context of prevailing conditions in form of additional market failures and market imperfections which have implications for *both* policy making as well as the actors' responses to policies. These impediments may be of different importance and come in different forms in country-specific contexts. However, applying the typology to the case study on China illustrated that in practice these impediments do indeed impact climate policy outcomes.

With respect to the level of the government and institutions, Chapter 2 argued that policy makers face a variety of constraints and conflicting incentives when formulating and implementing climate policies. Policy makers are no omniscient and omnipotent social planners. Instead they are subject to institutional capacity and time constraints as well as uncertainty and imperfect information (incomplete or potentially based on inadequate assumptions). Due to this, policy makers are not necessarily able to properly assess all considerations of which policy may actually be welfare optimal (or at least welfare improving) for optimal decision making. Natural science and economics can contribute information on potential climate impacts and mitigation costs. However, in order to be able to take informed decisions, policy makers need to grasp the complexity of the prevailing conditions, assess the validity of underlying assumptions of these scientific analyses and synthesize findings in the light of the country-specific context subject to their limited capacities. Even if these challenges to identifying the socially optimal climate policy could be overcome, political economy aspects likely complicate the implementation of appropriate policies. Unlike the assumption made by economic models, policy makers do not necessarily strive for the objectives of maximizing social welfare as a benevolent social planner is assumed to do. Aspirations for political power and re-election may incentivize policy makers to giving in to lobbying of powerful interest groups favoring sub-optimal polices or shifting unpopular policies and related costs further into the future. Moreover, the continuation of implemented policies may be threatened by subsequent governments as seen in the case of the repeal of the Australian carbon tax (Taylor 2014; Baird 2014), impairing the credibility of political long-term commitment. Anticipating these challenges that climate policy makers are likely confronted with, the choice of an appropriate policy design and information policy can play a crucial role in avoiding adverse side effects and gaining political and public support for policies (Bechtel and Scheve 2013).

Another important aspect highlighted in Chapter 2 is that the objective of climate change mitigation is strongly interrelated with a variety of other co-existing policy objectives. Economic analyses on climate change mitigation tend to put the climate change problem at the center of the analysis, often disregarding the existence of other policy areas or objectives. However, the case study of China in Chapter 2 as well as the policy analysis on Vietnam in Chapter 3 showed that economic development considerations for example rank higher on the political agenda than climate change in these countries. The findings on the interplay of different policy objectives in Vietnam are discussed in more detail below (see section 5.1.2).

The success of a policy with regard to achieving the desired emission reductions also depends on the reaction of consumers of carbon-intensive goods in reducing their consumption. Even with a carbon price in place the response of consumers to the price signal may differ from expectations. As part of its typology, Chapter 2 identified and discussed factors that may influence the response of households and firms to climate policy measures. Informational constraints, bounded rationality and routine-driven behavioral patterns may impede the exploitation of economically worthwhile abatement options. Individual preferences and risk perception as well as social or cultural influences affect individual responses and attitudes towards certain technologies that would serve to avoid GHG emissions.

Moreover, the strength of a policy and its consequences on GHG emissions also depends on other prevailing conditions. Analyzing the climate change problem economic models frequently assume that climate change is the only externality and that markets otherwise work perfectly. In reality, however, actors are confronted with a range of different market imperfections and suboptimal (‘second-best’) conditions (Lipsey and Lancaster 1956). Pre-existing taxes or subsidies may already distort behavioral responses. Imperfect information paired with high information and transaction costs may impede the exploitation of economically viable mitigation options. Imperfectly functioning financial markets and innovation markets lead to sub-optimal investments into low-carbon technologies. Market power and coordination failure can reinforce the tendency to resist changes and create a lock-in into the prevailing ‘dirty’ technologies.

Results from models, such as IAMs as well as other economic models, can provide important insights for policy makers contributing important information and guidance on policy options. However, as discussed in Chapter 2, to keep intricacy manageable, these models need to abstract from some real-world complexities and therefore can capture neither all levels of decision making nor all costs and benefits involved. This does not necessarily render these models impractical. In contrast, putting model assumption subject to a reality check can improve our understanding of the problem as well as our understanding of the meaning of the model results and their limitations. The typology presented in Chapter 2 provides guidance to policy makers to raise awareness of underlying assumptions, identify potential challenges and adapt policy designs accordingly. Moreover, it encourages economists to better communicate their results and the underlying assumptions and potential limitations.

Guided by this typology, Chapter 3 focused on the challenges in climate policy formulation and implementation faced by governments and institutions. Chapter 4 analyzed the response of households and firms to pricing policies. The analyses in both Chapters were conducted in the light of the underlying context of other market imperfections and externalities.

5.1.2. The politics of climate change - Climate policy formulation and implementation

Inspired by the findings on the challenges regarding the level of governments and institutions in Chapter 2, Chapter 3 took on the perspective of Vietnam in order to gain a more in-depth understanding of the determinants of climate policy formulation and implementation in a developing country. The case study in Chapter 3 aimed to answer the following questions:

- In the absence of a binding global agreement, what motivated Vietnam to launch unilateral climate policies as a Non-Annex I country?
- How can the policy change from a pure adaptation focus towards mitigation commitment in Vietnam be explained?
- Which role do non-climate policy objectives play for the formulation of climate change mitigation strategies and policies?

An important aspect raised in Chapter 2 is the co-existence of climate change mitigation on the one side and other objectives on the other. In fact, the case study in Chapter 3 confirmed that other policy objectives have strongly shaped Vietnam's climate and energy policy and that many of these other objectives rank much higher in priority for policy makers than climate change. Recalling the insights from collective action theory that each country faces strong incentives to free-ride on other country's mitigation efforts, Chapter 3 argued that the observation of voluntary climate change mitigation policies seems puzzling at first sight. While Chapter 2 analyzed the different potential obstacles presuming that policy makers generally pursue the implementation of climate change mitigation policies, Chapter 3 took a step back and asked which factors led to climate policy actually being put on the national agenda of a developing country like Vietnam.

Until recently, Vietnam had focused on climate change adaptation policies, emphasizing its status as a Non-Annex I country and the duty of industrialized countries to conduct and finance GHG mitigation measures. From this perspective, the launch of the Vietnam Green Growth Strategy and the National Strategy for Climate Change comprising both climate change adaptation and mitigation targets can be considered a recent change in the political agenda and discourse in Vietnam.

Based on an extensive literature review and 23 interviews with partly high ranking Vietnamese policy makers, bi- and multilateral donors and a range of other stakeholders, our policy analysis found that the political motivation for the Vietnamese Green Growth Strategy and other climate relevant polices has been largely shaped by a complex interplay of mostly *non*-climate objectives. The fact that Vietnam is highly vulnerable to climate impacts has raised political attention to the climate change problem already in the past. However, vulnerability concerns had mostly resulted in climate change adaptation policies and the call for industrialized countries to finance mitigation measures. Only recently, Vietnam announced that it would also be willing to take responsibility itself investing own financial resources into mitigation policies. The interviews revealed that this shift was driven by a complex interplay of different factors and objectives, however, vastly dominated by economic concerns. The recent slow-down in economic growth paired with a growing budget deficit made the need for addressing the prevailing structural inefficiencies in the economy more urgent. This was paired with fading national fossil resources confronted with surging energy demand raised energy security concerns and the motivation to invest in low-carbon technologies to reduce future import dependence. Additionally, Vietnam had to deal with a gradual phase out of 'conventional' development assistance for poverty reduction as it has achieved lower middle income status in 2009 while still being strongly dependent on foreign assistance. The restructuring of aid portfolios of important donors towards mainstreaming environmental and climate change issues together with the experiences in other Asian countries like South Korea, who had launched a Green Growth Strategy, have raised awareness for the option of 'green growth' policies in Vietnam. Our findings indicate that for Vietnam the Green Growth Strategy and climate change mitigation policies have not been driven by the objective to reduce GHG emissions. Instead it has been perceived as a way to modernize the economy and at the same time to secure access to low-carbon technologies, funding, technical assistance and capacity building from donors. The fact that large potential for low or even negative-cost emission mitigation potentials have been identified in Vietnam and these had remained untapped in the past, imply that there have been considerable barriers to their exploitation and that it cannot be taken for granted that these barriers would be addressed without the announced policies.

In this respect, the policy analysis in Chapter 3 corroborated many of the findings in Chapter 2 with respect to impediments to climate policy at the level of the governments and institutions. Interviewees reported that Vietnamese policy makers often lack appropriate information on saving potentials and technologies. Moreover, policy formulation and implementation suffer from a lack of institutional capacities to draft legal documents and administer their implementation. Especially with regard to monitoring and evaluation, the Vietnamese government often needs to rely on the technical and financial support from development assistance agencies. Interviewees have repeatedly stressed the need for more capacity development and technical assistance also in the future. Also political economy aspects have shaped the Vietnamese policy making. Strong political ties to state-owned enterprises exacerbate the pressure from powerful interest groups on policy making, having hampered the execution of power sector reforms and electricity pricing adjustments. Similarly, Vietnamese policy makers have been reluctant to enforce the phase-out of (mostly indirect) energy subsidies as they have faced public opposition to increasing energy prices, which was perceived as a threat to the rule of the Communist Party. With regard to investment barriers, interviewees in Vietnam reported a lack of financing possibilities to meet up-front investments that would be economically viable in the long-term, which relates to the problem of imperfect financial markets as discussed in Chapter 2. The non-competitive market structure in Vietnam, dominated by large state-owned enterprises receiving indirect subsidies to keep energy prices below production costs, further illustrates the role of other market imperfections and pre-existing distortionary subsidies as discussed in Chapter 2.

As Chapter 3 highlighted, Vietnam may not be an example of an extraordinarily ambitious climate policy. In contrast, GHG emission reductions may rather be described as a co-benefit of other policy objectives instead of being a policy objective per se. However, in view of the projected surge in GHG emissions for

Vietnam for the business-as-usual scenario and the sizable potential for efficiency improvements and emission mitigation in the industry and power sector, our results from the interviews for Chapter 3 imply that there may indeed be significant co-benefits to reap by combining economic restructuring and climate change mitigation efforts. From a climate perspective the question whether emission reductions are actually achieved is more important than what the underlying motivation for these were in the first place. In its INDCs submitted for the COP 21 in Paris, Vietnam pledges to unconditionally reduce GHG emissions by 8% compared to business-as-usual (BAU) by 2030 financed by domestic resources, while the emission intensity per unit of GDP is pledged to be reduced by 20% compared to the 2010 levels. Conditional on the case that international support through bilateral and multilateral donors is received, Vietnam pledges to increase its reduction target for GHG emissions to 25% compared to BAU by 2030 and the emission intensity target per unit of GDP to a 30% reduction compared to 2010 (The Socialist Government of Vietnam 2015). The GHG reduction targets are still formulated as compared to a steeply increasing BAU projection[1], indicating that emissions growth will continue in Vietnam. However, the change in the mindset of Vietnam's policy makers as implied by our interviewees seems to be enduring, which can be considered a small step in the direction low-carbon development efforts that should not be taken for granted. It remains to be seen whether Vietnam will fulfil its targets and whether it is even willing to go beyond the low-hanging fruits and intensify ambitions more. So far, the implementation of concrete measures has mostly been lacking. While Vietnam is building the first offshore wind farm in Asia, the annual coal consumption in 2014 had increased by 21% compared to 2013 and the share of electricity generation capacities from coal are expected to increase from 36% in 2015 to 56% in 2030 (EIA 2015). However, in a statement of January 2016 on the government homepage, the Vietnamese Prime Minister Dung announced that the Vietnamese power sector "*should protect the environment effectively, review development plans of all coal-fired power plants, build no more plants and gradually replace coal by gas while following strictly international commitments on cutting emission and promoting the development of renewable energy*" (Socialist Republic of Vietnam 2016). Between 2010 and 2015, Vietnam added over 8,000 MW of capacity in coal fired power plant, adding another 39 Mio tons of CO_2 annually. However, during the same period, almost 14,000 MW of coal power capacities were canceled in Vietnam, thereby potentially mitigating annual emissions of 61 Mio tons of CO_2 (Endcoal.org 2016; Endcoal.org 2015). This may be interpreted as a silver lining for the hope that Vietnam's climate policy will go beyond rhetoric.

5.1.3. From policies to emission reductions – The response of consumers to pricing policies

One important point made in Chapter 2 was that the success of policies in reducing emissions depends on the behavioral change of households and firms responding to these policies. In this light, Chapter 4 took a closer look at the response of consumers to pricing policies with a focus on the road transport sector in Europe. The transport sector is the only major sector which has exhibited increasing GHG emissions since 1990 making it the second largest GHG emitter in the EU after the power sector (EEA

[1] The Vietnamese INDC projects BAU GHG emissions to increase from 246.8 million tCO_2e in 2010 to 474.1 million tCO_2e in 2020 and 787.4 million tCO_2e in 2030 (The Socialist Government of Vietnam 2015).

2015b). Therefore, it is widely recognized that it will need to contribute a major share to reducing carbon emissions if Europe wants to comply with its pledges made in Paris (Creutzig et al. 2015). Analyzing the demand response for diesel and gasoline[2] consumption for road transportation in Europe, Chapter 4 addressed the following questions:

- How do households and firms in Europe respond to fuel pricing policies in the short and in the long run and which are the underlying dynamics?
- Which impact would fuel taxation reforms have on carbon emissions and on the exhaust of health-damaging air pollutants (fine particulate matter and nitrogen oxides) from road transport?
- How would the fuel tax reform proposals of ending diesel tax breaks as compared to introducing a carbon tax of 50€/tCO_2 perform with respect to reducing CO_2 and local air pollutants?
- How much could these fuel taxation reforms contribute to achieving European climate change mitigation targets for the transport sector?

Chapter 2 had named inertia and endowment restrictions to hamper immediate adjustments, thereby reducing the effectiveness of policies in achieving emission reductions in the short-run. Similarly, behavioral aspects such as accustomed consumption patterns may slow down behavioral changes as discussed in Chapter 2. In line with this, the analysis in Chapter 4 confirmed that consumers of transportation fuels do not adjust their consumption behavior immediately; instead they are subject to a dynamic adjustment process due to habit persistence and short-term inflexibilities in vehicle stock characteristics.

Although there is a considerable body of literature studying fuel price elasticities, reliable empirical estimates on recent European data, particularly with respect to diesel consumption, are comparably scarce. Yet, information on the expected demand response to envisaged climate policy measures and the process of the consumption changes over time is of major relevance to policy makers when designing climate policies and anticipating policy impacts on emissions especially with regard to complying with emission reduction targets. The dynamic econometric analysis in Chapter 4 revealed that - when the underlying dynamics, a potential fuel price endogeneity bias and the diesel shift observed in Europe are accounted for - the impact of fuel price changes on fuel consumption are found to be more pronounced in the short-run than previous literature suggests.

The results presented in Chapter 4 are especially interesting with respect to the consumption of diesel, as diesel has become the dominant road transportation fuel in many European countries within the last decades. Chapter 4 provides evidence that diesel demand in Europe tends to be more price elastic than gasoline demand, especially in the short run.

This finding on the diesel price elasticity is of special relevance in view of the recently rekindling debate around the health impacts of diesel vehicles. Despite some improvements in technology and catalytic

[2] Chapter 4 used the term petrol as it was written in British English due to the European context.

converters, diesel cars have continuously been criticized for emitting more NO_x and $PM_{2.5}$ per liter combusted than gasoline vehicles as shown by the emission factors in Chapter 4. The recent fraud scandal, revealing the use of illegal software in diesel car test cycles in combination with the discovery that the majority of diesel vehicles fail to meet air pollution emission standards in real driving conditions has recently evoked strong political and public interest and criticism in the preferential tax treatment of diesel cars in many European countries. In view of the fact that air pollution concentration limits continue to be exceeded in many European cities, it seems that emission standards for road transportation vehicles have so far largely failed to deliver the expected reductions in health-damaging air pollution levels. Therefore, the objective of reducing exhaust of NO_x and fine particulate matter constitutes a second motivation for addressing the transport sector with pricing policies next to climate change considerations.

The results from Chapter 4 imply that fuel pricing policies can be more effective than previously assumed in reducing fuel consumption and the associated emissions of carbon dioxide and health-damaging local air pollutants already in the short run. The presented fuel taxation reforms therefore seem to be a viable complement to reduce *both* air pollutant exhaust and carbon emissions from road transportation in the short run as well as in the long run, as they do not only foster fuel efficiency improvements but also reduce distances travelled. Countries exhibiting a large tax differential between diesel and gasoline could benefit from reducing exhaust emissions from road transport up to 17% for NO_x and 22% for fine particulate matter in 2020 by ending diesel tax breaks. At the same time CO_2 emissions from road transport could be reduced by up to almost 15% in 2020. The introduction of a carbon tax could reduce NO_x exhaust by between 7 and 10 % and $PM_{2.5}$ exhaust by between 8 and 11% in 2020, while CO_2 emissions would fall by between 7 and close to 10%. Both fuel tax reforms could make an important contribution to achieving the EU's CO_2 emission reduction targets for the transport sector. In many countries, abandoning the preferential tax treatment for diesel has nearly as strong an effect on carbon emissions as a 50€/tCO_2 tax on fuel. Chapter 4 also estimates income elasticities for fuel consumption, suggesting that GDP growth will increase fuel consumption and thereby also CO_2 emissions and air pollutant exhaust. If EU countries want to reconcile the policy objectives of steady GDP growth and climate change mitigation in the transport sector, the effects of income increases need to be counteracted by fuel pricing policies until the transition to a low-carbon transport system is achieved.

In contrast to emission standards, fuel taxation moreover raises revenues that can be used for reinvestment into pursuing other political or societal objectives such as building up 'green' infrastructure. Chapter 4 presented estimates on the potential for fiscal revenues associated with the policy scenarios for fuel tax reforms in Europe. We find that the presented fuel tax reforms could raise over 4 billion € in France and Germany and considerable amounts in other European countries already in the short run. These revenues could for example be re-invested in the build-up of infrastructure for electro-mobility, thereby overcoming the coordination failure barrier discussed in Chapter 2. Moreover, other studies have argued that 'green' taxation may be considered beneficial for pure fiscal reasons independent of climate or environmental considerations when facing tax competition (Franks, Edenhofer, and Lessmann 2015). As seen in Chapter 3, Vietnam has also made a first step in the direction of ‘green fiscal reforms’ with the introduction of an Environment Protection Tax (EPT) in 2012, though tax rates currently do not reflect carbon contents. Interview partners, who had been involved in the formulation and implementation of the EPT, have emphasized the advantages of environmental tax reforms in steering behavior of consumers into more sustainable consumption patterns while at the same time providing a basis for fiscal revenues (see also Rodi, Schlegelmilch, and Mehling 2012). Initially starting with low tax rates, Vietnam has increased the EPT in 2015 tripling tax rates on certain fuel types.[3]

5.2. Implications for fostering incentives for climate policy implementation

Celebrated as an historical breakthrough in international climate change negotiations, the Paris Agreement from December 2015 builds on a patchwork of very heterogeneous national pledges in form of Intended Nationally Determined Contributions (INDC). Though the agreement may be considered an important first step, these pledges now need to be followed by actions, i.e. the implementation of effective climate change mitigation measures at the national and subnational levels. As argued above, it remains to be seen whether pledges are put into practice and it is even less clear whether the necessary intensification of efforts that would bridge the gap between current pledges and the announced ’well below 2°C’- target will take place. More than three months after the Paris Agreement was opened for signature on April 22, 2016 out of the 197 parties to the convention only 21 parties – accounting for less than 1% of global GHG emissions - had already deposited their instruments of ratification, acceptance or approval. The ratification by the USA und China beginning of September 2016 was celebrated as a major step, increasing the share of global GHG emissions covered to about 39%.[4] However, even if the necessary threshold for entering into effect of at least 55 parties representing at least 55% of total global GHG emissions is reached, the non-binding legal status and the absence of a credible enforcement mechanism does by no means guarantee that countries will finally comply with their pledges. The efforts that countries will be willing to make in reducing their GHG emissions will strongly depend on national and individual incentives. These incentives result from the interplay of different objectives and political economy issues as well as dis-incentivizing barriers determining the change in behavior of actors responding to the policies subject to the prevailing market imperfections. The insights from all core chapters of this thesis aim to contribute to draw implications on how successful climate policy implementation can be fostered, addressing the following questions:

- What can we learn from unilateral climate policy with respect to strengthening incentives for compliance regarding the Paris Agreement?
- How can trade-offs be mitigated and synergies between climate change mitigation and non-climate objectives be taken advantage of in order to foster climate policy implementation?

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[3] According to Resolution 888a/2015/UBTVQH 13, the environmental protection tax rates rose from VND1,000/liter to VND3,000/liter (around 0.12€) for gasoline and for jet fuel, while diesel EPT rates increased from VND500/liter to VND1,500/liter (VietnamBreakingNews.com 2015).

[4] For the up-to-date status on ratification see http://unfccc.int/2860.php (last accessed Sept 10, 2016).

The insights from this thesis show that policy making is not necessarily driven by economic reasoning searching 'first-best' least-cost solutions. Instead, decision making is subject to constrained resources and information, political economy and overlapping objectives. Successful climate policy will need to take these complexities into consideration, acknowledge the existence of other policy objectives, anticipate and mitigate resulting trade-off but also identify the potential of synergies in striving for different objectives.

Integrating climate change, sustainability and economic development objectives

In the past, the debate has been dominated by the narrative that there is a trade-off between economic development and climate change mitigation. While there is evidence that in the past economic growth and industrialization has come along with increasing fossil fuel use and surging emissions (Jakob, Haller, and Marschinski 2012), many developing countries and emerging economies have meanwhile realized that while fossil fuel based economic growth may be more rapid, it also comes along with a range of detrimental side effects such as air pollution, environmental degradation (e.g. water pollution) and climate change, all of which are contrary to their objective of improving well-being and livelihoods. Given the strong increase in emissions from developing countries, it is clear that climate change mitigation will be impossible if developing countries follow the carbon-intensive path of development that industrialized countries have used before them. Many developing countries and emerging economies therefore acknowledge their own responsibility to avoid GHG emissions – despite low historic emissions – and understand that climate change is widely threatening their prospects for economic development and poverty reduction. As a consequence they are in search of 'new growth models' announcing their willingness to substitute rapid dirty growth by sustainable economic development with lower growth rates. Chapter 3 has shown that the restructuring of donors' aid portfolios towards climate change and 'green' policies can have some positive impact in form of promoting low-carbon development strategies as seen in Vietnam, though strategies still need to be followed by action. However, Chapter 3 also showed that even reforms that are widely acknowledged as welfare enhancing, like the phase-out of fossil fuel subsidies, face significant challenges when being put into practice.

Another important insight from Chapter 3 is that while Vietnamese policy makers are very much concerned about air pollution levels in their country, they do not yet seem to see a potential link between climate change mitigation policies and air pollution policies. This finding implies that air pollution concerns and climate change mitigation may have synergies that have not been put into context yet, as policy makers have so far treated the two issues as unrelated problems. Likewise for other externalities stemming e.g. from transportation. A study on China estimated that the sum of social costs caused by externalities from car transportation in Beijing is equivalent to around 7.5–15% of the cities GDP (Creutzig and He 2009). Raising awareness about the order of magnitude of such externalities and the potential for synergies may help to gain political momentum for the implementation of reforms that serve to also reduce carbon emissions.

The results from the interviews in Vietnam confirmed the impression that policy makers are bounded in their capacities and competences are divided between different institutions that insufficiently communicate or cooperate to identify negative side-effects or exploit synergies. Moreover, interviewees from development organizations have emphasized that development assistance could contribute to raising more awareness of co-benefits and trade-offs and provide assistance on how to address them. Due to its strong overlap with many other policy areas, climate policy should not exclusively be the responsibility of the Ministry of Environment, but it should involve ministers of finance, energy, economic affairs, development, transportation, urban planning, health and education. Climate protection needs to be considered a cross-cutting issue. Mainstreaming climate considerations in every level of policy making - national, regional and local - as well as different policy areas may help to foster many small contributions, potentially serving as stepping stones for larger scale changes.

Strengthening environmental effectiveness and political feasibility considerations

Chapter 4 presented estimates on the reduced CO_2 and air pollutant emissions that could be achieved by fuel taxation reforms. One may argue that addressing climate change and air pollution with a common measure may not necessarily be the least-cost approach, as the two externalities should be addressed by two separate policy instruments according to the Tinbergen rule (Tinbergen 1952). Moreover, one may argue that fuel taxation levels are already high in many European countries. However, considering the multiple negative externalities resulting from road transportation such as traffic accidents, congestion, noise additional to air pollution and climate change, the exact level of social damage resulting from road transportation is likely to be very high. The World Health Organization estimated the total economic cost of air pollution causing negative health impacts and mortality to amount to over US$ 1.5 trillion for the year 2010 - only for the countries of the WHO European Region (WHO Regional Office for Europe and OECD 2015). Out of the 48 countries considered by this WHO report, in 22 countries the economic cost estimates resulting from premature deaths from air pollution is at or above 10% of the countries' GDP, while for another 10 countries it even amounted to about 20% of GDP. And despite the introduction of various emission standards, concentration limits for harmful air pollutants continue to be exceeded in many urban areas in Europe (EEA 2015a). Apart from avoided economic costs for e.g. the health sector, it is a normative choice how society values improved health and avoided fatalities from the transport sector. Similarly, given the urgency and the potentially catastrophic consequences from climate change and the past trends in CO_2 emissions from the transport sector, effectiveness may be valued higher than economic efficiency considerations. In cases where efficient policy options clearly lack political feasibility, like a global carbon tax, more costly but effective options may be preferable to no policy at all in order to not compromise the goal of environmental effectiveness. Though ending diesel tax advantages may not be the optimal climate policy, the effect on carbon emissions would be considerable for many countries in Europe and such reform proposals may benefit from higher political and public support than carbon taxation in view of the diesel emission scandal and the negative health impacts from diesel exhaust.

Moreover, the integration of climate change and air pollution objectives being addressed by one instrument may help to increase public as well as political support and thereby political feasibility. The global dynamic problem of climate change characterized by a long time horizon is confronted with political systems that are characterized by nationalistic short-term thinking and the impossibility to credibly commit beyond legislative periods. This renders global intertemporally efficient solutions to the climate problem politically infeasible. Addressing the local externality of air pollution - which promises direct and immediate benefits – with a common policy can create leverage for addressing the global externality of climate change - with avoided damages dispersed over the planet and in the distant future - which would otherwise likely not be addressed. Moreover, climate policy measures that are coupled to other societal objectives may be less susceptible to be taken back by successor governments.

Learning from the enabling factors of polycentric policy

Conventional collective action theory predicts a tragedy of the commons if no external regulation is imposed. Elinor Ostrom (2010) has noted that these theoretical predictions are not necessarily supported by empirical findings on smaller scale management of common-pool resources. In this line, Chapter 3 has illustrated that voluntary mitigation efforts – though insufficiently ambitious - may be observed despite the absence of a globally binding climate treaty and credible global enforcement mechanisms. As one explanation, Ostrom names the potential of multiple benefits accruing through other objectives to motivate climate policy, as corroborated by Chapter 3, finding expected benefits from enhanced energy security, economic restructuring and access to finance and technology as main drivers for climate policy in Vietnam. Also Chapter 4 has shown that fuel pricing policies may be motivated by air pollution considerations in addition to climate change mitigation. Edenhofer et al. (2015) argue that exploiting this kind of incentives could at least partly contribute to "closing the 'emission price gap'" (p.140) and avoid carbon-intensive lock-ins.

Apart from this, Ostrom (2010) highlights the lessons from behavioral theory, stating for example that individuals may learn from interacting with each other. Repeated interactions may build up a relation of trustworthiness and reciprocity that can foster the basis for cooperation without external enforcement. Our findings for Vietnam (Chapter 3) illustrate that this may also to some extent apply to the context of international negotiations. Vietnamese interviewees have repeatedly mentioned the intention of Vietnam to establish a positive reputation as 'first mover' and trustworthy partner, with the hope that this may spill-over to other international relations such as trade negotiations or financial and technology cooperation. The foreseen review process for the Paris Agreement may help to strengthen the motivation for reputation building. Cole (2015) argues that polycentric approaches offer the possibility to experiment and learn, and may foster communication between parties, which may again contribute to building mutual trust.

Moreover, Ostrom (2010) highlights that actors do not only strive for self-benefit but – to a varying degree - include other-regarding preferences and moral values in their decision making. Already in the past, countries have shown commitment to reduce poverty in the world giving money for 'official development aid' (ODA). The willingness to give ODA has varied by country; for example the Scandinavian countries have been willing to give a higher share of their national income compared to other OECD countries (OECD 2014). While the willingness to give ODA may also partly be driven by other motivations (Inmaculada Martínez-Zarzoso et al. 2016; I. Martínez-Zarzoso et al. 2014; Alesina and Dollar 2000), moral values and philanthropy yet seem to play some role. In 2014, ODA has amounted to 161 billion USD (World Bank 2016a). Though many countries have remained behind their pledges to spent 0.7% of their gross national income on ODA, aid flows have continued to increase since 2005 in spite of the economic and financial crisis, which shows that strong political will can make a difference (OECD 2016). The problem of climate change is strongly intertwined with the issue of economic development and poverty reduction. Climate impacts endanger the lives and livelihoods of many people worldwide, threatening to wipe out past successes that the world has achieved in reducing poverty and improving livelihoods (Hallegatte et al. 2016). If global leaders are serious about the goal of ending extreme poverty in 2030 as pronounced by the World Bank (World Bank 2016b), these ethical considerations and fairness aspects with respect to historic responsibility may provide some ground to make financial means available if the political will is there. However, large scale financial inflows may also bear a significant risk for developing countries, especially if the institutional quality to manage financial resources is low (Jakob et al. 2014). Development assistance in form of capacity building, technical assistance and technology partnerships may help to address the mentioned barriers for effective climate policy implementation and mitigate the lock-ins in energy intensive infrastructure.

It is clearly still too early to assess to whether polycentric governance can prove effective in reducing global GHG emissions (Jordan et al. 2015). However, the targeted exploitation of GHG mitigation options related to co-benefits, the possibility of small-scale learning and mutual sharing of experiences as well as the stimulation of other-regarding preferences and reciprocity may provide opportunities for a multitude of smaller efforts that may help to build confidence and lead to non-negligible progress in combatting climate change.

Making use of the potentially fast-closing 'window of opportunity'

The past trends in GHG emissions show that a radical change in our current consumption behavior will be necessary to remain within the limits of the global carbon budget and avoid dangerous climate change. To incentivize this major change in emissions, a fundamental shift in policies will be required. The theories on policy change discussed in this thesis have in common that fundamental shifts in policy making are often triggered by specific events that call attention of the public and policy makers for a specific problem. The Fukushima accident has motivated the German 'Energiewende' and considerations of nuclear phase-outs in other countries. The diesel emission scandal has sparked policy reform plans of phasing out diesel tax breaks in France (Reuters 2015) and similar proposals in Germany (Umweltbundesamt 2015). In the words of Kingdon's 'Multiple Streams Framework', such events can open a 'window of opportunity' which can constitute a valuable political momentum for policy change. The Paris Agreement has also created such a momentum and it has already been accompanied by a variety of announcements, and pledges however, actions still need to follow. One of the most important lessons from Kingdon's Multiple Streams Framework is that such a 'window of opportunity' does not remain open for long as public and political attention fade over time and constraint resources other emerging issues will eventually lead to a crowding-out from the political agenda. Without courageous and dedicated policy entrepreneurs taking the lead on climate policy implementation, this historic opportunity of globally coordinating efforts to combat climate change - induced by the Paris Agreement - may pass without being taken advantage of.

Many people have a certain resistance against change as they favor the status quo. However, advertising for inaction in order to preserve the status quo is very misleading with regard to the climate change issue. This type of inaction may instead change our world for the worse and potentially even lead to catastrophic outcomes. Eventually, to preserve the status quo, we all need to make a change and prevent dangerous climate change from happening.

Further research

The findings from this thesis would encourage more work on identifying negative cost options, and estimating local potential for synergies. The literature related to co-benefits has already been growing recently (Driscoll et al. 2015; West et al. 2013; Nam et al. 2014; Dhar and Shukla 2015; Mayrhofer and Gupta 2016). Yet, the complexity and individuality of country-specific or community-specific conditions and preferences requires a multitude of case studies – for individual countries, communities or sectors – as well as comparative analyses. To be able to learn from past experiences, more empirical assessments of the effectiveness of already implemented measures would be very valuable. This needs to be complemented by qualitative studies assessing the underlying barriers that have hampered effectiveness or enabling conditions that fostered effectiveness in specific cases. This includes research on the effect of policy design details on environmental effectiveness and potentially arising negative side effects as well as political feasibility.

Given the high complexity of interactions and overlapping issues, transdisciplinary research would be highly encouraged. As highlighted before, experts from different policy fields need to enhance communication and cooperation – on the political level as well as on the level of research. Finally, to put climate policy into practice, stronger cooperation and communication between policy makers and researchers will be necessary.

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STATEMENT OF CONTRIBUTION

The core chapters of this thesis, Chapter 2 to 4, have been developed and written in cooperation with other authors as indicated in this section. The author of this thesis has made significant contributions to all three main chapters of this thesis, comprising conceptual design, preparing and conducting of interviews, data preparation and data analysis, methodological implementation as well as writing and revising. This section details the respective contribution of the author of the thesis to the three core chapters and acknowledges major contributions of others.

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The idea for the conceptual framework was proposed by all authors and then refined in several intense discussions with all authors of the paper. The author of this thesis has drafted section 2 on the "Theoretical View and Typology" of obstacles to mitigation policy. Iris Staub-Kaminski has drafted section 3 "The Case of China", Michael Jakob has drafted section 4 "Mitigation Policy and Abatement in Numerical Assessment Models" on the implications for IAMs and the Introduction. Robert Marschinski together with Michael Jakob drafted the conclusion. All authors engaged in discussions about and revisions of all sections. The Author of this thesis has been assigned to be corresponding author for the paper.

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The author of this thesis has conducted an intense background research on climate policy in Vietnam and other developing countries to find the case study object and formulate the research question in consultation with Michael Jakob and Jan Steckel. Moreover, the author prepared and organized the field trip and coordinated the interviews, including communication with interview partners and GIZ local office Vietnam, designed the questionnaires for the interviews and conducted the interviews in Hanoi, accompanied by Michael Jakob and Jan Steckel. The paper was then written in intense cooperation of all three authors, assigning main responsibilities for drafting different sections of the paper as follows. Jan Steckel drafted the section on "Vietnam's economic development and energy system", Michael Jakob drafted a large part of the section identifying the different drivers. The author of the thesis drafted the subsection "Understanding the policy change" and the section on "Energy and climate policies in Vietnam" as well as most of the "Discussion and conclusions" part and Introduction. All authors engaged in intensive discussions on and revisions of all sections.

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The author of this thesis developed the main research idea as well as the main methodological approach for the Chapter. Moreover, she conducted the literature review, compiled the data for the analysis from different sources, and was in charge of conducting the data analyses, including the econometric estimations in Stata as well as the calculations and maps for the reductions of CO_2, $PM_{2.5}$ and NO_x. Additionally, the author of this thesis was in charge of writing the paper. Nicolas Koch contributed the idea of adding the perspective of Error Correction Models to the paper. Moreover, he engaged in discussions on the overall framing of the analysis and provided assistance in how to address methodological challenges. Both authors engaged in the revision of the paper.

Tools and Resources

All chapters were written using the software Microsoft Word 2010 for word processing.

The Figures in chapter 2 and 3 have been prepared using Microsoft Word 2010 and Microsoft Office Excel 2010.

In chapter 4, the following tools have been used. For data processing and the econometric analysis, the statistical software STATA/IC Version 11 from Statacorp was used. For the analysis a range of user written STATA commands was used, these include xtabond2 (Roodman 2009), xtlsdvc (Bruno 2005) . Likewise, the tables presenting the regression results and graphs showing time series in this chapter have been prepared using STATA. The calculations of the emission reductions based on the estimates have been conducted using Microsoft Office Excel 2010, likewise for the figures containing histograms. For generating the maps of the distribution of expected emission reductions (CO_2, NO_x and $PM_{2.5}$) the author used the software QGIS Lyon (2.12.3). The underlying shp-files were downloaded from EUROSTAT[1]

The literature has been managed using Mendeley Version 1.15.3.

Finally, for compiling all chapters in a common document the software package LaTeX was used.

For chapter 3, we had assistance by a Vietnamese interpreter to translate in interviews with non-English-speaking interviewees.

References

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Roodman, David. 2009. “How to Do xtabond2: An Introduction to Difference and System GMM in Stata.” *The Stata Journal* 9 (1): 86–136. doi:The Stata Journal.

[1] http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units

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