

Moving Transport to Net Zero

What It Takes to Decarbonise the Global
Transport Sector

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1. Net Zero in the Paris Agreement and Its Impacts on Climate Policy

1.1. The New Paradigm of Climate Policy

With the adoption of the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC), achieving greenhouse gas (GHG) neutrality has become the key objective of international climate policy. GHG neutrality or net zero emissions means that after GHG emissions have been reduced as much as possible, any remaining emissions will need to be offset by removal of GHGs from the atmosphere (so-called sinks). Removal options are e.g. afforestation, reforestation or technologies such as bioenergy in combination with carbon capture and storage (BECCS) or direct air capture of CO₂.

The Paris Agreement thereby operationalises the ultimate objective of the UNFCCC, which “is to achieve (...) stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.” While this objective is very ambitious, the Convention neither specifies what would be a “dangerous anthropogenic interference”, nor at what level GHG concentrations should be stabilised, nor in which timeframe.

The Paris Agreement now specifies all of these aspects. According to its Article 2.1, the Agreement “aims to strengthen the global response to the threat of climate change, (...) including by (...) Holding the increase in the global average temperature to well below 2° C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels”. In addition, the Paris Agreement translates what achieving this long-term temperature limit means in terms of GHG emissions. Parties agreed that, firstly, global GHG emissions need to peak “as soon as possible”, secondly, that thereafter rapid reductions of global GHG emissions are needed and, thirdly, that “a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases” – i.e. net zero emissions – is needed “in the second half of this century” (Art. 4.1).

In addition to adopting the Paris Agreement, the Parties of the Paris climate conference also requested the Intergovernmental Panel on Climate Change (IPCC) to prepare a scientific assessment of the implications and feasibility of achieving the 1.5° C limit. The special report was published in 2018 and had two major findings (IPCC 2018):

- It makes a strong difference whether global warming is contained below 1.5° C or only below 2° C. In the latter case, climate damages will be substantially more severe than in the former case. Every bit of warming matters.
- Unprecedented action is required. To maintain a reasonable chance of containing global warming below 1.5° C, global GHG emissions essentially need to be halved by 2030 and be reduced to (net) zero by 2050.

In practice, however, the key sectors show significant differences in terms of their reduction potential. For instance, reducing emissions from industrial processes and agriculture to zero will most likely not be feasible, leaving achieving net zero emissions in these sectors to the use of sinks. As sink capacity, however, is limited, emissions that can physically be brought down entirely should not depend on using sinks

but instead reduce their emissions to zero. In fact, it is likely that to limit global warming to 1.5° C, even significant negative emissions will be required in the second half of the century, i.e. more GHGs will have to be removed from the atmosphere than are still emitted at this point (van Vuuren et al. 2018).

Limiting global warming to 1.5° C thus means decarbonising the world by mid-century, and developed countries even earlier than that. This is the main message from Paris: the age of fossil fuels needs to come to an end.

Over the last years, net zero targets have increasingly moved into the spotlight of climate policy. As of August 2022, 76 Parties have communicated a net zero target. These Parties represent 83 countries and 73.3% of global GHG emissions. While these numbers are impressive, the commitments need to be considered with caution: Not all of the net zero targets are backed by credible policies and plans to achieve them (Climate Watch 2021). Furthermore, they vary regarding the target year (e.g. USA and EU: 2050; China: 2060; India: 2070). While 14 Parties have put their net zero target in law and 39 Parties have placed them in policy documents, 23 Parties have so far only made political pledges (Climate Watch 2021, see Figure 1). It remains to be seen to what extent governments follow up their net zero targets with actual climate action. Pressure is rising to step up efforts in this regard.

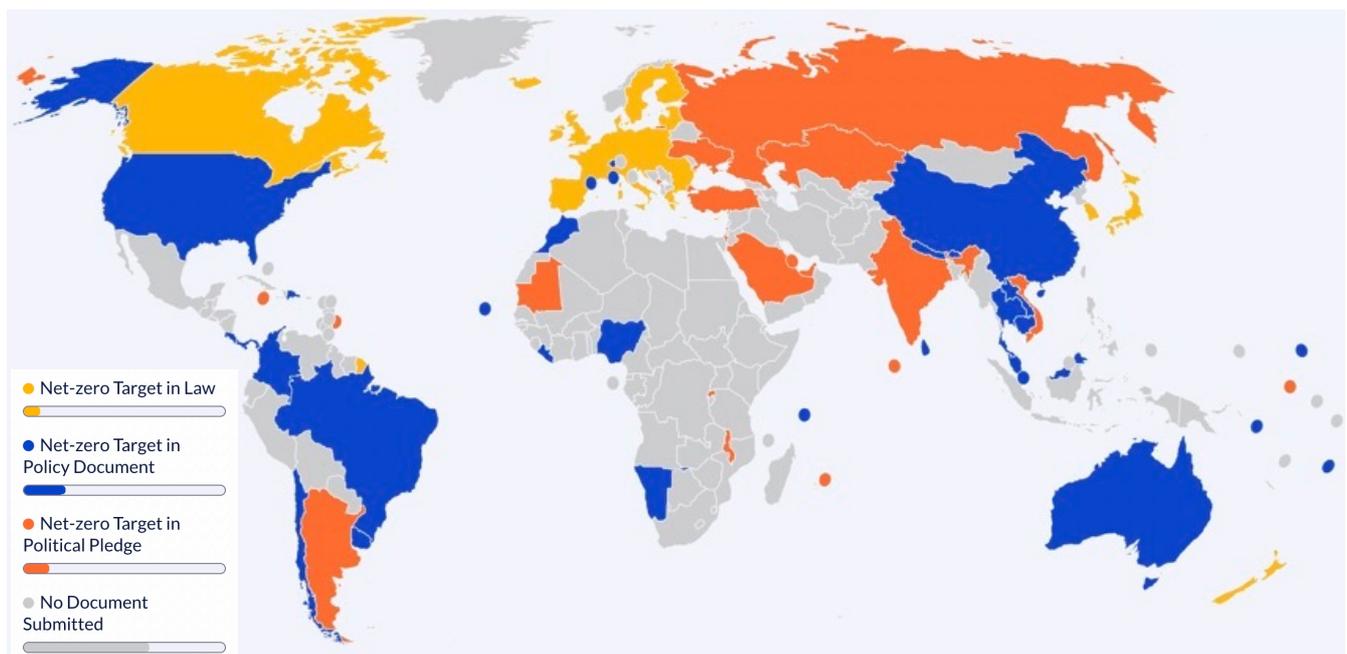


Figure 1 Parties with Net Zero Targets (Climate Watch 2021)

There are similar dynamics among non-state actors. In 2020, the UNFCCC High-Level Climate Champions for Climate Action – Nigel Topping and Gonzalo Muñoz – launched the Race To Zero campaign to rally non-state actors to take strong and immediate action to halve global emissions by 2030 and ultimately achieve zero emissions. By August 2022, the campaign had recorded net zero initiatives of 1,049 cities, 67 regions, 5,235 businesses, 441 of the biggest investors, and 1,039 Higher Education Institutions. Businesses that have pledged net zero targets include a substantial number of large automotive companies, such as Toyota, Volkswagen, Ford, General Motors, BMW, Nissan, Peugeot and Volvo, as well as several airlines such as Delta and American Airlines, Lufthansa, and British Airways (UNFCCC 2022). As with

governmental commitments, non-state actors will have to prove that their targets are not just empty words but lead to actual climate action.

1.2. Net zero in Transport

While at COP26, four new international initiatives have been launched focusing on enhanced transport action (UNFCCC 2021), transport still is one of the largest and fastest-growing GHG emission sources worldwide. In 2018, the transport sector accounted for nearly a quarter of energy-related global CO₂ emissions (8.5 Gt CO₂), of which over 70% were land transport (6.2 Gt CO₂eq) and maritime and aviation accounted for 8% and 7% respectively (0.7 Gt CO₂eq and 0.6 Gt CO₂eq, 7%) (IEA 2020). If current trends persist, GHG emissions from the transport sector are expected to increase by between 9% (ICCT 2020) and 16% (ITF 2021) until 2050 compared to 2015 levels. For net zero transport to stay within reach, it is essential to turn current emission trends around quickly and profoundly.

As net zero targets have only recently received momentum, there is so far only little literature shedding light on what net zero actually implies for different sectors. In its special report on 1.5° C, however, the IPCC not only argues for the need of global emissions to be halved by 2030 and be reduced to (net) zero by 2050, but also assesses pathways consistent with limiting warming to 1.5° C. In these pathways, carbon emissions from the transport sector would amount to between 2 and about 5.5 Gt CO₂ in 2050 (IPCC 2018).

According to the IPCC, human activities have been responsible for about 2,390 Gt CO₂ over the period from 1850 to 2019. To stay within the limit of 1.5° C of global warming with a likelihood of 67%, a maximum of 400 Gt CO₂ can be emitted from the beginning of 2020 (IPCC 2021)¹. Of this carbon budget, a recent study estimates 115 Gt CO₂ for the transport sector, most of which will be required for road transport (82 Gt CO₂), followed by shipping (19 Gt CO₂), aviation (11 Gt CO₂) and rail (3 Gt CO₂) (Teske et al. 2021). The sooner emissions are reduced drastically, the longer the world has to reduce the last tons of carbon emissions – this is true for all sectors, including transport.

In its recently published Net zero Emissions by 2050 Scenario, the IEA examines what net zero emissions by 2050 would mean for the energy sector (IEA 2021). In its analysis, it also includes the implications for industry, transport and buildings. In the IEA's scenario, transport emissions need to drop to about 5.5 Gt CO₂ by 2030 and 0.7 Gt CO₂ by 2050, which equals a reduction of about 20% and 90% respectively relative to 2020 levels (IEA 2021).

Furthermore, the ITF has developed scenarios which it claims put the climate goals of the Paris Agreement within reach (Reshape scenario) and on a fast track to achieving the climate goals, respectively (Reshape+ scenario) (ITF 2021). These scenarios assume that annual emissions from the transport sector must drop to about 6.0 Gt CO₂ by 2030 and 2.6 Gt CO₂ by 2050 (Reshape scenario) and to about 5.3 Gt CO₂ by

¹ The latest IPCC report puts the remaining carbon budget from 2020 onwards for limiting global warming to 1.5° C with a probability of 50% as 500 Gt CO₂ (IPCC 2022).

2030 and 2.3 Gt CO₂ by 2050 (Reshape+ scenario) to limit temperature increases to 1.5°C and avoid overshooting carbon budgets.

The emissions left in 2050 in these scenarios would have to be offset by negative emissions elsewhere, when net zero transport is the goal. However, it may be argued that transport emissions would indeed have to be as close to zero as possible for 1.5°C, because the potential for negative emissions is limited, and other sectors, for example agriculture, will probably not be able to reduce emissions to zero. Negative emissions will primarily have to be used for such cases.

Keeping this in mind, the question of how to completely decarbonise the transport sector has recently gained traction. First scenarios completely decarbonising the transport sector and describing the changes that need to happen in the transport sector in order to limit global warming to 1.5° or 2.0° C have been drawn up (Teske et al. 2021). Also, a roadmap identifying actions to reach net zero emissions by 2050 has been developed under the Marrakech Partnership for Global Climate Action. In its 2021 Climate Action Pathway Transport, the Marrakech Partnership defines intermediate steps for 2021, 2025, 2030 and 2040 regarding land transport, shipping, aviation, and resilient transport, that have to be taken in order to decarbonise the transport sector completely by 2050 (Marrakech Partnership 2021a, 2021b). Box 1 provides an overview of selected scenarios identified for low-emission and net zero transport.

Box 1: Scenarios for Low-Emission and Net Zero Transport

- In its special report on 1.5° C, the IPCC assesses **pathways consistent with limiting warming to 1.5° C**. In these pathways, carbon emissions from the transport sector amount to between 2 and about 5.5 Gt CO₂ in 2050 (IPCC 2018).
- The IEA's **Net Zero Emissions by 2050 Scenario** shows what is required for a pathway to globally reach net-zero energy-related and industrial process CO₂ emissions by 2050. It includes, inter alia, the implications for the transport sector, which it requires to reduce emissions by 20% by 2030 and by 90% by 2050 relative to 2020 levels. With a 50% probability, the scenario limits global warming to 1.5° C without a temperature overshoot (IEA 2021).
- The ITF assesses the impacts of different policy pathways on CO₂-eq. and local pollutant emissions, transport demand, accessibility, connectivity and resilience up to 2050. While in the **Recover** scenario, governments prioritise eco-nomic recovery by reinforcing established economic activities after the pandemic, the **Reshape** scenario includes the adoption of transport decarbonisation policies that are transformational, i.e. they change behaviour, increase uptake of cleaner energy and vehicle technologies, and improve energy efficiency and infrastructure. In **Reshape+**, governments reinforce Reshape's policy efforts and seize decarbonisation opportunities created by the pandemic (ITF 2021).
- In its **Climate Action Pathway Transport**, the Marrakech Partnership for Global Climate Action visions options to completely decarbonise passenger and freight transport by 2050 through a mix of actions focusing on avoiding and reducing trips, shifting to modes with zero carbon emissions, technical and efficiency improvements as well as infrastructure and systems (Marrakech Partnership for Global Climate Action 2021a, 2021b).
- Against a reference case, the Transformative Urban Mobility Initiative has developed a **2.0° C Scenario** as well as a **1.5° C Scenario** with transport energy-related CO₂ emissions reaching net zero by 2050 in both. In the 2.0° C Scenario, the uptake of electrific mobility is slow through 2025 and only increases towards 2030 due to policy measures including carbon pricing, EV credit systems, purchase incentives, and tightened CO₂ fleet emission targets. Supportive policy measures lead to increased use of public transport and improved energy efficiency. In the 1.5° C Scenario, policies are already implemented by 2025, resulting in early electric powertrain penetration as well as rapid improvements in energy efficiency and increased uptake of public transport and active mobility (Teske et al. 2021).

Changing course is particularly challenging in transport due to the longevity of urban settlement patterns and transport infrastructure. This is hardly considered in many

current net zero studies that often focus on electrification rather than on demand-side management. In many urban areas of the traditional industrialised countries, current urban forms have led to a lock-in of emission-intensive urban patterns and transport systems. Lowering transport demand in these countries would require substantial reconstruction (Driscoll 2014; Figueroa et al. 2014). At the same time, the risk of similar lock-ins in the global South increases with ongoing, massive urbanisation that repeats similar urban patterns and transport infrastructure (Seto et al. 2014).

The lifetime of the vehicle fleet similarly locks in high emission levels for a significant period of time. Assuming a vehicle lifetime of 15 years, to achieve zero CO₂ emissions by 2050, the last fossil-fuelled car would need to be sold in 2035. Any new fossil fuel passenger car sold after 2035 will generate emissions beyond 2050.

Urgent action is therefore required to bring the transport sector on track to the objectives of the Paris Agreement. However, a new paradigm has to be adopted in transport policy, and actions have to increase systematically and substantially to be able to master the challenge at hand. After presenting the new role of net zero in climate policy in general as well as in transport (chapter 1), this policy paper provides an overview of the implications of aiming at net zero for the transport sector (chapter 2). In this endeavour, it introduces the new paradigm required in transport policy to achieve net zero before looking at how different sub-sectors have to contribute to the overall task in general. Subsequently, the paper discusses barriers that are prevalent for the path towards net zero transport (chapter 3) and provides policy recommendations (chapter 4).

2. Implications of Net Zero for the Transport Sector

2.1. Optimising the Set and Increasing Pace and Intensity of Actions

When aiming at net zero emissions in transport, the basic approach to reducing transport emissions remains unchanged from what has been suggested in the past. However, the drastic shifts that are needed require a fundamental shift regarding the set, intensity and pace of the actions.

While many technological and operational options to drastically reduce GHG emissions are now readily available, implementing individual policies and measures does not suffice. Instead, an integrated and systemic approach is required that aligns targets, strategies and actions in all relevant spheres. This approach should, on the one hand, identify and utilise synergies with other issues such as health and the economy across the whole sector and beyond – including the energy and resource dimensions. On the other hand, it should avoid or at least minimise negative repercussions and conflicts of targets. For this purpose, national and local policies as well as public and private sector activities should be aligned and complement one another. Linking and packaging policies are a key tool in this regard. Also, an effective reporting system should constantly assess and review progress towards the goals and (sub-)targets set to reach net zero transport. Such a system is, for example, set up to continuously monitor progress towards achieving the sectoral emission reduction targets enshrined in the German Climate Change Act.

Policy interventions will differ with respect to what is most appropriate in terms of impact and (sub-)sector in different cities, regions and countries taking into account the different capabilities and also the differing needs to enable mobility access, in particular in industrialised and developing economies. However, for net zero, some of the policies and measures usually employed to reduce emissions are no longer good enough: Those, that, while they reduce emissions, would delay the radical shift to zero emissions transport beyond 2050. As the challenge is huge, the transport sector cannot afford to use, for example, Compressed Natural Gas (CNG) or hybrid vehicles as interim solutions and continue to burn fossil fuels for decades. If net zero transport is the goal battery electric vehicles with energy from renewable sources are essential. Otherwise, emissions will be locked-in for years (or even decades) and prevent achieving the scale and pace required in this transformation.

But the transport transformation needs to go beyond electric vehicles and entail both a mobility transition that reduces energy consumption without limiting mobility, and an energy transition in transport which allows the transport sector to securely cover remaining demand with carbon-neutral energy (Agora Verkehrswende 2017, see Figure 2).

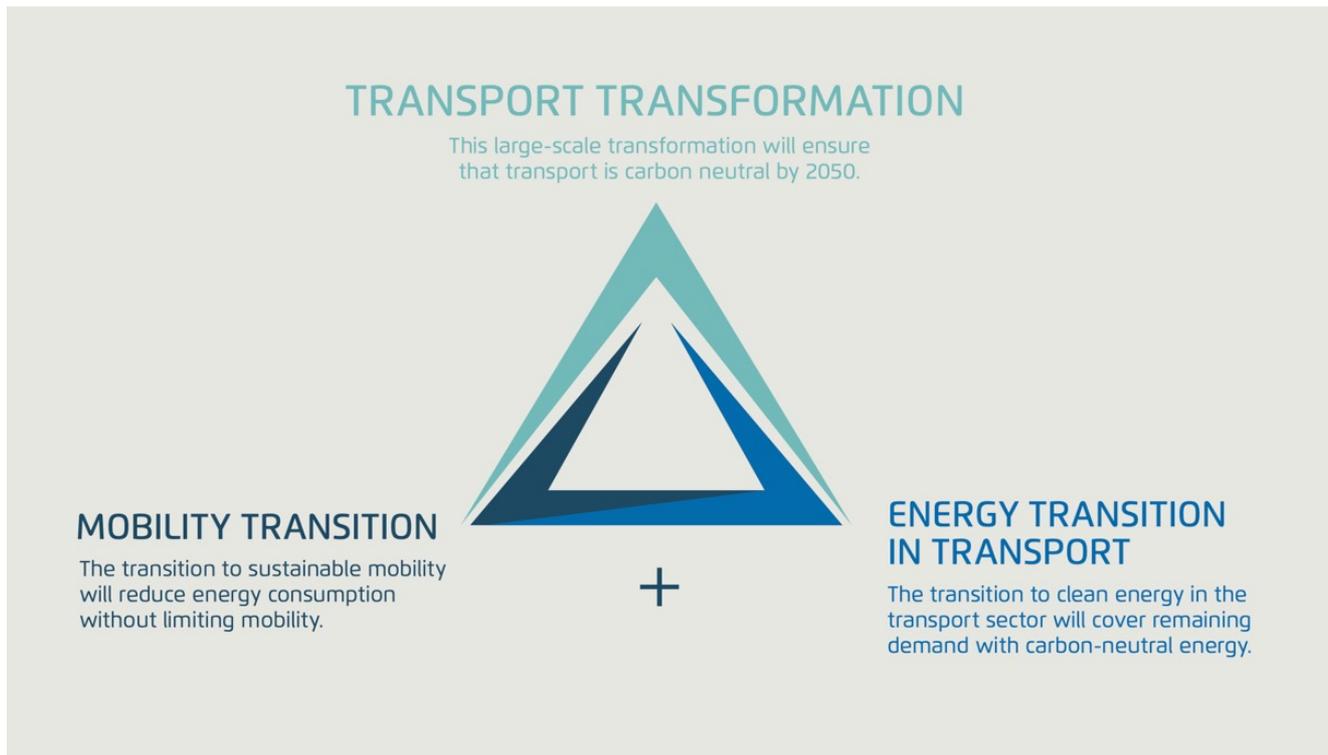


Figure 2 The Geometry of the Transport Transformation (Agora Verkehrswende 2017)

Generally, policies and measures to reduce emissions in the transport sector can be classified using the A-S-I approach. This approach differentiates between three main avenues to reduce GHG emissions in the transport sector. While the transport transformation's mobility transition refers to the first two avenues, the energy transition in transport covers the third:

1. Avoiding and reducing the need to travel and the trip length without limiting access to goods and services, e.g. through transport demand management and integrated land-use planning,
2. Shifting trips to low-carbon modes of transport, in particular to non-motorised transport (NMT, i.e. walking and cycling) or public transport (PT),) and rail, or by
3. Improving the energy and carbon efficiency of the currently used transport modes, vehicle technology and fuels as well as of the transport system, e.g. by introducing efficiency standards and electric propulsion systems using renewable energy

Employing the A-S-I approach not only reduces emissions but can also result in significant sustainability benefits such as better air quality, improved health, better energy security, reduced congestion and time savings as well as more local jobs.

When aiming at net zero transport, it is essential that the challenge becomes larger with growing demand for transport, and in particular motorised individual transport. Therefore, ambitious, effective demand-side measures have to be the foundation for the sector transformation ahead regarding both passenger and freight transport to change current projections regarding transport demand and bring down the challenge to a more manageable level.

Demand-side measures, of course, cannot stand alone. Instead, they have to be integrated with convincing options enabling, on the one hand, a reduction of trips, e.g. through video conferencing and carbon border taxes that reduce some freight transport, and, on the other hand, substantial shifts of the remaining trips to walking, cycling, and public transport, as well as rail and shipping in freight transport, respectively. Thus, for example, shifting transport from private cars to urban rail for longer urban trips reduces final energy use per passenger-kilometre by 91% (IEA 2020). Similarly, shifts from aviation to high-speed rail deliver 93% lower energy use per passenger-kilometre, and from trucks to freight rail 72% lower energy use per tonne-kilometre (IEA 2020).

However, it is not feasible to shift all transport demand to low-emission modes: Rail can only replace air travel on high-demand routes and limited distance (IEA 2019). Similarly, even a maximum shift of road freight to rail and inland waterways will leave significant transport demand for trucks: Rail services work best on major axes of freight transport and cannot compete with the flexibility of road transport, in particular regarding timely delivery and last-mile transport. Furthermore, shifting to active travel modes and public transport requires appropriate infrastructure and services, which may be limited in rural and peri-urban areas (ITF 2021).

In the end, moving the transport sector to net zero will only be feasible based on avoiding the need to travel and shifting transport to zero-/low-emission modes: Without first drastically reducing the overall challenge, the total amount of renewable energy and other resources that would be necessary in case technological improvements and electrification of propulsion systems were the main ingredients of a strategy for reaching net zero transport within the next thirty years would exceed available resources by far (see chapter 2.6). In Germany, for example, the transport sector consumed about 42 PJ of electricity in 2016. In a reference scenario developed for the German Federal Ministry of Economy and Energy, the transport sector's electricity consumption is expected to reach 100 PJ in 2030 and 240 PJ in 2050. Depending on varying (intensity levels of) climate policies and measures in the study's target scenarios, estimates for transport's electricity consumption range from 171 PJ to 190 PJ in 2030 and from 464 PJ to 532 PJ in 2050 (Prognos et al. 2021). The more the amount of additional electricity required is reduced by avoiding and shifting transport, the more feasible a transition towards net zero transport.

2.2. Pace of Decarbonisation of Transport Modes Differs

Technology maturity varies considerably between the different modes of transport. Therefore, pathways towards complete decarbonisation of transport modes differ, too. While low-emission technologies for passenger cars, in particular electrification, are readily available, many decarbonisation technologies for heavy duty vehicles, ships and aircrafts require more research and investment to reach a level of maturity to enable their large-scale deployment as they are still in prototype and demonstration phases (see Figure 3, IEA 2021). Thus, long distance transport will take the longest to decarbonise.

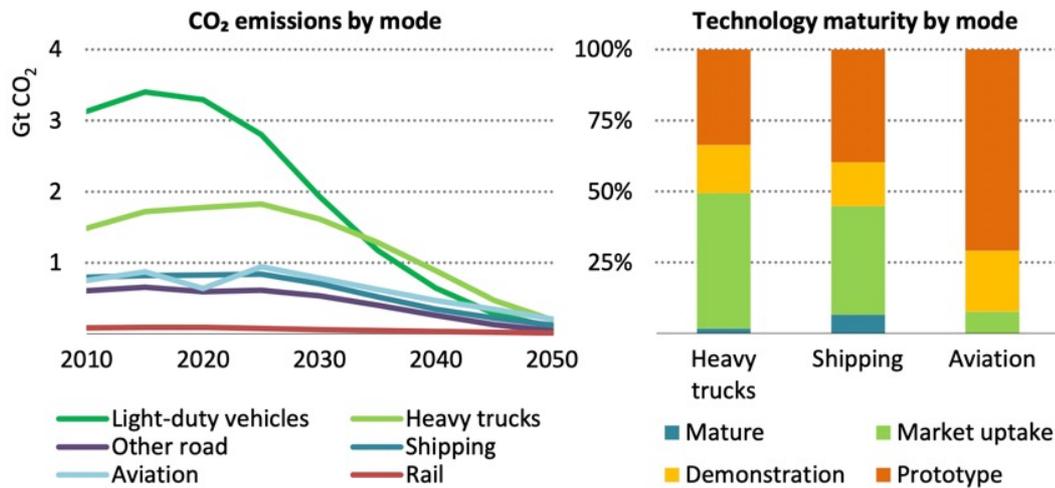


Figure 3 Global CO₂ Emissions 2010-2050 and Technology Maturity by Mode of Transport (IEA 2021)

To account for these circumstances, the following sub-chapters' analysis is divided into required actions for net zero transport regarding land transport, shipping and aviation. Along all sub-sectors, transport data has to be improved, and substantial efforts in research and development are needed, in particular regarding low-/zero-emission technology and fuels for long-distance transport. Furthermore, appropriate safety standards and regulation have to be developed, and the tax and incentive structure needs to be reformed in such a way that it supports the transition of the sector. Regarding all forms of transport, behaviour change needs to be incentivised with price signals and appropriate infrastructure as well as with advocacy for more sustainable consumption and travel patterns, and increased efforts are required regarding awareness, capacity building and sharing of best practice knowledge.

2.3. Land Transport

As discussed above, to significantly reduce the size of the challenge ahead in land transport, avoiding and reducing the need to travel and the trip length are essential. Transport and urban systems largely determine which mode of transport people choose and how freight is transported. Frequently, such systems are organised around motorised individual transport, leading to induced travel demand, urban sprawl, and neglect of shared and active modes of transport. Transforming systems instead of focusing on individual components within transport will therefore be much more effective to achieve net zero emissions in the limited period of time available (OECD 2021). This includes appropriate supply and distribution infrastructure such as multimodal hubs and intelligent transport systems, but has to go beyond that and consider options for reduced international freight transport.

Accelerated electrification of the vehicle fleet is an essential building block for global climate change mitigation strategies. Its overall contribution, however, depends critically on the integration with the energy dimension (see chapter 2.6). During the last few decades, bigger, faster and more powerful cars have eradicated almost all efficiency gains in powertrain technologies. The electrification of the entire vehicle fleet will only be viable and resource efficient as well as affordable if this trend is reversed. Therefore, there should be a clear focus on resource and energy efficiency as well as on boosting cost-effectiveness by significantly downsizing vehicle size and power.

Moreover, electric vehicles need to be well-integrated with other mobility services and infrastructure, and designed for shared use-cases and mobility as a service, which provides access for all (Lah 2021).

The following table provides an overview of the key instruments contained in the literature available that are required in land transport for achieving net zero in transport.

Table 1 Key Instruments for Achieving Net Zero Emissions in Land Transport (ITF 2021; Marrakech Partnership for Global Climate Action 2021a, 2021b; OECD 2021)

Avoid

Demand management: vehicle access regulation in cities; parking pricing and regulation; intelligent transport systems (ITS); improvement of load factors and logistics for urban freight; working regulations allowing telework or flexible working hours

Planning and land use: reduction of urban sprawl; improved connection of city and sub-urban areas; integration of land-use and transport planning towards higher density levels and mixed land use; inclusion of urban freight movement in transport management and land use planning; development of inclusive, accessibility-oriented, compact and resilient cities; re-allocation of road space to low carbon and space efficient modes as well as other uses; integration of loading/unloading spaces and consolidation centres into building codes; seamless inter-modality

Shift

Public transport: provision of safe, secure, comfortable, affordable, inclusive public transport services for all users, including infrastructure and operational improvements, and bus rapid transit and enhanced rail where densities support it; integration of public transport and other services such as ride sharing; alignment of COVID-19 recovery plans with investment in sustainable public transport; employment of new universal zero-carbon models of Mobility as a Service (MaaS), with demand-responsive transport to fill gaps in suburban and rural areas; improvement of planning, booking and utilisation through ITS and other platforms; seamless transfer of transport and payment across modes

Shared mobility: high-speed rail; prioritisation, up-scaling and investment in alternative, attractive sustainable transport solutions (e.g. high-quality public, shared and on-demand transport services); integration of shared mobility into the first and last mile of trips served by public transport as well as in existing transport networks, as part of a MaaS approach

Walking and cycling: integration between tactical urbanism and mobility planning; creation of networks of 15-minute cities with access to all services required on a daily basis; improvement of provision, including re-allocation of space, for walking and cycling; integration of active mobility requirements in all large-scale infrastructure projects planning; equitable access to all transport modes including MaaS

Freight: shifting goods movement from road to railway and/or inland waterways and maritime transport, where feasible; better linked multi-modal logistics hubs; integration of transport of goods and parcels in next-generation "MaaS for Climate"; low-carbon last-mile delivery schemes; reduction of administrative or financial burdens for rail freight

Improve

100% zero-emission electric light and heavy-duty vehicles, buses, and rail transport including infrastructure (e.g. charging infrastructure) and incentives in leading markets, per km CO₂ reductions for light-duty vehicles of 90% and for heavy-duty vehicles of 70% relative to 2005 for the remaining markets; autonomous vehicles and platooning (Marrakech Partnership for Global Climate Action 2021a)

Energy/fuels: substitution of fossil fuels with renewable electricity; low-carbon hydrogen and advanced bio-fuels; phase out of diesel only trains; fuel economy or CO₂ emission standards for light and heavy-duty vehicles; reduction of the carbon intensity of transport energy sources (increasing share of low-carbon fuel blending, integration of clean electricity and green hydrogen into regulatory policies, all renewables in the electricity grid); eco-driving

Regulation: elimination of fossil fuel subsidies; elimination of carbon pricing gaps; differentiation of taxation (mileage-based), access, road charges and parking fees favouring low emission vehicles; reduction of restrictions for high-capacity vehicles on certain corridors

2.4. Shipping

About 70% of global goods are moved by maritime freight transport (ITF 2021).

While it's a relatively efficient mode of transport with a comparatively low carbon intensity, its emissions are increasing constantly. In 2018, emissions from shipping amounted to about 1 Gt CO₂ (almost 3% of global CO₂ emissions). Under business-as-usual (BAU), they are projected to increase by between 0 and 50% over 2018 levels until 2050 to between 1 and 1.5 Gt CO₂ (IMO 2021).

Emissions from international shipping are not included in countries' Nationally Determined Contributions (NDCs). Shipping is regulated by the International Maritime Organisation (IMO). While the IMO has set targets, it has so far not adopted any meaningful measures to reduce maritime shipping emissions (ITF 2021). Furthermore, decarbonisation is challenging because the industry is fragmented, and has excess capacity and short investment horizons (Marrakech Partnership for Global Climate Action 2021b). Additionally, vessels have a long lifetime and there are currently not enough low-/zero-carbon options available (IEA 2021; Marrakech Partnership for Global Climate Action 2021b).

Options to avoid and reduce the need for international freight transport should be explored to scale down emissions from shipping. It should be noted, however, that currently, fossil fuels account for nearly 40% of all cargo in international maritime trade (UNCTAD 2021). In case of a complete phase-out of fossil fuels, these shipments will no longer be necessary. So far, this aspect may not have been considered sufficiently in available literature on how to reach net zero emissions on a global scale.

To reduce the overall challenge of decarbonising long-distance transport, trade regionalisation would be highly beneficial. Options to reform international trade as to make it compatible with the goals of the Paris Agreement should therefore be explored. Such options may include increasing transparency between the bodies of the World Trade Organization (WTO) and the UNFCCC, improving legal guidance on legitimate climate policy targets vs. unacceptable protectionism, and the promotion of climate policies through regional trade agreements (RTAs) (Dröge et al. 2018).

While there is a considerable potential for efficiency gains in the maritime sub-sector, the only way to decarbonise international water-borne travel is a shift of propulsion technologies and energy carriers. In these areas, the potential use of electricity is more limited. Hydrogen carriers, such as ammonia and low-emission synthetic fuels will play an important role (IEA 2021).

The following table provides an overview of the key instruments required in shipping for the path to net zero emissions in transport.

Table 2 Key Instruments for Achieving Net Zero Emissions in Shipping (IEA 2021; ITF 2021; Marrakech Partnership for Global Climate Action 2021a, 2021b; OECD 2021)

Shift and interconnectivity: promotion of modal shift from air to rail and water, and from road to rail or water, depending on commodity type; close alignment of shipping activities with other transport modes

Technology: Research, development, standards, and investment for new shipping technologies, zero-emission shipping and low/zero-carbon shipping fuels; inland waterways improvements

Finance: investments in alternative fuel production, distribution and supply infrastructure; phase out of fossil fuel subsidies and tax breaks; all direct and indirect subsidies for maritime transport conditional to environmental outcomes; redirection of investment towards energy efficient ships and infrastructure in ports; port fees; incorporation of the concept of stranded carbon assets into shipping finance; support for low-income countries to decarbonise maritime transport, including compensating aid for carbon pricing effects on trade

Regulation: inclusion of shipping into regional policy packages (including EU ETS); adoption of market-based measures at the IMO; international carbon price of USD 50-100/t CO₂; IMO and national regulations in line with Paris Agreement targets (focus on operational standards and zero-emission fuel adoption)

Energy/fuels: safe and efficient bunkering of low- and zero-carbon fuels at all ports; blending mandates; up-scaling of zero-carbon fuels/electrification of propulsion energy, in particular for domestic shipping in developed nations; availability of alternative energy supplies for shipping and port activities, from renewable sources at main ports

Operational efficiency: seamless maritime logistics chains, including digitalisation and automation as well as smooth data exchange and integration of international container transport (ICT) and planning systems of all stakeholders in the maritime supply chain; asset sharing, increases in load factor; optimisation of ship speed, port operations, voyage planning, weather routing, Ship Energy Efficiency Management Plan (SEEMP) as guidance

Energy efficiency and carbon intensity: renewal of fleets with newer, cleaner vehicles; carbon intensity targets per ship; tightened, redesigned Efficiency Design Index (EEDI), optimising vessel design and accounting for well to wheel emissions rather than just tank-to wheel; enhanced mandatory operational goal-based regulation on carbon intensity of ships calling at regional ports; environmentally differentiated port pricing; development of advanced weather routing systems to better utilise wind, waves, ocean currents, and tides

2.5. Aviation

Over the past decades, the substantial efficiency improvements in aircraft technology and design have been outpaced by the rapid increase of air traffic. In 2019, aviation accounted for 2% of global carbon emissions, with domestic aviation accounting for almost 40% of total emissions and two thirds of total flights (Marrakech Partnership for Global Climate Action 2021b). In case non-urban (or inter-city) passenger transport does not change course, its emissions will rise by 25% until 2050 compared to 2015. With a share of nearly 60%, aviation would be responsible for most of this increase (ITF 2021).

Long turnover rates, low profit margins, complex stakeholders and limited historic regulatory pressure make decarbonising aviation especially hard (Marrakech Partnership for Global Climate Action 2021b). Nevertheless, the International Civil Aviation Organisation (ICAO) has recognised the need to curb emissions from aviation. Thus, it has adopted a new CO₂ emissions standard for aircrafts in 2017, implements the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and has conducted a feasibility study for establishing a long-term CO₂ reduction goal for international aviation at the next ICAO Assembly in 2022. Efforts along these lines have to increase substantially when net zero transport is the goal. All options available to avoid and reduce air travel should be explored, for example to reduce

long-distance leisure-tourism and business travel, as they could help significantly to reduce the overall task at hand.

As in shipping, there is a considerable potential for efficiency gains in the aviation sub-sector and aircraft fleets, with the best potential for short-term emission reductions in maintenance and operational measures. However, to decarbonise international air travel, a shift of propulsion technologies and energy carriers is required. While the use of electricity is limited, hydrogen carriers will play an important role (IEA 2021). Sustainable fuels, however, are cost-intensive, their availability is limited, and their adoption slow (Marrakech Partnership for Global Climate Action 2021b). Long-haul aviation is most difficult to decarbonise, due to non-CO₂ impacts – in particular the formation of contrails and ozone at high altitudes – even when using synthetic fuels.

Key instruments required in aviation for achieving net zero in transport are presented in the following table.

Table 3 Key Instruments for Achieving Net Zero Emissions in Aviation (IEA 2021; ITF 2021; Marrakech Partnership for Global Climate Action 2021a, 2021b; OECD 2021)

Shift: replacement of short-haul passenger and freight aviation by high-speed rail and other, more sustainable modes

Airlines: reduction of weight on board (e.g. via removal of non-essential items, optimisation of water quantities, lighter equipment and fittings); optimisation of passenger load factors; incentives for lighter luggage; reduction of drag by regular maintenance and cleaning of aircraft and engines; regulation of economic fuel tankering; pilot training for eco-flying; optimisation of flight routes to benefit from winds and air temperatures; retrofitting of winglets on appropriate aircraft; energy-efficient aircrafts; SAF

Finance: reduction of all environmentally harmful subsidies in air transport; ticket taxes; new policies for investing in and driving down costs of Zero-Emission Aircraft (ZEA) and Sustainable Aviation Fuel (SAF) (e.g. Contracts for Difference (CFD)), reduction of 90% of all pollutants via combination of SAF and ZEA; achievement of decarbonisation targets envisaged by the Climate Champions (e.g. 2% SAF by 2025, minimum of 10% by 2030 and of 90% by 2040); assessment of alignment of aviation businesses with climate goals following the lines of the Poseidon Principles for shipping; linking of financial support packages for airlines to future emissions reductions and uptake of Sustainable Aviation Fuel (SAF)

Regulation: international framework for driving net zero carbon goals; implementation of ICAO CORSIA and participation of States at national level; national regulation targeting domestic aviation; carbon pricing and/or emissions trading for flights, domestic aviation; inclusion of non-CO₂ emissions into CORSIA and Emissions Trading Systems (ETS); market-pull and technology push policies; goal-oriented research programs

Energy/fuels: research and development for novel aircraft energy sources (e.g. hydrogen, electric, hybrid variations, ammonia, synthetic fuels); bio-fuels and e-fuels; clear split of sustainable alternative fuels into bio-fuels and e-fuels; shifting from gas to liquid hydrogen where gasification is derived from renewable sources

Operational efficiency: climate efficient routing; efficiency improvement in Air Traffic Management (ATM) and engine/aircraft design; use of most efficient flightpaths through established technologies and concepts of operations in communications, navigation and surveillance (CNS); Airport Cooperative Decision-Making (A-CDM)

Energy efficiency and decarbonisation targets: Carbon Neutral Growth from 2020 onwards; annual fuel efficiency of 2% for international aviation

2.6. Coupling Transport with the Energy Sector

To realise net zero transport, fossil fuels have to vanish completely, leading to a fundamental transformation of the energy sector. Even for the IEA scenario's transport emission reduction of 90% by 2050 relative to 2020 levels, the IEA assumes almost

full electrification of the global car stock, a fully electrified fleet of two- and three-wheelers, and 59% electric heavy-duty vehicles by 2050. All in all, electricity would account for about 45% of total transport energy consumption in 2050 (compared with 1.5% in 2020), and electricity demand from transport would rise from about 1 EJ in 2020 to about 35 EJ in 2050. Demand for batteries for transport would amount to 14 TWh (90-times more than in 2020), and public charging infrastructure for electric vehicles has to be developed massively fast (IEA 2021).

While total energy supply in the IEA's scenario in 2050 is nearly the same as in 2010, electricity demand rises significantly and amounts to almost 50% of total energy consumption in 2050. Therefore, total electricity generation is projected to increase by more than two-and-a-half times until 2050, with 88% of electricity generation in 2050 coming from renewables. This implies, on the one hand, a contraction of fossil fuel industries and, on the other hand, rapid upscaling of renewable energy, in particular of solar and wind power in this decade, as well as massive investments in electricity networks and energy storage. The costs and benefits of these developments will not be shared equally among countries, making international cooperation a key component of any pathway to net zero emissions by 2050 (IEA 2021). The International Transport Forum (2021) argues that historical cumulative emissions have to be linked with the responsibility for bearing the global costs of decarbonisation. Decarbonisation requires access to capital, technologies and capacities, which has increased substantially in economies that have gained the most from the use of fossil fuels during the last two centuries. Thus, these economies have not only the responsibility but also the ability to significantly support mitigation action in emerging countries through technology transfer and capital investments (ITF, 2021).

While solar PV and wind require land, a recent study by Carbon Tracker found that if global energy demand was only provided by solar panels, the land area required would actually be smaller than the land required for fossil fuels today (Carbon Tracker 2021). Additional land would, however, be required for hydrogen (and hydrogen-based fuels) as well as bioenergy production, which are to provide 30% and 15% of transport energy consumption in 2050, respectively (IEA 2021).

It is important to note that the IEA's scenario does not aim at net zero emissions in the transport sector, but rather at a 90% reduction of transport emissions by 2050 relative to 2020 levels. This means that additional action is needed to further reduce transport emissions or that emissions have to be reduced elsewhere to offset remaining emissions from transport, if net zero transport is to be achieved. However, the potential for negative emissions is quite limited and may have to be used for areas such as agriculture, where zero emissions are not feasible.

3. Barriers for Net Zero Transport

Though moving transport to net zero emissions is possible, there are many barriers that currently prevent timely implementation of the integrated systemic approach that is required. While the barriers preventing net zero transport are in substance the same as those for a transport sector compatible with 2°C, achieving the scale of the envisaged emission reductions in the limited period of time left requires systematically removing all barriers – the sooner, the better. Otherwise, reaching net zero transport by 2050 will not be feasible.

This chapter provides an overview of the most prevalent barriers for net zero emissions in the transport sector relating to governance (chapter 3.1), capacity and technology (chapter 3.2), finance and economy (chapter 3.3), and acceptability and individual preferences (chapter 3.4). Some of the barriers identified may be more important in specific local contexts and circumstances than in others and change over time. Furthermore, they can overlap and reinforce each other.

For this chapter, information contained in scientific literature was analysed and complemented with information gathered from country experts from Brazil, Chile, Colombia, Costa Rica, Ecuador, India, Indonesia, Morocco, Peru, Philippines, Thailand, and Vietnam.

3.1. Governance

A significant barrier for net zero transport consists in the **lack of adequate goals, strategies, policies and measures, and their aligned implementation**.

Thus, the first step towards achieving net zero emissions is setting the corresponding goal, defining an adequate strategy for achieving it, and identifying appropriate policies and measures. Without goal, strategy and corresponding, coherent policies and measures, as well as (perceived) effective leadership in ICAO and IMO as well as in national, regional and local government, reaching net zero emissions in the transport sector in time will not be feasible. To reach the required level of speed and intensity for the envisaged transformation, all sectoral objectives and plans have to be aligned, starting with improved coordination between and integration of ministries and agencies responsible for, in particular transport, land-use and environment. This may, for example, prevent real estate development and business-as-usual infrastructure planning from contradicting net zero emissions developments. Related barriers range from urban planning still being based on the concept of segregated land-use to the dominant paradigm of transport policy being mass motorisation, giving priority to car transport over other transport modes.

Other significant barriers to net zero transport results from the lack of appropriate action to implement national plans. Thus, for example, in spite of an increasing number of local authorities in the United Kingdom having declared “Climate Crises” and “Ecological Emergencies”, they still fail to implement changes on the ground such as the introduction of Low Traffic Neighbourhoods, road space reallocation and road closure (RTPI 2021b).

Furthermore, the **lack of a clear legal framework** may hinder decarbonising the transport sector in the limited time available, as is, for example, currently the case in Chile with its huge transition process centring around a new climate law.

Furthermore, there frequently is insufficient regulatory support for vehicle emission standards as well as for system optimisation by improved road systems, freight logistics and efficiency at airports and ports (Sims et al. 2014). A lack of common standards, for example for charging solutions for electric vehicles (Sims et al. 2014), as well as the integration in regions, for example regarding standards for trucks and interregional connections (e.g. railway) in Latin America, further complicate decarbonisation. On top, traffic regulations still give priority to car transport over all other transport modes in many countries, and currently existing fuel subsidies create incentives for private motorised transport.

Additionally, even where good plans and regulation is being developed, **this takes a lot of time**, as is the case, for example, in Thailand, Peru and Vietnam. However, as discussed, time to achieve net zero transport is limited.

Last but not least, there currently is **not even a process in sight that might consider reforming international trade** as to avoid and reduce the need for long-distance freight transport. Outside of large countries like the USA and China, long-distance transport via shipping and aviation would have to be discussed on an international level. Without changing course in these areas, mitigation efforts in land transport would have to be intensified further to put net zero transport within reach.

3.2. Capacity and Technology

Considering the size of the challenge ahead, the **relevant institutions are highly understaffed**. Thus, for the transformation of the transport sector as well as its repercussions on, in particular, energy, industry and demand for resources, there is a **lack of personal and experts** in implementing agencies and ministries on urban, regional and national level in developing as well as in developed countries. Without well-trained and experienced government officials, planners and engineers with knowledge on sustainable transport, however, developing and implementing comprehensive sustainable transport policies and programmes for net zero transport will not be feasible. Also, in cities, regions or countries with a **lack of adequate data, knowledge on MRV and capacities to conduct high quality ex-post impact assessments**, impacts of policies and measures may not be monitored in a structured fashion. This may result in misconceptions about the necessity and effectiveness of policies, prevent revisions and fine-tuning, and hinder effective and efficient emissions mitigation. Developing adequate personnel, however, takes time, which is of the essence when net zero transport is the goal. It should be noted that this barrier is aggravated by a general lack of knowledge and capacity in relation to, inter alia, (the acceptance of) objective information about climate change and its impacts as well as low-carbon options and their benefits among the general public, on the one hand, and among political decision-makers, on the other hand.

Besides a lack of capacity, huge barriers also result from the **non-availability of required and/or supporting low-carbon technologies**, in particular regarding long-distance travel. The situation is particularly dire in least developed countries. Thus, for example, a lack of electricity, charging and servicing infrastructure for electric vehicles hampers the electrification of the transport sector substantially and slows down the decarbonisation of the vehicle fleet. Furthermore, the **large amount of energy from renewable sources required for the**

electrification of the transport sector is a significant challenge (see chapter 2.6), and the electricity grid needs to be adapted to be able to cope with increasing loads and shifts in the demand profile that will result from the shift to electric vehicles. While this is already the case regarding emission reduction targets compatible with 2°C, it is even more so for net zero transport.

Technological barriers also exist, however, in other areas relevant for the transport sector, e.g. in **information technology and data**. Thus, for example, insufficient broadband in some regions prevents enhanced communications to reduce the need to travel (Sims et al. 2014). This is, inter alia, the case in the Philippines where the internet has a low reach and is relatively slow and expensive.

3.3. Finance and Economy

Overcoming the technological barriers identified requires substantial **finance and access to capital** – another significant barrier to net zero transport, which requires the full exploitation of available technologies. In particular for efficiency improvements, the switch to zero emission technology and infrastructure in transport, this problem is prevalent. Thus, even local governments aiming at decarbonising the transport sector are frequently underfunded and many cities are unable to meet requirements for loans or grants. In many cases, it is difficult to involve the private sector because of the limited capacities of local governments to effectively manage and structure public private partnerships (PPPs); Asset management regulations and high transaction costs further complicate endeavours. Therefore, cities often do not have adequate revenues to invest sufficiently in effective spatial planning as well as (improvements of) walking, cycling and public transport infrastructure and systems. The situation is aggravated by the COVID crisis, which further strains city budgets with rising health costs and a dent in public transport.

The barriers to net zero transport resulting from existing settlement patterns and infrastructure often lock in high levels of transport demand for unsustainable modes (see chapter 1.2). **Changing as well as building new sustainable infrastructure requires substantial efforts as well as time and money**, which are limited. It is, however, essential to invest in safe, high-quality infrastructure and conditions to facilitate non-motorized and intermodal public transport, as their lack is a key driver of individual motorisation in countries which currently have high levels of walking and cycling (Marrakech Partnership 2021b). Due to COVID-19, active mobility has become more attractive since early 2020, leading to additional efforts to increase active mobility infrastructure in many cities. For example, in India cycling has increased by 17% due to COVID-19. However, infrastructure for cyclists in India is still highly underdeveloped and unsafe. Also, the currently non-existing or minimal rail network in many countries prevents shifting transport to rail, as is the case in Brazil.

Barriers not only result from currently employed technology and existing infrastructure but also from **current patterns of industrial production**. In many countries, large shares of the industry sector will have to be transformed, inter alia, the automobile industry in developing countries and the extractive industry in developing countries. This causes friction – not least regarding jobs. On top, there is a high market segmentation in many developing countries, and small firms focusing on

zero-emission technologies face **high information and market-structure barriers**, preventing their success.

3.4. Acceptability and Individual Preferences

Besides barriers relating to governance, technology, capacity, finance and the economy, social barriers hamper transformations required for net zero transport. Thus, for example, the **lack of knowledge and awareness** regarding climate change issues amongst the general population leads to misconceptions such as the assumption that electrification of vehicles alone will suffice to decarbonise transport. This, again, prevents policies and measures required for net zero transport from being accepted.

In general, **people resist changing their habits and consumers are slow to accept new technologies**. Currently, there are widespread consumer preferences for car-based comfort compared to public transport which may be (perceived as) uncomfortable and poor regarding its levels of service. On top of passengers' lack of willingness to compromise on travel time and convenience (Council of Decarbonising Transport in Asia 2022), individual car ownership still has significant status value for many and is attributed to a certain lifestyle, adding to the attractiveness of car ownership beyond its purpose of providing mobility. **High levels of car dependency**, however, are a significant barrier to structural change aimed at reducing travel demand and at a modal shift towards walking, cycling and public transport (RTPI 2021b).

Also, **consumers are not willing to pay for and perceive financial barriers to zero/low-carbon mobility**. While the purchasing costs of zero-emission vehicles are higher than those of conventional ones, they may have an amortisation rate that makes the initial investment pay off after some time. However, consumers prefer short amortisation rates and apply discount rates as high as 20% while cost-savings from fuel efficiency beyond 2 to 3 years hardly factor into car purchase decisions. Unfortunately, the huge economy-wide benefits of net zero emission transport are not of great relevance for the purchase decisions of most consumers. Furthermore, the driving range is a concern for consumers considering the purchase of an electric vehicle.

Moreover, for fear of **public resistance** and not being elected to office again, **political decision-makers shy away from (openly supporting) choices for the transformative change that is required to achieve net zero in transport**.

Not only legacy automakers, who have made substantial investments in conventional vehicle technology, delay the shift to zero-emission vehicles to be able to extend the skimming of profits from vehicles with combustion engines, but also, inter alia, the ethanol lobby in Brazil as well as current bus and taxi operators who may be threatened by the introduction of organised public transport and new company structures. Thus, for example, in Peru, strong social and political conflicts around the formalisation of transport services cause friction.

There are still many actors who benefit from the current state of play and are not willing to recede. This leads not only to activities that hinder but even contradict policies and measures desperately needed for achieving net zero transport. In most countries, there are not even effective discussions centring on key aspects of avoiding and shifting transport yet. A mere focus on technological improvements and

electrification, however, will not suffice to reach the envisaged goal, in particular when this goal is net zero transport.

Figure 4 provides an overview of the key barriers identified for a transition towards net zero transport.

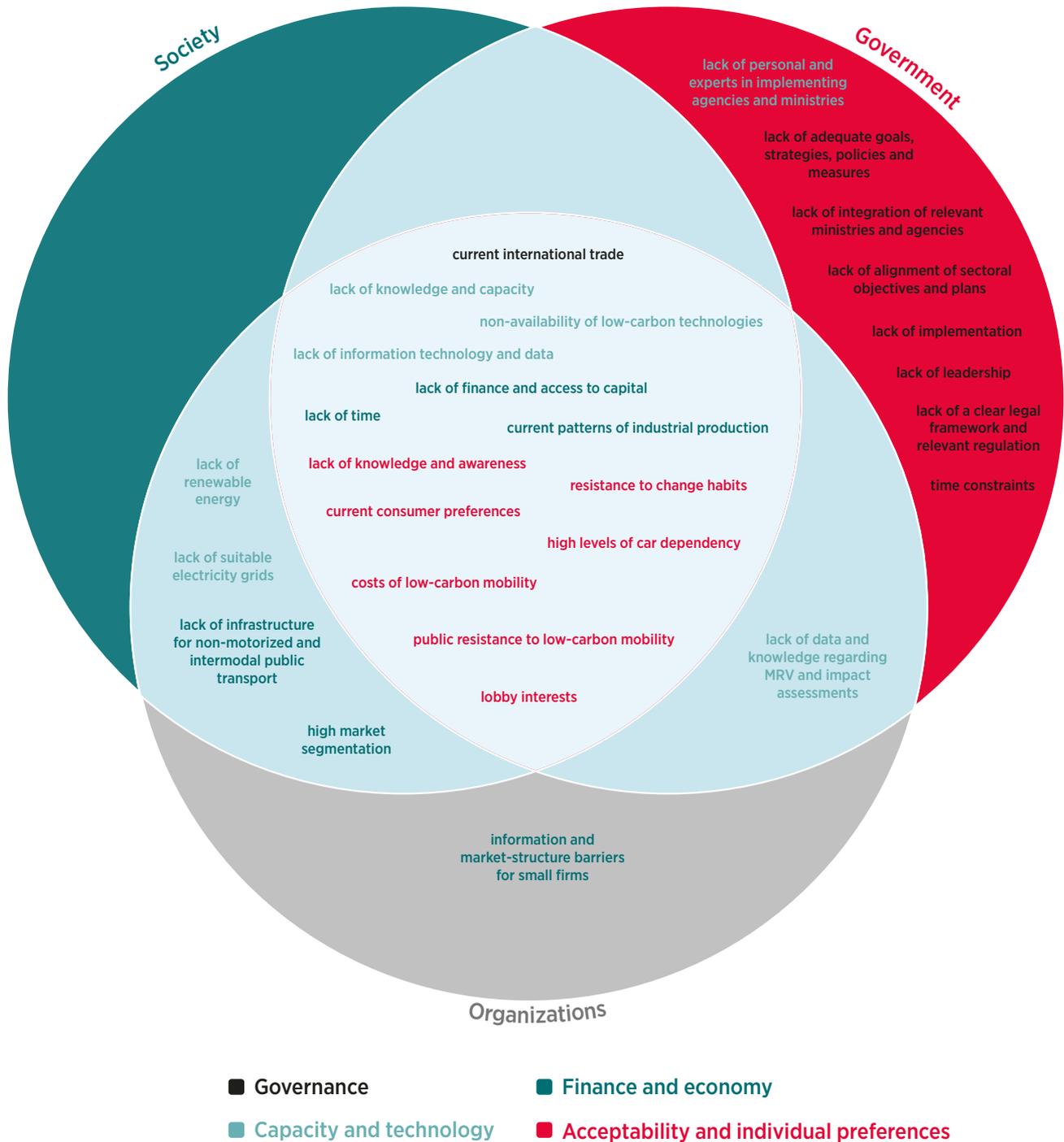


Figure 4 Barriers for Net Zero Transport (own illustration)

4. Moving Transport to Net Zero: Policy Recommendations

As described in chapter 1.2, moving transport to net zero emissions is possible but challenging and has to entail both a mobility transition that reduces energy consumption without limiting mobility, and an energy transition in transport which allows the transport sector to securely cover remaining demand with carbon-neutral energy. Achieving net zero transport therefore requires more systematic action than just reducing emissions with individual transport policies. A transport pathway towards net zero also has to strive for realising synergies with goals in other sectors as well as for maximising sustainability benefits of measures, and requires a reporting system to constantly assess and review progress towards the goals. Furthermore, all existing barriers have to be tackled at some point. This chapter provides policy recommendations on what is needed to move transport to net zero.

1. Adapt Decarbonisation Strategies to Different Transport Sub-sectors

Emissions reduction potentials and challenges vary significantly between transport sub-sectors. Adapting strategies to circumstances is therefore central – not only regarding local circumstances. Thus, while in urban passenger transport, avoiding unnecessary travel and shifting trips to active and public transport is key, technological improvements may be at the heart of regional and intercity transport decarbonisation with only limited options to reduce non-urban transport demand. To reduce emissions in freight transport, zero-/low-carbon technologies are essential, combined with the enhancement of system efficiency in freight and logistics (ITF 2021, Vieweg et al. 2021).

When adapting decarbonisation strategies to different transport sub-sectors, goals have to be operationalised individually, and backcasting should be used to decide on appropriate goals, strategies, policies and measures. This includes visioning the future desired conditions in transport (e.g. the envisaged reductions of vehicle fleets due to reduced travel demand) as well as in related areas such as land use planning and the energy sector to provide clear guidance for the transformation, followed by identifying steps to reach these conditions. Progress towards the achievement of the vision should be assessed and reviewed constantly to ensure achievement of the goals.

2. Prioritise and Significantly Increase Investment in Zero-/low-carbon Infrastructure

To tackle the barriers regarding infrastructure and support net zero transport, reduce transport demand, and make active travel and intermodal public transport the obvious choice, huge investments will not only have to be made in infrastructure for walking, cycling and intermodal public transport, but also in communication infrastructure, sustainable rail, waterways and multimodal hubs, both for passenger and freight transport. In this endeavour, low-cost options optimising existing systems (e.g. avoiding empty truck runs, sub-optimal routing, and under-utilised rail tracks) should not be neglected (Council of Decarbonising Transport in Asia 2022).

Due to its level of ambition, for net zero transport, the focus has to be on transforming systems instead of on individual components within transport, as such an

approach will be much more effective. Easy access to mobility should be prioritised, not increasing capacity (ITF 2021). Divesting money from fossil fuels and high carbon infrastructure as quickly as possible is essential for being able to reach net zero transport.

3. Massively Invest in the Development and Roll out of Zero-/low-emission Technologies

To accelerate innovation and bring down the costs of zero-/low-emission technologies to an economic level – in particular regarding the electrification of the transport sector – massive investments in development as well as in field testing and the roll out of these technologies and their applications are required.

To be able to reach net zero transport, technologies such as green hydrogen and green synthetic e-fuels will have to be employed at large scale for aviation and maritime transport, as there are no other options for their decarbonisation. In some cases, the direct use of hydrogen may be an option for heavy duty vehicles. As there is no room left for detours, investments should be channelled directly to the least carbon-intensive options and breakthrough technologies, within as well as beyond the transport sector.

4. Focus on a Just Transition to Overcome Social and Political Barriers

To be able to reach net zero emissions in transport at a global level, unprecedented transformative change is required. Such transformative change is only feasible with collective action and support from all stakeholders. To get the general public on board, a just transition including broad stakeholder engagement is of the essence. Working groups, round tables or national platforms for stakeholder input on sustainable transport can not only enrich the development of future mobility systems (Vieweg et al. 2021) but also reduce resistance to transformative action. In this process, non-transport sectors and private actors should be included, as many of them are inseparably linked to transport decarbonisation (ITF 2021). Also, a clear and attractive vision of the future of mobility and zero-carbon neighbourhoods as well as an understanding of the substantial benefits to different stakeholders will reduce resistance among local communities (RTPI 2021b). Pilot neighbourhoods, living labs and testing of measures at large scale (e.g. pop-up bike lanes for an entire city) may advance the cultural change that is required for the success of the transformation and convince both decision-makers and communities that change is possible – and appealing. Focus should be put on the significant sustainability benefits that a transformed transport system entails.

While there are many who will benefit from net zero transport, legacy automakers and their employees as well as current bus and taxi operators, for example, may be affected negatively by the transformations required. To achieve a just transition and reduce resistance, it is essential to organise the structural changes necessary to leave no one behind and plan for the future of those that are negatively affected. Strong communication channels between companies, consumer, universities and government labs should be established and used to enhance these processes. The German Commission on Growth, Structural Change and Employment may be a good example for such a process. It consisted of representatives from politics, the economy and

trade unions as well as from the scientific community, think tanks, environmental non governmental organizations (NGOs) and citizens' initiatives, and developed recommendations on the phase-out of coal in Germany as well as measures on social and structural development in areas where brown coal extraction is to come to an end. Despite valid criticism on its process and outcome, it has managed to integrate different stakeholders into important decision-making processes, and brought about a collective understanding regarding the challenges involving respective structural change.

Furthermore, for the transformation to net zero transport to succeed, the vision of, mandate for and responsibilities regarding net zero transport have to be made clear, shared and supported at all levels of governments. At international level, this implies a commitment to net zero emission targets and, for example, the engagement in the Transport Climate Action Initiatives launched at COP26 as well as the UNFCCC's Race to Zero campaign. On national level, sound sectoral plans have to be developed for decarbonising transport, and the local level should, in particular, focus on changing infrastructure to avoid transport and incentivise shifts to zero-/low-emission modes of transport.

Strong, effective leadership has to support the definition and implementation of goals, strategies and policies. A Ministry of Decarbonisation could boost mitigation efforts both at central, regional and local levels of government (RTPI 2021b) and support achieving better coordination and integration of ministries and agencies to align policies and measures, in particular those relating to transport, land-use and environment. In Germany, current efforts to integrate climate policy with the economy in the recently renamed German Federal Ministry for Economic Affairs and Climate Action are an example for an approach leading in this direction. National frameworks and investment programmes should support and empower cities in setting intermediate goals and in following a phased course towards building sustainable transport systems (Vieweg 2021).

5. Increase International Support and Cooperation

To significantly reduce the barriers regarding required technology, finance and capacity, international support and cooperation – as furthered, inter alia, with the above mentioned Transport Climate Action Initiatives and the Race to Zero campaign – will have to play a central part, for both developing and developed countries. To put net zero transport into reach, international support and cooperation have to increase considerably, enabling developing countries to leapfrog directly to sustainable transport systems – there is just no time left for detours.

International governance institutions cannot only provide guidance and signal to align actors across countries, set rules, and foster transparency and accountability in this endeavour, but can also provide means of implementation (capacity building, technology transfer, and financial resources) and enhance knowledge and learning (Oberthür et al. 2021). International support for developing countries may be delivered via international institutions such as the Green Climate Fund, processes such as the development of (new) NDCs, a club of frontrunners, but also via bilateral agreements of support and the involvement of international experts for policy advice, organisational or institutional development, or training measures Lessons learned and

best practices, for example those made within nationally appropriate mitigation actions (NAMAs), should be shared to improve the development and implementation of policies and measures for net zero transport. Furthermore, mitigation costs as well as potential conflicts with international trade rules and carbon leakage may be reduced by coordinated actions among countries and sectors. International cooperation and collaboration are especially important regarding efforts to significantly reduce emissions from shipping and aviation (IEA 2021), but also to ensure sufficient supply of required raw materials such as lithium and cobalt (Agora Verkehrswende 2017). Without substantial international support and cooperation, reaching net zero transport will not be feasible.

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