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Roadmap for the Integration of Sustainable Energy and Transport in Small Islands

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Friends and colleagues, please remain healthy and optimistic!

Alexander Ochs, Project Director & CEO, SD Strategies
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List of abbreviations

APEC	Asia Pacific Economic Cooperation
ASI	Avoid-Shift-Improve
BAU	Business as usual
BEV	Battery electric vehicle
BRT	Bus rapid transit
CAPEX	Capital expenditures
CO_2	Carbon dioxide
DPP	Diesel power plant
EV	Electric vehicle
GDP	Gross domestic product
GHG	Greenhouse gases
HEV	Hybrid electric vehicle
ICEV	Internal combustion engine vehicle
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producer
ITDP	Institute for Transportation and Development Policy
LCOE	Levelized cost of electricity
LEDS GP	Low Emissions Development Strategies Global Partnership
MCDM	Multi-criteria decision-making
NOx	Nitrogen oxide
OPEX	Operational expenditure
PHEV	Plug-in hybrid vehicle
PV	Photovoltaic
RE	Renewable energy
ROMELCO	Romblon Electric Cooperative
SMPI	Sustainable Mobility Plan for Islands
SHS	Solar home system
SO_2	Sulfur dioxide

SUMP	Sustainable urban mobility plan
TCO	Total cost of ownership
TOD	Transit-oriented development
UNDP	United Nations Development Program
USD	United States Dollar
V2G	Vehicle-to-grid

Executive summary

Transport and mobility on APEC islands are mostly based on internal combustion engine vehicles. The islands' dependence on fossil fuels for transport and energy services results in significant economic inefficiencies, local environmental pollution, and enormous negative social impacts. These become even more evident if the current performance of the energy and transport sectors and their business-as-usual development trajectories are compared to alternative pathways in which both sectors are closely integrated and centered on the efficient use of domestic, renewable resources.

A transition to an electric vehicles-based transport system can only be truly transformative if renewable electricity is supplied at scale. APEC islands have tremendous renewable energy potentials, and their energy and transport systems can be swiftly decarbonized. A deep transition to sustainable energy and transport systems will reduce the need for costly imports and public subsidies; bolster fiscal capabilities; improve public health; enable a higher quality of life; boost civic participation; create new and better employment opportunities; and strengthen climate resilience and mitigation.

Electric vehicles (EVs) are currently reaching cost parity with their conventional predecessors; they will soon be the cheaper option. The geographic and economic characteristics of small islands offer vast advantages for the roll-out of electric vehicles. EVs can be significant off-takers of renewable energy (RE), which will increase economy of scale and further reduce their generation costs as well as enhance electrical grid services and security of supply. RE generation is already highly competitive in price worldwide, and even more so on islands disconnected from larger grids.

These general observations are widely valid and apply to most APEC islands (to definitively conclude that they apply to all, a regional scoping study would be required). Still, islands vary widely with respect to a broad range of characteristics which all are crucial for the configuration of the energy and transport sectors in the present, and the options for pathways into a more sustainable future: population size, cultural practices and identity, stage of development and future vision, economic structure, availability and cost of renewables vis-à-vis fossil fuel resources, the configuration of political authority, legislative environment, and much more.

The design and implementation of the transition to sustainable energy and transport sectors needs to be founded on local, island-specific assessments. We present two exercises that islands can undertake to identify their own, preferred pathway to sustainability.

As a first component in the design of island sustainable energy and transport transition planning, we suggest the drafting of a stakeholder-oriented Sustainable Mobility Plan for Islands (SMPI) that entails a groundwork phase, strategy development, and the design and implementation of concrete transformative measures.

SMPIs, as presented here, rely on the Avoid-Shift-Improve (ASI) framework, a comprehensive strategy enabling a deep transition of mobility to sustainable technologies and practices. The creation of a transport sector featuring EVs powered by renewables is only one component, though a key one, of the broader set of ASI measures. However, action in all three areas – avoiding, shifting, and improving – contributes to a successful roll-out of an EV-based transport system:

- ‘‘Avoid’’ strategies address the need to reduce unnecessary transport by optimizing transport demand; they can also safeguard a synchronized advancement of e-mobility and renewables.
- ‘‘Shift’’ components aim to promote alternative transport modes on islands, such as walking and cycling, as well as building up a public, collective transport system; the public transportation sector has a large role to play in the successful deployment of EVs (and supporting infrastructure).
- ‘‘Improve’’ measures are designed to enhance the emissions efficiency of the vehicle fleet; a key strategy is to boost the widespread use of electric vehicles and gradually phase out conventional ones.

As a second component in the design of island sustainable energy and transport transition planning, we suggest the application of the multi-criteria decision-making (MCDM) approach that allows policymakers to select the most beneficial energy and transport integration scenario for their island based on specific criteria of high relevance to them.

Modelling the energy system of an island is essential to define optimal energy and transport integration strategies, as it allows for a comparison of alternative scenarios. MCDM consists of the following steps: establish a decision goal, define the evaluation criteria and their relative importance (weightings), assess alternative scenarios, and arrive at a final ranking and decision. To achieve effective and transparent decision-making, all relevant stakeholders in the energy and transport sectors need to be involved from the beginning.

This report provides an example of the evaluation of three different pathways through an assessment of the fictional Isla Sustainabilita: a business-as-usual, a moderate, and a progressive scenario. Evaluation criteria for alternative energy and transport scenarios include: resilience, upfront investment costs, Levelized Cost of Electricity (LCOE), CO_2 emissions and the overall environmental impact, local acceptance as well as job-creation potential. The adoption of the progressive scenario means the adoption of ambitious targets and the effective implementation of supportive policies for renewable energy and e-mobility.

Targeted public interventions are essential for the advancement of sustainable energy and transport on islands. An effective mix of policy and financial instruments can reduce existing investments risks in both sectors and create an attractive market environment for developers, financiers and implementers of sustainable energy and transport solutions. Specific targets and overall objectives, concrete policies and measures, as well as effective governance processes need to be designed and implemented in close cooperation with island stakeholders.

Much like politics, all energy and transport is local. Ready-to-implement island roadmaps need to consider the geographic, resource, political, social, economic and environmental situation of an island. They need to be designed specifically for, and in, each locality. The report at hand provides the rationale for a swift and ambitious transition and presents two tools for the design of location-specific roadmaps.

1. Introduction

The existing fossil fuel-based transport systems of APEC islands are unsustainable, often costly, and in many cases unreliable. This limits the development potential of local economies, negatively affects the health and quality of life of residents, endangers surrounding ecosystems, and contributes to global climate change.

Small, isolated islands in the APEC region are particularly vulnerable to the effects of climate change. Despite their miniscule share in total CO_2 emissions (Soomauroo et al., 2020), sea-level rise and the increasing incidence of extreme weather events threaten the very existence of many small islands (World Bank, 2017). Transitioning to renewable energy-based transport systems can enhance the resilience of islands by reducing the need for costly and climate-vulnerable imports of fossil fuels, improving the health of residents and protecting local ecosystems.

Transforming transport systems is a key prerequisite for creating sustainable societies on small islands in the Pacific. Small islands have the potential to serve as trailblazers, demonstrating the potential of decarbonized, efficient and effective transport systems throughout the entire APEC region. Member economies with many islands, such as the Philippines or Indonesia, could substantially reduce transport-related emissions by replicating the transitions of pioneering small islands (Ochs et al., 2012).

The renewable energy transition of the transport sector will consist of several components, including the encouragement of behavioral changes such as those suggested as part of the Avoid-Shift-Improve (ASI) framework (see chapter 3), but the most important driver will be the change from fossil-fueled vehicles to highly efficient electric vehicles (EVs) powered by domestic renewable energy resources.

Most APEC islands have high potential for wind, solar, hydro and biomass-based energy generation, which can provide affordable, reliable and sustainable electricity for homes and businesses and power a modern, clean transport sector. In addition, the use of EVs can make renewable energy generation more economically viable, by absorbing the oversupply of power from intermittent energy resources and, by increasing electricity demand, create economies of scale for renewable energy installations.

This Roadmap for the Integration of Sustainable Energy and Transport in Small Islands explores the opportunities which such a sector coupling based on domestic renewables offers to small APEC islands (chapter 2). It provides strategic and technical guidance for the transition to sustainable transport modes (chapter 3) and defines a multi-criteria approach for making the necessary changes to the energy system to enable the integration of electricity and mobility (chapter 4).

This report serves provides advice to island authorities interested in undertaking the challenging, but immensely rewarding effort to couple the energy and transport sectors as part to advance the use of renewables and EVs. It is the first of its kind in the APEC region – and potentially worldwide. It intends to provide information, analysis and a methodology to create tailored transition roadmaps for individual islands. The report introduces two tools that can be applied to identify pathways to sustainability supported by a broad range of stakeholders. The contribution of this report and the need for further advancement of this work are discussed in the conclusion.

2. Transitioning from fossil-fueled transport to sustainable mobility solutions based on domestic renewables

A quick and bold transition from fossil fuel-based transportation to alternative mobility solutions, including electric vehicles (EVs), is possible. It is in the economic, social, and public health interest of island residents and an indispensable prerequisite to both save local ecosystems and combat global climate change. However, the benefits of EVs will only fully materialize if the power they consume is generated from indigenous, renewable sources.

This chapter provides an overview of current transport and energy trends on Pacific islands and their associated economic, social and environmental impacts. Alternative development pathways involving EVs powered by domestic renewable energies will be explored. A transition to such pathways can produce enormous benefits if the energy and transport sectors are integrated. Since the former supplies the fuel for the latter, only a synchronized approach to the development of both sectors will produce viable, effective, and cost-efficient solutions.

2.1. Current transport trends and the impacts of fossil fuel-dependent transportation

In most APEC member economies, the annual motorization rate is relatively high, and in some economies–such as Viet Nam and Indonesia–it has been above 10% since the beginning of the century (Bakker et al., 2017). Mobility demand is expected to grow substantially in the coming decades, with estimated growth rates of 60% or more in some member economies between 2013 and 2040 (Bakker et al., 2017).

Transport across the APEC region is fueled primarily by petroleum products, predominantly diesel and gasoline. Islands are no exception. In most APEC member economies, the market for EVs is still immature, with the notable exceptions of China and the United States. Most economies lack robust policy and strategic frameworks for the electrification of transport.

As a result, mobility on most APEC islands remains dependent on fossil fuels. However, some islands (see e.g. Text Box 1) have implemented individual EV-based mobility solutions that encourage local authorities and societies to further embark on e-mobility pathways in the future.

2.1.1 Economic costs

Petroleum-based transport on APEC islands reinforces the fossil-fuel dependency of their electricity sectors. Carbon-intensive local transport systems exacerbate the exposure of small islands and, consequently, the member economies they belong to, to the volatility of oil prices in global markets. Any spike in oil prices leads to significant budgetary constraints for local administrations and a need for higher fuel subsidies from governments, thus increasing the burden on taxpayers.

The heavy reliance of the transport and energy sectors on fossil fuels, which often creates the need for substantial government subsidies, tends to distort local economies and lead to market inefficiencies. Where fossil fuel subsidies absorb significant tranches of the public budget, governments cannot allocate sufficient resources to reliable and resilient transport infrastructure, which in many cases is crucial because of the islands' topography (as many islands are volcanic or have extensive rainforest cover) and acute climate vulnerability (World Bank, 2017).

Isolated, poorly connected islands famously face exceptionally high fossil fuel costs for transportation as a share of local gross domestic product (GDP) (Gay et al., 2018). In some cases, petroleum tankers have to travel thousands of kilometers to supply remote islands. The distance from mainland Chile to Rapa Nui/Easter Island, for example, is approximately 3700 kilometers, so that the shipping of oil incurs hefty transportation costs. The costs associated with purchasing and shipping fossil fuels cannot be borne by the industrial and household end users alone, since islands often have small populations and small markets. The absence of economies of scale indirectly raises the cost of petroleum products to fuel local transport.

2.1.2 Social impacts

Small islands tend to have limited road networks, which can be a consequence of topographic factors, such as mountains, volcanos, or pristine and vulnerable ecosystems. Considering islands' large tourism sectors and high population and motor vehicle density, this can lead to significant congestion problems. Apart from impairing the daily economic life on the islands, severe traffic congestion further reduces the efficiency of a transport system based on individual use of internal combustion engine vehicles (ICEVs).

Conventional, ICEV-based transport on small islands results in high levels of local pollution and can create considerable negative impacts on public health and quality of life (Gay et al., 2018). The absence of public transport options further exacerbates air pollution as this leads to inefficient use of private passenger vehicles. Traffic-related air pollution in addition to emissions of diesel generators can severely affect densely populated areas. Islanders surrounded by heavy ICEV-based traffic also suffer from noise pollution, a significant threat to their quality of life and mental health. High noise levels negatively affect tourism, the main source of income for many APEC islands.

Safety is a crucial dimension of mobility. Rapa Nui/Easter Island's road safety record is considered to be worse than that of most of mainland Chile. Locals claim that the island's transport system is severely affected by the lack of respect for road safety regulations and the absence of monitoring authorities to enforce safety measures (Ochs, 2020).

The absence of public transportation also contributes to heightened levels of marginalization and gender inequality on islands. Low-income households do not have access to affordable and reliable transport; this hinders particularly the integration of women into socioeconomic life on since they often do not have access to private vehicles. This situation, in turn, further reinforces prevailing traditional notions of women's roles in the household and status in society. An electrified, public transport system has the transformative potential to modernize and reform local communities, alleviate social and economic marginalization of vulnerable and minority groups, and promote gender equality. By increasing their freedoms and expanding their options, previously marginalized groups are empowered to pursue more fulfilling lives.

Text Box 1: Mobility challenges and needs in Cat Ba, Rapa Nui/Easter Island and Romblon*

The islands of Cat Ba (Viet Nam), Rapa Nui (or Easter Island, Chile), and Romblon (the Philippines) share a number of characteristics with respect to their transport sectors, including the fact that all three depend almost exclusively on conventional, fossil fuel-based transportation. In addition, the absence of public transportation networks and the scarcity of basic transport infrastructure result in a lack of mobility options for many of these islands' residents.

Demand for transport is expected to grow rapidly over the next decade on all three islands, not least as a consequence of booming tourism industries which are of vital significance for their economies. Meeting this growing demand with an increase in the usage of internal combustion engine vehicles (ICEVs) will only further magnify the negative economic, social, and environmental impacts of conventional transport. An efficient, EV-based mobility system running on domestic renewables–including public transport, as well as non-motorized modes of travel–would produce enormous co-benefits for individuals and society as a whole.

On Rapa Nui, the excessive motorization rate and number of vehicles has already led to immense congestion of the island's limited road network. As a result, members of the local community are calling for a reduction of the total amount of permitted vehicles. The growth of the tourism sector has increased locals' concerns as without mitigating measures, it will result in more traffic and congestion. Transportation for persons without private vehicles on the island is currently supplied by privately operated, unregulated shared taxis (''taxis colectivos''), which are used mostly by residents. Rental vehicles and minibuses cater to tourists' needs by transporting visitors between the island's main sights and attractions.

The situation on Cat Ba is somewhat similar. The island lacks an effective public transport network while demand for mobility is expected to surge over the next decades as a result of economic and population growth, as well as an increasing inflow of tourists. In contrast to the situation on Easter Island, shared transport is provided primarily to tourists since many residents cannot afford the fares for these services. Besides the severe environmental impacts of the widespread use of petroleum-based vehicles, the lack of clean and public transport options threatens to widen the mobility gap between locals and tourists.

On Romblon, inadequate public transport infrastructure and the uneven distribution of economic activity–which is centralized around the island's capital, Romblon Town–pose major challenges for the transport sector. Projected future trends, such as strong economic growth and rising living standards, will lead to further growth of the already high number of cars owned by households in the capital, regardless of the poor road infrastructure.

2.1.3 Environmental effects

According to the International Energy Agency (IEA), the transport sector accounted for 24% of global direct CO_2 emissions from fuel combustion in 2019 (IEA, 2020). Without a shift to e-

*This textbox is based on three case studies that were prepared as part of this project. The islands of Cat Ba, Rapa Nui/Easter Island, and Romblon were profiled to demonstrate their current energy and transport situations, as well as potential future pathways. The island profiles are included in the bibliography as Ochs, A., Gioutsos, D. (2019) for Rapa Nui/Easter Island, Medimorec et al (2019) for Cat Ba, and Berthau et al (2019) for Romblon. They can be found on the SD Strategies website, at sd-strategies.com/apec-islands/.

mobility, projected demand growth will further entrench carbon lock-in and path dependencies in the transport infrastructure of small islands.

Whereas the contribution of small islands to worldwide CO_2 emissions is modest, the existential threat they face from global warming should incentivize them to place themselves at the forefront of the fight against climate change. Islands are highly vulnerable to rising sea levels, extreme weather events, potential water shortages, and reduced food production. Public transport and EVs based on decentralized, renewables-heavy local energy systems can make islands more physically and financially resilient to the impacts of climate change.

2.2 The sustainable development potential of renewably powered electric vehicles

During the last decade, the EV market grew rapidly. In 2019, the cumulative global EV fleet numbered 2.2 million vehicles, accounting for 2.6% of the global car market (IEA, 2020).

2.2.1 Electric vehicle market outlook

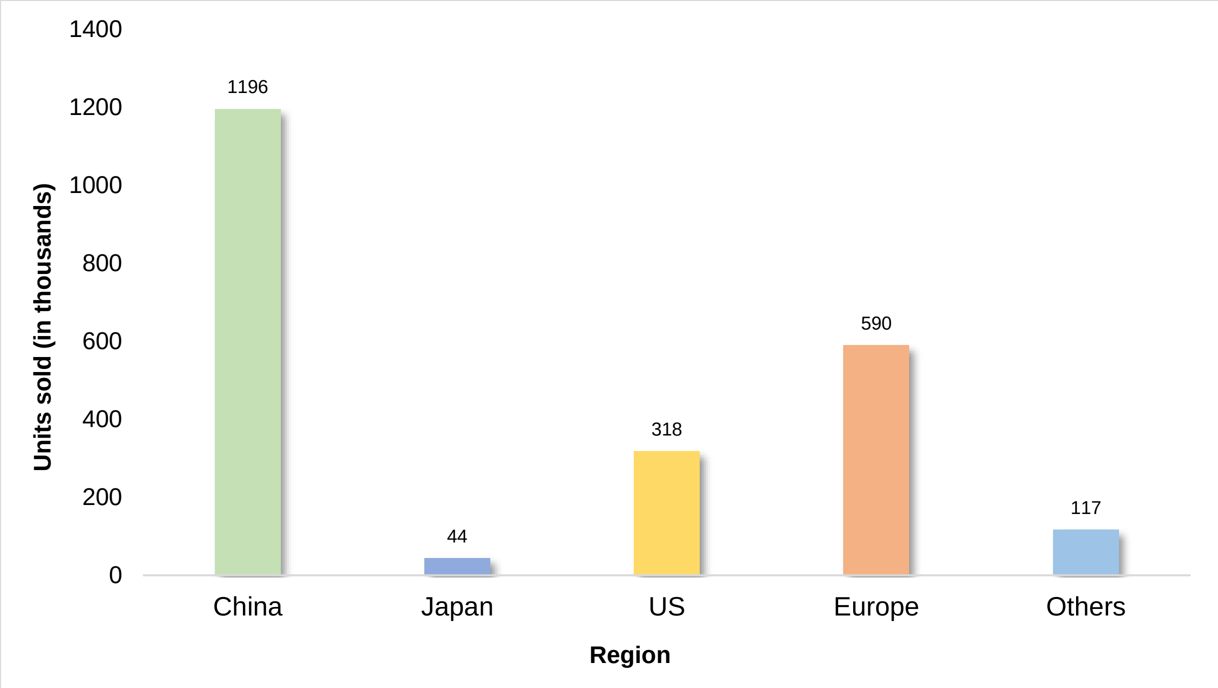
The EV market is expected to continue its expeditious growth in the years and decades to come. By 2040, half of all passenger vehicles sold will be electric (BNEF, 2020). Lower estimates such as those of the IEA – 300 million EVs, or 15% of the total car fleet, by 2040 – could save 3.3 million barrels of oil per day, or approximately 3% of the total oil demand that year. (World Bank, 2018).

In China and the US–both APEC members and the world's largest EV markets in terms of cumulative sales (see Figure 1)–the share of EVs in 2019 was 4.7% and 1.8% respectively (MEE, 2019, Maximilian, 2020). However, in the vast majority of APEC member economies, the EV market share is even more marginal, owing to a number of factors, such as capital expenditures (CAPEX) disparities between EVs and ICEVs; insufficient policy incentives; and inadequate infrastructure (namely charging stations and electricity distribution grids).

As long as the upfront investment costs required for EVs remain higher than those of ICEVs, government support in the form of financial incentives and regulatory interventions is essential. This is even more relevant on islands, where geographical isolation and diseconomies of scale add to the complexity of designing an optimal policy framework for the roll-out of EVs.

The lack of e-mobility and public transportation schemes entrenches the carbon lock-in of small islands' transport infrastructure. Local transport is typically unregulated, and vehicles exclusively privately owned. Island communities have repeatedly claimed that their transport systems are made inefficient by the high vehicle density (Ochs, 2020). Vehicle density is expected to increase further as a result of tourism, a key driver of transport demand on Pacific islands.

Figure 1: Battery electric vehicle and plug-in hybrid electric vehicle sales in 2019



China, US, and Japan are APEC member economies. ‘‘Others’’ include the rest of the APEC member economies.
Source: EV Volumes (2020). https://www.ev-volumes.com/

2.2.2 The cost of EVs

EVs are more expensive than ICEVs in terms of CAPEX. The cost of lithium batteries is the largest factor in the cost discrepancy between EVs and ICEVs (McKinsey & Company, 2019).

Text Box 2: Cost comparison of internal combustion engine and electric vehicles

Cost comparisons between EVs and ICEVs are particularly complex. They depend on an array of variables, such as the way electricity emissions are gauged, the size of the vehicles, the assumptions on driving patterns, and the accuracy of fuel cost estimations.

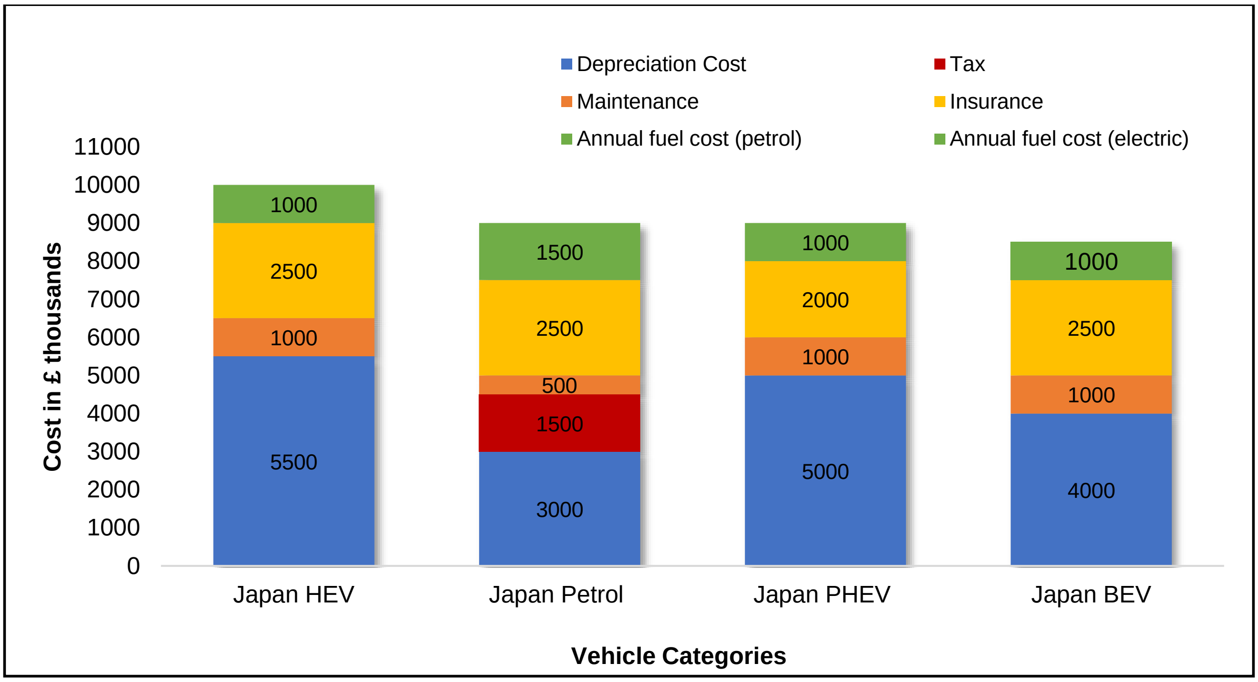
One of the most reliable metrics is the Total Cost of Ownership (TCO), which estimates the average lifetime costs of vehicles. The TCO includes purchase, maintenance, insurance, tax, depreciation, and fuel costs over the lifecycle of a vehicle. It differs worldwide as it depends on domestic factors, such as taxation, import tariffs, and fuel costs.

Although EVs require additional infrastructure, evidence suggests that the related investment costs can be significantly lower than the annual spending of small islands on fossil fuel imports. On some islands, the charging infrastructure can be even less expensive than in mainland regions because the traffic is exclusive limited to only a few main arteries. Thus, a less complex charging infrastructure is adequate.

However, the low operational expenditure (OPEX) of EVs, owing to their simple and efficient powertrain, offsets their relatively high upfront investment cost. The Total Cost of Ownership

(TCO) demonstrates the cost-efficiency of EVs in comparison to ICEVs over the lifecycle of a vehicle (see Text Box 2). As early as 2015, the TCO of electric cars in Japan, an APEC member economy, was lower than that of conventional and hybrid cars, due however at least in parts to higher taxes for ICEVs (see Figure 2). Because of the declining price of EV batteries (costs have fallen by about 16% annually between 2007 and 2019, see Kapoor et al. 2020), EVs are expected to reach CAPEX parity with ICEVs in 2021 (for data on Europe and China, see Gay et. al, 2021). From then on, EVs will be the most affordable option, thus making sustainable transport options more accessible to more people, worldwide and particularly on islands.

Figure 2: Total cost of ownership of hybrid electric vehicles, internal combustion engine vehicles, plug-in hybrid vehicles, and battery electric vehicles in Japan (UK£ thousand, 2015)



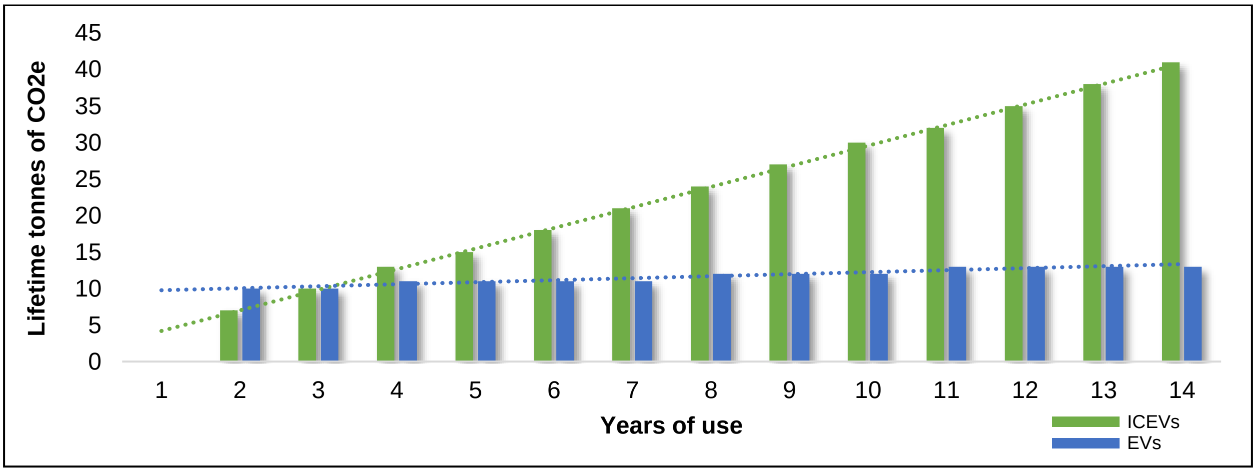
Source: Palmer (2018).

2.2.3 The climate performance of EVs

The transition to EV-based mobility is only meaningful in terms of combating climate change in energy systems with substantial renewable energy shares in the electricity mix. In an economy with a high share of coal in the electricity generation mix, uncoordinated growth of the EV market could offset the CO_2 emissions saved from the phase-out of ICEVs. In such a case, an EV would generate the same lifetime CO_2 emissions as the most efficient types of conventional vehicles, such as hybrid electric-petroleum vehicles. Similarly, the deployment of EVs on islands with diesel-based electricity would increase the demand for, and consumption of, fossil fuels.

The contribution of e-mobility to decarbonization is contingent on the penetration levels of indigenous renewable energies. EVs running on energy systems with a high share of renewables have a vast potential for reducing CO_2 emissions. While EV manufacturing is more emissions-intensive than ICEV manufacturing due to the battery production process, EVs can offset these emissions in less than two years provided renewables make up 45-50% of the electricity mix (Hausfather, 2019), as demonstrated by the most recent data from the United Kingdom, a non-APEC economy (see Figure 3).

Figure 3: Cumulative greenhouse gas emissions of an average new internal combustion engine vehicle and a new Nissan Leaf EV in the United Kingdom, 2019.



Source: Carbon Brief (2019).

Furthermore, the increase in electricity demand would de-risk renewable energy investments, as capital costs could be borne by a broader basis of end users and mitigate off-taker risks. Vice versa, the electrification of mobility will create a higher demand for the roll-out of renewables in the transport sector and, particularly on small islands, this could counterbalance the small size of local markets, which is often conceived as a major risk for investors. The electricity demand growth from EVs would also reduce the need for costly curtailments of solar PV generation; higher electricity demand will be capable of absorbing renewable energy surpluses.

2.3 The rationale for basing small islands' energy and transport sectors on renewables

The transport and electricity sectors on remote islands are burdened with the same problem: they are largely dependent on fossil fuels, requiring costly imports and significant subsidies. The situation on interconnected islands is different–their electricity matrix reflects the electricity mix of a member economy. For instance, the carbon intensity of the electricity system of the island of Cat Ba in Viet Nam is relatively low (Medimorec et al, 2019), as hydroelectricity makes up roughly 43% of Viet Nam's electricity mix (CIA World Factbook, 2017). While EVs constitute a modest share of short-distance shared transport options, primarily used by tourists, the absence of a public transport system renders local mobility inefficient. The adoption of a sustainable public transport scheme would allow for higher EV penetration, which could be supported by solar PV micro-generation. In this way, Cat Ba could pioneer the transition to sustainable energy and mobility in Viet Nam. Several islands in the APEC region that share similar characteristics could follow suit.

Sector coupling on non-interconnected islands is more complex, though equally necessary. In contrast islands such as Cat Ba, non-interconnected islands do not benefit from the deployment of renewables on the mainland. Economically, the purchase and long-distance transport of solid and liquid fuels are costly and inefficient. For example, the average generation cost per unit of electricity on Rapa Nui/Easter Island equates to approximately USD 258/MWh (Ochs, 2020), compared to USD 150 in mainland Chile (Bnamericas 2019). The Chilean government subsidizes the vast gap between the revenues and expenditures of the local utility. The same is done with fossil fuels for local transport, altogether a an economically and fiscally unsustainable situation.

2.3.1 E-mobility opportunities on small islands

The remoteness, topology, and limited market potential of small islands pose significant challenges for the electrification of local transport. These challenges, however, can be transformed into opportunities. Remote islands' isolated location and small economies encourage the transition to low-carbon transport systems as it translates to smaller carbon investment lock-ins; the mobility infrastructure and vehicle fleet of small islands are typically less path-dependent in comparison to the mainland (Soomauroo et al., 2020).

Small islands have another paradoxical advantage: due to smaller demand and market size, their electricity systems can be more rapidly decarbonized without large-scale, capital-intensive changes to the local infrastructure. The lifetime carbon efficiency of an EV will reach an emission break-even point much faster on islands with RE-based electricity than it would on a mainland with electricity systems largely reliant on coal-fired power plants (World Bank, 2018).

Since EVs have not fully achieved CAPEX-competitiveness in the world's core markets yet, small islands could showcase the "new mobility world" to promote the large-scale integration of transport and renewable energies globally. They can function as testing grounds for technology and market solutions and as prototypes of a successful transition to a commercially viable transport sector, and international funders might be willing to compensate them for this role. At the same time, due to their high climate vulnerability, small islands have their own incentive to pioneer climate-compatible solutions such as renewable-powered transport systems.

Small islands are also at an advantage because due their modest size EVs would require less frequent charging than those on the mainland, where vehicles often travel longer distances. The limited road network on small islands means that massive investment in charging infrastructure–one of the main drawbacks of the technology in larger systems–is not required. In addition, overwhelming the electricity distribution grid can be avoided. Even small-scale renewable energy generation can cover a significant level of EV penetration.

2.3.2 The excellent renewable energy potential of Pacific islands

Owing to geographical and climatic factors, islands in the APEC region have abundant renewable energy sources, notably solar and wind. Despite this potential, the majority of the islands rely on diesel-fired plants for their power supply. The costs associated with electricity generation on non-interconnected islands are some of the highest in the region (A.A. Eras-Almeida et al., 2020).

Recent reductions of the Levelized Cost of Electricity (LCOE) of solar PV and onshore wind energy have been impressive. Over the last decade, these costs have fallen by 51% and 49%, respectively (BNEF, 2019). Solar PV and wind are now the most cost-competitive energy generation technologies and thus perfectly positioned to advance the electricity transition of APEC islands. The associated cost reductions for the electricity supply make these technologies an attractive source to power the mobility sector as well (IRENA, 2019).

Solar energy generates high seasonal yields and can be combined with increasing EV penetration rates given smart charging strategies. Small-scale PV plants and solar home systems (SHS) are suitable for the limited market size of islands. The build-out of solar micro-generation will require the installation of storage facilities and mini-grids to maximize cost-efficiency and grid stability.

The main challenge in establishing a solar energy-based electricity system on islands is its high variability, that is, the absence of a baseload capacity that can match the demand forecasts without costly generation curtailments at times of surpluses or the risk of power scarcity in the winter. Onshore wind turbines can effectively alleviate these variability-related risks, by counterbalancing PV generation deficits during the winter, when wind achieves higher yields. Wind energy complements solar energy and can thereby provide a more base-loadable profile throughout the year. Moreover, wind turbines have a larger capacity than solar panels and can provide utility-scale solutions.

Several APEC member economies, such as Australia and Japan, could lead efforts to support the simultaneous advancement of solar and onshore wind on islands. Joint utility-scale solar and wind investments have been realized on the islands of Okinawa and King Island, resulting in significant CO_2 emissions reductions through a more sustainable electricity matrix (IRENA, 2016). However, islanders may strongly oppose the installation of large wind turbines. Especially in small islands, the erection of onshore wind parks faces local resistance, as well as technical complexities and additional costs due to remoteness and topology.

The difficulties faced in providing adequate waste management, declining agriculture and the growth of the tourism services sector on small islands of the APEC region point towards an opportunity to introduce bioenergy. Biomass plants could substantially increase renewable energy shares in the electricity mix of the islands. On the island of Romblon in the Philippines, a 2MW biomass plant will be soon providing close to 40% of the island’s electricity demand (Berthau et al, 2019). In this way, Romblon will cut down its dependency on diesel-based power, while the biomass plant will be providing the island with baseload electricity.

Pacific islands also have potential for marine energy generation: the conversion of wave, tidal, or ocean thermal energy to electricity. Wave energy technologies, notably, have vast potential in the Pacific (Bosserelle et al, 2015). Provided that financing conditions improve, wave energy could compete with diesel-based electricity in Pacific islands. The main drawback of energy installations in the ocean is the likelihood of visual pollution that may spark resentment among island communities.

Geothermal energy can offer a baseload alternative, notably for volcanic Pacific islands. However, local resistance is a factor that cannot be ignored, given the potential impacts of geothermal energy on surface stability. Geothermal also has a higher LCOE than onshore wind or utility-scale solar (IRENA, 2020). The undertaking of further research on geothermal energy in the Pacific is essential to provide governments and the private sector with the necessary intelligence.

While there are opportunities in emerging and nascent technologies in the APEC region, solar PV and wind, as the two leading sustainable energy sources, have outstanding potential on most APEC islands and can serve as a basis for the transition to a sustainable, EV-based transport system and the integration of energy and mobility.

2.3.3 Benefits of a transition to e-mobility based on renewables

An energy and transport system based on indigenous renewable energy sources will avert the negative impacts discussed in subsection 2.1. It will minimize exposure to the volatility of global oil markets and reduce the dependence on subsidies from governments.

Figure 4: Overview of benefits of an EV-centered transport system powered by domestic renewables

Economic	Minimized exposure to oil price volatility Budget allocation to sustainable infrastructure Diversification of local economies Local growth Job creation
Social	Quality of life Improved mental health Enhanced road safety Poverty reduction Opportunities for women
Environmental	CO_2 emissions reduction Improvement of local environment Reduced air and water pollution Climate change resilience

Government funding to local communities can instead be channeled to vital infrastructure, such as schools and hospitals. The transition to EVs based on local renewable sources can produce substantial economic, social, and environmental benefits (see Figure 4).

Renewable energy has the potential to boost local economic growth and reduce poverty levels. It can also diversify the economies of small islands, which rely predominantly on agriculture and tourism, sometimes in a lopsided manner. Job creation is one of several social benefits associated with the energy transition. Renewable energy investments are labor-intensive and in 2019, the renewable energy industry provided jobs for 11 million people worldwide (IRENA, 2019). In the quickly growing off-grid sector alone–particularly relevant for small islands–more than 400,000 people are already employed (IRENA, 2019).

In the context of Pacific islands, local engineering companies can plan and install the renewable energy systems for clients and offer maintenance contracts. The localization of supply chains will create new markets within a diversified economy. Renewable energy therefore has the potential to create new, long-term employment and offer low-income groups a chance to escape poverty.

Electric public transport will ward off congestion problems and diminish mobility costs for the local population. An efficient public transport system is also attractive for tourism–the economic backbone of many Pacific islands. On the islands, electric public transport should be first introduced in major tourist areas, where the revenues from tourism could help counterbalance the high initial costs of EVs. In addition, the growth of eco-tourism on small islands will strengthen the international stance of APEC member economies in terms of climate policy, while it can attract high-income tourists and increase the sophistication of the local leisure industry. Importantly, islands with a reputation for sustainability will display openness and innovation and thereby attract the global scientific community.

The deployment of EVs must be synchronized with the decentralization of the distribution grid to improve electricity access for households. Increased access to electricity will provide locals, notably women, with better education and social integration opportunities. The rate of employed women in the renewable energy sector is higher than in the conventional energy sector, at 32% and 22% respectively (IRENA, 2019).

EVs can contribute to enhancing grid stability and energy security. Under appropriate policy incentives, EVs can absorb renewable energy generation surpluses. Vehicle-to-grid (V2G) solutions, whereby EVs are capable of feeding electricity back into the grid, have the potential to bolster the stability of islands' distribution grids. They can also create significant cost efficiencies by providing balancing and ancillary services to the grid operator.

In terms of energy security, the expansion of renewable energy capacity, accompanied by investments in storage, will decrease power outages. Diesel-based energy systems on islands have led to security of supply problems. On the Filipino island of Romblon, the dependency of the electricity system on diesel generators led to frequent outages, which disrupted economic and social life. The installation of onshore wind turbines with a cumulative capacity of 900 kW stabilized the supply of electricity to a remarkable extent. Moreover, the commissioning of the new biomass plant will further enhance the security of supply in Romblon, particularly since biomass is more base-loadable than solar and onshore wind (Bertheau et al, 2019).

3. Avoid, Shift, and Improve: A transport-energy action framework applicable to APEC islands

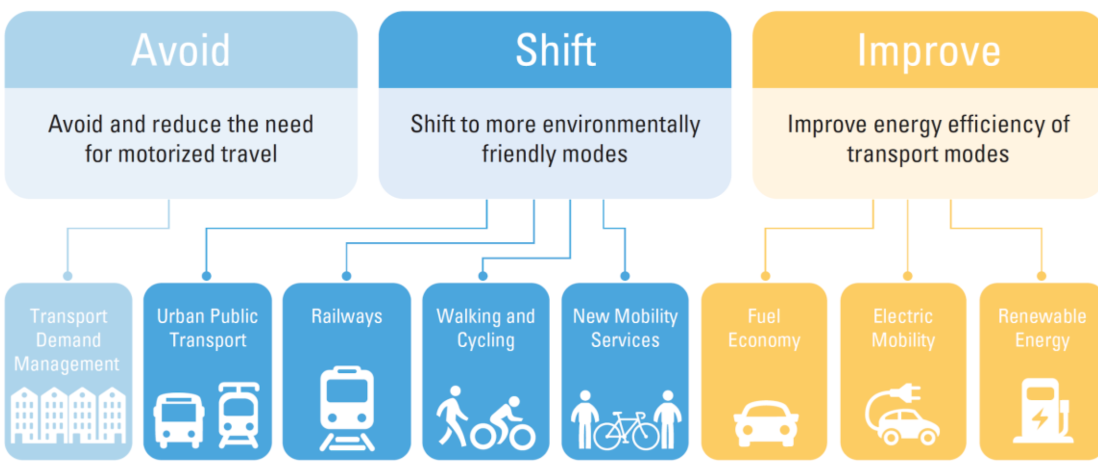
3.1 Introduction to the Avoid-Shift-Improve Framework

The Avoid-Shift-Improve (ASI) framework is a transformative, comprehensive strategy to reduce greenhouse gas (GHG) emissions, energy consumption and transport congestion by creating more sustainable and resilient mobility systems based on domestic renewable energy sources. The ASI approach was co-developed by GIZ and first described in a 1994 report of the German parliament´s Enquete Commission. (Transformative Urban Mobility Initiative et al. 2019).

The ASI framework can help islands reduce their residents' overall need for travel, shift travel from private, fossil fuel-powered transport modes to more environmentally friendly public and private modes and improve the efficiency of existing transport options.

The ASI framework taps into the particular advantages small islands enjoy in the effort to couple their energy and transport sectors, as described in subchapter 2.3.1. ASI primarily focuses on solutions to integrate green energy measures into existing transport systems.

Figure 5: Avoid-Shift-Improve framework for action on sustainable transport



SLOCAT (2018).

The ASI framework consists of three pillars:

- **Avoid** unnecessary passenger trips and freight movements and reduce travel distances through regional and urban development policies, integrative transport and spatial planning, logistics optimization, and travel demand management. All measures aim to increase *system efficiency*.

- **Shift** passenger and freight travel to more environmentally and socially sustainable modes, including public transport, walking and cycling (in the case of passenger transport), and railways or inland waterways (in the case of freight transport). These measures aim to improve *travel efficiency*.

- **Improve** the energy efficiency of transport modes through low-carbon fuel and vehicle technologies, increased vehicle load factors, and better managed transport networks. Increase the role of non-petroleum, low-carbon and renewable fuels. These measures focus on improving *vehicle efficiency*.

The ASI framework's comprehensive approach allows for all relevant aspects to be addressed thoroughly. Its flexibility, meanwhile, allows for modifications and adaptations to contextualize the strategy more effectively. To maximize impact, it is recommended to adopt a strong three-pronged approach with a balanced mix of measures from all pillars. The framework has gained traction in recent years and is widely used in the global transport community.

For this roadmap, the ASI framework has been adjusted to focus on the electrification of transport through renewable energy at small-island scale.

3.2 Applying the ASI framework to islands

This section gives an overview of 'Avoid', 'Shift' and 'Improve' measures and their roles in supporting islands in their transition to a sustainable transport system. The appropriateness and importance of each suggested measures must be individually assessed for each island. Guidance on the development of roadmaps for individual islands can be found in the final chapter.

3.2.1 Avoid

The first pillar of action, 'Avoid', aims to reduce overall demand for motorized transport, by reducing the number of trips required as well as reducing trip length. Strategic spatial planning can help restrict urbanization to a few limited areas to reduce travel distances and enable the provision of more services to island residents. Island authorities can also bring services closer to residents by allowing mixed land use and adjusting zoning regulations. Increasing the density of island communities makes it easier for residents to access jobs, education and other economic opportunities by walking, cycling and through the use of public transport. By coupling land-use planning and transport demand management, the need for motorized travel and the trip length can be effectively reduced.

'Avoid' measures are key components of energy and transport sector coupling. Increased use of non-motorized travel translates to smaller energy demand for transport. This means that less generation capacity is required to cover EV-based transport demand and prevents a situation in which diesel generators need to be employed to meet excess EV energy demand. 'Avoid' strategies thus will secure expeditious electrification of islands' transport systems on par with the expansion of local renewables capacities. Consequently, the break-even point of local transport-related CO_2 emissions compared to BAU will be reached much faster.

Improving land management on islands is also pivotal. It can allow for greater allocation and utilization of land for natural resources while satisfying the space requirements for onshore or offshore renewable energy generation. The decentralized nature of renewables makes them an ideal fit for efficient planning strategies on small islands. On larger islands, renewables have the potential to spur economic activity in remote or otherwise isolated areas. Their flexibility can mitigate the non-optimal spread of population, infrastructure, and resources found on islands, where economic activity and public funding is usually centered on one or a few urban agglomerations.

Targeted pricing instruments are also effective tools to disincentivize motorized travel by increasing the cost of travel in ICEVs. For example, low emission zones or, in the case of particularly populated islands, toll roads can be introduced. Such measures could incorporate higher fees for ICEVs, lower fees for EVs or both.

3.2.2 Shift

'Shift' measures aim to encourage and enable people to shift some or all of their travel from private, fossil-fueled of transportation to walking, cycling and public transport. In many cases, this requires the improvement of facilities and services.

Public transport can move more people while using less energy than individual motorized transport, resulting in lower GHG emissions per person, per kilometer travelled (SLOCAT, 2019). Core island population centers should be well connected by bus and potentially rail, if demand exists. To be effective, a bus service needs to be dependable, frequent and fast. On small islands, public transport can be provided by small electric buses. Such vehicles have already been introduced in Viet Nam. In the Philippines, many cities rely on jeepneys (typically 16-passenger mini-buses or refurbished jeeps). Recent efforts have been made to introduce electric jeepneys, which offer more attractive investment opportunities and other long-term advantages over diesel jeepneys (Agaton et al., 2019).

Although electric buses have higher upfront costs, their Total Cost of Ownership, which includes operation and maintenance costs (see chapter 2), is lower than that of diesel buses (Sclar et al., 2019). With support from government subsidy schemes, islands could deploy public fleets of electric buses. Bus routes on islands are typically shorter in duration and length than those on the mainland, thus making the adoption of electric buses even more appealing.

On islands with high-volume traffic corridors, the introduction of bus rapid transit (BRT) systems could help alleviate congestion and increase efficiency. According to Institute for Transportation and Development Policy (ITDP, 2017), the five main characteristics of BRT systems are: (1) physically separated, exclusive lanes; (2) stations and bus lanes at the center of the street; (3)

fare collection at stations and not in the buses, (4) platforms for boarding the bus, increasing accessibility for wheelchair users and (5) bus priority at intersections. A detailed guide on how to design and implement BRT systems is provided by the ITDP.[1] Economies like Canada, Malaysia and the United States (among many others) have successfully implemented BRT systems with electric buses (BRTData, 2020).

Whatever the mode of public transport chosen, an efficient transit system is of paramount importance to encourage widespread use. Transit stations or stops need to be safely and easily accessible by foot and provide easy access to education, work and leisure facilities. A certain frequency of services needs to be guaranteed in order to match users' needs and prevent overcrowding. Ideally, travel times using public transport should not be substantially longer than those using private transport.

In many settings (small islands with low-density settlements), electric rickshaws or three-wheelers might prove to be an attractive option. They can be introduced and regulated by public authorities and has the potential to operate as ride-hailing services. Electric rickshaws are gaining popularity in India and in recent years, they have been widely adopted in many low- and middle-income countries (UNEP, 2018). Shifting to electric two-wheelers would be a viable solution for Cat Ba, as it bears the highest benefits for Viet Nam (Oh et al., 2019).

Due to their relatively small size, islands are generally ideal places for cycling (unless they are extremely hilly). Not only does cycling reduce environmental impacts, it can produce many health benefits (provided air quality is reasonably good), as well as financial benefits. The net benefits of cycling outweigh any costs, as the example of Denmark shows (Cycling Embassy of Denmark, 2019). Given the fact that islands face high costs associated with the import of fossil fuels, bicycles are an affordable and practical alternative to ICEVs. If island authorities provide robust cycling infrastructure, including dedicated bicycle lanes, residents will be more inclined to travel by bicycle. Further required investments beyond infrastructure include road safety education and awareness raising, and ideally the provision of bicycles through subsidy or bike sharing programs.

3.2.3 Improve

The third pillar of the ASI framework focuses on measures to improve vehicle efficiency. The main objective of 'Improve' measures is to mitigate the pollution generated by diesel and gasoline vehicles by introducing electric vehicles, with the intention to eventually phase out ICEVs completely. Table 1 presents islands that have already introduced such ICEV phase-out targets.

[1] The guide can be found at: https://brtguide.itdp.org/

Table 1: Islands with phase-out targets

Island(s)	Phase-out targets (sales/registration)	Source
Balearic Islands (Spain)	Diesel cars by 2025, gasoline cars by 2035	Randall (2019)
Hainan (China)	Diesel and gasoline car sales by 2030	Xue (2019)
Iceland	Diesel and gasoline car sales by 2030	Warburton, S. (2018)
Ireland	Diesel and gasoline car sales by 2030	BBC (2019)
Sri Lanka	Government vehicles to be electric or hybrid by 2025, all vehicles by 2040	SLOCAT (2020)
Chinese Taipei	Buses to be electric by 2030, sales of fossil fuel-powered motorcycles by 2035, cars by 2040	Strong (2017)

These bold policy targets send a clear signal to the international automotive industry that a monumental demand shift is approaching, as a reflection of shifting consumer patterns. Ambitious policy targets must be coupled with equally ambitious interventions, including higher import duties on ICEVs than on EVs.

Fuel economy standards for new vehicles are generally decided by domestic governments. Local authorities on APEC islands can explore how to complement domestic legislation and implement more ambitious strategies to promote EVs. In addition to crucial domestic EV subsidy schemes, island authorities can roll out additional measures, such as municipal tax incentives for EV owners or a local surcharge on conventional vehicles, in proportion to their emissions intensity and contribution to air pollution.

Other measures to accelerate the shift to EVs include the introduction of purchase incentives to help overcome the burden of costly electric car models. Governments can act as trailblazers by first replacing government-owned vehicles with electric vehicles and encouraging others to follow suit. Other potential frontrunners include rental companies, as islands tend to have significant tourism sectors and thus a high demand for rental cars.

Support for e-mobility by regional authorities can be financed by budget savings through the reduction of fossil fuel imports and revenue from local environmental taxes. On islands with limited fiscal capacities, such as Rapa Nui/Easter Island, support from the government is essential. Subsidies for fuel imports could be used for supporting public and electric mobility instead. Government-backed support measures for ‘Improve’ strategies need to be tailored to each island’s administrative structure and socioeconomic conditions.

Text Box 3: The E-scooter leasing project in Romblon

Romblon Island's local electricity cooperation ROMELCO has joined forces with two Japanese companies, Honda and Komaihaltec, to supply electric scooters (E-scooters) powered by renewable energy, and thus couple the transport and electricity sectors. Three new wind turbines (900 kW), provided by Komaihaltec, are responsible for feeding electricity into the existing grid. Honda has supplied the E-scooters themselves as well as 17 charging stations, called "exchangers", spread throughout the island's road network. Residents can lease a scooter for USD 38 per month over a four-year period.

The uptake of scooters has been significant and many users now use them for their daily mobility needs. The shift from ICEVs to E-scooters has resulted in reduced local particulate matter and GHG emissions. The average range of an electric scooter with a fully charged battery is 42 kilometers and recharging the battery takes approximately 4 hours. If users do not want to wait the entire charging time, they can swap their batteries for fully charged ones at the exchangers for a fee of 0.70 USD. For comparison, one tank of gasoline provides a similar range but at a cost of 1.10 USD.

The new system addresses several of common problems that occur in island energy systems and offers numerous advantages for all stakeholders. The newly installed RE capacity mitigates blackouts, which are common on Romblon Island, and capacity shortages. System efficiency is maximized by utilizing excess electricity generated to charge the E-scooters. Residents also benefit from the accessibility and flexibility of the cost-effective transport mode.

The project has improved the economic performance of the entire energy system, as reduced fossil fuel imports have led to a reduction in costs and emissions. The project is currently in a four-year pilot phase–due to end in 2023–and has already received abundant positive feedback from the locals. As a result of this early success, it is likely that the project will be continued. In the next phase, the project should be extended to support an increase in the number of EVs as well as electric public transport. This would likely lead to decreased demand for private ICEVs, as well as emissions reductions, both of which are conducive to improving the quality of life on the island and attracting greater numbers of tourists.

Source: Berthau et al. (2019)

It is of paramount importance to ensure that, firstly, the transition to electric vehicles is matched by investment in renewable energy generation capacity, and secondly, does not lead to an overall increase in private vehicle travel. Otherwise, the increased energy demand may result in a greater dependence on conventional energy sources such as diesel-fueled power plants. Therefore, it is important that the avoid-shift-improve measures are implemented in the correct order.

The establishment of a sustainable electric transport system requires investment in renewable energy-powered charging stations for electric vehicles. Two main types of charging stations are currently available: fast chargers and slow chargers. Globally, around 10% of all charging stations are fast chargers. These are often made publicly accessible (IEA, 2019).

There are several business models which deliver short payback periods for capital investments in charging infrastructure, and car or scooter rental companies can support and share these costs. However, if the goal is to phase out ICEVs, a full charge of an EV at a charging station must be considerably cheaper than a tank of gasoline. Ideally, islands should support the installation of home-based charging points. A subsidy or lease program can be introduced to encourage homeowners to install solar PV systems on rooftops, to charge EVs and increase overall renewable energy generation capacity.

The introduction of electric cars will lead to new challenges, including increased electricity demand, for which new solutions such as smart charging and energy storage will have to be explored. If widespread EV recharging results in power shortages at night, utilities should identify affordable power storage solutions or incentivize users to charge their vehicles during the day (for example, at their workplace).

Islands can become testbeds for new technologies (e.g., solar-powered boats) and new services (e.g., electric car-sharing) through pilot projects. The successful pilot that introduced electric two-wheelers to the island of Romblon in the Philippines (see Text Box 3) exemplifies the potential of greener, cleaner transport solutions.

3.3 Planning cycle for islands

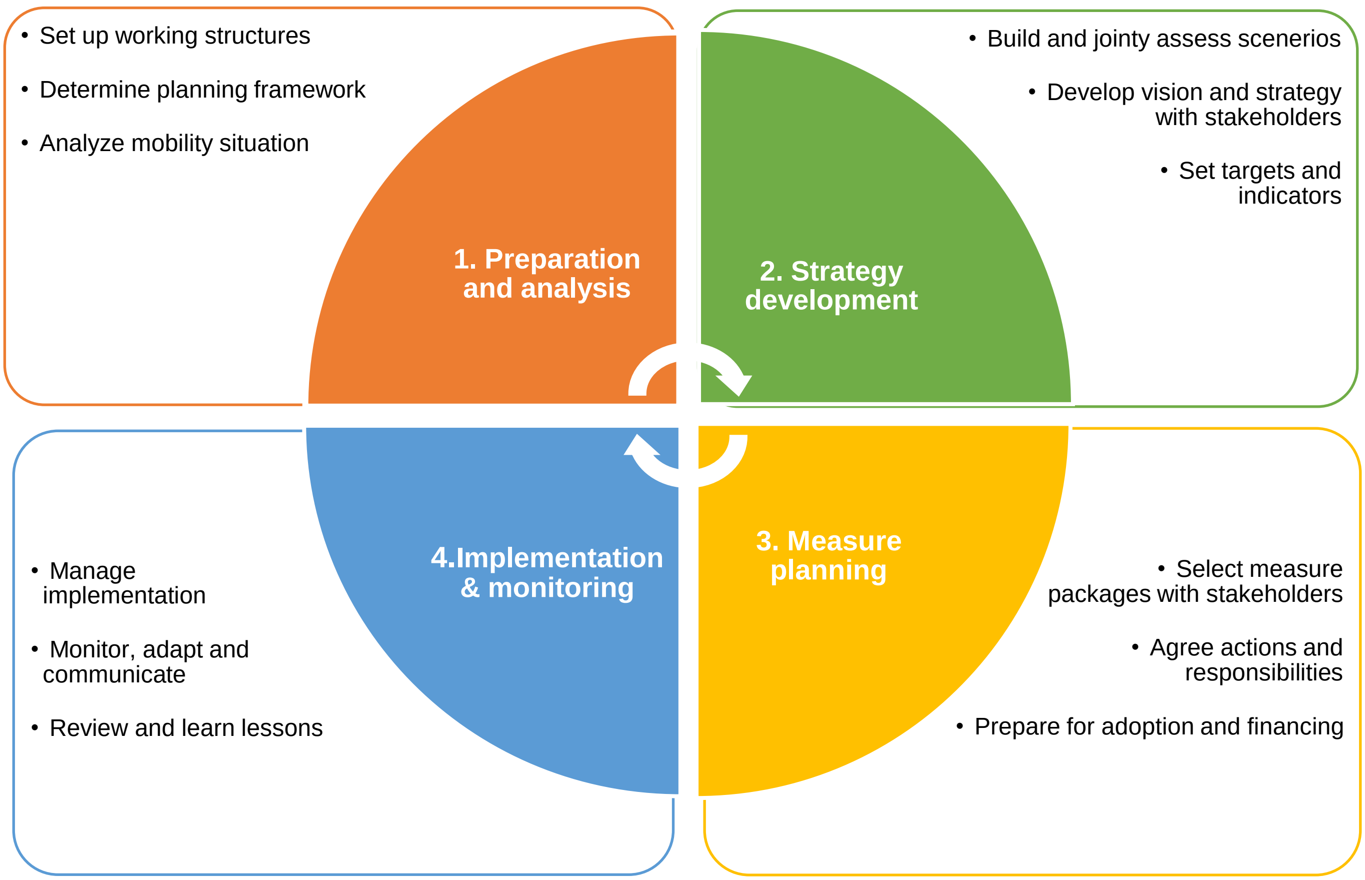
The planning process for the transition to a sustainable energy and transport sector should involve stakeholder consultations at every stage (e.g., with energy providers, transportation department, police, citizens, schools) to build broad community support.

Promotion of the use of public transport, as opposed to private vehicles, should be supported through all relevant central planning processes. In cities and towns, the concept of transit-oriented development (TOD) encourages the use of public transport to use available space more efficiently and create more livable, compact and accessible communities. The establishment of inclusive, mixed-use areas greatly reduces residents' need to use cars and, consequently, reduce energy consumption and GHG emissions.

Sustainable transport planning processes must be more comprehensive and integrative. The Sustainable Mobility Plan for Islands (SMPI, see Figure 6) is a strategic planning methodology designed to address transport-related challenges and the mobility needs of island residents. The SMPI is a modified version of *Rupprecht Consult*'s Sustainable Urban Mobility Plan (SUMP).

The SMPI planning cycle is comprised of four stages: (1) preparation and analysis, (2) strategy development, (3) measure planning and (4) implementation and monitoring. The objectives of the first stage are to obtain a firm commitment from policymakers to prepare a sustainable mobility plan and to conduct a detailed analysis of challenges and opportunities. On islands, policymakers from all relevant administrative levels will need to be involved at this stage.

Figure 6: Sustainable Mobility Planning for Islands



SD Strategies (2020). Based on: Rupprecht Consult (2019). Sustainable Urban Mobility Plan.

In the second stage, a strategy is developed to achieve sustainable mobility on the island, with clearly defined objectives and targets. The strategy should be based on a vision encompassing the whole island and all its residents. Targets that can be defined at this stage include the long-term phase-out targets for ICEVs mentioned above.

The third stage is focused on the planning of concrete measures for the strategy's implementation. During this step, the island may assess measures to promote electric mobility, TOD, walking, and cycling.

The fourth activity is concerned with implementation and subsequent monitoring and evaluation of progress made towards the goals of the sustainable island mobility plan (Rupprecht Consult, 2019).[2] In the cyclical nature of the process, results from this final step will be used to feed back into new planning and analysis to further improve the system.

The sustainable island mobility planning process is designed to cause a paradigm shift from a car-centered to people-centered transport planning. Implementing the ASI framework through

[2] A good way to initiate an SMPI process is to conduct a self-assessment questionnaire through ELTIS's online tool: https://www.sump-assessment.eu/English/start

this planning approach can stimulate a deep and impactful transformation of an island's energy and transport sectors.

Table 2 presents the concrete actions to be taken at each stage of the SMPI process, using the example of Rapa Nui/Easter Island. A comprehensive energy and transport integration plan is a key component of the SMPI process. On Rapa Nui/Easter Island, where electricity is generated predominantly through diesel plants and private ICEVs are the most commonly used means of transport (Ochs, A., Gioutsos D.,2020), the SMPI process must focus on a simultaneous shift from conventional to renewable energy and from conventional and private mobility modes to sustainable and shared ones. This requires a rigorous assessment of the risks and opportunities of different transport options.

Table 2: Application of the Sustainable Mobility Planning for Islands (SMPI) planning cycle to Rapa Nui/Easter Island, Chile

SMPI stage	**Actions**
Preparation and analysis	• Evaluate capacities and resources: Energy and transport situation on the island, government funding schemes • Plan stakeholder and community engagement with focus on energy and transport integration • Set timeframes and develop action plan • Assess opportunities and risks of different transport options
Strategy development	• Conduct capacity building and outreach activities aimed at local communities • Set measurable *Avoid, Shift and Improve* and sector-coupling targets • Identify indicators to monitor progress towards these targets
Measure planning	• Create and assess list of objectives, targets and indicators with stakeholders • Identify funding sources and assess financing capabilities • Develop financial plan and agree allocation of costs • Finalize and assure quality of SMPI document
Implementation and monitoring	• Coordinate implementation of individual actions • Inform and engage community and stakeholders • Monitor progress and adapt where needed • Disseminate outcomes and lessons learned

Sources: Rupprecht Consult (2019), Ochs, A., Gioutsos D. (2020), SLOCAT (2019).

SMPI processes on APEC islands must proactively involve a broad range of stakeholders, including local communities. Local resistance may be a major impediment to the roll-out of sustainable mobility infrastructure coupled with renewable electricity, as is currently the case on Rapa Nui/Easter Island where large SUVs have become an important status symbol and some renewables are met with suspicion (Ochs, A., Gioutsos D.,2020). Targeted and forward-looking SMPI processes that concentrate on capacity-building and outreach to residents can abate their concerns and increase buy-in and a sense ownership. Community outreach activities should focus on the co-benefits of decentralized and integrated energy and transport for Rapa Nui/Easter Island, such as enhanced economic and social opportunities.

The coordination of the different measures to implement the 'Avoid', 'Shift', and 'Improve'-framework may be challenging. Indicators and objectives must be carefully selected in close collaboration with local stakeholders and be subjected to a robust assessment and monitoring plan. For example, shifting from private mobility to car sharing and public transportation on the one hand, and replacing ICEVs with EVs on the other hand, are two separate actions that require broad participation of Rapa Nui/Easter Island's residents and have to be closely coordinated to deliver the desired results.

Sustainable mobility plans must also take into consideration the administrative structure of member economies and the available capacity of authorities. To ensure the successful design and implementation of an energy and transport integration plan on Rapa Nui/Easter Island, the local government, the regional government of Valparaíso, and central government agencies (Ochs A., Gioutsos D., 2020), alongside the local utility and businesses, must be involved in shaping its technical and financial aspects.

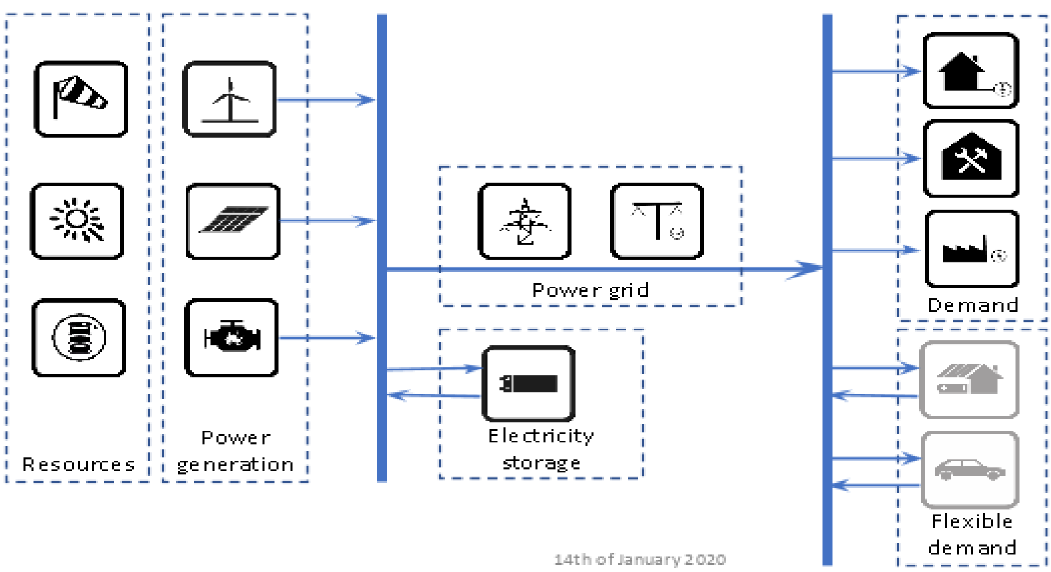
4. Planning sustainable energy and transport: A multi-criteria analysis for defining the right development path

The previous chapters have underlined the rationale for a sustainable energy and transport transition on APEC islands, and introduced a framework and methodology to help island authorities plan for this transition. Planning for the energy and transport sectors jointly is a complex endeavor that involves multiple dimensions and feedback loops. To help identify and account for all relevant factors, this chapter introduces a multi-criteria decision making approach connected to energy system modelling and planning.

4.1 Energy system modelling and planning

Energy systems consist of a supply side, with power generation; a demand side, with households, businesses and industry; and in between the two a transmission and distribution grid and energy storage. An example of an energy system diagram is given in Figure 7.

Figure 7: Example of an energy system and its components



Source: RLI (2020).

Conventional power planning and operations are limited to matching demand with supply using dispatchable thermal power plants. Capacity expansions are based on demand projections only. Operation strategies use a combination of base- and peak-load power plants to cover the demand on a least-cost basis. With the introduction of fluctuating and intermittent renewable energy sources such as wind and sun, planning and operation of energy systems becomes much more complex. Now not only the demand is variable, but so is generation, causing higher uncertainty in the system and requiring curtailments at times of overproduction. Extensive overproduction can significantly reduce the economic benefits of phasing out fossil fuel-based energy generation.

To prevent this, the energy supply needs to be forecasted as accurately as possible, based on long-term, seasonal weather patterns as well as multi-day weather forecasts. Two major solutions are available to reduce uncertainty and improve adaptability of the energy system: electricity storage and demand-side management.

Integrated planning for a sustainable energy system needs to consider power generation, storage capacity, and the flexibility of demand. EVs can play a pivotal role in increasing demand flexibility, as they can absorb excess energy at times of peak generation and serve as additional energy storage capacity. As the battery capacity of an EV ranges from 10 kWh to 100 kWh, the cumulative charging and discharging of an EV fleet in a given energy and transport cluster could have a significant impact on grid balance and performance, particularly on small, non-interconnected islands with installed generation capacities below 200 MW (Gay et al., 2018).

An increasing number of EVs would lead to an increase in power demand, but if charging and discharging is timed according to a smart control strategy, EVs can effectively serve as flexible and decentralized storage capacity. Passenger vehicles are parked for a large majority of the time. Therefore, their charging schedule can be adapted to the needs of the grid and the peak hours of electricity generation from renewable energy resources (IRENA, 2019). For example, EVs can be charged during the day to match the peak output of solar PV plants.

Local utilities can offer discounts or other financial incentives for EV charging at off-peak demand times, applying preferential time-of-use rates. Under controlled charging schemes, EVs absorb the surpluses of renewable energy generation and thereby reduce the need for expensive curtailment and grid-balancing measures.

When EVs make up over 30% of the total vehicle fleet, they have the potential to feed significant amounts of electricity back into the grid (Gay et al., 2018) through the use of vehicle-to-grid (V2G) technologies. EVs can provide balancing and back-up services to local utilities, such as voltage and frequency regulation (Sovacool et al, 2018). They increase the efficiency of electricity systems while reducing CO_2 emissions; and they reduce the need for costly fossil fuels in both the energy and the transport sectors.

The high complexity of sustainable energy systems paired with electric mobility necessitates a sophisticated planning process. The application of traditional planning criteria (such as security of supply, affordability, and environmental sustainability) results in many different possible supply scenarios. Energy system modelling tools can be used to identify which scenario best addresses all needs and objectives.

The first step of energy system modelling is to analyze the energy supply system: which installations are available, at what capacity and output? Then, individual system components can be integrated into the model. After the collection of input data, scenarios can be simulated, and component sizes or operational strategies can be optimized. The results of a comparative analysis of alternate pathways can be used to develop recommendations. Such recommendations should consider all stakeholders' needs and preferences. The multi-criteria decision making approach can help to effectively involve stakeholders in decision making.

Text Box 4: Types of energy system modelling tools

- **Macro-economic**: Birds-eye perspective on energy systems; aggregated, long-term, multi-sectoral; e.g. LEAP, GeneSys-Mod.
- **Techno-economic:** Detailed calculation of supply systems and components; energy flows in hourly time steps; optimization to minimize system costs; e.g. oemof, TIMES.
- **Project planning**: Detailed calculation of specific energy supply projects; technical and cash-flow analysis; restricted to smaller systems; e.g. HOMER Energy.
- **Grid modelling**: Stability calculations for electrical grids (voltage and frequency); e.g. DIgSILENT, ENAplan.

4.2 Multi-criteria decision making

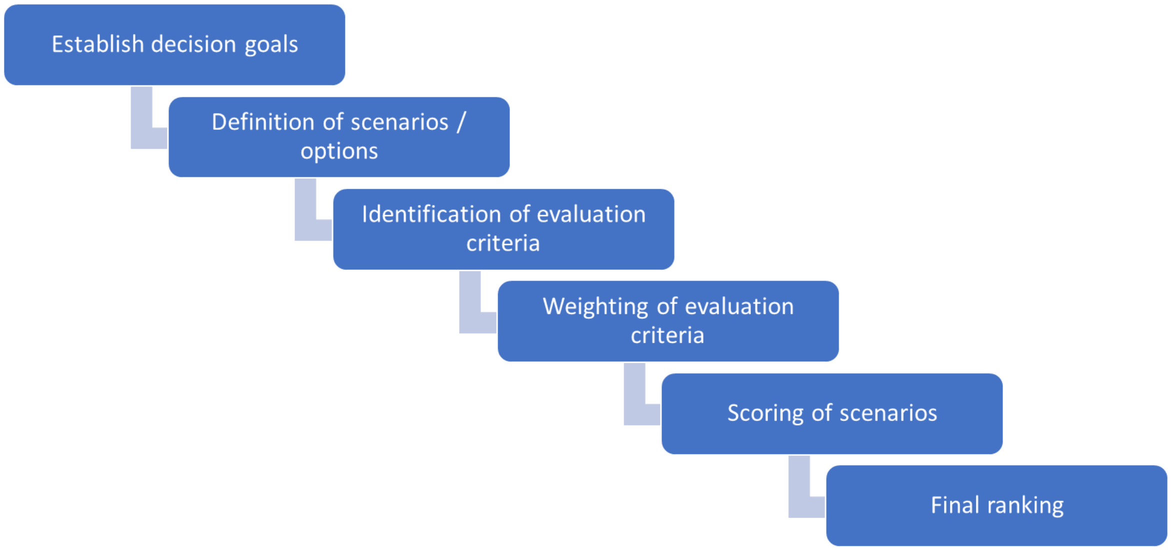
Multi-criteria decision making (MCDM) helps to identify optimal energy supply scenarios based on different qualitative and quantitative evaluation criteria. The selection and weighting of the criteria allow for interactive and transparent stakeholder involvement. Instead of asking every stakeholder (group) to present scenarios and recommend one – which is often time-consuming, controversial, and unproductive – they are asked to select and weigh the decision making criteria. Stakeholder inputs can be collected through interviews, expert consultations and group discussions.

MCDM has evolved into a large scientific discipline with a range of different approaches. Wang et al. (2009) have analyzed and summarized the basic steps of MCDM (see Figure 8).

First, a decision goal needs to be established. It is imperative for all stakeholders to agree on the overall decision goal(s), e.g. find the optimal future supply system for "their" island based on appropriate technical, economic, environmental, and social criteria.

The next step is to define possible scenarios or options which later will be evaluated. For energy systems, different combinations and sizes of power generation technologies (e.g. wind power, photovoltaic systems, conventional power plants) and storage systems can be used to cover specific fixed and flexible demand patterns as part of alternate energy supply scenarios. The scenarios can be calculated with the help of the energy system modelling tools presented in Text Box 4. Typically, technical and economic criteria receive the most attention in modelling, but MDCM allows decision makers to look beyond these two dimensions.

Figure 8: Sequential steps of the multi-criteria decision-making approach



The third step is to collectively define the evaluation criteria. Three types of criteria are distinguished: knock-out criteria such as yes/no or upper/lower threshold; quantitative criteria such as financial costs; and qualitative criteria such as low or high environmental impact. Interviews or questionnaires can be used to identify the evaluation criteria. The Delphi method or other statistical methods can be applied to process the gathered data.

The identification of evaluation criteria should follow certain principles: the criteria should reflect the main characteristics and the overall performance of the energy system (Wang *et al*., 2009). The comprehensive evaluation of multi-criteria assessments can deliver better results than the sum of several single-criteria evaluations.

It is crucial that the set of criteria is consistent with the decision-making objective. Indicators should be quantitative where possible, and clearly outlined if they are qualitative. The result of MCDM is more impactful if criteria can be compared.

Once the criteria have been defined, stakeholders are asked to weight their importance. Several approaches exist to determine the criteria's relative importance. The most straightforward method is a simple scoring of each criterion. Other methods include subjective weighting, e.g., placing the criteria in a hierarchy, and objective weighting, including through normalization.

The next step in MCDM is the development of a decision matrix, with the scenarios or options on one axis and the weighted criteria on the other. The matrix allows for a comparative analysis based on each scenario's performance for each criterion. For example, the total investment cost for each supply scenario is calculated and this number is then normalized to give each scenario a score. This score is in turn multiplied by the weight ascribed to the investment cost criterion by stakeholders, resulting in a weighted score that can be included in the final ranking of options.

It is possible for criteria to have either a positive or negative impact on the overall performance of scenarios. Obviously, low values are typically better for negative criteria (e.g. investment costs), while high values are better for positive criteria (e.g. renewable share in the energy mix).

In the final stage of MCDM, a final score is calculated for each scenario or option, allowing the scenarios to be ranked. Should final scores vary only marginally, a concluding stakeholder discussion is recommended to jointly select the best possible energy supply system for the respective island.

4.3. A practical example of multi-criteria decision making

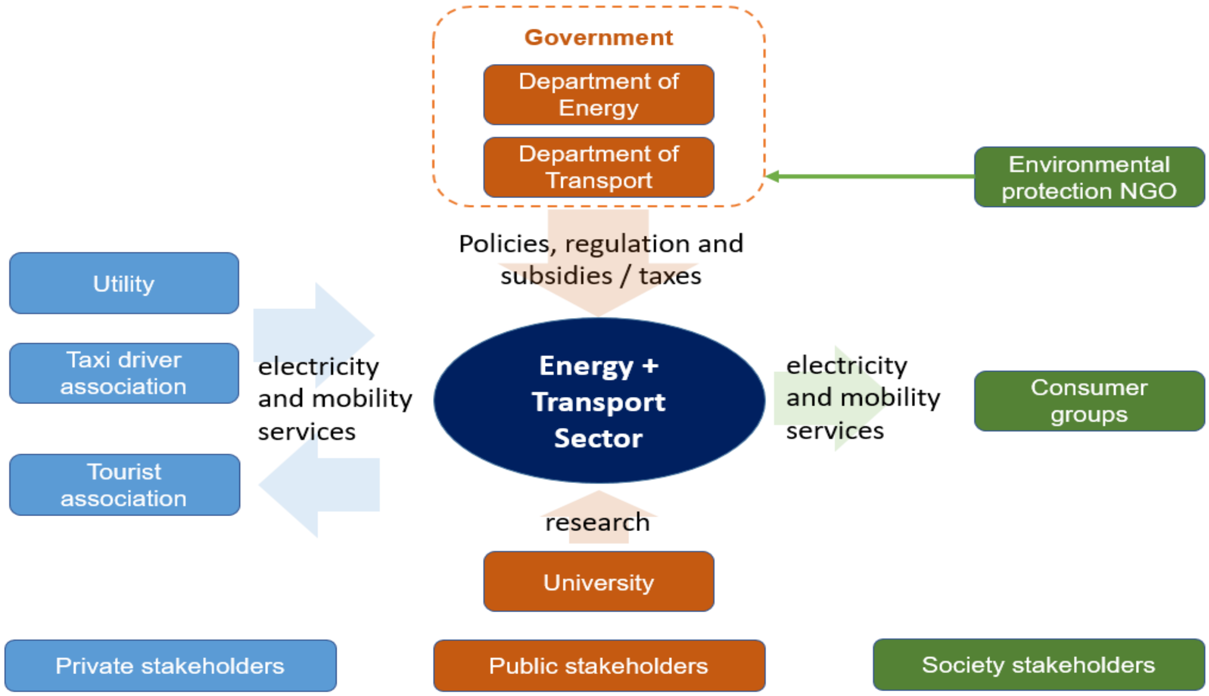
In this section, we provide a practical example of *how to apply a MCDM to island systems*. It is a simplified version of the described energy system modelling and planning approach, along with MCDM. The example is based on a fictional island named “Isla Sustainabilita,” located in Southeast Asia, with a population of 100,000.

4.3.1 Stakeholder involvement

The first step is to involve all relevant stakeholders to ensure that decision-making is transparent, inclusive, accessible and accepted by all (Olander and Landin, 2005). To achieve this objective, we recommend the drafting of a detailed stakeholder map before the start of the decision-making process. The stakeholder map should be as inclusive as possible, covering organizations, institutions and companies from both the public and private sectors, academia and civil society, as well as any other relevant individuals. Concrete examples of relevant stakeholders include the local utility, independent power producers (IPPs), transport system operators, ministries (e.g., Energy, Transport, Finance, Environment), planning agencies, non-governmental organizations, local or international research institutions, financing institutions and community leaders. The stakeholder map should clearly show the stakeholders’ functions in the island’s energy and transport systems, and the relations between them. An example for the fictional Isla Sustainabilita is provided in Figure 9.

In the following stage, stakeholders are invited to participate in the MDCM process. For small islands, we recommend initial meetings with representatives from all stakeholder groups to present the outline of the process and to collect initial feedback. It is possible to do this one-on-one, but group dynamics can be more conducive to discussion and deliver better results. In the initial meetings, expectations should be aligned and preferences for certain solutions or criteria, as well as any concerns, should be understood and taken into consideration. The initial meetings with stakeholders also present an opportunity to collect valuable data and information for the modelling and planning process.

Figure 9: Stakeholder map of Isla Sustainabilita



4.3.2 Definition of alternatives: energy supply and transport scenarios

The first technical step of the process is the definition of the different scenarios that will be evaluated and discussed. It is strongly recommended to identify at least three alternatives, which can be framed as conservative/BAU, moderate, and progressive. All scenarios need to draw on the current situation on the island and its renewable energy potential.

The island Isla Sustainabilita is home to 100,000 inhabitants and its main economic sectors are tourism, agriculture and fishery. The island consumes about 70 GWh electricity per year with a peak demand of 20 MW. The entire demand is supplied by one diesel power plant (DPP). The Department of Energy (DOE) has set new targets for RE shares in the electricity sector. An assessment of renewable energy resources conducted by the local university shows high potential for hydropower and high solar irradiation.

Transport on the island is mostly based on motorized vehicles, primarily two- and three-wheelers. Very few residents own a car. The majority of the population owns a motorbike or travels by taxi, typically privately-owned three-wheelers, also known as trikes. The island's beautiful beaches and lush mountainous landscape attract many tourists, who predominately rely on the taxi trikes for transportation. The taxis form a privately organized public transport service that is more energy efficient than individual vehicles because it can serve more people. The Department of Transport (DOT) has emphasized its interest in supporting public transport (the ‘shift’ portion of ASI) and also wants to increase the share of EVs on the island (ASI’s ‘improve’). As part of this effort, DOT wants to convince the taxi association to purchase and use e-trikes.

The introduction of RE and EVs (synonymously used for e-trikes) should be pursued as a public-private partnership (PPP) between the DOE and DOT on the one hand and the utility and the taxi association on the other. The DOE and DOT will finance the RE generation plants and the EV charging infrastructure, respectively, because the government expects that the measures will reduce demand for expensive, and heavily subsidized, fossil fuel imports. The utility will operate the RE plants, control the feed-in of RE to the grid and offer a power tariff to EV drivers lower than the usual cost (to provide a market incentive; made possible by the low marginal costs of RE).

We assume a small share of taxi drivers are willing to buy EVs without further subsidies because they expect that the fuel savings and lower maintenance costs will offset the higher price tag of EVs. To better compare low carbon pathways to BAU, we formulate three scenarios for our MCDM which will be evaluated in the subsequent steps.

Table 3: Description and characteristics of scenarios

Scenario name	Description	Energy sector	Transport sector (taxi-trikes only)
Business as usual	No changes in the energy and transport sector	RE share: 0% Peak load: 20 MW DPP: 25 MW	EV share: 0% EVs: 0
Moderate	Moderate increase of renewable power generation; moderate support for EVs	RE share: 40% Peak load: 21.2 MW DPP: 25 MW PV: 20 MW	EV share: 20% EVs: 2000 EV storage: 5 MWh Public charging stations: 200 (6 kW per station)
Progressive	Ambitious increase of renewable power generation; strong support for EVs	RE share: 80% Peak load: 21.2 MW DPP: 25 MW PV: 20 MW Hydro: 10 MW	EV share: 40 % EVs: 4,000 EV storage: 20 MWh Public charging stations: 400 (6 kW per station)

The scenarios and their generation and e-mobility characteristics can be further described as follows:

- The **business-as-usual scenario** represents a situation unchanged from the present configuration of the energy and transport system, where power is generated by a DPP and the transport is based on gasoline vehicles.

- In the **moderate scenario**, a large centralized solar PV plant is installed at a former industrial site and 2,000 taxi drivers switch to EVs. The charging of the EVs is not regulated or harmonized with the power system. Therefore, the peak demand will increase because of EV charging, with a maximum of 21.2 MW and an additional 1.2 MW for the charging stations.

- In the **progressive scenario**, the utility builds an additional "run of river" hydro power plant in one of the island's largest rivers. Due to the baseload availability of hydropower, the DPP is shut off during periods of low demand. The RE share increases due to the storage capacity of the EVs which are now integrated. As a result of this V2G approach, the EVs connected to the charging stations act either as a virtual battery storage or as a virtual power plant. Using dynamic power pricing, the tariffs are adjusted in real time depending on the load and the system stability, thus incentivizing favorable charging behavior of EV users, such as charging at night with cheap hydropower or during the afternoon using cheap PV power. Efficient charging behavior of EV users will help ensure that peak demand does not continue to increase under the progressive scenario. In this way, EVs can be used to stabilize the island's RE system through the V2G integration and further reduce their TCO by generating income from this service. In this scenario, it is assumed that a total of 4,000 taxis switch to EVs because of the expected financial benefits.

4.3.3 Definition and weighting of evaluation criteria

Representatives from all stakeholder groups gather at a workshop to define the criteria that will be used to evaluate the MDCM scenarios presented above. As the targeted vehicles (ICE and electric) on Isla Sustainabilita are privately owned by taxi drivers, their purchase costs are not considered in the economic evaluation, but the charging infrastructure is, because it is financed by the public partners. The vehicles are, however, considered in all other criteria because they affect the technical, environmental, and social performance of alternative scenarios.

The stakeholders then vote on the relative importance of each criterion using a rating scale from 0 (no importance) to 5 (highest importance). By normalizing the final ranking of the criteria, their relative weight is calculated.

Technical criterion: Reliability

The reliability of an energy and transport system indicates to what extent it manages to cover demand and the quality of its service. Low reliability can result in power outages, supply shortages, voltage fluctuations or faulty generators and vehicles. Climate science predicts that the severity and frequency of extreme weather events will increase with global warming, threatening small islands in particular. For this reason, climate resilience should be an important criterion for the choice of an island's energy system. All stakeholders on Isla Sustainabilita acknowledged the importance of the reliability of the energy and transport system to keep the island's economy and social welfare system intact. Therefore, this criterion received a very high rating of 4.8.

Economic criterion 1: Investment cost

Energy affordability is a key factor in energy system decision making, and thus it is important to compare the costs of fossil fuel and RE technologies. The primary upfront costs connected to a transition to a sustainable system include large investments in new energy and transport infrastructure. Many Isla Sustainabilita stakeholders expressed concern over the island's suffering economy due to recent industrial delocalization and called on the government to spend public funds carefully. As a result, the criterion of investment costs was rated a relatively high 4.0. However, the complex cost structure of different generation technologies and transport modes, including operation and management (O&M) and fuel costs, requires another cost criterion.

Economic criterion 2: Levelized Cost of Electricity

Levelized Cost of Electricity (LCOE) is a more holistic criterion because it does not only consider the investment costs but the full lifecycle costs associated with an energy and transport system. LCOE calculations assess the average cost per generated unit of electricity (usually expressed in kWh). The LCOE of a generation technology is calculated by dividing the sum of all costs associated with the system by the total electricity generated over the system's lifetime. The total cost consists of investment costs, fuel costs and O&M expenditures. The costs are discounted in order to account for the time-dependent value of money. The discount rate reflects the weighted average cost of capital and is a critical factor for capital intensive RE technologies. Figure 10 presents the formula to calculate annualized LCOE, as presented by IRENA (2019).

Figure 10: Formula of Levelized Cost of Electricity calculation

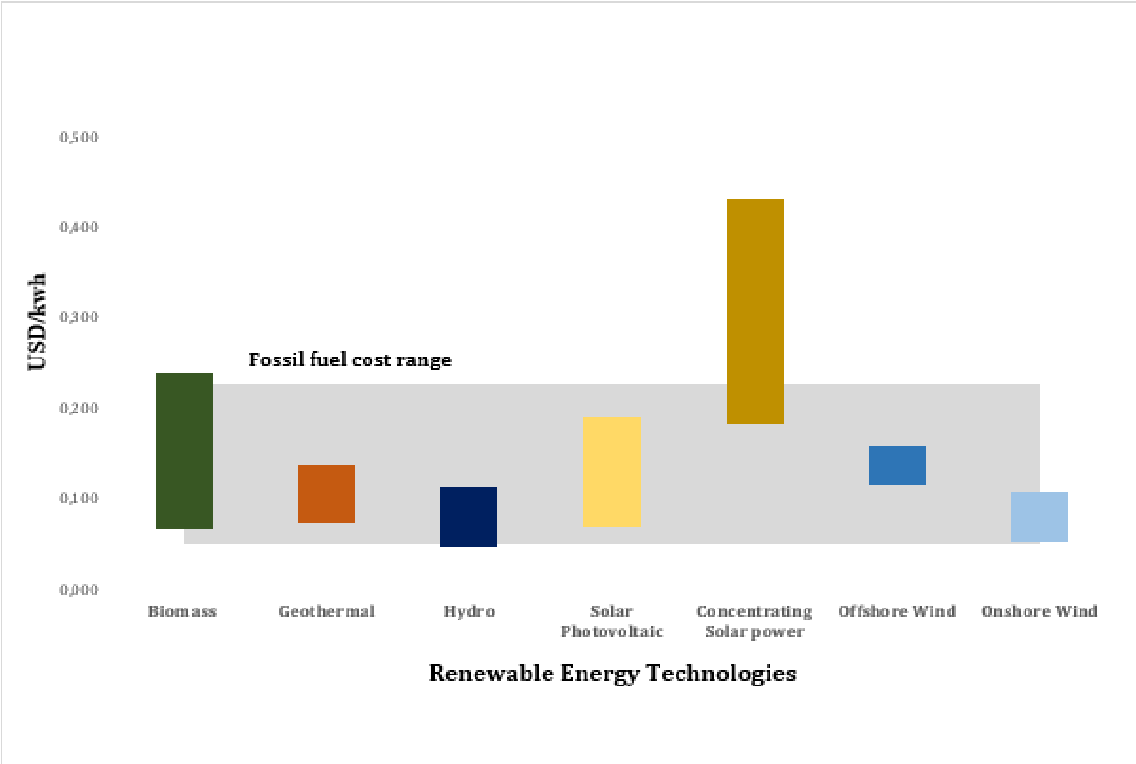
$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t = investment expenditures in the year t
M_t = operations and maintenance expenditures in the year t
F_t = fuel expenditures in the year t
E_t = electricity generation in the year t
r = discount rate
n = economic life of the system.

Source: IRENA, 2019.

Figure 11 **Error! Reference source not found.**compares the cost range of the LCOE for RE technologies relevant to small-island energy systems to that of fossil fuels. It reveals that RE technologies are highly competitive, particularly since fossil fuels costs on islands will be on the high end of the rage, due to the high fuel importation costs (see above).

Figure 11: Global LCOEs from newly commissioned utility-scale renewable power generation technologies, 2020



Source*:* IRENA (2020).

Stakeholders on Isla Sustainabilita were convinced that the LCOE should be the most important cost criterion in the evaluation of scenarios and therefore rate it higher (4.5) than the investment cost.

Environmental criterion 1: GHG emissions

Environmental NGOs on Isla Sustainabilita strongly advocated for the inclusion of environmental criteria in the MCDM process, because negative externalities are usually not included in LCOE cost calculations. Climate change mitigation is increasingly considered an important factor in energy and transport sector decision-making. Especially on islands, the effects of climate change are already noticeable (see chapter 2.1.3). Even though stakeholders agreed on the high importance of reducing GHG emissions, they argued that the impact of GHG mitigation by a small island, such as Isla Sustainabilita, on global climate change is very small and that the criterion should be weighted accordingly. The stakeholders rated this criterion 3.0.

Environmental criterion 2: Local pollution

For developing regions with minimal GHG emissions, GHG mitigation alone tends to be viewed as insufficient motivation for the implementation of RE and EVs. Therefore, Isla Sustainabilita University has stressed the importance of an additional environmental criterion, one that can underline the local environmental co-benefits of RE-based systems. Given that pollution of air, water, and soil degrade entire ecosystems and have direct impacts on islanders, including negative effects for tourism and agriculture, stakeholders agree on a final rating of this criterion of 3.7.

Social criterion 1: Public acceptance

Consumer groups on Isla Sustainabilita emphasized the importance of social acceptance for the effectiveness of any energy and transport strategy, stressing their political influence on voters. The groups further underlined the significance of health criteria for energy and transport planning. The tourist association agreed with the consumer groups' position on health criteria and added that noise and smell from traffic diminishes the attractiveness of the island for tourists. All stakeholders agreed on the high importance of this criterion and rated it 4.2.

Social criterion 2: Job creation

Projected employment effects are an important factor in any public decision. On Isla Sustainabilita, private and civil stakeholders acknowledged the importance of the issue but public stakeholders pointed out that the number of people employed in the energy and transport sector is low overall – and significantly lower than that in the tourism sector. For this reason, the criterion was rated moderately important at 3.0.

Weighting of the criteria

The normalization of the criteria ratings resulted in their weightings, listed in the following table (Table 4).

Table 4: Weighting of the criteria

Categories	Criteria	Importance	Weight
Technical	Reliability and resilience	4.8	0.18
Economic	Investment costs	4.0	0.15
	LCOE	4.5	0.17
Environmental	GHG emissions	3.0	0.11
	Local pollution	3.7	0.14
Social	Social acceptance	4.2	0.15
	Job creation	3.0	0.11

4.3.4 Evaluation of alternative scenarios according to the criteria

Together with the stakeholders, the planning experts developed both quantitative and qualitative scoring methods for each criterion. At a second workshop, Isla Sustainabilita stakeholders used these methods to evaluate the three scenarios.

Evaluation according to reliability

The reliability of the energy and transport system is evaluated qualitatively because some aspects that influence the operation of the system can only be quantified through highly complex methods. Therefore, stakeholders estimated the reliability of the system under each scenario using their expertise of the technology, assigning a score from 1 to 3 points. The power generation of the solar PV plant is dependent on solar irradiation, which means its output fluctuates greatly. The hydro power plant, on the other hand, generates power consistently as seasonal variation of water flows is low due to Isla Sustainabilita's proximity to the equator. As explained in chapter 4.1, EV integration into the power grid – balancing demand through the V2G approach – can help enhance the reliability of a RE-based energy system.

The DPP can also provide constant power supply, although maintenance requirements and fuel supply shortages can lead to load shedding and power outages. A DPP is typically more maintenance intensive than RE installations, due to the mechanical complexity of the engines and the consumption of lubricants. Regular and unforeseen maintenance needs can lead to generator shutdowns. Extreme weather events or geopolitical tensions can impact fuel imports and lead to supply shortages for both the DPP and the fuelling of ICE trikes. Decentralized RE technologies combined with electric mobility can improve the reliability of the entire system. Isla

Sustainabilita stakeholders discussed these aspects and allocated the following scores: business-as-usual scenario: 1 point; moderate scenario: 2 points; progressive scenario: 3 points.

Evaluation according to investment costs

The investment costs for the three scenarios can be calculated using cost assumptions and cost offers, which both allow for a quantitative scoring of the scenarios. Fossil generation technology is characterized by comparatively low investment costs per MW of capacity installed, especially in the case of small- or medium-scale diesel power plants; the technology is mature and widespread. The investment costs for RE installations are significantly higher than those for DPPs due to higher manufacturing and material costs (e.g. for PV modules) as well as higher installation cost (e.g. for hydropower plants). However, the costs associated with PV modules have declined by 90% over the last decade, which has accelerated the creation of favorable market opportunities. The average total installation cost worldwide is currently indexed at around USD 1,200/kW for PV and USD 1,500/kW for hydropower (IRENA 2019). It is assumed that the medium-sized PV and hydro plants in our fictional scenarios will be built at this price.

The purchasing costs for the EVs are not considered here since they are bought (or not) by private taxi drivers and not by public authorities, but the investment costs associated with installing charging infrastructure for the EVs do need to be included. Assuming that purchasing and installation costs per charging station amount to approximately USD 2,000 (The Mobility House, n.d.), the investment cost for charging stations will total around USD 0.4 and 0.8 million for the moderate and progressive scenario respectively. The RE generation capacity as listed in Table 3, would require investments of USD 24 and 39 million respectively, leading to overall investment costs of USD 24.4 million for the moderate scenario and USD 39.8 million for the progressive scenario.

Evaluation according to LCOE

The cost of diesel fuel depends on commodity market prices. Over the last two decades, the crude oil price has increased by an average of 5% per year. Small islands unconnected to mainland grids, such as Isla Sustainabilita, usually face much higher diesel fuel prices than the global average because of high transport costs. The cost of fossil fuels and associated subsidies are a heavy burden on public budgets – on Isla Sustainabilita, more than 30% of GDP is spent on fossil fuel imports, which is not unusual for a developing small island. In contrast, solar PV and hydropower are free from fuel costs because the energy resources (solar irradiation and water flow) are freely available in perpetuity and can be directly converted into electricity.

The generation costs of RE have become competitive with fossil-fueled generation costs in recent years. If the disadvantages regarding the cost of fossil fuel imports are considered, then it becomes clear that renewable technologies are the far more attractive option. Moreover, the remoteness of islands tends to increase maintenance costs, as spare parts for DPPs are expensive and can take a long time to be delivered. In the alternative scenarios, on the contrary, the utility can make a profit from selling excess RE to EVs. As a result, the LCOE is USD 0.20 for the BAU scenario, USD 0.14 for the moderate, and USD 0.16 for the progressive scenario.

Evaluation according to GHG emissions

The CO_2 emissions generated in the different scenarios can be quantified using the emission factor of diesel, namely 2.6 kg CO_2 per liter of diesel. Accounting for the efficiency of the DPP, this allows for the calculation of the total CO_2 emissions. A higher RE share in the electricity mix leads to lower emissions. The CO_2 emissions of vehicles must be included in the evaluation. In our fictional case, vehicles running on renewable electricity instead of gasoline leads to reduced CO_2 emissions. Assessing the current electricity generation under the BAU and the simulated generation under the alternative scenarios, the total CO_2 emissions per year for the given scenarios are as follows: BAU = 19.9 tons, moderate = 14.3 tons, progressive = 5.6 tons.

Evaluation according to local pollution

Isla Sustainabilita University has developed an environmental impact index that aggregates the impacts of air pollution (CO, NO_x, SO_2 and particulate matter) and acidification effects. The environmental index for the BAU scenario is the highest with 6.3, followed by the moderate scenario with 3.8 and the progressive scenario with 1.3.

Evaluation according to social acceptance

Social acceptance is partly influenced by the previous criteria and partly by multiple other factors; therefore, the scenarios have to be evaluated qualitatively. Negative externalities and environmental impacts from fossil fuel emissions directly concern and affect civil society. Oil spills on- and offshore can have severe adverse consequences for fisheries and agriculture and directly affect residents as well as tourists.

The air pollutants $NO_{x,}$ SO_2 and PM are harmful for human health. Globally, air pollution causes more than 7 million deaths per year (WHO, 2018). According to the stakeholders of Isla Sustainabilita, emissions from heavy traffic and the DPP have already been linked to a sharp increase in lung disease. The introduction of RE and EVs can therefore enhance the social acceptance of energy and transport scenarios. Additionally, the use of EVs leads to noise reduction which has the potential to reduce stress and positively impact mental health. Physical and mental well-being are important for the local population as well as for tourists. However, the plans for the hydropower plant have been heavily criticized by the tourist association because it affects the pristine image of the landscape.

Based on these aspects of social acceptance, the alternative scenarios score higher (progressive: 2 points; moderate: 3 points) than the BAU scenario (1 point).

Evaluation according to job creation

As mentioned in chapter 2.2.4, RE technologies can increase employment opportunities. The renewable energy sector is also known to employ a larger share of women than the traditional energy sector. Assuming the full realization of this potential on Isla Sustainabilita, the stakeholders score the progressive and moderate scenarios higher (2 points for both) than the BAU scenario (1 point).

Table 5: Final scoring and ranking of scenarios

		Business-as-usual scenario			Moderate scenario			Progressive scenario		
Criteria	*Weight*	*Score*	*Normalized score*	*Weighted score*	*Score*	*Normalized score*	*Weighted score*	*Score*	*Normalized score*	*Weighted score*
Resilience	*0.18*	*1.00*	*0.00*	*0.00*	*2.00*	*0.50*	*0.09*	*3.00*	*1.00*	*0.18*
Investment costs	*0.15*	*0.00*	*1.00*	*0.15*	*24.40*	*0.39*	*0.06*	*39.80*	*0.00*	*0.00*
LCOE	*0.17*	*0.20*	*0.00*	*0.00*	*0.14*	*1.00*	*0.17*	*0.16*	*0.67*	*0.11*
GHG emissions	*0.11*	*19.79*	*0.00*	*0.00*	*13.08*	*0.45*	*0.05*	*4.78*	*1.00*	*0.11*
Environment impact	*0.14*	*6.30*	*0.00*	*0.00*	*3.78*	*0.50*	*0.07*	*1.26*	*1.00*	*0.14*
Social acceptability	*0.15*	*1.00*	*0.00*	*0.00*	*3.00*	*1.00*	*0.15*	*2.00*	*0.50*	*0.08*
Total score				**0.15**			**0.59**			**0.62**

Total scores and ranking of the scenarios

In the final steps of the MCDM process, some scores must be inverted (when a high score has a negative effect) and normalized. The score for each criterion is multiplied by its weight and then the weighted scores are added up to produce the final score for each scenario. The results in Table 5 reveal that the progressive scenario scores highest, followed by the moderate scenario; the BAU scenario ranks lowest.

4.4 Final observations

By means of the example of the fictional Isla Sustainabilita, this chapter has demonstrated how the methodology of MCDM allows for the consideration of multiple interests in planning an integrated energy and transport system. It has also shown that for the development of a way forward that is broadly supported, it is crucial to a) include a broad range of public and private stakeholders, and b) jointly assess economic, social, and environmental criteria.

The results of our model case have shown that scenarios based on RE and EVs require large initial investments, but that this disadvantage is offset in the long run by the significant economic, environmental, and social benefits created. This assessment is in line with real-world projections, and increasingly real-world experiences, in island economies. The integration of RE and EVs leads to lower LCOE, lower transport-sector costs, a lower need for fossil fuel subsidies, and through that to enormous public savings over the system's lifetime.

The reduced fossil fuel consumption by both the energy and the transport systems will minimize adverse environmental and health impacts. Social benefits beyond health improvements include the reduction of noise, the protection of ecosystems (creating recreational opportunities), new jobs and positive impacts on income generation and business opportunities in areas such as tourism and agriculture.

In places with low income levels, the high initial investment costs can be a knock-out criterion for scenarios envisioning high shares of renewables in the energy mix and of EVs in the vehicle fleet. This is particularly the case if international public, private, or blended finance cannot be accessed. Even then, however, MCDM provides an opportunity to include key stakeholders in the planning process, leading to higher support levels for energy and transport investments, and thereby a more effective, integrative system. Pursuing a step-by-step roll-out of the transition to alternative, sustainable systems, starting with a moderate integration of RE and e-mobility, is a promising strategy for testing the evaluation criteria within the specific context of APEC islands.

5. Conclusion and outlook

The overall aim of this report was to increase awareness of the negative consequences of a business-as-usual (BAU) development of the energy and transport sectors on APEC islands. Outlining alternative pathways, we wanted demonstrate the economic, social, and environmental benefits which APEC islands can expect if they couple their energy and mobility sectors and transition towards EV- and RE-based, efficient systems. We have presented worldwide technology trends and how they are applicable to small islands. We then presented one tool (ASI and its use in SMPIs) that helps to define the role of EVs within a broad set of sustainable transport options, and a second (MCDM) that allows for the evaluation of different scenarios in the concrete setting of an island, exemplified by the fictive island Isla Sustainabilita.

The rationales provided in Chapter 2 can lead to a paradigm shift and help to build the necessary consensus among public decision-makers as well as key private stakeholders that a transition is possible and in the self-interest of island citizens – not just the global climate system. It is important that local stakeholders and international capacity-building initiatives pick up this narrative and mainstream it into public discourse and decision-making processes.

The ASI framework presented in Chapter 3 provides a concrete toolkit for creating a sustainable transport sector. SMPIs are the results of the concrete application of ASI. Following a strategic framework is necessary for an efficient transition to sustainable transport and energy modes. ASI provides policymakers with versatility, the ability to adapt and contextualize strategies based on each island's local conditions. Besides reducing overall transport demand and the expansion of public, collective transport, RE-fueled EVs are a key component of a transition to low-carbon mobility. APEC islands and member economies should discuss how the three ASI components can be more efficiently implemented in a closely integrated fashion. Guiding questions include: How to best run public transport systems on EVs? And how can overall traffic be reduced through household electrification and the smart use of digital control systems?

MCDM (Chapter 4) allows islands to pick the energy and transport development scenario or pathway that is in their best economic, social and environmental interests. Combined with a comprehensive energy modelling and planning approach, MDCM allows for an effective evaluation of a variety of alternative energy and transport scenarios. The MCDM framework embraces the engagement of all stakeholders in the decision-making process. The multi-criteria assessment outlines several economic, social, and environmental benefits to justify the high upfront investment costs for the integration of energy and mobility on small islands – especially since lifecycle costs have been proven to be lower for both REs and EVs than for conventional solutions, and lowest if both are integrated.

This report offers a roadmap insofar that it outlines pathways toward a cleaner, healthier, and more prosperous future for APEC islands through the transition to integrated, sustainable energy and transport systems. The provided tools allow for a selection of the most preferable pathway and the identification of its constituent components. APEC islands of course are highly diverse. They differ in area and population; available energy resources and demand; the nature of current transport and power supply systems; overall economic development and the importance of different sectors; cultural and political characteristics; and much more. This is why the next step for APEC islands will be to apply the tools provided here within their own, unique contexts. Islands need to evaluate their own situations and find their own preferred pathways; they need to use this report as a blueprint for their own island roadmap.

Once a specific pathway has been defined – say, a gradual but overall ambitious move towards the efficient use of a high share of both REs in electricity generation, and EVs in the public and private vehicle fleets – what comes next?

This next step after the creation of an island energy and mobility roadmap will be the design of an implementation plan. The key challenge is to source the necessary investment to embark on the sustainable pathway envisioned. In most APEC islands and member economies, the public sector will seek private-sector support and/or international technical and financial assistance. To attract financing, the investment environment needs to be attractive. Concrete tools exist that help to assess investment risks and barriers as well as evaluate policy and finance instruments that can be employed to mitigate these (for example, UNDP's Derisking Renewable Energy Investment (DREI) analytic tool). Assessing the applicability of such tools to the integration of transport and energy systems on APEC islands will be an important next step in moving from the definition of individual transitional pathways to their implementation. No time should be wasted in starting this analysis. Once the effectiveness of finance and policy design tools has been proven, these tools need to be applied in parallel to ASI and MCDM to individual islands contexts (depending on the configuration of the political system, responsible provinces and higher entities of political organization may need to be included).

APEC can play an critical role in further advancing the development and testing of roadmaps and implementation plans. This can be done best in islands that have already shown the determination and political will to move quickly and ambitiously towards sustainable energy and transport systems. Several APEC member economies and island representatives we worked with in this project are highly qualified in this regard. Collaborating with them will ensure that roadmaps and implementation plans will be followed by action. There is no reason to wait.

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