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RENEWABLE ENERGY PATHWAYS IN ROAD TRANSPORT

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FIA FOUNDATION

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The FIA Foundation is an independent UK registered charity which supports an international programme of activities promoting road safety, the environment and sustainable mobility, as well as funding motor sport safety research. Our aim is to ensure 'Safe, Clean, Fair and Green' mobility for all, playing our part to ensure a sustainable future.

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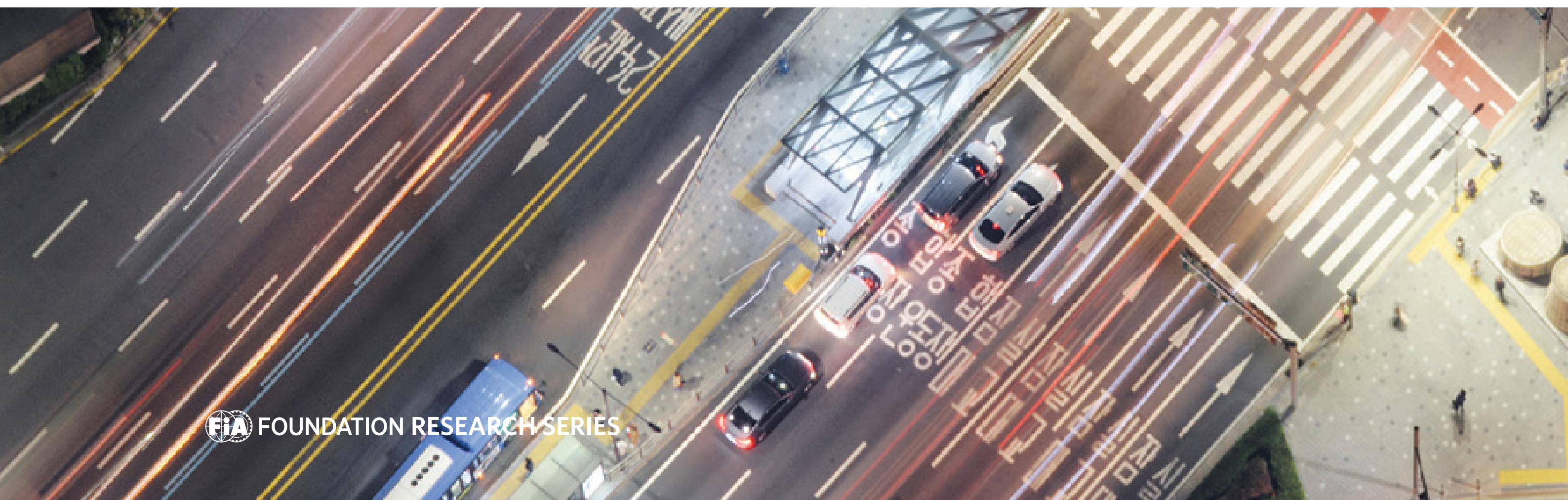
CONTENTS

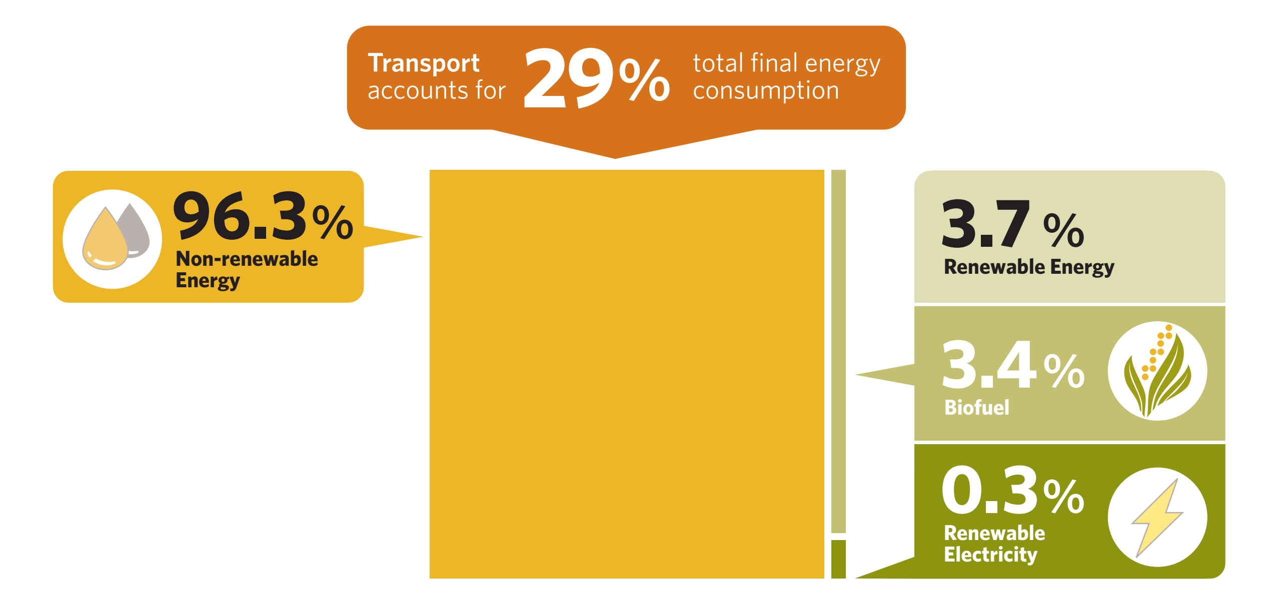


CONTENTS

EXECUTIVE SUMMARY

Road transport is estimated to represent over 70% of GHG emissions from the overall transport sector by 2050, if no further measures are taken. Energy demand for transport is growing much faster than any other sector. Transport still relies heavily on fossil fuels and has the lowest share of renewables, lagging far behind developments in the power generation sector as well as other end-use sectors. In 2018, transport represented 29% of total final energy consumption, but only 3.7% of this was met by renewable sources.

ENERGY CONSUMPTION AND RENEWABLE ENERGY SHARE IN THE TRANSPORT SECTOR, 2018



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A rapid and fundamental shift is required in the transport sector to enable the decarbonisation required to meet the objectives of the Paris Climate Agreement. Renewable energy will need to play a fundamental role in the transport systems of the future, which will be much more complex, with multiple players, technologies and direct implications for energy generation.

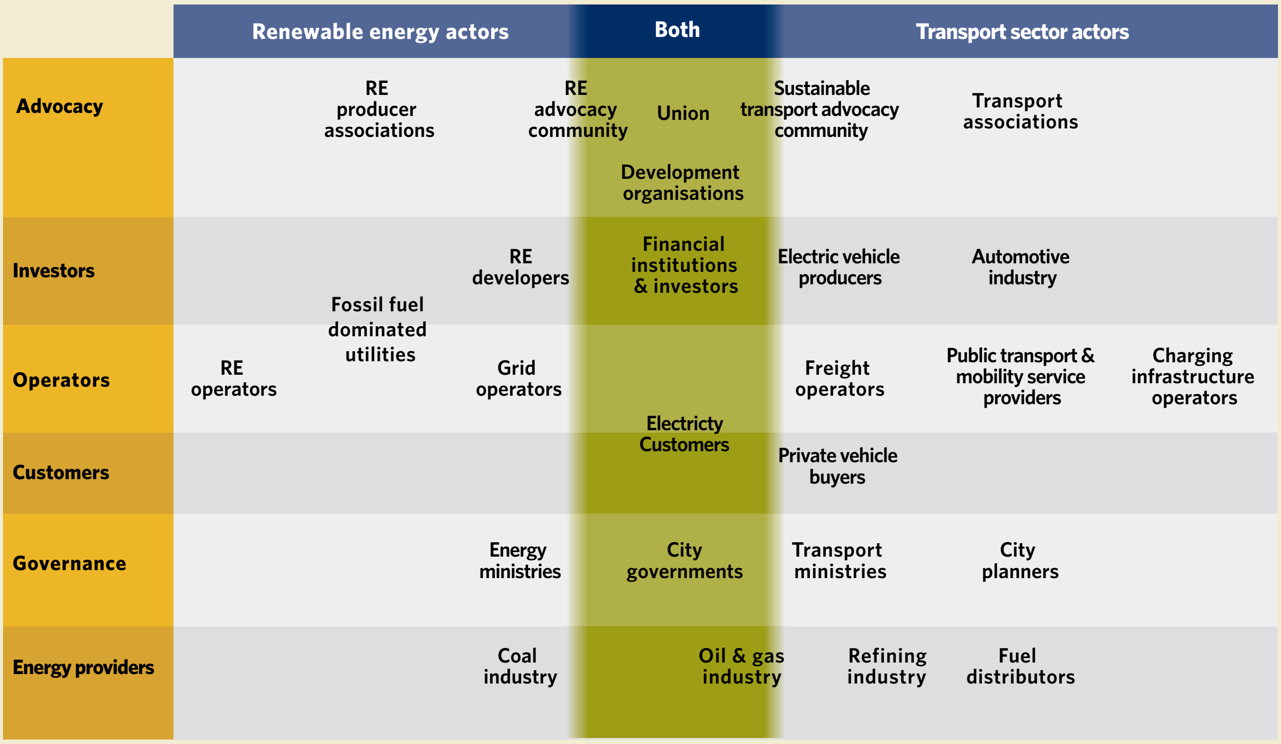
The transport and energy sectors are highly interlinked. To decarbonise our economy the transport and energy sectors thus need to align their strategies. The uptake of renewables in road transport depends on the rapid decarbonisation of the electricity sector, for direct use of electricity and for the production of renewable hydrogen, supplemented by the supply of advanced biofuels, particularly for use in heavy-duty trucks.

Renewable energy solutions for the road transport sector need to be embedded in a wider framework of actions that also reduce the demand for transport services, shift the choice of transport modes and increase the efficiency of vehicles (other elements of the Avoid-Shift-Improve framework). Decarbonising the sector with renewables will only be possible with ambitious policies that address all these aspects and that take an integrated view of the implications for the wider energy system, considering the sustainability of the overall supply chain of different technology solutions.

Experts need to make it easy for decision-makers and customers to manage increasing complexity. Renewable transport solutions need to be tailored to the specific context and use case. To achieve this, a large variety of actors need to improve collaboration to develop economically and financially viable solutions that appeal to end users.

Investment decisions on renewable energy generation and distribution infrastructure focus on finding the right technology for a given local context and depend on the specific local combination of demand, available energy sources and feedstocks, distribution options and economically feasible production processes. In comparison, **the road transport sector is traditionally more concerned with the vehicle technology and the required fuel infrastructure.**

ACTORS IN THE RENEWABLE ENERGY AND TRANSPORT SECTORS



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Which vehicle technology – with its corresponding renewable fuel – is most appropriate depends strongly on the type of vehicle and the use case. Passengers or freight, small or large vehicles, urban or non-urban, short or long distance, individual vehicles or fleets – all have different demands on the vehicle technology. Finally, there are differences in the development level of countries and regions, influencing renewable transport challenges and opportunities. There is no 'one size fits all solution' for enhancing the uptake of renewables in road transport.

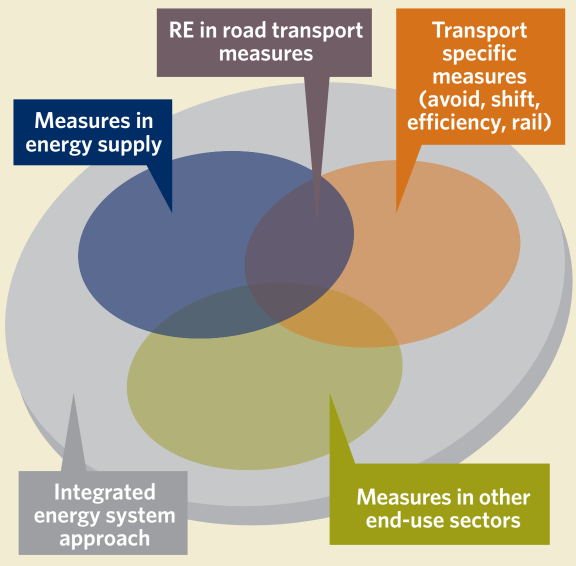
Biofuels are still the dominating renewable energy source in the transport sector, largely driven by blending mandates, which exist in at least 70 countries, although mostly with low blending rates. Biofuel production is still mostly first-generation ethanol and biodiesel, although the production of advanced diesel substitute fuels (HVO/HEFA) is increasing. The production of renewable electricity-based hydrogen is still very low, although the number of projects and installed hydrogen electrolyser capacity have grown considerably. Production processes for advanced biofuels and for PtX are not yet available at commercial scale, with the exception of HVO/HEFA.

Internal combustion engines dominate the vehicle market, accounting for 99% of the passenger cars produced worldwide, with the majority of these being gasoline or diesel. Shifts to new powertrains, such as battery electric or fuel cell electric vehicles, require major investments from the automotive sector as well as for charging and fuelling infrastructure. Many countries have put in place incentives for vehicle purchases as well as for the development of associated infrastructure. As a result, electric car sales have been growing steadily in recent years.

Increasing demand from transport electrification and growing variable renewable energy generation require a new paradigm concerning how electricity systems work. Technical solutions to capture synergies between the transport and energy system exist: unidirectional controlled charging (V1G) solutions are already commercially available. However, bi-directional vehicle-to-grid (V2G) solutions and vehicle-to-home/building (V2H/B) technologies remain in early deployment stages. Flexible power tariffs and power market reforms to enable and support such solutions are only slowly being implemented in individual countries.

Currently, only a few policies directly link renewable energy and transport ambitions. Truly integrated planning across sectors is largely absent, although the EU is in the process of developing a pioneering energy system strategy that integrates transport and other end-use sectors. At least 28 cities and 39 countries or states/provinces had independent targets both for EVs and renewable power generation, but the level of ambition varies and is in most cases not sufficient for a full decarbonisation across sectors. Only two countries have incentive schemes that link renewable energy requirements to vehicle or infrastructure subsidies.

THE ROLE OF RENEWABLE ENERGY IN ROAD TRANSPORT IN THE OVERALL ENERGY SYSTEM APPROACH



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The following recommendations aim to provide high-level guidance regarding what needs to happen to increase the share of renewable energy in road transport:

1 DEFINE A NATIONAL LONG-TERM ROADMAP FOR ENERGY AND TRANSPORT SYSTEM DECARBONISATION

- **Set long-term legally binding decarbonisation targets with a clear deadline and intermediate targets.** GHG emission targets need to be set economy-wide, energy sector wide, transport sector wide, and for individual transport sub-sectors. These targets need to be complemented by a clear vision regarding the renewable energy pathways to achieve them. Energy and transport sector targets need to be aligned and are ideally the result of integrated planning. Assigning clear responsibilities for target achievement is paramount.

- **Be clear on technology choices.** In designing policy instruments, decision-makers need to make a conscious decision in terms of whether they favour specific vehicle technologies such as battery electric or fuel cell electric vehicles, and thus specific renewable fuels, or if they leave this up to the market.

- **Ensure a life-cycle approach.** The transport sector needs to be accountable for up- and downstream emissions. A 'well-to-cradle' approach should be adopted as battery electric vehicles, hydrogen vehicles and biofuels gain market shares, extending beyond vehicle operation to vehicle production and recycling/disposal as well as fuel production and distribution.

2 ENHANCE COLLABORATION BETWEEN THE ENERGY AND TRANSPORT SECTORS AND ENSURE MULTI-LEVEL GOVERNANCE FOR THE IMPLEMENTATION OF RENEWABLE ENERGY SOLUTIONS

- **Create space for collaboration across sectors.**
  Energy and transport actors at all levels need institutionalised and permanent platforms to exchange and discuss tailored low-carbon vehicle choices and renewable energy solutions for their local context.

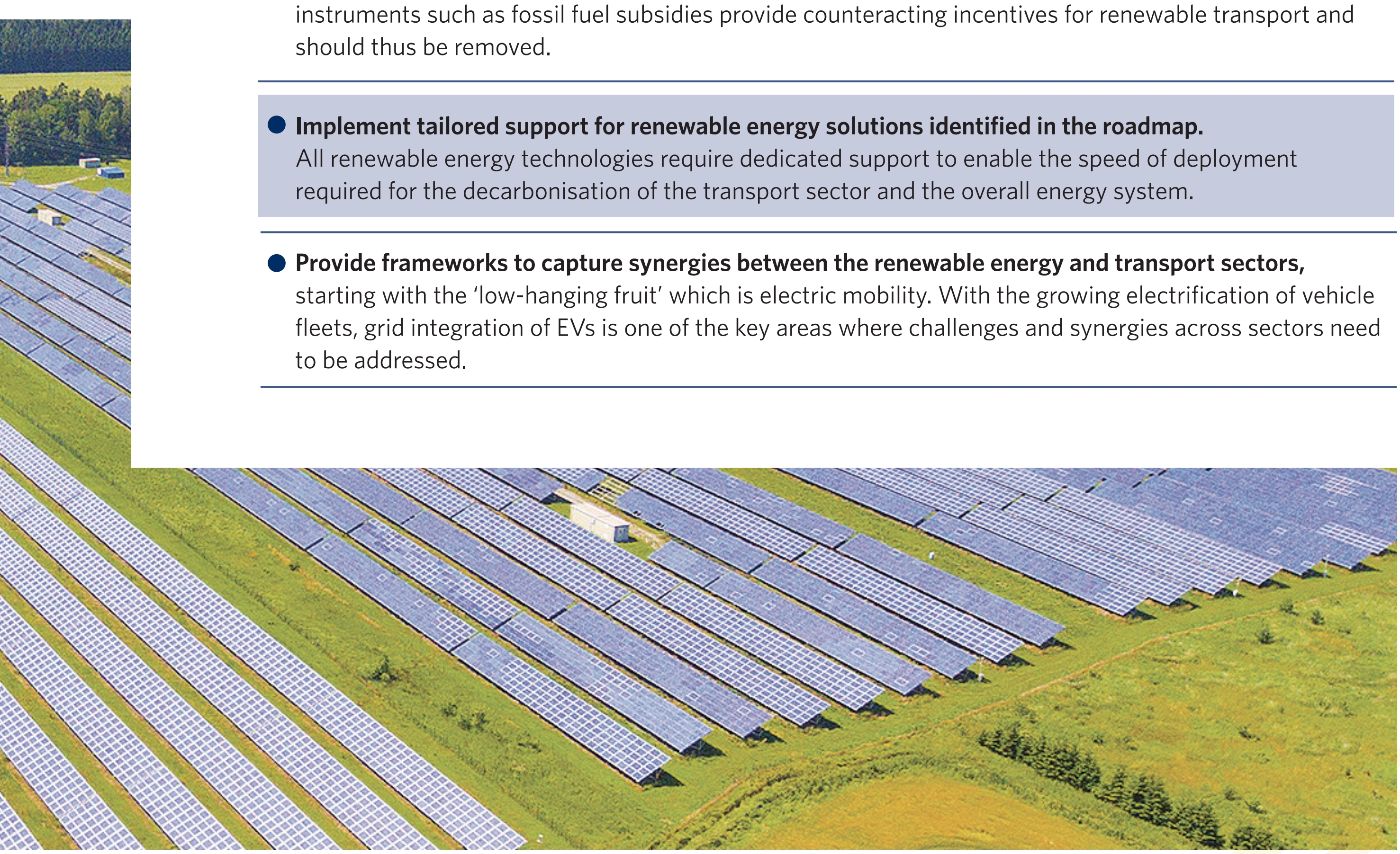
- **Ensure collaboration, coherence and consistency between decisions and policies made at different levels of government.**
  National regulation and policies need to enable local actors to implement renewable energy solutions that build on the locally available resources and are fit for the local circumstances and needs of their transport systems.

3 TAILOR POLICY INSTRUMENTS TO EFFECTIVELY IMPLEMENT THE ENERGY-TRANSPORT ROADMAP

- **Ensure the consistency of policy instruments.**
  There are several instruments in place that promote either renewable energy or low-carbon transport technologies. These instruments are often not well coordinated and might be inconsistent, which compromises their effectiveness to increase the share of renewables in transport. Other existing instruments such as fossil fuel subsidies provide counteracting incentives for renewable transport and should thus be removed.

- **Implement tailored support for renewable energy solutions identified in the roadmap.**
  All renewable energy technologies require dedicated support to enable the speed of deployment required for the decarbonisation of the transport sector and the overall energy system.

- **Provide frameworks to capture synergies between the renewable energy and transport sectors,** starting with the 'low-hanging fruit' which is electric mobility. With the growing electrification of vehicle fleets, grid integration of EVs is one of the key areas where challenges and synergies across sectors need to be addressed.



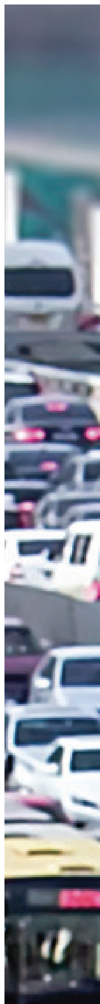
4 IMPROVE CROSS-SECTORAL KNOWLEDGE, DIALOGUE AND AWARENESS BETWEEN THE RENEWABLE ENERGY AND TRANSPORT COMMUNITIES

- **Develop a better narrative.**
  Both the renewable energy community and the transport community would highly benefit from a joint/cross-sectoral narrative that clearly emphasises the benefits of renewable energy and other complementary elements of the ASI framework in addressing the mobility needs of citizens and businesses, namely the provision of clean, reliable and affordable transport.

- **Ramp up formal training for new skillsets.**
  Enhanced formal training is needed in the context of the energy and transport systems of the future. Training programmes at universities and vocational trainings need to be updated to account for the linkages across sectors to better educate new generations of policy-makers, engineers, transport/energy/urban planners, economists, business owners, entrepreneurs, and other future decision makers.

5 DEVELOP TOOLS FOR ASSESSING CONTEXT-SPECIFIC CHALLENGES AND SOLUTIONS

- While many challenges for enhancing the uptake of renewables in road transport are relatively universal, the details vary – and so do the solutions. A toolset is needed to conduct context-specific diagnosis of the barriers and solutions for specific renewable fuels/electricity and low-carbon vehicles. This will support policy-makers in designing more adequate and effective regulatory and policy frameworks.



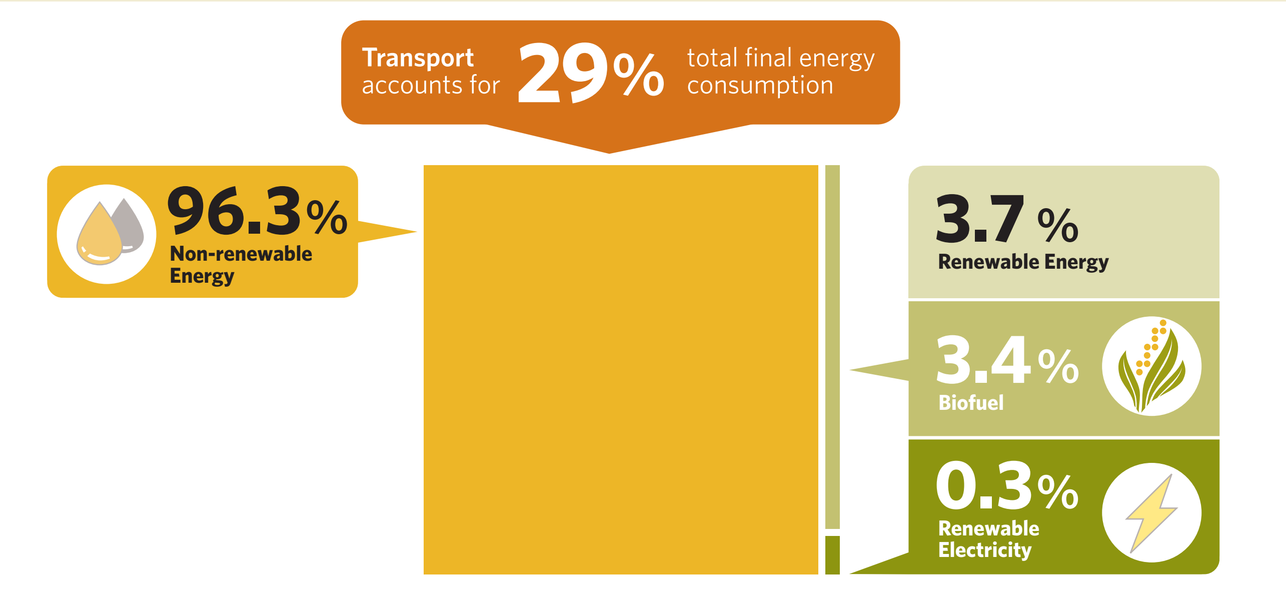
1. INTRODUCTION

When we talk about renewable energy, we first think about wind turbines, solar photovoltaic (PV) systems and other technologies for power generation. This is not surprising, seeing the tremendous development in this area over the last decades. Variable renewable energy (VRE) has become a mainstream electricity source and is increasingly cost-competitive compared to conventional fossil fuel-fired power plants. However, over 80% of final energy demand comes from heating, cooling and transport where the advance of renewable energy continues to lag far behind.

Energy demand for transport is growing much faster than any other sector and has the smallest share of renewables than any other sector.[1] In 2018, transport represented 29% of total final energy consumption, but only 3.7% of this was met by renewable sources.[2]

Because of a high reliance on fossil fuels, the transport sector was responsible for 25% of global energy-related carbon dioxide (CO_2) emissions in 2018.[3] Unlike other sectors, there is no sign of a change in trend and enhanced efforts are clearly needed.[4]

FIGURE 1.1: ENERGY CONSUMPTION AND RENEWABLE ENERGY SHARE IN THE TRANSPORT SECTOR, 2018



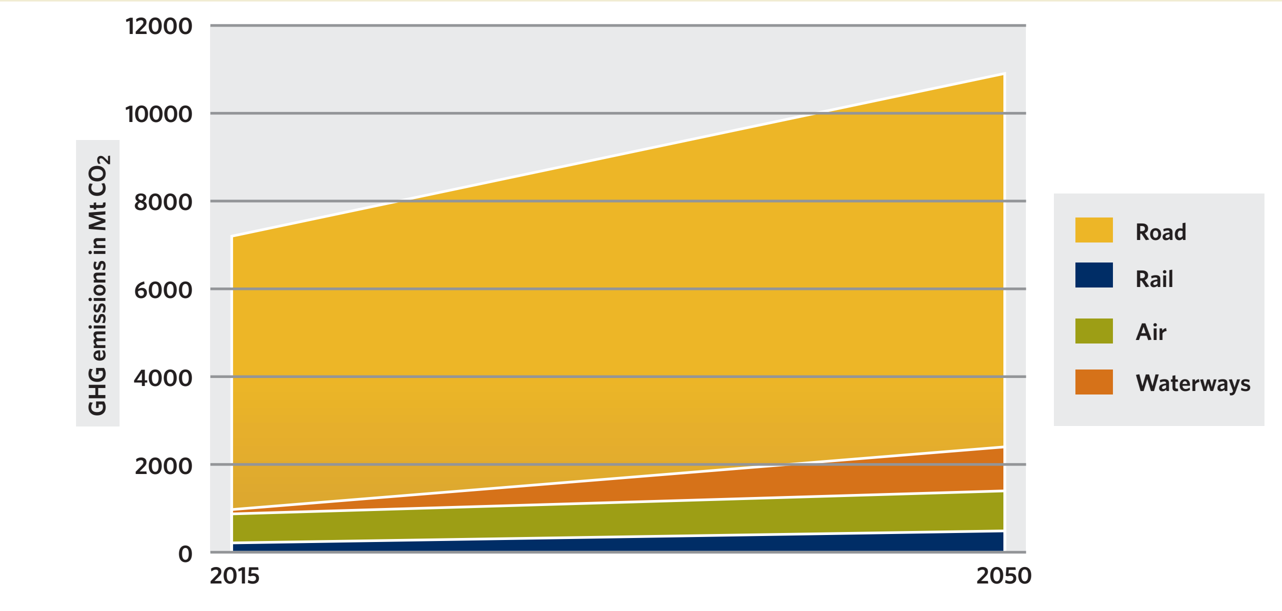
Source: own illustration based on IEA sources.[5]

Even if all of the announced policy measures are implemented, the transport sector is expected to increase greenhouse gas (GHG) emissions by 60% up to 2050, largely driven by increasing freight and non-urban transport.[6]

This report focuses on road transport, which is estimated to represent over 70% of GHG emissions from the sector by 2050, if no further measures are taken (see Figure 1.2).[7] This report therefore explores options for speeding up the deployment of renewable energy in road transport.[i]

A rapid and fundamental shift is required in the sector to enable the decarbonisation required to meet the objectives of the Paris Climate Agreement.[8] Renewable energy will need to play a fundamental role in the transport systems of the future.

FIGURE 1.2: CO_2 EMISSIONS GROWTH UNDER CURRENT POLICIES 2015 – 2050



Source: own illustration based on data from ITF.[9]

This will need to be a part of an integrated effort that increases the efficiency of the transport system and of vehicles[i], promotes non-motorised modes of transport and avoids some transport activity altogether, while securing mobility of people and goods (see Section 2.2). At the same time, electrification of the transport sector provides an opportunity for demand-side management through electric vehicles (EVs).[10]

The renewable energy community has been mainly concerned with finding economically viable combinations of supply and demand, often supported by policy instruments that trigger demand for renewables or make renewable options more competitive. With the rapid decrease in cost for many renewable electricity technologies,[ii] fully renewable scenarios are increasingly feasible and cheaper[iii].[11] The transport sector has had a strong focus on the efficiency of vehicles in the past, although efficiency gains have largely been offset by the growing number and increasing size of vehicles.[12]

Electrification receives increasing attention, mainly driven by developments in China, and more recently the EU and California. Electrification offers a good opportunity to decrease transport-related GHG emissions, particularly for countries with high shares of renewables in power generation. Although efforts to reduce air pollution have been the main driver for the EV exponential market growth over the last years, linkages between renewable power which also has air quality benefits, and electric vehicles are rare.[13]

Direct electrification is not (yet) a broad solution for some transport modes, like long-haul freight, shipping and aviation. The development of electricity-derived liquid or gaseous fuels, so-called electro-fuels,[iv] is a new pathway to develop renewable-based fuels, including renewable hydrogen or ammonia. These could be added to the renewable solutions portfolio available to decarbonise transport, which has so far mostly relied on conventional biofuels. These are technically mature, need no alterations to the vehicle - at least for lower blends - and have a history of government support, especially in Brazil and the United States (US). Advanced biofuels and renewable electro-fuels are mostly still in the development phase and require additional support to accelerate large-scale solutions and reduce costs.[14]

To date, most policy support for transport decarbonisation has focused on conventional biofuels and fuel economy policies. More integrated planning, dedicated policies and investment are needed to link alternative propulsion transport such as electric vehicles to renewable energy sources.

Increasing the share of renewables in the transport sector requires massive investments for production capacity and, for some solutions, also for distribution infrastructure and in the automotive industry. A joint understanding of the future trajectory for renewables in the transport sector will allow for targeted policy frameworks and provide long-term certainty for investors and project developers to ramp up investment in renewable energy solutions.

This report explores both the renewable energy supply perspective and the transport sector perspective in order to foster enhanced mutual understanding of the challenges and opportunities to rapidly increase the use of renewables in the transport sector. The focus is on where and how enhanced collaboration and better integration of the sectors is needed for the benefit of all.

The transport and energy sectors are highly interlinked. To decarbonise our economy the transport and energy sectors thus need to align their strategies. These sectors and all of the actors involved (see Figure 2.2) must work together to make the radical shift needed to phase out fossil fuels, address climate change and ensure the health of citizens.[15]

To ensure a common understanding, **Part I** of the report provides an overview of key concepts, available technologies and their market trends, as well as existing policy frameworks. **Part II** discusses potential future pathways and analyses key challenges deterring renewables penetration in the transport sector. Finally, the report presents guidelines for action that aim to overcome the identified challenges.

In developing this report, a workshop was held in September 2020 with stakeholders from the renewable energy and transport communities Discussions of the key challenges and recommendations which took place at the workshop are reflected in the findings of this report.

SIDEBAR 1: IMPACT OF COVID-19 ON THE UPTAKE OF RENEWABLE ENERGY IN THE ROAD TRANSPORT SECTOR

As lockdowns were imposed by governments worldwide in 2020 in response to the global health crisis of coronavirus (Covid-19), economic activities decreased substantially and total energy demand fell. Oil prices also dropped due to recent dynamics in the global oil market. Renewable energy has so far been the energy source most resilient to Covid 19 lockdown measures.

In the first quarter of 2020, global use of renewable energy in all sectors increased by about 1.5% relative to the same period in 2019. Although renewable electricity has been largely unaffected, demand has fallen for other uses of renewable energy, including transport.[16]

Calls for a "green recovery" have gained momentum, with a broad coalition of actors advocating for ambitious stimulus packages that prioritise renewable energy, energy efficiency, grid modernisation and resource-efficient transport. Rebalancing transport options post-Covid to ensure communities have access to reliable, convenient, affordable and sustainable transport will be essential to decarbonise and reboot our economy. The shift in travel demand and the operating landscape from Covid-19 will require new strategies and commercial models.[17] Despite governments' stressing the need for recovery plans that contain actions towards cleaner energy use in the transport sector, only a few have included climate actions for transport in their recovery plans.[18]

The following are some examples of the inclusion of the transport sector in national recovery plans:

- **Spain's** plan for boosting the automotive industry refers explicitly to decarbonisation and the need to achieving climate neutrality by 2050 through an economic and technological transformation.[19]
- In **France**, a EUR 20 million (approximately USD 22 million) fund was launched to support cycling when lockdown measures were eased, subsidizing bicycle repairs, cycling parking spaces and cycling training.[20] The recovery package also contains a EUR 7 billion (USD 7.8 billion) commitment to develop green hydrogen.[21]
- As part of the **Polish** recovery plan, the Climate Ministry provided a total of EUR 90 million (USD 101 million) subsidies for electric buses, of which EUR 15 million (USD 17 million) are aimed at financing electric school buses in rural areas and EUR 75 million (USD 84 million) are dedicated towards urban transport companies.[22]
- The **United Kingdom** (UK) approved an emergency travel fund of EUR 275 million (USD 308 million) to promote pop-up bike lanes, wider pavements, safer junctions, cycle and bus-only corridors as well as vouchers for bike repairs. Additionally, EUR 11 million (USD 12 million) enable local authorities to install up to 7,200 electric car chargers and an e-scooter trial will be fast-tracked to assess the benefits of the technology as well as its impact on public spaces.[23]
- **China** extended its subsidies and tax reductions for electric cars until the end of 2020. Moreover, China plans to expand its charging network by 50% this year to stimulate electric vehicle deployment.[24]

As the Covid-19 crisis continues to disrupt mobility routines, some regional governments and cities are also seizing what they perceive as a unique opportunity to promote new mobility behaviours that favour active mobility. These policies include speed limits and car-free zones in city centres (e.g. London and Athens), making road reallocations away from cars permanent, and investing in new infrastructure such as bicycle lanes, bicycle parking and expanded walkways. Cities are also providing rental services and subsidies for the purchase and maintenance of traditional and electric bicycles.

NEGATIVE IMPACTS OF COVID-19

Slowdown of transport biofuel production. Like other industries, renewables are exposed to new risks from

Covid-19, which vary significantly by market sector and technology. Even though countries all over the world began to gradually lift some lockdown measures in early May, their impacts are still far-reaching. Social distancing guidelines and lockdown measures have been triggering supply chain disruption and delays in project construction, as well as having a direct impact on the commissioning of renewable electricity projects, biofuel facilities and renewable heat investments.[25] The sharp reduction in crude oil prices puts further pressure on the biofuels industry, as lower petroleum product prices drag down biofuel prices. The effect of lower biofuel demand, drives stocks higher in many markets which reduces prices and compromises the profitability of production.[26] As a result, transport biofuel production is expected to contract by 13% in 2020 – its first drop in two decades.[27]

Decreased ridership of public transport. Public transport operations in cities have been severely affected. As metro and bus services have decreased, so has ridership, with usage falling 50-90% worldwide leading to severe impacts on employment in the sector and on the business model of operators. While some of the travel was diverted to walking and cycling, there has been an increase in use of private motorised vehicles, with negative impacts on air quality and congestion. As cities come out of lockdown, ramping up services to provide as much capacity as is feasible while ensuring safety and security for those who rely on the metro, light rail and bus will be challenging. With an estimated EUR 40 billion (USD 45 billion) of revenue losses in the European Union alone in 2020 due to the pandemic, many operators are in a critical financial situation and require assistance. The inclusion of USD 25 billion in emergency support for transit agencies in the US CARES Act, approved in March 2020, is one example of necessary policy support being provided in a timely fashion.[28] Additionally, the pandemic has highlighted the lack of health and hygiene concepts in mass public transport, which is now starting to be addressed by operators and will be crucial for the future of sustainable public transport.

POSITIVE IMPACTS OF COVID-19

Decrease in transport activity. The lockdown resulted in new ways of working and interacting. Home office and videoconferencing are now a common feature in everyday life, even where lockdowns are slowly being lifted. Companies had to quickly set up or broaden their IT infrastructure to enable continuation of work, and many have experienced how well this can work. While this is not an option for everyone and also comes with its own downsides, it can be expected that there will be a sustained change in how we work and interact, allowing for more flexibility and reducing unnecessary business travel.

Shift to active modes of transport. Unlike with public transport, there has been a resurgence in active modes of transport such as walking and cycling particularly in cities worldwide, particularly as lockdowns are lifted. To support this trend, a number of cities, such as Milan, Paris, Rome, Brussels, Berlin, Budapest and Bogotá, have reallocated street and public space to pedestrians and cyclists.[29]

Surge in sales of e-bikes. Between January and April 2020, cars sales dropped by about 9 million (roughly one-third of sales during the same period in 2019). The timing and extent of plummeting sales were dictated by the timing and stringency of lockdowns. In China, the world's largest car market, February 2020 sales were 80% lower than in February 2019. By April, US sales relative to 2019 had dropped by 50%, in Germany by 60%, and in France by 90%.[30] As lockdowns ease, initial signs point to robust latent demand for cars, and demand rebounds may be bolstered by the perceived safety and security benefits of cars compared for instance with public transport.[31] Rapid and continuous growth in EV sales has also stalled as a result of lockdowns, but so far electric car sales have generally been hit less hard than non-electric sales.[32] Indeed, EV sales prospects for the rest of 2020 are likely a silver lining in the current crisis cloud. Battery-powered bikes have become a compelling alternative for commuters who are being discouraged from taking public transport and/or ridesharing services. In March, sales of e-bikes jumped 85% from a year earlier. Amazon, Walmart and Specialized are sold out of most models. Even smaller brands like Ride1Up and VanMoof have waiting lists.[33]

PART I - STATUS AND MARKET TRENDS

2. KEY CONCEPTS

2.1 SUSTAINABILITY

Sustainability is a broad concept and there is no generally agreed definition. While there is an agreed framework for assessing sustainability, encompassing economic, social and environmental dimensions, in detail the concept means different things to different groups and in different contexts. Views on what is sustainable (or not) also change with the time horizon used; measures that may be less sustainable if looked at the short-term, may be very sustainable in the long-term, and vice-versa. Despite the challenge in operationalising the concept, it is essential for assessing the viability and attractiveness of different renewable energy solutions and decarbonisation pathways for transport. It is important to understand the different views to reach a joint understanding of the best way forward for decarbonisation.

Under the umbrella of the Sustainable Mobility for All (SUM4ALL) platform, the transport community has largely agreed that sustainable mobility needs to ensure universal access, efficiency, safety and "green" mobility, of which the latter should minimise GHG emissions, noise and air pollution.[34] In the renewable energy community, sustainability is mostly discussed within the context of hydropower, especially large-scale installations, and bioenergy, mostly related to the feedstocks used.[35] More specifically in the electrification of transport, the sustainability of batteries is increasingly discussed, resulting in the formulation of ten principles for a sustainable battery value chain by the Global Battery Alliance.[36]

Although the details differ, the sustainability discussions in the renewable energy and transport sector share many common elements and challenges (See Annex I). Both struggle with assessing related GHG emissions and defining the scope and methods for calculations[37] and with the multitude of tools and models[38] delivering substantial variations in results.

For bioenergy, sustainability largely hinges on the feedstock used, in combination with the selected production process. In a first stage, bioenergy is often grouped based on the feedstocks used.[39] Annex II provides an overview. First generation, or conventional biofuels, are based on food and animal feed crops. Biofuels based on energy crops[i], waste and agricultural residues which achieve GHG emissions savings above a defined threshold are often defined as second generation or advanced biofuels. Energy crops have a potential to compete with food crops for land, while waste and residues are limited in supply (see Section 3.1), encouraging the development of alternative vegetable oil feedstocks such as jatropha, camelina, and carinata. These can be grown on marginal lands and thus arguably do not compete with food production – a widely understood barrier to the use of conventional fuels. However, the development of entirely new feedstock supply chains has proven challenging and only limited volumes of alternative feedstocks are yet available.[40] Growing energy crops on marginal lands produces a certain amount of energy and non-energy-related GHG emissions and is, as such, not able to deliver zero GHG emissions.

For the electrification of mobility, sustainability largely depends on how far the electricity used is generated from renewable energy sources and on the sustainability of batteries. For the latter, sustainability issues arise from the mining of raw materials, with related social and environmental problems. The lack of traceability of the supply chain is not encouraging confidence in the sustainability of the end product. A further issue is the end-of-life treatment of batteries. When no longer fit for use in vehicles, batteries can and should be used for other purposes, for example to provide stationary storage for grid balancing. Once the end of their usefulness is reached, they need to be recycled, preventing harm to people and the environment, while at the same time limiting the need for input materials.[41]

For the purpose of this report, **sustainable renewable energy sources for road transport deliver absolute GHG emissions reductions compared to fossil fuel alternatives across the value chain, do not provide health risks for workers and the public and do not compete with resources used to food production.**

With sustainability at the core of many of the drivers and barriers for the deployment of bioenergy, including the setting of sustainability criteria[42] (see Section 5), and other renewable options for the transport sector, we come back to these concepts and definitions throughout the report.

2.2 THE AVOID-SHIFT-IMPROVE FRAMEWORK FOR DECARBONISING TRANSPORT

Experts in the transport sector developed a holistic approach that provides a framework for overall sustainable transport system design.

The avoid-shift-improve (ASI) framework prioritises the mobility needs of people and goods instead of road infrastructure and vehicles.[43]

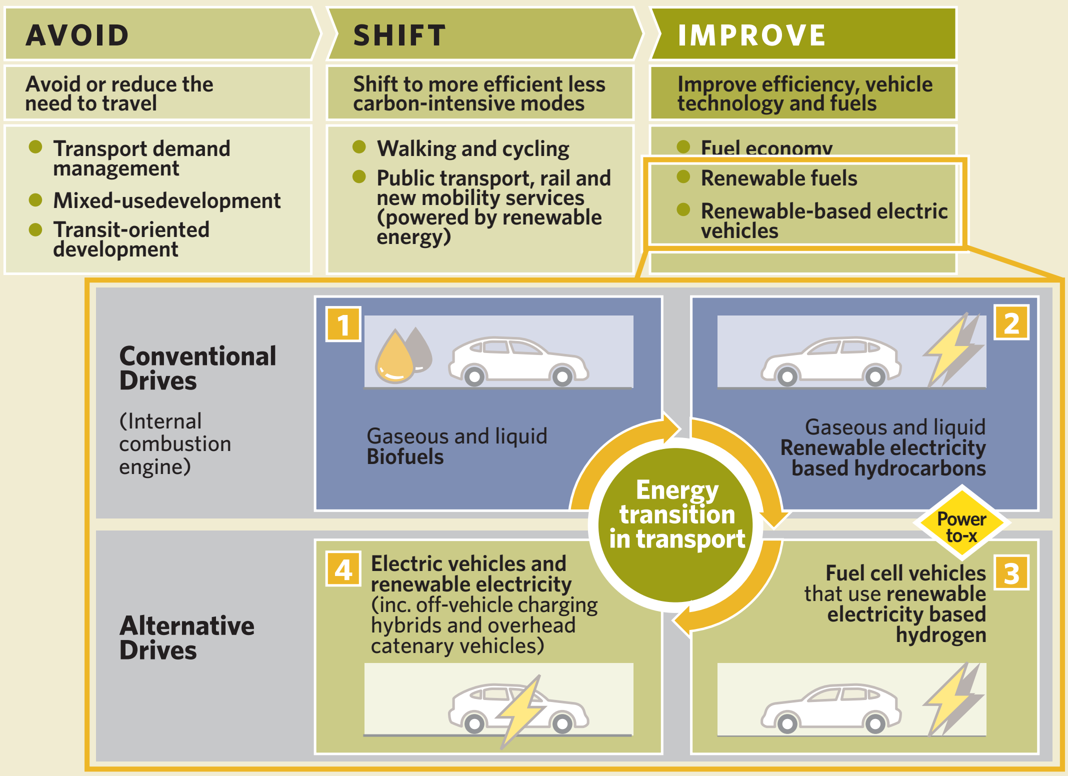
The framework aims to develop transport systems that reduce the overall demand for transport services (avoid) and incentivise more efficient modes of transport, such as high-capacity public transport and rail freight (shift). This also includes motivating a shift to non-motorised transport modes, i.e. walking and cycling. All of these elements contribute to transport systems that generate less travel and are overall more efficient, using less energy per kilometre travelled for each passenger (passenger-kilometres) and for each tonne of freight (tonne-kilometres).[44]

Avoid and shift measures require changes in the overall transport system setup – and are closely linked to urban and rural planning. Additional measures then address the efficiency of the individual vehicles and the carbon content of the fuels used (improve). The ASI framework is widely used by the transport community as a basic framework to define measures to enhance the sustainability of the sector.[45]

Another useful way to look at the required system changes has emerged over the last years. This approach differentiates the mobility and the energy transition, looking at all measures required to reduce the energy need without compromising mobility. This includes avoid, shift and energy efficiency measures for vehicles. The energy transition then aims to replace the remaining energy demand with renewable energy sources.[46]

Although this report focuses on the latter, it is essential to be aware that renewable energy solutions need to be embedded in the broader context of the ASI framework or the mobility transition. Without these other elements, energy demand from the transport sector will increase substantially, increasing the challenge of the transition to renewable energy alternatives. Renewable solutions include the use of (1) bioenergy, (2) electro-fuels based on renewable electricity, (3) hydrogen produced using renewable electricity, and (4) the direct use of

FIGURE 2.1: RENEWABLE ENERGY IN THE CONTEXT OF THE AVOID-SHIFT-IMPROVE FRAMEWORK IN THE TRANSPORT SECTOR



Source: adapted from REN21; Agora Verkehrswende et al.[47]

renewable electricity. Some of these options can be used in conventional motors, others require new propulsion technologies. Figure 2.1 illustrates the different options for the deployment of renewable energy in the transport sector within the context of the ASI framework.

2.3 ACTORS

When we talk about 'the (renewable) energy sector' or 'the transport sector', we need to be aware that each encompass a wide variety of actors that have sometimes complementary, sometimes opposing views – there is no single 'sector perspective'.

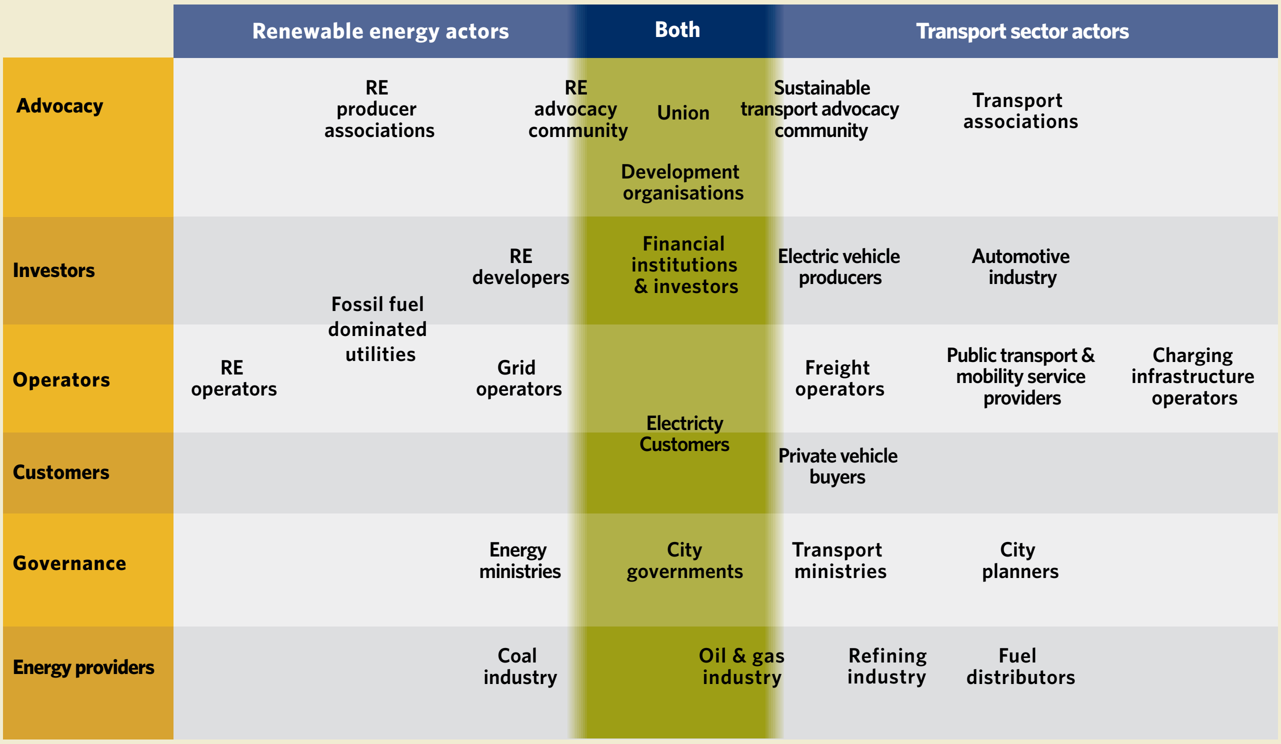
In this report, we try to provide an overview of the issues that the different actors face in transitioning to higher shares of renewable energy in the transport sector, providing a foundation for fruitful discussion on how to overcome barriers and speed up the uptake of renewables.

While some actors are currently only working in one of the two fields, either renewable energy or transport, others are active in both. Still, that does not necessarily mean that the same people are working on both topics. Development organisations and financial institutions, for example, invest in both sectors, but that does not necessarily mean that each individual entity does that, or that departments within institutions share a common view regarding the development of renewables in the transport sector.

Figure 2.2 provides an overview of relevant actors in both sectors. It includes the fossil fuel industry and associated actors as these strongly influence the discussion and decision-making in both sectors.

It is important to note that only part of the sustainable transport community is working on or aware of the importance of climate and related topics, such as renewable energy. The focus is mostly on access to mobility and tailpipe emissions, while upstream GHG emissions, for example from electricity generation, only play a minor role.

FIGURE 2.2: ACTORS IN THE RENEWABLE ENERGY AND TRANSPORT SECTORS



Source: own illustration.

3. TECHNOLOGY SOLUTIONS FOR ENHANCING RENEWABLES IN TRANSPORT

This section discusses the main technology options to decarbonise the transport sector, as perceived by the renewable energy and transport sectors. Section 3.1 focuses on the supply of renewable fuels and electricity for transportation applications and the elements that encourage or deter investment in supply capacity, from the renewable energy perspective. Section 3.2 analyses the transition to renewable energy from the transport sector perspective, where the mentioned renewable energy options have different implications for vehicle technology and distribution infrastructure. Section 3.3 assesses the nexus of the two sectors and which technologies are key for better integration.

3.1 RENEWABLE ENERGY: THE FUEL PERSPECTIVE

There are four general options for renewable energy use in the road transport sector, as illustrated by Figure 2.1: (1) gaseous or liquid biofuels, (2) renewable electricity-based synthetic fuels[i], (3) renewable electricity-based hydrogen and (4) the direct use of renewable electricity. Renewable electricity-based synthetic fuels and electricity-based hydrogen are often also referred to as power-to-X (PtX)[ii] as they include the conversion of renewable electricity to other forms of energy.

Most people are familiar with the options to produce renewable electricity, namely solar PV, wind power (onshore and offshore), geothermal power, hydropower, bioenergy and ocean energy. The available technologies for producing other transport fuels are less known, particularly since many are still under development. Understanding the different options is crucial, as source materials and processing technology have a large influence on their suitability for transport purposes, the cost-competitiveness of the resulting products and their attractiveness for investment. Figure 3.1 provides a simplified overview of the available conversion pathways.

Investment decisions on renewable energy infrastructure focus on finding the right technology for a given local context. Different generation technologies are available, and the individual investment will depend on the specific local combination of demand, available energy sources and feedstocks, distribution options and economically feasible production processes. The next sections briefly discuss these different elements and outline the main challenges for increasing production from the perspective of investors and project developers with a view to assessing their suitability for use in the transport sector.

Demand is key to make investment financially attractive

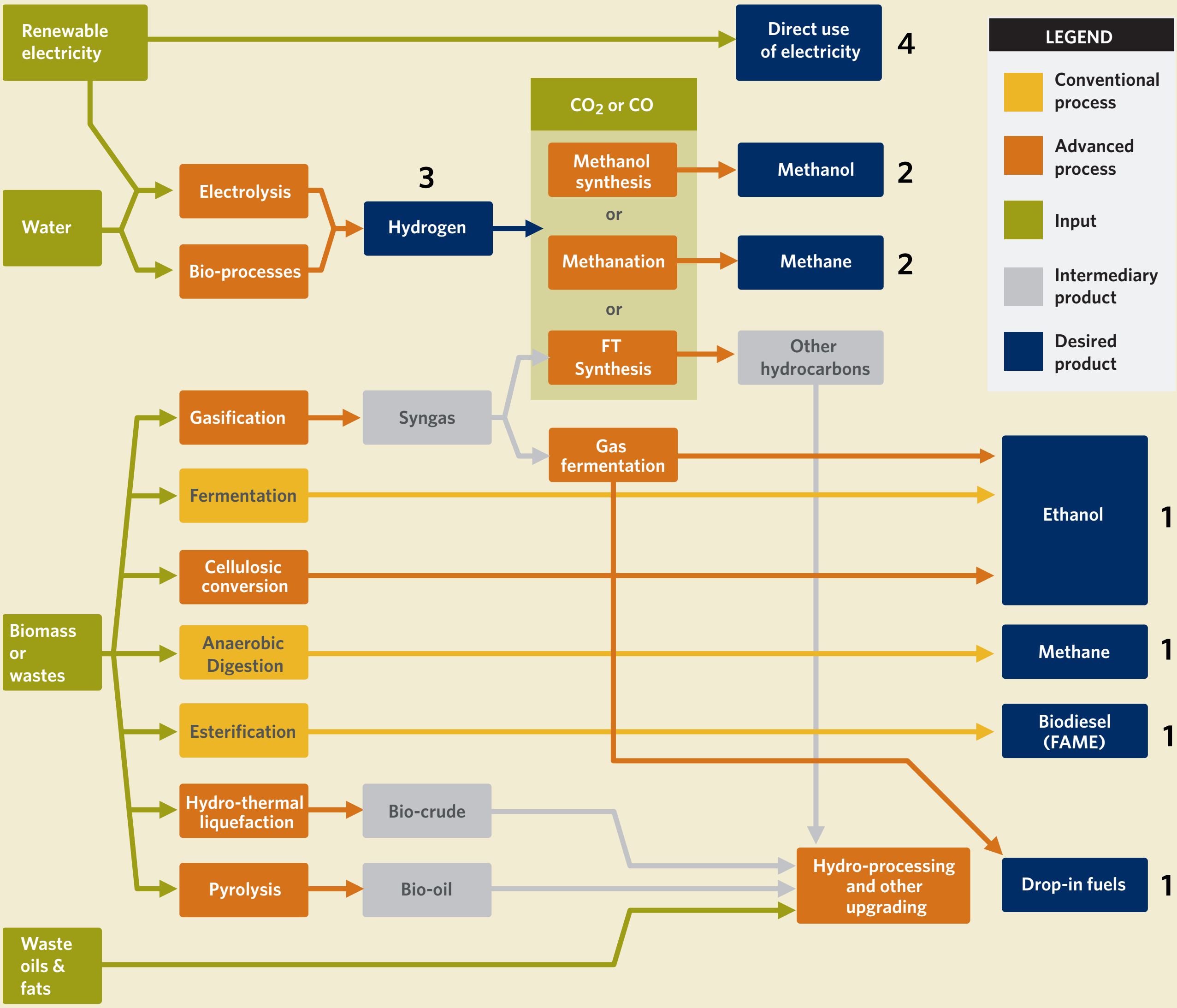
Transport is only one of many uses for renewable energy and electricity and many of the fuels – liquid or gaseous – and intermediate products can be put to a variety of uses. From a transport sector perspective that means that it is competing with other uses for the available renewable energy sources.

While many other factors play a role, investment in a new production facility is only attractive if there is certain – and ideally growing – demand. Related to demand a potential investor will ask:

- What is the current demand for the end product and any by-products of the production process?
- What is the expected future demand?
- Where is this demand located and how expensive is transport?
- How far are products usable for more applications, i.e. is there potential for larger demand?
- How cost-competitive is the end product [iii] compared to fossil fuel alternatives?

While the focus is often on the final product and its potential uses, an important factor for the financial viability of production facilities is the demand for intermediate products and 'waste' outputs such as heat, oxygen, animal feed or fertilisers. These products can either reduce production cost, if for example waste heat is re-used within the production process, or can generate additional income streams.

FIGURE 3.1: OVERVIEW OF CONVERSION PATHWAYS FOR RENEWABLE ENERGY USE IN TRANSPORT



Notes: Syngas = synthetic natural gas, a mixture of gases, mainly carbon monoxide, hydrogen and methane; FT = Fischer Tropsch; FAME = Fatty acid methyl ester; Drop-in fuels include diesel substitute fuels (hydrotreated vegetable oil, or HVO, and hydrotreated esters and fatty acids, or HEFA); numbers relate to the options for renewable energy use in transport, as presented in Figure 2.1: 1) Gaseous and liquid biofuels; 2) Gaseous and liquid renewable electricity based synthetic fuels; 3) Renewable electricity based hydrogen; and 4) Renewable electricity.

Source: adapted from Baldino et al.; Danish Energy Agency and Energinet; Krishnaraj and Yu.[48]

Generally, **electricity** consumption is still growing and efficiency measures are still being overcompensated by growing demand, due to increasing electrification in end use sectors.[49] However, demand depends on the transmission grid to which the generation is connected and is thus limited to the consumers connected to the particular grid, although decentralised renewable electricity generation at the point of demand or at low and medium voltage levels is becoming increasingly popular globally, often combined with battery storage. Apart from the availability of the natural resources for renewable power generation, grid infrastructure is therefore key in determining demand for individual renewable power installations.

Hydrogen, generated through electrolysis using renewable electricity or through bioprocesses, and called "green hydrogen", is chemically identical to fossil fuel-based hydrogen and is fully compatible with all uses of hydrogen. The differences from fossil fuel-based hydrogen[i] are in the production process and the related cost, similar to electricity. Hydrogen demand for transport is currently still in its infancy. The majority of hydrogen consumed today is for ammonia production (mostly for fertilisers) and in oil refineries. Limited demand also comes from iron and steel production, glass, electronics, specialty chemicals and bulk chemicals. However, current hydrogen production is almost exclusively fossil-fuel based (about 99%).[50] For the required full decarbonisation of the economy, all of the fossil-fuel based hydrogen will need to be replaced by renewable hydrogen, creating additional demand for new renewable hydrogen production facilities.[51]

Biogas[ii] is a much less standardised product. Depending on the production process and the stage of upgrading, it can contain different shares of various gases, meaning that the energy content and chemical properties can vary. In its most refined form, it consists mostly of biomethane which can be used to replace conventional natural gas and is often fed into existing natural gas networks. Alternatively, syngas can be refined to biomethane or liquid fuels. However, less refined biogases, with varying shares of methane or hydrogen, can also already be used for combustion.[52] Biogas from small-scale digesters is often directly used for heating and cooking. Almost two thirds of the biogas produced today is used for power and heat generation.[53] It is also used as a feedstock for the chemical industry. Further to refining the biogas to more concentrated levels, it can also be compressed or liquefied, which enables further applications, such as the use in heavy-duty vehicles.[54]

Liquid biofuels come in a variety of forms and are mostly used for transport. First generation ethanol and biodiesel are currently the main consumer products. They differ from fossil fuels in their blend wall properties[iii] [55] and are mostly used in blends with fossil gasoline and diesel.[iv] Advanced biofuels represented only 9% of biofuel production in 2018.[56] Current demand has been largely triggered by corresponding policies and future developments will also largely depend on policy choices regarding the energy pathways in transport, as most of these fuels are not yet cost-competitive with their fossil fuel competitors (see Sections 3.1 and 5).

Supply of sustainable feedstocks remains challenging

Availability of energy resources and feedstocks is key for deciding which renewable energy technology to adopt in a specific local setting. Considerations for investment include the energy content of available resources, the availability on a continuous basis, cost of the feedstock and the availability and cost of transport of any required inputs to the production facility.

For non-biomass renewable electricity generation, the feedstock comes for free, so the main considerations are availability and energy content in a specific location, which need to be high enough to make an investment economically viable.

For bio-based renewable energy, the main challenges are the continuous availability of feedstocks and changes in properties over time. To mitigate this, many biogas and biofuel plants can operate on a limited range of different feedstocks, although flexibility in feedstocks and in managing feedstock quality over time normally increases cost for pre-treatment. Plants can operate most cost-effective with a continuous feed, but not all feedstocks are available all year round.[57]

Energy, food and feed crops, for example, are only available once or twice a year at harvest and need to be stored, leading to losses of about 5-10%. Wastes are typically available throughout the year and low in cost, but rarely available in large enough quantities within reasonable transport distance to production facilities if not used on site. In general, low energy content limits the economically viable transport distance for feedstocks.[58]

There is often a trade-off between the cost of the feedstock and cost for pre-treatment. Waste and lignocellulosic feedstocks are cheap, but require complex and expensive pre-treatment and/or collection processes and the amounts available in the local radius of the plants are often limited. Producers typically address these challenges by using a mix of waste, residues and energy crops.[59]

BOX 1:

SUPPLY OF OTHER RENEWABLE FUEL PRODUCTION INPUTS

Feedstocks are the key issue for most bioenergy forms. However, other materials that are required in the production process for all types of renewable energy can also be a limiting factor. For the production of hydrogen, for example, the main feedstock – water – is normally not scarce, but can be an issue in water-stressed areas.[60] Other individual components required in the production process, for example for electrolyser membranes, can also be limited in supply. This highlights the need to develop full supply chains, creating a big potential for jobs and economic activity, and also opportunities to create local added value, although this also requires a close look at the sustainability of input production.

Production processes for advanced biofuels and PtX are not yet commercial

Most of the modern renewable electricity technologies are available at commercial scale and are increasingly cost competitive with fossil fuel alternatives, in some regions even becoming the cheapest available source and seeing tremendous growth over the last decade.[61] Solar PV and wind energy are technologically mature and proven in many local contexts. Concentrated solar power (CSP) has also reached commercial maturity and most new installations come with integrated thermal storage, reducing the variability of power supply. Geothermal and bio-power generation are also commercially available.[62] Ocean power is still largely in the development stage and there are a number of different technologies around tidal stream and wave energy being tested.[63]

The maturity of a technology in most cases directly translates into cost for installations (CAPEX) and thus the more mature it is, the less initial investment is required. It also indicates that earlier challenges in the production process have been overcome. However, with increased production new challenges can emerge. Larger shares of renewable electricity from variable sources will require enhanced grid balancing and higher shares of biofuels necessitate modifications in engines. These issues are already being addressed in some countries as demonstrated by VRE shares of 60% in Denmark and high shares of biofuel consumption in Brazil, respectively.[64]

Production processes for advanced biofuels and for PtX are not yet available at commercial scale, with the exception of HVO/HEFA. For some of the advanced bioenergy processes, it is difficult to achieve the economies of scale needed for fully commercial operations, owing to limited availability of regionally available feedstocks.[65] To solve this, plants can be built as bolt-on facilities, for example to existing first generation ethanol facilities, to reduce cost and enhance commercial viability.[66] Another option is to enhance efficiency through integration of production steps with existing refineries, which could work particularly for advanced drop-in fuels.[67]

Hydrogen production processes from fossil fuels are well established. Producing hydrogen with electrolysers using renewable electricity is still in its early stage, although alkaline electrolysis is a mature technology that has been around since the 1920s and proton exchange membrane electrolysis since the 1960s. Solid oxide electrolysis cells (SOEC) are still under development but have the advantage that they can be used in reverse mode as fuel cells, allowing them to easily provide grid balancing services.[68] This also means that fuel cell manufacturers are in a good position to build SOEC electrolysers, possibly enabling rapid commercialisation.

Cost assessments for different bioenergy processes show that for some processes, especially advanced cellulosic ethanol production, capital cost play the major role in overall costs, while for others, such as HVO production, feedstock cost is the main factor. Producing biofuels or biomethane from wastes is significantly cheaper than from biomass feedstocks, as the overall cost is influenced by the negative waste feedstock costs. Producing Fischer Tropsch products or gasoline synthetic fuels are significantly more expensive than producing methane or methanol, given the added process complexity and energy requirements.[69]

Distribution remains crucial and can add to cost

Commercial production of renewable energy is only attractive if the product can be distributed to the customer in a cost effective way. Accessing existing distribution infrastructure where suitable helps to reduce cost and makes the products more competitive. This is the case for renewable electricity, which mostly uses existing transmission grids, and for biomethane that is injected into existing natural gas grids. Liquid biofuels can also largely utilise existing distribution infrastructure, including those at filling stations.[70] However the use of existing gas and electricity grid infrastructure comes with cost, usually to ensure the quality of the end product, although it still saves substantial capital investment compared to building up completely new distribution channels.[71]

Where biogas cannot be injected into existing gas grids, the gas is usually transported by truck in high-pressure gas containers, or it is liquefied to increase energy density. Liquefying is energy intensive and expensive and only justified for long transport distances (>100 km) particularly where there are few available stops for refuelling.[72]

For renewable electricity the use of existing grid infrastructure comes with the challenge of how to integrate VRE, which can lead to additional investment needs for transmission lines and grid management as the share increases. Only solar PV, wind and CSP produce power variably, depending on weather, seasons and the time of the day. Solar PV and wind power have seen the largest growth over the last decade among renewable energy technologies, most of which has been without integrated storage.[73] There are a number of available solutions within the power sector to balance variability, including:

- **Supply-side:** enhanced weather forecasting, flexible generation options
- **Grid flexibility:** regional markets & interconnections, supergrids, large-scale storage
- **System-wide:** mini-grids & distributed systems providing services, optimising system operation, utility-scale battery solutions, PtX solutions, enabling technologies such as electric vehicles and heat pumps

Many renewable power solutions are dispatchable, such as hydropower, geothermal energy and biomass-based power generation. Additionally, enabling technologies that improve grid integration for variable sources already exist, including combining variable generation installations with battery storage, pumped hydro energy storage and the use of hydrogen, with different options suitable for different time scales, and with improved short-term forecasting for renewable power generation.[74] New CSP installations, for example, already typically come with thermal storage, and hybrid systems aim to use complementary generation patterns to reduce variability.[75] Additionally, enhancing and optimising the grid infrastructure and operations is key for a fully renewable power generation pathway (see also Section 3.3).

Managing demand is another alternative to address variable power generation from VRE. Traditionally, demand side management was mostly aimed at curtailing demand of larger, often industrial, customers. This developed further towards managing individual appliances and technologies, using modern communication technologies and appropriate incentives, such as time-of-use tariffs.[76] Increasing rooftop PV systems with battery storage and electrification in heating and cooling now allows for those systems to also provide two-way services, delivering power to the grid for balancing, and even including the creation of virtual power plants, which could reduce cost for transmission systems.[77]

The transport sector has traditionally not been involved in grid stabilisation, with the very limited demand for electricity - mostly from rail services - taken directly from the grid. With increasing electrification of the sector, it can, however, play a critical role for grid stability (see Section 3.3).

3.2 TRANSPORT SECTOR PERSPECTIVES

The road transport sector is traditionally most concerned with the vehicle technology and the required fuel infrastructure. Sustainability concerns have long centred both on air quality and on GHG emission. In the US, for example, the first legislation regulating air pollutants from light-duty motor vehicles was passed as early as 1965.[78] For decades, the number of vehicle technologies was rather limited, with combustion engines being the only commercially available option, and gasoline dominating the passenger vehicle market and diesel dominated freight vehicles. In some countries, liquefied petroleum gas (LPG) is also playing a role, mostly driven by the comparatively low cost for the fuel compared to gasoline and diesel and often supported by low taxes or other support systems. Gas, in compressed or liquefied form (CNG, LNG), has played only a small role at the global level.[79]

The landscape of vehicle technologies has broadened over the last decades (see Figure 3.2), starting with the (re)introduction[i] of hybrid models (HEVs) in 1997 that use a combination of an electric motor and an internal combustion engine. Here the battery is charged through regenerative braking and by the internal combustion engine with no external battery charging. In the early 2000s, this was followed by plug-in hybrid electric vehicles (PHEVs) that have the additional option to charge the battery externally.[80]

The last decade saw substantial growth in fully electric cars[ii] which run exclusively on electric power. The overall market shares are still small (only about 2% of the global market), and still much lower than PHEVs, but growth rates have been enormous (see Section 4.2). Fuel cell vehicles (FCEVs) are a special type of electric vehicle, where the electricity is not stored in batteries, but generated within the vehicle using hydrogen that combines with oxygen in a fuel cell.

BOX 2:

GHG EMISSIONS VS TAILPIPE EMISSIONS

The term 'emissions', can meanvery different things to different people, especially if they come from different sectors. It is therefore necessary to clarify the use of the concept in the context of renewable energy in road transport:

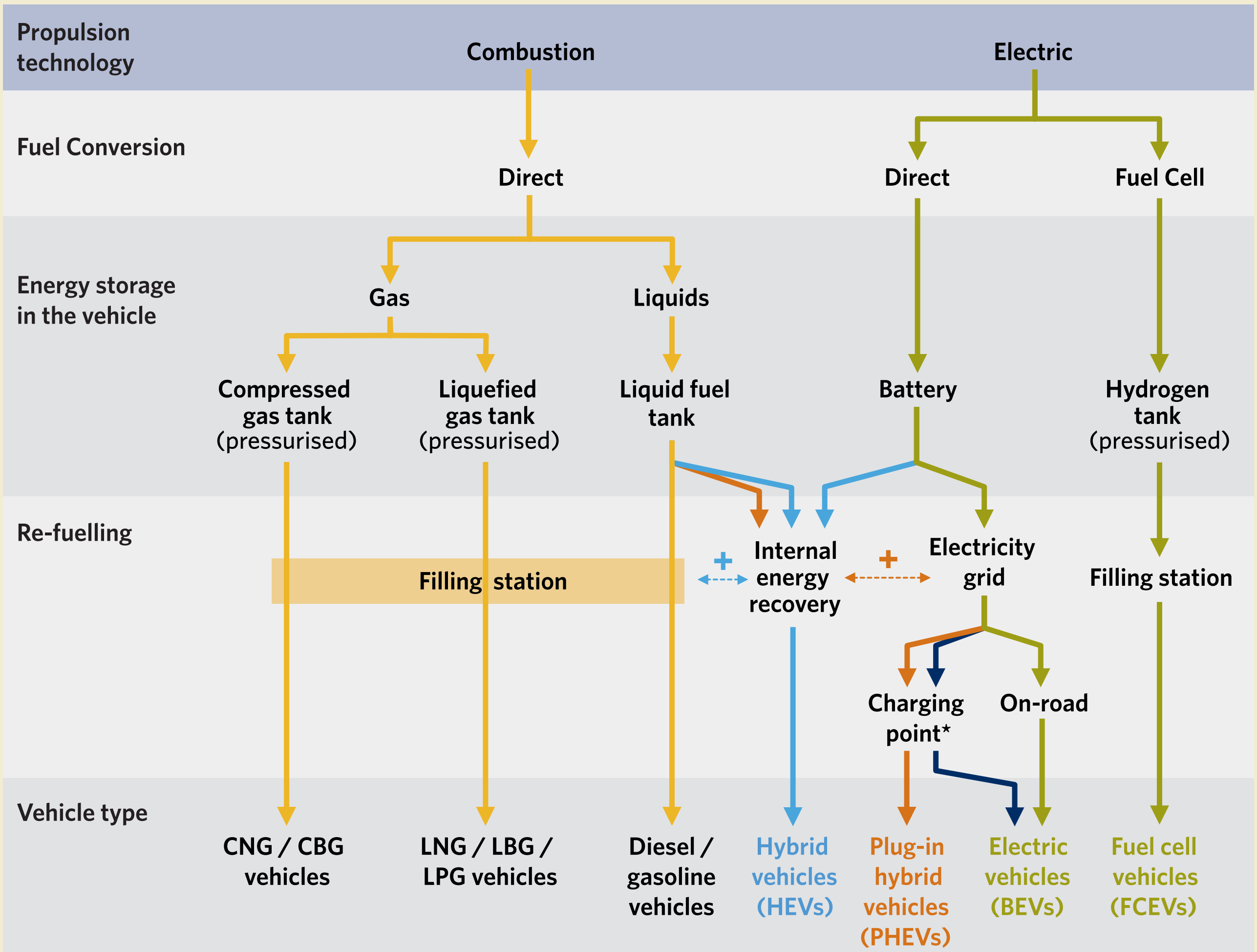
GHG emissions refer to the amount of greenhouse gases that are emitted by the vehicle through the combustion of energy or through other processes along the value chain, such as fugitive emissions from oil extraction or from agricultural processes during the production of biofuels.

Tailpipe emissions refer to the air pollutants emitted during the operation of a vehicle and in addition to the GHG gases emitted by the vehicle include particulate matter, volatile organic compounds, nitrogen oxides, carbon monoxide and sulphur dioxide. These affect people's health and can lead to ill health and premature death.[81]

Many measures that reduce GHG emissions from transport also reduce tailpipe emissions. However, not all measures to reduce tailpipe emissions also contribute to GHG emission reductions. A shift to electric or fuel cell vehicles, for example, can drastically improve local air pollution, but has no or little effect on GHG emissions if the electricity or hydrogen used is produced from fossil fuels.

In this context, it is important to note that the terms **"zero-emission vehicles"** and **"clean vehicles"** normally relate to tailpipe emissions.

FIGURE 3.2: OVERVIEW OF VEHICLE TECHNOLOGIES FOR ROAD TRANSPORT



*Charging points can also be supplied by off-grid genertion capacity and in the form of battery switching stations
** On-road means all solutions that charge vehicles while driving on the road, such as catenary lines
Hybrid vehicles have both a liquid fuel tank and a battery that is only charged through internal energy recovery
Plug-in hybrid vehicles have a liquid fuel tank and a battery that is charged from internal energy recovery, but that can also be charged externally from the grid

Source: own illustration.

The technology has only become commercial over the last few years and the number of vehicles deploying it is still very small.[82]

There are further variations to the main technologies. Bi-fuel vehicles, for example, add a second fuel supply system and storage tank to a gasoline engine, usually as a retrofit. Such systems can then run on either gasoline or the alternative fuel, normally biomethane or LPG. Dual-fuel engines use diesel fuel and gas simultaneously, with limited modifications required to the engine.[83]

Which vehicle technology – with its corresponding fuel – is most appropriate depends strongly on the type of vehicle and the use case. Passengers and freight have different demands on the technology. Whether a vehicle is used in an urban context, for regional transport outside urban centres or for long distances also plays an important role (see Figure 3.3 for an overview). There are also differences depending on whether individual vehicles or fleets are considered, for example for taxis, company vehicles or shared mobility services. Finally, there are differences in the development level of countries and regions, influencing challenges and opportunities.

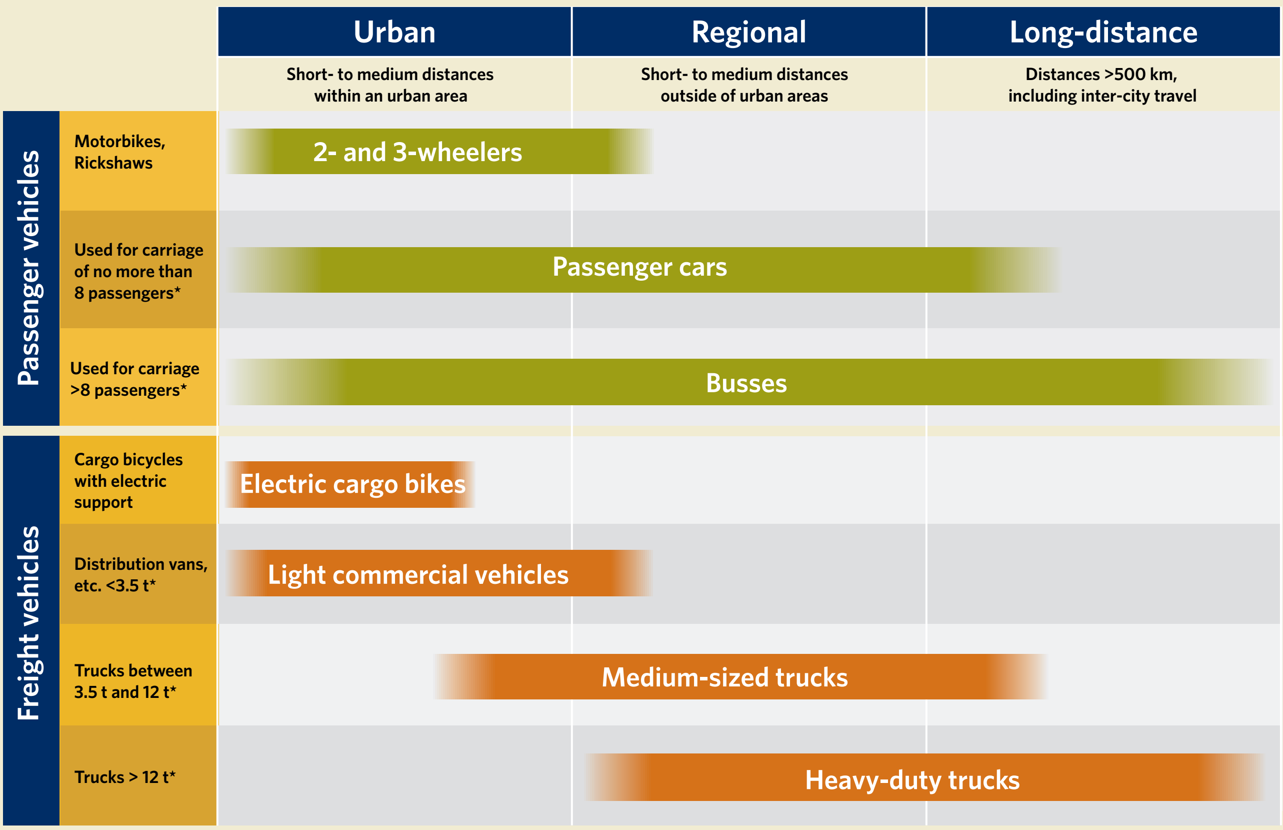
Range, fuelling infrastructure and cost of vehicles and fuel play a central role in technology choices for most applications. For passenger vehicles other factors play an equally important role. Vehicles are still very much linked to social status and have a representative value, and the status of alternative fuel vehicles in this context is not yet established.

There is no ‘one size fits all solution’ for decarbonisation. Fully electric vehicles and fuel cells are only part of the story. It depends on the vehicle size and use case as to what powertrain is most suitable.[84] The view on what the most appropriate solution for increasing the use of renewable energy in a given use context will also differ depending on the actor. The next sections provide an overview of the critical issues from the perspectives of some of the main actors.

The shift to EVs and other alternative vehicles requires substantial investments from the automotive industry

For cars and sport utility vehicles (SUVs), only a very limited number of producers control the majority of vehicle production.[85] For other vehicles, the market is less concentrated, but the issues that manufacturers are facing are very similar.[i] Production lines are highly automated, and complex supply chains exist, often deploying just-in-time approaches[ii]. Engineers and workers have been trained for decades to optimise internal combustion engine design and relating vehicle technology and vehicle design and maintenance. It is therefore not surprising that the industry has been struggling to embrace electric vehicle technology, which requires a completely new skill set for engine manufacturing, energy storage and vehicle design.

FIGURE 3.3: OVERVIEW OF MAIN VEHICLE TYPES AND MAIN AREA OF USE



* Based on classification of the European Alternative Fuels Observatory: https://www.eafo.eu/knowledge-center/european-vehicle-categories

Note: These represent only high-level categories. Most categories contain a variety of sub-categories that can have different implications for the suitability of individual renewable options.
Source: own illustration.

Uncertainty about which technology will prevail in the end hampered the willingness to invest large sums in research and development and the setup of alternative production lines for a long time.[86]

Research and development. Traditionally, car manufacturers have invested highly in research and development, although most of this has revolved around optimisation of the end product and the production process. Seven of the top 25 companies with the highest R&D investment in 2018 are car manufacturers, but they do not feature among rankings of the most innovative enterprises. Only one automotive company – Tesla – appears in one ranking of the world's 10 most innovative companies.[87]

Production lines. From the automotive industry perspective, blending of biofuels and development of drop-in fuels has been the most appealing solution. Existing vehicles need no or only limited adaptation, which means that current production lines, component supply chains and skills remain operational. For the electrification of vehicles and for hydrogen solutions[i], on the other hand, massive investments are required across the supply chain that will require new levels of collaboration and strategic partnerships to tap into new knowledge and innovation.[88]

Maintenance. Large-scale electrification will lead to much lower maintenance needs. Vehicle dealers and mechanics are likely to face major implications.[89] BEVs require less maintenance compared to conventional vehicles, because they have fewer fluids that need to be changed and far fewer moving parts that may need replacement.[90] A main focus for maintenance becomes the battery, where manufacturers already offer different options, from long-term guarantees to renting out the batteries and replacing them when needed.

Skills. The need for new skills also needs to reflect in training curricula at all levels and across the value chain. With a growing pace of electrification, also continuous training and career reorientation will be rapidly needed.[91] With increasing numbers of BEVs and FCEVs, the skill needed for producing the vehicles will change as will those of mechanics maintaining the vehicles and those disposing of the vehicles – and batteries – at the end of their lifetime. There are also job opportunities in these developments.

Business models. At the same time, business models are quickly changing, with a focus away from the production and sales of vehicles to the use of vehicles through shared mobility and automated driving. Ownership models of passenger vehicles are already changing, with more and more cars being leased instead of bought.[92] All of these factors affect vehicle sales, maintenance, intensity of vehicle usage and vehicle lifetimes. Manufacturers and vehicle dealers are starting to adapt to this new way of doing business[93] and governments need to make sure that regulatory frameworks enable new business models.[94] In parallel, new business models, inter alia, for charging and grid services are developing, offering new opportunities.

Consumers are largely concerned with convenient mobility

Private passenger vehicles

For the individual consumer, the decision of which vehicle to buy can be a complex process that is only partly determined by objective criteria.[ii] It is a decision that is not only very subjective, but also highly dependent on local circumstances, such as the existence of other means of transportation, local culture and available vehicle choices. While vehicle manufacturers do react to customer preferences, the end user can only buy what is on the market and locally available. A number of factors impact consumer choices:

Vehicle cost. The cost of the vehicle and the affordability compared to income is a key element in any purchase decision. Most customers focus on the initial price of the vehicle, rather than looking at overall lifetime cost. This puts more costly technologies, such as BEVs and FCEVs, at a disadvantage to ICE vehicles that can be run on conventional or advanced biofuels or electro-fuels. Potential cost savings through lower maintenance or lower cost fuels rarely factor in purchase decisions unless differences are significant and publicly discussed.

Fuel prices. The price of fuel plays a minor role for most purchase decisions. Only if the price difference is high enough or the customer is planning to drive extensively (e.g. taxis or sales representatives) will lower fuel cost outweigh higher vehicle cost. This was, for example, the case for LPG in Australia or diesel in Germany, where substantial price differences to regular gasoline led to a moderate uptake of these fuel technologies. Once a vehicle is owned, changes in fuel prices have limited impact on the distances travelled or on decisions to change the vehicle, unless forced by regulation or with extreme price differences.

Convenience. Consumers want to be able to travel whatever distance they want as fast as possible. Vehicles need to be easy to re-fuel and filling stations or charging points need to be available with sufficient coverage. For electric vehicles, for example, more than 85% of charging points are at home and/or the workplace.[95] Being able to charge your electric vehicle at home is not possible for everybody, especially in densely populated urban centres. Further development of battery range and expansion of public charging is essential to alleviate concerns about range-anxiety and to enable electric vehicles in urban areas. The time required for charging is also an important aspect for consumers.

Attractiveness. Private owners rarely make their choice purely on objective criteria. Criteria such as comfort, perceived reliability and brand also play a role.[96] Vehicles also convey status and are often linked to a specific image of success, daring or adventure – which is largely influenced by advertising, traditionally favouring larger cars and SUVs.[97] To some extent, customers express their personality through their vehicle. A wide enough range of models is needed to make any technology attractive for widespread uptake. This has favoured technologies that can be easily retrofitted in existing models or fuels that work with existing motors. With major brands starting to offer an increasing model variety of alternative propulsion vehicles, this situation is slowly changing.[98]

Commercial vehicles

For buses, trucks, fleets and other commercially used vehicles, similar considerations apply. However, economic and operational considerations play a much more fundamental role compared to more subjective elements, such as attractiveness. Conventional biofuels, for example, do not meet the energy density requirements for long-distance applications.[99] Commercial operators take a much closer look at overall lifetime cost, including fuel and maintenance. A key criterion for commercial activities is range and ease of re-fuelling. If range limits or long idle times for re-fuelling limit the use time of the vehicle, this seriously reduces the likelihood for uptake of a technology.

The type of renewable solutions selected for different transport applications need to fit with the wider energy system of an economy

From a societal perspective, decisions in the transport sector mainly aim to find the most appropriate technology solution for specific use cases and sub-sectors, with differences depending on the local context. The transport system is a crucial backbone of economies and social life. It needs to ensure access to mobility for passengers and efficient movement of goods. At the same time, air pollution, safety and congestion are posing increasing challenges, especially in urban centres, around the world.[100]

Overall system optimisation of transport systems will require drastic measures to change the mobility patterns towards more efficient modes (see Section 2.2). To maximise the share of renewable energy supply in transport we need to reduce the energy demand from the sector as far as possible (through avoid, shift and efficiency measures) and to balance transport sector energy demands for renewables with other sectors (See Sections 3.1 and 3.3). In short, to enable a maximum uptake of renewables across sectors, renewable energy needs to be deployed as efficiently as possible.

There are huge differences in the efficiency of transforming different types of renewable energy to the motive energy of a vehicle. Multiple conversion steps not only add cost, they also come with efficiency losses. While a fully electric vehicle can use around 69% of the renewable electricity generated, the additional losses for hydrogen conversion in a fuel cell vehicle lead to a significant drop in efficiency to 26%. Electro-fuels, with their additional step to produce the liquid fuel from the hydrogen, only use 13% of the original renewable energy for propulsion. This means that with widespread deployment of renewable electricity-based synthetic fuels compared to the direct use of electricity, renewable electricity demand for transport would be more than five times higher.[101] Similarly, production processes for biofuels have different levels of efficiency, depending on the feedstock used and the complexity of the production process.[102]

Solutions that are limited in their efficiency and availability for scale-up could be used as transitory solutions and for applications where more widely available and efficient solutions are not (yet) technically feasible – within and outside the transport sector. With only 30 years to reach the net zero emission objective set in Paris, solutions also need to avoid investments in infrastructure and vehicles that do not have the potential for full decarbonisation,[103] such as LPG and natural gas. Similarly, renewable electricity-based synthetic fuels can directly replacegasoline and diesel, making it unnecessary to develop a hydrogen supply infrastructure and introduce EVs. However, if they do not materialise, valuable time is lost. This poses a significant risk. Therefore, deployment of renewable electricity-based synthetic fuels should be focused on sectors where no viable alternatives exist.[104] Table 3.1 provides an overview and brief analysis of the different renewable energy options for road transport.

Production capacity and infrastructure development will be key to the success of most of the renewable energy options available in transport. Biofuels and synthetic fuels partially benefit from existing infrastructure, although some can require specific infrastructure or imply cost for additional treatment (see Section 3.1). Electric charging and hydrogen refilling networks will require substantive investments to create the network density required for widespread deployment.[105]

TABLE 1: THE CASE STUDY PARAMETERS AND COMPARING THE APPROACH

	COST*	ENERGY EFFICIENCY	SUSTAINABILITY**	COMPETITIVENESS WITH OTHER USES	AVAILABILITY AT LARGE-SCALE	MOST APPROPRIATE USE CASE
CONVENTIONAL GASEOUS AND LIQUID BIOFUELS	$	depending on feedstock & process	Low: high competition with food production	Medium: some use in power generation and residential heating/ cooking	Not without compromising sustainability	Bridge towards other renewables, fuel for residual ICE stock
ADVANCED GASEOUS AND LIQUID BIOFUELS	$$		Medium: mostly indirect land-use change (ILUC)	Low	Availability of feedstocks limits production	MDV, HDV
RENEWABLE ELECTRICITY-BASED GASEOUS AND LIQUID SYNTHETIC FUELS	$$$	Very low	High	Medium: high competition for intermediate product hydrogen, less for end product	Production technology not yet mature	
RENEWABLE HYDROGEN	$$$	Low	High	High: chemical industry, power generation (storage) + replacement of current fossil hydrogen	Vehicle technology not yet mature, fuelling infrastructure limits deployment	
DIRECT ELECTRICITY FROM RENEWABLE SOURCES	$$	High	High	High: other end-use sectors + replacement of current fossil power generation	Charging infrastructure limits deployment	Passenger vehicles (all types), LDV

* Cost indications cover total cost, including fuel, infrastructure and vehicles in the short- to medium term. Total cost is expected to decrease with technology maturity over time and with increasingly established infrastructure in place.
** Apart from conventional biofuels, sustainability depends strongly on local circumstances, so assessment is only indicative.
Sources: based on Baldino et al.; Danish Energy Agency and Energinet; Krishnaraj and Yu.[106]

Hydrogen, with its low efficiency and high cost for infrastructure will likely target specific road transport applications that are hard to electrify, such as heavy-duty long-distance transport.[107] It can also play a role in shipping, aviation and some other industries. The need for dedicated distribution infrastructure may limit its use to specific countries or regions.[108]

3.3 THE NEXUS OF RENEWABLE ENERGY AND TRANSPORT

The discussion of how to integrate a growing number of electric vehicles with existing power systems is gaining momentum. However, there are further implications for the wider energy system.

The following sections discuss aspects of the nexus between renewable energy and the transport sector.

Managing the energy system is becoming increasingly challenging

In traditional electricity systems, demand is viewed as variable but relatively inflexible and predictable. Small variations historically have been covered by operational reserves at fossil fuel or hydropower generators, where dispatchable power plants can be ramped up and down where necessary. Including growing VRE generation capacity and increasing demand from transport electrification requires a new paradigm concerning how electricity systems work.[109]

BOX 3:

VEHICLE-INTEGRATED SOLAR PV

The most direct way to ensuring renewable electricity is used in road transport is to directly integrate power generation from renewables into the vehicle. With technology improvements, cost reductions and increasing electrification, integrating high-performance solar cells into vehicles is attracting increasing interest from car manufacturers. The first car models are on the brink of becoming commercially available, enabling range extension without using larger batteries.

For larger vehicles, such as buses and trucks, integrated solar PV systems can go a long way to provide power for auxiliary systems as well as extending their travel range. With higher usage in commercial vehicles, integrated systems could soon become economically viable.[110]

Increasing energy demand. From a global energy perspective, renewable energy has seen tremendous growth over the last decade. However, modern renewable energy (excluding the traditional use of biomass) still represented only 11% of total final energy consumption in 2018.[111] This is because the last decade has also seen a rapid increase in energy consumption,[112] leading to a situation where the additional renewable energy capacity has mostly supported additional capacity needs from growing consumption. This leaves a large amount of fossil fuel use that remains to be replaced to achieve the agreed decarbonisation of the global economy by 2050, especially in the transport sector, which is still largely dominated by fossil fuels and is growing faster than other sectors. This poses challenges in allocating potentially scarce resources for the full decarbonisation of all sectors.

Biofuels, mostly in the form of biogas, are already used for power generation and in the industrial and residential sectors.[113] Apart from the already existing uses for hydrogen, renewable hydrogen could additionally play a role for energy storage in the power sector, enabling short-term as well as seasonal flexibility.[114] The share of electricity in final energy use is expected to increase significantly, and IRENA for example estimates that it could reach 45% to 60% depending on the region by 2050, up from 7% to 25% in 2017. Apart from electric vehicles, this includes heat pumps to provide heating and cooling for buildings and shifts in industrial processes towards electric furnaces, solar thermal, and heat pumps.[115]

With all sectors aiming to increase their use of renewable energy, scaling up renewable energy to provide sufficient supply in the appropriate form for different uses will be the challenge. This will require careful alignment of supply and demand planning.

Peak demand.[i] Supporting moments of exceptionally high electricity demand requires large and expensive backup capacity within any energy system. Adding EV charging to existing power demand patterns, could potentially add to the peak demand, particularly if based on current charging patterns which favour overnight charging when owners return home from work in the evening and buses and fleets returning to their bases. Charging patterns vary for different use cases and vehicle types, but current patterns could increase peak demand, if left unmanaged.[116]

Power grids. Electric charging stations can have significant impact on local grids on cables, distribution transformers, and other components as well as power quality or reliability. Especially for high concentrations of EVs, for high-voltage charging and in remote areas where this can pose challenges for the affected grids. Grids in remote areas, for example along transit corridors, are often not yet equipped for higher power levels.[117]

Household electric systems. EV charging, especially if combined with renewable energy generation at the household level, can provide challenges for household electrical systems and local distribution transformers.[118]

Technical solutions to capture synergies between the transport and energy system exist

Grid services from EVs. Private vehicles spend most of their lifetime parked, although patterns may change with increased shared mobility solutions, especially in urban settings. Nevertheless, with the steep increase in the total number of electric vehicles, total storage capacity in vehicles is projected to dwarf stationary battery storage capacity in the longer term.[119] Smart charging solutions can help to reduce peak demand, by adjusting the rate of charging to times with less overall demand. Unidirectional controlled charging (V1G) can do this. Vehicle-to-grid (V2G) solutions go even further and allow vehicle batteries to act as storage that can be used for grid balancing and system services[ii]. Similarly, vehicle-to-home/building (V2H/B) solutions integrate the vehicle battery storage with household or building electricity systems and can supplement household power storage (See also Section on solar-battery-EV systems below).[120]

To enable uptake of such technologies, business models need to account for the needs of the power system (remuneration from providing services to power systems) as well as of the vehicle owners (mobility and preserving the condition of the vehicle). Time-of-use tariffs or real-time-pricing can provide incentives to use such technologies, but in most cases more regulatory reforms are needed to enable EVs to provide auxiliary services to the grid (see Section 5).[121]

The key to any form of smart charging is communication technology. It not only allows customers to access public charging points and to manage billing, it is also essential to exchange information flows about grid loads, vehicle status and customer preferences. One example is the new ‘Plug and Charge’ technology, which is currently under development and which can help balance the grid while making the charging more convenient for customer.[122]

EV smart charging still requires comprehensive on-site testing and research to fully understand its costs and value. It also requires new enabling technologies (e.g. Internet of Things, artificial intelligence and big data), business models (e.g. pay-as-you-go), and system operation innovations (e.g. cooperation between TSOs and DSOs) to support implementation at scale.[123] With data exchange being at the heart of all smart charging solutions, standardised data exchange protocols and data protection are key to move the technologies forward.

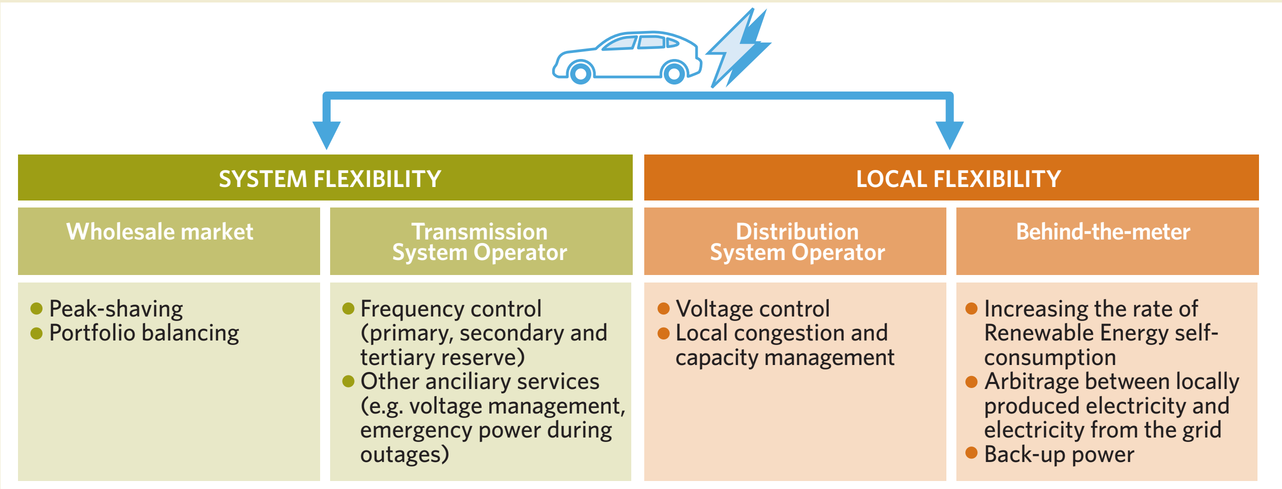
Hydrogen for ‘sector coupling’. The hydrogen production process through electrolysis can be used to balance the grid. The idea is basically to use excess renewable power to produce hydrogen and then use this for transport and other sectors.[124] However, this impacts the financial viability of the still costly production process and can increase the cost of the fuel for transport and other purposes, if not compensated through payments for grid services, as it reduces the operating time of the electrolysers.

BOX 4:

OPTIONS FOR GRID SERVICES FROM EVs

The most frequently discussed service that can be provided by EVs is the reduction of peak demand or 'peak shaving' which involves reducing the local stress on distribution grids. There are, however, other flexibility services that can have positive effects on system integration. For example, increasing the rate of renewable energy self-consumption has a direct influence on the uptake of renewables through electrification (see Figure 3.4).[125]

FIGURE 3.4: POTENTIAL RANGE OF FLEXIBILITY SERVICES PROVIDED BY EVs



Source: IRENA.[126]

Despite the low cost of the electricity in those times, electrolysers work most economically if they run continuously, and not only when excess renewable power is available.

Adapted grid design. Transmission and distribution grid networks can be designed in a more decentralised way, for example by incorporating larger scale storage systems at strategic points throughout the system, to allow meeting local peak load requirements without the need for transporting electricity through congested grid lines.[127]

Strategic infrastructure siting. Locating charging points at strategic points to encourage daytime charging, for example at the workplace or at shopping malls can help reduce peak demand.[128] Siting should also consider available grid infrastructure and loads.

Integrated solar-battery-EV systems. Directly integrating solar PV home systems with batteries and EVs can increase the financial viability of such systems and reduce pressure on the grid through self-consumption, especially in rural and suburban areas.[i] Such systems could become even more attractive under policy frameworks that allows households to sell their solar power at wholesale power market prices, and to earn grid services income.[129] Such solutions can also offer great opportunities for combining renewable power generation with electric mobility in remote areas in developing countries, where smaller EVs (often two-wheelers) can be used to add to or even replace stationary storage. For public charging, especially in urban environments, solar charging solutions can prevent the need for digging trenches for cables and save construction cost.[130]

However, with shorter parking times and the demand for fast and ultra-fast charging, the technical requirements for public solar-based charging are much higher. To maximise the use of solar power, different charging stations can also be aggregated into microgrids with shared battery storage, so that power generated or stored in unused stations can be used elsewhere.[131]

Battery swapping. Here the battery is exchanged with a fully charged one, eliminating the need to wait during charging. The batteries in the 'swap hubs' can be used for grid services.[132] Battery swapping can reduce 'range anxiety,' since fuelling up is as fast as with conventional ICE vehicles, while also reducing the need for high- and ultra-high voltage charging and the related challenges to the transmission grid. Solutions that combine fixed batteries that are charged when parking with exchangeable batteries could bring further flexibility and allow combining home charging with increased range.

The role of digital solutions. For EV charging, the key benefits of digital solutions, such as blockchain, are the possibility to have secure and cheap transactions, direct settlement and high interoperability and automation of services, enabling customer-to-customer solutions, for example to allow charging while at a friend's house.[133]

Overall, the technical solutions exist, but some are still under development and all require concerted efforts by policy-makers, grid operators, manufacturers and the ICT sector to enable a rapid scaling up of deployment.


53 137 982
CAUTION:
24 630 kg
140 km/h

4. MARKET TRENDS FOR RENEWABLE ENERGY SOLUTIONS IN TRANSPORT

This section discusses the main market trends underlying the decarbonisation of road transport from the renewable energy and transport perspectives in 4.1 and 4.2, respectively. Section 4.3 highlights examples of where the shift to "clean" vehicles[i] and the transition to renewable fuels and electricity have developed together.

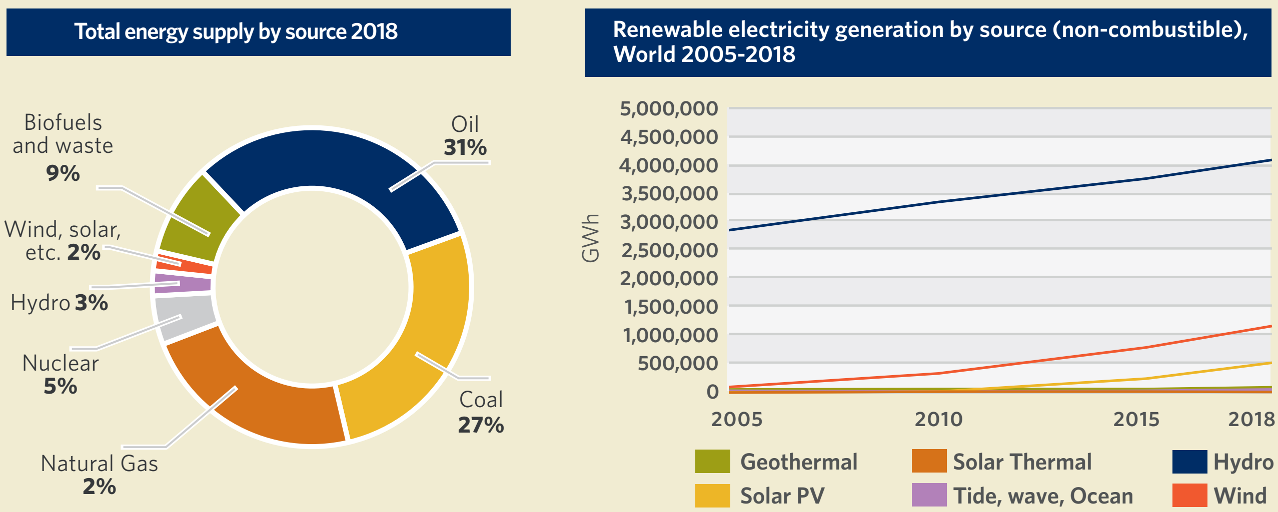
4.1 RENEWABLE ENERGY PRODUCTION

In 2017, the majority of renewable energy in total primary energy supply came from biofuels and waste (10%), most of this being from the use of solid biomass. Wind, solar, and other modern renewables still only represented 2% of total energy supply.[134]

Overall, shares mask the tremendous increases in renewable energy capacity deployed over the last decade (see Figure 4.1). In 2018, for example, investment in renewables capacity was about three times higher than the global investment in coal and gas-fired generation capacity combined.[135]

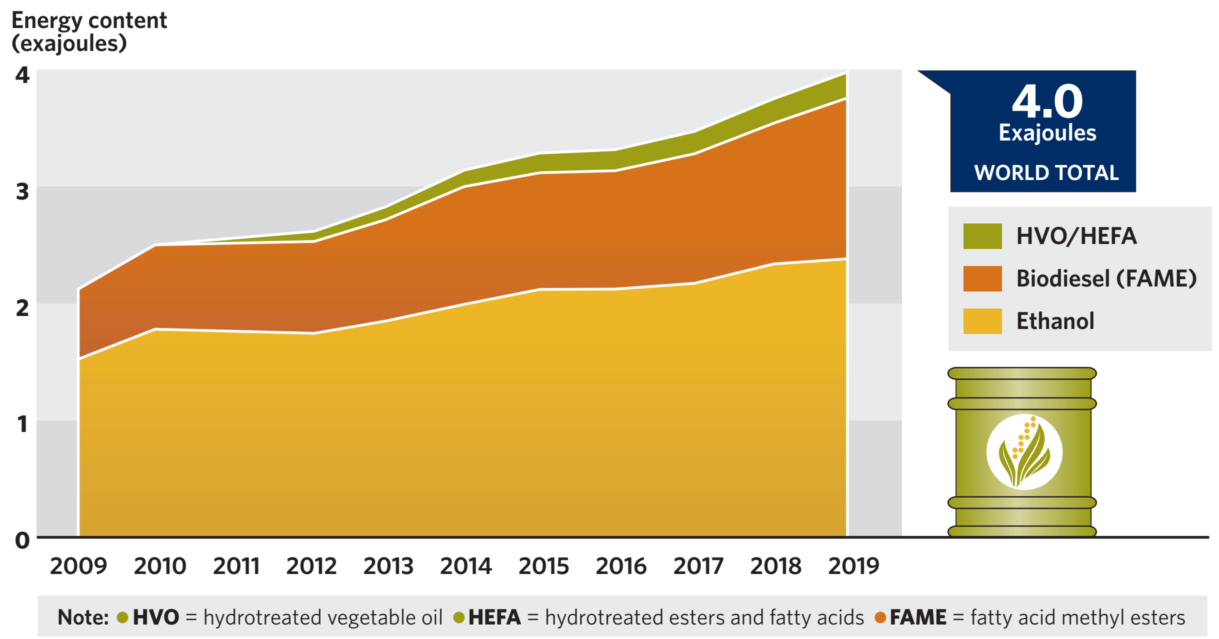
The overall share of modern renewable energy in total final energy consumption remains moderate at 11.1% in 2018. Most of this is from the use of renewable thermal energy (an estimated 4.4% of total final energy consumption), followed by hydropower (3.6%), other renewable power sources including solar PV and wind power (2.1%), and transport biofuels (1%).[136]

FIGURE 4.1: TOTAL PRIMARY ENERGY SUPPLY BY SOURCE (2017) AND RENEWABLE ELECTRICITY GENERATION BY SOURCE 1990-2017



Source: own illustration based on IEA.[137]

FIGURE 4.2: GLOBAL PRODUCTION OF ETHANOL, BIODIESEL AND HVO/HEFA, BY ENERGY CONTENT, 2009-2019



Source: REN21.[138]

Biofuels production has almost doubled over the last decade

Biofuel production and use in transport has been largely triggered by policies (e.g. biofuel blend mandates) which were instrumental in driving investment in biofuel production capacity (see Section 5).[139] Nevertheless, total investment in biofuels has been marginal compared to wind power and solar PV.[140] Global investments in biofuels production, including conventional and advanced biofuels, have been on a declining trend since the late 2000s/early 2010s.[141]

Global production of **liquid biofuels** totalled 161 billion litres, equivalent to 4 EJ, in 2019 (see Figure 4.2).[142] The liquid biofuels industry is concentrated on the production of ethanol and biodiesel. In addition, production capacity has increased for other diesel substitute fuels (HVO/HEFA)[i].[143] In 2019, ethanol accounted for around 59% of biofuel production (in energy terms), FAME biodiesel for 35% and HVO/HEFA for 6%. Other biofuels included biomethane and a range of advanced biofuels, but their production remained less than 1% of total biofuels production.[144]

The largest producers of liquid biofuels were the United States (41% share) and Brazil (26%), both of which mostly produce ethanol, and, more distantly, Indonesia (4.5%), China (2.9%) and Germany (2.8%). Consumption is largely domestic, although significant export/import flows exist, particularly for biodiesel.[145]

In the United States, around 6.4% of bus fleets use biodiesel, and in the EU 9.9% of buses use biodiesel and 0.6% use biogas.[146] Trondheim (Norway) introduced 189 new public buses running on either biogas or biodiesel in 2019, and the initiative is extending to other Scandinavian cities.[147] Public buses in Sweden have run completely on biofuels (dominated by biodiesel) since 2019.[148]

Biogas is still mainly used for electricity production, although the industry, particularly in North America, Europe and China, is beginning to diversify by refining increasing amounts of biogas to biomethane for use in transport.[ii] The worldwide share of biogas use as vehicle fuel, although still very low (<1%), is growing steadily.[149] **Biomethane** is used as a transport fuel mainly in Europe and the United States, which is the largest producer and user of biomethane for transport.[150]

US production has accelerated since 2015, when biomethane was first included in the advanced cellulosic biofuels category of the US Renewable Fuel Standard (RFS) and in state initiatives such as California's Low Carbon Fuel Standard, thereby qualifying for a premium (see Section 5).[151]

In Europe, the use of biomethane for transport increased 20% in 2018 to 8.2 PJ. As of 2018, there were 660 European plants producing some 90 PJ (2.3 billion cubic metres) of biomethane. Sweden remained the region's largest biomethane consumer, using nearly 60% of the total, followed by Germany, Norway and the United Kingdom.[152]

In the United Kingdom, a nationwide network of public biomethane refuelling stations for heavy goods vehicles was being installed on major routes to reach fleet operators across the country, serving major trunk roads and cities.[153] Similar networks were being developed in Finland and Sweden.[154]

Biomethane is also increasingly used for waste collection vehicles, as part of wider efforts to transition to a circular economy. In Berlin (Germany), the local waste management company operates a biomethane plant that uses 60,000 tonnes of source-separated waste as feedstock. On average, 95% of the biomethane produced by the plant is used internally to supply the 150 compressed natural gas trucks that collect the waste weekly.[155] Oslo (Norway) also expanded its use of biogas to waste disposal trucks in 2019.[156] In 2019, the City of Fresno (California, US) signed a two-year agreement with Clean Energy for liquefied biomethane, produced from solid waste, to power around 140 waste trucks.[157] Seattle (Washington, US) had 100 waste trucks as of 2019 – most of them powered by biogas from waste and biodiesel from vegetable oil – and the city planned to double this fleet by 2020.[158] Biomethane from dairy and landfill waste will power 86 waste trucks in Chicago (Illinois, US), 40 in Spokane (Washington, US) and 35 in Long Beach (California, US).[159] In Surrey (Canada), a biomethane plant opened in 2018 to convert municipal waste and power the city's waste collection trucks.[160]

More and more cities are also using waste to generate advanced biogas. In Spain, the city of Barcelona (with co-funding from the EU) has invested in an energy-efficient wastewater treatment system to produce biomethane for transport, and Vilasana has invested in biogas production from pig slurry plants for use in vehicles.[161] In 2017, Kolkata (India) invested in a pilot project for buses running on locally produced biogas from animal and human waste, with the low cost of the fuel being a main driver of the initiative.[162]

Vaasa (Finland) purchased 12 public buses to run on biogas from sewage sludge from its wastewater treatment facility and separately collected biowaste, highlighting the co-benefits of local job creation across the biogas value chain.[163]

Interest in biomethane has also increased in public transport in recent years. In 2019, the Public Transport Central Purchasing Office (CATP) and Ile-de-France Mobilités ordered 409 biogas buses to operate in the Paris metropolitan area (France).[164] Trondheim (Norway) introduced 189 buses powered by biomethane.[165] In the UK, the city of Bristol announced plans to procure 77 biomethane-fuelled buses.[166] Karachi (Pakistan) was developing a bus rapid transit system with more than 200 public buses fuelled by biomethane produced from 3,200 tonnes of cow manure; it was scheduled to begin operations in 2020.[167]

Taking existing gas infrastructure and available feedstock resources into account, countries with a high potential for establishing a biogas-as-fuel market in the near future include China and India. However, these countries still need to add significant infrastructure (biogas filling stations and vehicles) in order to enable the use of biogas as a transport fuel. Other countries with smaller populations already possess the established infrastructure for gas as vehicle fuel despite having less residual biomass available in absolute terms. These include Italy, Argentina, Colombia, Pakistan and Iran.[168]

The production of **HVO/HEFA** has experienced robust growth in recent years, rising 12% from 6 billion litres in 2018 to 6.5 billion litres in 2019.[169] One of the main reasons for this growth is rising demand from road transport, especially heavy goods vehicles.[170]

SIDEBAR 2: RENEWABLE ENERGY USE IN AVIATION AND SHIPPING

Aviation and shipping are characterised by long distances, heavy weights and high energy density fuels, such as kerosene and heavy fuel oil. The specific requirements of the sectors mean that renewable solutions such as biofuels and electrification are generally more challenging to implement in those sectors.

Electrification. While full electrification may be difficult for larger vessels and long distances, there are many applications in aviation and shipping where small vehicles are used for short and medium distances. Electrification of ferries is already starting and the first fully electric two- and four-seater airplanes are being tested.[171] In 2020, the world's largest all-electric container ship, the Yara Birkeland, was expected to take its first voyage, with the timeline being set back due to the Covid-19 pandemic.[172] For larger aircraft, hybridization is being tested. The E-Fan X, for example, is a hybrid-electric aircraft, currently being jointly developed by Airbus, Rolls Royce and Siemens.[173] In shipping, around 80% of oceangoing ships now use diesel-electric transmission systems. Although these do not yet allow propulsion by electric means only they could be further developed and integrated with on-board solar or wind generation.[174]

Hydrogen. The use of hydrogen-powered fuel cells for ship propulsion is still at an early design or trial phase – with applications in smaller passenger ships, ferries or recreational craft. No fuel cells have been scaled for and used on large merchant vessels thus far. In comparison to the currently used diesel engine, the fuel cell powertrain and fuel are still too expensive. In addition, international technical standards still need to be developed in order to use gaseous fuels (such as hydrogen).[175]

Ammonia. "Green" ammonia is produced by reacting nitrogen, separated from air, with renewable electricity-based hydrogen. It can be used as a fuel in shipping and aviation. Advantages to the direct use of hydrogen is that it is easier to store and can be burned in standard internal combustion engines. Nitrogen oxides, the only GHG emitted by the combustion of ammonia, could be eliminated by installing catalytic systems. Conventionally produced ammonia is already stored and handled in 120 ports around the world.[176]

In aviation, the British aircraft-engine manufacturer Reaction Engines is working on a fuel system in which ammonia is exposed to a catalyst that splits it into nitrogen and hydrogen, with the latter burned in the aircraft engine. As in shipping, the advantage of ammonia over hydrogen is that it can be more easily stored, although safety issues do still apply. However, ammonia is less energy dense than kerosene, so its use would be limited to short-haul flights.[177]

RE-based synthetic fuels. With synthetic fuels still being largely in the development phase, there is not yet a market in the aviation and shipping sector. Many in the sector regard such fuels as essential in delivering substantial GHG emission reductions from the sector. For example, the Global Alliance Powerfuels aims to make these fuels marketable and call for blending mandates for the sector.[178]

Policy efforts to mitigate GHG emissions from international aviation and shipping are coordinated largely at the international level by the International Civil Aviation Organization and the International Maritime Organization, respectively. However, some countries are also taking national measures: Finland, Norway, Brazil and Indonesia announced biofuel mandates for aviation while France and Germany established aviation taxes. Additionally, some countries published roadmaps related to domestic aviation and inland shipping. In 2019, Norway released an action plan for green shipping which outlines the government's ambition to cut emissions from domestic shipping and fisheries by half by 2030. Also, the United Kingdom published the "route map" for its Maritime 2050 strategy - a clan maritime plan - which entails research on incentives for zero emission shipping and encourages the uptake of low-carbon fuels.[179]

Consequently, the biofuels industry has progressively increased its investments in HVO/HEFA production facilities which are concentrated in Finland, the Netherlands and Singapore.[180] HVO/HEFA plants are large-scale and already commercial, but their long-term business expansion is constrained by the global availability of waste oils and fats-based feedstocks.[181]

Renewable electricity capacity is rising while cost continues to fall

More than 200 GW of new renewable power capacity was installed in 2019, of which 57% was solar PV (115 GW), followed by wind power (around 60 GW for 30%) and hydropower (some 16 GW for 8%). The remaining 5% of additions were from bio-power, geothermal power and CSP.[182] The share of electricity generated by VRE (wind and solar PV) has been on the rise in most countries around the world. Overall, at least eight countries[i] produced more than 20% of their electricity from VRE in 2019, with some countries shares reaching as high as 60% (Denmark).[183]

By the end of 2019, the total installed capacity of renewable energy globally (2,588 GW) was enough to provide an estimated 27.3% of global electricity generation. Hydropower still made up the majority (58%) of this estimated generation share, followed by wind power (22%), solar PV (10%) and bio-power (8%).[184]

Investment in renewable power capacity (excluding hydropower >50 MW and biofuels) reached USD 282 billion in 2019, compared to USD 99 billion investment in new coal, natural gas and nuclear power generating capacity.[185]

In 2019, for the fifth year in a row, net additions of renewable power generation capacity overwhelmingly outpaced net installations of both fossil fuel and nuclear power capacity combined, making up 75% of net additions.[186]

Renewable electricity shares are rising rapidly in many countries and regions. Over the past decade, the EU saw strong growth in its share of renewables in electricity generation, up from 19% in 2009 to an estimated 35% in 2019.[187]

In certain European countries, the shift was even more dramatic, such as in Denmark (from 39% to 77%) and Germany (16% to 42%).[188] In the United Kingdom, the share of renewable electricity generation increased from 8% to 38% between 2009 and 2019. In the United States, it only increased from 10.2% to 17.4%, even though 282 GW of capacity were added in 2019.[189] Despite China more than doubling its total renewable electricity production during the decade, the renewable share of electricity generation in the country grew more modestly from 16.6% to 26.4%.[190]

BOX 5:

RENEWABLE ELECTRICITY USE IN RAIL

Rail is the most electrified transport sub-sector, with three-quarters of passenger rail transport activity being electric. This represents a great opportunity to increase renewable energy uptake in the transport sector.[191] The share of renewables in rail transport currently only stands at 11%,[192] but several tenders and renewable energy purchase agreements have been recently signed between railway operators and renewable energy producers.

In the Netherlands, 100% of the electric trains have been powered by wind energy since 2017. Tokyo's (Japan) Setagaya light rail line has been using 100% renewable power (from geothermal and hydropower) since early 2019. The German railway company Deutsche Bahn signed the country's first offshore wind power purchase agreement (PPA) in an effort to source 100% of its electricity from clean sources. Under a recently signed PPA, a small portion of SNCF's (France) train operations will be sustained by utility-scale solar PV by 2022-2023. In 2019, the first 100% solar-powered railway line opened in Hampshire (UK).[193]
In addition to increasingly sourcing renewable electricity for railway operations, some countries like India, Australia and Argentina are also pursuing efforts to power railway stations with solar PV.[194]

Renewable power-to-X fuels are still in their infancy

Demand for **hydrogen** has grown more than threefold since 1975, although virtually all hydrogen is still produced from fossil fuels in 2019.[195] However, momentum for renewable hydrogen (produced through electrolysis) has been slowly building in recent years, especially for vehicle fuelling, with a growing number of countries implementing policies to support fuel cell vehicles and related infrastructure.[196] Globally, the number of projects and installed hydrogen electrolyser capacity have grown considerably from less than 1 MW in 2010 to more than 100 MW by mid-2020.[197]

In 2019, the electric utility Vattenfall and the oil and fuel company Preem were collaborating on designing a 20 GW renewable hydrogen facility in Sweden that is expected to become Europe's largest facility.[198] During the year, offshore wind power developers in Europe also advanced efforts to produce hydrogen from excess wind energy for greater grid flexibility or for use in transport and industry.[199] Ørsted (Denmark), the world's largest offshore wind developer, announced plans to use electricity from wind farms being built off the Dutch coast to produce hydrogen for sale to industrial customers.[200] Also in 2019, Siemens joined a partnership to develop a hybrid solar PV-wind power project in Australia for hydrogen production, and partnered with Shell (Netherlands) and grid operator TenneT (Netherlands/Germany) to propose a joint offshore wind power and hydrogen tender in Germany.[201]

The costs of low-carbon and renewable hydrogen produced via electrolysis fell 45% between 2015 and early 2020, but have remained high relative to non-renewable hydrogen.[202] Comparisons to conventional fuels are difficult due to differences in taxation and subsidies of gasoline and diesel across countries. However, the Hydrogen Council estimates that hydrogen could become competitive with other low-carbon alternatives at around 2 USD/kg H_2 for cars and at 3 USD/kg H_2 for trucks.[203] In China, renewable electricity-based hydrogen is currently produced at just under 3 USD/kg H_2.[204]

All stages of the power-to-liquid process have been demonstrated, producing **liquid synthetic fuels** based on renewable electricity. Sunfire has successfully run a demonstration-scale facility in Dresden (Germany) since 2014 and is currently planning a commercial-scale plant in Stavanger (Norway) which is scheduled to go operational in 2023.[205] Soletair Power has run a pilot at Lappeenranta University (Finland) and received funding in 2019 for further piloting which aims to improve air quality in buildings by capturing CO_2 and converting it to synthetic fuels.[206]

4.2 TRANSPORT MARKETS

The transport sector is driven by an ever increasing demand for mobility, especially in non-OECD countries.[207] Combined with increasing levels of income in many countries, this has led to a growing number of vehicles and increasing rates of motorisation across the globe.[208] Notwithstanding, total vehicles sales have remained relatively stable over the last years, with sales peaking in 2017 for passenger cars and 2018 for motorcycles, while commercial vehicle sales continue to grow.[209] As of 2017, around 99% of the passenger cars produced worldwide were equipped with internal combustion engines, with the majority of these being gasoline or diesel (95%).[210]

Conventional drives still dominate the market

While **cars** are running mostly on gasoline in most parts of the world,[i] diesel remains the primary fuel for **heavy-duty vehicles** (HDVs). The share of diesel in overall oil-based road fuel consumption rose from 38% in 2000 to nearly 45% in 2019, largely due to greater road freight activity.[211] Tailpipe CO_2 emissions from trucks and buses have risen by around 2.6% annually since 2000, with trucks accounting for over 80% of this growth.[212]

Urban **buses** account for around 8% of the GHG emissions (per passenger-kilometre travelled) associated with transport.[213] Diesel was the most popular bus fuel in 2019, used in half of the world's bus fleets, while another 17.4% of buses consumed diesel with additives, and compressed natural gas buses accounted for 10.5%.[214]

The number of **natural gas vehicles** (NGVs) worldwide has grown over the last few years. Globally, there were about 22.7 million NGVs operating in 2015 (compared to 28.5 million in 2019). Trucks fuelled by either compressed or liquefied natural gas accounted for around 1% of the total stock in 2015, with around half a million heavy-freight trucks on the road, mostly in India and China.[215] More recently, developments have favoured the penetration of methane for trucking in three regions: China, Europe and the United States.[216] In Europe alone, the number of registered natural gas vehicles rose by more than 70% (to more than 6,000 vehicles) in 2019.[217]

Although not an avenue for increased penetration of renewable electricity, **hybrid vehicles**, together with avoid, shift and efficiency improvements, contribute to reduced fuel demand and remain far more numerous than BEV and PHEV.[218]

Alternative drives are growing rapidly, but market shares remain small

Electric vehicles

The number of **electric passenger cars**[ii] on the road neared 7.2 million in 2019 with 3.4 million of them in China alone, up from only 17,000 in 2010. Nevertheless, this still represents less than 1% of all cars in circulation worldwide. In 2019, electric car sales were 40% higher than in 2018, which represents a slowing down compared to the growth rates of 63% and 58% for 2018 and 2017, respectively,[219] with BEVs growing faster than PHEVs. The slowdown is likely based on the scaling back of subsidies in China, aimed at spurring innovation.[220] Overall, while still small, the market is rapidly moving towards mainstream customer acceptance, with a growing number of models available from different companies, decreasing vehicle prices and increasing range.[iii][221] In the US, for example, there are currently 35 BEV models and 45 PHEV models available, with ranges from 60 to 402 miles.[222] China has an even larger range of models, with 34 manufacturers producing a variety of models. There are, however, large differences in the type of models and technology preferences – BEV or PHEV – between regions. While China has a larger range of popular small and micro BEVs, the US has a more equal portfolio of BEV and PHEV models.[223]

Urban **buses** represent a great example of rapid EV market uptake, mostly owing to depot availability for charging, municipalities' ambitions to reduce local air pollution, and the longer-term investment portfolios of some municipal fleet managers.[224] China has led the way in bringing domestically made batteries and buses to market, first to Chinese cities and increasingly to European as well as Latin and North American cities.[225]

Almost all of the world's electric buses (more than 98%) in 2018 were deployed in China, estimated to represent around 18% of China's total bus fleet.[226] Shenzhen, for example, has more than 16,000 electric buses in operation.[227] More than 2,100 electric buses are in use in European cities such as Berlin (Germany), London (UK), Rotterdam (Netherlands) and Moscow (Russian Federation), and e-buses are also deployed in Japan, the United States and Latin America.[228]

In Latin America, the demand for electric buses is surging. Santiago (Chile) already operates 200 e-buses, the largest fleet in the region, and was expected to add another 500 in 2020, supporting its plan to make 80% of the city's buses electric by 2022.[229]

Light commercial **trucks** operating in urban environments, especially those belonging to large coordinated fleets and logistics services, have also begun to electrify rapidly. China again leads the way: the country accounts for 65% of the global fleet of electric light commercial vehicles, with nearly 250,000 on its roads.[230] Many major postal and package delivery companies such as Amazon, DHL, DB Schenker, FedEx, the Ingka Group, UPS and the Swiss and Austrian postal services, have pledged to expand their electric fleets in the near future.[231] (See Sidebar 3)

A group of European manufacturers delivered electric medium-freight trucks to selected fleet operators (such as logistics companies and waste collection services) for commercial testing; these included more than 50 electric trucks from DAF, MAN, Mercedes and Volvo.[232] However, the market for electric medium- and heavy-duty freight trucks remains small. China was the first mover in the electrification of heavy-duty transport, where an estimated 1,000-2,000 medium- and heavy-duty electric trucks were sold in 2018, mostly for garbage collection and other municipal operations.[233] In Europe, the number of battery and plug-in electric trucks registered more than doubled between 2018 and 2019, with nearly 750 new vehicles registered, 80% of them in Germany.[234]

A growing number of zero-emissions medium- and heavy-duty truck models are becoming commercially available, reflecting the need to reduce emissions from vehicle manufacturing since it is the overall life cycle GHG emissions of vehicles and their fuels that need to be reduced.[235] The range of prototypes, demonstration trucks, and commercially available hydrogen fuel-cell and plug-in electric trucks continues to expand. Bollinger and Toyota (North America), Tata (India) and BYD and Chanje (China) introduced prominent new 2019 and 2020 models. In 2019, Daimler Trucks – the world's largest truck maker – committed to selling only zero-emission vehicles by 2039 and to abandon the development of natural-gas-powered trucks. The CEOs of Volvo and Scania also recently expressed their views that the electrification of HDVs is crucial to reach climate targets. Both Volvo Trucks and Renault Trucks started producing electric trucks in 2019.[236]

In recent years, **electric two- and three-wheelers**, including electric bikes, bicycles, scooters and motorbikes, have evolved as a convenient, rapid means of travelling in cities. In 2019, there were an estimated 800 million electric two-wheelers, at least 51 million three-wheelers and more than 200 million electric bicycles on the world's roads.[237] Over the past two decades, two- and three-wheeler fleets have expanded at an annual average rate above 7% in many middle- and low-income countries including Bangladesh, India, Indonesia, the Maldives, Myanmar, Nepal, the Philippines and Sri Lanka.[238]

The use of electric two-wheelers in European cities has surged since 2017, mostly through shared rental schemes.[239] More than 50 electric scooter companies are active in cities worldwide, some of which have started to link their scooters to renewable electricity.[240] For example, Lime – active in more than 100 cities across Europe, North America, Latin America, the Middle East and Asia – charges its entire fleet of 120,000 scooters with 100% renewable energy.[241]

Investments in **charging infrastructure** has also been essential in enabling the electrification of road transport. In 2019, the first electric highway was built in Latin America with 157 km served by four charging points, while China reportedly installed more than 1,000 EV charging stations per day.[242] Globally, there were an estimated 7.3 million electric vehicle chargers installed, with the majority (6.5 million) being private slow chargers. Publicly accessible chargers only represent 12%, with two thirds of these being slow chargers and one third fast chargers. While absolute numbers for public charging are still low, with 862,118 chargers installed globally, this represents a tremendous growth compared to the 3,994 installed chargers in 2010. China is dominating the market, with around 80% of publicly accessible fast chargers and 50% of publicly accessible slow chargers installed in 2019.[243]

Fuel cell electric vehicles

The hydrogen used in transport remains 99% fossil fuel-based. Although expanding more rapidly than ever, FCEVs still account for only 0.5% of new low-carbon vehicles sales.[244] The global stock of FCEVs doubled to 25,210 units at the end of 2019, compared to 11,200 at the end of 2018. Most of this growth was due to expansion in China which, since 2019, has the second-largest stock of FCEVs, followed by Japan and the Republic of Korea. The United States remain the world leader in FCEV stock, with approximately one in three FCEVs running on US roads.[245]

The situation in China and the Republic of Korea has been particularly dynamic in recent years, with new sales growing from a few units in 2017 to over 4,000 in each country in 2019. In China, the impressive progress was stimulated by policies supporting the adoption of fuel cell **buses** (with a stock close to 4,300) and light-duty trucks (over 1,800), making China the leader in global stock of fuel cell buses and **trucks**.[246]

At the end of 2019, 470 hydrogen **refuelling stations** were in operation worldwide, an increase of more than 20% from 2018. Japan remained the leader with 113 stations, followed by Germany (81) and the United States (64). Similar to FCEVs, the number of refuelling stations increased threefold in China in 2019 (from 20 to 61), giving China the fourth-largest number of stations, followed by the Republic of Korea, Japan, and Germany.[247]

4.3 THE NEXUS OF RENEWABLE ENERGY AND TRANSPORT

Energy for the transport sector accounted for 29% of total final energy consumption globally in 2018, and the sector is still dominated by oil and petroleum products.[248] Only 3.4% of global energy demand in the sector was met by biofuels and 0.3% by renewable electricity in 2018 (see Figure 1.1).[249]

Road transport accounted for around 75% of global transport energy use in 2018, with passenger vehicles representing more than two-thirds of this.[250] Road freight consumes around half of all diesel fuel and is responsible for 80% of the global net increase in diesel use since 2000, with the increase in road freight activity having offset any efficiency gains.[251]

Growing demand from all sectors coupled with supporting policies affect the market for biofuels, renewable electricity and PtX fuels as discussed in Section 4.1. In this section, we take a closer look at the market for technologies that enable a better integration of increased electrification of transport into the grid, particularly in combination with enhanced renewable electricity generation.

Smart charging is ready for market deployment, but more advanced applications are still only deployed at small scales

A number of solutions are available to support smart charging for customers, mostly using V1G. The WallBox home charging solution is a smart charging system that automatically charges EVs when energy costs are the lowest, managing recharge with intuitive sense technology. The SMATCH B2B solution by ENGIE allows the user to indicate charging needs while maximising the use of local renewable energy generation and reducing peak demand in the process. Similarly, the EVlink solutions developed by Schneider Electric offer smart charging solutions for home and public charging.[252]

Utrecht (Netherlands) launched its Smart Solar Charging system in early 2019 using locally produced solar electricity and linking it with EV charging. Utrecht's system enables EVs to participate in smart charging, or vehicle-to-grid (V2G) technology, which entails charging or drawing from EV batteries in response to the needs and capacities of the national electric grid (see Section 3).[253] Another smart charging project is being developed by the transmission system operator TenneT in the Netherlands, using the aggregator Vandebron. Vandebron aggregates a fleet of EVs to provide automatic frequency restoration reserve to the TenneT grid. To do so, the aggregator temporarily stops and restarts the charging sessions of EV customers. This service is facilitated mainly to Tesla drivers, who receive a payment in exchange for their participation.[254]

Integrated solar-battery-EV systems are ready for large-scale deployment

There are a number of grid-connected and off-grid solutions available in various countries that combine solar power generation with EV charging, for home and public charging. In China, the first solar-powered charging stations were installed in 2017. In 2019, the first solar-storage-charging microgrids were launched and further individual charging stations installed.[255] Envision Solar is offering different off-grid solar-powered charging solutions, mostly to business customers across the US.[256] The German energy company Innogy launched a first solar-based fast charging station near Duisburg, also offering peak load buffering services to the grid. The French DRIVECO developed a fully solar-powered charging station, charging up to eight vehicles at a time and creating a microgrid with other stations.[257] In India, Magenta Power started setting up solar powered charging points in 2018 in Navi Mumbai,[258] quickly rolling this out along corridors, starting with the Mumbai – Pune Expressway.[259] In Australia, CSIRO developed a solar-powered charging system, mostly aimed at household use, and is currently running a pilot phase.[260] Further reductions in energy storage cost will make integrated solar-battery-EV systems more economically attractive.

Other solutions for enhanced integration are still in their early stages

Strategic infrastructure siting. While siting of charging points at convenient locations for daytime charging, such as workplaces and shopping malls, is already under way, it is rarely part of a strategic effort to reduce peak demand or to move charging to locations that are favourable for the distribution grid.

Battery swapping for passenger vehicles was pioneered by Better Place already in 2008 in Israel with limited success. However, the model seems to receive revived attention, particularly for captive fleets and two-and three-wheelers. Battery-swapping stations exist for buses (mostly in China and the Republic of Korea) and two-wheelers, such as for example Gogoro, a successful start-up selling e-scooters and charging a monthly subscription fee to use the battery-swapping stations, some of which are already equipped with solar panels.[261] Gogoro is currently operating over 1,700 swapping stations around Taiwan, holding a 16% market share.

Blockchain technology has been deployed in the "Oslo2Rome experience", a 2017 initiative involving European utilities and encompassing 1,200 public and private charging stations equipped with the Share&Charge App of MotionWerk. The Share&Charge App is meant to allow EV users access to charging stations across Europe using blockchain for payment on the first borderless electric vehicle charging network. In the Netherlands, transmission system operator TenneT is piloting using blockchain technology for managing its grid, including managing EV charging.[262]

Linking vehicle charging / fuelling directly to renewable electricity generation is picking up momentum

There are some examples of linking EV charging directly with renewable electricity production, largely based on policy decisions of individual entities. Several cities are working to ensure that EVs are charged with renewable electricity. As of 2018, Austin (Texas, US) had installed more than 650 public EV **charging stations** that rely entirely on renewable power.[263] In Rabat (Morocco), the Moroccan Institute for Research in Solar Energy and New Energies is installing a series of solar-powered car ports to recharge EVs.[264]

There are also examples of electric waste **trucks** powered by renewable electricity. In 2019, East Waste was developing a 30 kW solar PV system in Adelaide (Australia) to provide clean electricity to its fully electric waste collection truck.[265]

Also, as more local governments transition to electric **bus** fleets, a few are linking them with renewable energy. In 2019, a bus charging station in Jinjiang's Binjiang Business District (Fujian Province, China) was charging its electric buses using solar power.[266] Portland (Oregon, US) announced that its entire electric bus fleet would be powered by wind energy.[267] The electric bus fleet of Bergen (Norway), consisting of 136 buses, was expected to start running on 100% renewable energy in 2020.[268]

In 2017, the Moreland Council and the Victorian State Government (Australia) built a commercial-scale renewable hydrogen refuelling station for waste collection (garbage) **trucks** aimed at tackling urban noise and air pollution.[269] In Europe, Akuo Energy and Atawey announced a plan in 2018 to deploy 33 renewable hydrogen refuelling stations to provide fuel for 400 hydrogen **logistics vehicles** in Paris and other French towns and cities.[270]

Hydrogen **buses** are scaling up rapidly, with several hundred already on the roads in certain Chinese cities.[271] A new H2Bus consortium in Europe, announced in 2019, aims to deploy 1,000 commercially competitive buses fuelled with hydrogen from renewable power, the first 600 of which are due by 2023 in cities across Denmark, Latvia and the UK.[272]

SIDEBAR 3: PRIVATE SECTOR-LED PLEDGES AND INITIATIVES TOWARDS A RENEWABLES-BASED ROAD TRANSPORT SECTOR

Fossil fuel and combustion-engine vehicle restrictions set by national and local governments put increasing pressure on car manufacturers to adapt their product portfolios. National phase-out goals going into effect 10 to 20 years in the future, the growing number of local access and circulation restrictions, and stricter EU emission standards for cars and vans in place from 2020 are eliciting responses from the auto industry. Many car manufacturers are increasingly committing to the production of models equipped with alternative propulsion engines, especially electric cars.[273]

Some private companies are also pushing forward with their own renewable energy initiatives in transport, sometimes regardless of government policy support. This includes efforts to couple EV charging with renewable electricity: In 2019, EVgo, the largest public EV fast-charging network in the United States, contracted for 100% renewable electricity. Another US company, Enel X, is undertaking a project in Hawaii to maximise EV charging at times when solar electricity generation is highest. In Nairobi (Kenya), the company M-KOPA has a pay-as-you-go programme that gives small loans to motorcycle owners who install solar PV systems at home to charge their vehicles.[274] In Europe (and elsewhere), the ride-hailing and car-sharing markets keep growing as does the industry's commitment towards electrification, with a few companies such as We Drive Solar in Utrecht (Netherlands) and WeShare in Berlin (Germany) procuring renewable electricity for charging.[275]

Other renewable fuels have also attracted the interest of the private sector. The Royal Dutch Shell oil company has hydrogen refuelling stations in UK cities that are supplying hydrogen produced on site using electricity from renewable sources. This is part of the company's goal of achieving net-zero carbon by 2050.[276] The supermarkets Waitrose (UK) and Carrefour (France) have also made pledges to reduce GHG emissions in their delivery services, hence why they have integrated several biomethane trucks into their fleets.[277]

Road freight is made up of many commercial businesses operated by private companies. This is a critical difference from the passenger road transport side where public actors are much more involved (including in the direct provision of services) and trip choices are associated with personal behaviour. For road freight, the private sector ultimately defines operational procedures and supply chains, thus private companies need to play a leading role in decarbonising the sector. Major postal and package delivery companies such as DHL, UPS and FedEx are expanding their low-carbon transport fleets.[278]

Recognition among peers and the wider public is also an incentive for businesses to decarbonize and increase the share of renewables in their fleets. Therefore, voluntary schemes where companies and other partners (e.g. governments and public entities at the national, regional or local levels) cooperate to achieve targets and implement low-carbon solutions play an important role as well. Some examples of institutionalised collaborative initiatives include:

- Launched in 2018, the **Transport Decarbonisation Alliance** is a collaboration between countries, cities/ regions, and companies to accelerate the worldwide transformation of the transport sector towards a net-zero emission mobility system before 2050.[279]
- **below50** a global collaboration that brings together the entire value-chain for sustainable fuels –fuels that produce at least 50% less CO_2 emissions than fossil fuels. below50 is creating a global campaign for local action, taking a global strategy and implementing solutions at a local level.[280]
- Launched at the 8th Clean Energy Ministerial meeting in 2017, the **EV30@30 Campaign** aims to accelerate the adoption of electric vehicles within the participating countries[i]. It sets a collective goal to reach a 30% sales share for electric vehicles by 2030. By 2020, 23 companies and organisations (including utilities, automotive and EV services sectors)[ii] support the EV30@30 Campaign.[281]
- Similarly, **EV100** is a global initiative led by companies committed to accelerating the transition to EVs by 2030. In 2019, 67 EV100 member companies from 80 markets worldwide had rolled out more than 80,000 EVs and over 1,100 EV charging stations. The number of EV100 members using 100% renewables for their EV charging also increased significantly from 29% to 43%, while the number of members at least partially powering vehicles with renewables increased to 88%.[282]

5. POLICY AND REGULATORY FRAMEWORKS

Policy making for transport decarbonisation entails coordination between all relevant ministries, government agencies and businesses at national and local levels. However, these groups represent multiple, and sometimes contradictory, interests and objectives,[283] including improving local air pollution, mitigating transport-related GHG emissions, increasing the renewable energy share, achieving equitable access to transport, reducing congestion, improving road safety, and creating economic opportunities.[284]

While the shift to alternative powertrains is mostly driven by transport policy, the production of renewable electricity and fuels is strongly driven by energy policy.[285] So far, the main goal of renewable energy policies has been to increase the capacity, share, and supply of renewable electricity and fuels in the energy mix. The transport sector's priority has been to grow the stock of "clean" vehicles with a clear focus on tailpipe emissions.[286]

However, the decarbonisation of the transport sector requires integrated, coherent and co-ordinated policy efforts at all levels (international, national and sub-national) and across policy sectors, including energy and transport policy, aimed at reconciling the production and use of renewable fuels with the adoption of cleaner vehicles. By the same token, the shift towards more renewables in the energy sector can only be helped by pressure from one of its biggest users – transport – for greater supply of these fuel types. Thus, the relationship could and should be beneficially mutually interdependent if policies that target the production of renewable fuels and electricity are integrated with incentives for clean transport.[287]

Key policies and regulatory frameworks implemented to advance renewable energy generation are analysed in section 5.1 while policies supporting the transition to cleaner vehicles are assessed in section 5.2. The main opportunities, challenges and best practices within these policy and regulatory frameworks are also discussed. Section 5.3 provides examples of integrated policies that help bridge the renewable energy-transport nexus.

5.1 THE RENEWABLE ENERGY PERSPECTIVE

Policies supporting the production and use of biofuels for transport continue to be the most common renewable energy policy in the road transport sector, with sustainability concerns over first generation biofuels contributing to growing policy support for advanced biofuels. Policies that stimulate the deployment of renewable energy in the power sector, increasing the share of renewables in the electricity mix, directly impact the share of renewables in transport, namely in EV fleets. Other renewable transport solutions such as renewable hydrogen and renewable electricity-based synthetic fuels are also slowly starting to attract policy attention.

Conventional biofuels are mostly driven by blending mandates

Biofuel **blending mandates**, i.e. the requirement for fuels to contain a minimum share of biofuel, remain one of the most widely adopted policies for increasing renewable fuels in road transport, and these policies are prevalent across all regions and countries.[288] To date, at least 70 countries have blending mandates for conventional biofuels at the national and/or sub-national level.[289] However, despite being mandatory, these policies are not always enforced which raises questions about their effectiveness.[290]

Most liquid biofuels are currently consumed through blending at low percentages such as E10 (10% ethanol, 90% gasoline), B5 (5% biodiesel, 95% diesel) and B2.[291] However, higher biofuel blend mandates exist in Europe, North and South America.[292] Examples include Brazil (E27), Costa Rica (B20), India (E20), Indonesia (B30), Paraguay (E25), Minnesota (US) (E20), Norway (E20) and Zimbabwe (E20).[293]

As a result of the ongoing debate about the sustainability of first-generation biofuels, policy makers are introducing **sustainability criteria**, including for example minimum criteria for GHG emission savings, to ensure that only sustainable biofuels receive policy support.

The EU, the US, Canada, and Brazil have established policy frameworks to promote biofuel sustainability which have led to growing interest in advanced biofuels (see next sub-section on advanced biofuels).[294]

Financial incentives for liquid biofuels exist in some countries such as Thailand, the US and Brazil, often in addition to blending mandates.[295] In 2016, Thailand supported E20 and E85 blends, going beyond the existing blending mandates, as well as a trial programme for the use of B20 in trucks and B10 for military/government use.[296] Brazil's RenovaBio programme, signed into law in 2019, includes estimated financial support of around BRL 9 billion (USD 2.2 billion) for the ethanol sector and another BRL 4 billion (USD 1 billion) for increased sugarcane production through tax exemptions.[297] The programme also introduced **emissions reduction targets for fuel distributors**, with the option to demonstrate compliance by buying traded emissions reduction certificates awarded to biofuel producers.[298] A few jurisdictions also provide financial support for distribution infrastructure to help bridge the nexus between biofuels production and its use for road transport (see Section 5.3).

Many countries also support biogas use as vehicle fuel with tax exemptions, investment subsidies or other incentives for biogas injection into the natural gas grid. Investments are being made based on such considerations in China, France, the UK and Scandinavia.[299]

Policy support for advanced biofuels is still limited

Standards that specify reductions in fuel life-cycle carbon intensity such as California's (US) Low Carbon Fuel Standard and Canada's Clean Fuel Standard are particularly effective in creating demand for advanced biofuels.[300]

By the end of 2019, eight countries[i] had specific **mandates** for advanced biofuels, and at least 16 EU countries as well as Thailand, the United Kingdom and the United States had future **targets** for advanced biofuels.[301] Finland set a target to increase the share of advanced biofuels in road transport to 10% by 2029.[302] The UK created a specific target for advanced waste-based biofuels, starting at 0.1% in 2019 and rising to 2.8% in 2032.[303]

The EU Renewable Energy Directive (RED) II includes a transport target requiring at least 14% of the energy consumed in road and rail transport to come from renewable sources by 2030. There are also dedicated objectives for advanced biofuels within the transport target; advanced biofuels must supply a minimum of 0.2% of transport energy by 2022, 1% by 2025, and at least 3.5% by 2030. Since 2015, a 7% cap for food/feed-competing feedstocks has been established to comply with the mandatory 10% renewables transport target for 2020 in the existing RED (Directive 2015/1513 regulating indirect land-use change, ILUC).[304]

The US Renewable Fuel Standard (RFS)[ii] requires obligated parties (fuel refiners, blenders, and importers) to supply increasing amounts of biofuel in road transport.[305] An increasing volume schedule is set annually for different biofuels, with cellulosic biofuel having its own mandate within the RFS.[306]

Public procurement programmes to support advanced biofuels are also being implemented in some jurisdictions. For example, Swedish regional authorities have used strict environmental criteria in public bus procurement for some time, leading to a remarkable increase in the use of renewable fuels in public bus fleets in recent years: Stockholm's public buses run mostly on liquid and gaseous biofuels, including 13% of advanced biofuels.[307]

Despite the dominance of market-pull policy instruments (as those mentioned above), significant resources also have been dedicated to supporting technology **research, development and demonstration**, in particular through grant instruments for advanced biofuels.[308]

Effective support for advanced biofuels must include both technology-push and market-pull instruments which are long-term, technology-specific, deal with the sustainability of feedstocks up front, and support offtake and cost containment.[309] Further enabling regulatory and policy frameworks for advanced biofuels would be particularly useful in Latin America, China and ASEAN countries, as they possess significant feedstock resources.[310]

Policy instruments for renewable electricity are well proven, but effectiveness is still hampered by persistent fossil fuel subsidies

Targets are the most popular form of policy intervention to spur investments in renewable electricity. As of 2019, 166 countries and over 350 cities had some form of target for renewables in the power sector.[311] Other policy instruments used to promote large-scale renewable power include renewable portfolio standards (RPS) and other quota obligations, feed-in policies (tariffs and premiums), auctions, and financial incentives (e.g. grants, rebates and tax credits).[312]

Increases in renewable electricity capacity are critical to ensure a full decarbonisation of the transport sector, especially fleets that run on electricity. Wellington (New Zealand), which had previously set a city-wide target for 78-90% renewable power by 2030, is capitalising on its high renewable electricity share (82%) to promote EVs as a way to increase the use of renewables in the transport sector.[313]

Technology maturation and declining costs, coupled with favourable policy attention, have also contributed to increasing interest in **renewable power purchase agreements** (PPAs) by cities as well as corporations to power their fleets.[314] For example, San Francisco (California, US) committed in 2017 to purchasing renewable electricity from two local projects – including a 61.7 MW wind project and a 45 MW solar PV project – to power its rapid transit system.[315] Several transport companies have also entered agreements to source renewable electricity to achieve decarbonisation targets. (See Box 5 and Sidebar 3).

BOX 6:

THE ROLE OF FOSSIL FUEL SUBSIDIES

A challenge to increasing the share of renewables has been persistent subsidies for fossil fuel consumption which increased 30% between 2017 and 2018. Fossil fuel consumption subsidies reached an estimated USD 400 billion in 2018. To put this in context, this is more than double the estimated support for renewable power generation.[316] 2019 saw a 38% rise in overall fossil fuel production support, with the transport sector responsible for just over a quarter and petroleum production for over two thirds of total subsidies.[317]

Whether supported by subsidies or not, low fossil fuel prices encourage further demand for fossil fuels and reduce the competitiveness of renewable energy solutions. As countries implement fossil fuel subsidy reforms, the reallocation of savings from reduced subsidies could for example aid in the energy transition and provide other economic, social and environmental benefits.[318]

The use of renewable electricity in transport thus presents a key opportunity for policy-makers to better integrate energy and transport policy in the context of decarbonisation (see Section 5.3).

Dedicated policies to support hydrogen are emerging, but yet rarely tied to renewable power

Until recently, the scaling-up of (renewable) hydrogen mostly relied on cross-cutting, technology-neutral policies aimed at climate change mitigation, such as for example California's (US) Low Carbon Fuel Standard and Zero Emissions Vehicle mandate, and China's New Energy Vehicle Mandate. However, direct policy support has started to emerge: By mid-2019, there were at least 50 hydrogen **targets and mandates** in place globally, with most relating to its use in transport, albeit rarely explicitly mentioning renewable hydrogen.[319] For example, Japan adopted a plan to set up 10,000 hydrogen refuelling stations and 10 million hydrogen fuel cell vehicles worldwide within 10 years.

The Republic of Korea introduced a roadmap for a hydrogen economy, which outlines the country's plans to increase the production and use of hydrogen vehicles, expand the production of fuel cells and build a system for the production and distribution of hydrogen.[320]

During 2019, several jurisdictions released **strategies and plans** for renewable hydrogen specifically, often in parallel with **financial incentives** to support their implementation. Australia released a National Hydrogen Strategy which allocates AUD 1.1 billion (USD 0.76 billion) to help fund renewable hydrogen R&D, hydrogen refuelling infrastructure, and a "clean energy" innovation hub to explore hydrogen storage and distribution.[321] The state of Western Australia launched a strategy that includes grant funding to study the use of hydrogen as a transport fuel.[322] The UK government announced a GBP 12 billion (USD 15 billion) plan to generate hydrogen using offshore wind power.[323] New Zealand also launched a roadmap for the development of a new renewable hydrogen industry.[324]

In June 2020, Germany launched its national hydrogen strategy, placing particular emphasis on renewable hydrogen.[325] The strategy targets a total capacity of 5 GW of hydrogen electrolyser installations by 2030 and an additional 5 GW up to 2035. The German stimulus package agreed in the same month includes EUR 7 billion (USD 7.8 billion) aimed at supporting the market uptake of hydrogen technologies in the country.[326]

In July 2020, the European Commission released its hydrogen strategy for a climate neutral Europe. A key aim of the strategy is to decarbonise hydrogen production, building on the cost reductions of renewable electricity and use it across industry, transport, and buildings sectors. For this, it envisions the installation of 6 GW of renewable hydrogen electrolysers in the EU by 2024 and at least 40 GW by 2030.[327]

Globally, over 220 electrolyser installations have come online since 2000 due to government support.[328] However, significant regulatory challenges remain for the use of hydrogen in road transport, mostly associated with the permitting and construction of necessary infrastructure and with the transport of hydrogen,[329] and hydrogen plans should be based on renewable energy to ensure it adds to decarbonisation efforts.

5.2 THE TRANSPORT SECTOR PERSPECTIVE

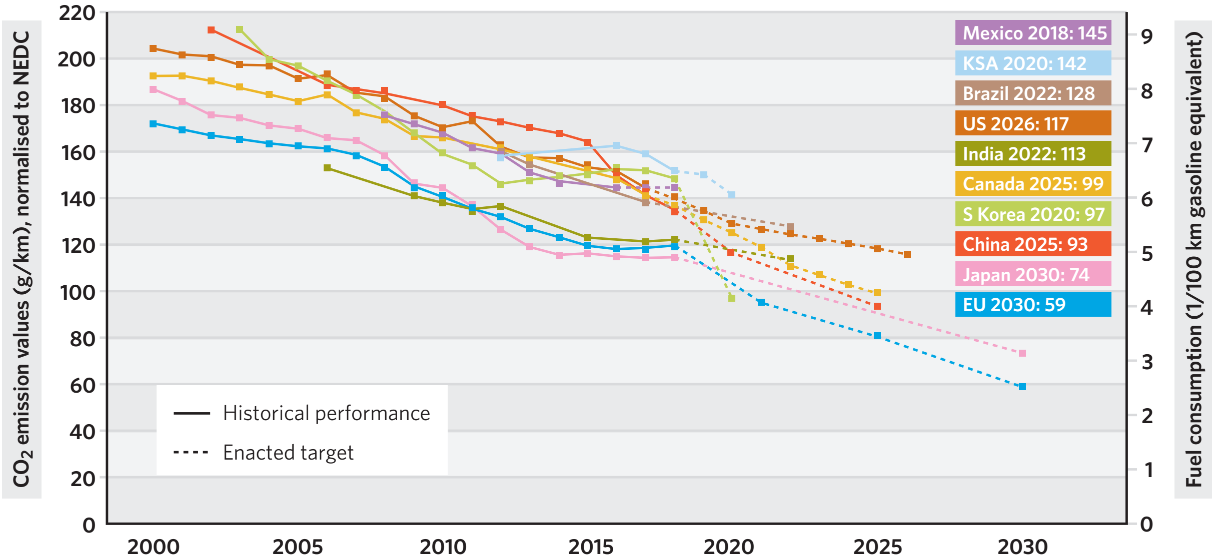
Most transport policy measures focus on improving fuel economy and reducing vehicle emissions of conventional vehicles or encouraging alternative/cleaner vehicles such as flexible-fuel vehicles and EVs, with the main goal of improving air quality.[330] Some of these policies also facilitate the uptake of renewables in the sector.

Vehicle emission standards are key to promote renewable energy in vehicles

Vehicle emissions standards typically regulate ground-level air pollutants associated with road vehicles. These emissions standards can indirectly incentivise the uptake of newer, more efficient vehicles, but are in principle designed for the improvement of air quality, not the reduction of GHG emissions. Additionally, gains in efficiency have in the past been overcompensated by growing vehicle size and increasing mileage.[331] Specific **GHG emission standards** have been increasingly implemented over the last decade, mostly for passenger cars and light commercial vehicles. They have helped to improve the CO_2 emissions performance and are becoming increasingly ambitious (see Figure 5.1). Some of these, such as the EU's CO_2 emission performance standards, include incentive mechanisms for zero and low emission vehicles[i], for example through relaxing the fleet target if a defined share of zero or low emission vehicles is exceeded.[332]

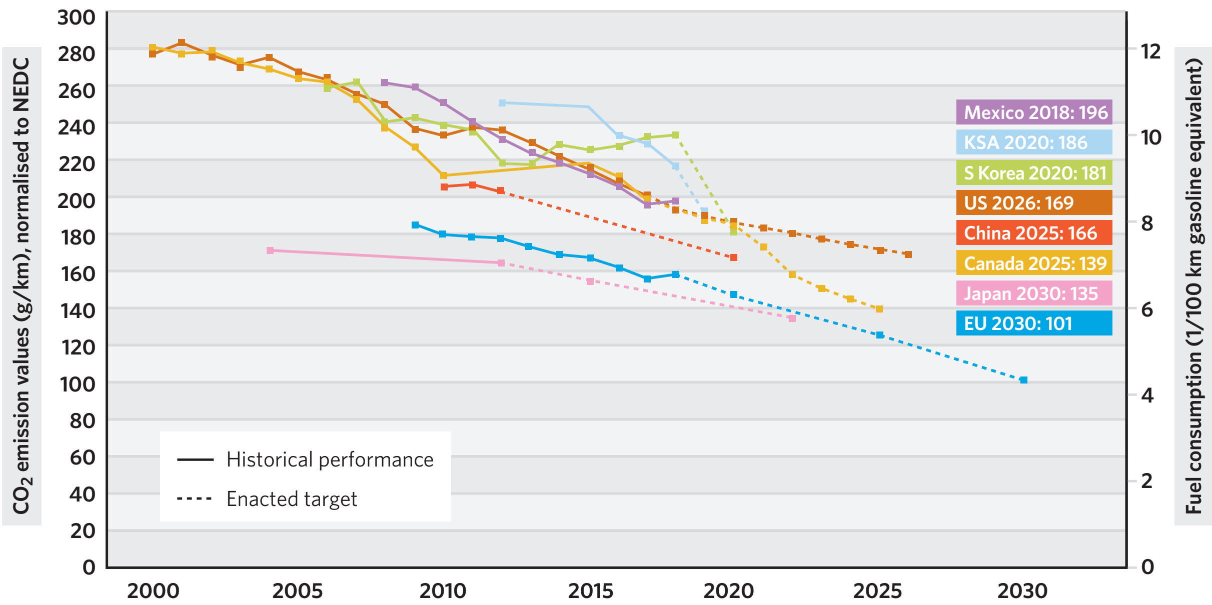
FIGURE 5.1: HISTORICAL FLEET CO2 EMISSIONS PERFORMANCE AND CURRENT STANDARDS (GCO2/KM NORMALISED TO NEDC) FOR PASSENGER CARS (TOP) AND LIGHT COMMERCIAL VEHICLES (BOTTOM)

Passenger car CO_2 emissions and fuel consumption values, normalised to NEDC



Updated May 2020
Details at www.theicct.org/chart-library-passenger-vehicle-fuel-economy

Light truck CO_2 emissions and fuel consumption, normalised to NEDC



Updated May 2020
Details at www.theicct.org/chart-library-passenger-vehicle-fuel-economy

Source: ICCT.[333]

At a sub-national level, Minnesota (US) implemented two standards to reduce emissions of CO_2 and other pollutants from light-duty passenger cars, trucks and SUVs.[334] In terms of heavy-duty vehicles, in 2019 the EU reached a provisional agreement on CO_2 emission standards for trucks.[335] Also implemented since 2019, China's Phase III standards are promoting the efficiency of new buses and trucks.[336]

GHG emission standards can support the uptake of renewables indirectly, but require agreement on the accounting of renewable energy sources, which is particularly challenging for biofuels.[337]

Vehicle fuel economy standards do not directly regulate GHG emissions but can help increase the share of renewable energy by cutting overall energy demand. However, efficiency gains have in the past largely been compensated by increasing size and weight of vehicles.[338] By 2019, only 37 countries had fuel economy policies for light-duty vehicles, covering 80% of the light-duty market globally, a total that is unchanged since 2017.[339] Five countries – Canada, China, India, Japan and the United States – had fuel economy standards for trucks, covering just over half of the global road freight market.[340]

Japan updated its fuel efficiency standards for trucks and buses in 2019, mandating efficiency improvements of 13.4% for trucks and 14.3% for buses by 2025 (compared to 2015). Argentina, Brazil, Mexico and South Korea are in various stages of developing policies to improve the efficiency of their HDV fleets.[341]

More and stricter fuel economy and CO_2 emission standards and regulations are necessary to foster the widespread deployment of renewable energy solutions for heavy freight trucks.[342]

BOX 7:

THE ROLE OF LOW-EMISSION VEHICLE ZONES

Cities are increasingly setting fuel and/or vehicle restrictions within their jurisdictions. As of mid-2020, low-emission vehicle zones (LEZs), which limit or prohibit the access of certain types of fossil fuel vehicles in defined city areas, are present in over 270 cities.[343] The majority of existing LEZs are in Europe, with some recently created in Asia, mostly in Chinese cities.[344] For example, in 2019 London (UK) introduced a municipal ultra-low emission zone, which imposes a charge for diesel vehicles whose engines are not certified to the latest Euro 6 standard, as well as for most petrol cars older than 14 years. The zone has recently seen an increase in charge and operating time, and will be expanded further geographically in 2021.[345]

Although their main goal is to improve local air quality, LEZs can promote renewable technologies, if designed accordingly. Some cities have set specific exemptions for low-carbon vehicles in their LEZs: In Madrid, for example, only BEVs, FCEVs, PHEVs with a minimum electric range of 40 km, and range-extended electric vehicles are allowed to circulate and park without restrictions in its LEZ, Madrid Central.[346]

While supporting BEVs and FCEVs can lead to enhanced use of renewables in the medium term, as increasing shares of electricity and hydrogen are produced with renewable energy, LEZs do not directly support the short-term uptake of renewables. To do so, requirements would need to be placed on energy sourcing, or available fuelling/charging infrastructure within the zones would need to be made fully renewable. Notwithstanding, these measures are forcing auto makers and truck makers to diversify powertrains.[347]

Fiscal measures need to be well designed to avoid increasing inequality in mobility access

Fuel taxes such as the German 'eco-tax' on fuels introduced in 1999 have been the main government tool to steer fuel demand together with reduced fuel taxes for specific fuels such as for diesel or LPG. It is important to note that some countries also subsidise fossil fuels for transport to ensure the mobility of their population, thus providing a negative incentive for the adoption of renewable energy in transport. In Brazil, there is a differentiated fuel taxation system that favours E100 over lower blend alternatives in some states.[348]

Some countries also use **taxation of vehicles** based on emissions and/or fuel economy. Such taxes can apply either when buying a vehicle or during ownership. Within the EU, for example, 16 countries have purchase taxes in place that directly relate to the CO_2 emissions of the vehicle and one, Denmark, based on fuel consumption. 15 EU countries have annual vehicle taxation in place that is linked to the CO_2 emissions of the vehicle.[349] However many of these have had limited benefits for the decarbonisation of road transport in the past. The growing preference for large passenger cars on the roads today shows that more ambitious and well-tailored fiscal interventions are required.[350] The French bonus/malus system, also referred to as 'feebate' system, is a good example of effective policy design, but also demonstrates the importance of careful design. The system has seen various adjustments, which have increased effectiveness over time.[i]

At the federal level, the US is providing a range of purchase incentives for fuel cell vehicles, PHEVs and battery electric two-wheelers as well as support for infrastructure development and alternative fuel vehicle manufacturers, mostly through **tax credits**.[351]

In 2020, 15 countries represented in the Economic Community of West African States adopted a set of policy instruments to support the uptake of cleaner fuels and vehicles in the region. These include a vehicle fuel efficiency roadmap that aims to double efficiency of the fleet by 2030 through a mix of fiscal incentives and other measures to promote electric vehicles.[352]

Pricing reforms are often perceived to put additional burden on lower income populations, since the tax or fee represents a greater portion of the income for those households. This is not necessarily true, as it depends strongly on the distance travelled by different modes and lower-income households have been shown to drive less and use less fuel than higher income households. Vehicle purchase taxes and incentives are also often perceived as benefitting higher income households, with zero emission vehicles still being more expensive in many markets and with lower-income households often purchasing used cars where benefits don't apply. Real effects and public perceptions need to be carefully analysed in the specific context and policies need to be tailored to avoid real or perceived inequalities. This can, for example, be achieved through needs-based discounts, using revenues for the benefit of disadvantaged groups or to reduce regressive taxes such as sales taxes.[353]

EV deployment targets are on the rise and increasingly ambitious

Several countries have set 100% EV targets[i] including Denmark, Netherlands, Norway, Slovenia, Cabo Verde and Sri Lanka.[354] India launched its National Electric Mobility Mission Plan, which includes a target of 7 million hybrid and electric vehicles by 2020.[355] Canada announced deployment targets for zero emission vehicles such as EVs in 2019.[356] Pakistan approved a national EV policy with targets aimed at seeing EVs capture 30% of all passenger vehicle and heavy-duty truck sales by 2030, and 90% by 2040.[357]

The California Sustainable Freight Action Plan is the first to set EV targets for freight, aiming to deploy over 100,000 zero emission freight vehicles and associated equipment while maximizing the share of renewable electricity in transport by 2030.[358]

Policy-makers are combining push and pull policies to trigger EV uptake

The mix of policy instruments adopted by high EV-uptake markets address the various prevailing consumer barriers of affordability, convenience, and awareness.[359]

China leads EV deployment globally. Since its landmark **national campaign** "Ten Cities, Thousand Vehicles", launched in 2009,[360] EVs have seen tremendous growth, initially driven by air quality concerns. Currently, EVs represent a key element of the national industrial policy.[361] This led to the introduction of the New Energy Vehicle (NEV) **mandatory credit policy**, which was launched in 2018.[362] Similar to the California Zero Emission Vehicle (ZEV) mandate, it requires manufacturers to achieve a predefined amount of NEV credits per year. Credits are assigned to individual models based on a number of metrics such as electric range and energy efficiency.[363] So far, China is the only country implementing industrial policies that not only favour NEV manufacturers, but that effectively **ban investment** in new ICE manufacturing enterprises that do not respect a number of energy performance related requirements.[364]

In most countries that support electrification in transport, targets and regulation are complemented by **financial incentives**. China's NEV programme includes a subsidy for different vehicle types, which has been constantly reduced as prices decrease and is scheduled to run out by 2022.[365]

Countries like China that are entering the phase of mass EV deployment have been restructuring their incentive programs and planning a reduction in direct subsidies.[366] In addition to China, Belgium, Canada, France, Germany, India and Spain have also started introducing **subsidy caps** based on the vehicle retail price to avoid subsidising the purchase of premium EVs and therefore that of luxury products.[367]

In the US, the state of California continues to offer a number of financial incentives to stimulate the uptake of EVs, including trucks, buses and off-road vehicles,[368] including the ZEV mandate which was already introduced in 1990, and taken up by nine other states.[369] In July 2020, California adopted the world's first mandatory sales requirement for zero emission heavy-duty trucks. The new Advanced Clean Trucks regulation requires manufacturers to sell increasing percentages of zero emission trucks. This complements existing fuel efficiency and GHG emission standards and aims to promote the change to alternative drive technologies. California plans to complement this with further regulation that will require fleet owners to purchase an increasing share of zero emission vehicles.[370]

Canada is also providing purchase incentives and tax write-off benefits to incentivise use in fleets.[371] India implemented the Faster Adoption and Manufacturing of Electric Vehicles in India Phase II (FAME Phase II) scheme, which includes a USD 1.3 billion budget over three years to reduce the purchase price of hybrids and EVs through rebates.[372] Colombia also established various incentives for EVs, including discounts on insurance premiums, exemptions on vehicle traffic restriction measures, and preferential parking.[373]

Several governments also stimulate EV growth through **public procurement** programmes. As part of its economy-wide roadmap to achieve net zero emissions by 2050, Costa Rica committed to public procurement of electric buses and taxis.[375] India's National Electric Mobility Mission Plan calls for replacing the national government's fleet of petrol- and diesel-powered vehicles with EVs.[376] In the United States, the state of Virginia dedicated USD 20 million to fund a new initiative to accelerate the deployment of electric school buses, and New York City committed USD 1.1 billion to purchase and deploy 500 electric buses for public transit.[377] Chile's capital city, Santiago, deployed 200 e-buses in 2019 as part of a plan to cut emissions and reduce air pollution.[378]

Fuel cell vehicle policies are strongest in Asia and often integrated with EV support policies

While deployment of FCEVs is low compared to PHEVs and BEVs, several countries have announced ambitious

targets towards 2030, including the US, China, Japan and the Republic of Korea, amounting to 2.5 million FCEVs.[379]

In 2019, the Republic of Korea announced its Hydrogen Economy Roadmap targeting FCEV passenger car production capacity of 6.2 million and the deployment of 40,000 fuel-cell electric buses, 30,000 fuel-cell electric trucks, and 1,200 hydrogen refuelling stations by 2040.[380] The Netherlands published a Climate Agreement containing a package of measures including targets for hydrogen production (500 MW of installed electrolysis capacity by 2025 and 3-4 GW by 2030) and mobility (15,000 FCEV passenger cars, 3,000 fuel-cell heavy-duty trucks, and 50 hydrogen refuelling stations by 2025, and 30,000 FCEVs by 2030).[381]

Many support policies and incentives for EVs also cover FCEVs to some extent, including the NEV credit policy and subsidies in China and the financial incentives provided in Canada. Incentive schemes for low or zero emission vehicles often provide differentiated support to consumers based on the vehicle technology and technical specifications.[382]

So far, none of the support policies for FCEVs directly link to renewable electricity-based hydrogen, although some countries are putting in place general support programmes for enhancing the share of "green" hydrogen (see Section 5.1).

Charging infrastructure expansion is largely driven by financial incentives

Governments play a key role in providing the charging infrastructure needed for expanding EV deployment, including the development of standards to ensure the interoperability of public charging infrastructure within and across city and even country borders, financial incentives, regulations and permits. Although the charging market is growing rapidly, there is currently a lack of network standards and physical format standards.[383]

The focus of policies has largely been to provide **financial incentives** for the setup of charging infrastructure. Germany introduced a support scheme for charging infrastructure, where publicly accessible slow and fast chargers can receive investment subsidies up to EUR 300 million (USD 336 million). The programme aimed to support the setup of a minimum of 15,000 charging points up to 2020. Currently, around 8,700 supported charging points are operational and another 13,300 have been approved.[384] In 2019, India's FAME Phase II scheme included a target of 2,700 charging stations in cities with more than 4 million inhabitants, as well as fast and ultra-fast charging stations along major highways.[385]

Canada announced funding of nearly CAD 100 million (USD 76.5 million) to deploy new EV charging and hydrogen fuelling stations.[386] The Netherlands committed to installing 2,000 charging points to support electrification of its national government fleet.[387] The US federal alternative fuel infrastructure tax credit supports 30% of the cost up to USD 30,000 and was retroactively extended to the end of 2020, after it had originally expired by the end of 2016.[388] At the sub-national level, the US state of New York provided USD 31.6 million to its regulated utilities to build up to 1,075 fast-charging stations to expand EV use.[389]

Public utility commissions can also develop policy to incentivise EV charging infrastructure by allowing utilities to deploy ratepayer-funded charging infrastructure.[390] For example, the public utility commissions for the US states of Maryland and New York authorised utilities to recover the cost of EV charging infrastructure from electricity ratepayers.[391]

5.3 THE NEXUS OF RENEWABLE ENERGY AND TRANSPORT

Decarbonising the transport sector through renewable fuels and electricity requires policy-makers to put forward integrated policies that incentivise and accommodate higher shares of renewable energy use in transport. These policies should link the use of renewable fuels and electricity with the use of low- or zero-emission vehicles. There are several areas where renewable energy and transport policy can be explicitly linked, namely the use of biofuels in road vehicles, electric mobility, including renewably-powered BEV and FCEV fleets, and opportunities for demand-side flexibility. A few examples of integrated energy and transport planning and policies in these contexts already exist - these are explored in the next sections.

Integrated planning across sectors and jurisdictions can provide opportunities to maximise synergies, but is still rare

Although most renewable energy policies are not integrated or co-ordinated across sectors or governance levels, examples of integration and coordination are emerging. Co-ordinated policy efforts often are organised under national or state-/provincial-level **energy or climate change plans, strategies or programmes**. For example, in 2019, Scotland introduced a comprehensive programme that sets out policies at multiple levels of governance (national and local) to promote renewables across all sectors of the Scottish economy.[392] However, such plans and strategies are not always developed in a cooperative way with stakeholders from all sectors and often exist alongside specific sector strategies, which in practice dominate sector activities. (See also Box 8).

In July 2020, the EU adopted a strategy for energy system integration which builds on the potential for synergies across different energy carriers and end-use sectors, including transport, electricity and buildings, using various existing and emerging technologies, processes and business models such as ICT, digitalisation, smart grids and meters and flexibility markets.[393]

Several countries have adopted **national urban mobility policies** (NUMPs) and, although most do not address renewable energy, some examples exist of NUMPs that act as tools for integrated planning between renewable energy and transport. In 2017, the Philippines implemented the Sustainable Transportation Act which promotes a sustainable transport action plan, integrated spatial and transport planning, the use of alternative fuels, walking and cycling, and public transport.[394] Also in 2017, India's Ministry of Housing and Urban Affairs published its Urban Green Mobility Scheme which aims to promote renewable fuels and electric mobility for public transport as well as walking and cycling while improving road safety.[395]

BOX 8:

CLIMATE POLICY FOR TRANSPORT DECARBONISATION

Climate policy has helped to link the efforts of the energy and transport communities towards the decarbonisation of road transport. Climate policies can directly or indirectly stimulate renewable energy deployment across all end-use sectors, including road transport, by mandating a reduction or elimination of GHG emissions (including net zero commitments), increasing the costs of energy from fossil fuels relative to renewables, and/or banning or phasing out the use of fossil fuels (see Box 9).

Net zero emissions targets have been proliferating around the globe both at the regional, national and sub-national levels.[396] For instance, Costa Rica launched an economy-wide roadmap to achieve net zero emissions by 2050, which includes specifications for policies to increase the use of renewables in transport.[397] At the sub-national level, Amsterdam and Rotterdam (the Netherlands) plan to reach zero-emission[i] urban logistics by 2025.[398] In 2019, the European Commission proposed a European Green Deal to create the first **carbon-neutral** continent by 2050 (with the exception of Poland).[399]

Carbon pricing and **emissions trading schemes** also are increasingly widely implemented policies to mitigate climate change. These measures have the potential to indirectly increase the deployment of renewable electricity and fuels in transport by increasing the relative cost associated with fossil fuels. However, many schemes do not cover all sectors, particularly transport is often excluded, such as for example in the EU Emissions Trading Scheme. By the end of 2019, at least 57 national and subnational governments and the EU had adopted some sort of price on carbon through either direct taxation or a cap-and-trade programme spanning 47 countries but covering only around 20% of global GHG emissions.[400]

Policies promoting the use of biofuels in transport need to address the sustainability of feedstocks and move beyond low biofuel blend shares

In addition to the policies already discussed in 5.1, some countries have also set **targets and plans** specifically for biofuel use in transport. Slovenia aims for 100% of heavy-duty trucks to run on biodiesel by 2030.[401] Finland plans to gradually increase the share of biofuels for road transport to 30% by 2029.[402] In 2018, India adopted a new national biofuel policy to implement its E20 and B5 blend mandates by 2030.[403]

Some jurisdictions promote the use of biofuels in road transport by supporting **associated infrastructure**. For example, in 2019 the US state of Minnesota enacted a grant programme that provides funding for biofuel blending infrastructure.[404]

It is however important that policies supporting the use of biofuels in transport increasingly acknowledge the sustainability of feedstocks, favouring advanced biofuels from non-food crop feedstocks which mitigate land use change concerns and generally offer higher lifecycle GHG emissions reductions than conventional biofuels.[405]

In order to replace higher shares of gasoline or diesel with sustainable biofuels, policy makers also encourage the use of flexible-fuel vehicles and drop-in biofuels. For example, the low carbon fuel standards that have been legislated in California (US) and British Columbia (Canada) have played a key role in drop-in biofuel production.[406]

Only a few targets and policies directly link renewable electricity and EVs

The global community needs a more ambitious, collective vision backed by policy mechanisms that provide concrete incentives for both EV adoption and renewable electricity.[407] However, so far, only few examples directly link targets or policies on EVs and renewable electricity.

As of early 2020, only three cities (Copenhagen, Denmark; Honolulu, Hawaii, US; and Paris, France) had **e-mobility targets directly linked to renewables.**[408]

However, at least 28 cities and 39 countries or states/provinces had **independent targets** both for EVs and renewable power generation, which could result in greater use of renewables for transport, especially when combined with financial incentives or other policy support.[409] However, renewable power generation targets need to be more ambitious to ensure a full decarbonisation of the transport sector through renewable electricity and hydrogen.

The German **subsidy programme** for charging infrastructure requires operators to supply renewable electricity for charging (renewable electricity procurement or self-generation).[410] Similarly, Austria's subsidy programme for the purchase of BEVs and FCEVs is linked to the requirement to source 100% renewable electricity or hydrogen.[411]

As discussed in Sections 5.1 and 5.2, although some policy instruments supporting EVs also cover FCEVs and a growing number of countries are creating strategies to increase the production of green hydrogen, none of such policy measures seem to specifically support the use of renewable hydrogen in FCEVs.

BOX 9:

BANS ON FOSSIL FUELS VS. BANS ON INTERNAL COMBUSTION ENGINES.

Other key instruments of climate policy that can incentivise renewables-based transport are **bans on fossil fuels** in road transport and **bans on internal combustion engines**. It is important to be aware that the two have different implications on the renewable options for transport. While bans on fossil fuels incentivize all forms of renewable energy, a ban on internal combustion engine vehicles encourage EVs and FCEVs, but adversely affect the uptake of biofuels in road transport.

By early 2020, at least 18 countries, states and provinces had committed to banning the sale of fossil fuel vehicles by 2050 or before[i].[412] For instance, the UK plans to bring forward the ban on ICE car sales from 2040 to 2035[413] and California adopted a ban for ICE vehicles by 2035.[414] At the local level, at least 35 major cities worldwide had plans to ban or heavily restrict the use of diesel vehicles, and circulation restrictions for petrol and/or diesel-powered vehicles had already been adopted in several more.[415]

Flexible power tariffs are emerging and further market reforms for grid services are slowly advancing

EVs can provide power system flexibility and resilience to the grid (see Section 3). To enable broad market uptake of such solutions, enabling policy, market and regulatory frameworks are necessary.[416] The key measures that are needed include time-of-use tariffs and eventually dynamic prices for EV charging, enabling value stacking and avoiding double charges, allowing EVs to participate in ancillary service markets, and providing incentives for smart charging infrastructure.[417]

Depending on the setup of the electricity system of a country, utilities can be publicly operated or private entities. However, most countries have clear regulations for utilities in place, and these need to allow for such flexible tariff options. Several utilities, mainly in the United States, have already adopted EV home **charging tariffs**, offering discounts to customers willing to charge when renewable energy is being generated most. In 2019, Southern California Edison (US) introduced a time-based rate that encourages customers to charge on weekdays and during off-peak hours on weekends, when solar power is abundant and then again at night when wind is often more available.[418] Austin Energy (US) has developed a network charging program, called the Plug-in EVerywhere Network that allows customers to source 100% of their electricity from wind. For USD 4.17 per month, customers have unlimited access to more than 800 charging stations within the city of Austin (Texas) network.[419]

Some governments are revising **power market rules** to allow more players such as those associated with renewable distributed energy resources (including EVs) to participate in ancillary services to the grid.[420]

As of 2019, Germany was testing a market-based approach to use distributed energy resources[i] to provide localised flexibility services to relieve network congestion.[421] Singapore fully liberalised its retail electricity market in 2019, enabling distributed energy resources to provide flexibility services.[422] Similarly, in the United States, New York was in the process of reforming state market rules in order to enhance opportunities for distributed energy resources to participate in wholesale markets.[423] Montana enacted a new law allowing electric utilities to implement demand-side management programmes with approval from the public utilities commission.[424] South Carolina also has a new law requiring utility integrated resource plans to include energy efficiency and demand response programmes.[425]

The EU's adoption of the new market design rules as part of the Clean Energy for All Europeans package includes opening European electricity markets not only to renewables and storage, but also to demand response.[426] The Australian Energy Market Commission also released proposals to open the wholesale electricity market to demand response.[427] Incentives for **smart charging infrastructure**, include for example, the United Kingdom, where since 2019 only home charge points that use 'smart' technology are eligible for government funding under the Electric Vehicle Homecharge Scheme.[428]

Double taxation and network charges[ii] can discourage uses that provide system-wide benefits using V2G technology.[429] The need for regulatory reforms to overcome these barriers has been recognised in some jurisdictions, including at the EU level. The EU 2020 Clean Energy Package proposes to remove such burdens.[430]

BOX 10:

INITIATIVES ADDRESSING RENEWABLES IN TRANSPORT

There are several ongoing initiatives and projects as well as other published reports that are relevant for the analysis of the nexus between renewable energy and transport. There are also various organisations that are actively exploring this topic. In this section, we highlight some examples of the above in order to shed light on work that can contribute to and strengthen this discussion.

The **Sustainable Energy for All** (SEforALL) has different activities that explore the link between energy and transport:

- The **Energy and Mobility Working Group** aims at implementing action on low emission mobility, particularly addressing the nexus between transport, energy and climate.[i]
- The **Sustainable Urban Mobility** work under the SEforALL initiative has looked at the energy/mobility nexus in the urban context.[ii]

The **SLOCAT Partnership on Sustainable, Low Carbon Transport** enables collaborative knowledge and action for sustainable, low carbon transport and bringing the voice of the movement into international climate change and sustainability processes.[431]

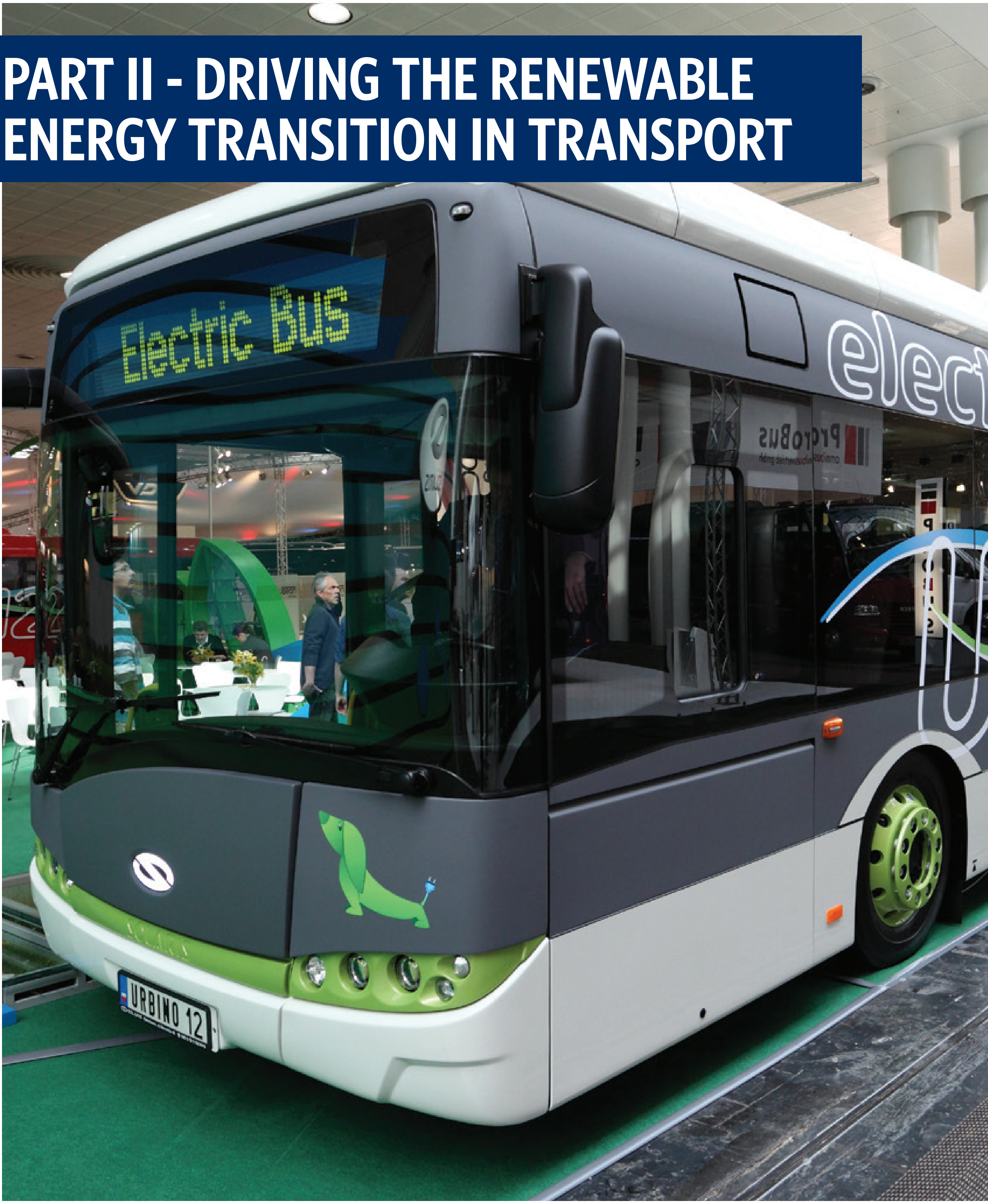
The International Transport Forum (ITF) has established the Decarbonising Transport Initiative which promotes carbon-neutral mobility to help stop climate change. It provides decision makers with tools to select CO_2 mitigation measures that deliver on their climate commitment.[432]

The **Action towards Climate-friendly Transport** initiative is a global coalition aiming to catalyse transport as an enabler of sustainable development in line with the 2030 Agenda and the Paris Agreement. The goals of this initiative are to create a market for zero-emission freight vehicles and foster global dialogue arenas with the private sector.[433]

Created in 2015, the **Paris Process on Mobility and Climate** (PPMC) is an open and inclusive platform for organisations and initiatives that support effective action on transport and climate change. Its main goal is to strengthen the voice of the sustainable transport community in the context of the United Nations Framework Convention on Climate Change and the Paris Agreement.[434]

For a full list of these resources, visit REN21's website: **https://www.ren21.net/**.

PART II - DRIVING THE RENEWABLE ENERGY TRANSITION IN TRANSPORT



6. RENEWABLE ENERGY PATHWAYS FOR TRANSPORT

There are different ways to decarbonise most transport modes, including road transport as discussed in previous sections. Choices to support different technologies for different use cases will have implications not only in the transport sector, but for the overall energy system, as it will impact the demand for different types of fuel from the sector. Several organisations have put forward energy scenarios comprising varying assumptions of renewable energy penetration in the transport sector.

Among the most prominent scenarios are the International Energy Agency's "World Energy Model", with its Sustainable Development Scenario and the International Renewable Energy Agency's "Renewable Energy Roadmaps" (Remap), with its Transforming Energy Scenario. These and the scenarios in the "Achieving the Paris Climate Agreement Goals" report from the Institute for Sustainable Futures at the University of Technology Sydney (ISF-UTS) make projections for the overall energy sector, as does BP's "Energy Outlook" with its Rapid and Net Zero Scenarios, compatible with 2°C and 1.5°C, respectively, and the "Paris Agreement Compatible Scenarios for Energy Infrastructure" (PAC). Further scenarios such as the International Transport Forum's High Ambition Scenario and Shell's 2018 Sky Scenario only model the transport sector. The scenarios analysed throughout this section go beyond perspectives based on existing and announced policies, they entail ambitious yet realistic transformational pathways for the energy and transport sectors that are needed to achieve the Paris Agreement climate goals.

Electrification. All analysed scenarios agree that two-/three-wheelers and light duty vehicles need to electrify as fast as possible. For passenger cars, the IRENA's Transforming Energy Scenario (TES) projects that 379 million electric cars will be on the world's roads by 2030 and 1,109 million by 2050, basically fully electrifying the global stock. In the TES, renewable electricity represents 37% of total energy consumption[i] by 2050 in the sector, with a small share of non-renewable electricity remaining.[435] The IEA incorporates the aims of the EV30@30 Campaign[ii] in its Sustainable Development Scenario (SDS)[iii] and envisions 80 million electric vehicles in 2025 and 245 million electric vehicles in 2030, well below the assumptions in IRENA's TES.[436] Additionally, the SDS projects that the global electric two-/three-wheeler stock reaches nearly 490 million (almost 50% of the stock) and sales reach 55 million units (80% sales share) by 2030.[437] The ISF-UTS scenarios project that in innovative regions, electric passenger cars would reach a share of up to 80% for BEV by 2050 under a 2°C compatible pathway.[438] Shell's Sky Scenario projects that by 2035, 100% of new car sales in the EU, US and China are electric.[439] The PAC Scenario even projects that all energy demand for passenger vehicles by 2050 will be electric.[440] This general agreement was further confirmed by a recent T4<2° Foresight Study based on a survey of 85 experts from the sector.[441] For other vehicles types, the technology choices are not quite so clear, although the abovementioned scenarios also project increased electrification for buses and to a lesser extent trucks.

Biofuels. Both the SDS and the TES envisage steep increases in biofuel use in the transport sector, mainly driven by the increasing amount of freight across the globe. In its TES, IRENA projects biofuel demand grow to 370 billion litres per year by 2030 and 650 billion litres per year by 2050 across all modes, with a focus on use in aviation and shipping, representing around 20% of total energy consumption by 2050.[442] The IEA's SDS forecasts an increase of biofuel production of 25% between 2019 and 2024, although most of that from conventional biogasoline, biodiesel and HVO. It sees advanced biofuels doubling production in that time frame, but remaining small due to the low starting point.[443] By 2040, the scenario projects a share of 14% for biofuels, with two thirds of this being used in road transport.[444]

Renewable electricity-based synthetic fuels. The analysed scenarios all project growing production and use of synthetic fuels in the transport sector. With growing production capacity, they increase the share of biofuels used, but also replace first generation biofuels. The largest part of this growth will, however, be in aviation and shipping, owing to the challenges of decarbonising these sub-sectors (see Sidebar 2).

Within road transport, the focus for the use of synthetic fuels is on heavy-duty trucks, but also play a large role in passenger transport in some regions, such as Latin America.[445]

Renewable electricity-based hydrogen. "Green" hydrogen does not yet feature prominently in any of the low-carbon scenarios for the road transport sector. While IRENA's TES includes a reduction of 1.7 Gt CO_2 per year from green hydrogen by 2050, around 80% of this is likely to be deployed in other sectors, mostly in industry.[446] In the ISF-UTS scenarios, FCEV play a larger role in some regions, especially in OECD Pacific and North America, with a share of 17% of passenger cars and light duty vehicles.

Fossil fuels. In many scenarios non-renewable fuels still play a significant role. IRENA's TES projects 44% of total energy consumption to come from non-renewable sources by 2050, the IEA's SDS 77% by 2040.[447] BP's Rapid Scenario projects a 40% share of oil by 2050 and the Net Zero Scenario still a 20% share of oil in total final consumption.[448] In Shell's Sky scenario oil and gas still account for just under a quarter of primary energy used,[449] while other scenarios, such as the 2°C and 1.5°C compatible pathways of the ISF-UTS, do not contain any oil or gas use by 2050.[450]

Table 6.1 provides an overview of the technology options that emerge as the preferred options in the

TABLE 6.1: COMMONALITIES AND DIFFERENCES IN TECHNOLOGY TRENDS IN DECARBONISATION SCENARIOS BY VEHICLE TYPE

VEHICLE TYPES	COMMONALITIES	DIFFERENCES
TWO- AND THREE-WHEELERS	Full electrification is the preferred option. Uptake mostly limited by cost considerations and turnover rates	Speed of uptake
PASSENGER CARS	Full electrification is the preferred option. Uptake mostly limited by cost considerations and turnover rates, in some cases with exceptions, for example fleets (e.g. taxis or shared mobility services)	Speed of uptake, uptake of FCEV
URBAN BUSES	Mostly electrification, but with some advanced biofuels/biogas and hydrogen applications depending on context	Shares of different solutions
URBAN DELIVERY TRUCKS	Mostly electrification, but with some advanced biofuels/biogas and hydrogen applications depending on context	Shares of different solutions
LONG-DISTANCE BUSES	No clear technology preference. Possibly plug-in hybrid vehicles in combination with advanced biofuels to allow switch to electric in urban areas. Hydrogen also discussed as option.	Shares of different solutions
MEDIUM- AND HEAVY DUTY TRUCKS	No clear technology preference. Advanced biofuels and hydrogen discussed as likely options. On-road charging as option for electrification.	Shares of different solutions
SPECIAL PURPOSE VEHICLES (E.G. AGRICULTURAL VEHICLES)	No clear technology preference. Advanced biofuels and hydrogen discussed as likely options.	Shares of different solutions

Sources: based on IRENA; ITF; IEA; Hydrogen Council; Teske et al.; Shell.[451]

assessed decarbonisation pathways. Although a clear pattern can be seen for most vehicle categories, there are differences in speed of penetration within different models. The pathways are designed at the global level, so there may be country or context specific differences.

Despite any differences in modelling approach and assumptions, different scenario exercises come to the joint conclusion that an energy transition – the transport sector as a significant energy end-use sector – is technically and economically feasible.[452] It will require deep political, economic and social changes and we are yet far from embarking on such a pathway.

7. KEY CHALLENGES HOLDING BACK RENEWABLE ENERGY IN TRANSPORT

We need to drastically speed up the uptake of renewable energy solutions in the transport sector to enable a full decarbonisation of the sector by mid-century. This will need to be supported by measures to reduce transport demand, shift to more efficient modes of transport and improve vehicle efficiency.

For road transport, this means that the majority of passenger cars, light-duty trucks and two- and three-wheelers will need to directly run on renewable electricity, with the rest running on high blends of advanced biofuels or renewable electricity-based synthetic fuels. For fleets, buses and heavy-duty trucks a mix of direct use of renewable electricity, renewable hydrogen and advanced biofuels is needed, depending on the individual use cases and local context.

We still see very few policies that directly link transport measures with renewable energy, which can be done, for example, through requirements for 100% renewable energy sourcing in incentive schemes. Far more important, however, is the absence of a vision for full decarbonisation of the entire economy in line with the Paris Agreement, although some jurisdictions, such as the EU, are slowly taking steps to developing such a vision. Visions alone will not motivate the markets, but should be the basis for clear and binding targets (see Section 8).

The transport sector is mostly still focusing on incremental efficiency improvements through fuel economy and GHG emission standards, and for many practitioners on the ground air pollution, safety and access to mobility still require urgent attention. Advanced biofuels, renewable electricity-based synthetic fuels and hydrogen need to bring down cost and create a stable demand.

While governments have many options at their disposal to steer markets, it is difficult for many countries, especially smaller ones, to support new passenger vehicle technologies without jeopardising mobility. Only a few manufacturers dominate the car market and decisions on technology are mainly made in the headquarters, which are mostly influenced by a few large markets. In many developing countries, the majority of vehicles are imported secondhand, so their leverage to steer markets can seem more limited.

One of the key challenges[i] to rapidly increasing renewable energy use in transport is that it requires a complex energy system that is tailored to the specific use case and local circumstances. There are differences depending on the development level of a country or region, whether we are looking at urban or rural settings, passenger transport or freight. This complexity makes it difficult to generalise other challenges, as they are very context specific and no 'one-size-fits-all' solution exists. However, some common themes can be identified (see Table 7.1).

There are also still very different views on whether we need to make clear technology choices now or whether this should be left to the market. Some argue that the fact that too many options are still on the table, leads to a situation where individual actors are unclear about the strategy of other actors, hampering the initiative for action. Most disputed is the role of hydrogen in passenger vehicles, especially as pursuing this technology means higher investment in charging/refuelling infrastructure if both BEV and FCEV options are deployed. Other concerns relate to the production of hydrogen and the challenge in converting to 100% renewables-based hydrogen production. Technology and market-related challenges are more specific to individual renewable energy solutions for the transport sector (see Table 7.2). However, also here, there are differences depending on local context.

TABLE 7.1: KEY OVERARCHING CHALLENGES

AREA	CHALLENGE
POLITICAL	**Political will:** There is a lack of clear policy signals, for example through ambitious GHG reduction or renewables targets for the economy and individual sectors and comprehensive policy packages that support renewable transport solutions, to create a stable investment environment.
	Stability: Investments required are in most cases huge and have long recuperation times. Policy frameworks need to provide sufficient long-term perspective and security to incentivise investment.
	Inconsistent and fragmented policy landscape: Many policies are in place at various levels of governance, but these are rarely coordinated and, in some cases, contradictory.
	Informality of transport systems: In many developing countries a large share of transport services is delivered by the informal sector, making it challenging to design appropriate incentives for renewable energy uptake.
	Distribution of decision-making power: Not all governments are equally able to influence decision-making of vehicle and component manufacturers. Many countries have no own vehicle production, or only for some types of vehicles, such as motorcycles. Even countries with production capacity, headquarters are often situated in other countries, and policies have limited influence on decisions there.
	Change in power dynamics: System changes are challenging existing power structures, as we can already see, for example, with new emerging players in the automotive sector. Incumbents are likely to oppose changes.
GOVERNANCE	**Lack of collaboration between different actors:** Energy and transport sectors are very much working in 'silos'. At the same time there is a lack of integration across different levels of governance (local, sub-national, national, international) and often an imbalance between actors in the energy and transport field, where in most countries energy decisions are very much centralised at the national level, while transport planning is often largely under the responsibility of local governments.
	Cultural and social dimension of the transition is missing: Discussions are focussing largely on technical solutions and less on understanding the changes to society that will result. R&D is largely focussing on technical solutions, but better understanding the social and cultural dynamics of renewable energy solutions and how to better inform and educate the wider population is equally important.
	Inertia: Policy-makers, manufacturers, utilities, grid operators and customers are slow in taking up new ideas and paradigms. Changes have been incremental and are typically a continuation of business as usual.
INFORMATION AND CAPACITY	**Lack of narrative:** Information on the available options for renewables in transport and the implications of deployment is too fragmented and sometimes contradictory. There is also limited information related to the benefits of linking renewable energy and transport. Policy-makers and decision-makers in the private sector need to have a better basis for decisions.
	The broader population needs to be better informed, as they will need to change behaviour and consumer decisions as well as provide a key to motivate change in policy and vehicle markets.
	Lack of technical capacity and skills. Renewable energy solutions in transport require a new set of skills and technical know-how. Electrical engineering and related skills are becoming more important and completely new fields, such as hydrogen fuel cell technology are emerging. This needs to factor in university and vocational training curricula, but also the existing workforce needs to be retrained.
	Complexity and transparency of energy and transport systems: Existing systems are already complex and in many cases not very transparent, for example in energy pricing. This can enhance the reluctance of involved actors (see Figure 2.2) to make changes and the likelihood that measures have unintended effects or are ineffective.

TABLE 7.2: KEY TECHNOLOGY AND MARKET-RELATED CHALLENGES

Technology and market-related challenges are more specific to individual renewable energy solutions for the transport sector. However, also here, there are differences depending on local context.

	ADVANCED BIOFUELS	RE-BASED SYNTHETIC FUELS	RE-BASED HYDROGEN	RENEWABLE ELECTRICITY
TECHNOLOGY	Efficiency of production process			Cost and diversity of EV vehicles
				EV range (actual and perceived, depending on application)
	Not yet fully commercial technologies			Grid integration for VRE
MARKET	Persistent subsidies for fossil fuel alternatives			
	High up-front investment cost for production and/or distribution infrastructure and long recuperation times for investment			High up-front investment cost for EV charging infrastructure
	The transport sector depends on the energy sector to supply renewable energy fuels and electricity			
	Larger scale availability will require substantial additional investment in production capacity			
	Not yet cost competitive			
	Agreed methodologies for assessing lifecycle GHG		Investment in charging/refuelling infrastructure	
	Availability of sustainable feedstocks	Availability of renewable electricity capacity	Safety concerns	

8. GUIDELINES FOR ACTION

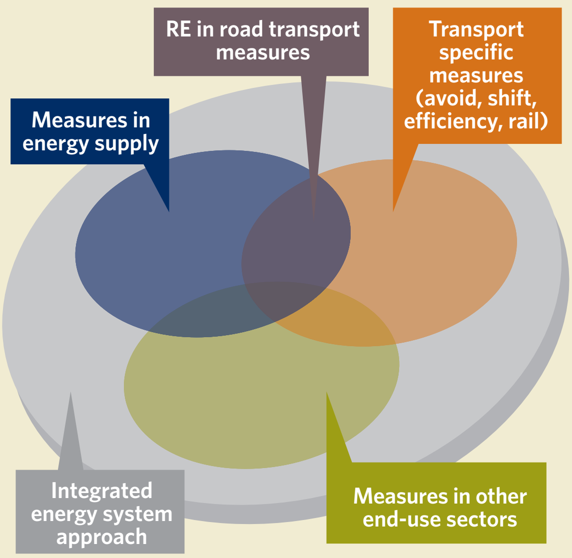
The future transport system will be much more complex, with multiple players, technologies and direct linkages to the power system. Experts will need to make it easy for decision-makers and customers to manage this complexity. The road transport sector will depend on the rapid decarbonisation of the electricity sector, for direct use of electricity and for the production of green hydrogen, supplemented by the supply of advanced biofuels, particularly for use in heavy-duty trucks.

Transport solutions need to be tailored to the specific context and use case, and will likely cascade from early adopters to global coverage, possible changing focus over time. For example, production capacity for advanced biofuels could be developed in early stages for the light-duty passenger vehicle market in more ambitious jurisdictions, such as California (US) and Europe, and could then find new markets in other countries, for trucks, and eventually in aviation and shipping. To achieve this, the actors identified in Figure 2.2 need to improve collaboration to develop economically and financially viable solutions that appeal to end users.

It is clear that renewable energy solutions for the road transport sector need to be embedded in a wider framework of actions that also reduce the demand for transport services, shift the choice of transport modes and increase the efficiency of vehicles (ASI framework). Decarbonising the sector with renewables will only be possible with ambitious policies that address all these aspects and that take an integrated look at the implications for the wider energy system. This needs to go hand-in-hand with energy policies that enable the rapid expansion of renewable energy generation and the development of business cases that illustrate the benefits of embarking on renewable energy and their related powertrains. Figure 8.1 illustrates how renewable energy in road transport needs to be embedded in a wider integrated energy system approach that will be able to deliver the Paris Agreement objectives.

Given the difference in starting point and challenges, policies and measures will necessarily vary between countries and for urban and non-urban settings. This report is therefore not recommending specific policy instruments to support the uptake of renewable energy in the road transport sector, but aims to provide a high-level guidance regarding what needs to happen to achieve this and what the wider community can do to support governments in this effort.

FIGURE 8.1: THE ROLE OF RENEWABLE ENERGY IN ROAD TRANSPORT IN THE OVERALL ENERGY SYSTEM APPROACH



Source: own illustration

1 DEFINE A NATIONAL LONG-TERM ROADMAP FOR ENERGY AND TRANSPORT SYSTEM DECARBONISATION

- **Set long-term legally binding decarbonisation targets with a clear deadline and intermediate targets.** GHG emission targets need to be set:

  - Economy-wide
  - Transport sector wide
  - Energy sector wide
  - For individual transport sub-sectors

  Long-term decarbonisation targets need to be complemented by equally binding intermediate targets and a clear vision regarding the renewable energy pathways to get there. Energy and transport sector targets need to be aligned and are ideally the result of integrated planning. This will spur innovation and provide the needed certainty for the private sector to make the necessary long-term investments, both on the transport side (vehicles and infrastructure) and concerning the production/generation capacity of renewable fuels and electricity. It will also support needed action to reduce energy demand in transport through measures to avoid and shift transport activity and enhance vehicle efficiency. Assigning clear responsibilities for target achievement is paramount to spur rapid action and communicate the sincerity of the long-term commitment as well as to ensure accountability in case targets are not reached on time.

- **Be clear on technology choices.** In designing policy instruments, decision-makers need to make a conscious decision in terms of whether they favour specific vehicle technologies and thus specific renewable fuels – in general or for individual use cases – or if they prefer to leave this up to the market. The most prominent example where this is the case is whether to favour BEVs over FCEVs for passenger transport or not. There are arguments for both scenarios and they strongly depend on individual circumstances, including social, economic, geographical and/or political factors. Making an informed and conscious choice will enable more transparency and better communication with the industry, the public and the rest of the actors involved, and likely improve the detailed design of policy instruments, making them more effective in delivering the existing targets. The decision also impacts renewable electricity generation needs to ensure that the used fuels (electricity and/or hydrogen) are produced from renewable sources and provides clarity to energy suppliers.

- **Ensure a life-cycle approach.** The transport sector needs to be accountable for up- and downstream emissions. Regulations need to cover sustainability impacts of vehicle production and disposal as well fuel production and distribution. A ‘well-to-cradle’ approach should be adopted as battery electric vehicles, hydrogen vehicles and biofuels gain market shares, extending beyond vehicle operation to vehicle production and recycling/disposal. Agreed accounting frameworks for different effects and fuels would facilitate a more accurate comparison between different low-carbon vehicle choices and renewable fuel options, allowing one to identify the most suitable solutions for specific contexts.

2 ENHANCE COLLABORATION BETWEEN THE ENERGY AND TRANSPORT SECTORS AND ENSURE MULTI-LEVEL GOVERNANCE FOR THE IMPLEMENTATION OF RENEWABLE ENERGY SOLUTIONS

- **Create space for collaboration across sectors.**
  Energy and transport actors at all levels need institutionalised and permanent platforms to exchange and discuss tailored low—carbon vehicle choices and renewable energy solutions for their local context. Collaboration needs to be improved across the energy and transport sectors, for example through inter-ministerial climate or sustainability councils. Collaboration also needs to ensure non-state actors, including the financial sector, academia, unions, environmental groups and civil society are involved in developing joint solutions. Governments can support this through the creation of dedicated cross-sectoral positions and departments that manage and support these collaborative processes.

- **Ensure collaboration, coherence and consistency between decisions and policies made at different levels of government.**
  Renewable energy solutions for road transport should build on the available local resources and be fit for the local circumstances and needs. The underlying decisions need to be relatively consistent over time while also allowing for some flexibility to adapt to changing circumstances (such as local needs and technological innovation), and should tie in with national policies and decisions. National regulation and policies need to enable local actors to implement renewable energy solutions in their local transport systems.

3 TAILOR POLICY INSTRUMENTS TO EFFECTIVELY IMPLEMENT THE ENERGY-TRANSPORT ROADMAP

- **Ensure the consistency of policy instruments.**
  There are already many instruments in place that promote renewable energy or the uptake of low-carbon transport technologies, but they are often not well coordinated and might be inconsistent – within each sector and across the sectors. Other instruments that are not directed at renewable energy or low-carbon transport technologies sometimes provide counteracting incentives, such as fossil fuel subsidies. Such instruments should be removed to make supporting measures more effective. Developing an integrated energy system strategy that encompasses needed developments for reduced energy demand and increasing renewable energy use in all end-use sectors is a good first step in developing a coherent policy framework.

- **Implement tailored support for renewable energy solutions identified in the roadmap.**
  All renewable energy solutions require dedicated support to enable the speed of deployment required for the decarbonisation of the transport sector and the overall energy system. Depending on the choices made for a specific context (see recommendation 2 above), policy instruments need to address the specific barriers to enhanced deployment and support the full supply chain of renewable fuels and corresponding vehicles.

- **Provide frameworks to capture synergies between the renewable energy and transport sectors,** starting with the 'low-hanging fruit' which is electric mobility. With growing electrification of the vehicle fleet, grid integration of EVs is one of the key areas where challenges and synergies across sectors need to be addressed. Ensuring standardisation and interoperability[i] are key elements for wide uptake and economies of scale. Any tools associated with new business models based on the grid services that EVs can provide need to be easy and somewhat beneficial for the customer to use or uptake will remain low. Also important are digital policy frameworks that clarify data ownership and data security for example for the operation of smart charging solutions.

4 IMPROVE CROSS-SECTORAL KNOWLEDGE, DIALOGUE AND AWARENESS BETWEEN THE RENEWABLE ENERGY AND TRANSPORT COMMUNITIES

- **Develop a better narrative.**
  The renewable energy sector has been successful in conveying the benefits of renewable energy in general across sectors and technologies, stressing the creation of local jobs, improving energy security and providing access to modern energy services. The transport sector has not yet managed to provide such a positive narrative, and much of the discussion is focusing on increasing cost, loss of jobs and convenience, whereas the opposite could actually be the case. The link to renewable energy is almost completely absent from the broader discussion. Narratives need to better reflect the mobility needs of citizens and businesses. They can showcase how renewable energy solutions, together with other ASI measures, can deliver convenient, reliable and economically feasible mobility. Here the renewable energy and transport communities can play a crucial role, especially if they work together. Once a better narrative is developed, this needs to be widely promoted. Modern social media should be used extensively, but also classical avenues and existing training fora, such as UN Habitat or the International Transport Forum.

- **Ramp up formal training for new skillsets.**
  Enhanced formal training in those areas where skills will be increasingly needed in the future is required. Electrical engineering, for example, is needed for new electric-powered vehicles (BEVs and FCEVs) as well as for enhancing renewable electricity generation and grid integration. Training programmes at universities and vocational trainings need to be updated to account for the linkages across sectors to better educate new generations of policy-makers, engineers, transport/energy/urban planners, economists, business owners, entrepreneurs, and other future decision makers.

5 DEVELOP TOOLS FOR ASSESSING CONTEXT-SPECIFIC CHALLENGES AND SOLUTIONS

- While many challenges for enhancing the uptake of renewables in road transport are relatively universal, the details vary – and so do the solutions. A toolset is needed to conduct context-specific diagnosis of the barriers and solutions for specific renewable fuels/electricity and low-carbon vehicles to support policy-makers in designing more adequate and effective regulatory and policy frameworks.

  This toolset could comprise:

  (i) a benchmarking framework to help objectively compare technological options and their implications for the energy and transport systems. Indicators should be linked to the Sustainable Development Goals framework and corresponding benchmarks could include e.g. the cost per PKM/TKM, jobs created/jobs lost, GHG emission savings per PKM/TKM, for each of the technology options; and

  (ii) decision-trees for defining how transport decarbonisation pathways and renewable energy options could translate into concrete policies depending on existing preconditions.

ANNEX I - COMPARISON OF SUSTAINABILITY CONCEPTS

The table below summarises the dimensions of sustainability and their meaning in the context of transport and renewable energy. Different modes of transport, vehicle technologies, and types of renewable energy will have different sustainability issues. The table provides an overview of what to look at when assessing the sustainability for different options.

	MEANING FOR		
	TRANSPORT[453]	BIOENERGY[454]	OTHER RENEWABLE ENERGY
ACCESS	Mobility for all, considering the needs of different groups	Access to modern energy	Same as bioenergy
SAFETY	Reduction of fatalities, injuries & crashes across all modes of transport	Mortality & disease from indoor smoke, Occupational illness, injury & fatalities from production and distribution	Occupational illness, injury & fatalities from production and distribution
EFFICIENCY	Transport systems are predictable, reliable, timely and cost-effective	Energy ratio compared to other energy sources Productivity & cost of feedstocks	Cost effectiveness per unit of energy of different technologies
(AIR) POLLUTION[455]	Air pollutants from local transport	Air pollutants from feedstock production, processing, distribution and use vs air pollution from fossil fuel use	Environmental pollution from battery production and discarding vs air pollution from fossil fuel use
GHG EMISSIONS	Different approaches: Well-to-wheel, tank-to-wheel, well-to-cradle	Different approaches: Accounting of LUC Inclusion of ILUC	Different approaches: Lifecycle vs operational Choice of reference energy for comparison
LAND USE	Mostly discussed in the urban context: alternative use of available public space	Competition with food production & other uses of feedstocks	Especially for PV/CSP and hydro: Competition with other uses of land
NOISE POLLUTION	Transport-related noise levels	No issue	Sometimes an issue with wind farms
WATER	No issue	Water use & quality	Mostly relevant for hydro, possibly CSP

ANNEX II - OVERVIEW OF BIOENERGY CLASSIFICATIONS

CLASSIFICATION COMMONLY USED		FEEDSTOCKS	MAIN SUSTAINABILITY ISSUES
1ST GENERATION	Conventional	Food and animal feed crops (e.g. wheat, corn, sugar cane, palm, soybean)	Direct competition with food production, with possible effects on availability and price
2ND GENERATION	Advanced*	Energy crops on regular farmland (e.g. Miscanthus, switchgrass, short rotation coppice and other lignocellulosic plants)	Displacement of food and feed production to other land, leading to indirect land use change emissions and other negative environmental effects
		Wastes & residues with alternative uses (e.g. manure use for fertilisation, tall oil as chemical feedstock)	Replacement of feedstock with other materials, also leading to potential indirect land use change or production emissions for alternative input materials
	Advanced	Wastes & residues without alternative uses	The sustainability is highly dependent on local factors, but can also include positive effects from reduced methane emissions, for example from waste disposal or manure storage[456]
		Energy crops on marginal land[i] (e.g. Jatropha)	
3RD GENERATION		Algae	High demand for water High demand for nitrogen and phosphorous, leading to potential emissions from fertiliser production

Source: Royal Academy of Engineering.[457]

ANNEX III - OVERVIEW OF RENEWABLE ENERGY PRODUCTION PROCESSES FOR TRANSPORT

PROCESS	PRODUCT	MATURITY	MAIN COST DRIVERS	COMMERCIALLY USEFUL BY-PRODUCTS
1 GASEOUS AND LIQUID BIOFUELS				
Aerobic digestion & upgrading (C)	Biomethane	Commercial	Feedstock Distribution (esp. grid injection)	Digestate (used for fertilisers)
Fermentation (C)	Bioethanol	Commercial	Feedstock	Distillers' dried grains (high protein animal feed)
Gasification & fermentation (A)	Bioethanol	Early commercial, but demonstration for transport fuels	Pre-treatment and upgrading	Chemical products
Cellulosic ethanol conversion (A)	Bioethanol	Early commercial	Pre-treatment Enzymes and other chemicals	Heat Nanocellulose (one facility)
Hydrothermal liquefaction (A)	Bio-crude	Demonstration	Alloy materials to prevent corrosion (CAPEX)	Char Off-gases
Pyrolysis (A)	Bio-oil	Early commercial for on-site combustion, but demonstration for transport fuels	Heating feedstock to needed temperature	Char Off-gases Water
Hydro-processing and other upgrading (A)	Drop-in fuels (biogasoline, biodiesel, bio-jet kerosine)	Commercial (using fats and oils)	Feedstock	Glycerine (some processes)

PROCESS	PRODUCT	MATURITY	MAIN COST DRIVERS	COMMERCIALLY USEFUL BY-PRODUCTS
2 GASEOUS AND LIQUID RENEWABLES-BASED SYNTHETIC FUELS				
Methanol synthesis (A)	Biomethanol	Demonstration		Requires CO2 (potential use for carbon capture)
Methanation (A)	Biomethane	Demonstration		Requires CO2 (potential use for carbon capture)
FT synthesis (A)	Drop-in fuels (mostly further upgrading required)	Commercial, but demonstration for transport fuels		Wax, Tail gas Other hydrocarbons (can be further refined to drop-in fuels)
3 RENEWABLE ELECTRICITY BASED HYDROGEN				
Electrolysis (A)	Hydrogen	Demonstration in combination with PtX production (commercial for other uses)	Electricity cost (depending on region)	Oxygen Heat (some processes)
Bioprocesses	Hydrogen			
4 DIRECT USE OF RENEWABLE ELECTRICITY				
Solar PV	Electricity	Commercial	CAPEX	
Solar CSP		Commercial	CAPEX	Grid services (if with storage)
On-shore wind		Commercial	CAPEX	
Off-shore wind		Commercial	Grid connection	
Geothermal		Commercial	CAPEX	Heat Grid services
Bioenergy-based		Commercial	Feedstock	Heat Grid services
Ocean energy		Demonstration	CAPEX, grid connection	

ACRONYMS

BEVs	Battery electric vehicles
CAPEX	Capital expenditure
CNG	Compressed natural gas
CO_2	Carbon dioxide
CSP	Concentrated solar thermal power
DSO	Distribution system operator
EU	European Union
EUR	Euro
EV	Electric vehicle
FAME	Fatty acid methyl ester
FCEV	Fuel cell electric vehicle
GHG	Greenhouse gas emissions
GW	Gigawatt
HDV	Heavy-duty vehicle
HEFA	Hydrotreated esters and fatty acids
HEV	Hybrid electric vehicle
HVO	Hydrotreated vegetable oil
ICE	Internal combustion engine
IEA	International Energy Agency
ILUC	Indirect land-use change
IRENA	International Renewable Energy Agency
LDV	Light-duty vehicle
LEZs	Low-emission vehicle zones
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MDV	Medium-duty vehicle
MW	Megawatt
NEV	New electric vehicle
NGV	Natural gas vehicle
NUMP	National urban mobility policy
OECD	Organisation for Economic Cooperation and Development
PHEV	Plug-in hybrid electric vehicle
PKM	Passenger-kilometres
PPA	Power purchase agreement
PtG	Power-to-gas
PtL	Power-to-liquid
PtX	Power-to-X
PV	photovoltaics
R&D	Research and development
RED	EU Renewable Energy Directive
RFS	US Renewable Fuel Standard
RPS	Renewable portfolio standard
SDS	Sustainable Development Scenario
SOEC	Solid oxide electrolysis cells
SUV	Sport utility vehicle
TES	Transforming Energy Scenario
TKM	Tonne-kilometres
TSO	Transmission system operator
UK	United Kingdom
US	United States of America
USD	United States dollar
V1G	Unidirectional controlled charging
V2G	Vehicle-to-grid
V2H/B	Vehicle-to-home/building
VRE	Variable renewable energy
ZEV	Zero emission vehicle

GLOSSARY

See REN21's Glossary, available online: **https://www.ren21.net/gsr-2020/pages/glossary/glossary/.**

OTHER NOTES

All exchange rates in this report are as of 31 December 2019 and are calculated using the OANDA currency converter **(http://www.oanda.com/currency/converter).**

FIGURES

TABLES

BOXES

SIDEBARS

FOOTNOTES

Page 10 i This report only looks at options for renewables for mobility. Mobile cooling for air conditioning and refrigeration require different technologies and policy interventions and are not part of this analysis.

11 i Vehicles in the context of this report generally mean all motorised forms of road transport, from motorcycles to heavy-duty trucks. Where only specific segments of vehicles are discussed, these are identified, for example 'passenger vehicles' or the specific vehicle types are used, such as 'buses' or 'trucks'.
ii Many renewable power technologies have become cost-competitive in a lot of countries and contexts over the last decade. For details see IRENA,
iii Renewable Power Generation Costs in 2019.
iv Especially when considering all of the negative externalities of fossil fuels and costs associated with climate change.
Electro-fuels, also known as e-fuels, are synthetic fuels that do not chemically differ from conventional fuels such as diesel or petrol, generated in procedures known as power-to-liquids (PtL) and power-to-gas (PtG). Renewable electro-fuels are generated exclusively from electricity from renewable sources.

16 i Regulations, such as defining GHG emission savings thresholds, are required to ensure that energy crops – also those grown on marginal lands - do not compete with food production.

20 i Also referred to as electro-fuels. They can be gaseous (methane) or liquid (ammonia, methanol and other hydrocarbons).
ii Power-to-X also includes power-to-heat applications, which are not considered in this report.
iii While the immediate consideration for fuel producers will likely be the cost competitiveness of the fuel, the overall competitiveness of the system, including vehicle and maintenance cost, will strongly impact the demand for each fuel alternative.

22 i Also referred to as 'grey' hydrogen, or, if combined with carbon capture and storage as 'blue' hydrogen.
ii The term 'biogas' is used here to group all gaseous forms of bioenergy, including gaseous forms of synthetic fuels. In a strictly technical sense, biogas is a mixture of methane, CO2 and small amounts of other gases produced in a first step in various production processes. For details see Danish Energy Agency and Energinet, Technology Data – Renewable fuels (https://ens.dk/sites/ens.dk/files/Analyser/technology_data_for_renewable_fuels.pdf, 2019); IEA, World Energy Outlook special report: Outlook for Biogas and Biomethane. Prospects for Organic Growth (Paris: March 2020), https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth.
iii Properties that limit the amount of biofuels that can be blended with fossil fuels without damaging the engines and fuel systems of vehicles. These include oxygen content, hydrophilicity and energy density.
iv Use of pure biogasoline and biodiesel requires engine modifications or dedicated engines, such as flexible-fuel vehicles which are largely used in Brazil. Unless modified engines are used, these biofuels can only be used in relatively low blends: ethanol maximum 15% and biodiesel 20%. See for example IEA Biofuels, The Potential and Challenges of Drop-in Biofuels (Paris: July 2014), http://task39.sites.olt.ubc.ca/files/2014/01/Task-39-Drop-in-Biofuels-Report-FINAL-2-Oct-2014-ecopy.pdf, 2014); IEA Bioenergy, "DROP-IN" BIOFUELS: The Key Role That Co-Processing Will Play in Its Production (Paris: January 2019), https://www.ieabioenergy.com/wp-content/uploads/2019/09/Task-39-Drop-in-Biofuels-Full-Report-January-2019.pdf.

25 i Some of the first vehicles produced in the early 1900s were hybrid vehicles. They were soon replaced by full gasoline vehicles due to their higher cost and lower power output. See "A Brief History of Hybrid Cars," CarsDirect, https://www.carsdirect.com/green-cars/a-brief-history-of-hybrid-cars, viewed 26 May 2020; Christopher Lampton, "What is the history of hybrid cars?," HowStuffWorks, https://auto.howstuffworks.com/fuel-efficiency/hybrid-technology/history-of-hybrid-cars1.htm, updated 9 April 2009, viewed 26 May 2020.
ii Also called battery electric vehicles (BEVs) to differentiate from PHEVs and HEVs vehicles.

27 i Some smaller, local manufacturers may be more flexible.
ii Just-in-time means that manufacturers hold very limited stock of components, which are delivered directly from parts manufacturers 'in-time' for production. This requires close integration with suppliers. Any changes in the production process and supply chain therefore require careful planning.

28 i Through fully electrical or fuel cell vehicles, respectively.
ii Including the decision of whether to purchase a vehicle in the first place. Attractive alternatives, including public transport and new mobility services, can influence this decision to some degree (see Section 2.2).

32 i Peak demand refers to the average capacity required to meet demand for the 1% of the hours with highest electricity demand throughout the year. Energy systems typically require 15-25% of generation capacity beyond those required for 90% of the hours of lowest demand. See IEA, Global EV Outlook 2020.
ii Depending on the composition of power generation capacity, vehicle batteries can also absorb overproduction at night.

Page 33 i Such systems work best in areas with individual housing where the vehicles remain connected during non-use times and charge using low voltage.

36 i Discussed in Box 2.

37 i Neste is currently developing advanced technology for pre-treatment for HVO production to increase feedstock availability. This could address current challenges in feedstock availability and drive production growth in the future.

ii For the distinction between biogas and biomethane see footnote iii on page 22.

40 i Denmark, Uruguay, Ireland, Germany, Portugal, Spain, Greece and the United Kingdom.

42 i Although there are countries with substantial shares of diesel cars, particularly for fleet operations, and countries with high shares of other fuels, such as biofuels in Brazil.

ii Including BEV and PHEV.

iii Range demand varies according to region, with Europe and North America favouring higher ranges.

48 i Canada, Chile, China, Finland, France, Germany, India, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Sweden and the United Kingdom.

ii This includes for example ChargePoint, Energias de Portugal, Enel X, E.ON, Fortum, Iberdrola, Renault-Nissan-Mitsubishi Alliance, Schneider Electric, The Tokyo Electric Power Company Inc and Vattenfall.

51 i Bulgaria, Croatia, France, Italy, Luxembourg, the Netherlands, the Slovak Republic and the United States.

ii The US RFS was established in 2005 and amended and extended in 2007 to include other types of biofuel, along with additional changes. The revised program began in 2010 and is ongoing.

53 i In EU regulation, a zero or low emission vehicle is defined as a passenger car or van with CO2 emissions between 0 and 50 g/km.

56 i For a full discussion of these adjustments and their effects see: ICCT, "Practical lessons in vehicle efficiency policy: The 10-year evolution of France's CO2-based bonus-malus (feebate) system", https://theicct.org/blog/staff/practical-lessons-vehicle-efficiency-policy-10-year-evolution-frances-co2-based-bonus, updated 12 March 2018, viewed 12 October 2020.

57 i All 100% EV targets or targeted ICE bans are on net sales only so far.

60 i Including CO2, NOx and particulate matter.

61 i Targets include the following: Cabo Verde, Canada, British Columbia (Canada), Hainan Province and Taipei (China), Costa Rica, Denmark, France, Iceland, Japan, Netherlands, Norway, Slovenia, Balearic Islands (Spain), Sri Lanka, Sweden, United Kingdom and Scotland.

62 i Distributed energy sources include mostly, but not exclusively, renewable energy sources and in this context also apply to electric vehicles for providing V2G grid services.

ii For example, the collection of fees both for charging a vehicle and for injecting power to the grid.

63 i For more details see: https://www.seforall.org/energy-efficiency-for-sustainable-development/energy-and-transport

ii Read the results here: https://www.seforall.org/publications/switching-gears-enabling-access-to-sustainable-urban-mobility

66 i Total energy consumption in the Transforming Energy Scenario is significantly reduced compared to the Reference Case based on avoid, shift and vehicle efficiency measures.

ii See Sidebar 3.

iii The Sustainable Development Scenario (SDS) provides a vision of how the global energy sector can evolve to achieve the energy-related SDGs, and it is developed based on what is needed to achieve the desired outcomes.

70 i Challenges identified in this section represent the authors' assessment based on the research conducted for the previous sections and expert interviews. We therefore do not attribute individual challenges or statements to specific reports or experts.

76 i Interoperability here refers to the compatibility of vehicle charging systems and charging infrastructure across vehicle manufacturers, models and charging point operators.

80 i Note that there is no common definition of marginal lands. For some examples of existing definitions see Giuseppe Pulighe et al., "Ongoing and emerging issues for sustainable bioenergy production on marginal lands in the Mediterranean regions," Renewable and Sustainable Energy Reviews, vol. 103 (1 April 2019), pp. 58-70.

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