

Article

Unique Opportunities of Island States to Transition to a Low-Carbon Mobility System

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Abstract: Small islands developing states (SIDS) contribute minuscule proportions to global greenhouse gas (GHG) emissions and energy consumption, but are highly exposed to climate change impacts, in particular to extreme weather events and sea-level rise. However, there is little research on potential decarbonization trajectories unique to SIDS. Here, we argue that insular topology, scale, and economy are distinctive characteristics of SIDS that facilitate overcoming carbon lock-in. We investigate these dimensions for the three islands of Barbados, Fiji, and Mauritius. We find that insular topologies and small scale offer an opportunity for both public transit corridors and rapid electrification of car fleets. The tourism sector enables local decision-makers and investors to experiment with shared mobility and to induce spillover effects by educating tourists about new mobility options. Limited network effects, and the particular economy thus enables to overcome carbon lock-in. We call for targeted investments into SIDS to transition insular mobility systems towards zero carbon in 2040. The decarbonization of SIDS is not only needed as a mitigation effort, but also as a strong signal to the global community underlining that a zero-carbon future is possible.

Keywords: SIDS; transitions; transport; low-carbon mobility; climate change mitigation; tourism

1. Introduction

Small islands developing states (SIDS) are among the first to suffer disproportionate climate impacts. Hurricanes wreck island economies, and flooding and sea-level rise may displace entire island communities. As a result, the people and governments of SIDS understand climate change with a sense of high urgency, as reflected in the United Nations Framework Convention on Climate Change (UNFCCC) climate negotiations [1]. Prime ministers and governments of SIDS ask the world to reduce Greenhouse Gases (GHG) emissions rapidly, to aspire to maintain global mean surface temperatures below 1.5 °C, and thus, prevent the worst climate change impacts threatening their islands from occurring.

SIDS themselves only contribute 0.5% of the global GHG emissions [2]. If SIDS implement strong mitigation action, this will hardly leave a dent in global GHG emission trajectories. Nonetheless, their high vulnerability motivates them to take any action possible in reducing their own emissions. Importantly, they could also provide success stories of transformations towards zero-carbon systems for other countries. Proofing the feasibility of decarbonizing energy and transport systems on small island systems could be a showcase that also fosters other efforts on climate change mitigation.

The insular character of SIDS provides specific challenges, but also opportunities for them. Remoteness and diseconomies-of-scale significantly affect overall sustainable development, especially increasing specific costs for transitioning the energy and transport sectors [3]. Misaligned energy and

transport goals result in an increase in local pollution levels [4], noise levels, congestion, lessened transport system resilience [5], and ultimately, compromised human health.

Despite those challenges, we here hypothesize that SIDS are in a position to transition faster, especially to low-carbon road transport, if they effectively utilize three distinct characteristics inherent to islands: Their insular nature, urbanization patterns, and role of tourism. As isolated islands, SIDS have the potential to implement a sustainable transport system as there is no interconnection with the land transport of other countries, making restructuring faster than that of networked and connected continental countries. Stemming from their small size, limited resources and isolated locations, SIDS possess less entrenched path dependencies and lock-ins owed to large networked scale that slow down transitions in other countries [6]. With their marked boundaries, infrastructures are isolated, display only modest network effects, and provide an opportunity for location-specific change that nonetheless is systemic in nature.

Linking this to the global challenge of decarbonization, SIDS could potentially lead the way as successful energy labs by providing solutions that can be replicated not only for renewables-based power generation [7], but also for sustainable transport in energy-autark regions, coastal regions, and cities of similar population size. In the transport sector, severe delays in meeting climate change mitigation goals exist [8,9], and therefore, positive examples for pathways towards zero-emission transport systems are urgently needed. CO₂ emissions from the transport sector account for 22% of global energy-related CO₂ emissions, which have experienced substantial growth in the past and are expected to double by 2050. The current transport sector relies almost exclusively on liquid fossil fuels, mostly crude oil. Reliance on energy-dense fossil fuels is expected to render decarbonization of the transport sector particularly difficult [8]. Transport demand has grown in parallel to economic development, and with structural changes, it grows faster than that of other sectors [10]. It is strongly influenced by the urban form and cultural norms and lifestyle, factors that are slow to change. Infrastructure phase-out is still uncoordinated on a policy level and not yet globally standardized, and a more fundamental change is needed to achieve modal shifts to less carbon-intensive modes. While electric vehicles (EV) are now marketable, they are more expensive than the conventional internal combustion engine and require a comprehensive refueling network. This underlines the need for positive pilots for zero carbon transport systems to achieve a global change in the transport sector towards decarbonization. SIDS can fill this gap of missing pilots as we investigate in this paper. We address this with three questions:

1. What are the current status quo and related challenges for the transition of the transport system?
2. What specific opportunities exist to address these challenges?
3. What recommendations can be derived for the pilots and for a global transition?

We respond to these questions, by focusing on three representative SIDS: Barbados, Fiji, and Mauritius. We will first introduce the SIDS with a review of their collective history in the climate negotiations playing field, and demonstrate how topographical features usefully constrain a transition of the transport system. We then specify how insular scale and the absence of network effects facilitate a carbon lock-out. We also work out the role of SIDS as tourist destinations and how this then facilitates the trajectories of the islands as laboratories of zero-carbon vehicles and shared mobility accelerated by the substantial tourism sector. Spatial geographic information system (GIS)—based observations allow us to explore the specific acute transport issues faced by islands [11]. We conclude with policy implications, relevant not only for SIDS, but also for other administrative units interested in an energy-autark local transition.

2. Background on SIDS and Pilot Islands

What is the role of SIDS in climate negotiations and why are they interested in energy transitions? Moreover, how does the current transport system of Barbados, Fiji, and Mauritius determine the challenges and opportunities for transition?

2.1. Unique Situations of Small Island Developing States

Small island developing states (SIDS) have been identified by UNESCO as a special cluster of nations on the basis of common challenges they face towards achieving sustainable development [12]. These arise from their small size, relative remoteness, narrow resource base, and vulnerability to global environmental and economic challenges, in particular, climate change [13]. Sea-level rise poses a severe threat to islands' existence and long-term inhabitability for its communities [2]. The underwater cabinet meeting held by the government of Maldives prior to the Copenhagen conference in 2009 highlighted the threat of climate change for low-lying nations [14], and brought SIDS and their precarious plight to the climate spotlight. This high vulnerability to sea-level rise was already recognized in the first assessment report of the Intergovernmental Panel on Climate Change [15]. The Intergovernmental Panel on Climate Change (IPCC) further notes that "some vulnerable regions, including small islands and least developed countries, are expected to experience high multiple climate risks even at global warming of 1.5 °C [13]". One recent example is Hurricane Irma, which displaced every single inhabitant of the Caribbean island of Barbuda and destroyed 90% of buildings and vehicles [16].

Regardless of their marginal demographical, economic and political weight on the multilateral level in general and in the context of an asymmetric negotiation power [17], SIDS have been instrumental in climate change talks by bringing an ambitious and progressive voice to the table. AOSIS, the Association of Small Island States within the United Nations, played a focal role in pushing for the 1.5 °C aspirational goal during the COP21, arguing the 2 °C goal was not sufficient. They have succeeded in efforts to "develop a specific negotiating agenda addressing areas which are of overriding concern to them and succeeded in having those concerns incorporated in a legally binding convention of historic importance" [18]. Notably, they played an important, unprecedented role in the negotiation of accounting for their agenda during the establishment of the climate change convention [18], and thereafter, they continued to advance the climate negotiation process itself, for example, in the shaping of the Copenhagen Accord negotiation process in 2009 [19,20].

There is a significant, yet still a mainly unexploited potential of islands to function as laboratories for technological, social, economic, and political transitions. The attraction of islands as fields of research studies comes down to their easily confined and demarcated spaces. Islands' characteristics provide several advantages in acting as living laboratories in the renewable energy transition. Their isolation makes them unique in studying the feasibility of a 100% renewables systems; examples of island systems combining smart technologies, cooperatives, local community energy projects and micro grids include the Isle of Eigg [21], El Hierro [22], Tokelau [23], and Ta'u of American Samoa [24]. Fiji recently became the first country to unite their economic and climate ministries, doing so to prove two-fold that sustainable development is possible and to act as a flagship for other countries to follow suit. SIDS can, therefore, not only influence global climate change mitigation via negotiation power, but also through providing technical and economic examples of transition pathways towards zero carbon. However, gaps remain in research on low-carbon mobility transition on islands. In developing strategies for sustainable development on islands, the transport sector is rarely analyzed as an integral part of the energy system or as part of the insular economic system, particularly its role in tourism [25]. With their small scale, and therefore, less entrenched network pathways, this global transformation platform now provides the SIDS, an opportunity to reconfigure patterns around sustainable transport system to prevent further path-dependencies and lock-in effects.

2.2. Characteristics of Barbados, Fiji, and Mauritius and Their Transport System

For our paper, we study three SIDS: Barbados (Caribbean), Fiji (Pacific Ocean), and Mauritius (Indian Ocean). These islands represent a broad cross-section in size, population densities, road networks, geographical location, degree of isolation, various transportation issues, and development stages (Table 1). For this paper, we only focus on the main island of each archipelagos; for Fiji, this is Viti Levu and the main island of Mauritius for the Mauritius archipelago. The number of inhabitants range from 285,000 (Barbados), to 600,000 (Fiji), and to 1,200,000 (Mauritius). Fiji has the lowest population

density and the lowest gross domestic product (GDP) per capita at 4300 USD. Barbados has the highest GDP at 16,800 USD/capita, and Mauritius has 10,500 USD/capita. Despite these differences, for all three islands, tourism is the main economic driver. The number of tourist arrivals ranges from roughly one to three times the number of inhabitants. This underlines the important role of tourists not only for the local economy, but also for the local infrastructure, particularly the transport system. An analysis of the power sector shows that all three islands have implemented sufficient power infrastructure to serve all inhabitants. Nevertheless, the supply structure is heavily dominated by fossil-based power generation. This especially drives the high electricity tariffs of Barbados as all costs are passed to the consumers and underline how expensive fossil fuel-based power generation is on islands.

Table 1. Summary of characteristics of pilot islands. The symbol “[#]” stands for “Number of Units” of the variable next to which it is located.

		Barbados	Fiji	Mauritius
Geographic characteristics	Location/Ocean	Caribbean	Pacific Ocean	Indian Ocean
	Area [km ²]	431	10,388	2040
	Population [#]	285,000	600,000	1,200,000
	Population density [# / km ²]	661	58	588
Transport system	Road Network [km]	1750	11,000	2066
	Tourist arrivals [# / year]	681,000	870,000	1,400,000
	GDP per capita [USD]	16,789	4323	10,547
	Size of street network [km]	1600	11,000	2040
	Individual cars [#]	108,057	84,558	226,645
	Buses [#]	444	2444	3107
	Taxis [#]	Not known	6394	6905
	Freight [#]	Not known	18,681	15,801
	State fleet [#]	Not known	1988	Not known
	Rental cars [#]	Not known	4040	Not known
	Two-wheelers [#]	2335	Not known	91,378
Electricity supply system	Electricity tariffs [USD/kWh]	0.28	0.14	0.18
	Installed power generation capacity	258 MW	549 MW	877 MW
	Fossil Fuel	239 MW	296 MW	735 MW
	PV	19 MW	27 MW	29 MW
	Wind	0	10 MW	15 MW
	Hydro	0	134 MW	61 MW
	Bioenergy	0	82 MW	37 MW

Across the three SIDS, the travel behavior and patterns are largely dependent on the spatial structure through which the urban structure has evolved. Public transport is characterized by unsatisfactory levels of service and congestion. For example, between 2006 and 2016, Mauritius has experienced a 59% increase in the overall fleet, dominated by a 120% addition in private vehicle ownership from 92,000 to 203,000; in contrast, buses have only seen a 19% increase from 2612 to 3107 [26]. With their high economic and car ownership growth rates within the past decades, both Barbados’ and Mauritius’ transport scenarios serve as a microcosm of the transport sector in developed countries [27], and a potential business-as-usual pathway scenario for other SIDS. Through urban sprawl, the need to travel and increased dependence on the private motorized transport mode are reinforced, and this leads to increased traffic congestion, energy consumption, and higher polluting emissions. The first national household travel survey [28] in Fiji found that 53% of trips are made on foot, cars have a modal share of 17%, public transport 17% and taxi 6%. For urban residents, this increased to 27% car usage and 12% taxi; reflecting the aspirations of many to travel by car and the inadequacy of public transport to cater to this market. This urban-rural divide in car usage is mirrored in other developing economies, such as India, where more wealthy urban areas have higher car use than rural areas, and contrasts with the Organization for Economic Co-operation and Development (OECD) countries which show inverse patterns [29]. Currently, Fiji’s mobility patterns are sustainable,

as modal shares are dominated by walking and using public transportation. The challenge lies in the predictable correlation between travel pattern and economic wealth: As economies become more advanced, the use of motorized transport, particularly private cars, increase. The transport sector in Fiji is at crossroads with policy and infrastructure options focusing on continuing this avoid-shift-improve method of transport and adequate supporting the economic development.

Figure 1 shows that the population of the three pilot islands is concentrated around the largest urban agglomerations, as in the case for the majority of SIDS. On Mauritius, Port-Louis has the highest population density at 147,448; followed by Vacoas-Phoenix at 106,022; Beau Bassin-Rose Hill with 104,086; Curepipe at 78,692 and Quatre-Bornes 77,308 [30]. In Viti Levu, the majority of the populations lives in Suva with 185, 13 inhabitants; with 71,573 and 71,048 on the West coast in Lautoka and Nadi, respectively; and 10,509 in Sigatoka on the southwestern coast [31]. The population density in Barbados is extremely concentrated around Bridgetown with 5996 inhabitants; and a further 82,533 inhabitants in St. Michael, 54,336 in Christ Church, 28,498 in St. James and 14,249 in St. Thomas [32]. The dominance of a conurbation around a single urban center can be observed with a skewed concentration of labor and administrative services in both Barbados and Mauritius. Similarly, Fiji also exhibits comparable patterns in addition to the sporadic settlements around the coast. Very similar patterns can be found on most SIDS, and this primacy of capitals and centralization makes the provision of services, including public transit, to small towns more difficult. The concentration of human settlements and valuable infrastructure also occur near the coast. In addition, climate impacts also interact with the transport system, resulting in several challenges [33] for the transportation sectors in Pacific island countries. These include the closure of roads, airports, harbors, bridges and other vital infrastructure systems, due to flooding, hurricanes, and landslides. These incidences will have adverse effects for SIDS, especially in times of disasters when these infrastructures are vital for relief, supplies logistics, and other essential functions.

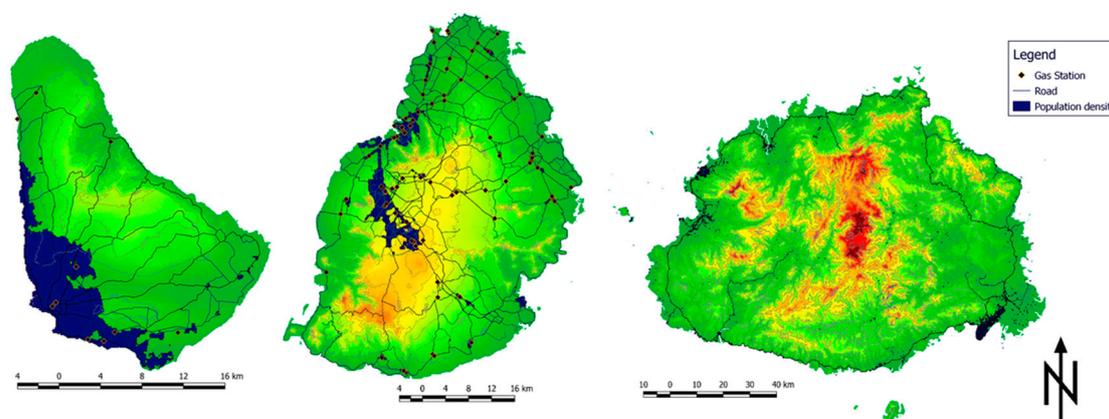


Figure 1. Maps of Barbados, Mauritius, and Fiji-Viti Levu (from left to right): Urban areas are mapped based on the Global Urban Footprint Data.

Despite massive differences in land sizes, SIDS face limited physical space. Most of them are only equipped with one main road stemming from the capital city, and arterial roads are impeded by topological features. The road networks of all three pilot islands are heavily constrained by the topography (Figure 1). Figure 2 also display two other characteristics of the transport infrastructure on islands. First, the road system is bounded by ring roads along the islands' shores and the arterial roads connecting settlements within the islands' interior. While this may be self-evident, it is nonetheless an important point for analytical departure, making insular road system distinct from the open-boundaries of continental urban systems. Second, there are few roads in the islands' interior, especially if islands are dominated by mountains or volcanoes. Transport activities, and livelihoods in general, remains

concentrated in a sweet-spot area between shores and mountain ranges reducing travel distances significantly compared to continental countries.

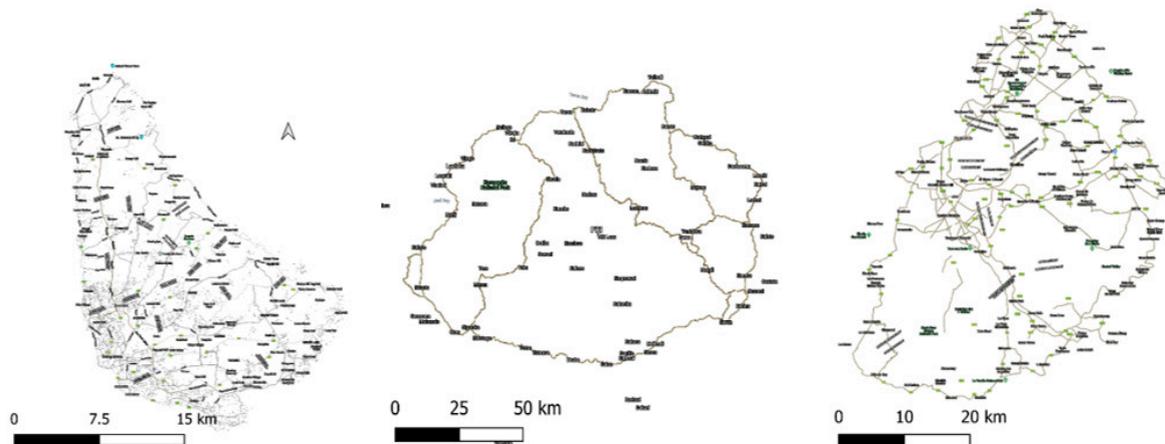


Figure 2. Maps of Barbados, Fiji-Viti Levu and Mauritius (from left to right): Road networks are mapped based on the OpenStreetMap data.

Through the maps, we identify three main types of road networks: A ring road along the coast, the main highway stemming from the capital cities, and smaller, paved roads outside the main population corridor. The specific physical-geological processes underlying islands' formations have a direct impact on the road network. Both Mauritius and Fiji stem from a volcanic origin leading to its specific relief, similar to islands, such as La Reunion and São Tomé and Príncipe. In Mauritius, the urban networks use the existing, sparse highway grid, and therefore, offer few connecting roads at medium altitude; they generally consist of parallel routes running from main urban corridor to the coastal strips. Having a high population density and only 2000 km of roads, congestion is a major issue in Mauritius. Fiji's topography restricted the 11,000 km road network to the spine or circumferential main roads with feeder roads, leaving few route alternatives. Barbados' 1600 km of road network stems from Bridgetown, the capital and given the small size of Barbados, is very dense, and includes a ring road. Trip lengths between points within the islands are not very substantial: In Barbados, the furthest points account for a distance of 34 km, in Viti Levu, this is 249 km between Nausori and Lautoka and 75.4 km between Souillac and Cap Malheureux.

In summary, we find that SIDS have certain distinctive road networks and defined travel patterns, which could favor electric vehicles through short travel distances and public transport through high-density travel corridors and ring roads. Still, the current transport systems are built heavily on individual car ownership, which usually means combustion engine-based cars. We can also observe that with increased GDP, the individual car ownership also increases on the pilot islands. It is, therefore, important to analyze trajectories out of these fossil-based and car-centric transport systems to achieve zero-carbon mobility considering the special characteristics of SIDS.

3. Turning Challenges into Opportunities: SIDS-Inspired Transition of Transport Systems

Historically, the specific development transition challenges of SIDS evolve from their small size, relative remoteness, narrow resource base, and vulnerable economic structures. Looking at systems transformation, these challenges can be translated into opportunities as small and less-entrenched systems can transform much faster than established large systems, which subsequently face lock-in dilemmas [34]. In order to validate this for our pilot cases, we first briefly elaborate on the theories of transition and second on the specific challenges and the opportunities that might occur from this.

3.1. Theories of Transitions and the Special Case of SIDS

Staying within low-carbon budgets demands an enormous escalation of sustainable actions; spanning the transition of the complete value chain of entire sectors. For the energy and transport sectors, this relates especially to the end-usage of fossil fuels. Past transformations have shown the importance of energy end-use demand in driving such transitions [35]. Energy demand and supply coevolve, with innovations mutually enhancing each other, but without energy service demand changes, the drastic changes in energy supply that emerge so impressively from the historical records, such as biomass and wood to coal and in turn from coal to oil, gas, and electricity would not have occurred. These changes affected the entire value chain of energy-related services and transformed entire economies. Whereas, historical observation of major energy transitions of established countries shows that they often spanned decades, countries with a smaller consumer base are able to switch and exit at a faster scale than others, since they are often driven by demand-side solutions.

Different elements influence the speed of transitions. Scale factor or market size denotes that larger systems change at a slower pace than smaller systems. Technological interrelatedness and infrastructure need to slow down the fluidity of the switch, for example. The more infrastructure-intensive, and complex technology systems are, the slower they are to change. Conversely, there are also factors that can speed up transition: The preexistence of niche markets that offer an early testbed for experimentation and scaling up novel technologies and comparative advantage, which can comprise multiple elements of performance, efficiency, and costs.

Energy transitions, especially those taking place on a smaller scale, can occur more quickly than expected. In the study of the coal to oil transition in the early 1900s, 20 countries from Latin America are examined [36]. The transitions of these smaller nations occurred at a faster and earlier scale than those of leading nations, and demonstrates that it is possible to leapfrog as these nations did. The authors demonstrate that the smaller the amount of consumption, the faster and earlier the transition took place, since the replacement cost of infrastructure was minor. This phenomenon is also explored in greater detail in an overview of rapid energy transition cases, such as cogeneration in Denmark [37].

Additionally, the transition to new systems can be achieved much faster by late adopters that can profit from early learning externalities [6]. Early pioneers can be captive of their early successes. By using history as an analogy, there is a possibility that it will precisely be the current energy periphery that might be the first to transition away from fossil fuels and also relatively rapidly, whereas, the current core countries (in this case, the OECD) may continue to be “lock-in” into fossil fuel systems for much longer and may face higher hurdles for transition [35,36]. We summarize the main points from each of the transition theories, which are applicable for the SIDS in Figure 3.

In conclusion, these theories provide a blueprint for SIDS to observe the barriers faced by bigger economies to avoid those miscalculations, leading to the advantage of late-adopters and the legacies of early pioneers. Therefore, factors enabling accelerated transition, especially regarding small-scale markets, the existence of niche markets, scaling up of novel technologies, as well as the ability to learn from the early pioneers acts to the advantages of the insular features.

3.2. Insular Scale and Topology as Facilitators of Sustainable Transport

With their small scale and dense road networks and population settlements, fleet electrification presents a viable decarbonization pathway for SIDS. Islands typically have high energy costs, due to a lack of economies of scales and expensive fuel costs resulting from their insularity and remoteness; providing them with a very significant financial catalyst to accelerate the transition away from fossil fuels. A switch to an electric fleet means not only major environmental benefits, but also substantial cost savings in fuel imports. Fossil fuel imports, for electricity and transport, comprise a large share of their GDP and limit their capacity to make strategic investments in low-carbon solutions. This has turned into a vicious cycle of paying for high fuel import bills, and therefore, having less money to spend on novel local infrastructures, leading to a high-carbon lock-in. This prohibitive fuel costs combined with the limited road network and the high potential of solar power can be two factors

advancing the implementation of electric vehicles on SIDS. The conversion of the private fleet will lead to major costs savings. In Barbados, the costs difference is \$1.67 and \$1.40 for a liter of petrol and diesel, respectively, compared to \$0.28 per kWh. In Fiji, these costs amount to \$1.01 and \$0.86 for a liter of petrol and diesel, respectively; whereas, the cost of electricity is \$0.14 per kWh; in Mauritius, it is \$0.18 per kWh, while the cost of a liter of petrol and diesel is \$1.39 and \$1.23. Many SIDS, confronted with growing energy demands, will be making investments in power capacity over the next decade [38], and given present trends, with vehicle ownerships continuing to rise, switching to EVs allows for greater energy security and lower-cost pathways. The continued expenditure on importing fossil fuels is a major source of government spending. The SIDS also belong to a group of the most indebted countries globally [39], and a complete switch to renewable energy sources would lead to savings of \$3.3 billion annually [22].

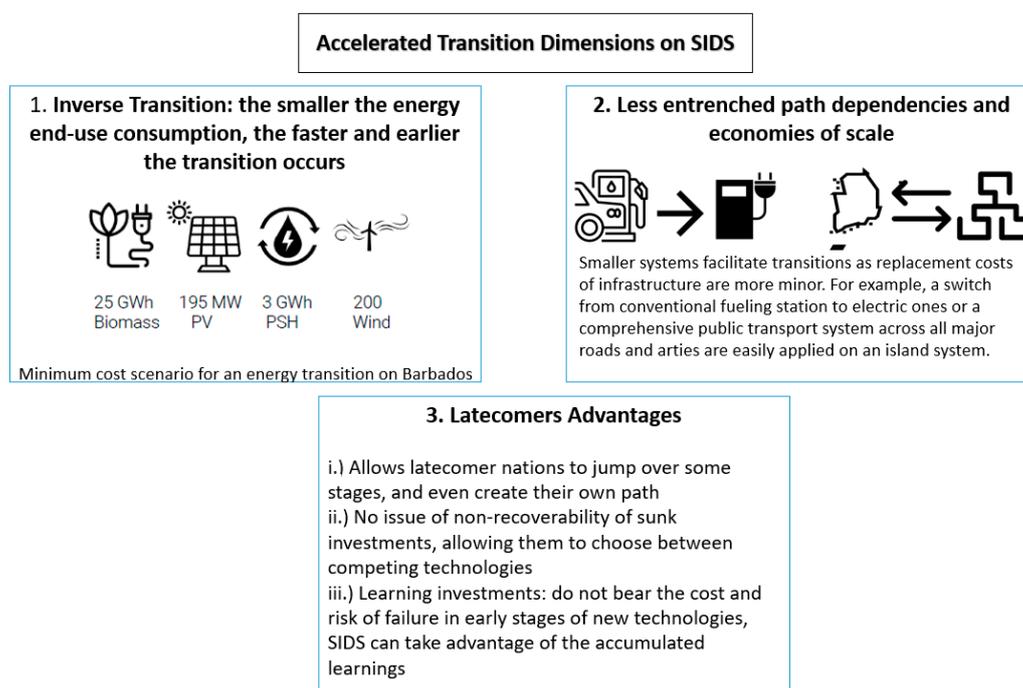


Figure 3. Summary of the three theories from energy transition studies and paths taken applicable to small islands developing states (SIDS).

Multimodality is important for achieving less carbon-intensive mobility patterns, and the innate topologies of the SIDS prove unique conditions for achieving this: A populated urban corridor, limited physical space and constricted road network delineate very clearly the potential of innovative forms of transport. This should be accentuated by policy through purchase incentives, stricter restrictions on CO₂ fleets and investments into electric buses and fleet. While private fleets comprise the highest percentage of vehicles types, and therefore, fuel consumption, a mass rapid transit system combined with feeder buses into the rural regions combined with on-demand services becomes a low hanging fruit. Crucially, a transition to EVs must be supported by a concurrent transition to low-carbon electricity to reduce GHG emissions effectively [40]. Through the integration with renewable energy sources, it is easier to control the charging conditions, and the predetermined routes and bus stations allow for easy calculation of optimal location and capacity of charging infrastructure. For private fleets, given the geographical spread of the road networks, a range of 200 km daily makes charging at home feasible. With continuous renewable energy capacity uptake, electric mobility adds to the storage capacity, resulting in higher sector coupling possibilities.

3.3. Investment Needs for Low-Carbon Mobility Infrastructure Along the Pilot Islands

Infrastructure stands between encouraging modal shifts [41] and carbon lock-in [42], and maintaining the existing mobility demand. If the infrastructure is not included in mobility and land-use planning, this may result in lock-in of high carbon emissions, deterring sustainable transportation transitions.

For a quick EV uptake, implementing charging infrastructure is a critical driver [43]. In a survey of potential EV consumers globally, 17% of the respondents identified a lack of charging infrastructure as their bigger concern when it comes to buying EVs [44]. However, often charging infrastructure will only be implemented if a sufficient penetration of EVs has been reached to justify such investments. If governments or private initiatives initially support the provision of charging infrastructure, this chicken or egg dilemma of EV implementation can be overcome without waiting for individual users to acquire and use a significant amount of EVs [45,46].

Barbados has already seen an initial EV uptake stimulated mainly by the private sector. Megapower Limited solved the aforementioned chicken or egg dilemma of electric vehicles and sufficient charging stations by installing 40 charging points across the island. Therefore, EV users are always within a five kilometers distance to a charging station. Through the installation of two solar PV covered carport infrastructure, they offset the electric vehicle charging from the grid. Barbados now has over 350 electric vehicles, despite no financial regulatory incentives, proving that adequate infrastructure can be a push factor in consumer choices. This is still a penetration below 1%, but shows that with relatively little investments, a transport transition on SIDS can be initiated.

The SIDS are still lacking in public charging facilities—although, given the closed road system and size of the islands, this is much less a concern for EV users than in countries where vehicles cover longer distances. In Figure 4, we estimate the necessary initial investments into charging infrastructure based on the ideal amount of public slow charging stations available at every 5 km. With all three islands spending a high percentage of their GDP on fossil fuel imports, a twenty-year investment into charging infrastructure will lead to long-term financial savings. Barbados currently spends 7% of its GDP on importing fossil fuel; covering its road network with charging infrastructure every 5 km amounts to an estimation of \$1,263,123 USD as opposed to the 355,005,000US\$ currently being spent. For Fiji, this switch is slightly higher more at 14% of GDP; yet still very much attainable for a 20 year investment project. In Mauritius, the investments comes to \$1,490,052 USD, a minimal sum in comparison to the yearly spending of \$766,476,793 USD on fossil fuel imports. The costs are the initial investment costs, as well as the total costs of ownership for the following 20 years [47]. For the SIDS and their previous investments in fossil fuels infrastructure, these initial investments will be substantial, but the various outcomes in terms of reduced imports of fossil fuels, GHG emissions, and traffic pollution are beneficial for the countries in the long-term. With the electric vehicle market on the islands still in its infant phases, public charging infrastructure will help create a market pull and help to overcome any range anxiety on behalf of freight sectors and tourists, who may not have the luxury of private charging.

Total transport electrification and the required infrastructure hold many barriers—namely the high costs of batteries, and therefore, the high costs of the vehicles themselves, social resistance, and the availability of charging stations. However, the SIDS, with a smaller consumer base and propelled through appropriate policy measures, as well as historically observing past energy transformations, may prove to be ideal testing grounds for a faster transition.

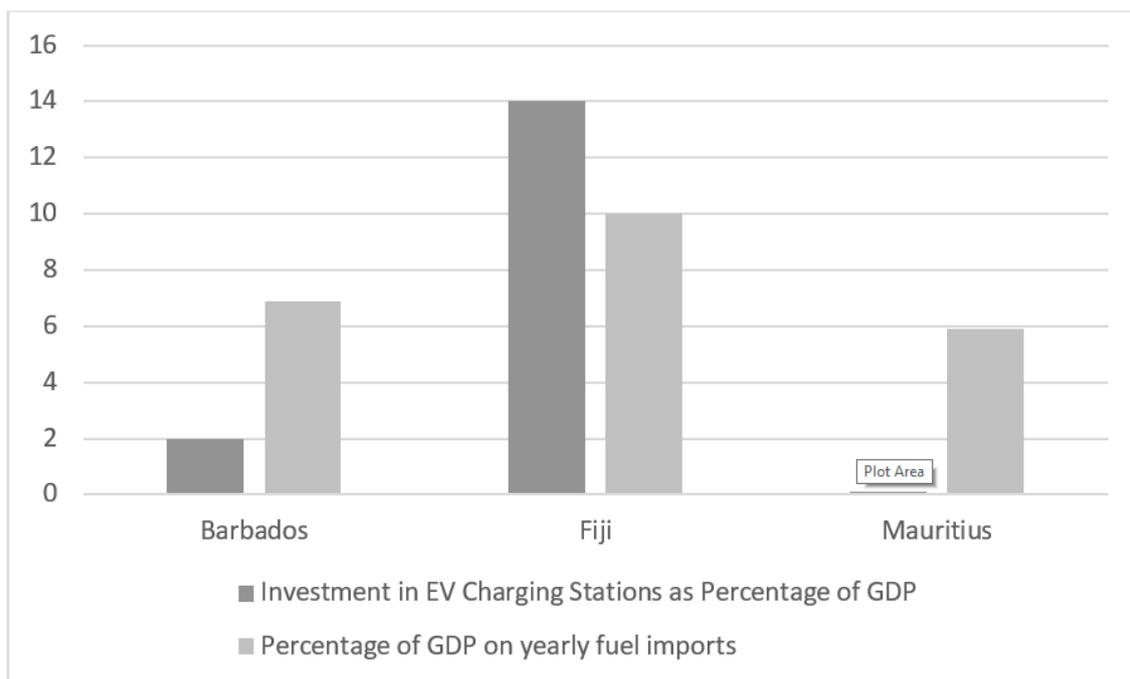


Figure 4. Investment in electric vehicle (EV) charging stations as a percentage of GDP compared to the yearly percentage of fuel spending.

3.4. SIDS as Tourist Generation Destinations as Accelerator of Shared and Low-Carbon Mobility

Tourism has since long and continues, to play a significant role in the development trajectories of SIDS, to the extent that the sector has become “an essential component of economic development” [48]. For a successful transition of the transport sector towards decarbonization, strong synergies with the local tourism sector are required.

The sector has not only been a tool for local and regional growth, income generation, forex inflow and employment creation in SIDS, but also poverty reduction [49]; in some cases, it is the most important source of foreign exchange and contributor to GDP. It is also simultaneously the main engine of growth and the source of demand on natural resources, energy, infrastructure, and services. For all three pilots, SIDS studied, the yearly number of tourists on the island outnumbered the number of residents in 2018. This sector has both a high demand for transport, and as travelers become more conscious of their carbon footprints, high demand for green technologies and combined with its economic power, therefore, it can be a major driver for the change of the transport system.

The potential inter-linkages between tourism and transport sector are unequivocal and plays two keys roles in the uptake of low-carbon transport solutions. The revenues generated from tourism tax becomes an important financial resource for the local government and tourism authorities to ensure money flow in eco-tourism and enhance the quality of the experience for tourists. Tourism transport demand stimulates movements, pushes capacity limits and places pressure on existing infrastructure and supply; therefore, securing the economic viability of local transport supply. Studies show that the majority of tourists find that their travel decisions would not be negatively impacted if their total vacation cost increased by one third and most visitors are willing to pay a nominal fee towards funding the conservation of coastal and marine resources in Barbados, translating into the possibility of higher willingness to pay for low-carbon modes. [50,51]. Furthermore, tourism provides a unique opportunity through which travelers have the chance to live-out an “ideal self”, thus, making tourism highly relevant and sought after with respect to self-concept development. This provides a change of routines, as habits have also been identified as an important aspect affecting intentions to change behavior [52]. With travelers, “selves” more dynamic and open to trying out new identities, the

psychology of travelers might provide insights and potentials towards changing transport behavior and mobility consumption. This adds to social emotions among tourists, and therefore, influences their economic and overall sustainable behavior.

With a tourist population equaling that of the local population, the SIDS need to provide adequate built-infrastructure and demand options for two different transport requirements. On average, tourists stay for 7 to 12 nights across the three islands [53–55]. The statistics also show that there is not much variance among the seasonality of tourists' arrival, although there is an uptake in January, July and December in all three islands. Touristic places of interest from hotels to museums are more spread out throughout the island, especially along the coast, as one of the biggest touristic attractions of the SIDS is the coastal landscapes, as can be seen in Figure 5. This produces travel patterns distinct from those of the local population, which mostly resides within the urban corridor, and for which the majority of the daily commute takes place within this corridor. This then provides the opportunity of tapping into the usage of the ring road and last-mile options. In 2018, for visiting cultural sites, the most popular mode of transport in Mauritius was taxi usage [55], and in Barbados, 8.9% of expenditure by tourism went to transportation [53]. Alternatively, the SIDS must invest in national transit maps using route data and potential new public transit lines, by focusing on touristic attractions with demand being served by on-demand sustainable options, such as e-scooters or establishing bike lanes.

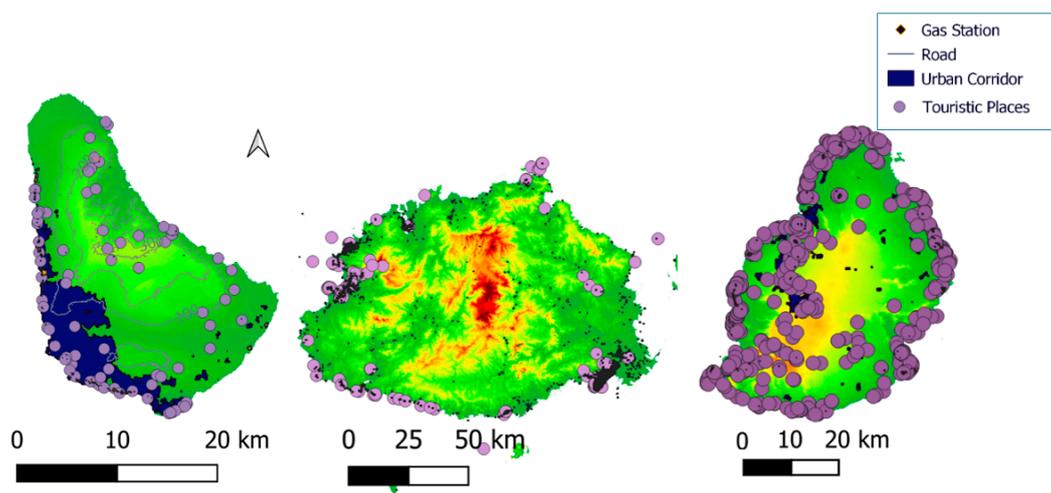


Figure 5. Touristic points of interests mapped in relation to the urban corridor and road network.

Rural transport is characterized and driven by tourism requirements in regions where there is a high level of importance attributed to the revenue leisure visitors can bring to peripheral areas [56]. The tourism market might only have minimal influence on public transport, which is generally centered on the requirements of the local population presenting an argument to support increased attention on transport services in rural communities [50]. From a consumer's perspective, time is also a crucial aspect of tourism travels. In rural areas with less public transport availability, visitors are more likely to use private modes, due to time constraints [57]. Furthermore, the fact that attractions are spatially scattered make tourists more car-dependent [58]. When traveling, tourists are also usually unfamiliar with the public transit network, which becomes another challenge. This has to be considered when linking the development of public transport and modal shifts to the tourism sector of SIDS.

Mobility transition in line with touristic transport needs should be encouraged and coordinated across the SIDS through tapping into the potentials of the ring road. With much of the SIDS touristic attraction on or near the coast, well-targeted and structured alternative and flexible modal shifts. By applying the effects of the implementation of mobility as a service (MaaS) in Lombardy in the Alps, a region heavily based on tourism, the viability of substituting private cars through MaaS is studied [59]. The younger generation (millennials) were targeted by awareness-raising campaigns,

technologies, and by promoting an integrated Alpine tourist package. When transferring this study to island states with no such pilot projects or a dearth of researching looking at MaaS on tourism in SIDS, it is imperative to have extensive knowledge of visitors' characteristics and their behavior towards different mobility options and subsequent mobility policies aiming at sustainable tourism. Given the widespread penetration of smart-phones and inexpensive data packages, future transport modes will be data-driven and user-centered, powered by the growth and use of smart devices. MaaS has led to different mobility streams: Car sharing, drive sharing and car-pooling, enabling the transition to sustainable mobility models. At its core, MaaS provides a real-time "subscription" of a certain duration of the personalized use of a bundle of public and private transport means, such as trains, buses, taxis, cars and bike-sharing, which is ideally used within one subscription. Tourism-based destinations are trying out a number of new solutions, from which SIDS could incorporate in their sustainable tourism blueprints. The EU Civitas project examines sustainable mobility pathways on six European islands: Las Palmas, Rethymno, Elba, Limassol, Funchal, and Valletta. Island specific solutions include the integration of ferries into the public transport network, EV charging points at touristic interest points, expansion of the public bike-sharing system, including e-bikes, and electric bus hop-on-hop-off service in the old town [60]. In Madeira, public transportation is promoted through a free audio-guide for smartphones [61].

In conclusion, SIDS' transition in the transport sector can be fostered by the tourism sector. It can be a driver for fast transition, as the international players are able to invest in necessary cars and infrastructure, causing rapid changes to the transport system of such small island states. A green tourist tax can help to implement MaaS solutions along ring roads, catering to the most important touristic destinations, but also providing initial public transport for the local population working in the tourism sector and those living in underserved rural communities. The transition process also profits from the international experience of the tourism companies, as well as from the sustainable and open mindsets of international tourists looking for green holidays.

4. Policy Implications for Local Decision-Makers

In this study, we suggest that there are three specific inherent characteristics to the SIDS that allow for a rapid transition: (1) A topography resulting in a constricted road network; (2) smaller scale leading to a less entrenched infrastructure network; and (3) the existence of an optimal experimentation landscape—the tourism sector. In order to facilitate this transition, policy changes focusing on the three distinct agendas are required. Islands are able to achieve a carbon-neutral energy system through the utilization of variable renewable energy sources (VRE) coupled with modal shifts and improving access to climate finance and funding opportunities to push for charging infrastructure and EVs.

Finance is a key leveraging factor to achieve the transition. Transport activities and emissions are forecasted to continue, as SIDS also strive for higher levels of development combined with the demand for transport and the built-infrastructure for a tourist population equating or higher than their own population. This further increase in demand requires a rapid and sustainable build-up of new investments. With a small network size and the ability to account only for a set number of cars, since there are no inter-country travels, charging infrastructure can easily substitute each of the fuel charging stations in the SIDS. The initial amount of investments needed is still lower than the yearly amount spent on fuel imports in Barbados and Mauritius, while for Fiji it is marginally higher. Financing can be sourced via international development banks or climate financing. The global community has committed at least USD 100 billion per year of financial resources from various sources, such as public funds and mobilized private climate financing for developing countries [62]. Improving access to climate finance and increasing absorption of funding opportunities are integral to speeding up the SIDS efforts to enhance adaptation and build resilience. SIDS will also need easier access to financial instruments, such as risk-sharing facilities, contingent credit, or international aid.

Insular policy makers could also consider the audacious move of implementing a carbon tax, thus, supporting the rapid phase-out of fossil-fueled cars and power plants [63,64]. Possibly, a climate

club of Annex-I countries, interested in advancing climate mitigation globally, could support this maneuver, in turn, by subsidizing low-carbon technologies, e.g., via financing the EV charging stations, and provided security collaterals for the up-front financing of photovoltaic power plants [65].

Redesigning transport infrastructure is another key leverage point. Transport planners can optimize the ring road structure of SIDS with an improved public transit network benefiting both the rural communities and tourists, resulting in the inclusion of local participation, raising awareness, and autonomy. Spaces with extensive and effective public transit networks are more attractive to tourists [66]. Furthermore, touristic experience benefits from a high-quality public transport network. Bus services dominate the public transport system on islands, due to their cost-effectiveness. Network inefficiencies relate to the supply of bus services failing to meet the demands of the traveling public. In order to improve this, decision-makers need to study mobility patterns and modal choice preferences. Route optimization may also have to adjust to new congestion patterns and infrastructure availability (road lanes, bus stops, etc.) by modifying the route network and allocate bus priority corridors. Through the use of big data curated towards transportation and tourism, we are able to understand how public transport is used at destinations, the precise distinction between urban and rural geographical spaces so as to transform public transport into a potential alternative model for travelling [67]. Socially, there also needs to be an understanding of the most important factors influencing tourist choices and satisfaction with public transport, and therefore, we can best encourage public transport use in tourism. A successful public transport system is one, which is responsive to the user's needs. The most optimal way to achieve this might be to develop a public transport system through assistance from the system's users—in this case, residents who feel underserved by rural public transport and tourists. Volunteered Geographic Information, VGI, crowdsource data, which is more detailed, local, and contextualized and aims to make routable data available and reduce information gaps. Within the context of tourism, VGI can aid in developing routing and navigation systems that recommend personalized routes in real-time to each travelers' specific needs. Local decision-makers and governments should work together with international development agencies to implement such innovative technological solutions. Still, another key obstacle towards a sustainable transport-tourism relationship is structural disparity. Transport is usually regulated through public bodies, whereas, tourism is primarily a framework of private businesses. Collaboration is needed to achieve a cohesive effort and understanding that neither sector can prevail within a sustainable framework without affecting the other is imperative [68].

Future mobility systems will be a combination of analyzing behavioral shifts among consumers, smart mobility services, restructuring of the infrastructure and policies of the energy system, as well as optimizing vehicle and fuel technology. If rightly steered and constrained by public policy, the digitalization of smart mobility offers huge opportunities to decarbonize transport [69], especially for island states with flexible touristic users. In Mauritius, the construction of a light rail metro transit throughout the urban corridor is envisioned, this then gives the possibility of electric feeder buses connecting bus stations from the rural catchment area to the metro stations and then different modal possibilities for the last-mile solution. In Barbados, Megapower Ltd., in addition to installing charging points across the island, is also investing in solar PV carports and medium scale wind turbine projects to further decarbonize the energy mix and offset carbon emissions from the grid. In the meantime, Fiji, with funding from the Green Climate Fund (GCF), is prioritizing investments in electric bus pilot projects, including charging facilities, training, maintenance, batteries and its disposals.

5. Conclusions

With our paper, we have investigated the special role of SIDS in the global decarbonization of transport systems. We showed that geographical and economic challenges could be turned into opportunities for SIDS. With their limited road network, high fuel import costs, heightened vulnerability to climate change, and relevance of the tourism sector, they are in a unique opportunity to transition rapidly into low-carbon systems. We identified two main types of carbon break-out dimensions impacting the sustainable transition and described how they can coevolve: (a) Infrastructural and

technological through the implementation of electric vehicles and charging infrastructure; and (b) behavioral by providing the tourism sector with a choice of low-carbon transport modes. Thus, SIDS could achieve and potentially lead the way as successful energy labs for energy autark regions, as well as coastal regions and cities of similar demography sizes.

The three islands explored represents the main transport typologies and the factors affecting a sustainable transportation transition on SIDS: Constricting geographical topology, a highly populated urban corridor and the potential to tap into the tourism sector allows the SIDS a leapfrogging opportunity to involve a mix of seamless mobility, a rapid transit system in the urban corridor and fleet electrification. Analyzing the street typology allowed us to understand, and therefore, optimize the space and interactions between the natural and built environment. While the SIDS differ regarding topology, due to their natural heritage (volcanoes, ravines), their urban development has followed the same pattern and their limited road network (even on the biggest SIDS Fiji) remains geographically constrained, making public transport in some cases attractive. The success factors for an accelerated transition of the transport sector on SIDS are summarized in Figure 6.

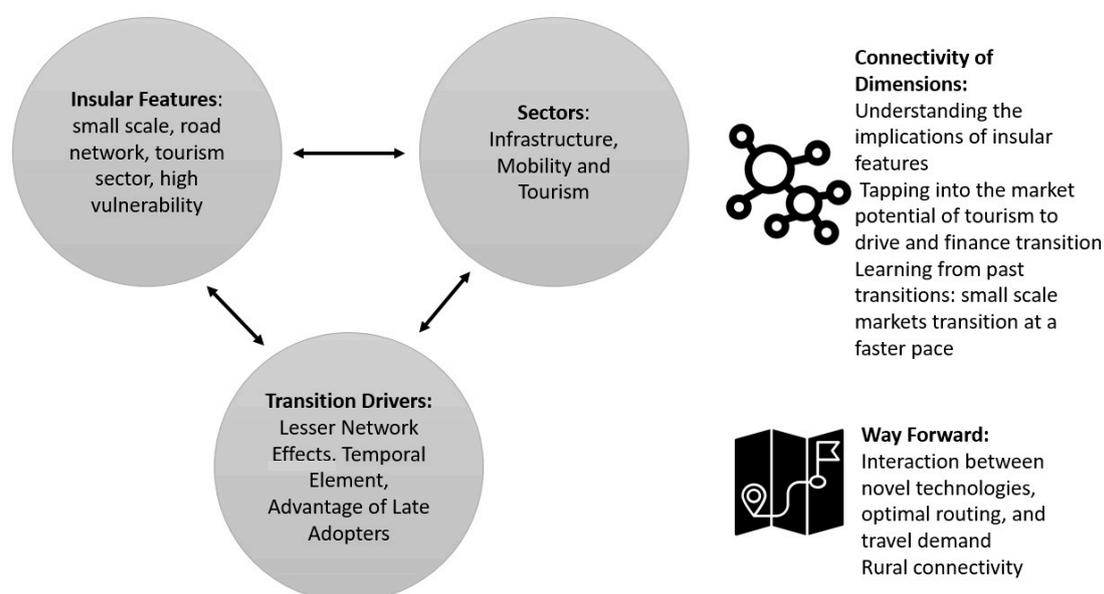


Figure 6. Factors for an accelerated transition on SIDS: Insular features include small scale, similar road networks, high importance of the tourism sector, and an increased vulnerability to climate change.

If SIDS embark now on their decarbonization transition pathways, they will not only create sustainable and resilience energy and transport systems, but also send a strong message to the international community. In fact, the SIDS already have several successful flagship projects in terms of sustainability, from the EV revolution in Barbados to increasing shares of renewables in the energy mix. Further collaboration within the SIDS and an island-based typology of geographical features, urban form and tourism parameters are useful in providing the islands with a framework for a faster and cheaper transition. While this paper focuses on three pilots SIDS, the assessment holds relevance for small islands worldwide, especially for the archipelagos of South East Asia and the Pacific Islands, where there is evidence of the similar spatial and economic constraints, as well as the augmenting impacts of unsustainable modes of transport.

This study has several limitations. The difference in the usage between household automobiles and other registered vehicles (taxis, car service vehicles, business-owned light-duty vehicles, and rental cars) leads to different policy implications and market pull to influence demand-side behaviors according to the markets. There are also differences in transport behavior between freight, household, and touristic travel. Data that is more precise is required for understanding and tracking private driving routes and trends for the optimization of public charging stations with respect to time, charging

locations, and demand projections. Our infrastructure switch calculations neither investigate how public charge infrastructure cost flows through the local economy, nor does it consider discounting factors. The idealized transition pathway remains only conceptualized, not modelled, yet is meant to provide an inspiring thought experiment for those seeking to push the transition on small islands. Detailed data on touristic behavior would also be useful, e.g., on those traveling via rental cars compared to those by public transport and shared mobility modes. Future research should look closely into the culture behind car ownership on small islands, as well as public outreach. Simulations and optimization of the public transport and state fleet vehicles should be studied as is it easier to support their deployment through legislation and regulation.

The IPCC Special Report on 1.5 °C demonstrates that delaying emissions cuts as laid out in the Paris Agreement will increase the challenge of reaching net-zero significantly, as well as tip the climatic system beyond a point (ice sheet melt and sea-level rise). The present emission trajectories countries are choosing to take further constraint the possibilities future generations have. While it is impossible to give the future generations a valid voice, those of the SIDS become the closest representatives—as they must deal with an increased impact of climate change now under much more difficult conditions and with limited resources.

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