How to decarbonise transport by 2050

Transport decarbonisation is needed and possible

September 2018

1. Introduction and scope

Later this year the European Commission will present a strategy to decarbonise the economy in line with the Paris Climate Agreement. Limiting global temperature rises to well below 2ºC will require achieving at least net zero emissions by 2050 and the full decarbonisation of all sectors of the economy where this is technically possible.

Transport is Europe's biggest [i] climate problem. Combined emissions of cars, vans, trucks, ships and planes are the EU's largest - and growing - source of greenhouse gas emissions. And whilst for sectors like power there is a clear commitment to decarbonise by 2050, officially the EU still assumes transport emissions will only decrease by 60% [ii], as mentioned in the 2011 Transport White Paper.

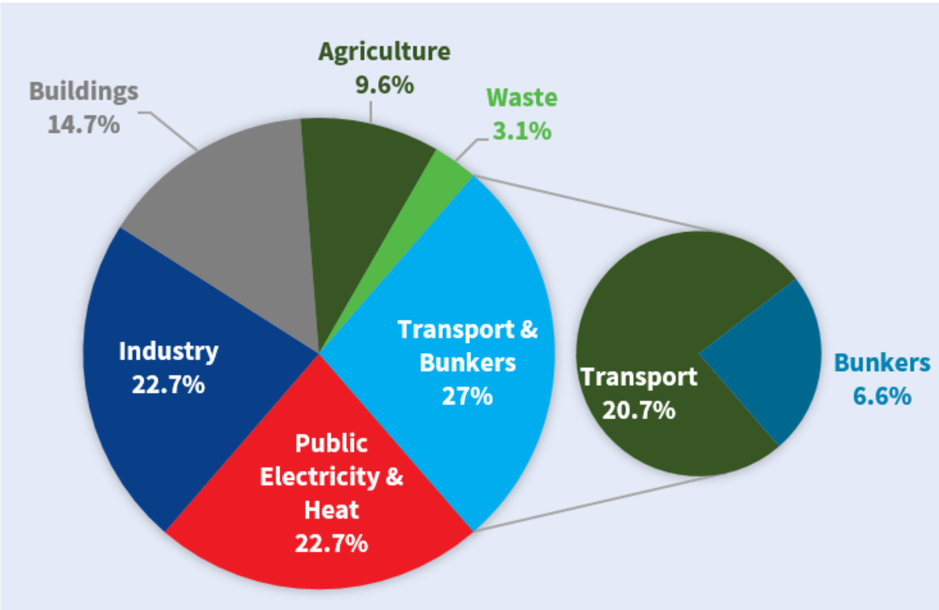

Figure 1: GHG emissions by sector in the EU in 2016

Keeping global warming well below 2°c requires EU transport to be zero emissions [iii] by 2050. This is particularly true given that some sectors (such as agriculture) may not be able to reduce their greenhouse gas emissions to zero.

The goal of this paper is to describe how transport can be decarbonised, and the implications for other sectors, particularly power production. The paper covers all transport modes: cars, vans, land freight (trucks and trains), ships and airplanes. In the case of aviation and shipping, we looked into how to reduce and then decarbonise the equivalent of energy sold to those modes in Europe, i.e. departing flights and voyages. This paper is a first high-level overview of the likely pathways but will be complemented by a series of more detailed research pieces looking into the different transport modes in more detail.

This paper mostly focuses on technological solutions from a powertrain / fuels perspective. Other alternatives, such as behavioural changes or modal switch might also play a role in achieving climate long-term targets. However, EU policy will not be a key driver for those societal changes. Therefore, even though we recognise the clear need to transform the transport system (for reasons related to quality of life, space usage, congestion) this is beyond the scope of this paper. One of the reasons is that the future of transport demand is very hard to predict. The system will undergo some key transformations in the decades to come that might change how, when and how much goods and people are moved. Automation and electrification may make transport more convenient and cheaper and could increase transport demand. Urbanisation, peak car and in particular sharing could greatly improve transport's efficiency. We will attempt to quantify the likely impacts of the three revolutions in a separate paper.

In summary, in this paper, we assume that transport behaviour remains mostly the same and transport demand will generally continue to increase as the economy grows.

2. Transport modes and their greenhouse gas emissions

Figure 2 below summarises the share of emissions per mode. Aviation and navigation represent the emissions associated with fuel sold in the EU including use for international trips. In the context of this report, international trips refer to trips between two different countries, either within the EU or outside the EU. Only domestic navigation and aviation refer to trips within the same member state. It is an important consideration, because some pieces of analysis tend to exclude international aviation (at least extra-EU flights) and international navigation.

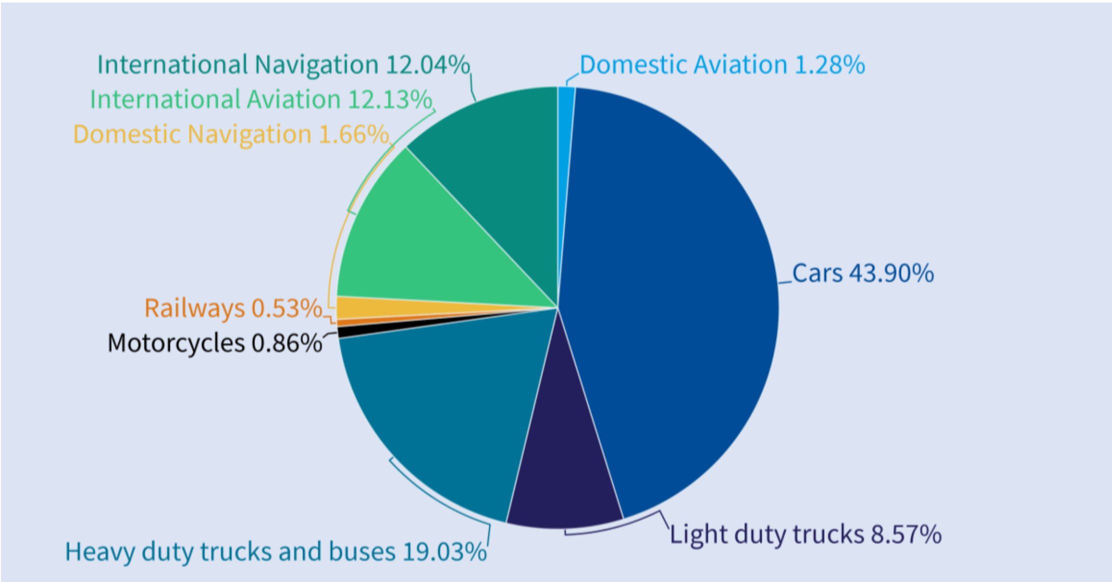

Figure 2: EU GHG transport shares in 2016

3. Land transport

The sections below explore how different land transport modes can be decarbonised. At the end of the section Figure 3 shows the impact of the decarbonisation pathways shown in the section.

3.1. Passenger cars

Cars are by far the most important climate contributor within the transport sector, as can be seen in figure 2 above. From a cost and efficiency perspective the pathway to decarbonise cars is relatively straightforward: electrification. Technically, there are other alternatives, such as hydrogen, sustainable biofuels (either liquid or gaseous) or synthetic diesel or petrol. However, each of this technical alternatives has downsides:

- Hydrogen: as can be seen in figure 5, hydrogen is significantly less efficient compared to battery electric vehicles. Several times more renewable electricity is required to produce the hydrogen to fuel the cars, in comparison to directly using that electricity to charge a car. This also partially explains why hydrogen will always be a more expensive alternative.
- Sustainable advanced biofuels: in addition to being way less efficient than battery electric vehicles as they are burnt in an internal combustion engine, the main issue here is a matter of availability and scalability. The (very) limited available feedstocks should be used to fuel other transport modes where alternatives are not available, such as aviation, or other parts of the bioeconomy, like bioplastics. Regarding biomethane, studies [iv] from the gas industry itself show that transport is not a cost-effective destination for biomethane and that it should be used by the industry and power sector.
- Synthetic diesel or petrol: a pathway based on e-fuels would be more inefficient than hydrogen as both the fuel production and the combustion are inefficient. The difference between directly using the electricity to fuel battery electric vehicles or to use it in complicated processes to capture carbon dioxide from the air and hydrolyse water, to then burn it in an inefficient internal combustion engine, is several orders of magnitude.

On the other hand, all the technical issues that were observed in the development of electric cars are being overcome:

- Price: battery pack costs have come down from $1000/kWh in 2010 to around $200/kWh [v] in 2017 and are likely to continue decreasing in the next years as investment and production capacity increase. Once costs reach $100/kWh - predicted between 2020 and 2025 - the upfront cost of an electric car would be below an ICE car. Running costs [vi] are already lower.
- Autonomy: the range of EVs continue to increase. As battery prices fall and battery densities increase, EVs have a longer range with models such as the Jaguar i-pace, the Audi e-tron or the Tesla model 3 reaching ca. 400-500km. In the next decade they might have a similar range to ICEs.
- Recharging speed: most users will not require fast charging, as they could charge their electric cars at home or in the office. However, fast charging is important for long interurban trips and to deal with range anxiety. Fast charging networks of up to 350 kW [vii] are already being developed across Europe today. Electric cars with a large battery of 100 kWh today (range of more than 500 km) could be fully charged in less than 15 minutes.
- Impacts on the grid: different studies [viii] have shown that, if managed properly, electric cars are not a burden on the electricity grid, but actually an opportunity to incorporate more renewables and avoid curtailment. Smart charging and vehicle-to-grid technology will play an important role on the years to come.
- Raw materials: batteries have certain raw materials that are currently mined only in a few countries. Cobalt is the best example. However, battery chemistries are evolving, and using less cobalt (3% is current state of the art). At the same time, recycling of batteries will also improve as more reach their end of life.
- Electricity origin: in Europe, the power sector has committed to decarbonise by 2050. Therefore, this won't be an issue in the timeframe of this study. In any case, already today an electric car is considerably cleaner [ix] than an ICE.

Given all of the above, there are compelling reasons to assume that BEVs are the optimal pathway to light duty vehicle decarbonisation. However, the transition must go relatively fast. In figure 3 below, direct emissions from cars up to 2050 can be seen, considering that all new cars sold in the EU are BEV by 2035. Even if it brings them closer to zero, assuming constant fleet renewal rates, it shows that 2035 is too late to sell the last internal combustion engine car.

3.2. Vans (light commercial vehicles)

The way to decarbonise vans is very similar to cars: battery electric vans. The arguments are identical to the ones used for cars. In addition, the market has been demanding them for years, even pushing some van users, such as DHL, to produce their own given the lack of supply in the market. Studies [x] show how battery electric vans will be cost-effective in the years to come. Others [xi] say it would be as early as 2020.

3.3. Land freight transport

Land freight transport decarbonisation has been subject to extensive research [xii] by T&E, which included the impact of modal shift to rail and improved logistics efficiency. When that stream of work started two years ago, it was unclear what the decarbonisation pathway would be. Catenary lines offer one technically and economically viable pathway, however, recently several truck manufacturers have made announcements that suggest trucks could be electrified through battery systems. One leading manufacturer (Scania) [xiii] has estimated that cost-parity of total cost of ownership of electric trucks would be reached in the 2020-2030 decade, making this pathway the most cost-effective to reduce emissions in the sector. The conclusion is clear, and aligned with T&E's analysis [xiv]: heavy duty electrification is possible, cost effective and likely also beneficial [xv] to the economy. We also explored other alternatives such as hydrogen - which remains a contender, see for example Nikola Trucks - or synthetic diesel, but the amount of renewables to produce the hydrogen or synthetic diesel needed would be very high. The detailed assumptions and reasoning are explained in this study [xvi].

3.4. Motorbikes

Motorbikes are responsible for less than 1% of total transport GHG emissions in the EU. For this reason, T&E has given little focus on regulation of motorbikes. However, when it comes to decarbonisation, there is a clear pathway: electrification.

In the case of petrol-powered mopeds and motorcycles below 50cc, sales in the first three months of 2018 increased by 50.8% compared to the previous year. Sales of larger electric motorbikes have also started, although currently they only represent a small percentage of the sales. From a technical or cost perspective motorbike electrification is eminently feasible, as illustrated by the announcement of Harley Davidson that it will start to sell electric [xvii] motorcycles.

3.5. Urban buses

Urban buses are evolving to battery electric powertrains very rapidly. Today, in large cities electric buses are already more cost-effective [xviii] than any other alternative, from a total cost of ownership perspective. Some manufacturers [xix] go as far as saying that by 2025, cities will only buy battery electric buses. Already in 2017, more than 90,000 electric buses were sold in China alone. Hydrogen buses could potentially also be part of the solution. However, as it has already been explained for cars, they are (and expected to be) more expensive and less efficient than battery electric buses. In our modelling, we have assumed that all new urban buses will be electric by 2030. T&E is finalising a detailed study on e-buses.

3.6. Coaches

Coaches are approximately responsible for 2% of all transport emissions in Europe. So far, there has been relatively little development on electric coaches. In Europe, only one company [xx] is currently performing long distance trips in electric coaches. So far, most bus manufacturers have been focusing on urban buses instead of coaches. Hydrogen is also being tested in coaches travelling longer distances in Scotland [xxi]. In any case, it is unclear what decarbonisation pathway coaches will follow. From an energy efficiency perspective, battery electric would make more sense. As electric trucks develop, there are no technical reasons to think that coaches could not be electric in the future.

3.7. Land transport summary

The table below summarises the battery electric sales of vehicles incorporated into our model. For intermediate years, sales are interpolated.

Sales of Battery Electric Vehicles	2025	2030	2035	2050
Motorcycles & Mopeds	30%	60%	80%	100%
Passenger Cars	20%	50%	100%	100%
Vans	20%	50%	100%	100%
Urban Buses	50%	100%	100%	100%
Coaches	10%	25%	50%	100%
HGVs (<16t)	10%	30%	80%	100%
HGVs (>16t)	10%	30%	80%	100%

Even if the percentages above are very ambitious, they are needed in order to achieve long-term goals. As seen in figure 3 below (left), even if all new passenger cars are fully battery electric by 2035, they would still be emitting a considerable amount of CO2 by 2050. This is assuming normal fleet renewal but one could also imagine that once all new sales are zero emission, the legacy fleet is phased out much quicker (right).

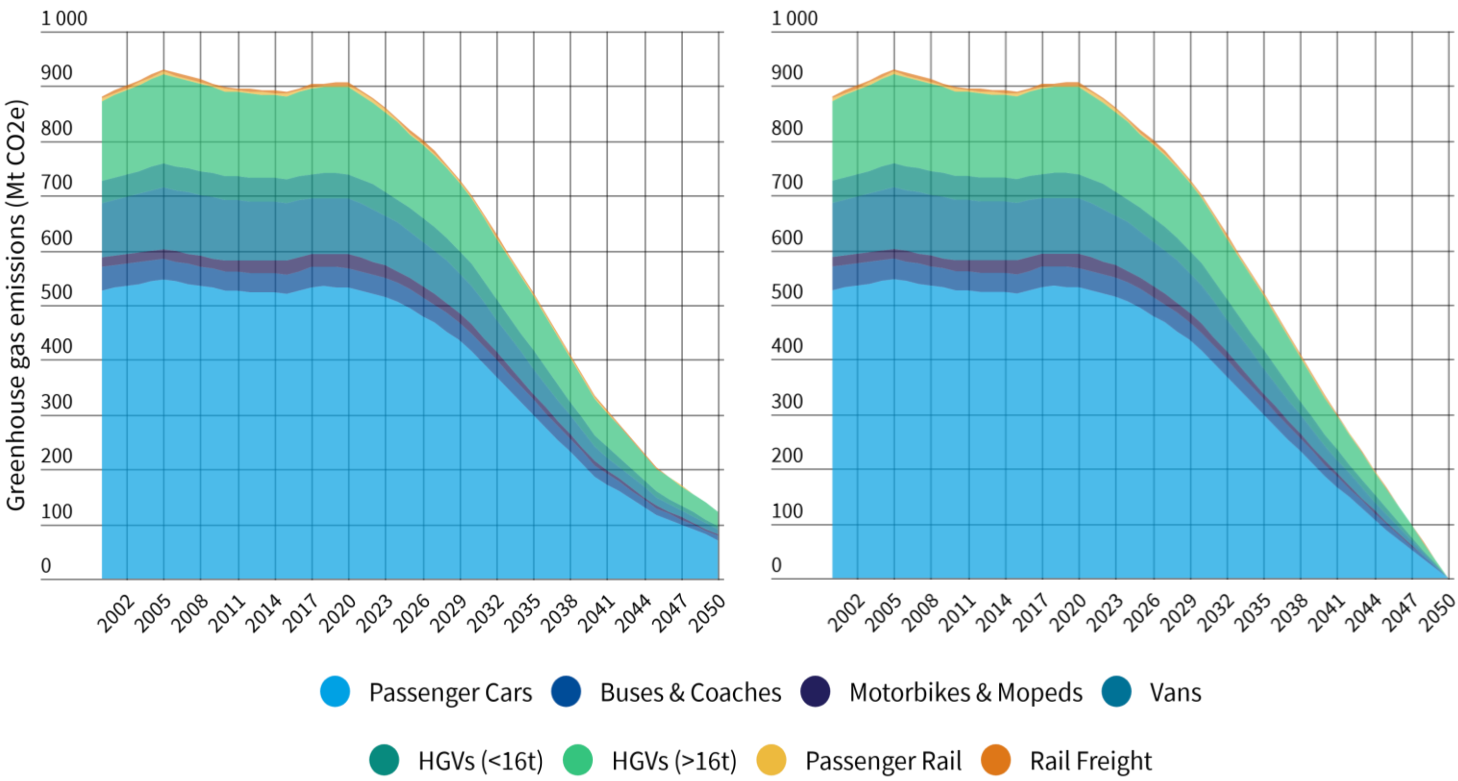

Figure 3: Evolution of EU transport emissions in a decarbonisation scenario, where the right hand side figure includes a scrappage scheme of ICE vehicles in the 2040s to ensure zero tailpipe emissions is met.

4. Bunkers

4.1. Aviation

Aviation will probably be the hardest transport mode to decarbonise. And even if that is achieved, the sector would continue to contribute to climate change through non-CO2 impacts. Aviation emissions increased 96% from 1990 to 2016, considering all fuel sold in the EU for intra and extra-EU flights. Aviation decarbonisation is not an industry nor an ICAO goal, which only talks about carbon neutral growth from

2020. This is not compatible with the Paris Agreement. In addition, ICAO, as an international organisation lacks the tools to adopt measures which will lead to the deep decarbonisation required. Measures therefore need to be advanced at a European level.

In an on-going T&E study - preliminary results below - we looked into different instruments that could help to decarbonise aviation, including a high carbon price to influence demand, efficiency and operational improvements and modal shift. Our analysis makes clear that, even if all these measures are positive to reduce emissions compared to a business-as-usual scenario, their impact is limited and exceeded by growing demand. Therefore, the only promising avenue to decarbonise aviation is the gradual decarbonisation of aviation fuel. From a technical point of view this is feasible.

Advanced sustainable biofuels (e.g. wastes and residues) can only be a small part of the solution as their availability is limited. What sustainable advanced biofuels exist should be directed to aviation in the 2050 framework as other transport modes such as cars, trucks and ships have better alternatives. Electric planes are two generations away, which implies that they will not make it on time for 2050. Hydrogen planes only exist on paper and they would require airports to be redesigned. Synthetic jet fuels are certified for up to 90% use in aircraft and have been used on a large scale in the past [xxii], although they were not produced from renewable sources. Depending on the electricity market, renewable energy deployment and fossil kerosene prices, today it may be 3 times [xxiii] the price of fossil kerosene, at least as long as kerosene remains untaxed.

Synthetic fuels require large amounts of renewable electricity to be clean. And as with biofuels, important safeguards need to be put in place to ensure they deliver on environmental integrity. Building up a synthetic fuels industry would also take significant capital investment over a long time horizon. The only way this industry could be developed is if it a stable, long term investment framework is created and enshrined in EU law.

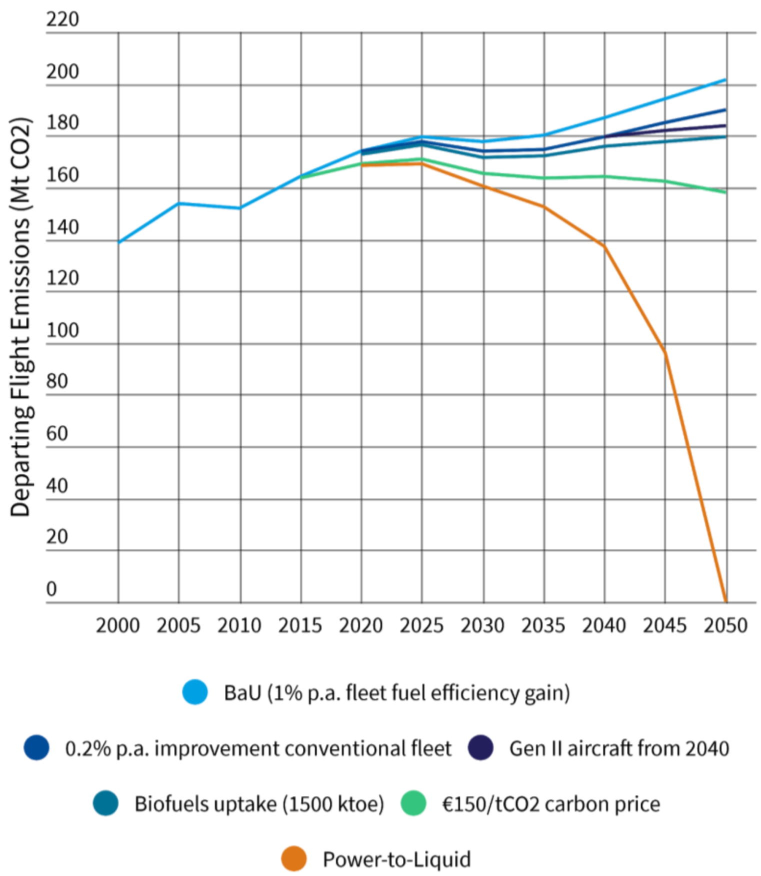

Figure 4: Evolution of International aviation emissions in the 2000-2050 period

4.2. Shipping

In previous long-term Commission projections, shipping was not included. However, as can be seen in Figure 2, domestic and international navigation are responsible for 14% of all transport emissions, too important to omit. As with other transport modes, the key to decarbonise shipping is to decarbonise the propulsion system. Battery powered ships already exist, but to date they are only used for relatively short trips and just ferries, which can be extended to relatively longer journeys as the technology matures. So renewable electricity will be needed to produce electrofuels like liquid hydrogen, ammonia, etc. to be used either in modified conventional internal combustion engine ships or fuel cell ships to cater the needs of the largest ships engaged in deep sea shipping.

An on-going T&E study looked at the efficiencies of different possibilities, and the conclusion is clear: although battery-electric propulsion appears to be the most efficient use of renewable electricity, a technology mix is a more likely pathway with different segments of EU shipping - domestic, intra-EU and extra-EU - choosing a combination of battery-electric, liquid hydrogen and liquid ammonia based energy sources. In a technology mix pathway, under the T&E assumptions, decarbonisation of the EU-related shipping would require around 25% additional electricity generation in the EU28 over the 2015 levels. This assumes 50% growth in maritime energy demand up to 2050, and no measures taken to deal with demand growth. If battery electric would be technically feasible for the entire EU shipping, it would be 11% of current production. On the other hand, going for a full electrodiesel alternative would imply the equivalent of 53% of electricity production today, which, in addition to what other transport modes and other sectors in general would require, would become unfeasible. In addition, enforcement of electrodiesel in maritime sector would be extremely challenging if not impossible. In conclusion, a technology mix including battery-electric (to be maximised), liquid hydrogen and ammonia would be the most desirable decarbonisation pathway for EU maritime transport.

5. Energy requirements

5.1. Efficiency first

For most transport modes, there are different decarbonisation pathways. For instance, cars can be decarbonised by using battery electric, hydrogen, power-to-liquid or power-to-gas vehicles, or even a combination of them in different types of hybrid vehicles. In all cases, renewable electricity will fuel the cars, either directly or indirectly.

However, different pathways imply very different amounts of renewable electricity needed. This is significant since transport is not the only sector that will need to move from fossil fuels (either liquid or gas) to renewable electricity, either as a vector or a raw material to produce fuels. And whilst there has been a breakthrough in solar and wind technology and costs, we are still far removed from a 100% clean grid.

Therefore, the amount of additional electricity needs to be minimised. The difference between the pathways can be several orders of magnitude. In this study the most energy efficient choices have been selected, unless otherwise justified. Below, in figure 5, an example of the efficiencies of using renewable electricity in passenger vehicles. Further below we quantified the amount of renewables that different pathways would imply.

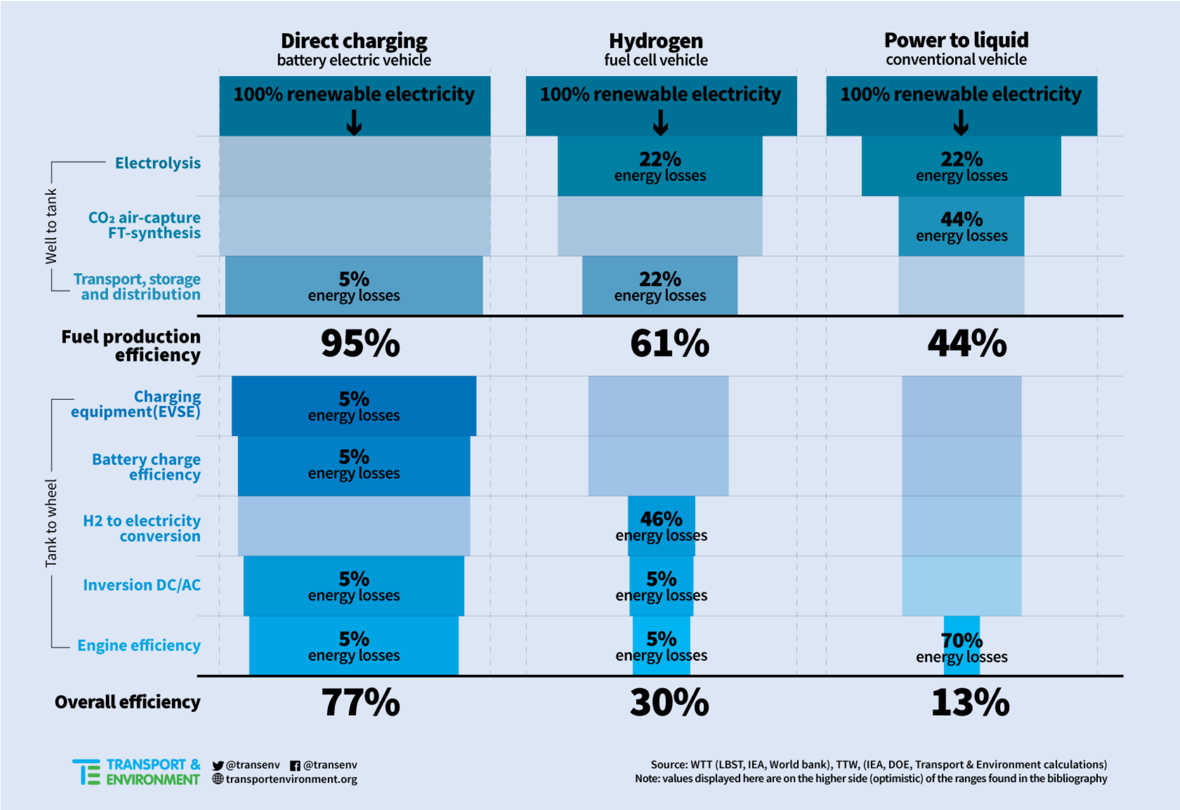

Figure 5: Efficiency of different passenger cars technology pathways based on renewable electricity

5.2. Additional electricity demand

All transport decarbonisation pathways are dependent on the availability of very high availability of renewable electricity. However, different pathways require different order of magnitude. The table below shows what we have modelled it would require, both in absolute terms (TWh) and as a percentage of 2015 electricity generation (3,234 TWh), to put the number into perspective.

Transport mode	Electricity Generation for electric vehicles (TWh)	Electrofuels		Optimal pathway
		Hydrogen/ Ammonia[1]	Synthetic diesel, petrol, and kerosene	
Motorbikes	33 (1.0%)	86 (2.7%)	195 (6.0%)	33 (1.0%)
Cars	586 (18.1%)	1530 (47.3%)	3462 (107.0%)	586 (18.1%)
Vans	142 (4.4%)	371 (11.5%)	839 (26.0%)	142 (4.4%)
Buses	87 (2.7%)	228 (7.0%)	515 (15.9%)	87 (2.7%)
Trucks (<16t)	111 (3.4%)	289 (8.9%)	654 (20.2%)	111 (3.4%)
Trucks (>16t)	368 (11.4%)	960 (29.7%)	1628 (50.4%)	368 (11.4%)
Trains	157 (4.9%)	411 (12.7%)	930 (28.7%)	157 (4.9%)
Total land transport:	1485 (45.9%)	3874 (119.8%)	8224 (254.3%)	1485 (45.9%)
Shipping [2]	350 (11%)	1032-1192 TWh (32-37%)	1718 TWh (53%)	798 TWh (25%)
Aviation [1]	N/A	N/A	1113 TWh (34%)	1113 TWh (34%)

[1] Ammonia only applies to the shipping sector

[2] There are differences between shipping and aviation projected fuel demands. In the case of aviation, in the on-going study we looked into demand management, efficiency improvements… Therefore, 2050 fuel demands are lower than in the BAU scenario after applying those measures. In the case of shipping, the on-going study has still not looked at the potential of some measures like improvements in fuel efficiency, low steaming… however, it is planned to do so.

The table shows that bringing transport close to decarbonisation is possible, but it should be done smartly. Given the lower efficiencies in producing hydrogen or synthetic diesel or petrol, they should only be used when truly no other alternative exists. Otherwise, the decarbonisation challenge would be unattainable.

6. Conclusions

This short high-level paper has shown how transport can be decarbonised in Europe by 2050. However, it has also shown that action needs to start immediately. Each single assumption that went into our modelling would require very strong political will to make them happen. Every single year those measures are delayed, the more unlikely it will be to have a decarbonised transport sector by 2050. Transport decarbonisation will be highly dependent on the decarbonisation of the power sector, and unless electricity demand considerably decreases compared to nowadays, additional power production in the continent, especially for the aviation sector, will be needed.

In the upcoming months, T&E will explore different transport modes in more detail, publishing specific reports with more details on how to implement those measures.

Further information

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Endnotes

[i] https://www.transportenvironment.org/newsroom/blog/reconfirmed-transport-europe%E2%80%99s-biggest-climate-problem
[ii] https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en
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