Navigating Island Futures in Transport

A guide to developing national transport strategies for Small Island Developing States

1st Edition | November 2021

Part III

IIIA: Menu of strategies
IIIB: Menu of technologies

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Navigating Island Futures in Transport: A guide to developing national transport strategies for Small Island Developing States | 1st Edition

Executive summary

Part I: A 21st Century approach to island transport systems

Part II: How to design a national transport strategy – a 5-phase process

Part III: Menu of strategies and technologies

ISBN 978-0-477-10259-9 (digital - 4 volumes)

This report may be cited as:

> Baker, N. and Campbell, A. (2021). *Navigating Island Futures in Transport: A guide to developing national transport strategies for Small Island Developing States*. Ministry of Foreign Affairs and Trade, New Zealand Government.

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Images: Adobe Stock, the Noun Project, and the authors, unless otherwise noted.

Supported by the New Zealand Aid Programme. The views expressed in this publication do not necessarily reflect those of the New Zealand Government.

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Abbreviations

BEV	Battery-electric vehicle
e-…	Electric, as in e-bike, e-motorbike, e-bus, e-truck
eg,	For example,
EV	Electric vehicle
E2W	Electric 2-wheeler
E3W	Electric 3-wheeler small format vehicle
GHG	Greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German development agency)
HEPS	Hybrid electric propulsion system
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
IEA	International Energy Agency
ITDP	Institute for Transportation & Development Policy
ITF	International Transport Forum
NCD	Non-communicable disease
PCREEE	Pacific Centre for Renewable Energy and Energy Efficiency
PHEV	Plug-in hybrid electric vehicle
SAF	Sustainable aviation fuel
SIDS	Small island developing states
SPC	Pacific Community
UNOPS	United Nations Office for Project Services
USA	United States of America
WASP	Wind-assisted propulsion
WOL	Whole-of-life

Contents

What's in Part III

Part III of this guide is where the 'rubber hits the road' – it provides you with a catalogue of strategies, technologies, policies, and other measures that have already been assessed for their suitability for small island countries.

It means you won't have to start from scratch in your search for practical and appropriate solutions to help deliver a sustainable and holistic transport strategy.

Part III is in two sections:

- **Part IIIA: Menu of strategies** – this section presents a range of strategies and approaches to help islands shift towards sustainable transport systems.
- **Part IIIB: Menu of technologies** – this section presents transport technologies for land, sea, and air transport. These have been assessed for their suitability for small island countries across different time horizons. Note that, given how quickly transport technology is changing, the information in Part IIIB will be updated every few years.

How to use Part III

Parts IIIA and IIIB are designed to be used in multiple ways. They can be used as a primary source of information and ideas as you develop a long-term sustainable transport strategy using the guidance in Part II.

For example, as you work through Part II's *Phase 3: Explore the future*, they will help explain some of the new trends and ideas in transport systems and technologies. This will help you formulate a vision of a desirable transport future.

Similarly, when working through Part II's *Phase 4: Design pathways*, they will help identify the appropriate strategy, technology, and policy options to meet a country's needs and provide guidance on how changes can best be sequenced over time.

The menus can also be used to improve the design of stand-alone or one-off projects by:

- providing technology options pre-screened for suitability to small island contexts, which will help to avoid inappropriate project design
- identifying the wrap-around policies, measures, and supporting systems required for the successful deployment of low-carbon transport technologies, which will help ensure projects are designed for success.

Designing pathways over time

Transport systems are inherently path dependent – they are costly and involve significant infrastructure, and they are intimately bound up with urban form and patterns of settlement. This means that the choices available today are constrained or enabled by historical decisions. And the decisions made today, will either enable or constrain future opportunities.

This path dependency is reflected not only in the physical transport systems themselves, but also in the institutions and organisation of transport systems, and in the dominant views on transport problems and solutions (Low & Astle, 2009).

Taking a long-term approach and mapping out pathways over time allows you to grapple with how to transform some of the more challenging aspects of your transport system.

For example, you might be tempted to think that, because roads and sidewalks are in poor condition today, the uptake of bicycles and micro-mobility can only ever be a minor part of the transport system, even though they are considered a highly desirable part of your transport future.

Taking a vision-led approach lets you challenge this assumption and design a pathway to realise your more ambitious vision.

Begin by imagining a future where a healthy, active community moves around easily on bikes and micro-vehicles. Then work out what you would need to begin doing now to enable that transition over time. You might include urban design and spatial planning for walkability and cyclability, followed by progressive upgrading of paths and roads. In the meantime, you might also mark out some dedicated bike lanes, and establish programs where children learn to ride bikes at school, so that in 10 years' time there is a generation that is accustomed to riding bikes.

Three time horizons

The guidance in Part **III** considers how strategies and technologies might be applied over three time horizons, out to 2050. This is to help you design those pathways to a sustainable future transport system.

The three time horizons are:

- Horizon 1 (**H1**): short-term – from now to around 5 years in the future.
- Horizon 2 (**H2**): medium-term – 5 to 15 years.
- Horizon 3 (**H3**): long-term – H3: 15 to 30 years.

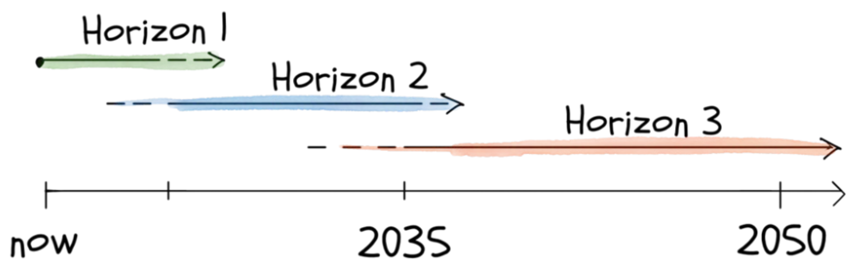


Figure 1: Time horizons H1, H2 and H3 from now to 2050

Part IIIA: Menu of strategies

What's in Part IIIA

This *Menu* describes a range of strategic approaches that small island nations can adopt when developing sustainable transport systems.

Each strategy is assessed for how well it responds to the transport challenges faced by islands.

The first section of Part IIIA provides a summary of all the strategies – covering land and maritime transport, and aviation. The summaries are loosely presented in a descending order of priority, with the most relevant and useful first.

The remaining **three sections** group the strategies as follows:

+ **Urban and land transport systems.**
+ **Sea transport and aviation systems.**
+ **Cross-cutting strategies.**

Here the strategies are described in greater detail, including information on the following:

+ a set of **measures** is suggested – described in the Explanation 1 opposite
+ possible **benefits** are discussed
+ risks or additional conditions that need to be taken into account are listed as **considerations**
+ how the strategy might look over the three time horizons – H1, H2, and H3 – is described under **pathways**.

The book symbol signals links to further external information on a topic.

Explanation 1: Type of measures

The **measures** or instruments that can be packaged together to form strategies include:

- **Planning:** includes land use planning, urban planning, street design, and providing for public transport
- **Regulatory:** standards for quality and performance, traffic restrictions on speed and where vehicles can go
- **Economic:** taxes, fees and levies, subsidies, and financial instruments such as loans
- **Information:** public awareness and behaviour change campaigns, street signs, information about bus routes, etc
- **Technology:** this refers to the types of technologies explored more fully in *Part IIIB Menu of technologies*
- **Infrastructure:** design, construction, and supply of infrastructure: eg, protected bicycle lanes, bike parking, electric vehicle charging, roads, ports

Summary of strategies

Urban and land transport systems

The strategies below follow a (loose) descending order of priority. There is some overlap between them.

Integrated land use and transport system planning: In general, this is the place to begin the journey toward a sustainable land transport system. At the macro scale, it looks at the location of communities, services, and economic opportunities, and considers the long-term risks of climate change and natural disasters. From there it is possible to identify where transport services and infrastructure are needed, and where infrastructure should be built.

Designing streets for people first: At the micro scale, this is about designing inclusive and safe urban streetscapes that encourage walking and cycling and that are accessible to all, creating connected and vibrant communities. When well designed, more compact urban areas with better services can contribute to a reduced demand for transport.

Cycling and micromobility (including electric-powered options): Encouraging a shift from private vehicle travel to micromobility can greatly reduce traffic congestion, fuel use and GHG emissions, and improve health. Ownership of small electric-powered mobility options is much cheaper than owning a larger format vehicle or using taxis and provides greater mobility independence for young people and those without access to larger format vehicles. Access to these travel options may also be provided through shared or short-term rental arrangements.

Small format EVs: Electric motorbikes (E2Ws) and motortrikes (E3Ws): This strategy encourages the use of small-format electric 2- or 3-wheelers, where appropriate, through street design, preferential parking, and charging infrastructure. It also supports the introduction of these technologies with quality standards, technician support, and battery life cycle management (including battery repurposing and export for recycling).

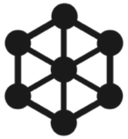
Public transport: Encouraging the use of public transport is an important means of reducing GHG emissions, even when buses are diesel. It is also crucial for accessibility and economic inclusion – many people rely on public transport to get to work or to bring their goods to market. Public transport is often undersupplied in small island countries.

Reducing car dependency: The increasing use of private vehicles brings myriad problems to small-island countries, including road congestion, abandoned vehicles, and GHG emissions. At the same time that a shift towards walking, cycling, e-micro-mobility and public transport is encouraged, the use of private cars should be discouraged. It is important that these alternative modes of travel are available to maintain the capacity of the overall transport system.

Electrifying vehicles: After that, the electrification of vehicles becomes important – however, to be effective at reducing GHG emissions, this requires accelerating the transition to renewable electricity generation. The electrification of transport also requires a suite of wrap-around support measures, including providing access to technician training, charging infrastructure, and full life cycle management of batteries.

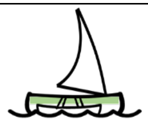
Managing the life cycle of vehicles and equipment: Many island countries deal with increasing numbers of abandoned vehicles. The introduction of battery-powered electric vehicles and small format e-mobility devices has the potential to exacerbate the waste issue. They will require careful end-of-life management of waste, including regional-scale programs to collect, export, and recycle vehicles, and to repurpose or recycle batteries. The costs need to be factored into the adoption of electric vehicles.

Sea transport and aviation systems



Integrated planning for inter-island transport systems: Inter-island maritime and aviation transport planning should take an integrated approach that considers the location of communities, services, and economic opportunities, and the long-term risks of climate change and disasters. A vision and policy direction for remote and outer islands communities should underpin this thinking, including the need to support regular transport services. Integrated planning would then consider the fleet specification, infrastructure and technologies that are needed over time for both aviation and maritime transport.

Greening ports and ground operations (maritime and aviation): Improving the infrastructure and operation of islands' ports to be more resilient and energy-efficient, and to reduce GHG emissions and other environmental impacts, is desirable for the short, medium, and long term.

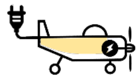


Personal small boats for coastal travel: Many small island countries have locally-developed technologies for small boats – often the result of generations of innovation and improvement. Their suitability for local construction and maintenance, and their minimal fuel use, suggests the 'old ways' should be encouraged for the future, updated with modern construction methods and materials.

New-build and retrofits using low-emission vessel technology, including sailing ships: Ships are often custom-designed and built for a particular context and application. That custom design can be used to incorporate combined technologies including wind propulsion, hull design, solar-/ battery-electric propulsion systems, and the use of low-carbon fuels to achieve significant reductions in fuel use and GHG emissions.

Improving operations to reduce fuel/ emissions: Options to improve the efficiency of existing vessels and reduce fuel use include improved voyage planning, weather routing, optimised engine operation, hull cleaning, specialised coatings, and optimising ballast and trim.

A regional approach to aviation services: A key option to improve viability of SIDS aviation (especially in the Pacific) is to consolidate national airlines into regional or sub-regional operations. The increased scale would enable both economic and service improvements from sharing centralised services and provide better utilisation of and flexibility within the fleet. It also allows for more cross-subsidisation between profitable routes and routes that are critical to connectivity for remote communities.



Low-emission aviation technology: There is little opportunity to reduce domestic aviation emissions in SIDS in the short to medium term. At present, there are no obvious practicable and affordable technological solutions that would bring benefits to islands against the already well-suited, robust, and efficient turboprops. The international aviation industry is working hard to develop low-emission technologies, expected to emerge and become more affordable and available in the global market in the medium to long term (H3). This strategy is really to 'watch this space' in aviation technology over the next decade or more.

Cross-cutting strategies

Connecting digitally: The increasing roll out of broadband internet to remote places is expected to continue, opening up the potential for providing digital access to services such as education and healthcare, and avoiding the need to travel.

Managing the life cycle of infrastructure: The location, design, and construction of roads and infrastructure should seek to increase resilience, while having regard to the local capacity and materials for maintenance and rehabilitation. Governments should be fully aware of the ongoing costs of maintaining and repairing infrastructure and earmark the necessary funding in their budgets or ensure it is otherwise provided for by a donor-sponsored trust fund or similar.

A note on cooperating with regional neighbours

Many small island countries will be too small to implement some of the suggested strategies on their own – but these may become viable if states cooperate with their neighbours.

Examples of measures that may need regional cooperation include:

- the whole-of-life management of waste equipment (ie, the export and recycling of vehicles and batteries)
- training technicians in new technologies
- standardisation of models and parts
- aggregating procurement to ensure supply and achieve better prices.

Development partners, including regional agencies, can help by resourcing these programs and ensuring they operate reliably, effectively, and are in place long term.

1 Urban and land transport systems

Overview

Cars have been the centrepiece of land transport in most places around the world for decades, and SIDS are no exception. The land transport and urban issues faced by islands, as set out in *Part I: A 21st century approach to transport strategies for small island developing states*, mean that a different approach is now required.

The discussion of urban and land transport systems on the following pages deliberately shifts away from thinking about cars as the primary mode of transport. The strategies and options discussed here take a broader view of sustainable urban and land transport systems, in line with the paradigm shifts set out in *Part I*.

The strategies presented here include integrating transport planning with spatial planning and urban design. They cover redesigning streets from being places dominated by cars and trucks to being places for people, cyclists, and children. They discuss the need for better public transport systems, that are safe and welcoming for all users. Then, when you have considered these ways of making transport more sustainable, affordable, and healthy, these strategies consider ways to discourage the use of cars. Electrification of the road vehicle fleet is presented here as a key part of the suite of sustainable land transport solutions – but it is not the only part. Finally, this guidance emphasises the need to take a whole-of-life view to the management of vehicles and equipment.

This section includes discussion of the following:

+ **1.1 Integrated land use and transport system planning.**
+ **1.2 Designing streets for people first.**
+ **1.3 Cycling and micromobility.**
+ **1.4 Small format EVs: Electric motorbikes (E2Ws) motortrikes (E3Ws).**
+ **1.5 Public transport.**
+ **1.6 Reducing car dependency.**
+ **1.7 Electrifying transport.**
+ **1.8 Managing the life cycle of vehicles and equipment.**

1.1 Integrated land use and transport system planning

> "Integrated land use and transport planning involves (1) aligning transport infrastructure and services with land uses in ways that reduce private vehicle kilometres travelled/auto-*dependency*, increases mass transit usage and supports freight logistics, (2) co-locating compatible land uses and higher densities in accessible locations, and (3) prioritising resourcing for 'public transportation' over new road construction and making it central to spatial planning and design at all physical scales." – Planning Institute of Australia, South Australian Division *(Planning Institute of Australia, South Australia Division, 2008)*

Integrated spatial planning is increasingly seen as a key instrument for achieving sustainable urbanisation, reducing the risks from climate change, protecting nature, and improving the well-being of populations. Integrating transport into spatial planning recognises that transport infrastructure and services both respond to, and drive, land use patterns, economic activities, and the location and design of settlements.

Integrated land use and transport system planning should be a high priority for small island countries, particularly for areas close to sea level and/or exposed to natural disasters, and for heavily urbanised areas. Many small island countries will need to have serious conversations in the near term about the risks and impacts of climate change on their settlements, land use, and infrastructure, including transport.

Small island countries have been experiencing high levels of rapid and unmanaged urbanisation, which are expected to continue and even accelerate in the coming decades (Asian Development Bank, 2013) (UN Habitat, 2015) (Mycoo & Donovan, 2017). At the same time, populations and infrastructure in small islands are concentrated in the relatively constrained coastal zone areas. These areas face immediate effects from climate change, including increased frequency and severity of cyclones and storms, with resulting losses of lives, homes, and critical infrastructure. These setbacks to socio-economic development are projected to accelerate in the coming decades (UN Habitat, 2015).

The development of *integrated spatial plans* is a process that will explicitly consider long-term hazards and risks from climate change, the process of urbanisation, and the changing economic profile of island economies. Integrated spatial plans allow managed change over time in settlements, land use, and infrastructure, including transport, in a way that:

- reduces exposure and vulnerability to climate and disaster hazards
- plans for services and infrastructure for a growing urban population
- aligns infrastructure plans with the socio-economic aspirations of regional populations
- builds local community cohesion and resilience
- protects biodiversity, forests, and water.

At the macro scale, integrated spatial planning, as it relates to transport, asks:

- Where are roads, ports, and settlements located relative to economic activities?
- What is their vulnerability to sea-level rise, more intense storms, and flooding events?
- Can these impacts be managed through repairs and rehabilitation, or do key assets need to be relocated?
- Is there a need for more connectivity to promote economic activity, and what is the best way to achieve this?
- Would it be better, for example, to build or improve a road, or to provide a sea transport route?
- What is the pattern of urbanisation and outmigration, and why are people moving?
- Where do we want settlements to be, and how will they be serviced?
- What are the expectations for tourism development and how will that affect transport needs?

At the more detailed level, it is about the design of neighbourhoods as places where people live, work, shop, go to school, and access other services. It is about creating places where people can interact with each other and move about in healthy ways.

Planning needs to be inclusive and encourage participation and cannot be seen as a technical or top-down process.

Measures

Integrated spatial and transport planning should include the following:

- Risk assessment to inform where best to site assets and infrastructure to achieve climate change and disaster resilience, and appropriate patterns of settlement and land use change. (See Explanation 2 below for a discussion of multi-hazard risk assessment).
- Focus on compact urban forms with planned services.
- Development of '20-minute neighbourhoods' or '15-minute cities' to reduce the need to travel to access good and services and create more vibrant and resilient local communities (see Explanation 3).
- Systems planning for transport infrastructure – identifying critical infrastructure, shifting long-lived assets away from disaster-prone areas, and designing transport for both connectivity and disaster response.
- Planning for transport infrastructure that is integrated with planning for water, wastewater, power, and telecommunications, to find ways to integrate layout and build multi-purpose assets, reduce costs, and improve quality and resilience.
- Processes that are inclusive and encourage participation, and that will not be seen as a technical or top-down.

Benefits

- Planned urban areas with increased density support a reduction in mobility needs, encourage a shift to public transport, and reduce energy use and GHG emissions.
- Better access to services for communities.
- Settlements and infrastructure avoid areas at high risk from climate change and natural disasters.

Considerations

Traditional land tenure systems are often raised as a barrier to discussing land use planning in small island countries (particularly in the Pacific). Of course, due regard must be given to customary land tenure and decision-making, and to how those systems are evolving over time. However, larger considerations are looming. Urbanisation is most often happening informally without processes in place to help urban areas accommodate new arrivals. More critically, risks from climate change now pose a threat to the very existence of many island communities. While challenging and confronting issues to discuss, addressing the location of infrastructure and settlements over the coming decades is essential. Following a process of drawing up scenarios and creating visions (such as set out in *Part II Phase 3*) can help create a safe space in which these conversations can take place.

Small island countries have some advantages when it comes to integrated spatial planning, due to their relatively simple institutional environments, and the smaller land areas involved. The landholders, key stakeholders, and relevant policymakers should be easier to identify and engage.

Pathway

Island countries are encouraged to start integrated spatial planning now (H1) to ensure that infrastructure built or rehabilitated in the next decade actively contributes to the desired vision for the future, increases resilience and adaptability, reduces exposure to climate change and natural disaster, and enables managed change over time.

> An example of integrated transport system planning is the Torres Strait Transport Infrastructure Plan (integrated strategy for transport services and infrastructure across land, sea, and air). https://www.tmr.qld.gov.au/projects/torres-strait-transport-infrastructure-plan (Maunsell, 2006)

Explanation 2: Multi-hazard risk assessment

A key consideration underpinning spatial planning is to understand the vulnerabilities and risks to transport infrastructure and settlements. This is especially important in the context of the increased hazards from climate change – sea-level rise and heightened storm activity. But it is important to carry out a spatially-explicit risk assessment across all the hazards that may occur, to inform spatial planning, as well as the design and construction of infrastructure projects.

A multi-hazard risk assessment will survey a range of issues that could include, for example, topography of land and coastline overlaid with scenarios for sea-level rise, slope and soil type, rainfall, and flooding, earthquake, and tsunami risk, all further overlaid with the location of settlements and key infrastructure.

This document from the World Bank discusses road network vulnerability assessments in the Pacific (World Bank, 2018)

This document from UN Habitat presents a vulnerability assessment of Apia, Samoa (Planning and Urban Management Agency, Ministry of Natural Resources and Environment, Samoa, 2014)

New Zealand guide to local climate change risk assessments

Explanation 3: The '15-minute city' and '20-minute neighbourhood'

There is a growing global movement to create '20-minute neighbourhoods' (eg, Melbourne) or the '15-minute city' (eg, Paris). The basic idea is to improve the quality of life in urban areas by locating everything people need within a 15-minute walk or bike ride, or a 20-minute round trip, which equates to around a kilometre's distance. By designing cities and neighbourhoods in this way, the need for travel is minimised and people can walk, cycle, or catch local public transport between homes, offices, schools, medical centres, restaurants, shops, parks, and recreation. Within the neighbourhood or community, people will interact more and develop closer social ties. It is a deliberate shift away from car-based urban areas and towards people-centred places.

In small island countries, this approach has the potential to contribute in several ways by:

- planning for the growing urban population and risks from climate change, by designing new neighbourhoods, and densifying and improving existing neighbourhoods
- increasing community resilience by increasing local social cohesion and distributing services across neighbourhoods
- reducing the need for car travel, and associated costs
- encouraging walking, cycling, and connectedness, which have obvious physical and mental health benefits.

A wealth of useful information about the '15-minute city' concept from C40 (C40, 2020)

A couple of short videos from Melbourne, Victoria (Government, 2021)

1.2 Designing streets for people first

At a finer scale, spatial planning is about the design of urban areas, and of streetscapes. People don't only use streets as a means of getting from A to B: they are also a place to shop, play, meet people, and sometimes just to sit and watch the world go by. Different people use and experience streets in different ways. Streets that balance the needs of different users within the sustainable transport hierarchy ensure accessibility, safety, and enjoyment for all. Streetscapes include sidewalks, bike lanes, bus lanes, and general traffic. They include pedestrian networks that are safe and comfortable.

> "Sidewalks are a fundamental form of urban infrastructure that facilitate walking, socializing, interacting, and doing business. They must be provided on all urban streets and be accessible to all users." – from the Global Street Design Guide *(National Association of City Transportation Officials, Global Designing Cities Initiative, 2016)*

Many small island streets are designed primarily for cars and trucks, and do not provide a safe or comfortable place for pedestrians or cyclists, let alone people with limited mobility, including seniors, caregivers pushing prams, and people living with disability. They may be uneven and in poor repair, they may not be fully connected, and there may be obstacles such as trees, parked cars, and lampposts, making it very difficult for people with limited mobility to move around the community. "Consequently, people with disabilities tend to stay at home and are rarely seen outside." (Babinard, McMahon, & Wee, 2016)

The accessibility and safety of streets are experienced differently by women and girls, along with vulnerable groups such as LGBTQI+ individuals. These groups may be subject to gender-based discrimination and violence on public streets, including sexual harassment, assault, and rape. At a basic level, street design that includes open spaces, high visibility, and good lighting can create safer places.

This strategy is about designing streetscapes to be safe and welcoming to pedestrians, cyclists, and people using mobility aids, and to enable people to interact with each other. This means ensuring sidewalks are sufficiently wide, have suitable all-weather surfaces, are free from obstacles, and have sufficient lighting for safety and shelter from the sun or rain.

The design of safe and welcoming streets can also play a key role in the development of tourism, as tourists seek out pedestrian friendly places where people interact.

Measures

- Socially inclusive, gender-equitable design of streetscapes.
- Connected sidewalks in good condition, with lighting and shelter.
- Protected bicycle lanes and convenient, secure parking infrastructure for bicycles and micromobility.
- Restrictions on speed and access for motorised vehicles, and reduced parking.

Benefits

- Improved physical and mental health from more active lifestyles.
- More connected communities.
- Green spaces and shade help reduce the effects of heat in urban areas.
- Increased foot traffic for business.

Considerations

Many urban areas are without high-quality utilities services – such as electricity cables, and water and wastewater pipes. Street design and construction should therefore also consider how these services may be incorporated.

Pathway

Designing streetscapes for people and renewing urban areas should be a H1 priority. Safe, connected sidewalks and bicycle lanes are a precondition for increased walking and cycling, and improving access for people with limited mobility.

The Global Street Design Guide is a comprehensive guide to street design – it applies to all streets, everyone, so only some aspects will be relevant to small island countries (National Association of City Transportation Officials, Global Designing Cities Initiative, 2016).

Designing Streets for Kids presents detailed guidance and cases studies from around the world – when street design is good for kids, it creates streets that are better for everyone (National Association of City Transportation Officials, Global Designing Cities Initiative, 2020).

Improving Accessibility in Transport Infrastructure Projects in the Pacific Islands from PRIF discusses ways to improve the accessibility of transport projects for people living with disability (Babinard, McMahon, & Wee, 2016)

The Guide on Integrating Gender into Infrastructure Development in Asia and the Pacific: Transport and roads from UNOPS and UN Women gives attention to mainstreaming gender issues in transport infrastructure

World Bank Handbook for Gender-Inclusive Urban Planning Design provides guidance on ensuring urban design works for women, girls, and sexual and gender minorities (World Bank, 2020)

1.3 Cycling and micromobility (including electric options)

The term 'micromobility' is used here to refer to small, lightweight electric- or human-powered modes of transport for short to medium distances, sometimes speed-limited to between 25km/h and 40km/h, carrying one or two people (see Figure 1). This includes bicycles, e-bikes, e-scooters, and e-mopeds (speed limited). One way of characterising this mode of transport is that "it can occupy space alongside bicycles" (Zarif, Kelman, & Pankratz, 2019). This means it is suitable for bike lanes and areas that bikes use but is unsuitable for sidewalks and for roads dominated by cars and trucks travelling at greater speeds (Zarif, Kelman, & Pankratz, 2019).

Electric micromobility (e-micromobility) has seen rapid uptake in recent years due to improvements in battery technology, a fall in purchase price as the industry scales up, and investment in supporting infrastructure, such as bike lanes. E-micromobility is a competitive alternative to car travel over short to medium distances (less than 1km to around 10km for e-bikes) (Yanocha & Allan, 2019). Since the emergence of e-micromobility in 2017 there has been a rapid expansion with shared e-scooter, e-bikes, and electric moped schemes available in 600 cities around the world.

While there can be fitness and confidence barriers to riding conventional bikes, access to e-bikes can reduce some of these as the physical effort required is much less. The lower speed limits of many SIDS roads are also conducive to the use of micromobility. Contemporary, rugged models suitable for rough and uneven surfaces and practical cargo-carrying models are already available. Charging can easily be performed using domestic outlets even when on rural-type low-power electricity supply circuits and can also be well-suited for charging from domestic-type solar electricity systems.

Use of micromobility will require careful consideration of the road safety implications and the need for street design that separates micromobility riders from cars and trucks, and from pedestrians, or else provides for safe sharing of roadways and sidewalks (as shown in Figure 2).

A cargo bike being used to transport packages (top), and bike lanes painted on a street (bottom) Images: Adobe Stock.

Measures

- Street design includes bike lanes, street speed limits, designated parking for cycles and other micromobility vehicles.
- Guidelines for the use of micromobility, particularly when used in shared spaces.
- Enforcement of speed limits and exclusion of vehicles from bike lanes.
- Small-scale finance/ low-cost loans to overcome purchase price barriers.
- Shared/ rental services (such as Flamingo or Lime Scooters).
- Education and demonstration campaign to help people become familiar and comfortable with the new technology.
- Minimum import standards for e-mobility (to ensure durability) and standardisation of models/batteries (to support repairs and maintenance).
- Protected bike lanes or ‘light individual transport’ lanes, bike/ e-micromobility parking, and changing facilities in workplaces.

Benefits

- Encouraging a shift from private light vehicle travel to micromobility can greatly reduce traffic congestion, fuel use and GHG emissions, improve health (as it is a fully or partially active form of transport), and air quality.
- Ownership is much cheaper than owning a vehicle or using taxis and provides greater mobility independence for young people and those without access to vehicles.

Considerations

Consideration should be given to whether to encourage the uptake of shared/ short-term rental of e-micromobility vehicles over privately-owned e-mobility vehicles. Increased micromobility can create safety issues where micromobility users share space with other transport options, including with pedestrians. It is important to work on street design to accommodate micromobility safely, as well as education for riders and car and truck drivers.

Pathway

The uptake of e-bikes should be encouraged in the short term (H1) by building dedicated bike lanes and parking and supporting and profiling early adopters to build familiarity in the community. H1 should also be used to establish low-cost financing mechanisms to assist people with the upfront purchase cost and to establish minimum import standards and standardisation of models.

With the right foundations laid in H1, mainstream uptake could be expected in H2.

This report from the ITF on Micromobility, Equity and Sustainability considers a range of issues around managing the deployment of e-micromobility (ITF, 2021).

This report from ITDP – The Electric Assist – recommends a range of policies to support the use of e-micromobility (ITDP, 2019).

An article looking at how e-micromobility is disrupting transport systems (Zarif, Kelman, & Pankratz, 2019).

Equation 1: E-bike in Tahiti Photo: Andrew Campbell

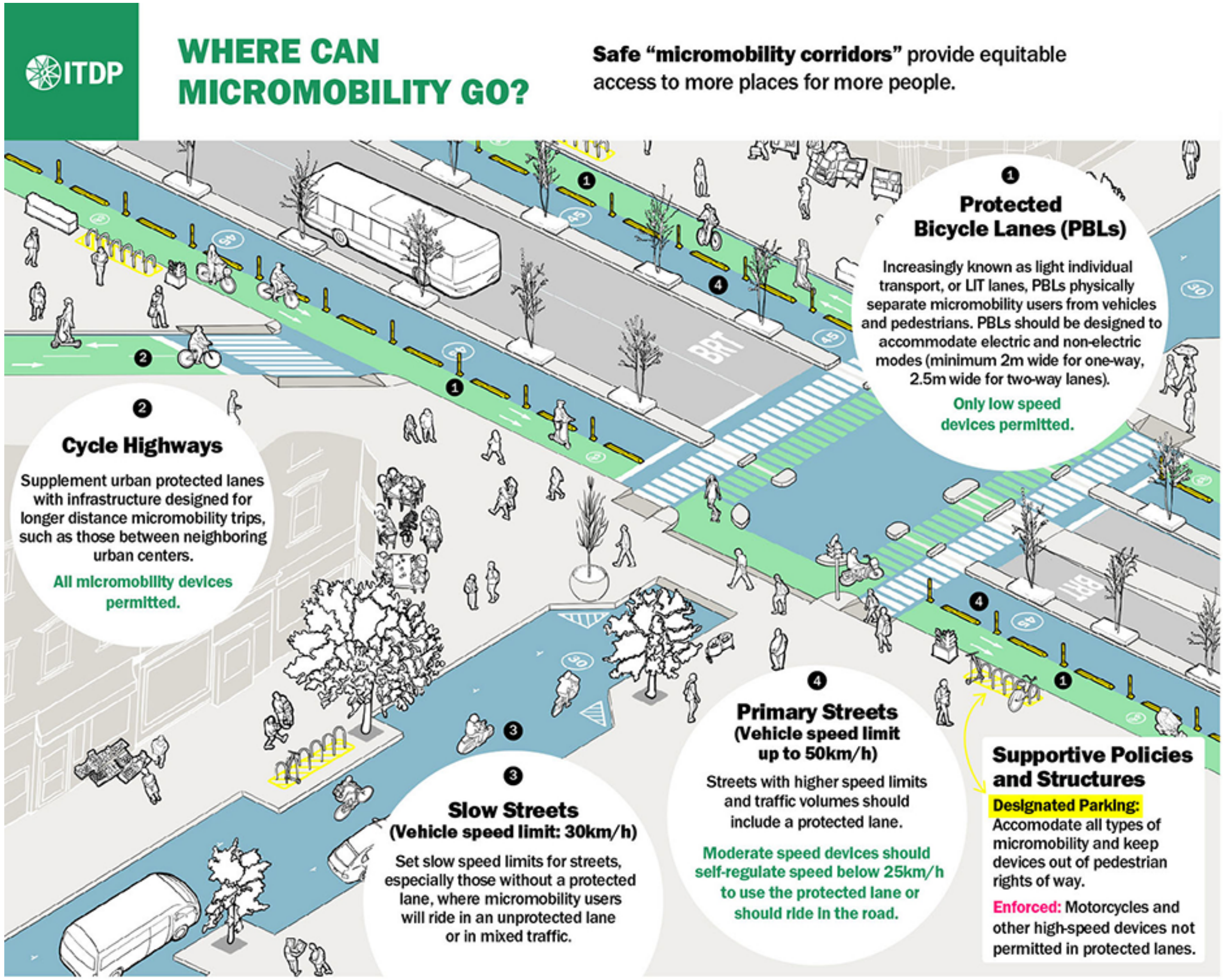


Figure 2: "Where can micromobility go?" infographic by the Institute for Transportation and Development Policy used under CC BY-NC (Institute for Transportation and Development Policy, 2020)

1.4 Small format EVs: Electric motorbikes (E2Ws) motortrikes (E3Ws)

Electric 2-wheelers (E2Ws) are rapidly gaining momentum with global sales increasing by more than 14 per cent annually. E2Ws now make up 80 per cent of China's 2-wheel fleet. Growth is also surging in the European Union, Latin America, the Middle East, North Africa, and Southeast Asia. Rapidly developing technology is seeing a shift from lead-acid batteries to lithium-ion batteries, and the growth in markets means supply chains are becoming more widely developed (Hertzke, Khanna, Mittal, & Richter, 2020).

In contrast to many areas in Asia and around the world, most small island countries do not have significant numbers of motorised 2-wheelers, even though the technology is well suited due to its utility, flexibility, ease of parking, and relatively low cost to own and operate. Rather than encourage adoption of gasoline 2-wheelers, most small island countries would benefit from moving to adopt small-format EVs – electric motorbikes (E2Ws) and motortrikes (E3Ws).

E2Ws are easy, cheap, and generally safe to charge at home and have low maintenance costs. Three-wheeler variants (E3Ws/e-rickshaws) can provide options for carrying passengers and light commercial goods and can be a good match with the low road speeds on many islands. Standardised platforms allow for batteries to be readily swapped, opening the possibility to establish 'battery-as-a-service' operations.

Use of E2Ws will require careful consideration of the road safety implications and the need for street design that manages the interaction between riders and cars and trucks, as well as training for riders and drivers.

Electric 3-wheeler (Photo: Adobe Stock)

Measures

- Demonstration of electric 2-wheelers to build familiarisation and experience.
- Driver safety awareness campaign.
- Rider training and licensing.
- Minimum import standards across all e-mobility (to ensure durability) and standardisation of models/batteries (to support repairs and maintenance, and to enable standardisation of charging equipment and connectors and/or battery-swapping services (see Explanation 4).
- Public parking and charging infrastructure.
- Support to develop the ecosystem of suppliers, servicing, and batteries.

Benefits

- Shifting people from cars to E2Ws or E3Ws will reduce GHG emissions, fuel use, traffic congestion, and local air pollution.
- Greater access to affordable, small-range mobility.

Considerations

The load carrying capacity of models should be considered carefully in places with higher rates of obesity to ensure vehicles are fit-for-purpose, safe, and durable.

The comfort factor of travelling on a 2-wheeler is quite different to travelling in a closed vehicle and it is possible people will need to experience riding one, or being a passenger, several times before they start to feel comfortable. Even then, it is not a suitable form of transport for everyone, and not suitable in all weather conditions.

Consideration needs to be given to how streetscapes are designed to avoid conflict between these small format EVs and pedestrians, or larger vehicles. Education is needed for riders and car and truck drivers on awareness, visibility, and safe driving.

Pathway

H1 could be a period of demonstration and familiarisation over the next few years, with support for local early adopters to help prepare for when they become readily available in small island countries. This period can be used to develop standards and equipment specifications, as well as protocols for use.

This would be followed by steady growth (H2) as local markets establish themselves and draw from global designs and experience.

Explanation 4: Charging, batteries, and battery swapping for e-micromobility and small format vehicles

Larger electric vehicles, such as cars, have onboard batteries that are very heavy and/or are integrated with their chassis. In comparison, modern batteries for e-micromobility and small format vehicles are generally compact and designed so that they are easily lifted by one person. This makes simple battery swapping possible, where an electric scooter user can quickly switch its battery rather than spend time waiting for the battery to charge.

Gogoro of Taiwan introduced a battery swap-based electric 2-wheeler in Taiwan in 2015, and also supports battery swap stations. In 2020, Gogoro reported over 1500 battery swap stations across Taiwan (Gogoro, 2020). Gogoro has also extended its business models to include E2W sharing and battery sharing. Gogoro maintains ownership of the battery, which removes this cost from the purchase price of the E2W – and the cost of some models of E2W are now lower than for their gasoline fuelled counterparts

A battery swap arrangement has the advantages of rapidly restoring vehicle range (Gogoro advertise battery swapping taking less than a minute), the potential to remove the cost of the battery from the upfront purchase price of the vehicle (making the electric option more affordable), standardisation, and passing the oversight of the battery's management to a service provider with specific battery expertise. The combination of standardisation plus expert oversight has the potential to achieve long service life from the battery cells, including by making battery repair more manageable and battery cell repurposing easier. A centralised battery service provider is also in a better position to manage appropriate battery repurposing, recycling, or disposal.

There is also potential for the same swap batteries to be used to provide off-grid household electricity, with some interesting opportunities to integrate solar generation, transport, and electricity supply in remote locations – many of these systems operate on low voltage and can make use of the vast array of electrical controllers and other equipment now available for the pleasure craft and mobile home markets.

In comparison to battery swapping for 2- and 3-wheelers, battery swapping for 4-wheeled vehicles, including buses, requires heavy lifting equipment (the batteries are large and very heavy), very specific vehicle designs, and reasonable vehicle numbers per battery swapping facility to make this economic. Demonstrations around the world have not been successful and would be even less likely to succeed in a SIDS setting.

1.5 Public transport

While some larger and more populous islands have some form of bus service, most transport in the urban areas of small island countries is provided by private light vehicles and taxis. Where there is a bus service, information about schedules may be hard to come by and services are often irregular. Bus services are privately owned, and some operate without any government support. In small island countries, public transport generally takes the form of buses, minibuses, and ferries. Travel by bus or minibus can provide a significant reduction in GHG emissions compared to travel by private vehicles.

The cost of owning a private vehicle is a great burden to the working poor, particularly as both cars and fuel are expensive due to the cost of transporting these to the islands. Journeys by public transport are cheaper than owning a car, so it can save money for people who switch.

Looking to the future, urban planning plays a key role in the effectiveness of public transport systems, which are difficult and expensive to provide to low-density populations. Therefore, as urbanisation accelerates, attention should be given to designing more compact urban areas.

Measures

- Public transport must be supported by the government through policy, planning, service standards, and funding.

Benefits

- Public transport has economic benefits for the whole community as it is often necessary for people to commute to their place of work, and taking public transport is cheaper than using a private car or taxi.
- On buses, people from different walks of life interact more, contributing to social cohesion.
- Shifting from private vehicles to buses or minibuses is likely to reduce congestion on the roads.
- Public transport encourages more walking, as people begin and end their journey walking from their home to the public transport stop. It also encourages the use of micromobility to begin and/or end their journey.

Bus in Suva, Fiji. (Photo: John Ray 2013 CC BY-NC-ND 2.0)

Considerations

Accessibility and safety: Consideration should be given to ensuring public transport is accessible to people with disabilities, including vehicles with built-for-purpose ramps/wheelchair lifts, and seatbelts. While cost may be prohibitive, at least a portion of services should be available to everyone. Measures can also be taken to make public transport safe for women, children, and vulnerable people – for example, in PNG the introduction of the women-only 'Meri Seif Bus' fleet has created a safe travel option for women and girls who almost universally have experienced violence on public transport (UN Women, 2016) (Christy, 2019).

Choice of technology for public transport on land: Globally, there is much discussion about the potential of electric buses to decarbonise public transport. In the short-term, however, electric buses may have only limited application in SIDS.

This is because the required charging infrastructure and on-site technical support present relatively large, fixed costs that mean a fleet size of at least 50 buses is likely to be needed to make economic sense. This is expected to change over time as the technology matures, but for now it means that full-size electric buses are suitable only for large fleets, which restricts their use to cities. In addition, the weight and design of the batteries and the high voltage electrical connections mean the buses are not well-suited for use on rough roads.

In general, compared to the second-hand diesel buses that are often imported for use in SIDS, full-size electric buses are not a viable option at this time. As the technology matures, they may become viable for some island applications in around 10–15 years (H2).

Electric minibuses – for example, the Toyota coaster – can be a viable option in H1. These are off-the-shelf, rely more on light electric vehicle technology, are more rugged and better able to travel across poorer quality roads, and can provide a relatively flexible fleet that can accommodate different numbers of passengers on different routes and at different times of day. Another good option is to fit out an EV commercial van to seat passengers, taking advantage of the increasing availability of such EV models in the global marketplace.

The good news is that, if people switch from private cars or taxis to public transport, even diesel buses can provide a significant reduction in fuel use, GHG emissions, and costs faced by passengers, depending on how many people use them.

Pathway

In H1, for countries without existing bus fleets, consideration should be given to establishing a system based on electric minibuses. For countries with existing diesel bus fleets, improvements could be made to operations, and consideration can be given to augmenting the fleet with electric minibuses.

Ride-sharing is also an H1 strategy, and further discussed in Explanation 5.

In H2, a watching brief can be kept on the viability of electric buses, including as used e-buses become available in the global marketplace.

This story from UN Women highlights important work in PNG to increase the safety of public transport for women (UN Women, 2016).

Explanation 5: Ride-sharing

Ride-sharing apps (such as Uber, Lyft, and Grab) provide convenient and more affordable transportation than private vehicles. Traditional taxis and ride-sharing services using cars can augment public transport by providing a 'last-mile' service, or by filling the gaps in frequency that affect areas with relatively lower population density. If well-designed, ride-sharing can provide greater access to mobility for young people, people with disabilities, seniors, and those for whom cars are unaffordable or undesirable.

Establishing ride-sharing services can maintain existing taxi driver jobs and create new jobs. Ride-sharing can only work effectively when a large proportion of potential users have access to smart phones and the internet, so it is not as equitable as public transport. However, it is likely that many island countries, particularly their urban areas, will have widespread ownership of smart phones and more affordable data over the coming decade.

It is unlikely that large players like Uber or Lyft would operate in small island countries. However, there are a number of packages available that provide similar services but are designed to provide a relatively low-cost option for use by small enterprises such as a 5- to 100-taxis fleet (for example Onde).

1.6 Reducing car dependency

People all over the world have become very adapted to using private cars. In most places car ownership is a powerful symbol of status and success, and something that many people aspire to. Car ownership brings a great deal of comfort and convenience, making life easier. Often when countries and development partners are working on new transport projects together, the first idea that comes to mind is improving private car transport.

In recent decades, however, small island countries have seen a proliferation of vehicles and the emergence of serious congestion problems on urban roads. An excess of vehicles affects quality of life in myriad ways. Journeys that used to take 10 minutes by car now take half an hour or more. This, in turn, leads to increased fuel use and GHG emissions, air pollution, and reduced economic activity. If not managed well, high vehicle numbers result in increased abandoned vehicles. And of course, owning a private car is expensive.

A strategic response to this problem needs to be multi-faceted: good quality, alternative transport options need to be available, including e-micromobility with supporting infrastructure, and better public transport services (see Explanation 6). Regulation can be used to restrict private vehicle parking and access to some streets, making them safer and more accessible to pedestrians, cyclists, and users of micromobility. Economic instruments, such as levies for whole-of-life management (ie, disposal/export/recycling), help to remove hidden subsidies for private cars and help to ensure would-be car owners face more of the true costs of owning a car.

Measures

These measures are drawn from other strategies and, when used together, can reduce dependence on cars:

- Integrate land use and transport planning – eg, 20-minute neighbourhoods – so that cars are needed less, and there are viable alternatives.
- Establish and promote public transport.
- Reallocate road space away from cars and toward pedestrians, cyclists, e-micromobility, and public transport.
- Introduce economic instruments so that car owners face more of the full cost of car ownership. For example, an import levy to fund end-of-life management.

Benefits

- Reduced GHG emissions, congestion, and costs.
- People-friendly streets, improved health and well-being, and increased community connectedness.

Considerations

A suite of the responses being applied in cities around the world, including congestion pricing on toll roads, parking fees, and the outright prohibition of vehicles in certain areas, are better suited for very large cities and probably not applicable in small island countries.

Increasing fuel taxes is also unpalatable as fuel prices are already very high, and alternatives are currently lacking.

Care is required to avoid ensure that appropriate use of light vehicles for important economic and community activities can continue.

Pathway

Land use and transport planning should be undertaken in H1 to reallocate road space away from private vehicles and towards pedestrians and micromobility. The use of active transport and micromobility should be encouraged, and public transport systems should be developed. Modest fees to support end-of-life disposal of cars could be introduced in H1.

In H2, once viable alternatives to cars are available, restrictions on the use of private cars may be introduced, including higher import fees, particularly on petroleum-fuelled vehicles.

Explanation 6: Improving the performance of internal combustion vehicles – not always an easy solution

Transport strategies often talk about improving the efficiency of internal combustion engines by reducing engine size or introducing newer engine or drivetrain technologies. This may be of limited use in some small island situations.

As a rule of thumb, the smallest, lightest vehicle with the most fuel-efficient technology that suits the application should be purchased. However, often such vehicles may not be fit-for-purpose in island conditions, where roads are often in poor repair, and where vehicles may occasionally carry heavy loads.

Further, newer fuel-efficient engines are often very sensitive to fuel quality issues (such as contamination from water and particulates because of poor handling and storage) and require specialist maintenance support, both of which can be issues in SIDS.

1.7 Electrifying transport

Over time, with increasing investment in renewable energy in SIDS, and the push to increase energy resilience and reduce carbon emissions, switching from petroleum-fuelled vehicles to electric vehicles (light and heavy) will make good sense.

In the meantime, care should be taken to properly assess future electric transport options for small island countries, with due consideration given to electricity supply, whole-of-life costs, and carbon emissions, and to the additional support measures required, including servicing and end-of-life battery management.

Emissions benefits from electrification depend on the proportion of renewable electricity used for charging: EVs produce around 35 per cent fewer in-service emissions than an equivalent gasoline-fuelled vehicle when charged with diesel-generated electricity. However, they also have significantly higher embodied carbon than conventional vehicles. In some cases, the use of EVs could result in overall higher emissions over the life of the vehicle than an equivalent standard petrol-fuelled vehicle, or a non-plug-in hybrid. (This is explained in Explanation 7: Embodied carbon in electric vehicles – why does it matter?)

Suitability of transport electrification will increase over time: In the medium-term (H2), reductions in the cost of batteries, and expanding global markets will make EVs as affordable as conventional vehicles to buy, especially with the growth of a second-hand market. Island electricity systems will also have increased the proportion of electricity from renewable sources. At this time the switch from petroleum-fuelled light vehicles to electric vehicles will make sense economically, as well as for emissions reduction. Some work should be done in H1 to build familiarity with the EV technology and prepare island countries for mainstream adoption in H2 and H3.

Looking further ahead, electric buses and other heavy electric vehicles have the potential to yield benefits. This will require further performance advances and cost reductions in battery technology (or in other electricity storage forms) from where things stand today.

Electrification of transport and the electricity grid: Transport electrification needs to be considered in the design and operation of electricity systems. While it can substantially increase the demand for power, potential exists to help balance load by managing when charging occurs. This can be of particular benefit for island grids with high levels of variable renewables (solar and wind). Because electricity infrastructure and supply are of variable quality across many SIDS, particular attention needs to be given to what is needed to support safe and reliable vehicle charging.

In the short to medium term (H1–H2), the primary way for electric transport to support balancing the grid load is through ‘price-driven demand response’ or ‘time-of-use charging’, where electricity tariffs are adjusted to encourage charging at times that provide benefit to the electricity system. For example, tariffs could be reduced to encourage charging in off-peak times for a diesel- or hydro-based grid, or during times of peak sunshine or wind for a grid that is high in variable renewables. In the medium- to long-term (H2–H3) technology is likely to allow the electricity supplier to control charging remotely (sometimes called ‘managed charging’).

There is a potential further step, where the batteries of electric vehicles are used to help stabilise electricity supply networks through managed import and export of electricity – referred to as ‘vehicle-to-grid’ (V2G). This step, should it eventuate, might be an option for islands in H3, but there are other options that might prove to be easier, more cost-effective, and more reliable, such as stationary batteries.

Measures

- Integrate planning of electricity grid development, charging infrastructure, and adoption of electric vehicles.
- Support some early adoption of EVs through uptake in government fleets, to build familiarity with the technology.
- Establish servicing capability.
- Ensure adequate supply of charging infrastructure.
- Implement time-of-use tariffs.
- Put in place technical and quality standards for imported vehicles and for charging equipment and systems, and guidelines for their use.

Benefits

Benefits are enhanced as the proportion of renewable electricity generation increases:

- Improved energy security and reduced imported fuel use.
- Reduction in GHG emissions.
- Reduced air pollution and environmental pollution from fuel storage and handling.
- Improved performance of the electricity supply system (if charging is well managed).

Considerations

Electrification of transport in islands is not the first strategy to apply but will become more important in the medium term (H2). It is necessary to carefully assess the costs and benefits, and to think about adoption pathways over time considering the existing vehicle fleet, the cost of EVs, and the availability of second-hand vehicles.

Pathway

In the short term (H1), attention should be given to demonstration projects to build familiarity with EVs and chargers, and to develop supporting systems for vehicle servicing and managing the reuse or recycling of post-vehicle batteries. In the medium term (H2), as EVs become mainstream globally and their purchase price reduces, and as island electricity systems have higher levels of renewables, islands can expect to see widespread adoption of EVs as a natural part of fleet turnover. Electric heavy vehicles may also start to become available to islands. In the long term (H3), EVs are likely to be the dominant form of light vehicle, and a greater uptake of heavy electric vehicles is also expected.

A detailed analysis from PCREEE of the implications of electrification of transport in Pacific Islands can be found here (Campbell, 2020)

Small format Renault 'Twizy' 45 electric vehicle in Tahiti Photo: Andrew Campbell

Explanation 7: Embodied carbon in electric vehicles – why does it matter?

While there is often a focus on the carbon emissions emitted during the in-service operation of a vehicle, the lifecycle carbon emissions include those associated with the build of the vehicle (also called the embodied emissions), transport of the vehicle to its place of use, servicing, and end-of-life disposal, less any credits that can be gained from end-of-vehicle-life repurposing or other recycling of parts or materials. For electric vehicles, the electric motors, batteries, and additional power electronics contain much more copper and other metals than are typically found in equivalent petroleum-fuelled vehicles. The additional material increases the amount of embodied carbon of an EV compared with petroleum-fuelled vehicle.

The in-service emissions of a passenger car EV charged from an all-diesel grid are around 35 per cent lower than an equivalent, standard gasoline-fuelled vehicle. For a new EV charged on a 100 per cent diesel-generated electricity system, the 'payback' on embodied carbon is between 5–15 years, depending on the number of kilometres travelled. This situation improves using increasing amounts of renewable electricity to charge the EV until in-service emissions are zero at 100 per cent renewables. Here, the payback on embodied carbon can be in the order of 1–5 years. It is likely that many EVs imported to islands would be second-hand, mid-way through their useful life, which would reduce the carbon payback period (as some payback has already been achieved in the first country of use).

Calculations also show that a non-plugin hybrid passenger car (HEV) fuelled by gasoline could return similar in-service carbon savings to a pure battery electric car (BEV) charged using all diesel electricity generation. The HEV would then provide a lower purchase price option for the same overall carbon emission reduction. However, a limitation of the HEV option is that benefit cannot be gained from later additions of renewable electricity generation to the electricity mix.

Calculating the build and in-service carbon emissions of a vehicle is complex and imprecise due to the many assumptions and generalisations required. It is none-the-less important to consider the full life cycle analysis to check that promising solutions do in fact make sense when the wider project and its various inputs are considered (Campbell, 2020)

1.8 Managing the life cycle of vehicles and equipment

Small island countries have limited space for landfill, and no in-country vehicle, scrap metal, or battery recycling operations. Pacific countries are increasingly importing cheap, second-hand vehicles from Japan, Korea, and China. While some countries have import controls (such as Fiji, where vehicles must be less than five years old), most others have no restrictions. In many cases, these cars arrive near the end of their useful life and within a year or two are no longer in service. In the absence of local processing of end-of-life vehicles and the high cost of transportation to remove them, it is often regarded as easier simply to abandon them (Lin, Nakajima, Yamasue, & Ishihara, 2018).

For this reason, while a few small island countries have schemes for exporting waste vehicles, abandoned vehicles are an increasingly common sight. These are not only an eyesore, starkly incongruous with the natural beauty of the islands, they also provide a habitat for disease vectors (such as rats and mosquitoes).

With the rise of vehicle electrification, particular attention is required to managing the life cycle of modern batteries, which have a limited life and may need to be replaced during the life of a vehicle. This presents several challenges, at least in the short-term (H1) time horizon. The kinds of batteries used for e-mobility contain, or can produce, hazardous chemicals and can cause fires and explosions if mishandled. This means that they need to be stored and transported with great care, and at some expense. At present, there is not a global ecosystem or even an established set of processes for recycling these batteries, and the cost of re-processing is currently greater than the value of the recovered materials (Chen & Tan, 2020). While it is expected that this industry will develop and costs will come down, the expense of disposal should be taken into account, as long-term storage on islands is not a good option.

One option to be explored is the repurposing of vehicle batteries for use as stationary electricity storage (either at household or grid level). Battery performance requirements for stationary energy storage are far less demanding than for vehicles and so batteries too tired to continue service in vehicles can still be very valuable for stationary storage.

Such an approach can significantly extend the useful life of vehicle-specification batteries, and therefore the waste and embodied energy (and GHG) associated with each kWh of electricity delivered by the battery.

The issues of waste management have often not been addressed in transport projects by development partners. With increasing interest from countries and donors in electric vehicle pilots, 'closing the loop' and addressing the whole life cycle of the equipment and batteries needs to be an integral part of project design (see Explanation 7: E-mobility waste). Any EV project should provide a circular economy/closed loop value chain approach to electric vehicles, and in the case of island countries, may require programs of a regional nature to oversee repurposing and put in place mechanisms for the collection, processing, export, and recycling of waste.

Measures

A program for managing the life cycle of vehicles and batteries would likely include measures such as:

- Regional-scale programs for repurposing batteries and for processing, exporting, and recycling vehicles, micromobility devices and batteries (for example, see the Taka Moana project (SPREP, 2018)).
- Battery ownership registration scheme.
- Import levies or other mechanisms to cover the cost of export and recycling or disposal of waste.
- Refundable deposits to ensure the expired batteries and vehicles are returned to a collection point rather than being dumped in the environment (noting these will both increase the upfront costs).
- An amnesty program and publicly-funded disposal of existing vehicles.
- Information campaigns on the process of disposing of vehicles/mobility devices.
- Guidelines for the safe handling, installation and use of repurposed batteries.

Better life cycle management will also be facilitated by:

- Ensuring the durability and quality of imported equipment by putting in place minimum quality standards and consumer information.
- Stipulating the maximum age of used equipment at time of import.
- Standardisation of models so that spare parts and technical support are more readily available.

Benefits

- Managing end-of-life vehicles and their components and wastes will mitigate the harm done by their abandonment, remove an eyesore, reduce pollution, and reduce the habitat for disease vectors and pests.
- Managing post-vehicle batteries is expected to result in far greater useful life for the batteries and reduce numerous hazards such as the risk of fire and soil contamination.

Considerations

Managing the life cycle of e-mobility equipment, vehicles and batteries will very likely require regional-level programs to achieve the necessary economies of scale. Few small island countries will be able to fund this entirely, even with the application of levies and deposits. Care needs to be taken not to disadvantage electric mobility against combustion engines through higher levies – consideration should be given to an overall levy and tax scheme for vehicles that encourages the phase-out of internal combustion engine vehicles, while ensuring that the waste management of all vehicles is funded. In the future, it is possible that the value of reclaimed materials will increase and cover a larger amount of the cost of recovery and recycling. Creating a viable end-of-life management program will require vision and sustained investment and support from regional bodies and development partners over decades. There is potential for enthusiasts to have a place in managing post-vehicle batteries (ie, by installing them in domestic solar electricity systems) but this needs to be carefully managed to ensure they have the necessary skills and the work is carried out safely.

Pathway

In H1, ensure any small-scale electric vehicle programs include whole-of-life management in their design and use this to test and develop the economics and logistics of whole-of-life management[1].

Establish a regional program to deal with the legacy waste issues and lay the foundation for significant uptake of EVs in H2. In H2, apply levies and deposits, insist that whole-of-life management is built into projects funded by development partners, and contribute to the ongoing viability of repurposing batteries, and of collection, export, and recycling of waste.

[1] This should be compared to the true cost of 'good management' of conventional vehicles, including the cost of disposal at end-of-life.

Explanation 8: E-mobility waste

In general, the proportion of waste recycled in Pacific Island countries is low. The combination of small quantities of recoverable materials, and the large distances to recycling establishments, makes it costly to recover most materials. The uptake of modern electric vehicles will lead to a greater quantity of end-of-life motors, power electronics (e-waste), and lithium-ion batteries. There is potential that the price of copper and the relatively large amount of recoverable copper in electric motors will be a driver for a sustainable recycling program for this component in SIDS. However, there is not the same potential for local development of end-of-life recycling or disposal of lithium-ion batteries across SIDS, at least in the short to medium term. Globally, recycling and disposal of lithium-ion batteries is still at an emerging stage – and currently separating and refining them into usable materials can be more costly than using virgin materials. Without local options for recycling or long-term disposal and, given the high costs of freight that lithium-ion batteries attract due to their fire hazard, there is a real risk that end-of-life lithium-ion batteries will become a waste issue in SIDS. This risk requires early intervention at the time any policies or programs to encourage the uptake of electric vehicles are designed.

In general, global EV manufacturers have declared that they would provide stewardship over the disposal of end-of-life lithium-ion batteries from their own vehicles. While this may be the case for vehicles that they have supplied new to a market, this stewardship may not be provided for imported used vehicles or may come at additional cost to cover the added logistics that might be involved. Manufacturers of other vehicle types, such as e-bikes and other small e-mobility vehicles, may not take on similar stewardship obligations for the lithium-ion batteries found in the vehicles they manufacture, as many sell ex-factory gate and do not assume responsibility beyond warranty obligations.

In their favour, lithium-ion batteries are expected to be in service for many times longer than lead-acid batteries. With good systems in place, the service period and useful life of lithium batteries could also be extended through repurposing and/or rebuilding (with these processes greatly aided through careful selection and design of the batteries in the first place). Doubling the useful life of a lithium-ion battery, which should be possible through careful management, has a similar effect to halving the end-of-life waste to be managed.

2 Sea transport and aviation systems

Overview

Maritime and aviation services are grouped together in this section as they provide complementary services between main island and outer island communities, and to tourist destinations.

Maritime and aviation inter-island transport are qualitatively different from land transport in SIDS, and the strategic options are not as readily apparent as those for land. Individual aircraft and seacraft are significant, long-lived investments often made by the government or a corporation. This means that each decision needs to be taken carefully to ensure the craft is suitable for its specific application. In contrast, land transport technologies are, for the most part, mass produced off-the-shelf vehicles with lower capital costs and shorter useful lifetimes

Whereas many global land transport strategies and technologies can be applied to islands, maritime and aviation transport systems in SIDS require a bespoke approach relevant to the specific context in which they sit.

Many island states have a rich heritage of maritime transport, including highly developed technologies and expertise in sailing and navigation. In some cases, the continuity of this expertise has been interrupted but it is now clear that indigenous technologies have a very important role should be held front and centre in the conversation about a long-term, sustainable maritime transport system.

Many SIDS, particularly those in the Pacific, are characterised by small and widely dispersed populations, spread across many islands. The provision of both inter-island aviation and shipping often involves long routes, and thin traffic and freight levels. To date, except for a few higher traffic routes, these are usually not viable without the support of subsidies.

Often ships are gifts from other governments or purchased second-hand as cheaply as possible, and therefore not necessarily with the best specification and design for the intended application. In recent years, many national airlines have traded up their ageing fleets, at significant expense, with the aim of boosting the tourism industry. The characteristics of these modern maritime and aviation systems bring many challenges in the form of cost, reliability, maintenance, and safety.

Options to reduce the use of imported fuel and decarbonise maritime and aviation transport are less straightforward than for land and urban transport. Off-the-shelf technologies for low-emissions maritime and aviation transport are only just emerging and examples of these early technologies tend to be very expensive and often come with some compromise when considering the types of duties demanded in SIDS. Yet there are real opportunities for low emissions transport options, as demonstrated by the SV Kwai, a sailing vessel which has been taking advantage of the trade winds across the Pacific to provide wind-powered passenger and cargo service since 2006.

This section includes discussion of the following:

+ **2.1 Integrated planning for inter-island transport systems.**
+ **2.2 Greening ports and ground operations (maritime and aviation).**
+ **2.3 Personal small boats for coastal travel.**
+ **2.4 New-build and retrofits using low-emission vessel technology, including sailing ships.**
+ **2.5 Improving operations to reduce fuel use and GHG emissions.**
+ **2.6 A regional approach to aviation service.**
+ **2.7 Low-emission aviation technology.**

2.1 Integrated planning for inter-island transport systems

As for land transport systems, thinking about inter-island maritime and aviation transport systems should begin with an integrated approach to spatial and transport planning. At the macro scale, this includes looking at the location of communities, services, and economic opportunities, and considering the long-term risks of climate change and natural disasters.

A vision and policy direction for remote and outer islands communities should underpin this thinking, including the need for regular transport services for passengers and goods to support the viability of outer island life and potentially to reduce or even reverse processes of urbanisation and out-migration.

The next step is to look at the routes and services needed:

- From where to where?
- How often are services needed?
- What are the requirements for accommodation for passengers and cargo type and capacity?
- What portion of services should be provided by boat and by air?
- What types of ships, aircraft, and infrastructure would best meet these needs?
- How do we factor in the life cycle of vessels and aircraft and plan for fleet renewal over time?

In the marine environment, the next step for integrated marine fleet planning and vessel specification is to consider:

- How do the vessels need to be used? For example, atolls or communities with beaches might be better serviced by catamarans or craft with ramps that allow beach loading and unloading, whereas islands with small docks and jetties and/or serviced by suitable loading equipment may be better serviced by a boat with a deeper draft.
- What are the predominant weather conditions? Can use be made of the trade winds?
- What other technologies could be used?
- What is the current composition of the fleet? What are the ages and conditions?
- What is the gap between the current fleet and what is needed?
- Are there current boats that could be retrofitted and refurbished, or should they be retired, and new boats built?
- What infrastructure is needed?

A similar process could be carried out for aircraft fleet planning.

Measures

Integrated spatial and transport planning should include the following:

- Assessing needs and demand for inter-island transport.
- Fleet planning, including design specifications and time frames for renewal.
- Considering opportunities to shift between aviation and maritime transport to reduce GHG emissions and cost.
- Assessing risk to inform where to site assets for climate change and disaster resilience, patterns of settlement, and land use change.
- Systems planning for transport infrastructure – identifying critical infrastructure, shifting long-lived assets away from disaster-prone areas, and designing transport for both connectivity and natural disaster response.
- Planning transport infrastructure together with water, wastewater, power, and telecommunications, to find ways to integrate layout and construction to build multi-purpose assets, reduce costs, and improve quality and resilience. For example, the use of airport runways as catchments, and port areas as locations for renewable energy facilities.
- Identifying sustainable business models that can support the needed provision of services. Typically, this has been very challenging, particularly in the Pacific.

Benefits

- Fit-for-purpose fleet composition.
- Better planning and delivery of services for communities in remote areas and on outer islands.
- Better cost management.
- Settlements and infrastructure avoid areas at high risk from climate change and natural disasters.

Considerations

Integrated systems planning for transport to remote areas and outer islands needs to be based on:

- a future vision for life in those areas
- policy direction on outer island economic development, urbanisation, and out-migration.

Following a process of drawing up scenarios and creating visions, such as set out in *Part II: Phase 3* of this guidance, can help create a safe space in which these conversations can take place.

Pathway

Island countries are encouraged to begin integrated inter-island transport planning now (H1) to ensure that infrastructure and ship or aircraft investments in the next decade:

- actively contribute to the desired vision for the future – which could contain, for example, aspirations for the viability and quality of life in remote areas and on outer islands
- increase resilience and adaptability, reduce exposure to climate change and natural disaster, and enable managed change over time.

> There appear to be very few examples of inter-island systems planning – this example from the Torres Strait Islands in 2005 (Maunsell, 2006).

2.2 Greening ports and ground operations (maritime and aviation)

Improving the infrastructure and operation of islands' ports to be more resilient and energy-efficient, and to reduce GHG emissions and other environmental impacts, is highly desirable for the short, medium, and long term.

The degree of change may be limited by affordability, technical capacity, and practicality as some green port measures will likely never be practical in smaller ports. For example, cold ironing (providing shoreside electrical power to ships in port, allowing the ship engines to be switched off) is feasible only in major ports supplied by robust electricity networks.

Shipping ports and airports should be considered as nodes in the integrated transport system described in section 2.1 and decisions on investment and improvement should be made in the context of priorities across the whole system.

Measures

- Energy-efficiency standards (codes and specifications for vehicles, equipment, and lighting, and their use, etc).
- Resilience preparedness (operational- and infrastructure-related).
- Reducing GHG and air quality emissions (eg, shore power of refrigerated containers).
- Pollution control preparedness.
- Managing light and noise pollution.
- Managing solid waste.
- Managing biosecurity.

Benefits

- Improved energy security and reduced GHG emissions.
- Reduced pollution (air, water, and noise).
- Improved overall ports management.

Considerations

Many measures have an upfront capital cost but may have a relatively short payback period (eg, energy efficiency measures). Other upgrades will require significant capital. Others still depend on management capability.

Pathway

Improved ports management can begin in H1 and be implemented incrementally. Some development partners are already focusing on upgrading ports and addressing vulnerability to climate change impacts and natural disaster.

Sea transport

2.3 Personal small boats for coastal travel

Many small island countries have locally developed technologies for small boats – often the result of generations of innovation and improvement. These are still being used in some places, but in others they have been displaced by modern motorboats. Their suitability for local construction and maintenance, and their minimal fuel use, means the 'old ways' should be more encouraged.

> "We read in a magazine that some people in Europe had designed this shock absorber for their catamarans. We wrote back and said: That's great, but there's this small island, smaller than a dot of a pencil point, that designed something like this about 2000 years ago." - *Alson Kelen, Waan Aelõñ in Majel (WAM) Director*

Traditional technologies for construction are often time-consuming and expensive, requiring specially cultivated trees and months of labour. However, modern boat building techniques and cheaper imported materials, such as marine ply and fibreglass, make it possible to locally manufacture and maintain light, functional small boats.

Battery electric motors can augment wind power on small sailing craft, making the craft more reliable and versatile. In places where traditional sailing and paddling boats have been displaced by motorboats, simple engine replacements with electric motors and batteries may be possible, charging the batteries with island-generated solar or wind power. This would reduce the need for petroleum, which can often be in short supply on outer islands. In the short term electric motors are still relatively expensive.

Measures

- Encourage revival of traditional sailing.
- Adopt hybrid, modern and traditional techniques for boat design and manufacture.
- Switch from petroleum- to battery-electric-powered systems.

Benefits

- Sailing is a form of physically active transport that encourages health.
- Local boat building can provide economic activity, jobs, and skills.
- Traditional technologies can be more suitable in many applications.
- Traditional sailing can strengthen culture.
- Electric propulsion systems will reduce dependence on fossil fuel and reduce GHG emissions when charged from renewable energy.

Considerations

Sailing boats may be considered less comfortable and less convenient, and therefore less desirable.

Developing the skills to build and operate sailboats, if that practice has been interrupted, requires dedicated leadership and a long-term program commitment. Such an approach is currently being taken in the Marshall Islands at *Waan Aelõñ in Majel* – a world-renowned school in Majuro, that trains youth to build both traditional sailing canoes, and modern boats, as well as learn traditional chants, legends, and proverbs.

Pathway

These approaches can all be pursued in H1, with battery-electric marine propulsion systems expected to become mainstream in H2.

A story about the Marshall Islands' *Waan Aelõñ in Majel* collaboration with GIZ to build a range of prototype sailing boats blending traditional and modern techniques. (Burns, 2021)

Clockwise from top left: Traditional canoes line up for race day in the Marshall Islands; building a hybrid design prototype in the Waan Aelõñ in Majel workshop; ‘WAMCat’ under way using only solar power and electric motor. *Photos © 2021 Waan Aelõñ in Majel*

2.4 New-build and retrofits using low-emission vessel technology, including sailing ships

Vessels are often custom-designed and built for a particular context and application that considers the numbers of passengers, quantity of freight, frequency of service, sea conditions, geography, and loading/unloading facilities. That custom design can also be used to incorporate measures that reduce vessels' fuel use and GHG emissions.

Unlike the mass-produced options available for low emission land transport (such as EVs), off-the-shelf options are not as readily available for maritime transport. A more creative approach is needed, combining a variety of available technologies in different ways, including wind propulsion, hull design, and battery-electric propulsion systems. Making use of these various technologies can achieve a highly suitable custom design with significant reductions in fuel use and GHG emissions.

As can be seen in Part IIIB of this guidance, aside from electricity, alternative low emission fuels are not on the short- to medium-term horizon for domestic maritime applications – some hydrogen-based systems are being considered in markets where the technology is being developed, but this technology is likely to be generations off application to vessels in SIDS.

The key technologies and design factors that can be combined to create low emissions vessels include:

- hull design that can both increase efficiency and provide boats that are fit-for-purpose – for example multi-hull vessels that provide for beach landings
- pure sailing boats, augmented with diesel, battery-electric or hybrid-electric propulsion systems, and perhaps combined with photovoltaic cells
- wind assisted propulsion (WASP) technologies – these are mostly being tested on large ocean liners, but some Flettner rotors, kites, or soft sails can be retrofitted or designed as part of a new build vessel.

How effective sailing vessels or WASP technologies will be depends on the prevailing winds, routes, and seasonal variations, and so design of individual vessels must be considered in the context of integrated service and fleet planning.

Because larger vessels for inter-island travel have a useful life of several decades or more, the design and selection of vessels today is important to avoid lock-in, and to enable retrofits of new technologies when they become available. Design of new builds or retrofits should be done in the context of fleet planning for the long term (as discussed in section 2.1 above).

Measures

- Design all new build vessels and retrofits in the context of integrated system planning and local sailing conditions.
- Keep a watching brief on developments of low emission small vessel technologies around the world.
- Pilot projects of novel designs for specific applications – locally appropriate and preferably drawing on island technologies in some way.
- Initiate training and skills development to ensure vessels can be operated by local crew, providing jobs.

Benefits

- Reduced fuel use and GHG emissions.
- Quieter and more comfortable journeys on boats with sails (although there may be less space for passengers).
- Traditions are nurtured and local culture is strengthened.

Considerations

Some aspects of design can add significant upfront cost – with variable payback periods. For wind-propelled vessels, the reliability of the service depends on the consistency of sailing conditions. Sailing ships require significant labour for operation and maintenance, which can provide employment opportunities, but also depends on training and the development of skills.

Pathway

Defining clear pathways to introduce vessel technologies that reduce fuel use and GHG emissions is important, but the diverse duties of vessels and specific designs this entails makes it difficult to generalise. Because the life of larger vessels spans 30–40 years, today's designs, investments, and builds need to consider how a vessel might be retrofitted in future to incorporate new technologies as they become more accessible and appropriate. This is an H1 activity – investment and design decisions for vessels today always need to consider the long-term aims. This might even mean in some cases it is better to refurbish an old existing vessel in the short term to prolong its life, and delay purchase of a newly built vessel for several years until more advanced technology options become available. This will avoid committing to decades with old technologies, while that vessel serves out its useful life.

This document from GIZ presents a full range of technical and operational options for reducing the emissions of vessels in the short to medium term. It was developed for the Marshall Islands and is likely to be applicable to other small island countries. (Vahs, et al., 2019)

The sailing vessel SV Kwai has been purchased by the Marshall Islands, forming part of the domestic shipping fleet. Here is a video of her previous life sailing trade routes across the Pacific Islands. (Petersen, 2019)

This video shows the range of vessel options being utilised in the Marshall Islands in pursuit of low-emissions, safe and affordable sea transport options

Scandlines ferries combine traditional diesel power with electric batteries. Photo: Adobe Stock

2.5 Improving operations to reduce fuel use and GHG emissions

Significant opportunities exist to improve the efficiency of existing vessels, resulting in significant fuel savings. These are very suitable for SIDS over all time frames.

Opportunities include improved voyage planning, weather, current, and tide routing,

The combination of modern electronics, software, and the ability to relatively cheaply transmit data even in remote SIDS locations now provides relatively easy and affordable access to complex routing algorithms that can take weather, current/tide, and wave patterns all into consideration for routing planning and on-voyage tracking and correction. This can also result in safer and more comfortable voyages.

There are also opportunities for improving vessel performance through the use of optimised engine operation, hull cleaning, specialised coatings, and optimising ballast and trim. Similar to the use of route planning systems, these options are available to existing and new-build vessels. Adoption of many of these technologies provides for lower fuel use, lower GHG emissions, and lower cost, and attention should be given to them in the short, medium, and long terms.

Measures

- Adopt technologies and operational practices to reduce fuel use and GHG emissions including:
    - weather, current and wave routing.
    - hull coatings/ cleaning, and best practice operation and maintenance of engines.
    - optimised ballast and trim.
- Investment decisions made on a whole-of-life basis, accounting for fuel savings.

Benefits

- Reduced fuel use and GHG emissions.
- Improved maintenance, which can lower costs and improve reliability.
- Increased safety.

Considerations

Significant training and improved incentives may be required to encourage better operational practices. Many islands don’t have dry dock facilities, which makes the maintenance of vessels difficult.

Pathway

Adoption of improved operational practices and assistive technologies, along with training programs, can begin in the short term (H1).

Aviation

2.6 A regional approach to aviation service

Aviation in SIDS (and particularly in the Pacific) has increasingly followed the model of countries establishing national carriers to provide domestic services, and some regional and international services. These carriers are mostly wholly or partly government owned, and heavily subsidised by governments who can often ill afford it.

The establishment of these small, individual national carriers is thought to have come about because of the perceived status of having a national or local airline, and the lack of regionally collaborative frameworks for the aviation sector. There are also cases of new aircraft being purchased without a sound economic case, placing further stress on national budgets.

With a few exceptions, these airlines suffer from various stresses related to finance, personnel, and the risk of disruption – an especially high risk during this time of COVID-19.

Studies over several decades suggest that for the Pacific aviation sector, a key option to improve viability is to consolidate national airlines into regional or sub-regional operations (Pryke, 2020). This increased scale would enable both economic and service improvements from sharing centralised services – management, maintenance, safety, training, ticketing, etc. It would also provide better utilisation of and flexibility within the fleet, share risk, and allow cross-subsidisation between profitable routes and routes that are critical to connectivity for remote communities, ensuring the latter are regular and affordable. Along with some of the strategies mentioned for land transport systems (such as region-wide waste management), a regional approach would overcome many of these issues and be a more rational approach to the problem of scale faced by many individual small island countries (Pryke, 2020) (Asian Development Bank, 2007).

Measures

- Amalgamate national domestic carriers into regional or sub-regional airlines.

Benefits

- Better utilisation of and increased flexibility within fleet.
- Better and more consistent services at affordable prices.
- Improved management capacity.
- Shared central services.
- Profits can be used to cross-subsidise routes to maintain critical services in remote communities.
- Improved risk management.

Considerations

Because national pride in having a flagged carrier and sovereignty over the services has been one of the reasons for the development of many small individual airlines, the political relationships within a region may be a barrier to collaboration and amalgamation.

Pathway

In the short term (H1), countries can engage with their regional counterparts, or mainland states, to begin to explore the potential for amalgamation.

2.7 Low-emission aviation technology

Reducing transport emissions is a key objective for SIDS due to their ambitious climate change targets. Domestic aviation emissions are likely to provide very few opportunities to do so, for two main reasons.

First, a very small proportion of current emissions are due to domestic aviation. For example, one recent study of fuel use in the Marshall Islands estimates domestic aviation emissions at around 3 per cent of total GHG emissions (Curd & Baker, 2019). Second, most island aviation transport is in the form of smaller turboprop aircraft, which are already significantly more fuel efficient than jet engines.

At present, there are no obvious practicable and affordable technological solutions that would bring a GHG benefit to islands against the already well suited, robust, and efficient turboprops. The international aviation industry is working hard to develop low-emission technologies, and these are expected to emerge and become more affordable and available in the global market in the medium to long term (H3).

These low-carbon technologies include:

- **hybrid-electric aircraft** – aircraft powered by a hybrid-electric propulsion system (HEPS) which combine petroleum-fuelled and battery-electric drive systems. These are in the experimental stage, but in the long term may be very suitable for SIDS as they are designed for the same applications as the robust turboprop planes that make up most island domestic fleets.
- **battery-electric aircraft** – globally, small 2-seater battery-electric aircraft are already in commercial use, including for flight training. Larger battery-electric aircraft are also emerging in the market, and these may find niche tourist applications in SIDS in the medium term, with more widespread use in the longer term as larger models of battery-electric aircraft with greater range become available.
- **sustainable aviation fuels** (SAFs) are an early stage, primary technology for global aviation emissions reduction. In the short term, they are not suitable for SIDS due to high cost, low availability outside of major airlines, and difficult logistics when used in a remote SIDS situation. Towards the long term, the cost may reduce, and they may become a feasible option for SIDS, but this is uncertain.

One final option for domestic aviation which is more likely to improve services rather than displace air travel, is the use of **drones** for delivering small cargoes, such as medicines, to remote places.

More detail about these technology options (with references) can be found in Part IIIB *Domestic aviation transport technologies.*

Measures

- Continue with existing, efficient, and robust turboprop aircraft technology.
- Keep a watching brief of global developments in aviation technology.
- Replace fleets with new technology in the medium to long term.
- Consider opportunities to shift some services to the use of drones.

Benefits

Benefits will depend on the technologies being available at an affordable cost in the medium to long term.

Considerations

There is a great deal of uncertainty and expense around new aviation technologies. Because of this, and the small contribution of domestic aviation transport to local GHG emissions, decarbonising aviation should be one of the lower priorities in a transport strategy for SIDS.

Pathway options

Keep a watching brief (H1), with possible adoption of new technologies in the medium to long term (H2–H3). A role for drones may be possible sooner (H1).

3 Cross-cutting strategies

3.1 Connecting digitally

Pacific Islands have largely been physically cut off from the outside world to keep their populations safe during the COVID-19 pandemic. The ensuing dramatic reduction in international, regional, and local travel has highlighted ways to reduce transport demand and offers an opportunity for islands to rethink how they are connected to the world, especially given their need for a zero-carbon future, and the high emissions costs of international air travel.

Videoconferencing and like communication arrangements offer ways to meet and share information and ideas. Many big international meetings have been replaced by virtual conferences. Families and friends who would have caught up in person are now having video-chat get-togethers.

Around 40 per cent of SIDS populations live in remote and rural areas (Mycoo & Donovan, 2017), and providing them with digital services is expensive and constrained by gaps in funding, personnel, and infrastructure. Consequently, small island countries are typically seeing depopulation of outer islands and rural areas as people move to the main urban centres or even further afield to other countries, seeking a better quality of life through access to basic services such as education, healthcare, banking, and improved economic opportunities and connection to family.

Is it possible that some of these services and opportunities could be provided remotely through the internet? At the end of 2018, mobile internet penetration was just 18 per cent of the population in Pacific Islands but this is forecast to expand to 33 per cent by 2025, with 4.9 million smartphone connections (GSMA Intelligence, 2019). Only a decade ago, broadband internet in the Pacific was rare; however, in recent years, several major undersea cable projects have been completed – the Manatua, Coral Sea, Tonga, and HANTRU-1 cables – with more on the way. Satellite projects are being deployed, including the Kacific remote broadband project launched in 2019, which extended the reach of cable broadband to several very remote places, and are expected to lower data costs (Schou-Zibell, 2020). Starlink has also recently begun commercial operation and allows a global-scale of satellite-based digital communications.

This major improvement in access to broadband opens up possibilities for small island countries to design and deliver services remotely, including banking, health, education, and work opportunities, with the potential to make life on outer islands more attractive and globally connected. One example is the rapid adoption of mobile banking in Papua New Guinea, mirroring a similar process in Africa, and demonstrating how services can be provided to remote areas with mobile technology.

Another application is to provide telemedicine services where a health professional consults, diagnoses, and prescribes on a video call. Recent advances in drone technology could enable the delivery of vital medicines or other health devices faster and more cheaply than medevac. This approach is already being used in remote places in Australia and Africa.

Around the world, education has also shifted to online learning, opening up the possibility for students in remote places to access courses from anywhere in the world.

A woman has a telehealth consultation with her doctor. Image: Adobe Stock.

Measures

- Shift mobile services to digital and advanced generation platforms, support the rollout of mobile towers to enable remote broadband access.
- Support rural electrification.
- Ensure locally appropriate content and services are available.

Benefits

- Providing services remotely through the internet can reduce travel.
- Telehealth services can greatly improve health outcomes by providing more informed, better managed, and more timely interventions.
- Remote education can provide higher quality and more specialised education, including using global platforms.
- Internet-based remote services have the potential to provide much needed opportunities and services to people living in remote areas, making life more attractive and reducing the rate of depopulation of outer islands and remote rural areas.

Considerations

There is a risk of excluding parts of the community who don't have access to online services, including those who could potentially benefit the most. Education and finance instruments could support parts of the population to take advantage of digital infrastructure and services.

Pathway

Roll out of broadband internet to remote areas is happening now. In H1, attention should be given to improving the availability of mobile internet devices and infrastructure in both urban and remote or rural areas, to improving the affordability of mobile data, and to the design of services to support remote and rural communities.

In H2, remote delivery of services is likely to be mainstream worldwide.

This paper describes the state of play of mobile digital connectivity in the Pacific (GSMA Intelligence, 2019)

This article from the ADB looks at how the Pacific can use digital tools to access banking services (Schou-Zibell & Phair, Covid-19 has created digital opportunities in the Pacific, 2020)

This article from the ADB looks at the rollout of internet across the Pacific (Schou-Zibell, 2020)

These articles describe how remote health services are already being revolutionised with drones and telehealth:

- around the world (Shaw, 2020)
- in Australia (Waters, 2021),
- in. Fiji (Rahiman, 2020), and
- in Vanuatu (Swoop Aero, 2018).

3.2 Managing the life cycle of transport infrastructure and assets – land, sea, and air

> Generally speaking, transport asset management encompasses strategic, financial, and technical elements related to the location of transport assets, engineering and design standards, maintenance and operation of physical assets, and contingency programming.
> World Bank (World Bank, 2017)

The prevailing approach to infrastructure in Pacific SIDS is often characterised as the 'build-neglect-rebuild' paradigm. This term encapsulates a range of constraints and failures across the life cycle of the asset, including the following:

- Infrastructure is geographically dispersed across tracts of ocean, which creates great difficulty in accessing sites, and makes construction and maintenance difficult and expensive.
- Access to construction materials, equipment, parts, etc, is difficult and equipment is usually not locally supported.
- Poor design – too often, foreign design expertise is unfamiliar with the particular limitations imposed by the local environment.
- Poor construction quality – due to a lack of deep skills in construction, poor construction standards, old equipment, poor regulations, and governance of standards.
- Limited financial resources (outside of donor-funded projects or large-scale private tourism development) and inadequate budgeting for repairs and maintenance, lead to low-cost solutions being chosen. This contrasts with developed economies, where choices are more often made on the basis of value over the life cycle of the asset.
- Poor maintenance and operation practices including the failure to set aside funds for maintenance and rehabilitation. Sectoral governance and management mean there is often a fragmentation of responsibilities and limited resources.

The issue of poor maintenance often extends to inter-island vessels, which has serious implications for the reliability and safety of services. Maintenance of aircraft, on the other hand, is generally managed well, with many aged twin-prop aircraft successfully and safely servicing domestic routes.

In addition to these challenges, climate change and natural hazards – king tides, storms, storm surge, cyclones, earthquakes, and erosion – pose serious risks to island transport infrastructure, including roads and bridges, docks and ports, airports, and airstrips. This is due to several factors:

- Often the asset is built at the edges of islands and at or near sea level, which means it is exposed to the hazards of waves, high winds, and storm surge.
- Often the structure is not robust due to inappropriate design, poor construction, and/or poor maintenance.
- Climate change is increasing natural hazards through sea-level rise and changes in the frequency and severity of storms (Baker & Week, 2012).

There are three key approaches to adapting infrastructure to climate change:

- **Planned retreat:** Development is moved away from the coast to minimise impacts on humans. Measures include land use planning and zoning, including coastal setbacks.
- **Accommodation:** The impacts of sea-level rise and storms are allowed to occur, and the consequences dealt with – for example, by raising roads on pylons or increasing drainage, and by anticipating rehabilitation costs for when damage does occur (through budgeting or insurance).
- **Protection:** Reducing the impacts of sea-level rise and storms by using hard or soft engineering – for example, building sea walls or restoring mangroves.

The critical message here is the need to take a whole-of-life view of the infrastructure beginning with assessing the need, the design, the type of construction, and the governance and financing for maintenance and rehabilitation. There have been improvements in recent years in the approach to this by many development partners.

Measures

Systems planning

Measures are as described in 2.1 *Integrated planning for inter-island transport systems*

Engineering and design

Measures to improve design and engineering include:

- Ensure design and construction standards are appropriate to the context. For example, consider using local materials, and local capacity for repair and maintenance as a key part of the design.
- Design for high performance and the ability to withstand impacts of natural disasters and provide resilience in the face of climate change.
- Ensure whole-of-life considerations are applied.
- For sea ports and airports, consider energy efficiency and renewable energy (see 2.2 *Greening ports and ground operations* (maritime and aviation))

Operations and maintenance

Measures to improve operations and maintenance across all transport infrastructure include:

- Performance-based contracts for rehabilitation and maintenance to enhance the sustainability of an asset over its life cycle.
- Ensuring donor-funded projects have mechanisms in place for asset management over time.
- Investment in strategic asset management capability, both within the country and through experienced international advisors.

Contingency planning

- Carrying out comprehensive risk assessments.
- Planning (including programming funds) for contingency.

Benefits

- Improved performance and reliability of infrastructure.
- More predictable national budget allocations.
- Effective maintenance reduces the cost of rehabilitation and rebuilding assets.
- Improved resilience to the impacts of natural hazards, climate change, and natural disasters.

Considerations

Beyond the initial investments in infrastructure, adequate financing for asset maintenance and rehabilitation is an ongoing constraint in SIDS. Any process to improve asset management must address resource constraints and improve budgeting at national and sub-national level to ensure there is adequate finance available for maintenance (estimated at 3.1 per cent of GDP in the Pacific) (Alejandrino-Yap, Dornan, & McGovern, 2013).

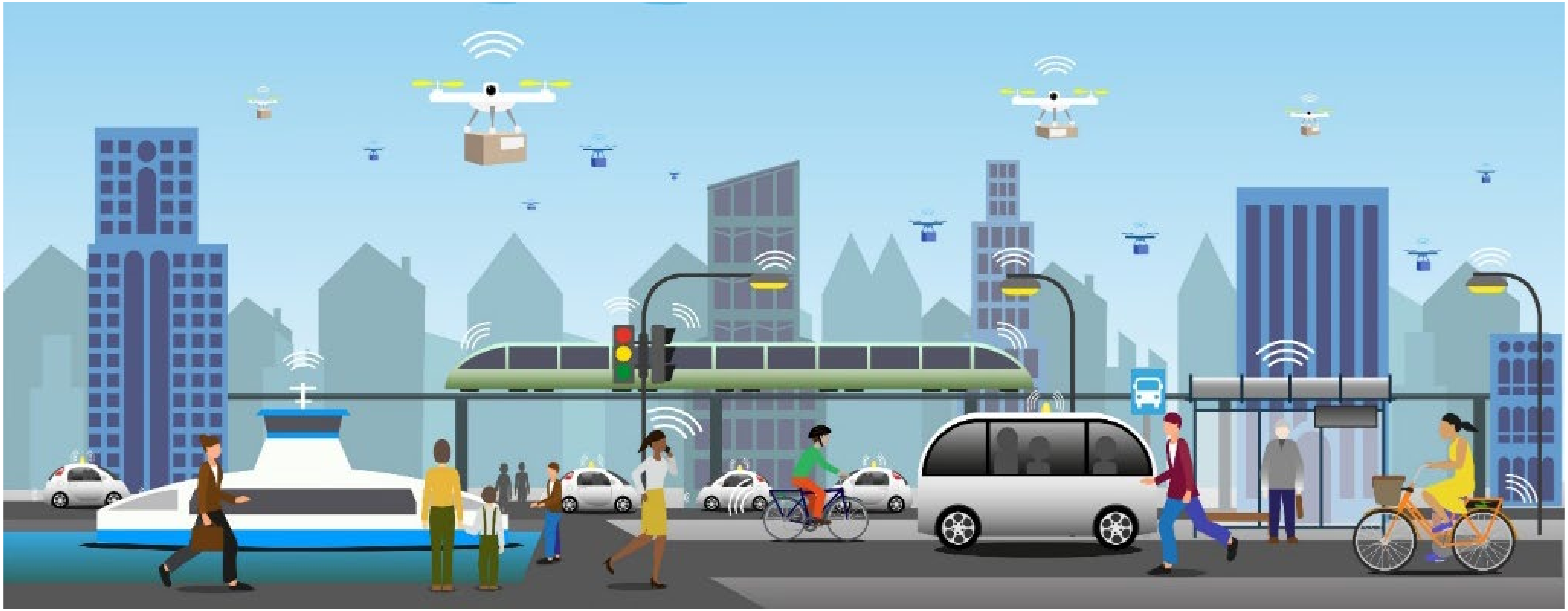
Capacity gaps in asset management at all levels, from strategic budget management to supervision of construction teams, is a long-term issue. A capacity-building approach will, in many cases, need to be supplemented with external expertise. Development partners need to analyse and ensure recipient governments are fully cognisant of the asset management liabilities associated with new infrastructure.

Pathway options

This approach to managing the lifecycle of infrastructure is applicable now and should be a very high priority.

Climate and Disaster Resilient Transport in Small Island Developing States: A Call for Action provides a roadmap and key recommendations for improving the life cycle management of transport infrastructure in SIDS. (World Bank, 2017)

Part IIIB: Menu of technologies



What's in Part IIIB

This *Menu of technologies* collates a wide range of transport technologies, assesses each one's ability to meet the needs of small island countries, and indicates the time frame in which they might be deployed.

Small island countries can use this Menu to assess quickly and accurately the technologies that may be relevant to their situation. The Menu of technologies is a key resource to support small island countries as they work through the strategy process in *Part II*.

The Menu is not intended to be definitive. Some technologies not recommended here may be successfully applied in a specific project or context, while others that have been assessed as broadly suitable, may not, in fact, work in a particular situation.

Part IIIB has three sections:

+ **Summary of the suitability of each technology**
+ **Assessment framework** applied when assessing the transport technologies
+ **Detailed tables** assessing each technology against the assessment framework.

The challenges in a fast-changing world

There are two important things to note. First, while the *Menu* gives an assessment of a transport technology's overall suitability, it is a simplified measure based on expert judgement of how all the factors work together. Second, at this moment in history, rapidly developing technologies are disrupting transport arrangements, and are being deployed in ways that are hard to predict, even just a few years ahead.

One example of a transport technology's ability to disrupt is e-micromobility. Shared e-scooters and e-bikes – which combine information and communication technology (ICT) location and billing technologies with cheaper, lighter battery technologies – were introduced for the first time in 2017 and only a few years later can be found in over 600 cities around the world (IEA, 2020). Similarly, ride-sharing apps (such as Uber or Lyft) have challenged the paradigm of private car ownership in many places around the world, again in just a few short years. In the coming years, further step changes in weight, cost, and performance are anticipated in battery technologies, which may completely rewrite the heavy land transport, aviation, and maritime options presented here.

This *Menu of useful technologies* is necessarily based on information available at the time of writing – collated from publicly available information, and the views of experts working with these technologies in practice. And, as described above, technology is changing fast – almost every day during the writing of this document there were announcements of new models of electric vessels, or aircraft technology, or policy commitments from car manufacturers. Therefore, although this document attempts to look forward at the potential suitability of these technologies in the medium term (5–15 years) to long term (15+ years), forecasting the rate of change is notoriously difficult and this uncertainty must be considered as countries make decisions about what best suits their future needs.

Summary of technologies

This section of Part IIIB provides a summary of how each transport option stacks up against the dimensions explained in the following section on the assessment framework. The aim is to flag which options are generally more suitable for small island countries. More information can be found in detailed tables in the following sections.

The technologies are divided into five broad categories:

+ **1 Urban and land transport technologies.**
+ **2 Sea transport technologies.**
+ **3 Domestic aviation transport technologies.**
+ **4 Energy and fuel technologies.**
+ **5 Supporting services.**

The colour coding applied to each option is explained in Table 2. Its suitability (or otherwise) is assessed at a high level, and also according to the three time horizons: H1 (<5 years), H2 (5–15 years), and H3 (>15+ years).

For example, gasoline-fuelled 2-wheelers are somewhat suitable in the immediate future (H1), somewhat unsuitable in the medium future (H2), and unsuitable in the long term (H3). Overall, they are assessed as somewhat unsuitable .

Table 1: What the colour codes mean

(dark green)	5	Very suitable
(light green)	4	Somewhat suitable
(yellow)	3	It depends on specific circumstances
(orange)	2	Somewhat unsuitable
(red)	1	Unsuitable

Urban and land transport technologies

Walking and micromobility

H1 H2 H3	**Walking** provides essential beginning and endings to personal journeys and provides the essential links between different transport modes. In this regard, walking is a cornerstone of personal travel and will remain so. The walkability of urban areas in SIDS can be improved through better street design, including connected and continuous sidewalks.
H1 H2 H3	**Wheelchairs** provide essential small distance mobility to those physically less able to walk unaided, providing added independence and mobility. Increasing prevalence of non-communicable diseases (NCDs) and resulting disabilities in SIDS means there may be increasing and unmet demand for wheelchairs. Infrastructure and buildings in SIDS are generally not wheelchair accessible and this is a significant barrier to their use outside the home. Suitability will improve over time only if there are improvements to infrastructure.
H1 H2 H3	**Bicycles** are an active mode of transport. Depending upon the quality of roads and tracks, bicycles are a good fit now and are expected to be ideal for island life in the medium and long term. A convenient, enjoyable, short-range personal transport option for able-bodied riders, bicycles are useful in urban, rural, and remote island scenarios. While relatively few people ride bikes now, strategies should focus on shifting infrastructure, urban design, and behaviour towards such more active transport modes over the medium term. Uptake can be increased with development of bike lanes in urban areas, through simple track maintenance in remote areas, and through the availability of more versatile versions of conventional bicycles (eg, cargo and fat wheel bikes).
H1 H2 H3	**E-bikes** are a highly suitable form of transport for SIDS now, and an ideal, low-cost, personal transport solution for SIDs in the medium to long term. A small motor and battery system provides motive assistance and the lower effort required compared to push bicycles will make them more attractive for many people. Contemporary, rugged models that are fit for use on rough and uneven surfaces and practical cargo-carrying models are already available. Charging can easily be performed using domestic outlets on existing low power electricity supply circuits (such as those often associated with connections in remote areas). In developing strategies, e-bikes should be encouraged in the short term, with thought given to changing attitudes, developing cycling-friendly infrastructure, and support supply and service industries (including providing guidance on component standardisation).
H1 H2 H3	**E-push scooters** are readily available now but are not suitable for most island situations due to poor quality roading/pathways. More rugged designs that are better suited to island roads and paths are expected to evolve and become more available. Charging can be easily performed using domestic outlets on existing electricity supply circuits. In the short term, there may be niche demonstration applications of e-scooters in some urban areas. Providing bike lanes (that also allow scooters) and standardising components will enable e-push scooters to be a very suitable transport option and a significant component of small island urban transport in the medium to long term.
H1 H2 H3	**Battery-electric mobility scooters** have the potential to greatly improve the quality of life for many people in SIDS who are ageing or live with disabilities. Mobility scooters will have only niche demonstration applications in the short term due to the poor condition of most sidewalks and lack of accessibility ramps, but uptake should be encouraged as they become more affordable, as more rugged designs provide for use across a wider range of situations, and as islands develop pedestrian- and micromobility-friendly infrastructure (and in this case, high-quality, well-connected sidewalks and ramps).

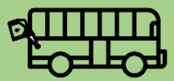
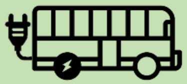
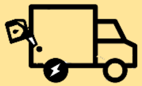
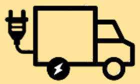
Small format vehicles

 H1 H2 H3	**Gasoline-fuelled 2-wheelers** ('step-through' style scooter and motorcycles) are currently well-suited for use in SIDS, but the need to rapidly phase out fossil fuels, plus the high air quality-related emissions of the 2-stroke engine scooters makes them unsuitable in the medium to long term. They cost relatively little to buy, have good range and fuel economy, and come in a wide variety of models for different applications across different terrains, including poor quality roads. It is, therefore, surprising that they do not already have a very wide penetration in most SIDS, as they do in Southeast Asia. It is suggested, however, that SIDS leapfrog this technology and instead adopt electric 2-wheelers.
 H1 H2 H3	**E2Ws – electric 2-wheelers** (scooters or e-motorbikes) are suitable for SIDS now and in the future and should be given serious consideration. Modern battery and motor technologies give them good range and they can be easily charged at home or with simple public charging infrastructure. Currently a key constraint is the limited availability in island markets. Strategies should consider how to develop supply chains (including providing guidance on quality and specification) and ensuring the technology can be supported locally in small island markets. In the short term, niche demonstration projects could test the application in an island context and build familiarity, laying the foundation for significant uptake in the medium to long term.
 H1 H2 H3	**E3Ws – electric 3-wheeled small format vehicles** are likely to be very suitable for SIDS in the medium to long term. As the technology is still developing, is not readily available, and is unfamiliar, they are unlikely to be suitable in the short term. E3Ws have the potential to provide future passenger taxi services, in inner urban, flatter, low-speed areas, and for tourist use. In the future, they are expected to bring many of the same benefits as E2Ws, such as being relatively inexpensive to buy and run, and easy to charge, with additional benefits of being able to carry multiple passengers and goods and providing some protection from rain. In the short term, strategies could include demonstration projects in tourist areas while keeping a watching brief on the technology in anticipation of application in the medium to long term.

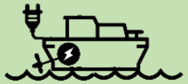
Medium format vehicles

 H1 H2 H3	**Internal combustion engine (ICE) vehicles** with currently available fuels are very suitable for islands in the short term, and a poor fit in the long term due to the need to decarbonise transport. The infrastructure and urban form of SIDS' main islands have been shaped by the automobile, with roading infrastructure providing for increasing numbers of cars, in turn making cars all but necessary for mobility. ICE light vehicles dominate main island land transport systems, as they do in many countries, due to their convenience, comfort, and versatility. In the short term, petroleum-fuelled light vehicles will remain a mainstay of main islands' land transport systems, although in the medium term the need to decarbonise, and the development of more attractive alternatives, makes ICE cars increasingly unsuitable. In the long term, after 2035, global supply chains for ICE vehicles may become limited and more difficult again for SIDS to access. There is also the possibility of a glut of cheap ICE vehicles as other countries seek to dispose of them quickly, which would need to be very carefully managed.
 H1 H2 H3	**Battery-electric vehicles (BEVs)** are powered by an electric motor supplied with electricity from an onboard battery and charged from a source of electricity that is external to the vehicle. They are somewhat suitable for SIDS in the short term, becoming very suitable in the medium to long term. The suitability of BEVs depends on the availability of infrastructure and services, including vehicle service support, a good quality, high-renewables electricity supply, and post-vehicle-life management for batteries. At present, BEVs are more expensive than their ICE counterparts and GHG emission benefits depend on the proportion of renewable electricity. As renewables increase, and the global market for second-hand BEVs grows, BEVs will become a more attractive option for SIDS. Strategies in the short term should consider demonstration in government fleets and support of uptake by enthusiasts to build familiarity, in anticipation of wider and increased uptake in the medium to long term.
 H1 H2 H3	**Plug-in hybrid electric vehicles (PHEVs)** have a petroleum-fuelled engine plus an electric drive system which can be charged from a source of electricity that is external to the vehicle, and these two drive systems can each partially or wholly propel the vehicle. PHEVs are somewhat suitable for SIDS now but may find niche applications over all time horizons where the application of the petroleum engine provides benefits (such as the redundancy it provides in disaster response scenarios). The suitability of PHEVs for islands is expected to increase over the next decade as the technology becomes normalised and cheaper, although the benefits depend entirely on how the vehicle is used and fuelled. In the longer term, they are less suitable in the context of decarbonisation if dependent on current fuels.
 H1 H2 H3	**Hybrid electric vehicles (HEVs)** retain the petroleum engine plus have a small battery and electric motor that captures then delivers back energy available from braking. HEVs are very suitable in the short to medium term in SIDS, becoming unsuitable in the long term due to the need to decarbonise almost entirely. HEVs are an established technology that, due to their fuel economy, has found favour in many island contexts, particularly in taxi fleets. HEVs offer around the same GHG reductions as a BEV charged from diesel-generated electricity, and yet, because they do not require external connection for charging, they are as convenient as pure ICE vehicles. Hybrids can be a stepping-stone towards electric vehicles as they are cheaper and introduce electric vehicle technology, providing experience to the motor service industry.
 H1 H2 H3	**Electric minibuses** are powered by a battery and electric motor drive system and charged using electricity from an external source. They are likely to be a very suitable transport solution for islands in the medium to long term, with a need to do some early demonstrations and build familiarity in the short term. They are far cheaper and easier to support, operate, and charge than full-size electric buses. At the same time, they provide a flexible fleet that may be better suited to smaller and more dispersed populations across both urban and rural areas, and better suited where there are narrower, winding roads. Electric minibuses could play a significant role in island passenger transport within 10 years and remain in the long term.

Large format vehicles

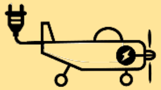
 H1 H2 H3	**Gasoline and diesel-fuelled buses** presently play a major role in the transport systems of some (not all) SIDS, providing affordable transport for many people. When well utilised, buses can be more energy-efficient and lower in GHG emission than cars (on a passenger-km basis) and, in the absence of viable alternatives, they are a very suitable technology in the short to medium term. In the long term, as the use of fossil fuels is phased out, it will become important to find alternatives to fossil-fuelled modes of every description, including buses.
 H1 H2 H3	**Electric buses (e-buses)** are powered by a battery and electric motor drive system and charged using electricity from an external source. In the short term, full-size e-buses are not suitable for SIDS. They are expensive, their technology is not proven in an island environment, their specialisation requires close support from the manufacturer, and the supporting charging infrastructure can add significant costs to a project – only large fleets are currently economically viable and there are few opportunities for these across the SIDS. They are expected to become more suitable in the medium to long term, as the cost of the vehicles comes down and proliferation in other regions provides necessary experience, plus opportunity to import second-hand units. However, their suitability will depend on high renewable electricity and upgraded grid infrastructure to allow for charging heavy vehicles. Running electric buses on diesel-generated electricity provides marginal GHG emission benefits and a long GHG payback period on the additional GHG emissions associated with the manufacture of an electric bus over a diesel bus.
 H1 H2 H3	**Hybrid trucks** incorporating an internal combustion engine plus a non-plug-in battery and electric motor system are in use in many parts of the world but, as they are expensive compared to their conventional counterparts and their technology is unfamiliar, these models are not well suited to SIDS in the short term. It may be that in the medium term, as second-hand units become available from overseas markets and service personnel gain familiarity with them, their affordability and suitability increases. In the long term, with the need to decarbonise transport, their use of conventional fuels will make them unsuitable.
 H1 H2 H3	**Electric trucks (e-trucks)** technology is presently in its infancy, and they are not suitable for islands in the short to medium term. Demonstration models exist but they are expensive and require specialised servicing support. As technology is developed, including the battery technology, a greater range of electric trucks is expected to emerge in the medium term, and some of these may suit SIDS applications. Their suitability is likely to increase in the longer term as the technology is mainstreamed elsewhere in the world, bringing about greater availability, a reduction in purchase price, and greater familiarity in the vehicle service industry.

Sea transport

 H1 H2 H3	**Personal paddling boats** are very well suited for limited applications in some island coastal communities over all time horizons. Watercraft powered by paddling are one of the most ancient modes of transport and the technology of their production and their handling are known to coastal communities around the world. While many traditional production technologies are labour-intensive and require special timber, modified versions can be locally made from low-cost imported materials such as plywood. While readily available, often craft of this type have been displaced by motorboats, so some encouragement may be needed for the resurgence of this transport mode.
 H1 H2 H3	**Personal sailing watercraft** (small sailboats) are an ideally suited transport technology for small islands for all time horizons. Many island communities retain deep knowledge around the production and handling of this often-world-class technology. The manufacture of small sailboats can be adapted to use lower-cost, more readily available materials and less labour than traditional methods. As pure sailing vessels, they produce zero emissions, although they may be made more versatile with the addition of small motors. They are an active form of transport and less convenient and comfortable than modern motorboats. However, supporting their use in island countries is an important part of fostering culture and heritage. It is expected that small sailing boats will remain ideally suited to many SIDS contexts for the foreseeable future.
 H1 H2 H3	**Small battery-electric propulsion motors** (up to around 4kW shaft power) are available and suitable for adoption in SIDS in the short term, where only short range is required. They are expected to be readily available to islands within the medium term, becoming the preferred technology for inshore small watercraft within the medium to long term as costs reduce further and range extends with improved electricity storage options. Small electric propulsion systems can replace existing inboard or outboard motors, including those used as auxiliary propulsion on larger vessels. At this small size, there is also potential to gain useful energy from onboard solar panels, rather than rely on onshore charging of the batteries, extending their useful range.
 H1 H2 H3	**Battery-electric small-to-medium boats** may find only limited applications in small islands in the short term but could become a very useful mainstream technology by the long term. At present, the technology is in early-stage demonstration around the world and is very expensive, particularly where significant onboard electricity storage is required. As with electric vehicles, the GHG emission benefits depend on the level of renewables in the electricity mix used for charging. Strategies could consider support for demonstration projects in the short term (eg, inshore tourism) to build experience with the technology in anticipation of greater uptake in the medium to long term.
 H1 H2 H3	**Electric ferries** powered by batteries, capable of carrying numbers of passengers and cars at slow to moderate speeds over short ranges, are already in service in some parts of the world. Their application is likely to be limited in SIDS in the short term due to the high cost of the vessels and onshore charging infrastructure, the need for specialist expertise, the need for high-powered charging systems, and their relatively short range. These will remain barriers to the adoption of this technology in SIDS for a number of years to come. As battery and engine technologies evolve in the longer term, it is expected these constraints will ease to make the technology more available to small island situations in the long term. Their longevity warrants consideration of intermediate hybrid specifications, with retrofit later as prices and/or changes in vessel service permit.
	**Sailing vessels** are very well suited to inter-island passenger and cargo transport over all time horizons. Indigenous people of the Pacific explored and settled across the ocean using perfectly optimised sailing technology, and later, Europeans used sailing ships to explore, colonise and establish global trade. Sailing ships were a mainstay of trade and commerce until the second decade of the twentieth century. The specific fit will depend on sailing conditions, design of the vessel and economic viability of the routes. Modern technologies have the potential to help optimise journeys by anticipating weather, currents and waves, improved hull and sail design, and by supplementing sail power with electric propulsion.

H1	H2	H3	
H1	H2	H3	Effort in the short term should be directed to developing suitable concepts and demonstrations, to be proven in the medium term, and scaled-up in the longer term.
 H1	H2	H3	Wind-assisted propulsion (WASP) technologies may have applications in the short term, either as a retrofit to reduce fuel use on existing vessels, or as part of the design of new builds. Despite a long history of trials and demonstrations, commercial use of wind-assisted propulsion technologies is still largely at the experimental or demonstration stage. Many groups are involved in developing wind-assist technologies, and there does not appear to be any one favoured technology. It is therefore expected that little more than demonstration can be expected in the short term, small-scale adoption in the medium term, and uptake as practicable in the longer term.

Domestic aviation

 H1	H2	H3	Drones are already being used to deliver small cargoes such as medicines to remote places in several countries, including Africa and Australia. In the short term, application of drones to telemedicine services in SIDS could be done on a demonstration basis, with the technology and practice becoming normalised and widespread in the medium to long term (and likely alongside other drone applications).
 H1	H2	H3	Battery-electric aircraft, where onboard batteries power an electric motor-driven propellor, are at an emerging stage. In the short term, this technology is not suitable for SIDS because it is still limited to small aircraft travelling small distances. Significant advancements in electrical energy storage are required before commuting-type aircraft become commercially available. In the medium to long term, small electric aircraft may be incorporated into the fleet, possibly for niche tourist applications, with the possibility of increased uptake in the long term as technology and affordability permits.
 H1	H2	H3	Hybrid-electric aircraft (aircraft powered by a hybrid-electric propulsion system (HEPS) comprising combined petroleum-fuelled and battery-electric drive systems) will, in theory, be very suitable for SIDS as they are designed for the same applications as the robust turboprop planes that comprise most island domestic fleets. The technology is still in the experimental stage, with major demonstrations expected within five years, and commercialisation in primary markets in the medium term. This will lead to the opportunity to include hybrid aircraft in island fleets in the medium to long term from fleet turnover in the primary markets.

Energy and fuels

H1 H2 H3

EV charging systems are essential to support the uptake of EVs across all formats. In the short term, this is likely to consist mostly of 'slow-charging' (eg, at private dwellings), with a few demonstration 'fast-charging' stations for light vehicles (eg, at vehicle dealerships, hotels, or government offices). A planned approach to charging infrastructure is needed to prepare for the medium term, which will require partnerships across electricity providers, major users (such as taxi fleets or government departments), and site owners.

H1 H2 H3

Hydrogen as a fuel is unlikely to be suitable for SIDS in the short to medium term. While there is much discussion globally of the 'hydrogen economy', the production of green hydrogen, the transport and storage of hydrogen for vehicles, and the use of hydrogen as fuel by vehicles are early demonstration technologies that present significant engineering challenges, particularly in a SIDS environment. In the long term, it is possible, but highly uncertain, that hydrogen production, handling, and fuel cell vehicle technology will develop to the point that it can be managed within a SIDS context outside of specific, controlled applications. However, given the long timescales involved, there are other technologies involving the storage of electrical energy that may prove to provide at least equal performance but be more suitable in the SIDS context.

H1 H2 H3

Biodiesel that is locally produced may have some limited application in the short term, but its viability is highly dependent on access to reliable, cheap sources of suitable feedstock and the ability to manufacture quality biodiesel from this feedstock. Coconut oil is often mentioned as a feedstock but currently the world price of raw coconut oil is high due to demand for its use in food and cosmetics. Modern engines require high-quality fuels and affordably achieving the quality required is an issue in an island context. An alternative is to use lower quality biodiesels in older engines, but this comes with risk. Use of raw coconut oil is riskier still but can sometimes work in low blend proportions in standard fuels in older slow- and medium-speed engines. These are not future-focused options. The landed cost of internationally produced, "drop-in" quality biodiesels can be two or more times the cost of diesel, the production or diversion of the feedstock can conflict with food production, and there may be some uncertainty over emissions benefit. While some applications may remain, the usefulness of biodiesel as a transport fuel is expected to decline in the medium to long term as other technologies take over.

H1 H2 H3

Alternative fuels (excluding hydrogen or biodiesel) are currently not affordable nor available at scale in the islands, and significant advancements in technology will be required for this to change. While Fiji has the potential for at-scale ethanol production, the costs to produce and then use the ethanol in the vehicle fleet are currently prohibitive. Other alternatives present only microscale opportunities and the difficulty to provide quality assurance would likely relegate their use to specific projects involving older technology engines. New technology conversion processes may present opportunities in the long term.

H1 H2 H3

Sustainable aviation fuels (SAFs) are an early stage, primary technology for global aviation emissions reduction. In the short term, they are not suitable for SIDS due to high cost and very low availability – supply chains will preference major airlines in Europe and the United States (US). Towards the long term, it is expected that SAF use will eventually spread to island countries as they are part of the global supply chain for aviation fuels.

H1 H2 H3

Supporting services

H1	H2	H3

There are many opportunities for **app-based software services** to support better use of existing transport services and/or support the introduction of new transport services. There is an expectation that transport-related software services will continue to evolve globally, and that many of these will find their way to the Pacific Islands and provide benefits to both users and transport providers. Policy support would be needed to ensure safety and consumer protection, and to raise awareness of how to use the services.

H1	H2	H3

Marine energy efficiency measures include various approaches to achieving significant fuel savings and are very suitable for SIDS over all time frames. The combination of modern electronics, software, and the ability to relatively cheaply transmit data even in remote SIDS locations provides opportunity for the use of sophisticated trip planning systems. As well, optimised engine operation, hull cleaning, specialised coatings, and optimising ballast and trim can bring about significant improvements in vessel performance. Many of the technologies involved are expected to see performance improvements and decreased costs over time. Adoption of many of these technologies provides quick payback due to fuel saving, and attention should be given to them in the short, medium, and long terms.

H1	H2	H3

Green ports: improving the infrastructure and operation of island ports to be more resilient, energy-efficient, and to reduce GHG emissions and other environmental impacts is highly suitable for the short, medium, and long terms. However, the degree of change may be limited by affordability, technical capacity, and practicality – some green port measures will likely never be practical in smaller ports. For example, cold ironing (where a ship uses shore power while it is in port), is feasible only in major ports supplied by robust electricity networks.

Assessment framework

The framework looks across 15 dimensions that should be considered when assessing the suitability of each technology option such as its affordability, carbon footprint, convenience, and any need for specific infrastructure. Table 1 shows the questions considered in assessing each dimension, and the relevant indicators for each. It also provides a short clarifying description.

Table 2: Framework used to assess the general suitability of transport technologies for application in SIDS over different time horizons

Dimension	Considerations	Indicators	Comments/ Description
Type of journey/ service	• What type of trips is the technology suitable for? • Over what distance or terrain? • In what conditions?	Short ~ 15–30-minute walk (<2km) Medium (2–50km) Long (>100km) Passenger (how many) Freight (how much) Urban, rural, inter-island, distance Terrain – eg, paved roads, dirt tracks Journey conditions – eg, rain, heat	Some technologies are suitable for short journeys around town for one or two persons, such as e-micromobility, which requires paved roads and has a short range, or electric outboards, which are suitable for short coastal trips. Others, such as hybrid-electric vehicles, can be used for journeys over hundreds of kilometres.
Overall suitability by time horizon	Summary of the general suitability of the technology, and time horizon in which the technology might be deployed, according to the state of technology development, various factors related to deployment, and drivers such as the desire to adopt low-carbon options, broadly assessed against small island countries' context. This is necessarily high-level and generic, and assessment of specific applications may be found to be more or less suitable.	**General suitability**: 5 = Very suitable 4 = Somewhat suitable 3 = It depends on specific circumstances 2 = Somewhat unsuitable 1 = Unsuitable **Time horizon**: H1 Short term (<5 years) H2 Medium term (5–15 years) H3 Long term (>15 years)	There are no standard definitions of time horizons. In this document, we suggest broadly the timeframes in which technologies may be most suitable. For example: • Bicycles can be used now (H1) but strategies to increase uptake may take a decade or more. • EVs can be introduced now (H1) to build familiarity and experience, but larger numbers won't be expected in the Pacific for 5–10 years (H2), as they become more affordable, and as the second-hand market builds etc. • Longer-term (H3) technologies are likely to produce zero or near-zero GHG emissions, and the H3 time frame may be marked by a diminishing petroleum fuel supply chain.

Dimension	Considerations	Indicators	Comments/ Description
Global technology outlook (feasibility/ availability)	• Is the technology technically and economically feasible? • If not now, is it likely to be in the future? • Is the technology in production? • How widespread is deployment? • If not now, when is it likely to be widely deployed?	**Prototype:** A concept is developed into a design, and then into a prototype for a new device. **Demonstration**: The first examples of a new technology are introduced at the size of a full-scale commercial unit. **Early adoption**: At this stage, they are still at a cost and/or performance disadvantage to established technologies, which may require supporting policy to address (eg, electric and hydrogen-powered cars). **Mature:** As deployment progresses, the product moves into the mainstream as a common choice for new purchases. (IEA, 2020)	Sometimes technologies are suggested for SIDS as a solution to GHG emissions or energy challenges, without an indication of the technical or economic feasibility of the technology, or the likelihood of feasibility in the future. This section briefly assesses the current state and outlook based on current information.
Affordability/ cost	• What is the upfront purchase price of the technology compared to other options? • What are the operation and maintenance costs? • What is the whole-of-life cost (including disposal)? • How does the cost of this option compare to other options?	$ very affordable/ cheaper than existing options $$ affordable $$$ expensive $$$$ very expensive	Affordability is a relative indication of societal/ economic cost across technologies on a *service basis.* A comparison of passenger transport options broadly considers the cost on a *passenger-km basis*, and freight is considered on a *tonne-km basis*. Whole-of-life (WOL) thinking can be used to ensure costs across the whole life are considered, including import, purchase, fuelling, maintenance, and end-of-life recycling and disposal. Purchase price is an indication of upfront capital costs, while operating costs are how much it costs to run from year to year. The perspective of societal/ economic cost has been used here – how much it costs to provide the bus service, rather than how much it costs the rider to purchase a bus ticket. These ratings are indicative only, given the many costs and benefits that might be included in a total economic analysis and how this might vary given specific contexts and technology supply options.
Supply/ availability	• Are there supply chains that could make the technology available to islands?	5 = Readily available 4 = Somewhat available 3 = It depends 2 = Somewhat unavailable/ difficult to access 1 = Very difficult to access	Supply chains for transport equipment depend on many things, including the size and attractiveness of the market. For example, at present even some major developed economies have only limited access to EVs, due to the limited supply going to more attractive markets. This can be expected to be a constraint for SIDS.

Dimension	Considerations	Indicators	Comments/ Description
Carbon footprint	• What are the greenhouse gas (GHG) emissions compared to other options, on a whole-of-life basis? • What up-front 'embodied' GHG is involved in its manufacture? In its use? • How might this be shared through shared use of the vehicle?	5 = Very low GHG emissions considered over life of option 4 = Low GHG emissions over life 3 = Similar GHG emissions to current mainstream options 2 = Slightly higher GHG emissions 1 = High GHG emissions compared to current mainstream options	Considers both the day-to-day (operational) GHG footprint on a comparative basis in terms of kg CO_2-e per person-km for passenger transport, and kg CO_2-e per t-km for the transport of freight, as well as GHG 'embodied' through the production and distribution process. If the additional embodied GHG can be quickly paid back through day-to-day GHG savings, this gives an overall low GHG emission option.
Energy security	• What is the effect on energy security for islands? • Does it reduce energy use? • Does it use cheaper fuel? • Does it reduce reliance on imports?	5= Significantly reduces energy supply concerns 4= Moderately reduces energy supply concerns 3= It depends 2= Moderately increases energy supply concerns 1= Significantly increases energy supply concerns	'Energy security' is a complex and contested term. This framework uses the International Energy Agency (IEA) definition of energy security in a broad sense as the: "uninterrupted availability of energy sources at an affordable price" (International Energy Agency, 2019). In general, for SIDS, energy security includes a reduction in dependence on imported fuel and improved resilience to price rises and price shocks.
Convenience, comfort, safety, and accessibility	• How convenient or comfortable is it? • How accessible is it for elderly or people with disabilities?	5 = High comfort and convenience, to 1 = Uncomfortable/ inconvenient	This is a very general assessment only – specifics would depend on the context and the particular users.
Infrastructure & refuelling requirements	• What are the infrastructure requirements? • How doable is this likely to be in island countries? • What are the refuelling requirements?	5 = Very manageable 4 = Manageable 3 = It depends 2 = Requires significant effort and attention 1 = Onerous requirements – potentially not cost-effective or manageable for many small island countries	This element is assessing what the requirements are for infrastructure or refuelling to support the technology, assessed against what is usually available and workable in small island countries. For example: • E-push scooters need well-formed pavements or roads. • Mainstream battery electric vehicles require different types of charging infrastructure. • Alternative fuels may require separate and well-maintained fuel handling systems.

Dimension	Considerations	Indicators	Comments/ Description
Operation & maintenance requirements	• Are the technologies suitable for small island countries' conditions and context (eg, maritime wet/salty conditions)? • Can they be supported by current small island country capabilities? • If not, how difficult would it be to develop required capability? • How practical is the technology option likely to be in the small island country situation?	5 = Very suitable for the context/ very manageable 4 = Somewhat suitable/ manageable 3 = It depends 2 = Somewhat unsuitable 1 = Very unsuitable	This element is a general assessment of the capability for SIDS to locally support the operation and maintenance of the technologies involved, which includes the ability to provide timely servicing through minimal downtime in the event of an unscheduled event. Its consideration in combination with the availability of necessary infrastructure forms a vision of how secure the ongoing operation of the technology is.
Waste/ end-of-life disposal	• What are the requirements for end-of-life product management, comprising re-use/repurposing of components through disposal/waste management?	5 = No or easily managed requirements 4 = Minimal requirements 3 = It depends 2 = Some management 1 = Significant management required	This factor considers the need for active management at the end of life of the vehicle – for example, the recovery, export and reprocessing of batteries or car bodies.
Environmental & social impact	• What environmental or social impacts could arise from this technology? • On balance, are the effects positive or negative?	5 = Considerable environmental and/or social benefits 4 = Overall, some benefits 3 = It depends 2 = Overall, some concerns 1 = Considerable environmental and/or social harm	Benefits may include: • Health benefits from improvements to local air quality and reduced noise. • Reduced congestion due to smaller physical footprints of vehicles and/or greater shared use of vehicles. • Improved access to mobility, including those through the addition of new services and/or more affordable options. • Health benefits from using active modes of transport such as cycling and push scooters. Negative impacts may include toxic waste, or reduced safety. The resulting assessment is a very general overview.
Local value chain/ economic	• Resource availability? • Can hardware be built locally? • Maintained locally? • Provide jobs and economic opportunity?	5 = Significant opportunities for local participation in the value chain 4 = Some increase in opportunities 3 = It depends 2 = Minimal new opportunities 1 = (Very) few opportunities for local participation in the value chain	This considers the degree to which a technology contributes to local value chain economic opportunities. This can be highly subjective. For example, an Uber-style vehicle-hailing app may be sourced and supported offshore, and a high proportion of its profits go overseas. However, its presence provides locals with driving jobs and can improve the level of service offered to locals and, overall, provide local value gains associated with this.

Dimension	Considerations	Indicators	Comments/ Description
Required complementary systems and policies	• What other things need to be in place to enable this technology to be used? This includes policies, systems, infrastructure, off-island recycling supply chains, etc.	5 = No requirements 4 = Minimal new requirements 3 = It depends 2 = Moderate new requirements/supporting mechanisms 1 = Very substantial requirement for policies and measures	Some technologies will require policies and systems to be in place for them to be implemented. For example, electric vehicles will require battery recycling programmes, charging infrastructure, and increasing renewable electricity generation if the intended outcomes are to be achieved. Policies could direct the various markets and industries involved to better manage the market development processes and outcomes.
Other considerations	• Are there any other issues that need to be taken into account?		This section presents any other issues or considerations of note. For example, the potential for wide quality variation, and the need to set minimum quality standards for e-micromobility technologies.

Detailed tables

1 Urban and land transport technologies

Walking and micromobility

1.1 Walking

Walking is a basic travel mode that is essential to link with and/or support most other transport modes.			
Type of journey/ service	Short-distance.		Short-distance travel across a wide range of terrains.
Overall suitability	**H1**	**5**	Walking provides essential starts and finishes to personal journeys and provides the essential links between different transport modes. In this regard, walking is a cornerstone of personal travel and will remain so. The walkability of urban areas in SIDS can be improved through better street design, including connected and continuous sidewalks.
	H2	**5**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Mature		While in recent decades walking has been displaced by motorised transport, there is an increasing push to redesign urban places to encourage more walking.
Affordability/ cost	Whole-of-life	$	N/A
	Purchase	$	
	Ongoing	$	
Supply/ availability	5		N/A
Carbon footprint	5		Zero emissions (some embodied emissions in the construction of sidewalks and other supporting infrastructure).
Energy security	5		Nil imported fuel energy requirements.
Convenience, comfort, safety and accessibility	3		Convenience dependent on weather, length of trip, and time available. In some places simple devices such as parasols can greatly increase comfort. Safety from other transport modes dependent on infrastructure. Personal safety variable depending on a wide range of factors.
Infrastructure & refuelling requirements	4		Urban design and supporting infrastructure are required for walking to be practical, safe and enjoyable.
Operation & maintenance requirements	5		N/A
Waste/ end-of-life disposal	5		N/A
Environmental & social impact	5		An active mode of transport that can provide health benefits as well as social benefits in creating more connected and cohesive communities.
Local value chain/ economic opportunity	4		N/A
Required complementary measures	3		In SIDS, encouraging walking will depend on improved urban design and streetscapes focused on walkability. There may be a need to address other barriers to physical activity including obesity and NCDs, and cultural norms.
Other considerations			

1.2 Wheelchairs

Non-motorised wheelchairs provide improved mobility to those physically less able to walk. They are fit for moving around home and workplaces that cater for their use and for small-distance commuting where the surfaces on which they are used are relatively level and smooth.			
Type of journey/ service	Very short-distance, single passenger.		Suitable for very short-distance commuting on well-formed and mostly level surfaces.
Overall suitability	**H1**	**3**	Wheelchairs provide essential small-distance mobility to those physically less able to walk unaided, providing added independence and mobility. Increasing prevalence of non-communicable diseases (NCDs) and resulting disabilities in SIDS means there may be increasing and unmet demand for wheelchairs. Infrastructure and buildings in SIDS are generally not wheelchair accessible and this is a significant barrier to their use outside the home. Suitability will improve over time only if there are improvements to infrastructure.
	H2	**3**	
	H3	**4**	
Global technology outlook (feasibility/ availability)	Mature		Centuries-old design made easier to use through gradual improvements that include more compact, low-weight and foldable designs.
Affordability/ cost	Whole-of-life	$	Simple designs are relatively cheap to buy and maintain.
	Purchase	$	
	Ongoing	$	
Supply/ availability	4		Readily available for import, although high-specification models can be difficult to acquire.
Carbon footprint	5		Zero emissions in service. Negligible embodied emissions.
Energy security	5		Nil imported energy requirements.
Convenience, comfort, safety, and accessibility	3		Often considered an essential tool by users, and one that can be inconvenient, but this is weighed up against the convenience of added independence that the use of the wheelchair provides.
Infrastructure & refuelling requirements	2		Significant infrastructure is needed for wheelchairs to be used outside the home. Homes, workplaces, shops, doctors etc require wheelchair accessible ramps, doors, toilets etc. Sidewalks must be smooth, connected and free of gaps with safe places to cross traffic.
Operation & maintenance requirements	5		Simple construction and easy to maintain.
Waste/ end-of-life disposal	5		Small footprint. Tend to be maintained so that they have very long lives.
Environmental & social impact	5		Provides added level of independence and mobility to users, both of which are desired.
Local value chain/ economic opportunity	5		Wheelchairs are suitable for local business to import, sell, maintain, repair and rent.
Required complementary measures	2		Significant infrastructure requirements. Building codes for wheelchair accessibility.
Other considerations			-

1.3 Bicycles

Bicycles are an active mode of transport. Centuries-old design, simple technology, affordable and easy to repair at local level. Suitable for short-distance commuting. Convenience and comfort depend on availability of parking at either end, weather, temperature (less favoured as part of normal transport routine in hot climates).

Type of journey/ service	Short-distance, single passenger.		Suitable mainly for commuting. Suitable for use on all existing roads and surfaces, including mountain bikes on bush/remote island tracks.
Overall suitability	**H1**	**4**	Bicycles are an active mode of transport. Depending upon the quality of roads and tracks, bicycles are a good fit now and are expected to be ideal for island life in the medium and long term. A convenient, enjoyable, short-range personal transport option for able-bodied riders, bicycles are useful in urban, rural, and remote island scenarios. While relatively few people ride bikes now, strategies should focus on shifting infrastructure, urban design, and behaviour towards such more active transport modes over the medium term. Uptake can be increased with development of bike lanes in urban areas, through simple track maintenance in remote areas, and through the availability of more versatile versions of conventional bicycles (eg, cargo and fat-wheel bikes).
	H2	**5**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Mature		Centuries-old design, available now and suitable for all future time horizons. A wide range of specialised bicycle technologies and componentry available in market. Simple bicycles more suited to SIDS environment.
Affordability/ cost	Whole-of-life	$	Simple designs relatively cheap to buy and maintain.
	Purchase	$	
	Ongoing	$	
Supply/ availability	5		Readily available for import, including second-hand bicycles.
Carbon footprint	5		Zero emissions in service. Very low embodied emissions.
Energy security	5		Nil imported energy requirements.
Convenience, comfort, safety and accessibility	3		Convenience depends on weather, temperature (use for daily commuting less favourable in hot climates), availability of parking at either end (infrastructure requirement) and others. Less accessible for many elderly or people with disabilities (although modified bicycles are available). Access to showering and changing facilities support the use of bicycles for daily commuting. Safety on roads is improved through education and awareness campaigns for both riders and drivers, and by cycle-friendly infrastructure design.
Infrastructure & refuelling requirements	5		Increasing urban use is likely to need bike parking and safe bicycle or shared lanes (many countries are supporting bicycling through the provision of dedicated and shared paths for cycling) to increase comfort and safety and encourage a greater number of users.
Operation & maintenance requirements	5		Bicycle components subject to corrosion from maritime environment. Supported by owner-provided, very basic maintenance and/or use of new designs and materials. Also requires easy access to local basic maintenance and parts support in order to avoid disuse for simple reasons.
Waste/ end-of-life disposal	5		Consideration should be given to reusing frames and parts, and to overall disposal, although because of the volume of the components involved, this is far less of a problem than with other forms of transport.
Environmental & social impact	5		Zero emissions, exercise leading to improved health (eg, reduction in diabetes, obesity, and heart disease). Managed use has potential to reduce traffic congestion.
Local value chain/ economic opportunity	5		Bicycles are suitable for local business to import, sell, maintain, repair, and rent.
Required complementary measures	3		Significant increased use of cycling requires significant behaviour change to overcome attitudinal barriers, and changes to roads and urban design.
Other considerations			

1.4 Electric-bikes (E-bikes)

Electrification increases the convenience and accessibility of cycling, with the potential to replace full-size vehicles, yielding both emissions reduction benefits, as well as the health benefits that arise from active transport. E-bikes come in a wide range of designs that makes them suitable not only for individual commutes, but also for shopping, running errands, dropping kids to school, etc in both urban and off-road contexts. E-bikes have become a popular transport option for personal and small freight transport in many cities in Europe.

Type of journey/ service	Short-distance, single rider + one or two child passengers		Suitable for day-trip distances of up to around 40km. Electric bikes come in a range of styles including 'cargo-bikes' which can be easily used for small freight, dropping children at school, running errands, etc. Weather depending, e-bikes have the potential to replace some car journeys. Different base designs provide for use across different terrains including powerful mountain bike options.
Overall suitability	**H1**	**4**	E-bikes are a highly suitable form of transport for SIDS now, and an ideal, low-cost, personal transport solution for SIDs in the medium to long term. A small motor and battery system provides motive assistance and the lower effort required compared to push-bicycles will make them more attractive for many people. Contemporary, rugged models that are fit for use on rough and uneven surfaces and practical cargo-carrying models are already available. Charging can easily be performed using domestic outlets on existing electricity supply circuits. In developing strategies, e-bikes should be encouraged in the short-term, with thought given to changing attitudes, developing cycling-friendly infrastructure, and support supply and service industries (including providing guidance on component standardisation).
	H2	**5**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Mature but technology also still developing		Globally, electric bicycles are widely available now, and the technology is expected to continue to improve in performance and come down in cost over time.
Affordability/ cost	Whole-of-life	$$	Upfront purchase price of reasonable quality e-bikes ranges USD1000 to over USD5,000. Charging costs are very low – eg, 20 cents for a 500Wh charge (based on current, typical island electricity prices) for 20-50km of travel. Reasonable quality replacement batteries cost USD300-600 (for a 500Wh battery) and may need to be replaced or refurbished after around 3-4 years.
	Purchase	$$	
	Ongoing	$$	
Supply/ availability	5		Readily available for import now and expect an increasing second-hand market over time.
Carbon footprint	5		Very low energy requirements. Some emissions related to this if charged from diesel-generated electricity. Nil if charged by renewable electricity. Significant reduction in emissions if replacing a trip that would otherwise be done by car.
Energy security	5		Very low energy requirements. Nil reliance on imported energy if charged from renewable electricity.
Convenience, comfort, safety and accessibility	3		Electrification of bicycles increases the convenience and comfort of cycling, opening up pedal-assisted bicycle use opportunities to all, and in particular to older and less able-bodied riders. As for regular bicycles, convenience depends on availability of parking, safety of routes, weather and temperature. For e-bikes, convenience also depends on the charging options available. The added power of e-bikes can make inexperienced riders more prone to accidents compared with ordinary bicycle use. Safety on roads is improved through education and awareness campaigns for both riders and drivers, and by cycle-friendly infrastructure design.
Infrastructure & refuelling requirements	4		Increased urban use likely to need bike parking and safe bicycle or shared lanes. Charging is simply done through the use of standard electricity wall socket outlets, usually taking 3-5 hours. The charging requirements are also a good match with some home/off-grid solar systems. There is potential for battery swapping to develop and be provided on a commercial basis.
Operation & maintenance requirements	4		Bicycle components subject to corrosion from maritime environment. Regular basic maintenance and some replacement of parts is required. There is potential for standardisation of the battery and electric drive components, enabling local village repair and support as well as cost reduction through high-volume, one-design manufacture. There is also opportunity for battery swapping at a local village level.
Waste/ end-of-life disposal	4		Consideration should be given to end-of-life disposal, and in particular to the design of batteries to provide easy refurbishment and repurposing of battery components. Some degree of parts standardisation is also expected to enable more economical repair/maintenance, resulting in longer life of both e-bike and batteries.

Environmental & social impact	5	Very low emissions. Exercise can lead to improved health and reduction in diabetes, obesity, and heart disease. Advantage of electric assistance found to greatly lower barrier to cycling for aged and less physically able. Potential to reduce traffic congestion.
Local value chain/ economic opportunity	5	Electric bicycles are suitable for local business to import, sell, maintain, repair and rent.
Required complementary measures	3	Significant increased use of e-bikes requires significant behaviour change to overcome attitudinal barriers, and changes to roads and urban design. Guidelines/standards required to manage battery design, quality, use, refurbishment, repurposing, and end-of-life disposal.
Other considerations	3	Battery swapping and standardised configurations also lend themselves to integration with off-grid domestic power systems. Selection of e-bikes should be made on the basis of whole-of-life costs, including longevity and disposal. Cheaper bikes and batteries are available but are unlikely to last as long, and there can be a heightened fire risk with the use of cheaper battery systems with poorly-managed charging systems.

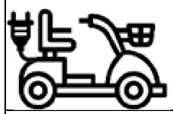
1.5 E-push scooters

Battery-electric push scooters (e-push scooters) have become a practical reality due to recent advancements in battery technology. A transport mode that offers convenience through easy storage, relatively low rider activity, and ease of use by non-disabled riders. Currently limited to short-distance, urban foot and roadway use. Potential for designs to evolve to provide improved safety in use, access to a wider range of riders, and use on a wider range of road and track types.

Type of journey/ service	Short-distance, single passenger.		Currently limited to short-distance, urban foot- and roadway-use for single riders. Range and where they can safely be used is increasing with availability of more powerful versions with further evolution expected.
Overall suitability	**H1**	**3**	E-push-scooters are readily available now but are not suitable for most island situations due to poor quality roading/pathways. More rugged designs that are better suited to island roads and paths are expected to evolve and become more available. Charging can be easily performed using domestic outlets on existing electricity supply circuits. In the short term, there may be niche demonstration applications of e-scooters in some urban areas. Providing bike lanes and standardising components will enable e-push-scooters to be a very suitable transport option and a significant component of small island urban transport in the medium to long term.
	H2	**5**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Mature and designs still evolving.		Technology and availability sufficiently mature to provide for the very rapid rise in uptake in major cities in the world beginning in 2017. Technology is still developing and there is potential for designs to evolve into partial-autonomous, partial-balancing and/or more rugged versions increasing where they might safely and comfortably be used.
Affordability/ cost	Whole-of-life	$$	Current basic form is relatively inexpensive for motorised transport, for reasonable quality ranging USD300 to USD1000. Relatively simple. Quality variants robust and near maintenance-free; however, lack of standardisation and lack of parts supply may result in early scrapping. Very low cost to charge battery.
	Purchase	$$	
	Ongoing	$$	
Supply/ availability	5		Readily available from China. Potential for overseas and local supply through recycling and refurbishment.
Carbon footprint	5		Provides new form of mobility. Global experience indicates e-push scooter use results in a decrease in GHG overall by displacing more GHG-intensive modes (rather than adding new GHG to what might have been carried out by walking), and by making mass-transport systems more accessible by providing convenient first/last mile transport to transport hubs. Little embodied carbon as battery size is small.
Energy security	5		Very low energy requirements. Nil reliance on imported energy if charged from renewable electricity.

Convenience, comfort, safety and accessibility	3	Easy to store, use, and charge. Comfort and convenience are weather-dependent. Suited for more able-bodied users. Current designs are more prone to accident than bicycles. Safety is improved through education and awareness campaigns for both riders and drivers, and by scooter-friendly infrastructure design.
Infrastructure & refuelling requirements	4	Currently require well-formed pavements or roads. E-scooters are new, and methods of sharing spaces with other modes of transport have yet to mature. Would benefit from space designs allowing sharing of modes. Easy to charge and potential for public charging to evolve to add to convenience of use. Further benefits to be realised through component standardisation.
Operation & maintenance requirements	4	Quality models expected to have few maintenance requirements. However, cheaper models are less durable and likely to have short lives, particularly in maritime environments. Potential for standardisation enabling local village repair and support, cost reduction through high-volume, one-design manufacture, and provide some consumer protection with respect to quality (i.e., the latter to avoid import of low-quality, short-life e-scooters).
Waste/ end-of-life disposal	4	Although the volume of waste relatively small for each scooter, risk of significant waste if life is short and it is considered easier and cheaper to replace rather than repair. Consideration should be given to end-of-life disposal, and in particular to the design of batteries to provide easy refurbishment and repurposing of battery components.
Environmental & social impact	5	A partially active travel mode. Safety is an issue in spaces shared with road traffic or pedestrians. Poorly used and parked shared scooters also cause negative attitudes to their use. Use has potential to result in overall reduction in main-road congestion.
Local value chain/ economic opportunity	4	Electric push scooters are suitable for local business to import, sell, maintain, repair, and rent.
Required complementary measures	3	Benefit expected from standards and guidelines for designs (eg, minimum quality and safety standards on imports) and use. Requires behaviour change to overcome attitudinal barriers of both riders and other road/path users, and changes to roads and urban design. Guidelines/standards required to manage battery design, quality, use, refurbishment, repurposing, and end-of-life disposal.
Other considerations		

1.6 Electric mobility scooters



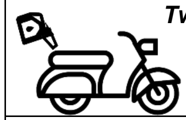
A range of normally battery-powered, small 3- and 4-wheelers providing walking-speed and short-distance mobility for less-abled persons living in urban settings. Expect increased uptake due to increasing affordability and performance (from battery advances and cost reductions, lighter construction, and designs providing use on a wider range of road types). However, they generally need well-formed paths, roads, and ramps.

Type of journey/ service	Walking-speed, short-distance, single passenger		Short-distance, personal travel currently confined to well-formed roads and pathways, offering an alternative to walking for older people and people with disabilities.
Overall suitability	**H1**	**3**	Battery-electric mobility scooters have the potential to greatly improve the quality of life for many people in SIDS who are ageing or live with disabilities. Mobility scooters will have only niche demonstration applications in the short term due to the poor condition of most sidewalks and lack of accessibility ramps, but uptake should be encouraged as they become more affordable, as more rugged designs provide for use across a wider range of situations, and as islands develop pedestrian- and micromobility-friendly infrastructure (and in this case, high-quality, well-connected sidewalks and ramps).
	H2	**4**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Mature but also developing.		Mobility scooters using lead-acid batteries have been in use for many decades and there are established markets for them. Recent advances in battery and electric motor technology have brought about new, lighter, more affordable, and more convenient options.
Affordability/ cost	Whole-of-life	$$	

	Purchase	$$	A basic model costs around USD2,000, with some models costing USD5,000. A range of lightweight variants, including portable, foldable 3-wheeled scooters, are available for as little as USD1,000. Near zero-maintenance and low cost to operate – as low as USD1 per week for electricity.
	Ongoing	$	
Supply/ availability	4		Not currently a mainstream transport mode, but demand from an aging global population, increasing affordability, and increasing urbanisation expected to result in sector growth.
Carbon footprint	5		Very low. Some emissions related to this if charged from diesel-generated electricity. Nil if charged by renewable electricity. Little embodied carbon as battery and motor are small, and body is of generally light construction.
Energy security	5		Very low energy requirements. Nil reliance on imported energy if charged from renewable electricity.
Convenience, comfort, safety, and accessibility	3		Depending on circumstances, typically maintains or improves mobility for people with disabilities living in areas with well-formed roads and paths. Generally safe due to their low speed.
Infrastructure & refuelling requirements	3		Most often charged from standard electricity mains socket outlets. Requires well-formed paths, roads, and ramps.
Operation & maintenance requirements	4		Near-zero maintenance if reasonable quality. Battery and motor-related technology common with other e-mobility forms and could be supported by same service personnel and would also benefit from some degree of standardisation.
Waste/ end-of-life disposal	4		Although the volume of waste relatively small for each mobility scooter, risk of significant waste if life is shorter due to low quality. Consideration should be given to end-of-life disposal, and in particular to the design of batteries to provide easy refurbishment and repurposing of battery components.
Environmental & social impact	5		Improves level of self-sufficiency and connectedness for older people and people with disabilities.
Local value chain/ economic opportunity	5		Best if developed alongside other small e-mobility forms to share supporting resources.
Required complementary measures	3		Improvements to paths, roads, and ramps. Best if developed alongside other small e-mobility forms, such as e-bikes, to share supporting resources. Benefit expected from standards and guidelines for designs (eg, minimum quality and safety standards on imports) and use. Guidelines/standards required to manage battery design, quality, use, refurbishment, repurposing and end-of-life disposal.
Other considerations			-

Small-format vehicles

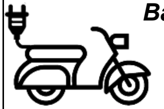
1.7 Gasoline-fuelled 2-wheelers



Two-wheeler motorcycles powered by gasoline-fuelled engines are the most common motorised vehicle across Central Asia – a result of their utility, flexibility, ease of parking, and relatively low cost to own and operate. For Asia, the majority of these are step-through scooter-types powered with small engines. Somewhat surprisingly, motorised 2-wheelers are relatively uncommon in Pacific islands, except in Tuvalu (where they dominate motorised transport), and the Cook Islands.		
Type of journey/ service	Short- and medium-distance, 1-2 passenger	Provide short- and medium- distance travel for a single or small number of passengers and/or small volume/weight of goods. Step-through scooters and many motorcycles are designed for use on sealed roads, but some variants of 2-wheelers are designed for all-terrain use. Motorcycle taxis are popular in many parts of Asia.

Overall suitability	**H1**	**4**	Gasoline-fuelled 2-wheelers ('step-through' style scooter and motorcycles) are currently well-suited for use in SIDS, but the need to rapidly phase out fossil fuels, plus the high air quality-related emissions of the 2-stroke engine scooters makes them unsuitable in the medium to long term. They cost relatively little to buy, have good range and fuel economy, and come in a wide variety of models for different applications across different terrains, including poor-quality roads. It is, therefore, surprising that they do not have a very wide penetration in most SIDS, as they do in SE Asia. It is suggested, however, that SIDS 'leapfrog' could this technology and instead adopt electric 2-wheelers.
	H2	**2**	
	H3	**1**	
Global technology outlook (feasibility/ availability)	Mature		Gasoline-powered 2-wheelers are a mature technology. For many Asian countries, they outnumber passenger cars 6-8-fold. Global production is around 40 million per year. Globally, there has been a steady shift from the use of simple, more powerful, but more polluting 2-stroke engines to the use of gasoline-fuelled, 4-stroke engines.
Affordability/ cost	Whole-of-life	$$	A popular model of gasoline-fuelled, step-through scooter in Central Asia retails for around USD1,800, with market-entry models at around USD1,200. Yearly operating costs could range from USD300 for small distances travelled to USD800 or more for medium distances travelled, including insurance, tyres, and servicing. Low-speed mopeds (motorised, pedal-assisted two wheelers) offer a cheaper option but tend to be only suitable for single-person, short-distance travel on well-formed surfaces, and tend to use basic and highly polluting engines.
	Purchase	$$	
	Ongoing	$$	
Supply/ availability	5		Readily available with some established supply chains to SIDS.
Carbon footprint	4		Gasoline-fuelled 2-wheelers consume a fraction of the fuel a passenger car does, creating the opportunity for 70-80% reduction in GHG footprint if mode switching from a single-occupancy car. Consume gasoline (with GHG emissions associated with this) and no low-carbon fuel alternatives.
Energy security	4		Consume gasoline, but relatively little compared with passenger cars (– and mode switching from single occupancy cars will reduce fuel consumption by around 70-80%).
Convenience, comfort, safety and accessibility	3		Motorised 2-wheelers provide convenient transport in favourable weather. The lower road speeds of many small islands, and the safety associated with this, suggests that there is potential for the increased use of motorised 2-wheelers.
Infrastructure & refuelling requirements	4		Gasoline-fuelled, motorised 2-wheelers can use the same roads and refuelling stations as passenger cars. Their small fuel tank size also lends them to easy remote refuelling from containers (and to supply from village stores, in remote locations). They can also be used on remote, single tracks, extending their versatility over passenger cars.
Operation & maintenance requirements	4		The service requirements of gasoline-fuelled, motorised 2-wheelers is well established, and no specialist tools are required.
Waste/ end-of-life disposal	4		End-of-life motorcycles create a small amount of waste compared with passenger cars but will still require a disposal plan.
Environmental & social impact	4		Two-stroke, gasoline-fuelled 2-wheelers are high polluting and pose increased health risk to rider and local community. The exhaust and noise emissions of a 4-stroke 2-wheeler are better, but air quality emissions range from similar to far worse than those of a typical passenger car. Switching from cars to motorbikes can reduce traffic congestion. Use of motorised two wheelers can also provide greater access to affordable, personal transport.
Local value chain/ economic opportunity	5		Local businesses expected to develop to support any growth in 2-wheeler population and use, including import, sales, and maintenance.
Required complementary measures	3		Rider and driver education on safety and road sharing between motorbikes and cars. Behaviour change campaign and incentives to make 2-wheelers a desirable alternative to cars where their use makes sense.
Other considerations	3		There are no suitable fuel alternatives to gasoline – need to consider leap to electric-powered 2-wheelers, rather than a transition that involves the intermediate deployment of gasoline-fuelled 2-wheelers.

1.8 Electric 2-wheelers (E2Ws)



Basic forms of electric, 2-wheeler motorcycles and motor scooters (E2Ws) using lead-acid batteries have been around for decades. The availability of lithium-ion and other modern batteries has opened E2Ws to a far broader market, competing with gasoline-fuelled 2-wheelers. There are signs in some markets that E2Ws will undergo a very rapid rate of uptake.

Type of journey/ service	Short- and medium-distance, 1-2 passenger		Provide short- and medium-distance travel for one or two passengers and/or small volume/weight of goods. Step-through scooters and many motorcycles are designed for use on sealed roads, but some variants of electric 2-wheelers are designed for all-terrain use.
Overall suitability	**H1** **H2** **H3**	**3** **5** **5**	E2Ws are suitable for SIDS now and in the future and should be given serious consideration. Modern battery and motor technologies give them good range and they can be easily charged at home or with simple public charging infrastructure. Currently a key constraint is the limited availability in island markets. Strategies should consider how to develop supply chains (including providing guidance on quality and specification) and ensuring the technology can be supported locally in small island markets. In the short term, niche demonstration projects could test the application in an island context and build familiarity, laying the foundation for significant uptake in the medium to long term.
Global technology outlook (feasibility/ availability)	Mature and developing		Although the IEA indicates that the population of electric 2-wheelers was 300 million in 2018 (most of which were in China),[2] they are at an emerging stage for many countries. The global market is showing signs that there will be a rapid uptake of electric 2-wheelers in the next few years, in those countries with existing motorised 2-wheeler use. Developments such as standardised battery swapping are expected to further encourage uptake.
Affordability/ cost	Whole-of-life Purchase Ongoing	$ $$ $	Currently, electric step-through scooters with batteries are similarly or higher priced compared to petroleum-engine, step-through scooters, but manufacturers predict that they will become lower priced within a few years as mainstream production develops. Battery swapping and the ability to sell the electric 2-wheeler without the requirement to buy and own a battery is already lowering the purchase cost of electric 2-wheelers over their gasoline counterparts in some markets. Operating costs for an electric 2-wheeler tend to be around 30%-50% cheaper than for petroleum-fuelled 2-wheelers, a result of lower servicing and maintenance costs and lower energy costs. Low-speed mopeds (motorised, pedal-assisted two wheelers) offer a cheaper option but tend to be only suitable for single-person, short-distance travel on well-formed surfaces.
Supply/ availability	3		The supply of quality electric 2-wheelers has yet to be well established outside of the countries in which they are manufactured.
Carbon footprint	5		Calculations indicate electric 2-wheelers produce 40% less GHG than the equivalent petroleum 2-wheeler when using diesel-generated electricity for charging, through to zero in-service emissions if charging using all-renewable electricity. They have relatively little embodied carbon as their motor and battery are reasonably small.
Energy security	5		Reduces use of imported fuel compared to the use of cars or petroleum-fuelled 2-wheelers. Use no fuel imports if charged with all renewable electricity.
Convenience, comfort, safety, and accessibility	3		Motorised 2-wheelers provide convenient transport in kindly weather. The lower road speeds of many small island countries, and the safety associated with this, is a good fit with the use of motorised 2-wheelers.
Infrastructure & refuelling requirements	4		Electric 2-wheelers can be charged from a variety of sources, including standard electricity mains socket outlets and, with the right equipment, direct from home/off-grid solar PV systems. Expected that publicly available charging would encourage their use. There is also opportunity for battery swapping.

[2] noting that the IEA statistics possibly include the smaller motorised-pedal ('moped') 2-wheelers that are common in China.

Operation & maintenance requirements	4	Electric 2-wheelers are expected to have similar service requirements when it comes to tyres, but quality electric drive systems tend to require significantly less maintenance than their petroleum counterparts. Fault repair currently requires a specialist because the technology is new rather than complicated. This situation is expected to change quickly with familiarity. Standardisation of main components is expected to provide many benefits.
Waste/ end-of-life disposal	4	Volume of waste relatively small for each electric 2-wheeler. Consideration should be given to end-of-life disposal, and in particular to the design of batteries to provide easy refurbishment and repurposing of battery components.
Environmental & social impact	5	Electric 2-wheelers expected to provide greater access to affordable mobility, including for people with disabilities and for those living in remote areas, with many associated social and economic benefits.
Local value chain/ economic opportunity	5	Local businesses expected to develop to support any growth in 2-wheeler population and use, including import, sales, maintenance, and repair of batteries and other electric systems for electric 2-wheelers.
Required complementary measures	3	Electric 2-wheelers will require new supporting skillsets to be developed in small island countries. Benefits expected from parts standardisation and other measures to ensure quality, ease of repair, and recycling and avoidance of short-life product. Guidelines/standards required to manage battery design, quality, use, refurbishment, repurposing, and end-of-life disposal. Rider and driver education for safety. Benefits expected from access to public charging and battery swapping.
Other considerations		

1.9 Ultra-light electric 3/4-wheelers (E3Ws)

	***A range of small, electric-drive, light construction 3- and 4-wheeled vehicles targeting lower-speed, on-road and pavement passenger and cargo transport (including use in pedestrian-friendly areas). Tend to have open cabins, avoiding the need for forced air conditioning, while still providing some shelter from the weather.***		
Type of journey/ service	Short- to medium-distance, multi-passenger and goods		Short-to-medium-distance public passenger and cargo transport services, particularly suited to urban, flatter terrain, first-mile/last-mile transport connection, local delivery, etc. Their small cabin space and light construction may be a limiting factor in some situations for small island countries.
Overall suitability	**H1**	**2**	E3Ws are likely to be very suitable for SIDS in the medium to long term but, as the technology is still developing, is not readily available, and is unfamiliar, they are unlikely to be suitable in the short term. E3Ws have the potential to provide future passenger taxi services, in inner urban, flatter, low-speed areas, and for tourist use. In the future, they are expected to bring many of the same benefits as E2Ws, such as being relatively inexpensive to buy and run, and easy to charge, with additional benefits of being able to carry multiple passengers and goods and providing some protection from rain. In the short term, strategies could include demonstration projects in tourist areas while keeping a watching brief on the technology in anticipation of application in the medium to long term.
	H2	**4**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Early adoption. Technology still developing.		The use of 3-wheeled tuk-tuks is a vital part of many Asian city transport systems. Their electrification has been driven by a need to lower their air quality emissions and there are many 'e-trikes' in demonstration across Asia. Electric quadricycle use is emerging in many cities in Europe. The technology is both mature, in that vehicles are available commercially, and developing, in that electric battery and motor drive technology is still evolving and further improvements are expected. There are also many cheap, low-quality variants available in the global market.
Type of journey/ service	Short- to medium-distance, multi-passenger and goods		Short-to-medium-distance public passenger and cargo transport services particularly suited to urban, flatter terrain, first-mile/last-mile transport connection, local delivery, etc. Their small cabin space and light construction may be a limiting factor in some situations for small island countries.

Affordability/ cost	Whole-of-life	$$	Purpose-built e-trikes range in price from USD5,000 to USD10,000. A Renault Twizzy, a (4-wheeled) electric quadricycle, retails at around USD15,000. Operating costs a fraction of those for operating a passenger car. However, currently electric-powered versions typically come at a premium and payback period on that premium of at least 3-5 years are typical. Expect cost reduction as battery technology improves and costs lower.
	Purchase	$$	
	Ongoing	$	
Supply/ availability	3		Currently not a mainstream vehicle option outside country of manufacture, unless for a specific project.
Carbon footprint	5		Low energy requirements, especially when compared to a passenger car. Per-passenger trip GHG emissions lower again when fully utilised – normal, in-service loading of at least 5 passengers was found in a Philippines e-trike deployment. This could result in a decrease in per passenger trip GHG emissions of up to 80% compared to single-occupancy passenger vehicle use, for charging from diesel-generated electricity. GHG emissions nil if charged by renewable electricity. Relatively little embodied carbon as motor and battery are reasonably small.
Energy security	5		Very low energy requirements compared with those for a passenger car and lower again if multiple passengers. Some emissions related to this if charged from diesel-generated electricity. Nil if charged by renewable electricity.
Convenience, comfort, safety and accessibility	3		Smaller cabin spaces and lighter construction may not be fit for some island applications. Generally, lack modern passenger car safety features such as airbags, seatbelts, protective cages. Can also be less stable. In the absence of anti-collision systems, more suited for use in low-speed traffic areas.
Infrastructure & refuelling requirements	5		Can be charged from standard mains electricity socket outlets. There is also opportunity for battery swapping and potential for the use of medium-rate, public charging.
Operation & maintenance requirements	4		The service requirements of electric 3-wheelers are similar to those for electric 2-wheelers, including that fault repair might require a specialist because the technology is new rather than complicated, or because of the specific design or components involved. This situation is expected to change quickly with familiarity. Standardisation of main components is expected to provide many benefits.
Waste/ end-of-life disposal	4		Small amount of waste due to small volume of disassembled/compacted vehicle. Consideration should be given to end-of-life disposal, and in particular to the design of batteries to provide easy refurbishment and repurposing of battery components.
Environmental & social impact	5		Nil exhaust emission and low noise of electric 3-wheelers provide benefits in urban use. Potential to provide more affordable public transport.
Local value chain/ economic opportunity	4		Local businesses expected to develop to support any growth in 3-wheeler population and use, including import, sales, maintenance, and repair of batteries, and this could be established alongside that established for the electric 2-wheeler market.
Required complementary measures	3		Improvements to roads. Driver education and behaviour change campaigns. Development of support services. Minimum quality standards to avoid import of low-quality, short-life and/or difficult-to-recycle product.
Other considerations	3		There is a history of use of petroleum-fuelled, motorcycle-based 3-wheelers and tuk-tuks providing vital public passenger transport in many Asian countries, yet almost complete absence of these vehicles in small island countries. Such vehicles are unlikely to become established in small island countries, but opportunity is seen for their (modern-day) electric counterparts.

Medium-format vehicles

1.10 Internal combustion engine (ICE) cars and light vans

			***Automotive 4-wheeled passenger and light commercial vehicles, normally mass produced to internationally recognised standards, and wholly powered by a petroleum-fuelled internal combustion engine (ICE). They are the dominant form of road transport in most island countries. Reasonable decreases in fuel dependency and carbon emissions can be gained by shifting to smaller vehicles and shifting to more modern engine and drivetrain arrangements (for example, such as hybrid), and also through better utilisation of vehicles (including through the use of shared transport mechanisms).***
Type of journey/ service	Short-to-long-distance, several passengers and goods transport		Short-through-long-distance travel, single-to-multiple person occupancy, generally light goods transport, on- and off-road depending on variant. Cars and vans offer protection from most weathers. Provide safe, comfortable, and convenient transport, for those that can afford them.
Overall suitability	**H1**	**5**	Internal combustion engine (ICE) vehicles with currently available fuels are very suitable for islands in the short term, and a poor fit in the long term due to the need to decarbonise transport. The infrastructure and urban form of SIDS' main islands have been shaped by the automobile, with roading infrastructure providing for increasing numbers of cars, in turn making cars all but necessary for mobility. ICE light vehicles dominate main island land transport systems, as they do in many countries, due to their convenience, comfort, and versatility. In the short term, petroleum-fuelled light vehicles will remain a mainstay of main islands' land transport systems, although in the medium term the need to decarbonise, and the development of more attractive alternatives, makes ICE cars increasingly unsuitable. In the long term, after 2035, global supply chains for ICE vehicles may become limited and more difficult again for SIDS to access.
	H2	**3**	
	H3	**1**	
Global technology outlook (feasibility/ availability)	Mature and production expected to decline.		There is over a century of development behind 4-wheeled automobiles, resulting in a wide range of model variants designed to meet a broad range of service types. The past 50 years have also seen developments to meet increasingly stringent exhaust emission regulations, increasing fuel economy requirements, the commercialisation of fuel alternatives to gasoline and diesel, and the commercialisation of battery-electric systems. Many major car manufacturers have now committed to phasing out production of ICE vehicles and switching instead to vehicles powered by electric-drive systems.
Affordability/ cost	Whole-of-life	$$	Imported new and used. Taking Fiji's example, relatively flat terrain allows a choice of cheaper, smaller-engine models. Entry level for new, mid-sized passenger cars and vans around USD20,000 and USD25,000 respectively, and around half of this for a 5-year-old used import. Owner-operator costs of around USD1,000-$4,000 annually, depending on annual mileage.
	Purchase	$$	
	Ongoing	$$	
Supply/ availability	5		Readily available new and used.
Carbon footprint	3		Use petroleum fuels and reasonable GHG emissions associated with this, particularly on a per-passenger trip basis for low occupancy. However, can provide similar-to-better GHG emissions to per-passenger trip by bus for high occupancy.
Energy security	3		Reliant on the import of high-quality petroleum fuels.
Convenience, comfort, safety, and accessibility	5		Convenient, comfortable, all-weather. Use as taxis provides wider access to transport by passenger car.
Infrastructure & refuelling requirements	4		Cars require expensive infrastructure in the form of roads, carparks, and petroleum fuel supply chains. While a great deal of this infrastructure is in place already, it requires maintenance, repair, and renewal on a regular basis. Some upgrade of fuel-related activities may be required to maintain the quality requirements of modern engines.
Operation & maintenance requirements	4		Service requirements well established, including grey markets for parts and service of common vehicles. Latest- and non-common-model vehicles tend to be avoided due to risk of non-availability of parts and/or trained service providers, and risk of extended downtime associated with this.

Waste/end-of-life disposal	3	Reasonable volume of end-of-life scrap and few mechanisms available for disposal in small island countries other than landfill or open-field dumping. Import of near-end-of-life vehicles makes situation worse.
Environmental & social impact	3	Use can lead to air quality issues, made worse by generally poor level of maintenance and increasing congestion in urban areas (the latter as a result in growing vehicle population).
Local value chain/ economic opportunity	4	Local supply chain and local maintenance and repair already well established for common light vehicle models, including grey market parts supply and service support.
Required complementary measures	3	Minimum import requirements could improve vehicle safety specifications and avoid import of near-end-of-life vehicles. Interventions may also address end-of-life removal of vehicles from islands. Improved management of fuel quality required in some areas to support the use of modern vehicles.
Other considerations	5	Generally, light 4-wheelers travel small annual distances in small island countries, opening the opportunity for ride- and vehicle-sharing as a means to improve on utilisation and to reduce environmental footprint.

Explanation 1: Types of cars from conventional to pure electric

'Simple' battery and electric motor combinations, as in battery-electric vehicles (BEVs) have no on-board petroleum-fuelled engine (and are sometimes referred to as pure or all-electric vehicles).

Plug-in hybrid electric vehicles (PHEV) have a petroleum-fuelled engine that might, at times, fully or partially propel the vehicle, including configurations where the vehicle's on-board engine is only used to recharge the on-board batteries (the latter sometimes referred to as a 'range-extender' configuration).

Alternative arrangements to plug-in (conductive) charging of BEVs and PHEVs, including battery swapping, (inductive) contactless charging, and occasional charging of the onboard batteries on the move through overhead wires (as demonstrated in several European truck projects).

There are also models of hybrid vehicles that are not plugged in (simply referred to as a hybrid electric vehicle, or HEV) – their batteries are only charged by regenerative braking or possibly by electricity generated by the on-board petroleum-fuelled engine. HEVs do not draw electricity from an external source and are often not classified as electric vehicles when considering a country's electric vehicle population. Such non-plug-in variants have good fuel economy compared to their internal combustion engine (ICE)-only variants and are becoming popular as taxis for this reason. The technology is also becoming more prevalent as vehicle manufacturers strive to meet increasingly stringent international fuel economy (and related GHG emissions) requirements, and air quality emissions regulations.

Summarising the status and future of these electric vehicles:

- BEVs provide greatest all-electric range. Currently their purchase price is similar to a PHEV but higher than a HEV, which is higher again than a standard petroleum-fuelled (ICE) vehicle of similar type. The total cost of ownership (TCO) of BEVs over several years is becoming lower than that of an ICE and is similar to that for a HEV. The purchase price of BEVs is forecast to become lower and their performance better than ICEs due to improvements in battery technology, and when this happens BEVs will be financially more attractive than ICEs, HEVs and PHEVs right from purchase, and followed by lower operational costs. Although their maintenance requirements are low, maintenance and repair currently require highly skilled practitioners.
- A driver of a PHEV can select all-electric operation when there is sufficient battery charge for this to happen. PHEVs often have a small, 30-50km all-electric range (the range deliberately limited to keep their battery and electric system small and affordable). This can be charged by an external source of electricity, as has been mentioned. The TCO of a PHEV over several years is currently slightly higher to comparable with that of an ICE and is expected to become reasonably better than an ICE over time. However, the presence of the internal combustion engine will likely maintain operating costs higher than those of a BEV. As with BEVs, specialist technicians are required to provide maintenance and support for the electric drive system.
- HEVs can provide up to 30% lower fuel consumption compared with their standard ICE counterparts when operating in urban and stop-start driving conditions, performance that is achieved through capturing the energy of braking and feeding this back to the drive wheels when required. They have very limited all-electric range and the driver cannot normally select all-electric operation other than by driving very slowly when the battery has charge. Although service personnel should have reasonable competency before they work on a HEV, experience from some countries indicates that HEV service support can be provided without specialist training (although this is not recommended).

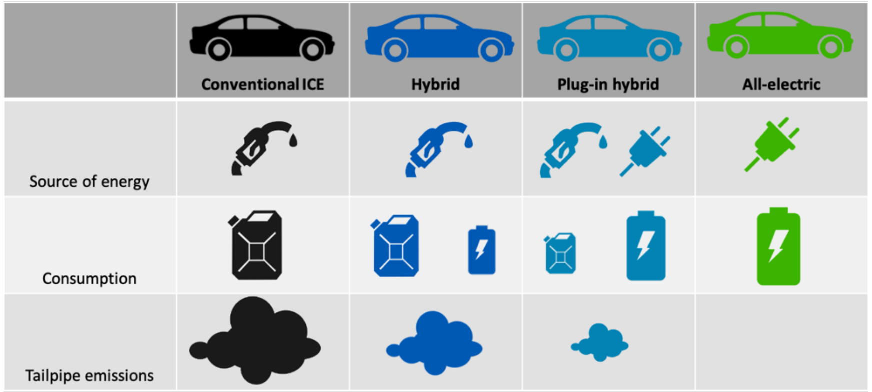


Figure 3: Types of cars from conventional to pure electric

1.11 Battery electric vehicles (BEVs)

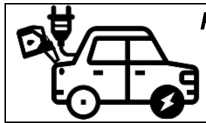
Automotive 4-wheeled passenger and light commercial vehicles, normally mass produced to internationally recognised standards, and wholly powered by an electric motor supplied electricity from an onboard battery, charged from a source of electricity that is external to the vehicle. The Nissan Leaf, the first mainstream production battery electric vehicle (BEV), was launched in 2010. The technology is now considered both mature – globally there are around 8 million BEVs – and maturing – new batteries are extending range and convenience is approaching that of petroleum-fuelled vehicles. BEVs are expected to become mainstream within a decade, propelled by their normalisation and the expectation of price parity with petroleum-fuelled counterparts. Currently limited to smaller light vehicle models.[3] Commercial and heavier light EVs are in development.

Type of journey/ service	Short- to long-distance, 1-several passenger and goods transport		Short- through medium-distance travel (extending to long-distance travel where infrastructure supports this or for latest EV model variants), single to multi-occupancy, generally light loads if commercial, generally for use on well-formed roads (although off-road variants are in development).
Overall suitability	**H1**	**3**	Battery-electric vehicles (BEVs) are somewhat suitable for SIDS in the short term, becoming very suitable in the medium to long term. The suitability of BEVs depends on the availability of infrastructure and services, including vehicle service support, a good-quality, high-renewables electricity supply, and end-of-life management for batteries. At present, BEVs are more expensive than their ICE counterparts and GHG emission benefits depend on the proportion of renewable electricity. As renewables increase, and the global market for second-hand BEVs grows, BEVs will become a more attractive option for SIDS. Strategies in the short term should consider demonstration in government fleets and support for enthusiasts in order to build familiarity, in anticipation of increased uptake in the medium to long term.
	H2	**4**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Mature and developing.		BEV technology is mature: BEVs are becoming mainstream – they are becoming normalised, and it is expected that they will reach purchase price parity with petroleum-fuelled counterparts, then become cheaper as battery technology develops. Several governments have given timelines for when bans will be imposed on the purchase of petroleum-fuelled vehicles, and some vehicle manufacturers have declared timelines for shifting to exclusive manufacture of EVs.
Affordability/ cost	Whole-of-life	$$	Currently price of BEVs higher than for equivalent petroleum-fuelled vehicle. BEVs made more affordable through import of used vehicles, often providing carryover of EV subsidy provided in country of origin, plus tax reduction for EVs, in case of Fiji. At the time of writing, purchase price premium of 10-30% with no tax incentives, taking to the order of 2.5 years (for high vehicle use) to 7 years (low vehicle use) for savings from lower cost of energy and maintenance to break even on price premium.
	Purchase	$$$	
	Ongoing	$	
Supply/ availability	3		Used imports available. Unknown service support and low-rate household power connections discouraging uptake. For new vehicles, elevated demand from other countries plus lower than forecast vehicle manufacture due to COVID-19 currently limiting the availability of BEVs in secondary markets (which small island countries tend to be). Also, significant investment for a new vehicle supplier to enter a market with a new technology. Both importers of new and used vehicles can also be reluctant to import where demand is low or unknown.
Carbon footprint	4		In-service emissions for BEV are expected to be around 30% less than for a petroleum-fuelled ICE when charged with diesel-derived electricity, falling to zero emissions when charged with 100% renewable energy. However, BEVs have higher embodied (or build) energy than ICEs and it can take several years (see box on embodied carbon) of in-service emissions savings to break even on this starting GHG emission.
Energy security	4		A 30% reduction in petroleum fuel consumption expected for charging from diesel-derived electricity. Nil imported fuel requirements if charging from all-renewable generation.

[3] For road vehicles classes, a 'light vehicle' is often defined as a vehicle with gross (laden) vehicle weight of not more than 3.5 tonnes.

Convenience, comfort, safety, and accessibility	5	Convenient, comfortable, all-weather. Use as taxis provides greater access to technology by wider population (which is why use as taxis is targeted in EV promotional and familiarisation campaigns). Lower range of earlier EVs less of an issue with expected smaller range requirements on islands.
Infrastructure & refuelling requirements	3	Potential for most charging to occur conveniently through the use of slow charging at private dwellings. However, this may require upgrade of household electricity supply circuits, and upgrade of local supply networks (particularly if several EVs are charging on the same local network). Mainstream EV use will need fast recharging to be established and requires careful management to avoid high-cost installations and stress on electricity supply infrastructure.
Operation & maintenance requirements	3	BEVs typically require less servicing and maintenance. However, they require specialist skills and equipment when needed. Small island countries will need to develop this capability. In general, response to Covid-19 has resulted in greater use of remote support methods, which should aid the use of remote specialist support, but this capability has yet to be developed in the automotive sector.
Waste/ end-of-life disposal	3	The motors and batteries are relatively large, and consideration must be given to end-of-life repurposing, recycling, and/or disposal. For the remainder, reasonable volume of end-of-life scrap and few mechanisms available for disposal in small island countries.
Environmental & social impact	4	General reduction in environmental footprint compared to conventional vehicles, including reduction in noise and local air quality-related emissions. In the long term, expect BEVs to provide more affordable transport, including through enabling the introduction and use of autonomous technologies.
Local value chain/ economic opportunity	4	Local supply chain expected to develop, including import, sales, maintenance, and repair of EVs, as well as managing the end-of-life options for batteries.
Required complementary measures	3	Likely to require government support to establish and to manage end-of-life options. Requires information campaign as part of EV normalisation and upskill programme, training of technicians, establishment of charging infrastructure, and other preparation for mainstream EV uptake. Also requires early encouragement to gain early adoption and experience, in readiness for national-scale uptake.
Other considerations	4	Early adoption is important to set the scene for earlier normalisation and earlier significant uptake of EVs – bringing forward the time at which EVs provide significant, national-scale benefits.

1.12 Plug-in hybrid vehicle (PHEVs)



Plug-in hybrids (PHEVs) have a petroleum-fuelled engine plus an electric drive system, each of which can partially or wholly propel the vehicle. Different to an HEV, PHEV can be charged from an external electricity source. At the time of writing, there were relatively few PHEVs in small island countries. PHEVs are expected to become mainstream within a decade, propelled by their normalisation and flexibility in areas with unreliable electricity supply. PHEVS can be operated without charging, but this forgoes the advantages of the electric drive system.

Type of journey/ service	Short- to long-distance, several passenger and goods		Short- through long-distance travel, single to multi-occupancy, generally light loads if commercial, on- and off-road depending on variant.
Overall suitability	**H1**	**3**	Plug-in hybrid electric vehicles (PHEVs) are somewhat suitable for SIDS now but may find niche applications over all time horizons where the application of the petroleum engine provides benefits (such as the redundancy it provides in disaster response scenarios). The suitability of PHEVs for islands is expected to increase over the next decade as the technology becomes normalised and cheaper, although the benefits depend entirely on how the vehicle is used and fuelled. In the longer term, they are less suitable in the context of decarbonisation if dependent on current fuels.
	H2	**4**	
	H3	**3**	

Global technology outlook (feasibility/ availability)	Mature and developing.	PHEV technology is mature now. Battery and other developments are expected to continue improving them. PHEVs are expected to become mainstream within a decade, propelled by their normalisation, their ability to selectively operate in all-electric mode, and their ability to provide range conveniently, when required (an advantage that is less beneficial in an island situation).
Affordability/ cost	Whole-of-life: $$ Purchase: $$$ Ongoing: $$	Without incentives or subsidies, the purchase price of a PHEV is expected to remain higher than an ICE or a BEV, but the TCO is expected to become lower than for an ICE in the H2-H3 timeframe (a result of lowering purchase price plus lower cost of energy). PHEVs are made more affordable through import of used vehicles, often providing carryover of EV subsidy provided in country of origin, plus tax reduction for EVs, in case of Fiji. .
Supply/ availability	3	Used imports available. For new vehicles, elevated demand from other countries plus lower than forecast vehicle manufacture due to COVID-19 currently limits the availability of PHEVs in secondary markets (which small island countries tend to be). Importers of new vehicles face significant costs in supporting a PHEV model and are reluctant to begin without known demand for vehicles.
Carbon footprint	4	No fuel consumption in all-electricity mode (which can be selected by the driver). Lower fuel consumption of hybrid system when in ICE-mode results in up to 30% lower in-service GHG emissions compared with their non-hybrid, all-petroleum-fuelled counterparts. Further reductions in in-service GHG emissions are possible through the combination of higher RE in the electricity mix plus greater use in all-electric mode. PHEVs generally have higher embodied (or build) energy than their petroleum counterpart. It can take several years of in-service savings to break even on the additional embodied carbon of an EV over its all-fuel counterpart (see box on embodied carbon).
Energy security	4	Use of PHEVs is expected to result in modest through very large decreases in consumption of imported fuels, depending on the proportion of time they are operated in all-electric mode and the proportion of renewable electricity used to charge them.
Convenience, comfort, safety, and accessibility	5	Convenient, comfortable, all-weather. Use as taxis provides access by a greater population.
Infrastructure & refuelling requirements	5	Fast recharging is not necessary as PHEVs can operate on all-fuel mode. Potential for most charging to occur conveniently from private, slow charging, when vehicle not used, but may require upgrade of household electricity connection, and local electricity supply network if many EVs are charging at the same time.
Operation & maintenance requirements	3	PHEVs require similar servicing and maintenance to their petroleum-fuelled counterparts, but specialist skills and equipment will be required for the battery and electric drive system.
Waste/ end-of-life disposal	3	The motors and batteries are moderately large, and consideration must be given to end-of-life repurposing, recycling, and/or disposal. For the remainder, reasonable volume of end-of-life scrap and few mechanisms available for disposal in small island countries.
Environmental & social impact	3	General reduction in environmental footprint compared to conventional vehicles if all-electric mode often used, including reduction in noise and local air quality-related emissions.
Local value chain/ economic opportunity	3	Local supply chain expected to develop, including import, sales, maintenance, and repair of EVs, as well as managing the end-of-life options for batteries.
Required complementary measures	3	Likely to require government support to establish and to manage end-of-life options. Requires information campaign as part of EV normalisation and upskill programme, training of technicians, establishment of charging infrastructure, and other preparation for mainstream EV uptake. Also requires early encouragement to gain early adoption and experience, in readiness of national-scale uptake.
Other considerations	3	Early adoption is important to set the scene for earlier normalisation and earlier significant uptake. However, long-term outcome may suggest effort is better directed to promoting the use of BEVs. That said, the flexibility of two different power systems may provide a useful flexible demand for locally produced fuels, should small-scale, high quality biofuels manufacture become a reality in the future.

1.13 Hybrid vehicles (HEVs)

Hybrid vehicles (HEVs) retain a petroleum engine and use a small battery and electric motor to capture energy during braking and deliver this back to propel the vehicle. Since the first mainstream production example of this technology, the Toyota Prius, debuted in 1997, hybrids have become a mature and well-established technology. HEVs are already in widespread use in Fiji. Hybrids offer around the same fuel and GHG reductions as a fully electric vehicle charged on diesel-generated electricity.

Type of journey/ service	Short- to long-distance, 1-several passenger and goods transport		Short- through long-distance travel, single to multi-occupancy, generally light loads if commercial, on- and off-road depending on variant.
Overall suitability	**H1**	**4**	HEVs are very suitable in the short to medium term in SIDS, becoming unsuitable in the long term due to the need to decarbonise almost entirely. HEVs are an established technology that, due to their fuel economy, has found favour in many island contexts, particularly in taxi fleets. HEVs offer around the same GHG reductions as a BEV charged from diesel-generated electricity, and yet, because they do not require external connection for charging, they are as convenient as pure ICE vehicles. Hybrids can play the role of a ‘stepping stone’ towards electric vehicles as they are cheaper and introduce electric vehicle technology, providing experience to the motor service industry. Hybrids are expected to remain a useful element of island vehicle fleets in the medium-term.
	H2	**5**	
	H3	**2**	
Global technology outlook (feasibility/ availability)	Mature		HEVs have become mainstream – it is now difficult to meet some global regulatory performance requirements without some form of electric assistance in a vehicle manufacturer’s vehicle range.
Affordability/ cost	Whole-of-life	$$	Price of HEVs higher than for equivalent petroleum vehicle. HEVs made more affordable through import of used vehicles. Tax reduction for EVs in Fiji is sufficient to remove their price premium over non-hybrid variants. Otherwise, payback period for purchase price premium of 1-3 years, depending on utilisation, can be expected.
	Purchase	$$	
	Ongoing	$$	
Supply/ availability	5		Used imports readily available to Pacific Islands.
Carbon footprint	4		Lower fuel consumption of HEVs results in around 30% lower in-service GHG emissions compared with their all-petroleum counterparts (similar to the savings achieved through use of a BEV charged from diesel generation-derived electricity).
Energy security	4		Hybrids use around 30% less imported fuel than their all-petroleum counterparts, providing increased fuel security.
Convenience, comfort, safety, and accessibility	5		Convenient, comfortable, all-weather. Use as taxis provides greater access.
Infrastructure & refuelling requirements	3		As for all petroleum-fuelled vehicles, there is significant roading and fuel supply infrastructure supporting the use of HEVs. While there is a great deal of this infrastructure in place already, it requires maintenance, repair and renewal on a regular basis. Require assurance of fuel quality to provide for most modern engine types.
Operation & maintenance requirements	4		HEVs require a similar level of servicing to modern petroleum vehicles. Grey-market repairers in many countries have quickly acquired the skills necessary to provide service support for the battery and electric drive system (although it is recommended that work be carried out by those trained in the field).
Waste/ end-of-life disposal	2		Reasonable volume of end-of-life scrap and few mechanisms available for disposal in small island countries. Consideration should be given to end-of-life repurposing, recycling, and/or disposal of batteries and motor.
Environmental & social impact	4		Some benefits to air quality compared with conventional vehicles. Provide more affordable transport.

Local value chain/ economic opportunity	4	Much of the local supply chain, including grey market, already established. Some additional capability building may be required to support the battery-electric drive system, but some countries have shown that this can be relatively easily achieved at a grey-market level.
Required complementary measures	3	Likely to require government support to establish and to manage end-of-life options. Requires information campaign as part of a promotion, normalisation and upskill programme. Also requires early encouragement to gain early adoption and experience, which adds to the normalisation of other electric vehicle types.
Other considerations	4	Early adoption is important to set the scene for earlier normalisation and earlier significant uptake. Fiji's experience is important to other small island countries, in this regard.

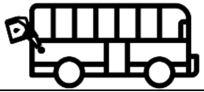
1.14 Electric minibuses

			***Automotive 4-wheeled light and heavy road vehicles designed for the carriage of 8-20 passengers, powered by a battery and electric motor drive system, and charged using electricity from an external source.***
Type of journey/ service	Short- to medium-distance, multi-passenger transport and/or freight		Can provide a range of multi-passenger and/or freight transport services. Although most models are suited for use on high-class roads, some models are also suitable for use on more rugged roads. Smaller format (8-20 passengers) and mixed passenger and freight enables a variety of uses. Combined passenger and freight options are particularly attractive for island situations.
Overall suitability	**H1**	3	**Electric minibuses** are likely to be a very suitable transport solution for islands in the medium to long term, with a need to do some early demonstrations and build familiarity in the short term. They are far cheaper and easier to support, operate and charge than full-size electric buses. At the same time, they provide a flexible fleet that may be better suited to smaller and more dispersed populations across both urban and rural areas. The development of charging and servicing systems to support BEVs is in line with what is needed to support electric minibuses. Electric minibuses could play a significant role in island passenger transport within 10 years and remain in the long term.
	H2	5	
	H3	5	
Global technology outlook (feasibility/ availability)	Mature but still developing		The technology is both mature (the same technology is used for passenger car EVs), and improving through steady improvements to batteries, motors and related systems. These improvements have seen electrification of vehicles expand into heavier vehicle formats – minibuses included. The expectation is that many new models will become available as variants to promised electric commercial van releases. Their range combined with flexible charging options is expected to provide flexibility in meeting required a wide range of passenger and/or freight transport services.
Affordability/ cost	Whole-of-life	$$	Electric minibuses are generally produced by volume manufacture of the base commercial van platform plus before- or after-market retrofit for passenger use. They are becoming purchase-price competitive with petroleum-fuelled counterparts, particularly for smaller models. Slightly lagging predictions for passenger car EVs, it is expected that price parity will be common for new vehicles in the global market in about 5 years' time, with price parity of used electric minibuses into the islands occurring at much the same time. It is expected that they will have low maintenance requirements, although access to supporting services could be an issue over the next 5-7 years as local capacity develops. The cost of energy is expected to be far lower than for an equivalent petroleum-fuelled counterpart, although some upfront costs may be involved if it is necessary to install dedicated, fast charging infrastructure (which could be shared between several electric minibuses. The alternative of night-time use of public fast-charge facilities might also be an option).
	Purchase	$$$	
	Ongoing	$$	
Supply/ availability	3		There are a few electric minibus model options available in the market today. It is expected that most significant vehicle manufacturing groups will have electric commercial vans (and passenger variants) in the marketplace within 5 years and that used first-generation models will be accessible to the islands at much the same time.

Carbon footprint	4	Expect a 20-30% reduction in in-service GHG emissions for charging using diesel-generated mains electricity, with potential for nil in-service GHG emissions if charging using renewable electricity. However, there is a reasonable amount of embodied carbon associated with the batteries and electric motor which could take several years of in-service GHG emissions to break even on.
Energy security	4	Around a 20%-30% reduction in imported fuel consumption for use of diesel-derived electricity for charging, through to nil reliance on imported fuel if charged using renewable electricity.
Convenience, comfort, safety, and accessibility	4	Modern minibuses provide comfortable, all-weather transport. Convenience to the user depends on frequency, routing and others.
Infrastructure & refuelling requirements	3	Current model electric minibuses can be charged at slow- through to fast-rates. Operations best supported by access to fast charging, providing for flexibility in how the minibus can be used (i.e., with fast top-ups providing a relatively fast return to service, should this be required). Also potential for minibuses to be charged from public fast chargers at night when they are otherwise seldom used.
Operation & maintenance requirements	3	Service support yet to be established and has the potential to be problematic in the short term but expect this to be developed on the back of capacity building to meet the support service requirements of other EV types.
Waste/ end-of-life disposal	3	Medium-sized volume of end-of-life scrap. The batteries, power electronics and motors tend to be larger than used on passenger car EVs. Refurbishing, repurposing and end-of-life disposal practices will need to be developed for batteries and then carefully managed. Expect extended use of the batteries would be encouraged due to their value when repurposed as stationary electricity storage applications (including in support of providing fast charging in areas where electricity supply is limited).
Environmental & social impact	4	Nil local exhaust emissions and low noise emissions, providing for better environments. Expect electric minibuses to provide affordable public passenger transport.
Local value chain/ economic opportunity	4	Expect local industries to develop in support of electric minibuses, on the back of developing supporting services for other EV types.
Required complementary systems and policies	3	Likely to require government support to establish and to manage end-of-life options, particularly for the batteries. The use of minibuses may require greater coordination on routing and timetables so that the services provided become an integral component of the public transport system. Benefits expected from shared and electronic ticketing.
Other considerations		-

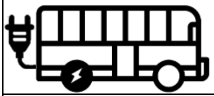
Large-format vehicles

1.15 Petroleum-fuelled buses

	***Automotive 4-wheeled heavy vehicles designed to carry multiple passengers and powered by petroleum-fuelled (normally diesel) engines.***		
Type of journey/ service	Short- to long-distance, multi-passenger transport		Provide on-road short-, medium- and long-distance passenger transport where there is sufficient demand for multi-person transport.
Overall suitability	**H1**	5	Gasoline and diesel-fuelled buses presently play a major role in the transport systems of some (not all) SIDS, providing affordable transport for many people. When well utilised, buses can be more energy-efficient and lower in GHG emission than cars (on a passenger-km basis) and, in the absence of viable alternatives, they are a very suitable technology in the short to medium term. In the long term, as the use of fossil fuels is phased out, it will become important to find alternatives to fossil-fuelled modes of every description, including buses.
	H2	5	
	H3	2	
Global technology outlook (feasibility/ availability)	Mature		Petroleum-fuelled buses are a common form of passenger transport across the globe. Most are diesel-fuelled.
Affordability/ cost	Whole-of-life	$	To the service provider, there is often a balance between regulated public transport fares and affordability to provide service. For SIDS, many buses are imported used, significantly reducing purchase cost, plus the grey market is well-established to support common (older) models (and older engine types are less susceptible to fuel quality issues). It is expected that age and/or other restrictions would bring about improvements in air quality emissions performance through eliminating old, poorly performing buses and such practices as repowering using scrap-grade engines. From a passenger point of view, buses provide one of the cheapest transport options for medium- and long-distance travel.
	Purchase	$	
	Ongoing	$	
Supply/ availability	4		Readily available through import of used vehicles, importing on demand.
Carbon footprint	4		Many buses are diesel-fuelled and the higher efficiency of diesel engines results in lower GHG emissions than for equivalent gasoline-fuelled buses. GHG emissions low on a per-passenger-km basis if occupancy high, compared to average passenger car use.
Energy security	2		Reliant on the supply of high-quality imported diesel fuels.
Convenience, comfort, safety, and accessibility	3		Modern buses provide comfortable, all-weather transport. Convenience to the user depends on frequency, routing and others. Buses that provide for people using wheelchairs and mobility aids with low floors and hydraulic 'kneeling' are globally available. However, such buses are best suited to high-quality roads.
Infrastructure & refuelling requirements	4		Use established refuelling stations. Uptake of more modern engine types of dependent on assurance of fuel quality.
Operation & maintenance requirements	4		Service support for current fleet well established, including grey market for parts and service. Newer bus models with advanced engines/systems will require support by specialists plus new parts supply chains. The lack of these presents a risk to operators, and acts as a barrier to the uptake of more modern, low-emission engine technology.
Waste/ end-of-life disposal	3		Large volume of end-of-life scrap. Tend to be refurbished so that they provide long service life, delaying their disposal. Few suitable options available when disposal is required. The introduction of air quality emissions requirements and/or age-related restrictions will limit the practice of maintaining very old buses.

Environmental & social impact	3	Provides important, affordable mass-passenger transport. Without good management, can result in high per-person local air quality emissions compared with standard passenger car use. Assurance of fuel quality and local market support of modern engine technology are barriers to the uptake of low-emission buses.
Local value chain/ economic opportunity	4	Provides important, affordable mass-passenger transport, supporting society in general from school attendance to providing essential transport for industry workers. Operation of buses supported by local industries and employment. Also supports local coachbuilding.
Required complementary systems and policies	3	Likely to require government support to establish and to manage end-of-life options. As part of a public transport system, buses need coordination on routing and timetables, service level agreements and sometimes subsidies from government. Benefits expected from shared and electronic ticketing. Improvements in fuel quality are an enabler for uptake of low-emission engine variants.
Other considerations		

1.16 Electric buses



Automotive 4-wheeled heavy vehicles designed for the carriage of multiple passengers, powered by a battery and motor electric drive system, and charged using energy from an external source.

Type of journey/ service	Short- to medium-distance, multi-passenger transport		Currently provide on-road short- and medium-distance passenger transport where there is sufficient demand for multi-person transport. Long-distance transport by e-bus requires further developments for it to be cost-effective but expect this to change within a few years. Not suited for use on rough roads.
Overall suitability	**H1** **H2** **H3**	2 4 5	In the short term, full-size e-buses are not suitable for SIDS. They are expensive, their technology is not proven in an island environment, their specialisation requires close support from the manufacturer, and the supporting charging infrastructure can add significant costs to a project – only large fleets are currently economically viable and there are few opportunities for such across the SIDS. They are expected to become more suitable in the medium to long term (as the cost of the vehicles comes down and proliferation in other regions provides necessary experience plus opportunity for the import of second-hand units), although their suitability will depend on high renewable electricity and upgraded grid infrastructure to allow for charging heavy vehicles. Running electric buses on diesel-generated electricity provides marginal GHG benefits and a long GHG payback period on the additional GHG associated with the manufacture of an electric bus over a diesel bus.
Global technology outlook (feasibility/ availability)	Mature and developing		The technology is both mature (IEA reports the global population of e-buses in 2020 was around 600,000) and improving. Improvements in battery performance and reduction in battery cost are expected to result in both lower cost and more flexible e-bus options, with rapid advancement encouraged by a ban on petroleum-fuelled buses in many major cities in the world. Use on small islands still a relative unknown with respect to battery and electrical system performance in warm, humid, and maritime environment.
Affordability/ cost	Whole-of-life Purchase Ongoing	$$$$ $$$$ $$$	Present-day, reputable e-bus manufacturers generally target orders of at least 50 buses and price e-buses accordingly, with small orders of 1 to 5 e-buses incurring significant cost premiums (eg, for one supplier, taking the purchase price for a 10 metre e-bus from USD180K to USD320K) (personal communication). In addition, there may be significant costs in establishing charging infrastructure and providing manufacturer's technical support locally, again with costs escalating on a per-bus basis for small e-bus numbers. Combined, despite lower energy costs, currently the total cost of ownership (TCO) of 1-2 e-buses could be many times higher than providing the equivalent service using a similar class of diesel-fuelled bus, whereas the TCO for a fleet of 50-100 e-buses can be lower than for diesel-fuelled equivalents. As battery performance improves, battery cost reduces, service support becomes more universal, and operation in small island environments is more understood, expect the TCO of 'island specification' e-buses to become less than for diesel buses, even when deployed in small bus numbers.

Supply/ availability	3	Available new in small numbers, expected to incur a large price premium. Available used from China and sometimes on lease from China and other countries. Expect increasing availability as global market expands.
Carbon footprint	3	Some small improvement in in-service GHG emissions expected, even for charging using diesel-generated mains electricity, with potential for very low in-service GHG footprint if charging using RE. However, high amount of embodied carbon associated with the (normally) large battery capacity required, on which it may take >10 years of in-service GHG savings to break even for a new e-bus.
Energy security	4	A small, around 10% reduction, in imported fuel consumption expected for typical e-bus operation using all diesel-derived electricity for charging. Nil reliance on imported fuel if charged using renewable electricity.
Convenience, comfort, safety, and accessibility	4	Modern buses provide comfortable, all-weather transport. Convenience to the user depends on frequency, routing, and others.
Infrastructure & refuelling requirements	2	Constraints in electricity supply and the need to constrain charging infrastructure costs will likely limit small island e-bus deployments to the use of slower overnight charging (but still very fast, by passenger car EV standards), possibly with one such charger per bus, with buses fitted with reasonably large batteries to provide their daily range (even for island use). Note that this specification is contrary to the current global trend of >100 e-bus fleet deployments, which tend to use buses with small onboard batteries and ultra-rapid charging.
Operation & maintenance requirements	2	Service support yet to be established and has the potential to be costly to provide, particularly if shared across only a small number of vehicles. Expect significant reduction in the cost to provide service support as systems become more universal and locally supported, and operation of e-buses in maritime, small island environment become understood.
Waste/ end-of-life disposal	3	Large volume of end-of-life scrap. The batteries, power electronics and motors are large, and refurbishing, repurposing and end-of-life disposal practices will need to be developed and then carefully managed. Expect extended use of the batteries would be encouraged by their value when repurposed as stationary electricity storage applications (including in support of providing fast charging in areas where electricity supply is limited).
Environmental & social impact	5	Nil exhaust emissions and low noise emissions, providing for better environments. Expect electric buses to provide one of the most affordable public passenger transport options in the future.
Local value chain/ economic opportunity	4	Will be initially reliant on support from international service providers but expect at least moderate level of local support to be established in long term, with local enterprises built around this.
Required complementary systems and policies	3	Likely to require government support to establish and to manage end-of-life options, particularly for the batteries. As part of a public transport system, buses need coordination on routing and timetables, service level agreements and sometimes subsidies from government. Benefits expected from shared and electronic ticketing.
Other considerations		

Explanation 2: Charging for buses

Global evolution in heavy electric buses has seen a movement towards the use of smaller batteries and more frequent and faster charging. The advantages include reduced vehicle weight and cost, sometimes less passenger space loss to the batteries, and more flexible operation. Such charging has progressed to ‘flash charging’ over the tens of seconds that a bus stops to pick up passengers. This formula is more suited to Mass Rapid Bus Transit systems in densely populated cities and is not well suited for the bus densities that are found in small island countries. Also, flash charging would present a difficult electrical demand to provide for in a small island electricity supply setting. But given this evolution, the generally smaller distances travelled on the islands might still provide the opportunity to use buses with smaller battery capacities, avoiding the high cost of large batteries and higher vehicle weight (and related higher level of road damage), and may also avoid loss of passenger space to batteries.

1.17 Hybrid-electric trucks (non-plug-in)

Four-wheeled heavy vehicles designed for the carriage of freight using an internal combustion engine plus a non-plug-in battery and electric motor system, the two drive systems automatically working together to reduce on-road fuel consumption.

Type of journey/ service	Short- to long-distance freight		Goods carriage. Provide best performance in short- and medium-distance trips where there is a lot of stop-start and/or congested road operation. Can also be used for long-distance transport but with limited advantage over non-hybrid variant.
Overall suitability	**H1**	3	Hybrid trucks are in use in many parts of the world but, as they are expensive compared to their conventional counterparts and their technology is unfamiliar, these models are not well suited to SIDS in the short term. It may be that in the medium term, as second-hand units become available from overseas markets and service personnel gain familiarity with them, their affordability and suitability increases, but in the long term, with the need to decarbonise transport, their use of conventional fuels will make them unsuitable.
	H2	4	
	H3	3	
Global technology outlook (feasibility/ availability)	Mature and developing		Globally, has been in mainstream production and commercial use for over 10 years. Expect gradual increase in global uptake as a lower-cost and transitional technology to all-electric trucks.
Affordability/ cost	Whole-of-life	$$	10% premium price over non-hybrid variant. Up to 20% cheaper to operate (due to reduced fuel consumption and lower maintenance costs) in short-trip, stop/start operation returning payback periods of the order of 3-4 years.
	Purchase	$$$	
	Ongoing	$$	
Supply/ availability	3		Available used from Japan but unfamiliarity, parts and service support risk likely a deterrent to importation.
Carbon footprint	4		Expect around 20% reduction in fuel consumption in stop-start operation through to minimal reduction for free-flowing travel, with equivalent reduction in GHG emissions associated with this. Some amount of embodied carbon associated with battery – which is relatively small for size of vehicle, but still comparable with battery size of passenger car BEV.
Energy security	4		Expect around 20% reduction in fuel consumption in stop-start operation through to minimal reduction for free-flowing travel.
Convenience, comfort, safety, and accessibility	5		Convenient, comfortable, all-weather.
Infrastructure & refuelling requirements	4		Use established roads. Use established fuel stations. Tend to be fitted with newer engine types and fuel quality needs to be assured.
Operation & maintenance requirements	3		Variant is new to islands and may take time to establish parts and service support. Advantage that not totally dependent on hybrid system, and experience from other countries has also shown grey market can learn skills required.
Waste/ end-of-life disposal	3		Large volume of end-of-life scrap and few mechanisms available for disposal in small island countries. Consideration should be given to end-of-life repurposing, recycling, and/or disposal of batteries and motor.
Environmental & social impact	4		Small reduction in noise and air quality emission expected, particularly compared to petroleum-fuelled counterparts operating in urban environments. Expected to provide more affordable goods transport.
Local value chain/ economic opportunity	4		Much of the local supply chain, including grey market, already established. Some additional capability building may be required to support the battery-electric drive system, but some countries have shown that this can be relatively easily achieved at a grey-market level.

Required complementary measures	3	Likely to require government support to establish and to manage end-of-life options. Skills to be developed to fully support the battery and electric motor hybrid system. Assurance of fuel quality right through to end use.
Other considerations		

1.18 Battery-electric trucks (all electric, plug-in)

Electric-powered 4-wheeled heavy vehicles designed for the carriage of freight.

Type of journey/ service	Short- to medium-distance urban freight transport		Early variants have targeted trucks/operations where electric drive provides greater benefits: eg, urban (where low noise is beneficial), stop-start use (where regenerative braking is particularly advantageous). This includes use for urban rubbish collection and urban goods delivery. Electrification currently not a good match with very heavy trucks and/or long-distance travel due to the large battery capacity requirements.
Overall suitability	**H1**	1	Electric trucks (e-trucks) technology is presently in its infancy, and they are not suitable for islands in the short to medium term. Demonstration models exist but they are expensive and require specialised servicing support. As technology is developed, including the battery technology, a greater range of electric trucks are expected to emerge in the medium term, and some of these may suit SIDS applications. Their suitability is likely to increase in the longer term as the technology is mainstreamed elsewhere in the world, bringing about greater availability, a reduction in purchase price, and greater familiarity in the vehicle service industry.
	H2	3	
	H3	4	
Global technology outlook (feasibility/ availability)	Demonstration		Globally, the number of electric trucks is small, with the majority of those in China (German, 2020). Their electric drive technology is similar to that for buses, but there are many more variants of truck to consider, plus less predictable routes making electrification of trucks less attractive than for buses. As a result, e-trucks are generally manufactured at a very small scale. Expect further developments as electrification technology, in general, develops.
Affordability/ cost	Whole-of-life	$$$$	Currently purchase price substantially more than for diesel-fuelled variant – the design and build are still specialist in nature. Recharging infrastructure may also add significant cost to an electric truck project if fast charging required and infrastructure cannot be shared across other vehicles. In-service operating costs typically in the order of 50%-70% of a diesel variant but providing specialist service support could add significantly to this cost.
	Purchase	$$$$	
	Ongoing	$$	
Supply/ availability	2		Typically made available on a specific project/order basis. Suppliers less likely to provide to small island countries due to concerns/cost providing support services. Therefore, expect uptake to follow well behind global market – although this then offers the opportunity of purchasing used e-trucks.
Carbon footprint	4		Expect around 10% reduction in in-service GHG emissions expected even when charging using diesel-derived electricity, through to no in-service GHG if charging using all-renewable electricity. Reasonably large added embodied carbon associated with batteries and motor, on which it could take up to 10 years of in-service operation to break even if charging using diesel-derived electricity, to a few years' breakeven if charging using renewable electricity.
Energy security	4		A small, around 10%, reduction in imported fuel consumption expected for a typical e-bus operation using all diesel-derived electricity for charging. Nil reliance on imported fuel if charged using renewable electricity.
Convenience, comfort, safety, and accessibility	5		Convenient, all-weather. Expect to provide more affordable freight transport in long term, including due to ability to operate extended hours in urban environments due to low noise.

Infrastructure & refuelling requirements	2	Best coupled with ready access to fast charging. GHG benefits are really only achieved with significant levels of renewable electricity generation. Use established roads. Low tolerance of rough roads and therefore not well matched with many agricultural-related tasks.
Operation & maintenance requirements	2	Service support yet to be established and has the potential to be costly to provide, particularly if shared across only a small number of vehicles.
Waste/ end-of-life disposal	3	Large volume of end-of-life scrap. The batteries, power electronics, and motors are large and refurbishing, repurposing, and end-of-life disposal practices will need to be developed and then carefully managed. Expect extended use of the batteries would be encouraged by their value when repurposed as stationary electricity storage applications (including in support of providing fast charging in areas where electricity supply is limited).
Environmental & social impact	4	Nil exhaust emissions and low noise emissions, providing for better environments. Expect electric trucks to provide one of the most affordable freight transport options in the future.
Local value chain/ economic opportunity	2	Will be initially reliant on support from international service providers, but expect at least moderate level of local support to be established in long term, with local enterprises built around this.
Required complementary measures	3	Likely to require government support to establish and to manage end-of-life options, particularly for the batteries. As part of a public transport system, buses need coordination on routing and timetables, service level agreements, and sometimes subsidies from government. Benefits expected from shared and electronic ticketing.
Other considerations		

2 Sea transport technologies

2.1 Personal paddling watercraft

			***Personal paddling watercraft are a millennia-old technology for active, short-distance transport on the water. They can be built and maintained locally, without any infrastructure requirements. While inconvenient by today's standards – they require physical effort and active dress codes – they were likely at one time a convenient transport option.***
Type of journey/ service	Short, inshore		Suitable for short coastal, lagoon, or inland waterway voyages. An active transport mode that can be relatively inconvenient but may offer the most practical option when travelling across water.
Overall suitability	**H1**	**5**	Personal paddling boats are very well suited for limited applications in some island coastal communities over all time horizons. Watercraft powered by paddling are one of the most ancient modes of transport and the technology of their production and their handling are known to coastal communities around the world. While many traditional production technologies are labour-intensive and require special timber, modified versions can be locally made from cheap imported materials such as plywood. While readily available, often craft of this type have been displaced by motorboats, so some encouragement may be needed for the resurgence of this transport mode.
	H2	**5**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Mature		Millennia-old design, available now and anywhere, suitable for all future time horizons.
Affordability/ cost	Whole-of-life	$	Paddling boats are cheap to build and maintain and have no direct operating costs.
	Purchase	$	
	Ongoing	$	
Supply/ availability	5		Traditional paddling boats tend to be wooden and can be built and maintained locally. Many islands have their own traditional designs. The use of fibreglass and plastic has also been used in construction.
Carbon footprint	5		Zero emissions.
Energy security	5		No fuel is required.
Convenience, comfort, safety, and accessibility	2		Physical effort is required. Therefore, it may be less convenient, comfortable, perhaps even feasible for the less able-bodied. Range and applicability are also limited, as use may become impractical and even unsafe in some weather and water conditions. .
Infrastructure & refuelling requirements	5		Uptake beyond necessity may require shore-based facilities to make paddling more convenient.
Operation & maintenance requirements	5		Operation and maintenance requirements are simple and can be met locally (also see the point below).
Waste/ end-of-life disposal	5		Traditional paddling boats tend to be built from wood, which has several modern-day, suitable end-of-life disposal options. They can also be built of fibreglass and plastic or have fibreglass coatings. These latter options require careful disposal – the volumes of waste are not significant, but fibreglass and plastics do not break down easily.
Environmental & social impact	5		Zero emissions. An active transport mode with health benefits associated with this.

Local value chain/ economic opportunity	5	Paddling craft can be built, maintained, and disposed of locally.
Required complementary systems and policies	3	Require initiatives that bring about behaviour change – for example, support to clubs or other social networks to provide awareness of paddling and to provide access to paddling boats on a trial basis.
Other considerations		

2.2 Personal sailing watercraft

			***Sailboats use the wind as their power source. 'Small' in this context refers to those craft often operated on lagoons and protected coastal waters, with displacements of up to a few tonnes. There is a huge range of traditional and modern sailboat designs, often optimised for the specific needs, and local climatological and geographic conditions. Modern sailboats are often augmented with an auxiliary motor or engine, while traditional small boats are wind-only with only paddle for back-up power. Hybrids of modern and traditional design, construction, and operation technologies have the potential to contribute to a revival of small sailing craft in islands.***
Type of journey/ service	Short- and medium-distance, personal transport.		Small sailboats are suitable for short trips, predominantly coastal or on lagoons. Depending on the design, speeds can be as high as 20 knots for some traditional Pacific Island designs. However, they are naturally dependent on weather conditions. Level of comfort depends on type of vessel. Carry 1-4 people, typically up to 6-7m in length.
Overall suitability	**H1**	**5**	Personal sailing watercraft (small sailboats) are an ideally suited transport technology for small islands over the short to long term. Many island communities retain deep knowledge around the production and handling of this often world-class technology. The manufacture of small sailboats can be adapted to use cheaper, more readily available materials and less labour than traditional methods. As pure sailing vessels, they produce zero emissions, although they may be made more versatile with the addition of small motors. They are an active form of transport and are less convenient and comfortable than modern motorboats but supporting their use in island countries is an important part of fostering culture and heritage. It is expected that small sailing boats will remain ideally suited to many SIDS contexts for the foreseeable future.
	H2	**5**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Mature		Many choices are available when it comes to production, drawing on a palette of traditional and modern techniques.
Affordability/ cost	Whole-of-life	$	The cost and affordability of a sailboat depend on the materials and production method. Traditional designs can be relatively low-cost to build, maintain, and repair but labour-intensive (and relying on cheap local labour rates). Fibreglass is sometimes used in local construction. The use of plastic in multiple-vessel, factory production is emerging. The use of small, electric systems for auxiliary propulsion is beginning to emerge. The energy requirement of any auxiliary propulsion tends to be minimal.
	Purchase	$$	
	Ongoing	$	
Supply/ availability	3		Small sailboats are often made in small numbers/as one-offs. Traditional boat building still exists. As shown by Waka Ama, new building methods can be quickly embraced and established widely, although those built according to traditional methods tend to be more robust. If auxiliary used, market tends to keep to reputable, common brands and models.
Carbon footprint	5		Small sailboats have zero or near-zero GHG emissions associated with their operation, and relatively minor GHGs associated with their build.
Energy security	5		Wind is, by nature, a locally – if intermittently – available energy resource. Petroleum-fuelled auxiliaries, if used, would rely on imported fuel, but expect minimal annual consumption. Use of solar panels, batteries and small electric-powered auxiliaries emerging.
Convenience, comfort, safety, and accessibility	3		Total dependence on the wind can be compromising and inconvenient. Operation of watercraft comes with additional risks over land-based. Sail-based propulsion requires a certain skill base.

Infrastructure & refuelling requirements	4	No or minimal fuel is required. Many small boats can be landed on the beach or pulled up to small docks or pontoons so minimal infrastructure is required.
Operation & maintenance requirements	4	Operation requires some degree of skill and effort. In general, small sailboats require small but regular, low-skill-level maintenance. Common models of auxiliaries normally well supported by local grey market. .
Waste/ end-of-life disposal	4	Suitably maintained, small sailboats are expected to enjoy long lives. Several options for disposing of end-of-life traditional craft. Disposing of craft built of fibreglass or plastic requires management. The volume of waste is normally small but does not break down.
Environmental & social impact	5	Environmentally, sailing and sailing craft have negligible environmental footprints, while less convenient and comfortable, the activity, skill, and cultural heritage associated with sailing may have great social meaning and value – with the specifics clearly varying between locations.
Local value chain/ economic opportunity	5	Potential to build both traditional and other-material small sailboats locally (the latter as shown by the number of Waka Ama boats made in the islands).
Required complementary systems and policies	3	Awareness raising. Information-sharing hubs to aid appropriate use of new materials and new technologies (eg, electric propulsion). Support youth sailing and other activities that reach out to and promote sailboat use.
Other considerations		

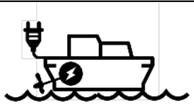
2.3 Small battery-electric propulsion

Use of an electric motor and battery to provide the propulsion for a personal watercraft. Includes the use of an electric outboard, electric inboard, electric water jet-drive, and an electric long-tail (where the propellor is mounted at the end of a long shaft that is positioned over and out from the stern of the watercraft). Electric propulsion can be a cost-effective option for small personal watercraft today where only small motor power (<1-2kW – which, due to the high torque of the electric motor, provides similar performance to a 2-4Hp gasoline outboard) and only a small battery is required. This arrangement may be augmented by on-board solar generation, extending range to possibly providing all necessary propulsion energy. Small electric motor and battery systems may also be used for auxiliary propulsion: for example, on sailing craft.

Type of journey/ service	Slow-speed and short-range		Cost, and the associated need to mostly keep to small electric motor and battery systems, limits the use to slow-speed (displacement-mode operation) and short-range applications – speed on water plus distance quickly uses a lot of energy, which requires larger (and more expensive) battery systems.
Overall suitability	**H1** **H2** **H3**	**3** **4** **5**	Small battery-electric propulsion motors (up to around 4kW shaft power) are available and suitable for adoption in SIDS in the short term, where only short range is required. They are expected to be readily available to islands within the medium term, becoming the preferred technology for inshore small watercraft within the medium to long term as costs reduce further and range extends with improved electricity storage options. Small electric propulsion systems can replace existing inboard or outboard motors, including those used as auxiliary propulsion on larger vessels. At this small size, there is also potential to gain useful energy from onboard solar panels, rather than rely on onshore charging of the batteries, extending the useful range.
Global technology outlook (feasibility/ availability)	Demonstration		Electric propulsion is emerging. There has been particular, recent growth in the use of electric propulsion for small vessels and there are many new manufacturers and suppliers of small electric propulsion systems. Most small electric propulsion systems are based on the use of low voltage (with similarities with the technology used with e-bikes and electric 2-wheelers, although the batteries are normally marinised and often have additional safety features). Globally there are many thousands of vessels with small (<10kW) electric propulsion systems and many groups actively involved in growing the industry.

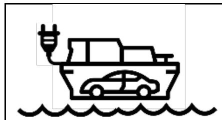
Affordability/ cost	Whole-of-life	$$	Battery-electric propulsion systems currently come at a cost premium over petroleum equivalents. The premium is lower for small electric motor and battery systems – electric long-tail fishing vessels operating in Bali reportedly have a payback period of 12-18 months over the use of their gasoline-fuelled counterparts. This limits cost-effective deployments to low-powered craft and/or craft operating across short distances.
	Purchase	$$	
	Ongoing	$	
Supply/ availability	4		Small electric propulsion systems are becoming more readily available in the market, particularly in the <10kW range. Above this, designs tend to be tailored to the specific vessel, are ordered specifically from suppliers, and use higher voltages, which introduces another level of sophistication. Expect low-voltage system components to become standardised as the market develops to where larger electric propulsion systems and even batteries are off-the-shelf purchase items.
Carbon footprint	4		The GHG emissions associated with the operation of electric boats depends on the electricity source, and ranges from around a 30% reduction in greenhouse emissions for the replacement of a 4-stroke outboard with an electric propulsion system charged from diesel-generated electricity to no in-service emissions if using all-renewable electricity. There is little embodied carbon in the build of the electric motor and battery, for small motor and battery systems.
Energy security	4		Overall, expect an improvement in energy security due to reduction in fuel used, even when charging using diesel-generated electricity, through high energy security realised through use of renewable electricity, although the total amount of fuel saved by each personal watercraft may only be to the order of 100 litres per year. Potential to use on-board solar-generated electricity provides another level of self-sufficiency.
Convenience, comfort, safety, and accessibility	5		Range of the vessel is small, unless augmented using solar. Low-noise, low vibration.
Infrastructure & refuelling requirements	4		Potential for battery swapping for small and personal watercraft. Safety implications if charging while on the water or at the beach and methods appropriate for ‘small islands’ have yet to be established.
Operation & maintenance requirements	4		Expect very low maintenance requirements. Market still developing and until parts supply and service support has been established, there is a risk of extended downtime should a fault occur.
Waste/ end-of-life disposal	4		The amount of the materials involved for a personal-sized watercraft is expected to be small, in the first instance. High value of copper in motors expected to support recycling of this component, even in island situation. End-of-life repurposing and disposal of batteries requires development and management.
Environmental & social impact	4		Environmental benefits from low noise, nil exhaust emissions, and no fuel spills.
Local value chain/ economic opportunity	4		Potential for local industries to develop in support of small-powered electric propulsion technologies.
Required complementary systems and policies	4		Requires business plan for developing the industry that includes consideration of awareness, technology demonstrations, and upscale methods. Development of charging codes and infrastructure. Management of battery repurposing and disposal.
Other considerations			

2.4 Battery-electric small-to-medium-sized vessels

			***10- to 50-tonne vessels propelled by electric motor and battery system. Includes the use of electric outboards, electric inboards, and electric water jet-drives. Electric propulsion systems are more energy-efficient than petroleum-fuelled systems and their high torque can also provide (beneficial) high thrust in low-speed operation. Use is currently limited by the typically high energy requirements of vessel propulsion, and the large and heavy battery packs required to provide significant range/hours of operation.***
Type of journey/ service	Short-distance and/or slow speed		Battery-electric boats are more suited to those applications where the total on-board electricity storage requirements can be kept low – which includes vessels operating in low-speed displacement mode and vessels operating between ports that are a relatively short distance apart, allowing frequent charging of the vessel. Maintaining a boat in planing mode (where the boat skims across the surface of the water) takes far more energy and is generally not a good application for electric propulsion for existing technology.
Overall suitability	**H1**	**2**	Battery-electric small-to-medium boats may find only limited applications in small islands in the short term but could become a very useful mainstream technology by the long term. At present, the technology is in early-stage demonstration around the world and is very expensive, particularly where significant onboard electricity storage is required. As with electric vehicles, the GHG benefits depend on the level of renewables in the electricity mix used for charging. Strategies could consider support for demonstration projects in the short term (eg, coastal tourism) to build experience with the technology in anticipation of greater uptake in the medium to long term.
	H2	**3**	
	H3	**4**	
Global technology outlook (feasibility/ availability)	Demonstration		Electric propulsion is an emerging technology. Commercial vessels around 10-50-tonne tend to require high-voltage battery-electric systems built in accordance to class rules and/or guidelines. Combined with the one-off nature of vessels of this size, design, installation and ongoing support of the associated equipment is currently a specialist area adding to the cost and difficulty to provide and support this type of technology in island situations. It is expected that on-board battery or other electricity storage systems will become simplified and cheaper as the technology develops and is standardised, making electric propulsion more accessible. Globally, the number of electric vessels in this class are in the hundreds.
Infrastructure and refuelling requirements	Whole-of-life	$$$	Electric outboards, inboards and jet units currently come at a cost premium over petroleum-fuelled equivalents, plus onboard battery storage adds another, very high-cost premium. The land-side charging infrastructure can also add significant cost to battery-electric vessel application, particularly where high charging rates are required. The cost of electricity for charging would normally be expected to be lower than for fuel for an equivalent fuel-fired vessel (but this depends on the cost of the charging infrastructure and how this cost is paid for), and maintenance costs are low for battery-electric systems.
	Purchase	$$$$	
	Ongoing	$	
Supply/ availability	2		Systems tend to be tailored for the vessel and require specialist design, supply and install. Expect designs to become standardised as the market develops to where larger electric propulsion systems and even batteries are off-the-shelf purchase items.
Carbon footprint	4		The GHG emissions associated with the operation of electric boats depends on the electricity source, and ranges from around a 30% reduction in greenhouse emissions for the replacement of a 4-stroke inboard/outboard with an electric propulsion system charged with diesel-generated electricity, to no in-service emissions if using all renewable electricity. The embodied carbon in the build of the batteries (and GHG emissions associated with this) can be significant for large battery sets.
Energy security	4		Overall, expect an improvement in energy security due to reduction in fuel used, even when charging using diesel-generated electricity, through high energy security realised through use of renewable electricity.
Convenience, comfort, safety, and accessibility	4		Vessel range limited, particularly for larger vessels. Low noise. Low vibration. Safety of modern battery systems managed through stringent specification of battery systems that includes detailed safety requirements.
Infrastructure & refuelling requirements	2		Will likely require special charging infrastructure. Potential to also require on-shore battery storage if very high rates of charge are required, otherwise may require reasonably long standdown periods for charging if batteries are large.

Operation & maintenance requirements	3	Electric propulsion and battery technology at this level currently requires support by specialists and this poses a risk to 'remote-island' operations, at least in the short term.
Waste/ end-of-life disposal	2	High value of copper in motors expected to support recycling of this component, even in island situation. End-of-life repurposing and disposal of batteries requires development and management – particularly important due to the large size of batteries involved.
Environmental & social impact	4	Environmental benefits from low noise, nil exhaust emissions, and no fuel spills.
Local value chain/ economic opportunity	2	Highly dependent on offshore expertise and will likely remain this way until there are significant developments in technology. There may be specific, one-off projects that make sense due to a combination of favourable circumstances.
Required complementary systems and policies	2	More likely to be carefully managed, specific projects, with controls on the end-of-first-life battery management developed as part of the project.
Other considerations		Further reading on electric ferries is provided by the report "Opportunities for Electric Ferries in Latin America", Liebreich Associates, February 2021, available at the time of writing this report at https://publications.iadb.org/en/publications/english/document/Opportunities-for-Electric-Ferries-in-Latin-America.pdf

2.5 Battery-electric ferries

	***Passenger and freight-carrying vessels powered by electrical propulsion systems powered by chargeable batteries. The technology is at an emerging stage, is very expensive, and is dependent on the close support of highly skilled personnel. Ferries typically make frequent and regular trips – which can make them well-suited to battery-electric power with recharging between trips during loading and unloading. Battery-electric, and diesel-electric hybrid ferries are now being built and used in several places around the world.***		
Type of journey/ service	Short-distance, multi-passenger and freight marine transport		Currently limited to short-distance routes. Expect viable range to increase as battery performance improves, but batteries alone will not be able to provide the primary energy source for long-distance travel without several major breakthroughs in energy storage, generation, and energy transfer.
Overall suitability	**H1**	**1**	Electric ferries powered by batteries, capable of carrying numbers of passengers and cars at slow to moderate speeds over short ranges, are already in service in some parts of the world. Their application is likely to be limited in SIDS in the short term due to the high cost of the vessels and on-shore charging infrastructure, the need for specialist expertise, and the need for high-powered charging systems. These will remain barriers to the adoption of this technology in SIDS for a number of years to come. As battery and engine technologies evolve in the longer term, it is expected these constraints will ease to make the technology more available to small island situations in the long term. Their long life warrants consideration of hybrid, intermediate specifications with retrofit later as prices and/or changes in vessel service permit.
	H2	**3**	
	H3	**4**	
Global technology outlook (feasibility/ availability)	Demonstration		Batteries and electric propulsion systems suitable for larger vessels are still in a developing stage and those vessels currently in service are highly dependent on the support of specialists across a number of fields. Expect the technology to become both standardised and normalised to where it can be supported locally.
Affordability/ cost	Whole-of-life	$$$	Purchase cost of battery-electric ferries can be several times higher than their petroleum-fuelled equivalents, with operation continuing to be dependent on close-by specialist support. Expect significant reductions in these costs with advances in batteries technology and designs, and standardisation.
	Purchase	$$$$	
	Ongoing	$$	

Supply/ availability	1	The technology is at an emerging stage. Currently, most electric ferry projects are based close to marine technology hubs that can support the research and development nature of the work involved. Currently, small island deployments would not be in the best interests of suppliers or the emerging industry because of the added risks involved, and the added costs in supporting the technology. This status will need significant developments in the industry before it changes.
Carbon footprint	4	In-service GHG emissions reduction highly dependent on the source of the electricity used for charging the batteries. Expect a reduction of to the order of 20% for charging using electricity from mainly diesel-fired generation, through to near-zero, in-service GHG emissions for the use of all-renewable electricity. Electricity supply could be complex to provide the latter.
Energy security	3	Expect at least some improvement for charging using diesel-fired electricity generation, through to significant improvement in energy security if electricity systems can be configured to provide charging from mainly renewable sources.
Convenience, comfort, safety, and accessibility	5	Lower noise and low vibration. Charging and dependence on high charge rates could be inconvenient and increases risk to operation. New status of technology and unknown behaviour in island environment increases risk to operation. Limited range likely to prevent dual use of ferry for search and rescue and other.
Infrastructure & refuelling requirements	2	Land-side charging infrastructure must be provided. Could be complex in order to provide the high charge rates required.
Operation & maintenance requirements	3	Expect low maintenance requirements. However, providing service support is likely expensive due to specialist nature of work and the need for this to be provided locally at least in part. Expect requirements to ease as designs mature and standardise.
Waste/ end-of-life disposal	2	High value of motors and batteries expected to result in their refurbishment and/or repurposing – a very long life expected for these components as a result. The batteries involved are very large and end-of-life repurposing and disposal practices for batteries must be developed and batteries managed through them.
Environmental & social impact	4	Beneficial to the environment due to low noise, low vibration, and nil stack emissions and lack of oil spills if all-electric.
Local value chain/ economic opportunity	2	Highly dependent on support from off-shore specialist technicians for many years.
Required complementary systems and policies	2	Requires complementary shore-side charging infrastructure. Although not envisaged to be required for some time, end-of-life battery repurposing and disposal systems.
Other considerations		Further relevant reading on electric ferries is available from the report “Opportunities for Electric Ferries in Latin America”, Liebreich Associates, February 2021, available at the time of writing this report at https://publications.iadb.org/en/publications/english/document/Opportunities-for-Electric-Ferries-in-Latin-America.pdf

2.6 Sailing vessels

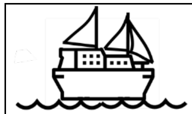
Vessels with soft sails providing the main means of propulsion. Soft-sail sailing vessels have been in use for centuries. Their dependence on the wind and the advent of more time-reliable, mechanical propulsion means has largely relegated their use to leisure and to remote-island use. Given the target to decarbonise transport, there is some opportunity to rekindle and modernise soft-sail medium-sized sailing to provide regular passenger and freight transport in the islands, when wind is sufficiently reliable. Sailing vessels can be fitted with auxiliary engines to ensure schedules can be maintained.

Type of journey/ service	Short-to-medium-distance, multi-	Have potential to become utility vehicles of the sea, providing a wide range of ‘utility’ passenger and freight services between islands.

	passenger and freight		
Overall suitability	**H1**	**4**	In general, sailing vessels are well suited to inter-island passenger and cargo transport over all time horizons. Indigenous people of the Pacific explored and colonised this ocean using perfectly optimised sailing technology, and later, Europeans used sailing ships to explore, colonise and establish global trade. Sailing ships were a mainstay of trade and commerce until the second decade of the twentieth century. The specific suitability will be dependent on sailing conditions, design of the vessel and economic viability of the routes. Modern technologies have the potential to help optimise journeys through anticipating weather and currents, improved hull and sail design, and by supplementing sail-power with electric propulsion. Effort in the short term should be directed to developing suitable concepts and demonstrations, to be proven in the medium-term, and up-scaled in the longer-term according to how effectively they capture the imagination of transport users.
	H2	**4**	
	H3	**4**	
Global technology outlook (feasibility/ availability)	Demonstration for commercial activity		The convenience and reliability of fossil-fuelled propulsion has largely replaced sailing as a practical means of passenger and freight marine transport apart from for leisure, lifestyle, and in remote and poorer islands. The technology involved has also stood still for several decades. There are now new materials and new systems that could integrate with and modernise soft-sail sailing, to make it more comfortable and more reliable. An auxiliary propulsion source, such as a small, fuelled or electric outboard, would make a sensible addition in a commercial operation.
Type of journey/ service	Short- to medium-distance, multi-passenger, freight		Have potential to become utility vehicles of the sea, providing a wide range of 'utility' passenger and freight services between islands.
Affordability/ cost	Whole-of-life	$	The production of vessels is generally very time consuming. Whereas traditional boats may be seen to be low cost due to minimal labour rates, small vessels made commercially can become costly if standard labour rates apply.
	Purchase	$$$	
	Ongoing	$	
Supply/ availability	3		Commercially targeted 'utility' sailing vessels would best be purpose-designed for task and made in the islands. This could feasibly happen.
Carbon footprint	5		Wind is a renewable energy and sailing contributes zero GHG emissions. An electric auxiliary would also have no in-service GHG emissions if powered by on-board solar or electricity from other renewable sources.
Energy security	5		Depending on any auxiliary propulsion used, can have zero or near-zero consumption of imported fuels.
Convenience, comfort, safety, and accessibility	2		Dependence on wind and weather can be inconvenient (and costly, in a commercial operation). Sail can be more stable and provide a better level of comfort in seaway compared to motor-powered vessels. May be benefits from new shore-side infrastructure, but not essential.
Infrastructure & refuelling requirements	4		May be benefit from providing complementary service infrastructure, but not essential.
Operation & maintenance requirements	4		Maintenance normally within capability of crew. Operating the sails may require additional crew.
Waste/ end-of-life disposal	4		Disposal is dependent on the construction materials and potential for reuse.
Environmental & social impact	5		Very low-noise, nil-emission transport. Potential to maintain local variations in design fostering cultural identity and pride.

Local value chain/ economic opportunity	4	Potential to develop a local industry with routes across island heritage.
Required complementary systems and policies	3	Demonstration. Awareness programme. Coordination across potential operators. Standardisation of vessels and equipment. Information sharing.
Other considerations	3	Cultural aspects are highly relevant and dependent on location. Just-in-time logistics is more difficult to implement for businesses relying on sea transport.

2.7 Wind-assisted propulsion (WASP) technologies

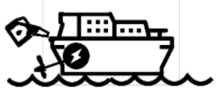


Wind-assisted propulsion (WASP) technologies supplement the main engine of a ship through the use of sails or other devices. In favourable wind conditions, sailing speed can be increased, or the main engine can be powered down or switched off. WASPs tend to be organised into three main categories: traditional-type sails; rotor sails, and kites and other concepts. In global shipping, rotor sails appear most advanced commercially. Wind assisted propulsion (or WASP, or hybrid sailing ships) promises fuel and GHG savings even for the largest vessels, and a number of early commercial initiatives, including many different designs, are underway around the globe.

Type of journey/ service	Short- to long-distance, multi-passenger and freight marine transport		There is a wide range of wind-assist technologies, and these have been trialled on an equally wide range of vessels. Many are deck-mounted, or at least deployed from the deck, and provide options for retrofits or for new builds.
Overall suitability	**H1**	**3**	Wind-assisted propulsion technologies may have applications in the short term in islands either as a retrofit to reduce fuel use on existing vessels, or as part of the design of new builds. Despite a long history of trials and demonstrations, commercial use of wind-assisted propulsion technologies is still largely at the experimental or demonstration stage. Many groups are involved in developing wind-assist technologies, and there does not appear to be any one favoured technology. It is therefore expected that little more than demonstration can be expected in the short term, small-scale adoption in the medium term, and uptake as practicable in the longer term.
	H2	**4**	
	H3	**5**	
Global technology outlook (feasibility/ availability)	Demonstration		Commercial use of wind-assisted propulsion technologies is still largely at experimental or demonstration stages and is attracting some significant companies involved in ship building. There is an array of soft and hard sail arrangements under trial, as well as kites and rotors. There are numerous compromises with wind-powered systems, including their early development stage, taking up valuable deck space, and (for some) heeling. There does not appear to be a preferred wind-assist technology emerging.
Affordability/ cost	Whole-of-life	$$	Because of its early developmental stage, wind-assist technology tends to be deployed in one-off demonstration projects and is supported by highly skilled staff – a recipe for high costs. Costs will decrease as the technology develops and with the introduction of standardisation. Some developers of wind-assist technology claim that vessel fuel savings of up to 20% are possible. Published data suggests that average fuel savings of 8-12% are typical. Payback on investment is expected to be in the range of 2-4 years.
	Purchase	$$$	
	Ongoing	$	
Supply/ availability	3		Wind-assist technology is still at an early stage of development and early focus by developers is usually on deployments that are close to the developer's home base, which is Europe, in many cases. This does not present much opportunity for involvement by SIDS.

		However, soft-sail wind assist technology is not a significant departure from the crafts that are available on the islands, offering opportunity for SIDS to further develop this technology.
Carbon footprint	4	Fuel savings of 10% and up to 20% may be achieved, reducing GHG emissions by an equivalent amount.
Energy security	4	Fuel savings of 10% and up to 20% may be achieved.
Convenience, comfort, safety, and accessibility	3	Wind-assist technologies may introduce some compromise, potentially including additional heeling, use of valuable deck space, and adding complexity to the operation of a vessel.
Infrastructure & refuelling requirements	5	Wind-assist technologies tend to be self-contained and do not require other infrastructure.
Operation & maintenance requirements	3	The developmental stage of wind-assist technologies normally requires attendance by trained personnel and possibly technical experts. Once developed, expect that existing crew members would be capable of managing the operation of wind-assist systems.
Waste/ end-of-life disposal	5	Additional material compared to that of the vessel would be very small and therefore any increase in waste negligible.
Environmental & social impact	4	Reduces fuel consumed. Has the potential to reduce stack emissions.
Local value chain/ economic opportunity	4	Potential for soft-sail wind-assist to be developed and deployed in the islands. Otherwise, dependent on supply of technology and knowledge from overseas. Expect local industries to develop capability to support overseas-sourced technologies.
Required complementary systems and policies	3	Consider the feasibility of developing and deploying island-developed soft-sail wind-assist technologies and, if feasible, develop a business case and business plan and chart for deployment.
Other considerations		See findings of the ‘Technical and Operational Options Catalog’ of the Marshall Islands project ‘Transitioning to Low Carbon Sea Transport in the Republic of the Marshall Islands’, August 2019 published at the time of writing this report at https://www.changing-transport.org/wp-content/uploads/TLCSeaT_TechnicalAndOperationalOptionsCatalog.pdf

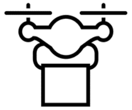
2.8 Diesel-electric hybrid vessels

			***Small- to medium-sized vessels powered by diesel-electric hybrids (where an electric motor and battery propulsion system works with a petroleum-fuelled engine to provide all-electric to all-fuel propulsion depending on circumstances and hybrid arrangement). Hybrid systems enable short periods of all-electric propulsion, for example, for operating in and around ports, plus propulsion derived from operating the petroleum-fuelled engine, the latter providing normal vessel range (as compared to the short range typical of all-battery-electric vessels).***
Type of journey/ service	Short- to long-distance voyages, multi-passenger and freight.		Hybrid systems have similar operation to all-petroleum-fuelled vessels except that all-electric operation can be selected providing short periods of all-electric, zero-emission, low-noise operation when required.
Overall suitability	**H1**	**2**	Diesel-electric hybrid systems take many forms. Simple systems involving only small batteries, such as those that eliminate generator use when a vessel is at anchor, are suitable today. Systems that are integrated into a vessel’s main propulsion are still relatively new and the technology is very expensive. Normally this would push the technology outside that suitable for SIDS, but the long life of a vessel also requires consideration, and earlier uptake of the technology might be justified for specific vessel projects. In the medium to
	H2	**3**	
	H3	**4**	

			long term, expect that diesel-electric hybrid systems will find itself increasingly in competition with all-electric propulsion, particularly where the onboard energy storage requirement is small.
Global technology outlook (feasibility/ availability)	Demonstration		Hybrid propulsion systems are still in a development stage and those hybrid vessels currently in service tend to be highly dependent on the support from specialists across a number of fields. Expect the technology to become both standardised and normalised to the point where it can be supported locally.
Affordability/ cost	Whole-of-life	$$	As for electric vehicles, hybrid systems have smaller batteries than all-electric systems and this generally results in a cost for a hybrid vessel significantly below that of an all-battery-electric vessel, but more than a petroleum-fuelled vessel. Efficiencies of the hybrid system can result in a 10% fuel savings, plus lower maintenance costs due to reducing engine operating hours.
	Purchase	$$$	
	Ongoing	$$	
Supply/ availability	1		The technology is still at an emerging stage, expensive, and requires local support by skilled personnel. Suppliers may be reluctant to supply to islands until the systems are in common use in primary markets.
Carbon footprint	4		Reductions in fuel consumption of around 10% have been realised, presenting a like decrease in GHG emissions.
Energy security	3		Reductions in fuel consumption of around 10% have been realised.
Convenience, comfort, safety, and accessibility	5		Provides lower-noise, nil-stack emission operation when low-power or no propulsion is required.
Infrastructure & refuelling requirements	2		No additional infrastructure requirements.
Operation & maintenance requirements	3		Dependent on support by skilled personnel. Typically, longer periods between engine servicing.
Waste/ end-of-life disposal	2		Large amount of materials to dispose of. Relative to normal, petroleum-fuelled vessels, has the addition of modern batteries that will require end-of-life repurposing and disposal to be developed and managed. Also has a motor, but value of copper in the motor expected to be a driver for its recycling.
Environmental & social impact	4		Beneficial to the environment in which all-electric operation is used due to low noise, low vibration, and nil stack emissions.
Local value chain/ economic opportunity	2		Expect to be highly dependent on support from off-shore specialist technicians for many years.
Required complementary systems and policies	2		Will require knowledge of the technology so that it can be considered future vessel supplier tenders.
Other considerations			

3 Domestic aviation transport technologies

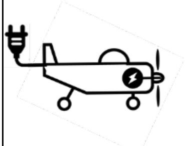
3.1 Drones

	***An unmanned aircraft controlled remotely or autonomously. They comprise aircraft that generate their lift from horizontally revolving rotors, fixed wings moving through the air, or their combination. Most are powered by battery-electric motor systems, which is where the bulk of global interest lies. Current applications include aerial photography and surveillance, air sampling, goods delivery, and agricultural operations. Many groups are working toward providing drone-based passenger services.***		
Type of journey/ service	Wide-ranging, from fast parcel delivery potentially to passenger transport.		Drones can deliver a wide range of services including parcel and goods delivery, surveillance, and agricultural work. Potential to also deliver passenger transport services in the future. An example of current-day drone use is asset surveillance, where drone-mounted cameras are used to check electricity supply infrastructure and replace the use of vans, trucks and helicopters (and significant labour resources) to do the same.
Overall suitability	**H1**	**3**	Drones are already being used to deliver small cargoes such as medicines to remote places in several countries, including Africa and Australia. In the short-term, application of drones to telemedicine services in SIDS could be done on a demonstration basis, with the technology and practice becoming normal and widespread in the medium to long term (and likely alongside other drone applications).
	H2	**4**	
	H3	**5**	

Global technology outlook (feasibility/ availability)	Early adoption		Globally, there are many established commercial delivery-, surveillance-, photographic-, and agricultural-related operations involving drones. The use of electric-powered drones is expected to grow exponentially as technology is developed for new tasks. Developments will also increase effective range and payload capacity (several are trialling 1-tonne capable delivery drones). Expect useful range to increase, from current 20-140km to +300km. Electric, pilotless air taxis are also in development.
Affordability/ cost	Whole-of-life	$	Some sectors have seen a rapid rise in drone use because drones can provide same services at a fraction of the cost. Systems required when sharing airspace with other activities (including commercial aircraft) currently add significant upfront costs and complexity, but it is expected that solutions will become cheaper (and more accessible) as technology develops. Low in-service costs due to low energy cost and low maintenance of battery-electric systems.
	Purchase	$$	
	Ongoing	$	
Supply/ availability	2		Commercial systems able to share airspace are still at a demonstration stage and not widely available. Expect complete systems to be available in the marketplace by 2030.
Carbon footprint	5		Many drone operations can displace use of far more energy-intensive transport options (for example, surveillance replacing the use of 4-wheel vehicle and possibly helicopters). Small battery sizes also lend themselves to charging using local, renewably generated electricity. Hence, potential to fully decarbonise some transport-related services. Motors and batteries involved are small and attract little embodied carbon.
Energy security	5		Potential to avoid some fuel-consuming transport services, increasing energy security. Availability of drones may introduce new services, but associated, new energy requirements small, and charging using renewable electricity would avoid a new demand for petroleum fuels.
Convenience, comfort, safety, and accessibility	5		Potential to provide wider access to new, more convenient and/or more affordable transport-related services.
Infrastructure & refuelling requirements	5		Minimum additional infrastructure requirements.
Operation & maintenance requirements	4		Low maintenance requirements. Some specialist skills required but standardisation and the use of remote support services expected to allow local support.

Waste/ end-of-life disposal	4	Drones and their batteries are small. Even so, batteries will require end-of-first-life repurposing and/or disposal methods to be developed and for this to be managed. However, likely carried out under stewardship of parent service supply company.
Environmental & social impact	5	Potential to provide more affordable and/or beneficial services, for example, urgent medical deliveries.
Local value chain/ economic opportunity	4	Potential to lower costs of existing services and to introduce new, beneficial services, with economic benefits associated with this. Expect local entities to set up and partner with overseas suppliers to provide these services.
Required complementary systems and policies	4	Shared use of airspace requires attention. End-of-life battery management.
Other considerations		

3.2 Battery-electric light aircraft



Battery-electric aircraft, where onboard batteries power an electric motor-driven propellor, are at an emerging stage. All-electric propulsion is currently limited to smaller aircraft due to their smaller energy requirements – it is difficult to provide the necessary onboard energy storage using batteries on larger aircraft due to the high weight and high costs of current battery technology. Examples include Pipistel's (Slovenia) all-electric 2-seater trainer (Pipistrel Aircraft, n.d.) ***and Liaoning General Aviation Academy (LGAA) 4-seater, short-distance (300km) aircraft*** (Xinhua, 2019)***. Expect that commercial operation of 19-seat commuter-type aircraft will occur in the 2026-2030 timeframe*** (Alcock, 2020) (Kaminski-Morrow, 2020)**.**

Type of journey/ service	Fast, short-distance passenger travel.		Short-distance flights between land and sea airstrips. Suitable for fast, island-to-island passenger transport but currently limited to small aircraft.
Overall suitability	**H1**	2	In the short term, this technology is unsuitable for SIDS because it is still at an experimental stage and is limited to very small aircraft – significant advancements in electrical energy storage are required before commuting-type aircraft become commercially available. In the medium to long term, small electric aircraft may be incorporated into the fleet, possibly for niche tourist applications, with the possibility of increased uptake in the long term as technology and affordability permits.
	H2	2	
	H3	4	
Global technology outlook (feasibility/ availability)	Demonstration		Apart from a small number of small aircraft models, the use of electric-powered aircraft is at an experimental level. There are many groups working in the field. Expect all-electric, 19-seat commuter aircraft to be in commercial use within the decade. The practicability of larger, all-electric aircraft is limited by the weight and cost of batteries and significant improvements in electrical energy storage will be needed to make such aircraft viable. (ITF, 2021)
Affordability/ cost	Whole-of-life	$$	Currently available in 2- to 4-seater models only. Minimal energy and maintenance costs.
	Purchase	$$$	
	Ongoing	$	
Supply/ availability	1		Only small, all-electric aircraft have been certified and are available. Expect larger, commuter-type aircraft to become available over next decade.
Carbon footprint	4		Around 30% lower in-service GHG emissions for use of diesel-derived electricity through to zero in-service GHG emissions for use of renewable electricity.
Energy security	4		30% less petroleum fuel use if charged using diesel-generated electricity, through to no imported fuel requirements for charging using renewable electricity.

Convenience, comfort, safety, and accessibility	4	Provides low-noise, short take-off and cheaper air transport.
Infrastructure & refuelling requirements	4	Requires air-side charging. Larger aircraft, when they become available, will require fast to ultra-fast charging rates which may stress local electricity supply networks.
Operation & maintenance requirements	4	Although maintenance support requires specialist skills, specialist skills are already required in aviation sector, plus electric drive systems have very low maintenance requirements. Potential to be a good fit with the SIDS environment once battery technology develops and become standardised.
Waste/ end-of-life disposal	3	Scrap value of motors likely to encourage good recycling practices. Batteries will require end-of-life repurposing and disposal methods to be developed and the processes managed. Repurposing of end-of-first-life of batteries will be particularly important for aircraft as batteries would likely need to be replaced relatively early in their lives for safety and range reasons, compared to use in other forms of mobility.
Environmental & social impact	4	Low noise. Potential to provide more affordable air transport.
Local value chain/ economic opportunity	4	Expect services to largely replace those for petroleum-fuelled aircraft rather than bring about significant change. Potential for lower-cost transport to aid economic activity.
Required complementary systems and policies	4	Aviation authorities may require changes to regulations.
Other considerations		

3.3 Hybrid-electric powered aircraft

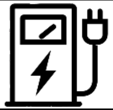
	***Fixed-winged aircraft powered by a hybrid-electric propulsion system comprising combined petroleum-fuelled and battery-electric drive systems, the two systems often working together to provide benefits including lower fuel consumption, and shorter take-off distances/increased maximum take-off weight (MTOW), with the presence of the petroleum-fuelled system retaining range (with the potential of range extension). Technology is currently at an experimental stage. Many of the significant suppliers to the aero industry are involved in development projects. The technology has yet to reach commercialisation***. (Perry, 2020)		
Type of journey/ service	An alternative propulsion system for wide range of aircraft.		Once commercialised, hybrid-electric propulsion systems are expected to result in lowered fuel consumption for same service.
Overall suitability	**H1**	**1**	Conceptually, hybrid-electric aircraft are very suitable for application in SIDS as they are designed for the same applications as the robust turbo-prop planes that comprise most island domestic fleets. The technology is still in the experimental stage, with major demonstrations expected within five years, and commercialisation in primary markets in the medium term. This will lead to the opportunity to include hybrid aircraft in island fleets in the medium to long term.
	H2	**1**	
	H3	**4**	

Global technology outlook (feasibility/ availability)	Prototype		Hybrid-electric propulsion systems are at an early experimental level. Noteworthy parties are involved in development across small to large aircraft. Technology is expected to mature to become a mainstream technology. First commercial use predicted to several years away (ITF, 2021), (Xie, Savvarisal, Tsourdos, Zhang, & Gu, 2021).
Affordability/ cost	Whole-of-life	$$	

	Purchase	$$$	Currently not available commercially. Expect to be come at a cost premium due to the increased hardware requirements. Fuel savings of up to 50% have been predicted for short-distance flights.
	Ongoing	$	
Supply/ availability	1		Currently experimental and not commercially available. May see introduction of technology in H3.
Carbon footprint	4		Fuel savings of up to 50% have been predicted for short-distance flights, corresponding to a similar reduction in GHG emissions.
Energy security	4		Fuel savings of up to 50% have been predicted for short-distance flights
Convenience, comfort, safety, and accessibility	4		Lower noise operation. Benefits from increased MTOW.
Infrastructure & refuelling requirements	4		No change in infrastructure needs.
Operation & maintenance requirements	4		Predicted lower maintenance costs. Energy costs reduced up to 50%.
Waste/ end-of-life disposal	3		Overall, little change in waste characteristics apart from addition of batteries (as engine size decreased due to added power provided by electric motor). Batteries will require end-of-life repurposing and disposal methods to be developed and the processes managed. Repurposing of end-of-first-life batteries will be particularly important for aircraft as batteries would likely need to be replaced relatively early in their lives for safety and range reasons, compared to use in other forms of mobility.
Environmental & social impact	4		Lower noise. Potential to provide more affordable air transport.
Local value chain/ economic opportunity	4		Expect services to largely replace those for non-hybrid, petroleum-fuelled aircraft rather than bring about significant change. Potential for lower cost transport to aid economic activity.
Required complementary systems and policies	4		None required.
Other considerations			

4 Energy and fuel technologies

4.1 Electric vehicle charging



Infrastructure that allows the traction batteries of electric vehicles to be charged from mains electricity or another source of electricity that is external to the vehicle. Ranges from simple, low-power, and relatively low-cost systems designed to charge EVs from household electricity socket outlets to large, high-powered, and high-cost units designed to rapidly charge passenger car-type EVs in 20-30 minutes.

Type of journey/ service	Charging of EVs		Simple ‘conductive’ charging (where the EV is physically connected to the electric supply via plugs and cables) is common today, ranging from charge rates of the 1kW of portable charging ‘bricks’ plugged into electricity mains socket outlets (and taking +10 hours to charge for a typical present-day passenger EV) to large and costly ‘fast’ roadside chargers charging at 50kW or more (and taking less than 30 minutes to charge a current day passenger EV). The increasing battery capacity of future EV models (and current heavy EVs) lends itself to greater than 100kW charge rates, but such chargers are expensive, can stress local electricity supply networks particularly in an island situation, and are largely unnecessary in a SIDS setting. Opportunity for cheaper, 25kW public chargers. Global studies have found over 90% of charging is carried out at home but that it is still important to provide public charging.
Overall suitability	H1 H2 H3	3 5 5	EV charging systems are essential to support the uptake of EVs across all formats. In the short term, this is likely to consist mostly of ‘slow-charging’ (eg, in households), with a few demonstration ‘fast-charging’ stations for light vehicles (eg, at vehicle dealerships or hotels). In the medium term, a planned approach to charging infrastructure is needed, in partnership with the power utility, major users (such as taxi fleets or government departments), and site owners.
Global technology outlook (feasibility/ availability)	Mature and improving		Globally, electric vehicle charging technology is both mature (EV charging has been established in many markets and there are hundreds of suppliers of charging equipment built to international standards) and developing (including with respect to third-party/electricity supplier control of the charge event, public charging at ultra-fast charge rates, and contactless charging).
Affordability/ cost	Whole-of-life Purchase Ongoing	$ $-$$$ $	Range from USD400 for a portable charger (these are often provided with an EV at the time of purchase) through USD60,000 for a 50kW charger including simple installation. An upgrade of the electricity supply network, if required could double the cost or more. Home, wall-mounted (and fixed wired … considered by many safety authorities to be a minimum standard) chargers range in price from USD1,000 to USD2,500, and an additional USD500-1000 for (future) third party-controlled charging equipment.
Supply/ availability	4		There are numerous global suppliers. Supply to SIDS should not be an issue. Electricity supply to rapid chargers may be an issue, but few may be required.
Carbon footprint	5		As for EVs.
Energy security	5		As for EVs.
Convenience, comfort, safety, and accessibility	4		If the electricity supply capacity is sufficient, at-home, at-work, and opportunistic public charging is convenient as they avoid dedicated trips for recharging. Dedicated charging trips take far longer than the equivalent vehicle petroleum refuelling exercise. Electricity supply circuits will need to be checked to ensure that they have sufficient capacity for the intended charging.
Infrastructure & refuelling requirements	3		The additional demand from charging may require electricity supply network upgrades, including upgrading/installing a new transformer. Such upgrades are very expensive and sites for chargers are best chosen to avoid them. Note that even a single, low-charge-rate charger can over-stress a low-current home electricity supply circuit and/or house electricity connection, requiring management of this risk.
Operation & maintenance requirements	3		Low maintenance. Requires trained installers, and greater skill base again for installation and maintenance checks on fast chargers. May require marine specification for fast chargers to avoid early deterioration.

Waste/ end-of-life disposal	4	Smaller chargers are relatively compact, presenting a relatively small disposal footprint. Larger units contain significant amounts of economically reclaimable copper (even in a SIDS setting), and some utilities already have acceptable disposal options for such equipment.
Environmental & social impact	5	Supports the use of EVs, enabling the EV-related benefits.
Local value chain/ economic opportunity	4	Supports the local use of EVs. Otherwise, provides little local value as chargers normally imported completely built up and they have minimal service requirements.
Required complementary systems and policies	3	Require standards and guidelines to manage the specification of equipment, its installation, and use. Requires supporting policy for public charging – land use and on-sale of electricity. Require checks on suitability of site wiring for providing EV charging. Consider how to manage the time of use demand from EV charging.
Other considerations		

Explanation 3: Additional considerations for EV charging systems

Unmanaged, charging could add pressure to already stressed electricity supply networks. Properly managed, electric vehicles might actually support the supply of electricity. The PCREEE report 'Options for Integrated Electric Mobility and Renewable Power Markets in the Pacific Island Countries and Territories (PICT)' (Campbell, 2020) identified five main options that could do this, some of which involve technologies that are still in early development. The following provides short descriptions of these options, ordered in their availability to use today:

- **Local-site managed charging**, where charging of a vehicle is managed according to other demands for electricity on the site and/or what local electricity generation is available (eg, from on-site solar PV or wind generators). The complexity of local-site managed charging ranges from manual switching, based on an assessment of loads, through automatic management and balancing of electricity demand and supply. The automated technology involved is available in the global marketplace, there is potential for local-site managed charging to benefit individuals now, and the technology would be particularly appropriate for use where households have low-power electrical connections (which can be common outside main PICT centres).
- **Time of use (TOU) electricity pricing,** where electricity tariffs change during the day and are set and advertised to encourage customers to shift demand to periods that suit the electricity supplier (and also benefit EV owners, if they choose to charge when electricity is cheapest). TOU pricing requires the use of TOU or 'smart' meters. Enabling this option, EPC (Samoa) has begun the rollout of smart meters, beginning with commercial customers. TOU pricing may also be used in a way that results in a net reduction in GHG emissions.
- **Vehicle-to-home (V2H),** where the EV is plugged into a device that allows electricity to be exported from the vehicle to an isolated or local electricity circuit. This technology is available in the global marketplace and could be installed by individuals, providing them with a short-term backup electricity supply when the grid is down. However, standalone battery systems and standby generators may provide more cost-effective and convenient power supply when grid supply is not available.
- **Grid-scale managed charging**, where the electricity supplier has control over when and/or at what rate charging of an electric vehicle occurs, which has the advantage of shifting demand from electric vehicle charging to times when it is more beneficial to the grid supply – for example, when there is excess renewable energy available. Some form of grid-scale managed charging will be necessary when there are enough EVs charging to place a significant demand on the grid. However, the technology involved is still evolving, reducing it to a watching-brief technology.
- **Vehicle-to-Grid (V2G)**, where the electric vehicle is plugged into a device that connects the electric vehicle's propulsion battery to the grid and allows the electricity supplier to control the import and export of electricity to and from the electric vehicle's battery. This could aid balancing of supply and demand on the grid and could bring about a small increase in the proportion of renewable generation incorporated in the grid. However, V2G technology is still a long way from being perfected, and it is too difficult to plan and prepare for V2G integration at this early stage, reducing V2G to a watching brief technology.

The characteristics of the charging requirements of electric micromobility also lend themselves to charging from domestic- and small-scale solar photovoltaic systems, enabling full use of electricity generated if the vehicle is plugged in and requires charge. Such an arrangement can be operated in isolation from the grid supply.

4.2 Hydrogen as a fuel

Hydrogen is a fuel that can be combusted in a spark-ignition engine to produce engine power (a method that is now considered a past technology), or it can be an energy carrier and used in a fuel cell to produce electrical energy via electrochemical reactions. Hydrogen can be produced and stored by various means, and this is the basis of the so-called 'hydrogen economy', where hydrogen becomes central to various energy systems. Globally, the majority of hydrogen is currently produced from fossil fuels such as natural gas, and these methods have GHG associated with hydrogen's production. 'Green hydrogen' refers to hydrogen produced from renewable sources, including the use of RE to drive electrolysis of water (the splitting of water into hydrogen and oxygen). 'Blue hydrogen' refers to hydrogen produced from fossil fuels in processing that also captures and stores carbon to avoid, or at least reduce, the GHG emissions. 'Grey hydrogen' is that produced from natural gas.

Type of journey/ service	Provides an alternative to traditional fuel systems		Potential to provide an alternative to petroleum in the future as a flexible fuel for transport. However, given the many obstacles to its use and expected rates of advance in other technologies, the latter may bring about better solutions.
Overall suitability	**H1**	1	Hydrogen as a fuel is unlikely to be suitable for SIDS in the short to medium term. While there is much discussion globally of the 'hydrogen economy', the production of green hydrogen, the transport and storage of hydrogen for vehicles, and the use of hydrogen as fuel by vehicles are early demonstration technologies that present significant engineering challenges, particularly in a SIDS environment. In the long term, it is possible, but highly uncertain, that hydrogen production, handling, and fuel cell vehicle technology will develop to the point that it can be managed within a SIDS context outside of specific, controlled applications. However, given the long timescales involved, there are other technologies involving the storage of electrical energy that may prove to provide at least equal performance but be more suitable in the SIDS context.
	H2	2	
	H3	3	
Global technology outlook (feasibility/ availability)	Prototype and early demonstration		The use of hydrogen as an energy carrier has been emerging for decades and still requires technology to develop further before it becomes commercially viable as an alternative in everyday transport scenariosoptions.
Affordability/ cost	Whole-of-life	$$$$	Technology is currently very expensive and current energy inefficiencies and technology levels in storage, transport and energy retrieval processes generally make hydrogen unaffordable and impractical outside specific, demonstration projects. For small island countries, commercial/mainstream use of hydrogen is dependent on the availability of low-cost renewable electricity.
	Purchase	$$$$	
	Ongoing	$$$$	
Supply/ availability	2		Plant used to produce, storage, transport and handle hydrogen currently of specialist nature and is normally designed and ordered for the specific project involved.
Carbon footprint	4		For small island countries, potential for low-GHG 'green hydrogen' from renewable electricity hydrolysis processes in the future (but option to be weighed up against more efficient use of renewable electricity to charge EV batteries and/or battery energy storage.
Energy security	4		Potential to provide energy security if excess renewable electricity is available, providing an opportunity to produce hydrogen economically.
Convenience, comfort, safety, and accessibility	2		Use is not convenient – currently requires specialist equipment for production, storage, transport, transfer, and use, and trained personnel to support this equipment. High standards required to be maintained to keep safe.
Infrastructure & refuelling requirements	1		Currently requires specialist equipment and skills not available in small island countries outside of research setting.
Operation & maintenance requirements	2		Currently requires specialist involvement across many aspects, with initially high dependency on international experts.
Waste/ end-of-life disposal	3		Fuel cell vehicles have many similarities to battery electric vehicles, and the end-of-life waste management requirements of fuel cell electric vehicle (FCEVs) is also similar to that of BEVs, including the need to develop and manage the end-of-vehicle life repurposing or disposal of batteries. It is expected that the high value of the metals contained in the fuel cells will drive good disposal practices for this component.

Environmental & social impact	5	Hydrogen fuel cell vehicles do not have exhaust emissions and provide low-noise operation.
Local value chain/ economic opportunity	2	Initially highly dependent on international specialist support. Expected to take reasonable time before technology has developed for public use, and local industries have the capability to support the use of hydrogen in transport.
Required complementary systems and policies	2	Requires introduction and adherence to equipment and operational standards to assure safety, particularly for use of vehicles outside of controlled environments.
Other considerations		

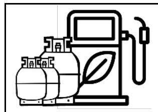
4.3 Biodiesel

Biodiesel is derived from vegetable oils or animal fats using a chemical process called esterification. The refined product of this process is a mix of monoalkyl esters that are far more fluid than the original oil or fat, making them more suitable for use in internal combustion engines (or furnaces) than the original oil or fat. Poor management of feedstock quality and/or manufacturing process can result in poor quality fuels suitable only for managed use in older engine types or for non-engine use.

Type of journey/ service	Alternative fuel		Provides an alternative to diesel. Can be used neat or in blends with diesel if engines are designed for its use. More suited as a fuel for older diesel engine types.
Overall suitability	**H1**	3	**Biodiesel that is locally produced** may have some limited application in the short term, but its viability is highly dependent on access to reliable, cheap sources of suitable feedstock and the ability to manufacture quality biodiesel from this feedstock. Coconut oil is often mentioned as a feedstock but currently the world price of the grade of coconut oil suitable for making transport fuels is high due to demand for its use in food and cosmetics. In addition modern engines require high-quality fuels and affordably achieving the quality required is an issue in an island scale and context, as is managing production wastes. An alternative is to use lower quality biodiesels in older engines, but this comes with risk. Use of raw coconut oil is riskier still but can work in low blend proportions in standard fuels in older slow- and medium-speed engines or otherwise carefully managed. These are not future-focused options. The landed cost of internationally produced, “drop-in” qualitybiodiesels can be two or more times the cost of diesel, the production or diversion of the feedstock can conflict with food production, and there may be some uncertainty over emissions benefit. While some applications may remain, the usefulness of biodiesel as a transport fuel is expected to decline in the medium to long term as other technologies take over.
	H2	2	
	H3	2	
Global technology outlook (feasibility/ availability)	Mature		The production and use of biodiesel are mature and biodiesel is in commercial use globally.
Affordability/ cost	Whole-of-life		It is possible to construct a plant locally using new and used, local and imported equipment. Low returns make it difficult to financially justify new plant. Has the potential to incur significant costs on the part of the user if quality is not adequately managed.
	Purchase	$$$	
	Ongoing	$$$	
Supply/ availability	2		Requires a reliable and cheap source of feedstock. Coconut oil is normally too expensive or of too low a grade if affordable (and the use of low-grade feedstocks can lead to the production of poor-quality biodiesel that is unsuitable for engine use). The supply of used cooking oil is limited and using it would compete with its use as animal feed. Production also requires access to reasonably high-quality methanol (or possibly ethanol).
Carbon footprint	4		Depending on feedstock, can result in up to an 80% reduction in GHG emissions compared to using imported diesel.
Energy security	4		Up to an 80% reduction in energy imports possible for the use of biodiesel produced from locally available feedstocks and imported methanol. Potential to use indigenous ethanol as an alternative, but likely less viable.

Convenience, comfort, safety, and accessibility	3	Feedstock collection through processing can normally be managed to provide a convenient and safe routine. Can be difficult to maintain quality, putting engines at risk.
Infrastructure & refuelling requirements	2	Requires support of a suitable testing lab. For some tests, will require sending samples offshore, which can be expensive. Process produces a methanol-rich slurry by-product that may be difficult to dispose of.
Operation & maintenance requirements	4	Can be difficult to maintain quality which may require occasional non-engine, alternative use. Expect local workforce can develop the capability to operate a biodiesel plant and provide the necessary quality controls.
Waste/ end-of-life disposal	3	Disposal of the methanol-rich by-product and process wash water may be an issue.
Environmental & social impact	3	Can provide reasonable reductions in GHG emissions compared to the use of diesel. However, the scale of plant is limited and can only provide a small contribution overall because of this.
Local value chain/ economic opportunity	4	Has the potential to be owned and operated entirely by locals.
Required complementary systems and policies	4	Requires recognition of need for, and policing of, fuel quality standards and waste management.
Other considerations		Can be difficult to maintain quality where process and quality systems not strictly adhered to. More of a current-day, or even a past technology in this regard, and not a future-focused option, except in very small blend ratios with diesel (as modern, low-emission engines are generally not tolerant even of small variations in quality).

4.4 Alternative Fuels – non-H2 and non-biodiesel

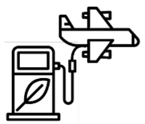


Alternatives to petroleum fuels for use in automotive-type internal combustion engines. Air quality, climate change, and other drivers have resulted in the use of a range of fuels in heavy vehicles, including natural gas (compressed natural gas [CNG], liquified natural gas [LPG], renewable natural gas [RNG – produced or recovered from biowastes including wastewater, and sometimes also referred to as biogas]), liquid petroleum gas (LPG), different alcohols (both used neat, and in low- and high-proportion blends with traditional fuels), dimethyl ether, biodiesel (both used neat, and in low- and high-proportion blends with petroleum diesel), and hydrogen. Globally, use of low-blend proportions of biodiesel or ethanol have provided relatively easy mechanisms for use of alternative fuels. Beyond this, use of alternative fuels is normally confined to specific projects due to the differences in how the fuel is stored and used. Limited by this, the technology involved in the use of an alternative fuel may be relatively mature, but is typically far from mainstream, and projects can be difficult to make economic for this reason. Because they are frequently raised as options, hydrogen and biodiesel are considered separately.

Type of journey/ service	Fuel alternative.		Provides an alternative energy/fuel for use in internal combustion engines.
Overall suitability	**H1**	1	**Alternative fuels** (excluding hydrogen or biodiesel) are currently not affordable nor available at-scale in the islands and significant advancements in technology will be required for this to change. While Fiji has the potential for at-scale ethanol production, the costs to produce and then use the ethanol in the vehicle fleet are currently prohibitive. Other alternatives present only micro-scale opportunities and the difficulty to provide quality assurance would likely relegate their use to specific projects involving older technology engines. New technology conversion processes, including small-scale enzymic bioethanol production, may present opportunities in the long term but there is unlikely to be a place for SIDS in the period before.
	H2	1	
	H3	3	
Global technology outlook (feasibility/ availability)	Demonstration.		The use of alternatives was once mature. However, the use of alternatives to gasoline and diesel is becoming more difficult due to the high-quality fuel requirements of more modern engines, and the difficulty to meet these requirements using current technology at SIDS-scale production levels.
Type of journey/ service	Fuel alternative.		Provides an alternative energy/fuel for use in internal combustion engines.

Affordability/ cost	Whole-of-life		Imported, high-quality alternatives to petroleum fuels expected to be very expensive compared to standard gasoline and diesel due to their premium in overseas markets and additional cost of specific shipping requirements. Generalising, local production would be expected to be in small volumes, which currently tends to have high costs associated with processing and ensuring quality for use in modern engines. An alternative is to accept lower quality and confine its use to older engines, which has little promise in the future. There is potential for economic, small waste-to-fuel production in the distant future.
	Purchase	$$$	
	Ongoing	$$$	
Supply/ availability	2		Not considering hydrogen or biodiesel, very few options providing the quality required for assured operation in automotive type engines.
Carbon footprint	3		Depends on the feedstock and production process. There is potential for low lifecycle emissions, especially if derived from a biowaste feedstock stream, but care required to account for GHG emissions in the supply of feedstock through to the supply of the finished alternative fuel product.
Energy security	3		Potential to provide energy security if locally produced and use of imported energy for process heat/energy is low.
Convenience, comfort, safety, and accessibility	2		Use tends to be limited to specific projects in arrangements that tend to be less convenient than for the use of traditional fuels and may require additional safety controls.
Infrastructure & refuelling requirements	2		Use tends to be project-specific in nature and requiring additional controls with respect to fuels storage and handling.
Operation & maintenance requirements	2		May require special fuel handling and/or engine retrofit in order to use. May require additional engine service requirements.
Waste/ end-of-life disposal	3		Fuels normally fully consumed during use. However, need to also consider any waste by-products associated with local manufacture. For example, glycerol waste slurry and wash water from biodiesel production can be difficult to dispose of in an appropriate way.
Environmental & social impact	4		Many alternatives are less harmful to the environment than gasoline or diesel in the event of a spill (however, this attribute often means that the fuel is also less stable in storage).
Local value chain/ economic opportunity	3		May involve a local supply chain that also provides a useful disposal of a waste stream
Required complementary systems and policies	3		Alternative fuels use expected to be confined to specific projects which presents the opportunity to set project-specific management controls.
Other considerations			

4.5 Sustainable aviation fuels (SAFs)



Aviation is responsible for 3% of global man-made GHG emissions (D.S.Lee, et al., 2021)***. Sustainable Aviation Fuels (SAFs) are a demonstrated technology that can reduce carbon emissions by up to 80% across their lifecycle for the use of the most low-carbon feedstocks and production processes. In 2019 SAFs contributed less than 0.1% of global commercial airline fuel consumed and current commitments indicate that this will only rise to around 1% by 2030*** (Teter, 2020)***. Cost is a significant barrier – SAFs are currently more than double the cost of conventional fuels. Increased volumes and improved processing are expected to lower the cost of SAFs, but they are expected to remain at a premium without some form of financial intervention*** (World Economic Forum, 2020)***. The global aviation industry is working to accelerate the scale-up of SAFs as one part of global aviation's pathway to net zero emissions*** (ITF, 2021)**.**

Type of journey/ service	Fuel alternative		SAFs are 'drop-in' fuel alternatives – requiring few changes, if any, for their use.
Overall suitability	**H1**	**2**	

	H2	**2**	**Sustainable Aviation Fuels** (SAFs) are an early-stage, primary technology for global aviation emissions reduction. In the short term, they are not suitable for SIDS due to high cost and very low availability – supply chains will preference major airlines in Europe and US. Towards the long term, it is expected that SAF use will eventually spread to island countries, as they are part of the global supply chain for aviation fuels.
	H3	**3**	
Global technology outlook (feasibility/ availability)	Prototype		Several different processes and feedstocks are in development. Limited by early stage in development and costs of fuel.
Affordability/ cost	Whole-of-life	-	Currently commercial SAFs are produced at around twice the cost of petroleum aviation fuels (Le Feuvre, 2019).[4]
	Purchase	$$$	
	Ongoing	-	
Supply/ availability	1		Difficult to justify supply and use outside of producer countries (which Pacific islands are not) while volumes of SAFs are a small proportion of global aviation fuel consumption. Expect availability in the islands in the distant future due to islands' part in the global supply chain for aviation fuels.
Carbon footprint	4		Up to 80% reduction compared with conventional aviation fuels, when low-carbon feedstocks and processing are involved (AIr Transport Action Group, 2017).
Energy security	3		It is expected that SAFs will be imported. Their use therefore does not provide any change to energy security.
Convenience, comfort, safety, and accessibility	2		Although the industry is targeting 'drop-in' fuel solutions, where SAFs are largely indistinguishable from standard aviation fuels and provide same range, etc., small differences in makeup may require additional controls for their transport, storage, handling, and use.
Infrastructure & refuelling requirements	2		May require additional controls for their transport, storage, handling, and use, but otherwise expect to use existing infrastructure once in mainstream use.
Operation & maintenance requirements	2		May require additional controls for their transport, storage, handling, and use.
Waste/ end-of-life disposal	5		Consumed as part of their normal lifecycle.
Environmental & social impact	4		Potential to rekindle aviation use (and provide social and other associated benefits) should the GHG emissions burden of aviation discourage air transport.
Local value chain/ economic opportunity	3		Little change expected to importation and use of standard aviation fuels. Use of SAFs might rekindle travel to the islands should the GHG emissions burden of air travel discourage tourism and other island income sources.
Required complementary systems and policies	2		May require additional controls for their transport, storage, handling, and use. Any changes required would be set by global bodies.
Other considerations			

5 Supporting services

5.1 App-based software services – including ride-hailing apps

In a transport context, software services use algorithms and data to match requests and demands for transport services with transport services that are available at a given time. As for ride-sharing apps, the software service may then manage the provision of those services. Software services include those that support ride-hailing, food delivery, freight consolidation, freight dispatching and tracking, vehicle sharing, and vehicle rental (including bike and scooter rental).

Type of journey/ service	Managed logistics of transport services.		Demand and supply matching service normally supported by payment gateways and service management mechanisms, in the case of transport, enabling easier and more time/energy-efficient provision of transport services.
Overall suitability	**H1**	4	There are many opportunities for **app-based software services** to support better use of existing transport services and/or support the introduction of new transport services. There is an expectation that transport-related software services will continue to evolve globally, and that many of these will find their way to the Pacific Islands and provide benefits to both users and transport providers. Policy support would be needed to ensure safety and consumer protection, and to raise awareness of how to use the services.
	H2	5	
	H3	5	
Global technology outlook (feasibility/ availability)	Mature and developing		The first ride-hail app to be launched was UBER, in 2009. The use of ride-hailing apps is now globally well established. Similar apps manage food delivery, vehicle hire, and the movement of freight. Market competition is expected to drive new developments that provide further improvements in the transportation of people and goods.
Affordability/ cost	Whole-of-life	$	Many software services are provided on a subscription basis – where a supplier sets up a multi-user system, then charges users a proportion of each transaction fee managed by the software services or charges a monthly or other subscription fee for the use of the software service. Some providers of software services also charge a set-up fee, which, for example, enables small numbers of operators or even individuals to set up their own systems – getting around the problem that small islands are unlikely to attract the likes of UBER, for example. As an example, Onde provide a ride-hailing app service starting at a one-time set-up fee of USD7,000 (for UBER-like hailing capability), plus an ongoing low percentage on transaction fees.
	Purchase	$	
	Ongoing	$	
Supply/ availability	4		There are several (global) providers offering software services for ride-hailing, freight handling and logistics, ferry passenger-and car-bookings, and booking systems for public electric vehicle charging points. The software services can be set up and maintained remotely and do not require local support to do so.
Carbon footprint	4		Many transport apps result in lower fuel consumption for providing the same service: some ride-hailing apps provide ride-sharing, reducing the vehicle distance travelled across two or more ride requests; associated routing maps normally provide the best route, freight apps enable freight consolidation and backloading. Overall, a reduction in fuel use, and GHG emission is expected.
Energy security	4		In general, expect a decrease in fuel consumed by transport providers through use of software services, providing increased energy security.
Convenience, comfort, safety, and accessibility	4		Software services enable easy matching of transport service request with transport providers and can provide greater access to transport services. Many apps also provide information that makes the transport service more convenient to use, and safer.
Infrastructure & refuelling requirements	3		Users require good access to cloud-based communication services.
Operation & maintenance requirements	5		Little direct O&M requirements as normally provided by software provider.
Waste/ end-of-life disposal	5		None.

Environmental & social impact	4	Often provides greater access to more affordable transport options, with social benefits associated with this. However, may disrupt existing service providers.
Local value chain/ economic opportunity	4	Often provides greater access to more affordable transport options, reducing the cost of doing business. Use of software services may also result in the provision of new transport services and new business opportunities associated with this.
Required complementary systems and policies	2	May require clarification of regulations with respect to use of private vehicles for providing public/commercial services and employer/contractor status of transport service providers.
Other considerations		

5.2 Marine energy efficiency measures

There are many factors involved in optimising the operation of a vessel, and many cost-effective measures that can be made to reduce energy consumed (or otherwise reduce GHG emissions and/or increase energy security) with little or no compromise to the provision of the transport services provided. *Such measures can include:*

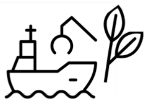
- *Vessel speed reduction (including just-in-time arrival)*
- *Voyage planning, weather, current, and tide routing*
- *Ballast, trim, and draft optimisation*
- *Auxiliary load optimisation (including turning off unnecessary loads)*
- *Optimised engine operation*
- *Scheduled maintenance*
- *Hull and propellor coatings and surface management*
- *Freight consolidation and logistics improvements*

And despite 'age-old' vessel operating experience in the islands, there are still improvements that can still be made to the operation of a vessel.

Type of journey/ service	Improvements to existing operations		Operational efficiency measures offer the potential for lower energy consumption and/or lower costs and/or improved service provision to existing operations.
Overall suitability	**H1**	**4**	Marine energy efficiency measures include various approaches to achieving significant fuel savings and are very suitable for SIDS over all time frames. The combination of modern electronics, software and the ability to relatively cheaply transmit data even in remote SIDS locations provides opportunity for the use of sophisticated trip planning systems. As well, optimised engine operation, hull cleaning, specialised coatings, and optimising ballast and trim can bring about significant improvements in vessel performance. Many of the technologies involved are expected to see performance improvements and decreased costs over time. Adoption of many of these technologies provides quick payback due to fuel saving, and attention should be given to them in the short, medium and long terms.
	H2	**4**	
	H3	**4**	
Global technology outlook (feasibility/ availability)	Both mature and developing		The energy crisis of the 1980s, climate change, and energy security concerns have driven research into energy optimisation of marine transport for many decades. Traditional ways and a lack of awareness have impeded the deployment of many of those that are mature. New technology and reduced costs of technology continue to offer more options suitable for island circumstances.
Affordability/ cost	Whole-of-life	$	Some measures require little to no investment: for example, those that involve procedure/behaviour changes. Significant decreases in the cost and increased availability of electronics, software, and GPS systems have enabled far wider access to navigational and routing aids, and logistics systems. Entry weather-routing packages begin at around US$1000 for components and a US$100/y subscription. Entry wave, current and weather routing packages are around US$300/y subscription. Expect several of these measures to provide short payback periods (but sector may require support to identify those that are appropriate, and to aid their first deployments).
	Purchase	$	
	Ongoing	$	

Supply/ availability	4	Measures range from differences in procedure through to those requiring importation (including download) of technology. For both, lack of awareness can be a significant barrier to local availability.
Carbon footprint	4	Overall, expect a small reduction in fuel consumption for provision of the same level of service, for no or near-zero GHG emissions in deploying the measure, resulting in a decrease in carbon footprint. As an example, scheduling and just-in-time arrival could bring about fuel savings of the order of 10% through small moderation of peak vessel speeds.
Energy security	4	Overall, expect a small reduction in fuel consumption and increased energy security arising from this.
Convenience, comfort, safety, and accessibility	4	Changes to operation for the most part are unchanged or very small. Navigational aids have the potential to increase the comfort and safety of voyages.
Infrastructure & refuelling requirements	5	No additional infrastructure requirements.
Operation & maintenance requirements	4	Some energy efficiency measures may place additional demand on crew workload.
Waste/ end-of-life disposal	5	Generally, no additional waste or end-of-life disposal requirements.
Environmental & social impact	4	Some measures may improve the reliability of services, but generally expect relatively little outward change in services provided.
Local value chain/ economic opportunity	5	Minimal change expected – measures involve changes in behaviour and possibly the use of relatively low-cost equipment, with little association with local businesses.
Required complementary systems and policies	2	Programme to keep current with global developments and provide awareness and support of those expected to benefit the islands.
Other considerations		

5.3 Green ports



The term 'green port' is a generic term used to describe ports that have introduced measures to reduce the environmental footprint of the port and of vessels while they are using the port. *'Green port' measures can include:*

- *Energy-efficient measures (vehicle, equipment, and lighting specification and use, etc.)*
- *Resilience preparedness (operational- and infrastructure-related)*
- *GHG and air quality emissions reduction (eg, shore power of refrigerated containers)*
- *Cold-ironing (where shore power is used by vessels to avoid operating the vessel's engines).*
- *Pollution control preparedness*
- *Management of light and noise pollution*
- *Management of solid waste*
- *Management of biosecurity*

Type of journey/ service	Improvement to current operations and infrastructure.		Ports are an essential component of sea transport in the islands. Green port initiatives provide guidance aimed at lowering the environmental footprint and increasing the robustness of port facilities and operations.
Overall suitability	**H1**	**4**	Improving the infrastructure and operation of ports to be more resilient, energy-efficient, to reduce GHG and other environmental impacts is highly suitable for the short, medium and long terms in the islands. However, the degree of change may be limited by
	H2	**4**	

	H3	**4**	affordability, technical capacity, and practicality – some green port measures will likely never be practical in smaller ports: cold-ironing (where a ship uses shore power while it is in port), for example, is feasible only in major ports supplied by robust electricity networks.
Global technology outlook (feasibility/ availability)	Individual mechanisms mature, combined concept emerging.		Globally, the green port concept is still developing. Individual green port measures are mature in themselves, with the umbrella green port philosophy providing a more holistic approach across them. A Green Pacific Port initiative was established in 2018 and agreed to by Samoa, Solomon Islands, and Tonga. The Solomon Islands Port Authority is aiming for Noro Port to be carbon-neutral by 2030.
Affordability/ cost	Whole-of-life	$$	Major infrastructure projects such as establishing and improving port infrastructure can be costly. The cost per tonne handled also increases significantly for smaller ports due to their lower utilisation and sometimes their remoteness. A practical approach is required to ensure a balance between green port targets without compromising the delivery of essential transport services – some smaller ports struggle to maintain existing loading equipment, let alone to aspire to more modern equipment. The Solomon Islands Port Authority reports an 8% savings in energy during its green port pilot (SPC, 2018). Some individual measures are reasonably low-cost and effective – changes to more efficient lighting, for example, has payback periods of 12-18 months (Morgano, Phon-Amnuaisuk, & Johnston, 2014).
	Purchase	$$$	
	Ongoing	$$	
Supply/ availability	2		The various technologies involved are available, but affordability may be a barrier to their uptake, particularly for smaller ports and/or for those that are more remote.
Carbon footprint	4		The Solomon Islands Port Authority's green port pilot had indicated fuel savings of 8%, which is a reduction in GHG emissions of similar proportions.
Energy security	4		Fuel savings of 8% were found during the Solomon Islands Port Authority's green port pilot, increasing fuel security.
Convenience, comfort, safety, and accessibility	4		It is expected that following a green port strategy would increase a port's productivity and safety through considering a broad suite of measures.
Infrastructure & refuelling requirements	4		A green port strategy targets improvement to infrastructure.
Operation & maintenance requirements	4		A green port strategy targets improvement to operations and maintenance.
Waste/ end-of-life disposal	4		A green port strategy targets improved management of wastes.
Environmental & social impact	4		A green port strategy targets the use of lower environmental impact methods. Cleaner ports and port areas expected to provide wider community benefits.
Local value chain/ economic opportunity	4		A green port strategy targets improved resilience, with expected economic benefits across the local community.
Required complementary systems and policies	4		Given their role as key nodes in the transport system, planning for ports must be integrated with the wider, long-term transport strategy.
Other considerations			

References

Air Transport Action Group. (2017). *Beginner's Guide to Sustainable Aviation Fuel Edition 3.* ATAG.

Alcock, C. (2020, September 23). Heart Unveils Electric Propulsion System for ES-19 Airliner . *Aviation International News*, pp. https://www.ainonline.com/aviation-news/air-transport/2020-09-23/heart-unveils-electric-propulsion-system-es-19-airliner.

Alejandrino-Yap, M. C., Dornan, M., & McGovern, K. (2013). *Infrastructure Maintenance in the Pacific: Challenging the Build-Neglect-Rebuild Paradigm.* Pacific Region Infrastructure Facility. Sydney: Pacific Infrastructure Advisory Centre. Retrieved from https://www.theprif.org/sites/default/files/documents/build_neglect_rebuild_revised_full_report_2014.pdf

Asian Development Bank. (2007). *Oceanic Voyages: Aviation in the Pacific.* Manila: Asian Development Bank. Retrieved from https://www.adb.org/sites/default/files/publication/29759/aviation-pacific.pdf

Asian Development Bank. (2013). *Moving from Risk to Resilience: Sustainable Urban Development in the Pacific.* Manila: Asian Development Bank (ADB). Retrieved from https://www.adb.org/sites/default/files/publication/31200/moving-risk-resilience-sustainable-urban-development-pacific.pdf

Babinard, J., McMahon, C., & Wee, J. (2016). *Improving Accessibility in Transport Infrastructure Projects in the Pacific Islands.* Sydney: Pacific Regional Infrastructure Facility (PRIF). Retrieved from https://www.theprif.org/document/regional/transport/improving-accessibility-transport-infrastructure-projects-pacific

Baker, A. J., & Week, D. (2012). *Infrastructure and Climate Change in the Pacific.* Canberra: Australian Government Department of Climate Change and Energy Efficiency, Australian AID.

Bongardt, D., Stiller, L., Swart, A., & Wagner, A. (2019). *Sustainable Urban Transport: Avoid-Shift-Improve (ASI).* GIZ. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (GIZ). Retrieved from https://www.transformative-mobility.org/assets/publications/ASI_TUMI_SUTP_iNUA_No-9_April-2019.pdf

Burns, E. (2021, May 21). WAm takes new tack. *Marshall Islands Journal*, pp. https://marshallislandsjournal.com/wam-takes-new-tack/.

C40. (2020, July). *How to build back better with a 15-minute city*. Retrieved from C40 Knowledge Hub: https://www.c40knowledgehub.org/s/article/How-to-build-back-better-with-a-15-minute-city?language=en_US

Campbell, A. (2020). *Options for Integrated Electric Mobility and Renewable Power Markets in the Pacific Island Countries and Territories (PICT) Draft Technical Background Paper.* Pacific Centre for Renewable Energy and Energy Efficiency/ Pacific Community. Retrieved from https://pcreee.org/event/online-validation-regional-e-mobility-policy-and-program-pacific-islands

Chen, Z., & Tan, D. H. (2020, October 22). *Designing batteries for easier recycling could avert a looming e-waste crisis.* Retrieved from The Conversation: https://theconversation.com/designing-batteries-for-easier-recycling-could-avert-a-looming-e-waste-crisis-146065

Christy, A. (2019, December 13). *Papua New Guinea – "Meri Seif" Women & Girls Safe Bus Transport System.* Retrieved from Women's UN Report Network: https://wunrn.com/2019/12/118532/

Cozzi, L., & Petropoulos, A. (2021, January 15). *Carbon emissions fell across all sectors in 2020 except for one – SUVs*. Retrieved from International Energy Agency: https://www.iea.org/commentaries/carbon-emissions-fell-across-all-sectors-in-2020-except-for-one-suvs

Curd, J., & Baker, N. (2019). *Marshall Islands Transport Emissions.* Wellington: draft report provided to the NZ Ministry of Foreign Affairs and Trade and the Government of the Marshall Islands.

D.S.Lee, D.W.Fahey, A.Skowron, M.R.Allen, U.Burkhardt, Q.Chen, . . . L.J.Wilcoxm. (2021, January 1). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment, 244*, https://doi.org/10.1016/j.atmosenv.2020.117834.

German, B. (2020, June 16). China dominates electric trucking. *Axios*, pp. https://www.axios.com/electric-trucking-adoption-china-us-europe-15315520-3afd-4228-9af2-075fae17c4b3.html.

Gogoro. (2020, January). *2019 - Accelerated Transformation*. Retrieved from Gogoro.com: https://www.gogoro.com/news/2019-a-year-of-accelerated-transformation/

Government, V. S. (2021, March 23). *20-minute neighbourhoods*. Retrieved from Department of Environment, Land, Water and Planning - Planning:

https://www.planning.vic.gov.au/policy-and-strategy/planning-for-melbourne/plan-melbourne/20-minute-neighbourhoods

GSMA Intelligence. (2019). *The Mobile Economy Pacific Islands 2019.* GSMA Intelligence. Retrieved from https://www.gsma.com/mobileeconomy/wp-content/uploads/2020/03/GSMA_MobileEconomy2020_Pacific_Islands.pdf

Hertzke, P., Khanna, J., Mittal, B., & Richter, l. (2020, October 6). *Global emergence of electrified small-format mobility.* Retrieved from McKinsey.com: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/global-emergence-of-electrified-small-format-mobility

IEA. (2020). *Clean Energy Innovation .* Paris: IEA.

IEA. (2020). *Global EV Outlook 2020.* Paris: International Energy Agency. Retrieved from https://www.iea.org/reports/global-ev-outlook-2020

Institute for Transportation and Development Policy. (2020, March 24). *As the Impacts of Coronavirus Grow, Micromobility Fills in the….* Retrieved from Transport Matters: https://www.itdp.org/2020/03/24/as-the-impacts-of-coronavirus-grow-micromobility-fills-in-the-gaps/

International Energy Agency. (2019, December 2019). *IEA Areas of Work: Energy Security*. Retrieved April 14, 2021, from https://www.iea.org/areas-of-work/energy-security

ITDP. (2019). *The Electric Assist: Leveraging e-bikes and e-scooters for more livable cities.* New York: Institute for Transportation and Development Policy .

ITF. (2021). *Decarbonising Air Transport: Acting Now for the Future.* Paris: OECD Publishing.

ITF. (2021). *Micromobility, Equity and Sustainability: Summary and Conclusions,.* Paris: OECD Publishing.

Kaminski-Morrow, D. (2020, March 9). Norwegian authorities aim for electric aircraft debut by 2030. *Flight Global*, pp. https://www.flightglobal.com/air-transport/norwegian-authorities-aim-for-electric-aircraft-debut-by-2030/137146.article.

Le Feuvre, P. (2019, March 18). *Are aviation biofuels ready for take off?* Retrieved from IEA: https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off

Lin, H.-T., Nakajima, K., Yamasue, E., & Ishihara, K. N. (2018, November 23). Recycling of End-of-Life Vehicles in Small Islands: The Case of Kinmen, Taiwan. *Sustainability, 10*(12), 14. doi:https://doi.org/10.3390/su10124377

Low, N., & Astle, R. (2009). Path dependence in urban transport: An institutional analysis of urban passenger transport in Melbourne, Australia, 1956–2006. *Transport Policy*, 47-58. doi:10.1016/j.tranpol.2009.02.010

Maunsell. (2006). *Torres Strait Transport Infrastructure Plan.* Brisbane: Queensland Government. Retrieved from https://www.tmr.qld.gov.au/projects/torres-strait-transport-infrastructure-plan

Menon, J. (2019). *Guide on Integrating Gender into Infrastructure Development in Asia and the Pacific: Transport and roads.* UN Women/ UNOPS. UN Women/ UNOPS. Retrieved from https://asiapacific.unwomen.org/-/media/field%20office%20eseasia/docs/publications/2019/03/ap-bls19062_tr_web.pdf?la=en&vs=5728

Morgano, D., Phon-Amnuaisuk, S., & Johnston, P. (2014). *Development & Implementation of PEEP2 energy efficient lighint projects in the Pacific.* for PALS Project Steering Commitee & Lighting Workshop, Nadi, 27-28 May 2014.

Mycoo, M., & Donovan, M. G. (2017). *A Blue Urban Agenda: Adapting to Climate Change in the Coastal Cities of Caribbean and Pacific Small Island Developing States.* Washington DC: Inter-American Development Bank. Retrieved from https://publications.iadb.org/publications/english/document/A-Blue-Urban-Agenda--Adapting-to-Climate-Change-in-the-Coastal-Cities-of-Caribbean-and-Pacific-Small-Island-Developing-States.pdf

National Association of City Transportation Officials, Global Designing Cities Initiative. (2016). *Global Street Design Guide.* Island Press.

National Association of City Transportation Officials, Global Designing Cities Initiative. (2020). *Designing Streets for Kids.* Island Press.

Perry, D. (2020, August 6). UK firm EAG details development roadmap for hybrid-electric regional airliner. *Flight Global*, pp. https://www.flightglobal.com/air-transport/uk-firm-eag-details-development-roadmap-for-hybrid-electric-regional-airliner/139641.article.

Petersen, C. (2019, December 31). Living Life Unpeeled youtube channel. *Traveling on Sailing Cargo Ship Kwai to the Most Remote Islands in the World*.

Pipistrel Aircraft. (n.d.). *Alpha Electro.* Retrieved October 2021, from Pipistrel Aircraft: https://www.pipistrel-aircraft.com/aircraft/electric-flight/alpha-electro/

Planning and Urban Management Agency, Ministry of Natural Resources and Environment, Samoa. (2014). *Apia, Samoa - Climate Change Vulnerability Assessment- Abridged Report.* Nairobi: UN Habitat.

Planning Institute of Australia, South Australia Division. (2008). *Integrated Landuse Transport Policy Statement.* Adelaide: Planning Institute of Australia. Retrieved from https://www.planning.org.au/documents/item/281

Pryke, J. (2020, May 28). *Cab Pacific airlines pull out of the dive?* Retrieved April 18, 2021, from Lowy Institute: The Interpreter: https://www.lowyinstitute.org/the-interpreter/can-pacific-airlines-pull-out-dive

Rahiman, L. (2020, November 13). Retrieved from The Strategist: Australian Strategic Policy Institute: https://www.aspistrategist.org.au/covid-19-could-lead-to-telehealth-revolution-in-fiji/

Schou-Zibell, L. (2020, June 29). *The internet is coming – with risks and benefits – to new areas in Asia and the Pacific.* Retrieved from Asian Development Bank Blog: https://blogs.adb.org/blog/internet-is-coming-risks-and-benefits-to-new-areas-asia-pacific

Schou-Zibell, L., & Phair, N. (2020, July 6). *Covid-19 has created digital opportunities in the Pacific.* Retrieved from Asian Development Blog (ADB): https://blogs.adb.org/blog/covid-19-has-created-digital-opportunities-pacific

Shaw, B. (2020, May 28). *Drones are Taking Off in Healthcare .* Retrieved from PharmaBoardroom.com: https://pharmaboardroom.com/articles/drones-are-taking-off-in-healthcare/

SPC. (2018, September 3). *'Green Pacific Port initiative' looks to improve port operations across the Pacific.* Retrieved from Pacific Community: https://www.spc.int/updates/news/2018/09/green-pacific-port-initiative-looks-to-improve-port-operations-across-the

SPREP. (2018, March 20). *"Moana Taka Partnership" Unfolds Exciting Recycling Possibilities For The Pacific Islands.* Retrieved from SPREP: https://www.sprep.org/news/moana-taka-partnership-unfolds-exciting-recycling-possibilities-pacific-islands

Swoop Aero. (2018). *The world's first two-way medical drone logistics network in Vanuatu.* Retrieved from Swoop Aero: https://swoop.aero/stories/vanuatu

Teter, J. (2020). *Aviation Tracking Report June 2020.* Paris: IEA.

UN Habitat. (2015). *Urbanization and Climate Change in Small Island Developing States.* Nairobi: United Nations Human Settlements Program (UN Habitat). Retrieved from https://sustainabledevelopment.un.org/content/documents/2169(UN-Habitat,%202015)%20SIDS_Urbanization.pdf

UN Women. (2016, November 15). *Making public transport safe for women and girls in Papua New Guinea.* Retrieved from UN Women: https://www.unwomen.org/en/news/stories/2016/11/making-public-transport-safe-for-women-and-girls-in-papua-new-guinea

Vahs, P. C., Wagner, S., Peetz, T., Strasser, S., Richter-Alten, H., & Arriens, C. (2019). *Technical and Operational Options Catalogue in the project Transitioning to Low Carbon Sea Transport in the Republic of the Marshall Islands.* GIZ. Retrieved from https://www.changing-transport.org/publication/reducing-fuel-consumption-and-emissions-from-inter-atoll-and-inside-lagoon-transport/

Waters, C. (2021, February 22). Medical deliveries by drone ready for take-off in Australia. *The Age*, pp. https://www.theage.com.au/business/small-business/medical-deliveries-by-drone-ready-for-take-off-in-australia-20210219-p573z8.html.

World Bank. (2017). *Climate and Disaster Resilient Transport in Small Island Developing States: A Call for Action.* Washington DC: The World Bank. Retrieved from https://openknowledge.worldbank.org/bitstream/10986/28798/1/120998.pdf

World Bank. (2018). *Supporting Road Network Vulnerability Assessments in Pacific Island Countries.* World Bank.

World Bank. (2020). *Handbook for Gender-Inclusive Urban Planning Design.* Washington DC.

World Economic Forum. (2020). *Clean Skies for Tomorrow Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation.* World Economic Forum.

Xie, Y., Savvarisal, A., Tsourdos, A., Zhang, D., & Gu, J. (2021, April). Review of hybrid electric powered aircraft, its conceptual design and energy management methodologies. *Chinese Journal of Aeronautics, 34*(4), https://www.sciencedirect.com/science/article/pii/S1000936120303368.

Xinhua. (2019, 10 28). 4-seater electric aircraft makes maiden flight in China. *Xinhua News*, pp. http://www.xinhuanet.com/english/2019-10/28/c_138510016.htm.

Yanocha, D., & Allan, M. (2019). *The Electric Assist: Leveraging e-bikes and e-scooters for more livable cities.* New York: Institute for Transportation & Development Policy. Retrieved from https://www.itdp.org/publication/electric-assist/

Zarif, R., Kelman, B., & Pankratz, D. (2019, April 15). *Small is beautiful: Making micromobility work for citizens, cities, and service providers.* Retrieved from Deloitte Insights: https://www2.deloitte.com/us/en/insights/focus/future-of-mobility/micro-mobility-is-the-future-of-urban-transportation.html