How to decarbonise European transport by 2050

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Executive Summary

Transport is Europe's largest climate problem accounting for 27% of its GHG emissions in 2017. Transport pollution is causing the illness and premature deaths of hundreds of thousands of Europeans. Meanwhile the EU spends over 200 billion a year importing oil to power its transport fleet. A shift in spending from imported oil to domestically produced technology and energy would not only have major economic benefits but would also help eliminate transport pollution and carbon dioxide emissions.

This report summarises a series of studies by Transport & Environment. It demonstrates that transport can and must be decarbonised by 2050 at the very latest, not only to limit global warming but also to ensure Europe's competitiveness, its energy sovereignty and the health and well-being of its 500 million citizens.

Curbing demand and a shift to cleaner transport modes is important to reduce the amount of energy and other resources required to deliver zero emission mobility. The policies that can reduce demand for transport are well-known and are being rolled out in many of Europe's cities. However, demand reduction can only reduce emissions by a certain amount; it cannot achieve decarbonisation. This means that if we are to achieve net zero emissions in 2050, all transport vehicles, from cars to airplanes, will need to run on zero emission energy in the future. This report, as well as many other reports, concludes that the only form of zero emission energy that has the potential to power transport at scale is electricity. It can be deployed either directly (e.g. battery cars, catenary trucks) or in the form of other energy carriers (hydrogen, electrofuels). This also means that the decarbonisation of the power sector is a prerequisite for a zero emission transport system.

Decarbonising the entire European economy will require a holistic approach. Most transport modes can be decarbonised following different pathways. However, they have very different implications for the overall energy system. Unless ways are found to exponentially increase the amount of zero emission electricity at low cost it will remain important to minimise the need for additional clean electricity. This means that an approach focused on using the most efficient pathways (direct charging) wherever possible is recommended. Given the much lower efficiencies of hydrogen but in particular electrofuels, these are optimally used only where no other alternatives exists.

Very large investments will be needed in the renewables sector, but also in electricity transmission grids. Shipping and aviation are sectors where vast amounts of hydrogen and synthetic fuels will be required. If all transport modes would be decarbonised by using synthetic fuels, the decarbonisation challenge would be unattainable due to the amount of clean electricity required. The difference between an optimal pathway based on mostly direct charging and an one based on inefficient electrofuels is almost three times more clean electricity needed, four times more if looking at land transport only.

Our studies and modelling have also shown that action needs to start immediately. The current approach of slow progress until 2030 and very rapid progress after 2030 makes the achievement of net zero in 2050 considerably harder, but also means we will exceed the carbon budgets available to meet 1.5°C, and come dangerously close to 2°C.

The last internal combustion engine car needs to be sold during the early 2030s and by 2035 at the latest if the EU is to decarbonise transport by 2050. The EU can achieve a zero-emissions fleet by switching to battery-electric and hydrogen fuel cell cars, though the latter option will require far greater amounts of additional zero emission electricity. Higher fuel taxes and road charges, coupled with car-sharing and shifting motorists to other forms of transport, could be deployed to reduce the number of cars, tackle congestion and make cities more liveable. The heavy lifting in terms of emissions reductions requires a shift to zero-emission vehicles by 2035 at the very latest. Any remaining combustion engine cars still on the road in 2050 will need to be banned.

Greenhouse gas emissions from trucks and buses in Europe could be completely eliminated by 2050. Because the huge amounts of oil this would displace, decarbonisation of trucking would be cost effective, both for society and for the logistics industry. While decarbonising trucks and buses is possible, mainly through a combination of battery, hydrogen and catenary technology, it will not happen without ambitious policies such as a zero emission vehicle mandate for buses and trucks. On top of that, infrastructure to allow the use of electricity in land freight is required, while cities will need zero-emission freight strategies. Increased logistics efficiency and modal shift can facilitate the achievement of the 2050 goal.

By driving out the use of fossil kerosene fuel in aviation through carbon pricing and requiring aircraft to switch to synthetic fuels, and advanced biofuels to a very limited extent, the climate impact of flying can be reduced dramatically. Zero emission electrofuels and very low carbon advanced sustainable biofuels can be produced today and deployed immediately using existing engines and infrastructure. Electrofuels are produced by combining hydrogen with carbon dioxide, but to do this sustainably the hydrogen must be produced using renewable electricity and the CO_2 captured directly from the air. Estimates on the additional cost of synthetic kerosene vary with some studies claiming cost parity in 2050 but this would require very cheap electricity. In our report we assumed synthetic kerosene will remain more expensive and tickets become around 23% more expensive. Whilst synfuels can solve aviation's CO_2 problem, the non-CO_2 problem will require additional measures to be mitigated.

Battery powered ships offer the most efficient and immediate solution to decarbonise short sea voyages within the EU. Longer journeys will ultimately require liquid hydrogen and liquid ammonia produced with zero-emission electricity. Powering ships calling at EU ports with a combination of the three would require around 25% additional renewable electricity compared to total EU electricity production today. This is a considerable amount but still half of what is required by other options like synthetic methane or synthetic diesel.

Decarbonising transport is possible, but each single assumption that went into our modelling would require new policies to realise them. In most instances this will take the form of new laws and regulations, very often at European level. The more we delay those measures, the harder it gets to achieve a decarbonised transport sector by 2050.

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List of acronyms

AFID	Alternative Fuels Infrastructure Directive
BAU	Business-as-usual
BEV	Battery Electric Vehicles
EEDI	Energy Efficiency Design Index
EU	European Union
EV	Electric vehicle
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse gas
HGV	Heavy Goods Vehicle
ICAO	International Civil Aviation Organization
ICE	Internal Combustion Engine
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
PtL	Power-to-Liquid
SEEMP	Ship Energy Efficiency Management Plan
TCO	Total Cost of Ownership
ZEV	Zero Emission Vehicle

1. Why this report?

The Intergovernmental Panel on Climate Change (IPCC) special report on limiting global warming to 1.5ºC[i] made it clear: rapid and far-reaching transitions are needed in all sectors, including transport, in order to reach net zero emissions by 2050. This includes full decarbonisation of all sectors of the economy where this is technically possible. Europe, due to its historical contribution to climate change, should lead the way.

Limiting global warming to 1.5°C requires EU transport to be zero emissions[ii] by 2050 at the very latest. This is particularly true given that some sectors (such as agriculture) may not be able to reduce their greenhouse gas emissions to zero. If the EU would want to truly stick to 1.5ºC warming and avoid (or at least reduce) reliance on as yet unproven technologies such as carbon capture and sequestration to achieve negative emissions, transport decarbonisation would need to happen before 2040. A transition to zero emission transport in a 20 to 30 year timeframe implies a radical and necessary overhaul of the transport system, essentially reversing an emissions trend that has persisted for over a century.

In November 2018 the European Commission will present a strategy to decarbonise the economy in line with the Paris Climate Agreement, following the request by European governments[iii].

The goal of this paper is to describe how transport can be decarbonised, and the implications for other sectors, particularly electricity 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 summary of the each of the sectoral roadmaps that T&E has worked on during the last months: land freight[iv], passenger cars[v], aviation[vi] and shipping[vii]. Other recent T&E papers (on urban buses[viii] or vans[ix]) also helped to shape this T&E's 2050 vision on how to decarbonise transport. This paper complements the first high-level overview of this vision that was submitted during the Commission's public consultation process[x].

2. The Problem

Transport is already Europe's largest[xi] 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%[xii], as mentioned in the 2011 Transport White Paper.

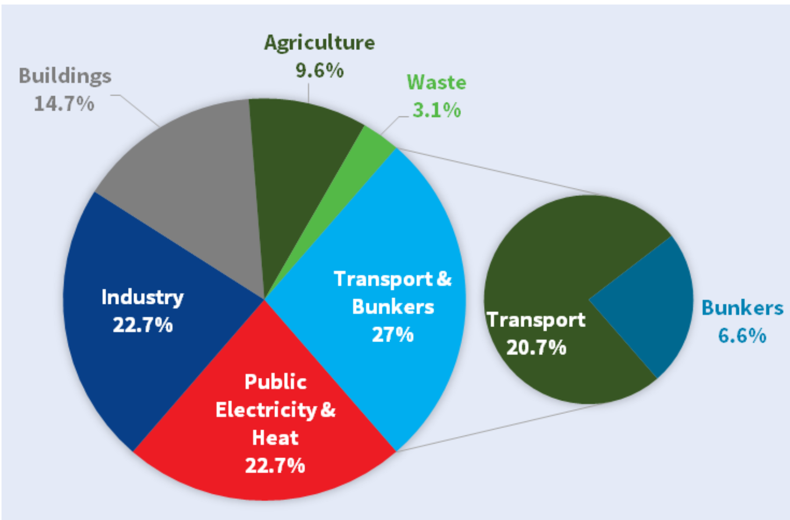
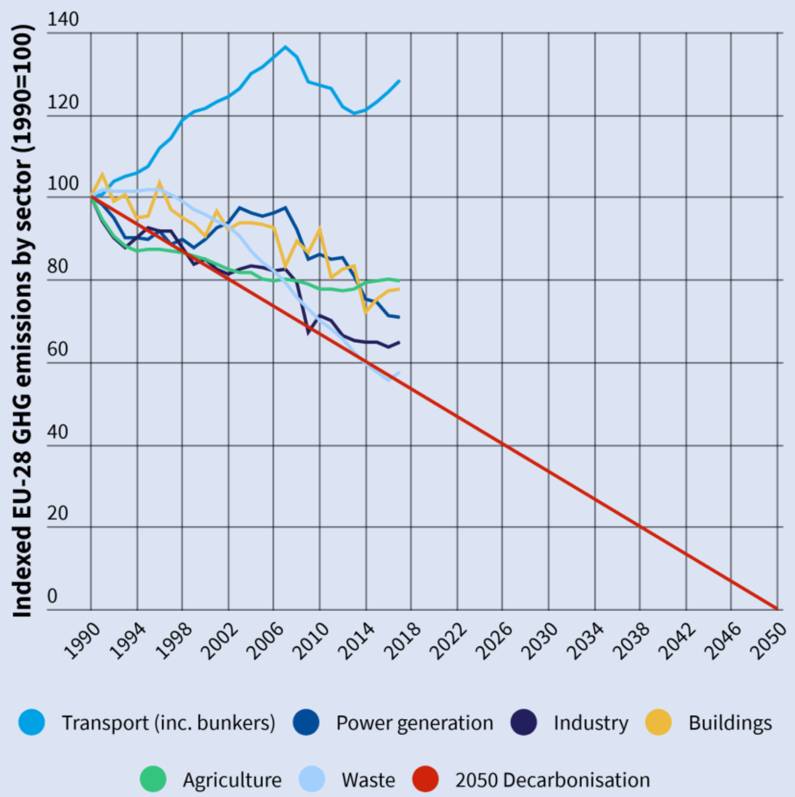


Figure 1: GHG emissions by sector in the EU in 2016

Updated data to be soon published by T&E shows that energy dependency on oil imports has increased in recent years. In 2017, oil imports (in volume terms) were 8% higher than in 2014 and at the highest level since 2008. Of the total volume of petroleum products imported to the EU, the majority (75%) is imports of primary crude oil, which is used as feedstocks for EU refineries. As of 2017, the EU relies on imports for 89% of its crude oil supply, adding to €180 bln. Additionally, over €45bn was spent on imports of refined fuels, such as diesel. Most of this demand, around two thirds, is from the transport sector, particularly from road transport. This lack of energy sovereignty can be reversed through transport decarbonisation, as it would imply moving away from petroleum products into locally produced clean energy sources, like renewable electricity[1].

Transport emissions are not only the largest contributor to climate change in the EU. They are also of the only sector which emissions are above 1990 levels, as can be seen in the Figure 2. Emission reductions in other sectors have been partially offset by the emissions growth in the transport sector.



Source: Transport & Environment from Member States' reporting to the UNFCCC (1990-2016 data) and EEA's approximated EU greenhouse gas inventory (2017 data)

Figure 2: Indexed evolution of EU GHG emissions per sector

Figure 3 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 flights and voyages 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.

[1] Cambridge Econometrics, 2018. Oil dependency in the EU (in the press).

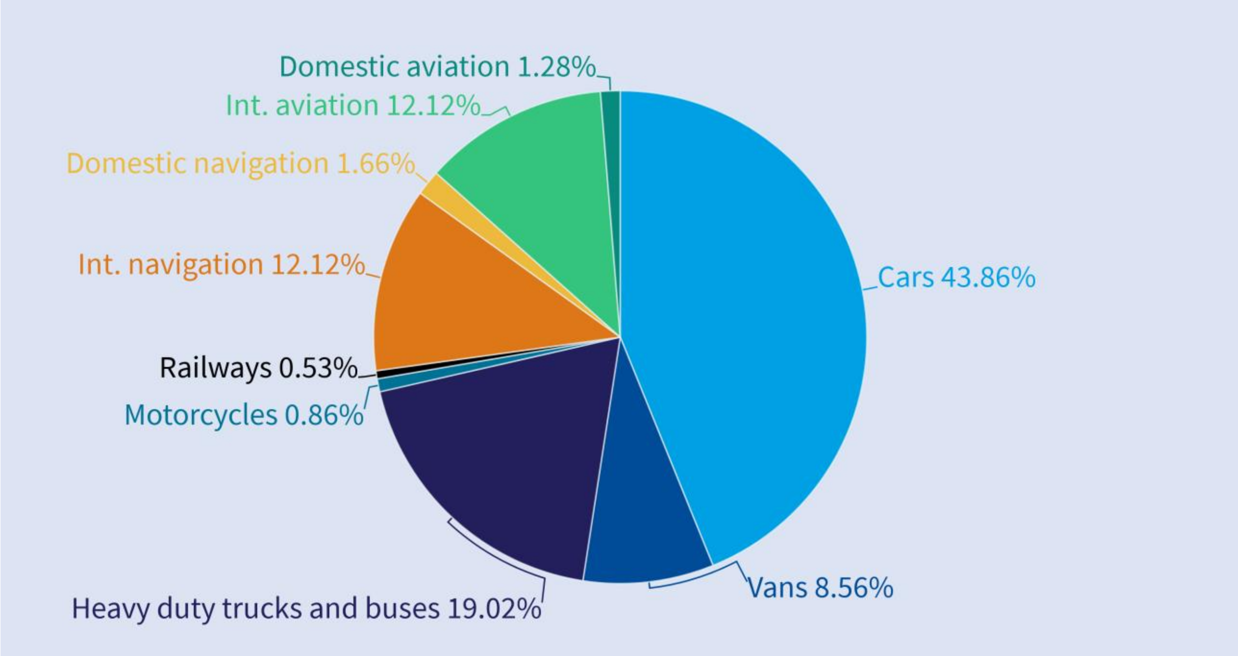


Figure 3: EU GHG transport shares in 2016[xiii]

Surface transport accounts for around three quarters of all EU transport emissions. Within that category, light duty vehicles (cars and vans[2]) are the largest emitters. Even if all sectors are important, decarbonising cars is of vital importance and the most urgent due to its total contribution. Additionally, the technology is already available.

Light commercial vehicles, or vans, are a neglected area of EU road transport policy as they are often exempt from safety and environmental policy such as driving regulations or tolls, compared to their direct competitors, trucks. This enhances their attractiveness and in part explains why their use and emissions are growing.

Heavy duty vehicles represent around a fifth of all EU transport emissions, a quarter if looking into road transport only, and its importance is expected to increase[xiv]. Unless emissions from trucks are dealt with, it will be impossible to meet climate targets.

Aviation is already a major and growing emitter. In Europe its emissions have doubled since 1990, and globally they could, without action, double or treble by 2050[xv]. Such emissions growth needs to be reversed and brought to zero by 2050 if we are to meet the goals of the Paris Agreement. Aviation is at risk of having its emissions locked in due to the growth in passenger numbers and aircraft fleet, consuming the limited carbon budget to remain within the 1.5°C and 2°C targets of that Agreement.

Finally, shipping is one of the largest GHG emitting sectors of the global economy, responsible for around 1 Gt of CO_2eq every year[xvi]. If shipping were a country, it would be the 6th biggest GHG emitter in the world. EU related shipping is responsible for about one fifth of global ship GHG emitting on average 200 Mt/year. This speaks to the absolute necessity of including maritime transport in the development of an EU 2050 economy-wide decarbonisation strategy and the subsequent financial, investment and regulatory decisions that will be needed.

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[2] In Figure 3, they were originally referred as light duty trucks, which is an IPCC category, but these emissions generally reflect those of so called vans in the EU.

3. The Solutions

3.1. Scope of the report

The sectoral analysis in each individual T&E study mostly focused on technological solutions from a powertrain or fuels perspective. Other alternatives, such as behavioural changes or modal switch must also play a role in achieving climate long-term targets, and they were also explored in the research pieces, together with potential measures to materialise them. However, EU policy might not be a key driver for those societal changes but rather cities, regions, and national policy levers.

Therefore, even though we recognise the need to transform the transport system (for reasons related to quality of life, space usage, congestion), it was not the main focus of this series of papers. 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. As an example, driverless vehicles and electrification may make transport more convenient and cheaper, drastically increasing transport demand. On the other hand, urbanisation, sharing, and peak car could lead to greatly improved transport efficiency, reducing congestion and creating liveable cities. Some of these future trends will be analysed in more detail in an upcoming T&E paper in an attempt to quantify the likely impacts of the three revolutions (electrification, automated and shared).

In summary, in this series of papers, we assumed that transport behaviour remains mostly the same and transport demand will generally continue to increase as the economy grows. This is also in line with the European Commission modelling approach, which will allow for direct comparison and input into their work. In some cases we explored alternative scenarios and the impact of behavioural changes driven by policy.

Regarding the methodology, for land transport, we used T&E's European Transportation Roadmap Model (EUTRM[xvii]). In the case of aviation and shipping, ad-hoc models were developed. For more details consult the methodology sections of each individual study.

3.2. Land transport

3.2.1. Passenger cars

Synthesis of Roadmap to decarbonising European cars:

Our report showed that there are multiple pathways to reach zero in passenger cars, including the adoption of clean technologies (battery electric, hydrogen fuel cell, electrofuels). Policies to curb demand (such as modal shift to public transport, cycling and walking) reduce the amount of clean electricity and other resources required to deliver zero emission mobility.

Behavioural measures are estimated to curb car use, accelerate modal shift and improve load factors, together reducing emissions from the car fleet in 2050 (compared to 2015) by 40%. This represents a 28% reduction in 2050 compared to the projected baseline emissions that incorporate the effects of the current policies including 2030 car CO_2 targets. A more aggressive demand reduction scenario was also modelled, halving CO_2 emissions compared to the 2050 baseline. Reductions on this scale will only be possible through ubiquitous adoption of shared vehicles and very aggressive policies to restrict and raise the cost of private car use. However, our analysis demonstrated that whilst demand reduction measures can play an important role in terms of emission and resource demand reduction and creating more liveable cities, on their own they cannot decarbonise personal mobility.

To achieve full decarbonisation a fleet of entirely zero emission vehicles (ZEVs) will be needed by 2050. This implies selling 100% zero emission vehicles by the early 2030s and by 2035 at the very latest. However, this would still not be enough to achieve zero emissions in 2050 and means the use of legacy internal combustion engine (ICE) vehicles sold before 2035 should be restricted and ultimately banned by 2050.

Incremental improvements to existing ICEs vehicles will not achieve the required emissions reductions as there is a limit to the efficiency improvements possible and it is not possible to produce low and zero carbon fuels cost-effectively, sustainably and in the quantities required.

By 2030, advanced biofuels are expected to contribute only 3.5% of all transport fuels (including cars, trucks, aviation) and their growth beyond this date is likely to be constrained due to land availability and competing industries. To produce sufficient synthetic fuels to power all passenger cars in 2050 in the baseline scenario would require clean electricity production equivalent to 68% of the size of the current EU electricity production, due to the inefficiency of both the production process and ICEs, as explained in a section below. This doesn't take into account that other sectors, such as aviation, might actually depend on synthetic fuels to decarbonise. Similarly, the gas industry equally cannot produce sufficient biomethane sustainably from wastes and residues to power a European car fleet, while it should be prioritised in sectors currently using fossil gas, and fossil gas is not an option if cars are to be decarbonised.[xviii]

The future vehicle fleet will need to be powered with electricity. This will most probably largely be directly, through batteries, but could also be achieved through hydrogen fuel cell vehicles using zero carbon hydrogen. The electricity industry has committed to decarbonising electricity, the emissions trading system (ETS) is finally working and the price of renewables is falling – electric cars could become a complement to smart, zero emissions grids. Plug-in hybrids or range extended variants are not fully zero emission and are only a transition technology. Our analysis showed that the optimal solution from an electricity generation, cost, and efficiency point of view for cars is battery electric vehicles (BEVs).

Even assuming 100% ZEV sales from 2035 the CO2 emissions are only reduced by 89% by 2050 compared to 2015, even after applying demand reduction measures, with around 55 Mt of remaining CO_2 stemming from the remaining ICE cars on the road. A faster phase-in the early 2030s would therefore be preferable or alternatively tackling these emissions requires measures to accelerate fleet renewal, such as time-limits to vehicle type approval and zero emission zones or ICE bans in cities or entire regions. This means that the utility and value of ICE cars decreases sharply from the 2030s onwards. If the older polluting vehicles are retired, then the EU car segment can be fully decarbonised in 2050.

The amount of additional clean electricity required to power a fleet of battery electric cars in Europe in 2050 would be 475 TWh, or 14.7% of the electricity generated in the EU in 2015. Smart charging will significantly reduce grid upgrade costs and support higher shares of renewables. Fuel cell cars are an alternative but face even greater hurdles than BEVs. Specifically, a lack of commercial models, poor overall energy efficiency and high costs of both the vehicle and zero carbon hydrogen. With the performance and price of batteries allowing ever longer ranges in combination with ultrafast charging in less than 15 minutes the benefits of fuel cell over battery technology are being eroded. To see what the effect of FCEV vehicles, rather than purely BEV, would be on electricity demand, if 10% of vehicle activity was from these vehicles in 2050 (equivalent to about 20% sales in 2050). In this case electricity demand would be 551 TWh, or around 15% more than in pure BEV scenario. If FC vehicle activity was doubled to 20% in 2050, this would create a demand of 627 TWh of additional, clean electricity to produce and then use hydrogen from electrolysis.

3.2.2. Light Commercial Vehicles (vans)

A CE Delft analysis[xix] for T&E looked at current market as well as emission technologies and their costs in the light commercial vehicles sector. Amidst the rapidly decreasing battery costs, CE Delft showed that electric vans in the smaller segment have already reached cost parity with diesel models in 2018. Larger ones will reach cost parity in the 2020s. Others[xx] say it would be as early as 2020. The key barrier remains a lack of appropriate supply.

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. For the purpose of this exercise, we considered that all new vans would be zero emissions by 2035, as with cars.

3.2.3. Land freight transport

Synthesis of Roadmap to climate-friendly road freight and buses:

Our report assessed how the EU could achieve zero GHG road freight and buses by 2050. The report analysed "off the shelf" technologies and strategies (defined as low hanging fruit), such as improving fuel efficiency in diesel trucks or moving more freight into railways. In addition, it also assessed how we could move beyond "low hanging fruit" and fully decarbonise the road freight sector. The main conclusion of the study was that it is possible to decarbonise land freight by 2050. However, that would require a significant shift in policy and ambitious and early action to make it happen.

Regarding the "low hanging fruits", the study found out that fuel efficiency standards for trucks are the single most effective measure towards decarbonisation. Binding standards for new trucks and buses would deliver the 30-50% fuel efficiency improvements and CO_2 reductions. This could be achieved with conventional (diesel) technology and would be cost-effective for truck users (lower fuel bills).

The share of rail freight in the EU could be increased from today's 18% to 23%. This would require a significant expansion of the EU's railroad capacity, higher fuel taxes or enhanced road user charges and a modernised, competitive and customer-oriented rail freight sector. In countries without rail infrastructure, waterway freight transport could play this role.

Logistics efficiency could be improved. Currently 20% of trucks drive around empty. When loaded, trucks are often partially filled (around 50%). In theory there is potential to remove these inefficiencies i.e. by increasing transport-km costs, the application of green freight programmes and through digitalisation. The real potential is however likely much smaller.

Combined, the above measures could reduce road freight emissions by 36% compared to the business-as-usual scenario. Even if key, it is far from decarbonisation.

Full decarbonisation requires a shift to new technologies and energy carriers. To reach zero GHG emissions by 2050, renewable, decarbonised electricity is fundamental. In trucking, two main alternatives were explored: hydrogen and full electric (either battery or e-highways). These are fast-evolving technologies. In fact, a few months after we published our first study we had to update it to reflect new market developments.

Hydrogen or fuel cell trucks could offer an alternative (or - less likely - complementary) pathway to zero-emission trucking though this would require hydrogen to be produced based on renewable electricity. Currently hydrogen is mostly produced from natural gas. Whilst currently there are no hydrogen trucks on sale, an American start-up called Nikola has announced it will start selling hydrogen trucks from 2020. The drawbacks to hydrogen as a truck fuel are the very high vehicle/technology costs, the high cost of the refuelling infrastructure and the inefficiency of the hydrogen system. Indeed, the "hydrogen pathway" is less efficient than its full electric counterpart, and therefore requires more electricity, as explored in a later section.

E-highways could power long distances trucks with renewable electricity whilst they drive. The Siemens e-highway concept connects a hybrid electric truck with overhead lines through a pantograph (like a tram). This trolley truck concept is being trialled in Sweden, Germany and California in cooperation with Volvo and

Scania. By 2050 40-60% of highway trucks could be e-highway trucks. The advantage of the e-highway system is its high efficiency, its flexibility and the comparatively lower vehicle and infrastructure cost – since only a small part of the road network needs to be 'electrified'. According to the German environment agency it is by far the most cost effective route towards zero/low emission trucking (compared to hydrogen and power to liquid/gas). However, the biggest barrier is the coordinated roll-out of charging infrastructure across EU highways.

On battery electric trucks, a T&E paper[xxi] looked at the potential of battery electric heavy duty trucking in the EU, in particular for the more difficult long haul segment, by analyzing the technical feasibility, regulatory and market enablers and inhibitors, together with environmental impacts. We provided an overview of the electric truck markets, which show more heavy duty trucks with longer ranges being announced. In the European market, sales and series production have been announced by MAN, Volvo, Mercedes and others. Tesla in the US will release its long range Semi in 2019. To test the technical feasibility of these trucks and to compare them with their diesel counterparts, the paper used technical data and a simplified road load equation to compute the energy requirements for these vehicles, and the battery required to achieve the ranges claimed by manufacturers. The paper analysed charging strategies and potential solutions to overcome the significant power requirements on the grid from fast charging. In terms of total electricity generation, a European fleet of battery electric vehicles could require around 15% of present day generation. The technical analysis enabled a total cost of ownership (TCO) comparison between diesel and battery electric trucks, considering wages, maintenance, insurance, fuel and electricity prices, and road charging. Other studies by Scania[xxii] or Mckinsey[xxiii] also concluded that cost-parity would be reached in the 2020s, even for the largest trucks.

3.2.4. 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 to regulation of motorbikes. However, when it comes to decarbonisation, there is a clear pathway: battery electric.

In the case of electric-powered mopeds and motorcycles below 50cc, sales in the first three months of 2018 increased by 50.8%[xxiv] 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 motorcycles[xxv].

3.2.5. Urban buses

Urban buses are the first transport mode where electrification is having a significant impact today. This trend is driven primarily by the rising awareness of toxic air pollution in our cities from internal combustion engines and supported by the compelling economic, comfort, and noise advantages. Already in 2017, more than 90,000 electric buses were sold in China alone[xxvi].

We expect urban buses to be the first transport mode to reach zero emission thanks to electrification. Some manufacturers[xxvii] go as far as saying that by 2025, cities will only buy battery electric buses.

The European market is quickly ramping up. In 2017, the number of electric bus orders more than doubled (from 400 in 2016 to more than 1,000)[xxviii]; the next years are projected to follow the same tendency as manufacturers scale up production and their offerings. In 2018, the market share is estimated to be around 9%, marking the transition from niche to mainstream and the beginning of a steep and necessary uptake curve. Incumbent bus manufacturers are now seriously stepping up their game. Daimler, Scania, MAN, Volvo, and Iveco are actively promoting their full electric buses which are either already in series production or will be in 2019/20. This timely engagement by the traditional European manufacturers and their announced commitments to the electrical drivetrain are proof of this radical market change.

As T&E showed in its recent report[xxix], electric buses already offer a better TCO than diesel buses when external costs are included. When only health costs are considered (air quality and noise), electric buses are roughly on parity with diesel buses.

In our modelling, we have assumed that all new urban buses will be electric by 2030. Hydrogen buses could potentially also be part of the solution and we calculated the additional clean electricity demand a hydrogen pathway would create. However, they are (and expected to be) more expensive and less efficient than battery electric buses (see section on energy efficiency below).

3.2.6. 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[xxx] 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[xxxi]. In any case, it is unclear what decarbonisation pathway coaches will follow. From an energy efficiency perspective, battery electric would make more sense. Both options are analysed regarding additional renewable electricity needed in a later section.

3.2.7. Trains

Trains play an important role in decarbonising European transport as they are energy efficient and can be easily electrified. However, in 2011, only around two thirds of railway energy consumption in the EU was from electricity[xxxii]. In terms of the share of electrified railway lines, there is a large difference between Member States ranging from less than 10% in Estonia, Lithuania, and Ireland to more than 75% in Sweden, the Netherlands, Belgium and Luxembourg. Based on the additional increased demand that is assumed to occur from shifting passengers from cars to trains and freight from trucks to trains, railway energy demand and activity will approximately be double what it is today in 2050. Electrification of railways is a clear and proven technological pathway. Where this may not be economical, hydrogen fuel cell locomotives could provide a cheaper alternative. Electrification also improves energy efficiency compared to diesel locomotives; we assume that this equate to 20% improvement across the fleet by 2050.

3.3. Land transport summary

Table 1 summarises the fully electric sales of vehicles incorporated into our model. For intermediate years, sales are interpolated.

Table 1: Assumptions of zero emission vehicles for each mode. §Rail is by activity, not by sales

Sales of Zero Emission Vehicles	2025	2030	2035	2050
Motorcycles & mopeds	50%	100%	100%	100%
Passenger cars	15%	40%	100%	100%
Vans	20%	50%	100%	100%
Urban buses	50%	100%	100%	100%
Coaches	10%	25%	50%	100%
HGVs (<16t)[3]	10%	30%	80%	100%
HGVs (>16t)[4]	5%	30%	80%	100%
Rail (passenger and freight)§	70%	80%	90%	100%

[3] The values indicated here for are not those modelled in T&E's original roadmap for land freight published in June 2017. The values have been adjusted based on our better understanding of the issue today.

[4] The values indicated here for are not those modelled in T&E's original roadmap for land freight published in June 2017. The values have been adjusted based on our better understanding of the issue today.

Even if the percentages above are ambitious, they are the minimum needed in order to achieve long-term goals. As seen in Figure 4 below (left), even if all new vehicles are fully 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).

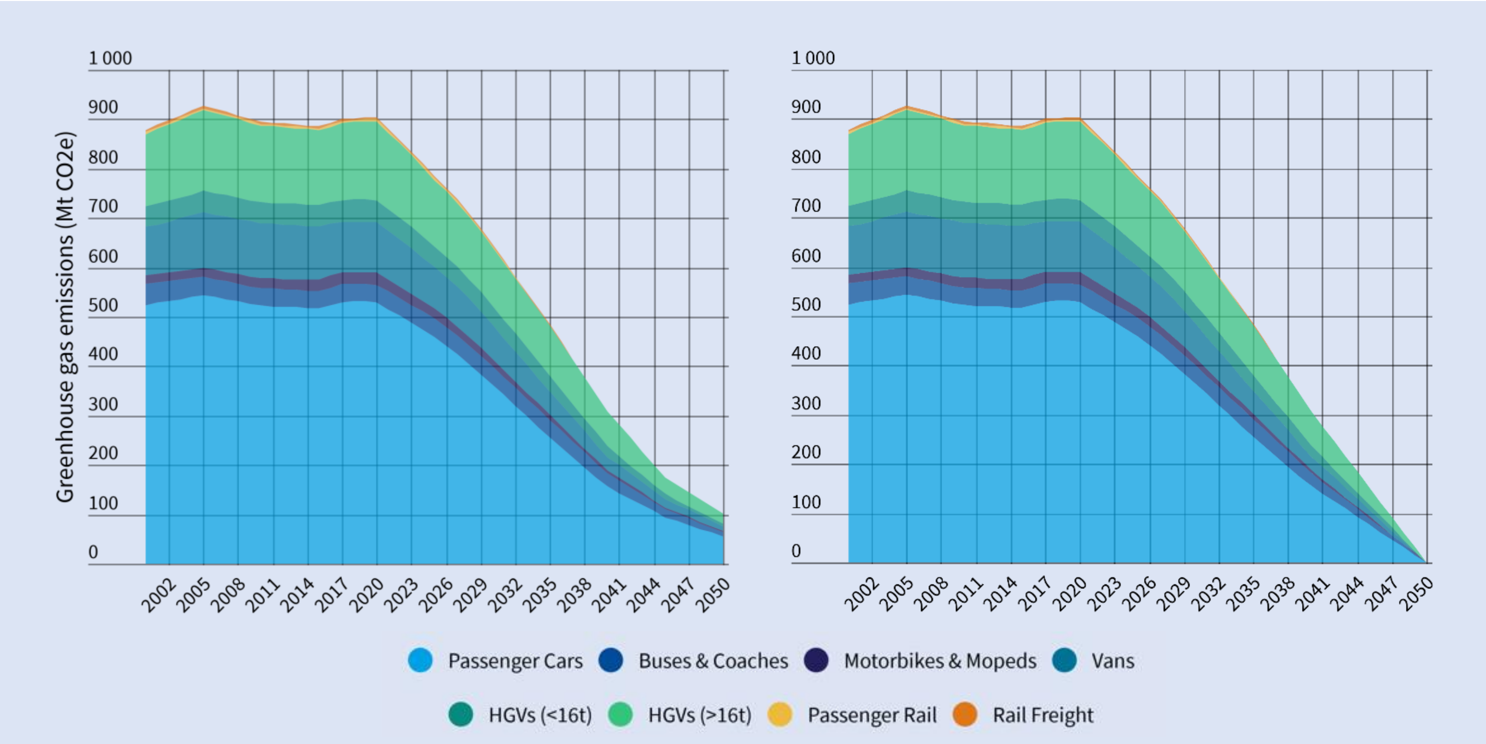

Figure 4: (Left) GHG for land transport modes with rapid adoption of ZEVs, and (Right) gradual applying ICE bans in the mid 2040s to achieve decarbonisation by 2050

3.4. Bunkers

In energy terms, bunkers are the energy consumption of ships and aircraft. While domestic flights are covered by national targets, oftentimes emissions from international flights and voyages are excluded. The Kyoto Protocol requested states to work through the UN's aviation and shipping agencies, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO), to develop measures to limit emissions from the sector.

The Paris Agreement has upended this approach, as it requires parties to develop economy-wide targets and therefore include international aviation and shipping. Furthermore the Paris Agreement requires complete decarbonisation of all sectors of all economies. ICAO, with its weak target of net 2020 emissions and reliance on offsetting instead of cutting emissions, is only capable of delivering a global minimum effort. Much more ambitious action at national and regional level, of the sort proposed below, is required. In shipping, countries are currently attempting to regulate maritime emissions through the IMO with the EU's 2023 deadline looming large. Currently, the IMO has a target of reducing emissions by at least 50% by 2050, which is far from decarbonisation in explicit terms. Experience, notably with aviation at ICAO, shows that international agreements tend to fall short of the required stringency in order to exact necessary behavioural, technological and economic changes in the industry. Therefore, it is likely, possibly imperative that complementary and supplementary regional actions will have to be taken to put the maritime industry on a sustainable decarbonisation pathway.

For the reasons above, we looked in two in-house studies who to decarbonise both sectors in the EU, summarised below.

3.4.1. Aviation

Synthesis of Roadmap to decarbonising European aviation:

While uncertainties exist, we do know that the sector will have a substantial fuel demand well into the 2030s, 2040s and beyond, the period when our economy needs to increasingly decarbonise. T&E's aviation decarbonisation report put forward measures to limit that fuel requirement, but ultimately the remaining and substantial fuel demand will need to have its carbon content eliminated. The process of cutting and then decarbonising that fuel demand was the focus of that study.

The report found that the expected technology and operations improvements will not mitigate the expected fuel demand and emissions growth from aviation. Generating incremental efficiency improvements from current aircraft designs is becoming ever more costly and difficult. Further operational improvements remain possible but do not achieve decarbonisation and require the right policies to be in place. To significantly reduce the expected fossil fuel demand and ultimately eliminate it from the sector would require further measures.

Carbon pricing needs to play a central role in bringing forward further reductions in fuel demand. Exempt from kerosene taxation and with most European aviation emissions excluded from the EU ETS, there is much that needs to be done.

The report showed that introducing fiscal measures that, combined, represent a carbon price equivalent to €150 a tonne can moderate demand fuel demand growth from the sector through incentivising a combination of design and operational efficiency improvements and modal shift. Other measures highlighted by the report include stricter fuel efficiency standards and incentives to speed up fleet renewal. Our report found that, combined, these measures could cut fuel demand by some 12 Mtoe, or 16.9% in 2050 compared to a business as usual scenario.

However that still leaves substantial and increased fuel demand in 2050. The report examined how the carbon footprint of the remaining fuel demand could be cut and, where possible, eliminated. With today's technology this can only be achieved through the use of sustainable alternative fuels. It demonstrated that this is no easy task, highlighting the issues faced in Europe to date in reducing the carbon intensity of fuels used for road transport.

To decarbonise aviation, new types of alternative fuels need to be brought forward. Our report focused on synthetic fuels, namely electrofuels (known as synthetic kerosene or power-to-liquid), which will be needed to close the gap. Electrofuels are produced through combining hydrogen with carbon from CO_2. With the hydrogen produced using additional renewable electricity and with the correct source of CO_2 (air capture), such fuels can be close to near zero emissions and carbon circular. Strict safeguards are needed to ensure synthetic kerosene would be produced only from zero emission electricity.

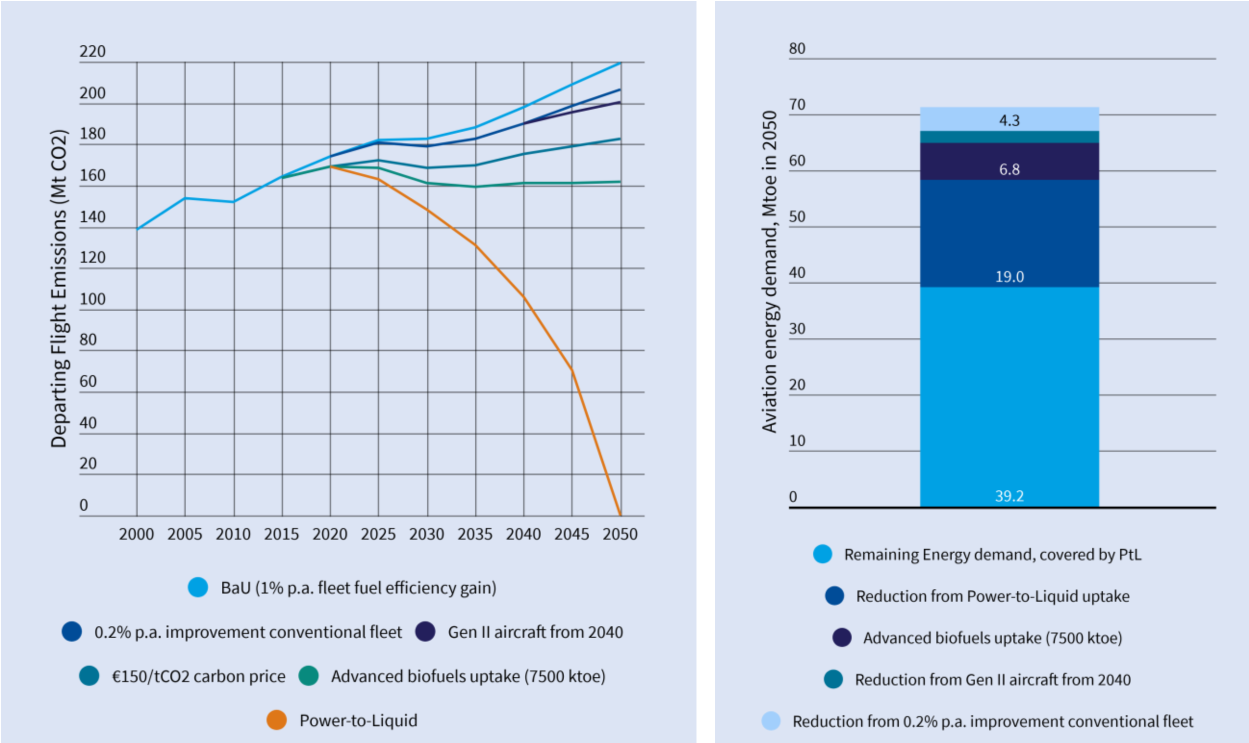

Figure 5: (Left) Reduction in European departing flight CO2 emissions. (Right) PtL consumption of European departing flights in 2050 after demand reduction measures have been applied.

If produced at scale, electrofuels are likely to cost between three and six times more than untaxed jet fuel. At a cost of €2,100 per tonne in 2050, electrofuel uptake will increase ticket prices by 59%, resulting in a 28% reduction in projected passenger demand compared to a business-as-usual scenario. However, compared to the ticket price with an equivalent CO_2 price of €150 a tonne, the ticket price increase would only be 23%. The report found that introducing a progressively more stringent low carbon fuel standard (GHG target) on aviation fuel suppliers will leave all operators flying within or from Europe needing to purchase such fuels. These rising fuel costs will increase operating costs which will inevitably be passed onto consumers, causing a fall in demand for jet fuel compared to forecasts and reducing the volume of alternative fuels that will be required to replace kerosene.

A further note of caution in the report was that while the use of such fuels can put aviation on a pathway to decarbonisation, getting to zero emissions, the generally accepted term for decarbonisation, will be difficult because producing alternative fuels which, on a life cycle basis, are 100% carbon free is very challenging. Advanced biofuels could play a role in substituting fossil fuel demand in aviation. However, strict sustainability safeguards are needed to ensure advanced biofuels offer genuine emission savings - these are not yet in place. If fuels with poor environmental and climate credentials would be excluded, the potential supply of advanced biofuels would be very limited. Our report finds that they could play a role - meeting up to 11% of the remaining 2050 fuel demand in our scenario - but alone won't be available in the quantities needed. This is partly because non-transport sectors will also have a claim to biomass feedstocks, reducing availability.

The report did not rule out the role that radical new aircraft designs could play in significantly reducing aviation emissions, for example hydrogen or electric aircraft. However such aircraft are not expected to be in operation in significant numbers until the 2040s, and will find it especially challenging to replace conventional aircraft for long-haul flights. What is less speculative is that significant liquid fuel demand will exist right through to 2050, and for that reason, the report focuses heavily on how such fuels can be decarbonised. Should hydrogen aircraft technology develop more rapidly this would not be at odds with significant investment in synthetic fuels as hydrogen is a key input for electrofuels.

Aside from decarbonising aviation fuels, the warming from aviation's non-CO2 effects at altitude is considerable and is a challenge that is barely being touched. While the report discussed these effects and identified possible mitigation approaches, there remains a lack of policy focus and investment in scientific research on this topic. This failure to act means we are unable to propose a suite of mitigation measures nor estimate their effects. What is clear is that the European Commission must meet its obligations under the EU ETS Directive to foster further research and, resulting from that, come forward with proposals on measures by the start of 2020.

Finally, the report does not recommend offsetting as this is a solution that is incompatible with the decarbonisation logic of the Paris Agreement. The report outlined what action should look like: aggressively cutting fuel demand, moderating the expected growth in air travel, decarbonising the remaining fuel, and addressing the sector's non-CO2 effects.

3.4.2. Shipping

Our report assessed potential technology pathways for decarbonising EU related shipping through a shift to zero carbon technologies. The report did not try to quantify the emissions reductions that specific regulatory measures to be introduced at the IMO or EU level might contribute towards decarbonisation by 2050 because there are too many uncertainties. We took a more limited first approach and investigated how zero carbon propulsion pathways that currently seem feasible to decarbonise shipping.

It is now generally accepted that ship design efficiency requirements, while potentially having an important impact on future emissions growth, will fall well short of what is needed. Further operational efficiency measures, such as capping operational speed, and a range of short & mid-term measures, such as Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) or wind propulsion, will be important to immediately peak energy consumption and emissions, but will be insufficient to decarbonise the sector or reduce its growing energy needs. In this context, this study assumes that with all the likely immediate measures adopted, energy demand for EU related shipping will still grow by 50% by 2050 over 2010 levels. This is within the range of the 20-120% global BAU maritime energy demand growth estimate[xxxiii].

The decarbonisation of shipping will require changes in onboard energy storage and use and the necessary accompanying bunkering infrastructure. The study identified the technology options for zero emission propulsion that, based on current know-how, are likely to be adopted. It was not exhaustive nor prescriptive because the ultimate pathways will likely depend on both the requirements of the shipping industry in terms of cost, efficiency and safety, and on the future renewable electricity sources that the shipping sector will need to compete for.

It is essential that any regulatory and economic policies to support any of the shipping technology pathways analysed in the report take account of the impact on the need of European renewable electricity production, while maintaining the highest sustainability criteria.

Our study recommended to prioritise battery-electric and hydrogen (pure and/or in the form of ammonia) technologies from sustainable renewable sources to decarbonise shipping. Although battery-electric propulsion appears to be the most efficient use of primary energy, a mix of battery, hydrogen, and ammonia technology is a more likely pathway for the different segments of EU shipping. Varying combinations of battery-electric and carbon-free fuels are likely to be pursued depending on the available renewable energy.

We found the least energy efficient technology pathways to decarbonise shipping to be those based on synthetic hydrocarbons - electro-methane and electro-diesel, using CO_2 from air capture. In addition, since synthetic methane and synthetic diesel would still emit GHG at the vessel level, the practical enforcement of their use under any emission reduction requirement could be very challenging, if not impossible for port/flag authorities. This because these synthetic fuels have very similar chemical characteristics to their fossil equivalents making it very difficult to easily distinguish between them (especially when blended); and since synthetic fuels are an order of magnitude more expensive than their fossil equivalents, the large price difference would provide a strong incentive for operators to cheat on any regulatory requirement to use these synthetic fuels thus creating a large competitive distortion.

Furthermore, the theoretical climate neutrality of synthetic methane would not be achieved if, as with LNG, methane leakage and slip were to take place during the transportation, bunkering and on-board combustion of the fuel. Technology pathways delivering zero GHG emissions at the vessel level would seem to be preferable.

There are also implications for the current investment in fossil LNG bunkering infrastructure for ships, which it is claimed could be used in the future for synthetic methane bunkering. Since synthetic methane is one of the least sustainable and enforceable technology pathways for shipping, the report also warned against public investment in LNG bunkering infrastructure with the hope that it would underpin synthetic methane uptake in the future.

Although the report didn't quantify biofuel pathways for shipping, the enforcement and sustainability problems identified involving synthetic methane are applicable to biofuels, too. Shipping's unique global refuelling patterns make it impossible to apply strict sustainability criteria for biofuels nationally or regionally because of the "collective action" problem and the mobility of bunker fuel suppliers in avoiding strict regulation. Port-state control of sustainability would be problematic too, as sustainable and non-sustainable biofuels would have similar apparent physical properties and be difficult to differentiate. Blending and mixing along the fuel supply chain and tank mingling with other fuels, would create even further difficulties for those port-state controls deciding to perform random checks. These all come in addition to sustainability and availability issues surrounding biofuels. Therefore, we recommend to reserve any available sustainable advanced biofuels to the aviation sector.

4. Energy requirements of decarbonisation

As described in previous section, we explored different decarbonisation pathways for most transport modes. 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. Below, in Figure 6, an example of the efficiencies of using renewable electricity in passenger cars. Similar proportions also apply to all transport modes. Further below we quantified the amount of renewables that different pathways would imply.

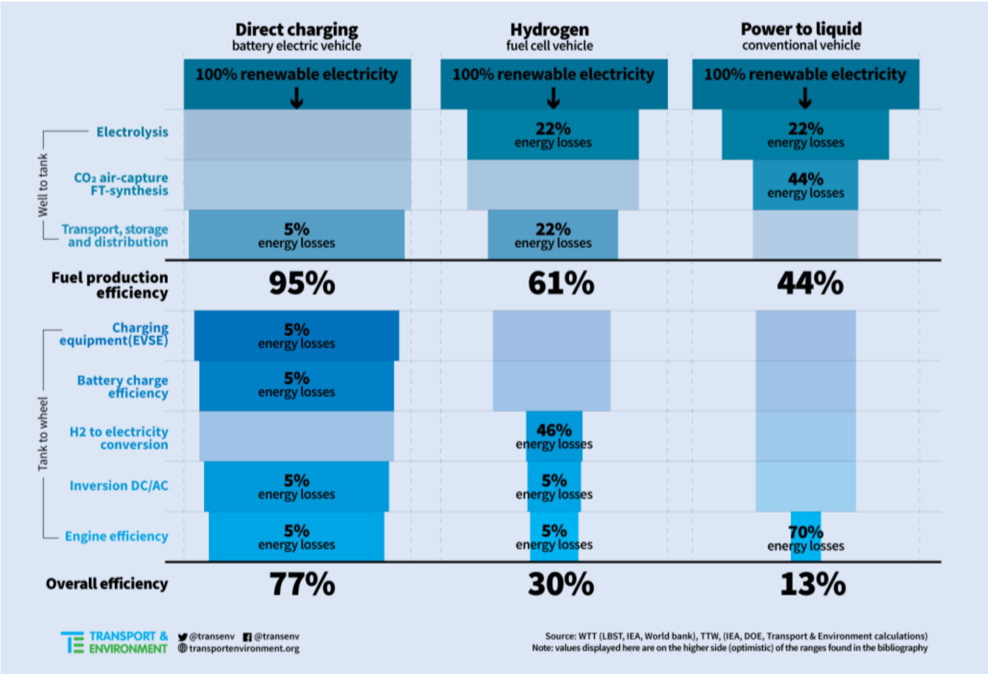

Figure 6: Efficiency of different passenger cars technology pathways based on renewable electricity. Details of assumptions to produce this graph are in Appendix 3 of the car decarbonization paper.

The table below shows what our studies concluded, both in absolute terms (TWh) and as a percentage of 2015 electricity generation (3,234 TWh)[xxxiv], to put the number into perspective. It is important to keep in mind that, as explained in previous sections, this is the electricity demand in scenarios that include other measures to also reduce demand or increase efficiency.

Table 2: Amount of clean electricity needed to decarbonise different transport modes. For details on calculations, read each individual study. In some cases (cars, trucks, aviation and shipping), demand reduction measures were applied. If those were not achieved, the amount of electricity would be higher. §As trains are already predominately electric, this value corresponds to running the remaining train stock in 2050 on hydrogen.

Transport mode	Electricity Generation for electric vehicles (TWh)	Electrofuels		Optimal pathway (TWh)
		Hydrogen/ Ammonia[5] (TWh)	Synthetic fuels (diesel, petrol, gas and kerosene) (TWh)	
Motorbikes	34 (1.1%)	90 (2.8%)	203 (6.3%)	34 (1.1%)
Cars	475 (14.7%)	1236 (38.3%)	2187 (67.6%)	475 (14.7%)
Vans	146 (4.5%)	381 (11.8%)	672 (20.8%)	146 (4.5%)
Buses	119 (3.7%)	310 (9.6%)	547 (16.9%)	119 (3.7%)
Trucks (<16t)	112 (3.5%)	292 (9.0%)	515 (15.9%)	112 (3.5%)
Trucks (>16t)	364 (11.2%)	949 (29.4%)	1676 (51.8%)	364 (11.2%)
Trains	145 (4.5%)	219 (6.8%)§	NA	145 (4.5%)
Total land transport:	1395 (43.1%)	3479 (107.6%)	5799 (179.3%)	1395 (43.1%)
Shipping	350 (11%)	1032-1192 (32-37%)	1718 (53%)	798 (25%)
Aviation	N/A	N/A	912 (28.2%)	912 (28.2%)

[5] Ammonia only applies to the shipping sector

Table 2 above shows that technologies directly using clean electricity as an energy vector are considerably more energy efficient than others. For land transport, as explained in previous sections, theoretically all options could be used to decarbonise transport. Clean electricity is also a limited resource. In addition, other transport modes, like aviation and shipping, also need it. If non-efficient alternatives would be used in land transport, the chances of decarbonising all transport would be lower.

Regarding aviation, its report highlighted the enormous demand on renewable electricity if fuel demand remains high and electrofuels are the only way to decarbonise. Using electrofuels to meet the expected remaining fuel demand for aviation in 2050 would require renewable electricity equivalent to some 28% of Europe's total electricity generation in 2015 or 95% of the electricity currently generated using renewables in Europe. However, with today's technology, synthetic fuels are the only technically viable solution that would allow aviation to exist in a world that avoids catastrophic climate change.

The complete decarbonisation of EU-related shipping in 2050 would require 11-53% additional renewable electricity generation across the EU28 over the 2015 levels. Literature is nascent on the different techno-economic options likely to be available, but almost completely lacking on the possible impacts of maritime decarbonisation on the broader energy system(s). Understanding these impacts is nevertheless essential, because it will influence financial and economic decision making by the EU and member states, including those related to investment in future renewable energy supplies and new ship bunkering infrastructure. This is what we attempted to do with our study. A considerable level of additional investment will be required shore-side charging stations, hydrogen/ammonia production plants, new ship propulsion and energy storage designs and the widespread provision of new port bunkering infrastructure.

5. Carbon budgets for European transport

This report has described the measures required to decarbonise European transport by 2050; this will be an enormous challenge and a reversal of the growth of transport emissions for over a century. This section quantifies the cumulative emissions for each mode and compares it with the carbon budgets that were recently updated in the special 1.5°C IPCC report.

The carbon budget is the amount of anthropogenic GHGs that can be emitted without exceeding thresholds in CO_2 concentrations that would result in global average temperature rises. The Mercartor Institute on Global Commons and Climate Change has calculated the global budgets with a 66% probability based on the IPCC report[6]; i.e. if emissions can be kept under the threshold, there will be a 66% chance that the global warming will be limited to the prescribed temperature. For 1.5°C the global budget is 383 Gt CO_2 eq. and for 2°C the global budget is 1033 Gt CO_2 eq., at the time of writing. From the beginning of 2018, the 1.5°C and 2°C budgets are 420 Gt CO_2 eq. and 1070 CO_2 eq., respectively.

There are several approaches to assign the budget between countries as outlined by, among others, the Öko Instut: historic responsibility, there is an onus on countries that have benefitted from high historic emissions to decarbonise faster than those countries who have not; share of global population, which assumes that per capita emissions should be equal, and; grandfathering, where the remaining budget is divided by the current share of emissions. For simplicity, the latter approach is used, however this also happens to give Europe the highest budget out of all the methods. The use of this method does not endorse this allocation, but it should be highlighted that the budgets calculated here are higher than what could be considered equitable across the world.

Global GHG emissions (excluding LULUCF) were estimated to be 49.3 Gt CO_2 eq[xxxv] in 2016. From Member State reporting to UNFCCC, the European Union emitted 4.5 Gt CO_2 eq (including from international aviation

[6] https://www.mcc-berlin.net/en/research/co2-budget.html

and bunker fuels), or 9.1%. Using 2016 as a base year only for determining the budget shares in a grandfathering approach, this would mean that the EU's carbon budget is 34.9 Gt CO_2 eq to limit to 1.5°C or 94.3 Gt CO_2 eq for 2°C. Based on the share of each mode, each sector would then be allocated the budget as shown in Table 3.

Table 3: Carbon budget allocation based on grandfathering approach, compared to the cumulative GHG emissions for each mode in a decarbonisation by 2050 trajectory. §Note that for shipping emissions, no trajectory was calculated to get to zero in 2050, therefore its budget is not calculated.

Transport mode	Share of EU emissions in 2016	Carbon Budget from 2018 (Mt CO_2 eq.; 66% probability)		Cumulative emissions 2018 to 2050 (Mt CO_2 eq)
		1.5°C	2°C	
Motorbikes	0.23%	89	227	439
Cars	11.90%	4564	11628	9225
Vans	2.32%	891	2269	1721
Trucks & buses	5.16%	1979	5041	4976
Trains	0.14%	55	139	112
Aviation	3.64%	1395	3553	3861
Total§	23.39%	8972	22857	20310

The results of this analysis are rather telling: despite all modes rapidly decarbonising to zero by 2050, cumulative emissions are well above the 1.5°C carbon budget. In terms of the 2°C budget, aviation overshoot the budget, although the transport sector as a whole manages to remain within the budget. This indicates firstly, that the measures and uptake of zero emission vehicles will need to happen much faster than modelled here, and secondly, highlights the important role of short term energy demand measures, such as road charges, fuel taxes, and inducing shift to less polluting modes will need to happen faster and to an even greater extent that has been described herein. The zero emission vehicle uptake and the demand reductions considered in this report series are already considered to be ambitious, but not enough for 1.5°C.

Another approach with the carbon budgets would be to calculate the year in which decarbonisation must take place. A simple approach is to take a linear trajectory from this year's (2018) emissions and calculate the year to decarbonise, although this may result in a year that is later than what may be realistically achieved considering the sudden drop off of emissions rather than the more likely trajectory of plateauing and and then increasingly falling emissions. With this approximation, the entire fleet (not sales) of cars, vans, and heavy duty vehicles would theoretically need to be zero emission by 2035, motorbikes by 2025, and trains by 2032.

This will be a challenge that must be tackled together, by the European Union, Member States, cities, urban centres, car and truck manufacturers, the shipping industry, airlines, fuel refineries, electricity providers, and of Europeans themselves.

6. Conclusions and policy recommendations

This synthesis report based on extensive research has shown how transport can be decarbonised in Europe by 2050. Our studies have shown that bringing transport close to decarbonisation is possible, but it should be done smartly. Tackling demand is key to reduce the amount of energy and other resources required to deliver zero emission mobility. Very large investments will be needed in the renewables sector, but also in electricity transmission grids. 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.

Our studies have 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 will be needed.

Regarding cars, back casting from where the EU needs to be in 2050 exposes the inadequacy of proposed EU 2030 car CO2 regulations. If sales of zero emission cars are to reach 100% by 2035 at the latest, significantly more than 35% of new cars should be zero emission vehicles by 2030, the current level being negotiated by the regulation. Without delay, a review in 2023 at the latest is needed to align the 2030 CO2 standards for cars with the Paris-compliant trajectory, i.e. at least 50-60% in 2030. An indicative target of zero emission for all new cars sold after 2035 at the latest is necessary to indicate a clear direction to the industry and provide enough lead time. Governments must reform national vehicle taxation policies to speed up transition and create the required TCO parity by means of purchase taxes to raise the costs of ICE's and lower those of ZEVs. The Alternative Fuels Infrastructure Directive (AFID) shall be updated to set mandatory charging infrastructure targets for member states and ensure full coverage and interoperability of the EU's Core and Comprehensive road network by 2030. Finally, via an enabling framework, support a timely development of EV supply chain in Europe, including competitive manufacturing of safe and sustainable batteries (the EU Battery Labelling and Battery Directive review).

However, even with 100% ZEV sales after 2035, the remaining fleet of fossil cars will continue to emit close to 60Mt of CO2 in 2050, even more if demand is not reduced, so additional measures are needed to speed up fleet renewal. Limits to EU vehicle circulation length (via type approval), national support to retire old cars and zero emission zones in cities will all help drivers retire their old polluting cars faster and enable the EU to achieve full decarbonisation of the entire car segment in 2050.

For vans, ambitious 2025 and 2030 van CO2 standards would be an step in the right direction, complemented by an effective zero emission crediting and debiting system. The Eurovignette directive should extend the current road charging rules to also cover large vans to create level playing field for cross-border freight transport.

For land freight, the first step is to have ambitious CO_2 standards for trucks and trailers, combined with a ZEV benchmark for trucks. National governments should introduce, expand and redesign tolls so as to accelerate the market take-up of zero or low carbon trucks. National governments should consider gradually increasing diesel tax, ideally in bigger groupings of countries (to avoid fuel tax tourism). Revenues could be used to fund the transition of the sector.

Cities need to adopt zero-emission freight strategies as to increase bottom up pressure on truckmakers to invest in zero emission trucks. As with other modes, the right infrastructure needs to be built, as all alternatives (battery electric, e-highway or hydrogen trucks) require it to operate. The EU should use its post-2020 transport budget lines to co-finance such projects, and avoid spending on technologies which do not have the potential to decarbonise.

For buses, cities, procurement authority and public transport operators need to start procuring electric buses en masse to replace their aging and polluting fleets, while communicating to manufacturers so they can ramp up scale of production, reducing prices. Focusing on a TCO-focused approach by shifting from upfront payments to lease or loan payments is also important, while including external costs in the tendering process when comparing different options. The EU should incentivise and deploy financial instruments to fund the transition, in particular easily accessible directly to cities. Setting a zero-emission bus mandate as part of the HDV standards for both 2025 and 2030 would also be a step in the right direction.

Gas vehicles should be excluded from the scope of the Clean Vehicle Directive. Finally, a temporary additional weight allowance for zero-emission buses should be introduced to limit the passenger restrictions due to the additional weight from the batteries.

Decarbonising aviation fuels will require significant investment, and significant investment requires certainty. That is why policy-makers need to turn their attention now to the safeguards and policies needed to bring such fuels to market, so that the availability of these fuels can be ramped up in line with the sector's need to decarbonise. More specifically, we propose:

- Cut fuel demand from the sector below projected levels through a carbon price equivalent to €150 a tonne achieved through a range of measures including kerosene taxation and a strengthened EU ETS;
- Cut fuel demand through additional measures such as stricter aircraft CO2 standards and incentives for fleet renewal;
- Further reduce the climate impact of aviation through a progressively more stringent low carbon fuel standard on aviation fuel suppliers, conditional on the necessary safeguards being in place, to bring aviation close to zero emissions by 2050; and
- Ensure the Commission brings forward proposals to address aviation's non-CO2 effects by the start of January 2020, as required by the revised EU ETS Directive.

For shipping, we recommend to prioritise battery-electric and hydrogen (pure and/or in the form of ammonia) technologies from sustainable renewable sources to decarbonise shipping. Although battery-electric propulsion appears to be the most efficient use of primary energy, a tech mix - battery, hydrogen, ammonia - is a more likely pathway for the different segments of EU shipping - domestic, intra-EU and extra-EU. Varying combinations of battery-electric and carbon-free fuels are likely to be pursued depending on the available renewable energy and operational needs of individual ship owners. Some key measures in the short-medium term are:

- Amend the AFID to stop mandating LNG bunkering infrastructure for maritime and inland ports, while mandating hydrogen bunkering infrastructure for seagoing and inland ships, and stop public (EU or national) funding of LNG bunkering infrastructure.
- Remove the opt-out clause in the AFID for making available shore-side electricity infrastructure for seagoing and inland ships in European ports, and exempt shore-side electricity from excise taxes or tax fossil marine fuels at the same or higher levels. Consider temporary exemption of shore-side power supply from network charges, too.
- Explore an EU-wide harmonised methodology for determining port discounts for zero emission ships, while allowing ports to decide on the offered discount levels.
- Mandate zero emission short-sea shipping (SSS) in the EU following Norway example[xxxvi], starting with passenger ships and gradually extending to other ship types. For deep-sea shipping a 12 and then 200 nautical miles CO2 emission control area (CO2 ECA) should be explored in order to incentivise the gradual uptake of zero emission technologies.

References

[i] Intergovernmental Panel on Climate Change, 2018. Global Warming of 1.5 °C. https://www.ipcc.ch/report/sr15/

[ii] Öko institut, 2016. Targets for the non-ETS sectors in 2040 and 2050. https://www.oeko.de/en/publications/p-details/targets-for-the-non-ets-sectors-in-2040-and-2050/

[iii] European Council, 2018. March 2018 conclusions. https://www.consilium.europa.eu/media/33430/22-euco-intermediary-conclusions-en.pdf

[iv] Transport & Environment, 2017. Roadmap to climate-friendly land freight and buses in Europe. https://www.transportenvironment.org/publications/roadmap-climate-friendly-land-freight-and-buses-europe

[v] Transport & Environment, 2018. Roadmap to decarbonising European cars. https://www.transportenvironment.org/publications/roadmap-decarbonising-european-cars
[vi] Transport & Environment, 2018. Roadmap to decarbonising European aviation. https://www.transportenvironment.org/publications/roadmap-decarbonising-european-aviation
[vii] Transport & Environment, 2018. Roadmap to decarbonising European shipping. https://www.transportenvironment.org/publications/roadmap-decarbonising-european-shipping
[viii] Transport & Environment, 2018. Electric buses arrive on time. https://www.transportenvironment.org/publications/electric-buses-arrive-time
[ix] Transport & Environment, 2018. CO2 emissions from vans: time to put them back on track. https://www.transportenvironment.org/publications/co2-emissions-vans-time-put-them-back-track
[x] Transport & Environment, 2018. T&E response to Future climate and energy policy - a Strategy for long-term EU greenhouse gas emissions reductions https://ec.europa.eu/clima/consultations/strategy-long-term-eu-greenhouse-gas-emissions-reductions_en
[xi] Transport & Environment, 2017. Reconfirmed: Transport is Europe's biggest climate problem. https://www.transportenvironment.org/newsroom/blog/reconfirmed-transport-europe%E2%80%99s-biggest-climate-problem
[xii] European Commission, 2011. Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en
[xiii] Member State report of GHG Inventory to UNFCCC. Available: https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2018
[xiv] Transport & Environment, 2015. Too big to ignore – truck CO2 emissions in 2030. https://www.transportenvironment.org/publications/too-big-ignore-%E2%80%93-truck-co2-emissions-2030
[xv] Carbon Brief, 2016.Analysis: Aviation could consume a quarter of 1.5C carbon budget by 2050 https://www.carbonbrief.org/aviation-consume-quarter-carbon-budget
[xvi] Third IMO GHG study, 2014. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third%20Greenhouse%20Gas%20Study/GHG3%20Executive%20Summary%20and%20Report.pdf
[xvii] European Transportation Roadmap Model (EUTRM). More information and data sources available: https://www.transportenvironment.org/what-we-do/eu-transport-policy/emissions-modelling
[xviii] Transport & Environment, 2018. Natural gas-powered vehicles and ships – the facts https://www.transportenvironment.org/publications/natural-gas-powered-vehicles-and-ships-%E2%80%93-facts
[xix] CE Delft, 2017. Van use in Europe and their environmental impact. https://www.cedelft.eu/en/publications/1968/van-use-in-europe-and-their-environmental-impact
[xx] The Telegraph, 2018. Electric vans will deliver on cost by 2020, says UPS. https://www.telegraph.co.uk/business/2018/04/01/electric-vans-will-deliver-cost-2020s-says-ups/
[xxi] Earl, T. et al., 2018. Analysis of long haul battery electric trucks in EU. Available at: https://www.transportenvironment.org/publications/analysis-long-haul-battery-electric-trucks-eu
[xxii] Scania, 2018. The Pathways study: Achieving fossil-free commercial transport by 2050. https://www.scania.com/group/en/wp-content/uploads/sites/2/2018/05/white-paper-the-pathways-study-achieving-fossil-free-commercial-transport-by-2050.pdf
[xxiii] McKinsey, 2017. What's sparking electric-vehicle adoption in the truck industry? https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry
[xxiv] https://www.visordown.com/news/general/bottom-falls-out-european-scooter-sales
[xxv] https://www.harley-davidson.com/us/en/motorcycles/future-vehicles/livewire.html Consulted on 14 Nov 2018.
[xxvi] Bloomberg, 2018. Electric Buses in Cities. Driving Towards Cleaner Air and Lower CO2 https://data.bloomberglp.com/bnef/sites/14/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf
[xxvii] Bloomberg, 2017. MAN's $583,000 Electric Urban Bus to Test Cities' Spending Plans. https://www.bloomberg.com/news/articles/2017-11-13/man-s-583-000-electric-urban-bus-to-test-cities-spending-plans
[xxviii] Market data provided by Stefan Baguette, ADL Market Analyst and Product Manager.
[xxix] Transport & Environment, 2018. Electric buses arrive on time.

https://www.transportenvironment.org/publications/electric-buses-arrive-time
[xxx] Electrive, 2018. Flixbus launches first long-distance electric bus route in France
https://www.electrive.com/2018/04/11/flixbus-launches-first-long-distance-electric-bus-route-in-france/
[xxxi] Fuel Cells and Hydrogen Joint Undertaking. European Hydrogen Transit Buses in Scotland https://www.fch.europa.eu/project/european-hydrogen-transit-buses-scotland
[xxxii] UIC and CER (2015) Rail transport and environment: facts & figures. Available:
http://www.cer.be/publications/latest-publications/rail-transport-and-environment-facts-figures
[xxxiii] CE Delft, 2017. Update of Maritime Greenhouse Gas Emission Projections
https://www.cedelft.eu/en/publications/2056/update-of-maritime-greenhouse-gas-emission-projections
[xxxiv] European Commission, 2017. EU energy in figures.
https://publications.europa.eu/en/publication-detail/-/publication/2e046bd0-b542-11e7-837e-01aa75ed71a1/language-en/
[xxxv] Netherlands Environmental Assessment Agency, 2017. Trends in global CO2 and total greenhouse gas emissions: Summary of the 2017 report.
https://www.pbl.nl/en/publications/trends-in-global-co2-and-total-greenhouse-gas-emissions
[xxxvi] Maritime Clean Tech, 2018. Norwegian parliament adopts zero-emission regulations in the fjords.
https://maritimecleantech.no/2018/05/03/norwegian-parliament-adopts-zero-emission-regulations-fjords/