Electrifying Transport – A Global Perspective

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1 Introduction

The Paris Agreement aims to achieve climate neutrality i.e. a balance between the anthropogenic greenhouse gas (GHG) emissions and GHG sinks by the mid of this century. Since energy consumption is responsible for roughly three quarters of the global GHG emissions, there has always been a strong focus on the related GHG sources. The focus on the climate debate so far has been on electricity generation, but in the last years, also the future mobility is gaining increasing attention[1].

The main technology options to achieve climate neutrality in the transport sector are electrification (electro-mobility, fuel cells or e-fuels i.e. liquid or gaseous synthetic fuels produced with electricity) and biomass. The electrification route is connected with power consumption, i.e. it will contribute to the Paris climate goal by using climate-neutral electricity production. A third option to achieve climate-neutral fuels is the combination of classic fossil fuels with carbon dioxide removal technologies (see **Figure 1**).

Apart from technological solutions, also behavioural changes can induce a reduction of mobility-related emissions e.g. by using public transport, changes in global supply chains, new work approaches and digital communication. However, in the end, this will reduce the demand for transport, but still necessitates the development of climate-neutral transport technologies.

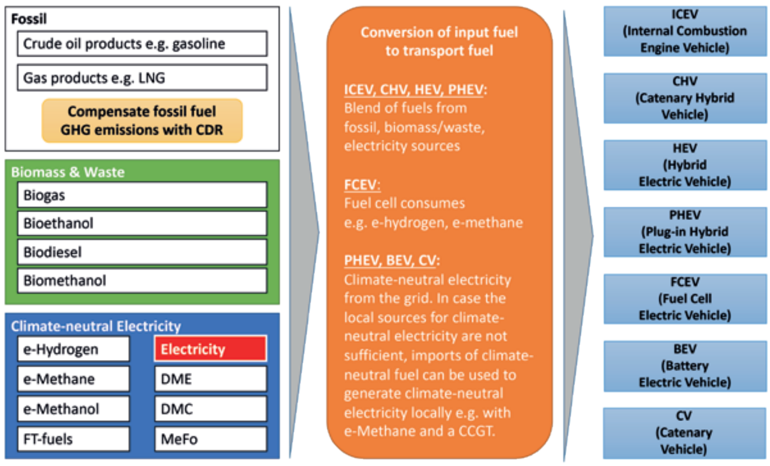

Fig. 1.
Electrification is part of the solution for climate-neutral transport. This does not only include electro-mobility, but also the production of synthetic fuels using climate-neutral electricity. The most common power trains are on the right side.

2 Transport – current situation

Transport-related CO_2 emissions (in total 8.1 Gt) have a share of 21 % of the global GHG emissions in 2018. Since 1990 they increased by 77 %. The top-20 transport emitters incl. International Aviation and International Shipping are responsible for 82 % of the global transport emissions. The three biggest transport emitters in 2018 were the United States (1.8 Gt), China (0.94 Gt) and India (0.29 Gt). The three biggest relative increases in transport emissions since 1990 took place in China (780 %), Indonesia (374 %) and India (348 %)[2].

In 2018, transport-related energy consumption has a share of 29 % of the global energy consumption (the latter is 9,938 Mtoe resp. 115,579 TWh resp. 416,104 PJ)[3]. For comparison, the global electricity consumption in 2018 was 22,135 TWh globally (i.e. 19 % of the global energy consumption). This clearly indicates the challenge of electrifying transport as a whole, though for a rigorous comparison the efficiencies of the respective transport fuel and the corresponding engines need to be taken into account. The IPCC mentions in their report an overall efficiency for mobility of 32 % globally[4], i.e. for 35,000 TWh energy input a mechanical energy of 11,200 TWh would result. Consequently, for engines with higher efficiency, the total demand for energy (including losses) would also decrease tremendously.

Fossil fuels dominate the fuel mix of global transport heavily[5]. The current contribution of electricity to transport globally is less than 2 %.

Transport shows a higher overall energy use for passengers (60.7 % of total energy consumption for transport) in contrast to freight (39.3 %). For the modes of transport, the global picture shows that the light-duty vehicles are responsible for almost three quarters of the passenger related energy consumption (72.1 %), air transport for 16.9 %, bus for 6.3 %, rail for 1.9 % and 2/3-wheeler for 2.7 %. Concerning freight, truck transport (heavy, medium and light) is responsible for 69.6 % of the freight related energy consumption, marine for 18.1 % and rail for 5.5 %.

Transport is very important for society. Firstly, for economic reasons: transport enables the extension of value chains across the globe and facilitates international trade. Secondly, private transport is a human right: Article 13 of the Universal Declaration of Human Rights asserts the freedom of movement. Consequently, finding climate-friendly solutions for transport is of utmost importance in order to maintain these benefits for human society in a sustainable way.

1 Weltenergierat Deutschland, Energy for Germany 2020 (Pathways to Climate Neutrality) and Energy for Germany 2018 (Climate Protection in Road Traffic)

2 Calculations based on figures by Crippa, M., Oreggioni, G., Guizzardi, D., Muntean, M., Schaaf, E., Lo Vullo, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J.G.J., Vignati, E., Fossil CO_2 and GHG emissions of all world countries – 2019 Report, EUR 29849 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-11100-9, doi:10.2760/687800, JRC117610.

3 IEA, World energy balances 2020: Overview, Paris, July 2020.

4 Sims R., R. Schaeffer, F. Creutzig, X. Cruz-Núñez, M. D'Agosto, D. Dimitriu, M. J. Figueroa Meza, L. Fulton, S. Kobayashi, O. Lah, A. McKinnon, P. Newman, M. Ouyang, J. J. Schauer, D. Sperling, and G. Tiwari, 2014: Transport. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

5 EIA, International Energy Outlook 2019 with projections to 2050, September 2019

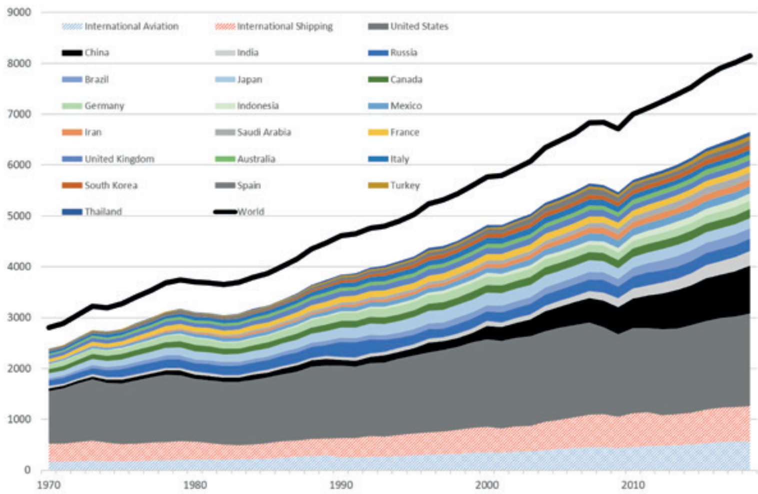

Fig. 2.
Transport-related CO_2-emissions (2018; based on data by EDGAR).

3 Technology Options

3.1 Transport modes

The various transport modes need different technological answers to become climate neutral. For light-duty vehicles (LDVs) i.e. cars, sport-utility vehicles and even small trucks, battery electric vehicles are one key technology. Furthermore, fuel-cell electric vehicles and even the classic internal combustion engine vehicle have the opportunity to become part of the solution, provided the production of the fuel is climate-neutral, as is the case with the so-called blue and green hydrogen. Hence, carbon neutral LDV transport is ensured by climate-neutral electricity production.

For the freight transport by trucks, ships and trains the path to climate neutrality is less straightforward. Some emission reduction will result from the use of biofuels for trucks and ships and efficiency gains in parallel. A fuel switch to electricity is a viable option for freight trains and delivery trucks. Fully electric trucks could also work for a major part of light and medium-duty trucks with typical operational distances of up to 200 kilometres per day. For heavy-duty trucks battery-electric solutions are developed as well as alternative fuels e.g. hydrogen for fuel cells or synthetic fuels (also called synfuels or e-fuels) for internal combustion engines. With PtL-production (Power-to-Liquid), climate-neutral electricity will then also be the cornerstone for decarbonized freight transport.

For aviation, there are currently four technology options under discussion: electric aircrafts, biofuels, e-fuels and classic fossil fuels combined with carbon-dioxide-removal (CDR) technologies. The further technological development will decide about the winning technologies and their contribution. Similarly, for international maritime transport e-fuels and biofuels are existing solution. In both cases, technical requirements of the transport mode make e-fuels inevitable.

The driving force for alternative fuels in the transport sector is no longer the fear, that the world will run out of fossil fuels like oil and gas, but the requirements of the Paris agreement to become climate-neutral by the mid of this century. Apparently, not only electric vehicles will lead to new demand for electricity by the future climate-neutral transport – but also the e-fuels. Hence, it is instructive to look at these fuels in more detail.

3.2 Synthetic fuels

Electrolysis of water produces hydrogen, sometimes called e-hydrogen. The hydrogen can be used directly in both gaseous and liquefied form. In motor vehicles, fuel cells are used in combination with electric motors. Gaseous hydrogen, which is stored in a pressure tank, is currently used in cars.

With the so-called methanation the e-hydrogen and carbon dioxide react to produce methane. Since natural gas overwhelmingly consists of methane, it can be completely substituted by e-methane – and the existing infrastructure for natural gas (pipelines, LNG facilities) can immediately be used. Since (fossil) natural gas already serve as a transport fuel for trucks, busses and ships, there is also the opportunity to blend the natural gas with e-methane and reach the climate goals in a stepwise process. Additionally, bio-methane is a second source for climate-neutral methane. Given the already existing international gas transport infrastructure, synthetic methane would immediately allow international optimization of its production – and increase the security of supply by offering various sources.

The e-hydrogen can also serve as raw material for methanol synthesis. Methanol is a fuel on its own or can be blended with gasoline for internal combustion engine vehicles. However, also fuel cells can work with methanol. Methanol is one of the mostly produced organic chemicals worldwide, i.e. there is also some transport infrastructure present.

With the Fischer-Tropsch synthesis and the e-hydrogen as raw material, any petroleum-based fuel can be produced e.g. kerosene. In comparison with the use of e-hydrogen, the Fischer-Tropsch fuels would be available for immediate use in the current transport framework.

Further technologies are DME synthesis (Dimethyl ether), OME synthesis (Oxymethylene ether) and other oxygen-containing energy sources as dimethyl carbonate (DMC) or methyl formate (MeFo).

It should be noted, that synfuels typically have a lower energy density compared with their conventional fossil equivalents. For OME it is roughly 50 %, i.e. double the volume is needed. The production of e-fuels consumes electricity. In the literature, a broad range of energy consumption is given, depending on the used technology and its current efficiency[6].

Fuel	Min	Max
Hydrogen	1.23	1.72
Methane	1.54	2.00
Methanol	2.08	2.33
FT-fuels	1.55	2.78
OME	2.70	3.03
DME	1.96	2.22

Tab. 1.
Electricity consumption in kWh per kWh produced fuel.

The production of synfuels costs additional amounts of energy in comparison with a battery electric vehicle. Additionally, the efficiency of internal combustion engines is typically worse than fuel cells or electrical engines. These arguments would clearly put EVs in favour. However, using EVs necessitates regional electricity production

6 Source: FfE, Welche strombasierten Kraftstoffe sind im zukünftigen Energiesystem relevant? (6th Feb 2019)

and grid transport, which often leads to challenges with regards to social acceptance. Furthermore, it might also make economic sense to produce the synfuels at sites not only with high social acceptance for climate-neutral electricity production but also with excellent conditions e.g. with high full-load hours for wind or PV generation. The overall production costs for imported synfuels might then be lower than local electricity production.

Currently politics in many countries concentrate on battery solutions for transport, since they view e-liquids and e-gases as mainly important for the industry sector. This might change over time, learning how realistic battery solutions will be for all modes of transport and for all countries.

Synthetic fuels could also become interesting for use as fuel for power plants e.g. e-methane for CCGTs, if the goals for climate-neutral power generation cannot be met in one country or region due to e.g. missing social acceptance.

4 Global scenarios

4.1 World Energy Scenarios 2019

In its 2019 version of the World Energy Scenarios[7], the World Energy Council emphasized, that the total energy demand for mobility is driven by the dynamic development of population and GDP growth that is offset by efficiency improvements. All three scenarios of the WEC – with their names Unfinished Symphony, Modern Jazz and Hard Rock – see a co-development of EVs, ICE efficiency, ride sharing, autonomous vehicles and new modes of transport is already fundamentally reshaping personal transport demand. In the two scenarios Unfinished Symphony and Modern Jazz the energy demand growth is limited to 2040, based on the rapid price reduction of EVs, achieving sales price parity with ICEs by 2030. This development accelerates the penetration of EVs. Commercial transportation will experience a decreasing energy intensity due to more efficient engines and a rise in the use of alternative fuels such as biofuels and hydrogen. With these changes, by 2040 electricity and hydrogen capture 10-16 % of total energy consumed by transport in Unfinished Symphony and Modern Jazz.

The scenario Hard Rock differs notably in that the weaker global policy coordination of fuel and efficiency standards and limited technology transfer result in a much slower uptake of EVs and alternative fuels. Consequently, the transport sector experiences energy demand growth of 28 %, and oil remains the dominate fuel.

Hydrogen emerges in all three scenarios by 2040 to a notable extent in the overall energy mix. This is driven by excess renewable power generation in Modern Jazz or by security of supply concerns in Hard Rock.

4.2 EIA International Energy Outlook 2019

The EIA reflects in their reference case current trends especially concerning economic and demographic development, but does not anticipate future technological breakthroughs.

Demand for transportation grows in non-OECD countries and is rather flat in OECD-countries. In non-OECD, transportation energy demand increases by 77 % from 2018 to 2050. In OECD countries, the interplay between improving vehicle fuel efficiency and growing demand result in a total projected transportation energy use declining by 1 % from 2018 to 2050. Consequently, by 2050 non-OECD accounts for almost two-third of the world's transportation related energy use. Main driver in non-OECD is the growth in passenger travel. The EIA reference case starts with a transportation energy demand of about 35,433 TWh (2018) and ends in 2050 with 49,001 TWh.

The share of transportation fuels from alternative energy sources increases, but sill oil-based products dominate the transport fuel mix: Within the transportation sector, the use of refined petroleum and other liquid fuels continues to increase through 2050, but its share decreases from 94 % to about 82 % as alternative fuel use slowly increases. The primary fuel for transportation is motor gasoline (including additives as ethanol) and accounts in 2050 for 32 % of the world's transportation-related energy. Air travel demand continues to rise globally leading to a doubling of jet fuel consumption from 2018 to 2050.

The fastest growing forms of transportation energy are natural gas and electricity. The EIA scenario projects an increase in OECD of LDVs from 3.5 million vehicles (2018) to 169 million vehicles (2050) and in non-OECD from 2.2 million vehicles (2018) to 260 million vehicles (2050). Consequently, the share of electricity used in transportation almost triples, also due to higher electricity use for rail transport. Nevertheless, transportation accounts for less than 6 % of total delivered electricity consumption in 2050.

For comparison: the 2050 electricity consumption in transport of 2,465 TWh is higher than the combined global wind (1,429.6 TWh) and PV production (724.1 TWh) in

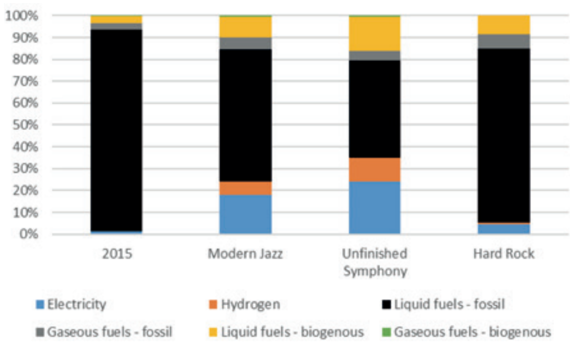

Fig. 3.
The fuel mix for transport in 2060 in the three world energy scenarios. Also in 2060 fossil fuels will have in the optimistic scenario a high share in the fuel mix.

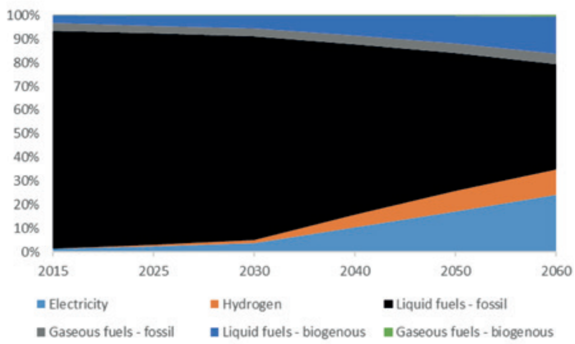

Fig. 4.
The scenario unfinished symphony shows the highest electricity share for transport. Especially, after 2030 the economics for electric transport solution improves substantially.

7 World Energy Council, World Energy Scenarios 2019 – Exploring Innovation Pathways to 2040 (London 2019)

2019[8]. Consequently, also the not very ambitious electrification of transport in the EIA reference case would necessitate stronger investments in renewable generation in order to cover the transport demand by renewables.

Fuel	2018 in TWh	Share in %	2050 in TWh	Share in %
Motor gasoline	14,181	40.0 %	15,911	32.5 %
Diesel	12,717	35.9 %	13,532	27.6 %
Jet Fuel	3,740	10.6 %	8,616	17.6 %
Residual Fuel Oil	2,362	6.7 %	1,687	3.4 %
Natural Gas	1,583	4.5 %	6,536	13.3 %
Electricity	479	1.4 %	2,465	5.0 %
LPG	248	0.7 %	142	0.3 %
Other Liquids	122	0.3 %	112	0.2 %
Sum	**35,433**	**100.0 %**	**49,001**	**100.0 %**

Tab. 2.
EIA reference case evolution of transport fuel consumption between 2018 and 2050.

4.3 BP Energy Outlook 2019

The BP Energy Outlook 2019[9] also emphasizes that the efficiency gains limits the energy demand in a strongly growing transport sector. The lion's share of efficiency gains will occur in road transport – both passenger and freight – whereas the efficiency gains in maritime and air transport are limited. Growth centre for transport in the BP scenarios is Asia.

In the "Evolving transition"-scenario, oil continues to be the dominating energy source declining from 94 % to 85 % by 2040. Electricity would provide around 5 % in 2040 (corresponding to 1,725 TWh). This corresponds to a number of electric vehicles of around 350 million by 2040, of which around 300 million are passenger cars i.e. 15 % of all cars. Since electric vehicles will do shared-services largely, around 24 % of passenger vehicle kilometres are electric in 2040.

BP also developed a "Lower-carbon transport" scenario including a large number of measures to reduce carbon emissions, in order to address climate concerns. These measures incentivize fuel switching towards electricity leading to half of the reduction in emissions relative to the "Evolving transition"-scenario. Due to these measures, the electrification of vehicle kilometres will increase from 24 % to 37 %. This scenario clearly indicates that legislative and regulatory activities can have an enormous positive impact on electrification of transport.

4.4 Shell Sky Scenarios[10]

One of the pioneers in scenario work is the oil major Shell. In 2018, Shell published the Sky scenario illustrating a pathway for society to achieve the goals of the Paris Agreement. Transport also plays a key role in this scenario. Sky describes a very rapid transition where more than half of global car sales in 2030 are electric, and all passenger car sales by 2050. Since the whole energy system in this scenario is based on electricity, the global electricity consumption will increase to roughly 100,000 TWh per year. The transport sector in 2050 consumes 7,133 TWh electricity.

4.5 IEA EV Outlook 2020[11]

The IEA report mentioned that in 2010, globally only about 17,000 electric cars were present. However, this figure increased to 7.2 million electric cars by 2019 – with almost half of the electric cars in China. IEA considers two scenarios: Stated Policies Scenario (SPS), incorporating existing government policies, and the Sustainable Development Scenario (SDS), which is fully compatible with the goals of the Paris Agreement. Electric vehicles play a crucial role to meet the climate goals and to address local air pollution. Within SDS, the global electric vehicle stock (excluding two/three-wheelers) increases by 36 % annually, leading to 245 million vehicles in 2030 i.e. over 30 times above today's level. Other than two/three-wheelers, growth is strongest for LDVs. The electricity consumption connected with electric vehicles would be 1,000 TWh globally. In the SPS, the global electric vehicle stock (excluding two/three-wheelers) reaches nearly 140 million vehicles by 2030 and accounts for 7 % of the global vehicle fleet. This translates into an electricity consumption of 550 TWh.

4.6 WEC PtX-roadmap

The Weltenergierat Deutschland addressed the international aspects of PtX-technologies in a recent report[12]. The report does not only consider the use of PtX for transport, but also e.g. for heating and cooling or industry.

The report emphasizes the major advantage of a global PtX market for synthetic liquid fuels (such as diesel, heating oil, gasoline, kerosene, methanol) and synthetic gases (such as hydrogen or methane): they can be fed into the current energy system with existing infrastructure. This might be especially interesting in densely populated areas, where the regional demand for energy is rather high, but the opportunities are limited to produce climate-friendly electricity in this region. Consequently, energy imports will pave the way for a climate-friendly transformation of the energy system.

The report considers three different scenarios with a low case (10,000 TWh annual global PtX demand), reference case (20,000 TWh) and the high case (41,000 TWh). A rough calculation shows, that an annual production of 20,000 TWh requires 8,000 GW installed PtX-capacity.

The biggest export potentials are attached to countries like e.g. Russia, Canada, US, South Africa, Saudi Arabia or China.

4.7 Wrap-up of the scenarios

The scenarios show that oil-based transport will have a substantial share in the next decades, unless very strong political action will be taken. Since most of the transport growth will take place in non-OECD, the global picture will be determined largely by Asia.

Note, that there could also be electricity consumption due to PtX, which is not made visible in each scenario. So far, the consideration of electro-mobility concentrated on the demand for electric energy, not on the load. For the latter it is assumed, that digitalisation will lead to situations where simultaneous loading is avoided in order to maintain the grid stability.

8 BP Statistical Review of World Energy 2020 (69th edition), London 2020
9 BP Energy Outlook 2019 edition, London (2019)
10 Shell
11 IEA, Global EV Outlook 2020, Paris (June 2020)
12 Weltenergierat Deutschland, International Aspects of a Power-to-X roadmap,Berlin (2018)

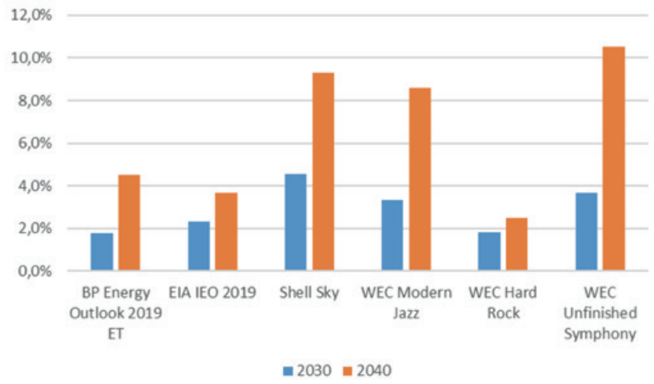

Fig. 5.
The share of electricity in the global transport fuel mix 2030 and 2040.

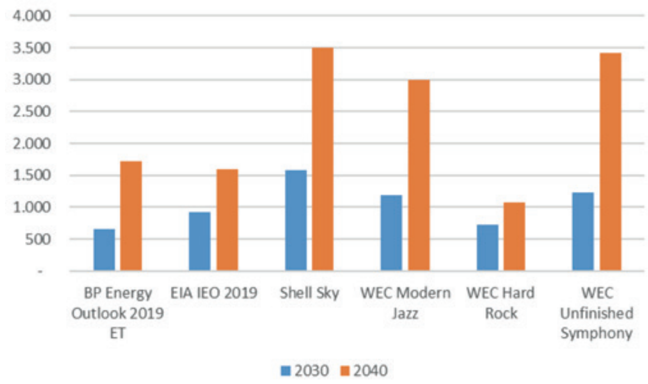

Fig. 6.
Global electricity consumption in transport for 2030 and 2040 in various scenarios.

5 International Development

5.1 G20 Transport Task Group

Within the G20-countries, the Transport Task Group (TTG) was established to reduce energy demand and environmental impacts of transport and to enable best practice exchange among the G20-countries about measures. A strong focus is put on heavy-duty vehicles. A good overview of the activities in the G20-countries has been published recently (giz et al., Towards Decarbonising Transport 2018 – A Stocktake on Sectoral Ambition in the G20, November 2018). This initiative clearly shows, that the transport sector is in the beginning of a transformation. Some of the G20-countries already declared some political targets or published even laws regarding future transport technologies. The G20 members account for 85 % of the world economy and 75 % of global trade, consequently they are responsible the lion's share of global transport activities.

5.2 Clean Energy Ministerial EV30@30

The Clean Energy Ministerial (CEM) initiated a deployment campaign specifically for electric vehicles. The initiative targets at least a share of 30 % EVs of the total vehicle sales by 2030. This initiative concentrates on electric passenger cars, light commercial vans, buses and trucks – including BEVs, PHEVs and FCEVs.

5.3 CORSIA

For air transport the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is in place as one mean to achieve the industry's commitment to carbon neutral growth from 2020 ("CNG2020"). Under CORSIA, airlines will be required to buy carbon offsets to compensate for their growth in GHG emissions. These offsets are generated by carbon reduction projects in developing countries. All airlines operating international flights are mandated to monitor their fuel consumption emissions. Of course, this is only a first step towards a fully carbon-neutral air transport.

5.4 Country examples

The various G20-countries consider various instruments in order to trigger changes in the transport segment e.g. technology standards for emissions and/or efficiencies, tax incentives for purchasing the vehicle and/or the fuels, technology bans, alternative fuels. For the recently often announced ICE bans in various jurisdictions, it is still possible, that this ban will be relaxed, provided synfuels or biofuels will be used. Other countries have high shares of biomass-based alternative fuels, making a phase-out of ICEs rather unlikely – at least in the near and medium term.

- **Argentina** mainly concentrates on biofuels (mandatory share of 12 %) and on incentivizing public transport. The interest in electromobility is limited.
- **Australia** has currently no explicit national policy, but state policies, that vary strongly. None of these state policies has a general EV target. However, there is a strong interest in exporting climate-neutral hydrogen especially to the Asian markets e.g. Japan.
- **Brazil** – similar to Argentina – has no explicit electric vehicle implementation goals, but a mandatory share of 27 % for bioethanol in gasoline and a mandatory share of 12 % for biodiesel.
- **Canada** has set zero-emission vehicle targets of 100 % of new vehicle sales by 2040 with intermediate steps of 10 % ZEV sales by 2025 and 30 % by 2030. In 2019, the ZEV sales share was 3.5 %. An analysis by the Canadian government assumes a higher electricity demand of 30 TWh annually by 2040. In parallel, also biomass will contribute a similar amount of transport energy. Canada is also a member of CEM EV30@30.
- **China** is a member of CEM EV30@30 Initiative. Additionally, China has the target of 25 % sales of PHEV, BEV, FCEV by 2025. A study by State Grid China assumes 50 million EVs in China by 2030 with a total electricity demand of 200 TWh. A recent report from the Innovation Centre for Energy and Transportation (iCET) made the first public proposal of a timeline for the phaseout of petrol and diesel vehicles across China. According to the Beijing-based thinktank, 2030 is premature, but an entire phaseout could be possible by 2040.
- **France** has declared a phase-out of ICEVs: no sales of new cars using petrol and vans using fossil fuels by 2040. In December 2019, France published the Loi d'Orientation des Mobilités. It aims carbon neutrality of land transport by 2050. The ramping up of EV cars is targeted with 500,000 PHEVs and 660,000 BEVs by 2023 and 1.8 million PHEVs and 3 million BEVs by 2028. France is also a member of CEM EV30@30. The French grid operator RTE expects in a most ambitious scenario 15.6 million EVs by 2035 with an annual demand of 48 TWh consumption per year. RTE also sees the potential benefit of roughly 40 GW storage capacity by the EV batteries.
- **Germany** plans to cut its transport related emissions by 40 % to 42 % by 2030 as part of the Climate Action Programme 2030. The target is 7 to 10 millions BEVs and FCEVs by 2030. The German government uses the assumption, that 1 million EVs consumes 2 TWh of electricity. Hence, the 2030 target would lead to an electricity demand between 14 and 20 TWh. For

comparison, the challenge in air transport is higher: the German government assumes an energy demand of 270 TWh electricity to produce the needed e-kerosene based on the 2018 consumption.

- **India** is a member of CEM EV30@30 and has as such a rather ambitious target. A variety of forecasts for India exist ranging between 70 TWh and 100 TWh additional electricity demand by 2030.
- **Indonesia** has some targets with regards to biofuel content of sold fuels, that came under pressure due to the Covid-19 induced price reductions of crude oil. For electro-mobility the targets are very modest with a targeted share of 1 % for EVs and 5 % for hybrids by 2050 and an intermediate target of 2,200 EVs by 2025.
- **Italy** targets 6 million electrically powered vehicles including 4 million BEVs.
- **Japan** is also a member of CEM EV30@30. Japan has set a target for "next-generation vehicles" to account for 50-70 % of new car sales by 2030, including a target of 20-30 % for BEVs and PHEVs.
- The **Republic of Korea** targets 430,000 BEVs and 67 000 FCEVs (2022) and a share of 33 % BEV and FCEV of vehicle sales.
- **Mexico** is also a member of CEM EV30@30. The electric vehicle sales should have a ratio of 50 % by 2040 and 100 % by 2050.
- **Russia** and **Saudi Arabia** have no dedicated targets for electromobility.
- **South Africa** targets more than 2.9 million EVs by 2050. This should be achieved by requirements on the total annual fleet changes.
- **Turkey** has no dedicated targets for electromobility.
- The **United Kingdom** is a member of CEM EV30@30. However, the UK even wants to overachieve this target and aims a share of 50 %-70 % of sales with electric cars. By 2035, no sales of new ICEs will be allowed.
- The **United States** have no nation-wide programme for promoting alternative transport fuels. However, there are 11 federal states aiming for 3.3 million ZEVs (PHEV, BEV, FCEV) by 2030. Additionally, biofuels play an important role in the US to deliver lower carbon emissions in the transport sector.
- **Netherlands** is also a member of CEM EV30@30. The National Climate Agreement was announced in 2019 and includes a 30 % reduction in CO_2 emissions from inland and continental transport. Besides its former commitment to reach 100 % of ZEVs in new passenger cars sales by 2030, the government introduced targets for taxis and FCEVs. By 2025, half of the taxi fleet should be ZEVs, and by the same year the ambitions is to have 15,000 FCEVs on the streets, aiming for 300,000 FCEVs by 2030. By 2025, it aims for all new public bus sales to be electric, preparing for a full stock of electric buses in public systems by 2030. Further it aims to deploy 3,000 FCEV heavy-duty vehicles. The 30 to 40 largest municipalities have to implement a zero-emission zone for freight vehicles (LCVs and HDVs) by 2025 and long-haul freight has to improve its CO_2 intensity by 30 % by 2030.
- The **Nordic Region** (Denmark, Finland, Iceland, Norway and Sweden) is quite ambitious with regards to electrification of transport. Norway, Finland and Sweden are members of the CEM EV30@30. The estimated power demand to serve the 4 million electric cars in 2030 is around 9 TWh for the Nordic region. This is equivalent to about 2-3 % of estimated electricity demand for the region in 2030. Norway even wants to reach 100 % zero-emission-vehicle sales by 2025. Sweden and Denmark want no sales of new diesel or petrol cars by 2030. Also by 2030, Iceland will no longer register new diesel and gasoline cars. Denmark targets 1 million electrified vehicles, Finland 250,000 BEVs, PHEVs or FCEVs.

6 Conclusion

The transport sector needs electricity in order to decarbonize – and especially carbon-free electricity. Electricity might serve as primary fuel for transport e.g. for battery electric vehicles or for catenary vehicles like trains with overhead supply. Additionally, electricity might also serve as primary fuel for the production of synfuels e.g. e-kerosene in order to enter transport modes, where battery solutions might lead to economic or technical challenges. In total, this will lead to a higher demand for climate-neutral electricity. A complete electrification of transport will lead to an electricity demand in the magnitude of order of today's global electricity consumption i.e. meeting the Paris climate targets will not only pose the challenge to decarbonize the existing electricity generation – but also to build the additionally needed capacities in a climate-neutral manner. To produce the needed amounts of electricity, the countries choose various ways: some prefer renewable generation; other will also consider nuclear power generation. Especially, the latter solution might become interesting for the export of hydrogen and other synfuels, provided that the production costs are economically convincing in comparison with green hydrogen and green synfuels and that these imports will find acceptance by the importing countries.

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