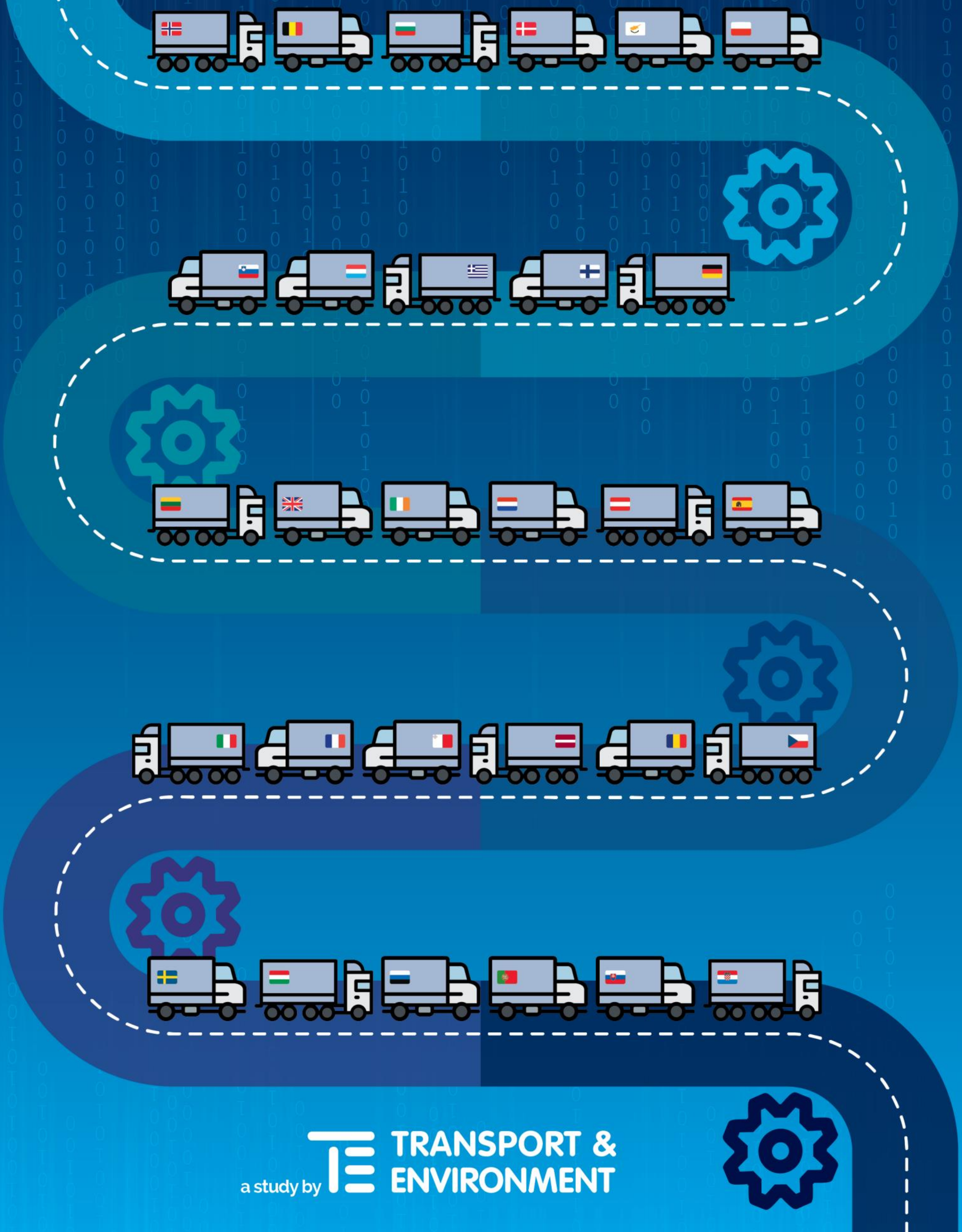
Roadmap to climate-friendly land freight and buses in Europe

June 2017



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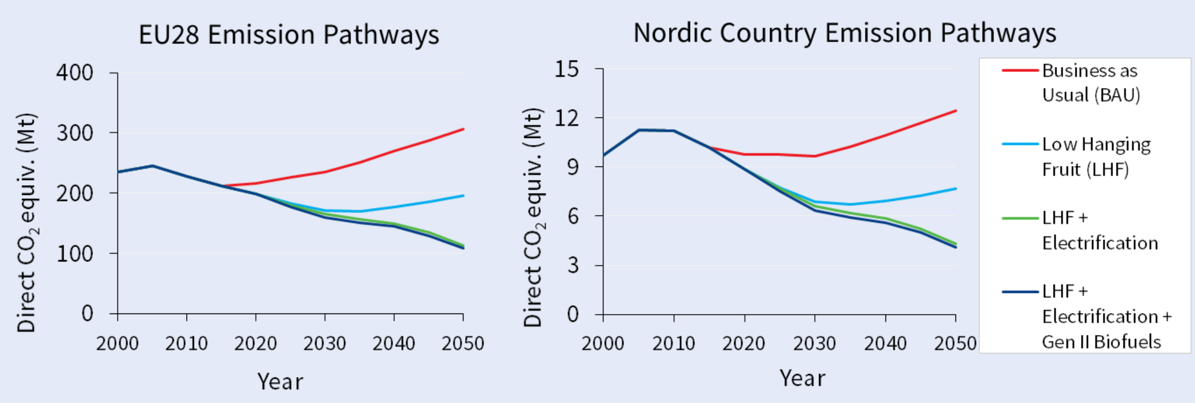
Executive Summary

In Europe, and Nordic countries, transport is the single largest emitter of greenhouse gases (GHG) and thus the biggest contributor to climate change. In the case of light duty vehicles, battery electric vehicles are now widely seen as the fastest and most cost-effective pathway towards decarbonisation. For heavy vehicles the pathway is far less clear. Road freight emissions in the Nordic countries and the EU are still above 1990 levels and are expected to continue increasing in the coming decades.

This report assesses how the EU and Nordic countries 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. For this we looked at technologies such as catenary-hybrid, battery electric, hydrogen and power to liquid. All of this information was fed into T&E’s in-house transport model.

The main conclusion of the study is that it is possible to decarbonise road freight and buses by 2050, both in the EU and in the Nordics. However, that would require a significant shift in policy and ambitious and early action to make it happen. The graph below summarises the key findings of the report following different emission pathways following the options detailed herein.



Efficiency first – the low hanging fruit

1. 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).

2. 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.

3. 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.

Beyond “low hanging fruit” – towards full decarbonisation

Although advanced sustainable biofuels can make a small contribution to reducing road freight emission it is clear that full decarbonisation of the road freight sector cannot be achieved with conventional (diesel) technology. Full decarbonisation requires a shift to new technologies and energy carriers. To reach zero GHG emissions by 2050, renewable, decarbonised electricity is fundamental. The Nordic countries are uniquely placed to lead the transition towards zero carbon trucking. Most of them already have an almost completely decarbonised electricity grid, and still have potential to install additional renewable capacity to fuel e-highway trucks or potentially produce power-to-liquids for internal consumption or exports. The key question is how clean electricity can be used as a truck and bus fuel.

1. Battery electric vehicle technology is limited to small and medium trucks with short, urban mission profiles. Given the rapidly falling battery costs, predictable routes and easy overnight recharging, delivery trucks and urban buses can, and should, become fully electric.

2. 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.

These two options combined would cut emissions an additional 27% compared to the business-as-usual by 2050. Combined with the low-hanging fruit options, it would cut emissions by 63% by 2050.

3. 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 almost 3 times less efficient than its full electric counterpart, and therefore requires more electricity. It is important to bear in mind that fully decarbonising the existing grid is already a significant challenge. Such a significant increase in electricity capacity is not likely to be realistic.

4. Power to liquid/Gas means using clean electricity to produce a gaseous or liquid fuel. If the electricity is renewable this could result in zero-emission fuel which could be used to power a combustion engine. In theory this pathway would not require moving beyond combustion engines to achieve decarbonisation. However, the amount of additional renewable electricity required to power the - already much more efficient - trucking fleet would be huge. Compared to the amount needed to fuel battery electric or e-highway trucks, more than 5 times less efficient, placing huge strain on the European power supply. As a result power-to-X could play a role as a complement to the e-highway pathway but is unlikely to be a realistic stand-alone solution nor a complement to hydrogen because of the demands this would place on the electricity system.

As both hydrogen and power-to-liquids require massive amounts of renewable electricity, other options would need to be considered as well beyond the assumptions considered in this study, for example reduced freight transport demand, higher modal share, or invest in innovation in order to ensure that large trucks can run on batteries when off the catenary lines.

Policy recommendations

Whilst decarbonising road freight is possible, it will not happen without ambitious policy interventions, at all levels.

1. CO_2 standards for trucks and trailers. CO_2 or fuel efficiency standards provide manufacturers and suppliers with long term planning and investment certainty. The Commission will propose a first CO_2 standard for some truck categories in 2018. This will need to be complemented by more aggressive standards for all trucks and trailers for 2030. Standards should exhaust the cost-effective technology potential (30-50%) and push hybrid technology for trucks with a high share of start and stop driving. This will facilitate the shift towards e-highway trucks.

2. A zero emission vehicle (ZEV) mandate/quota for buses and delivery trucks. California and China have ZEV mandates for passenger cars, establishing mandatory targets for vehicles emitting zero emissions. These have provided a huge boost to the global EV market. The Commission is considering a ZEV mandate for urban buses. It should introduce a ZEV mandate not just for buses but for all delivery trucks. Accompanying the ZEV mandate should be a cross-cutting “low/zero emission trucking” strategy both at EU but perhaps also at Nordic level.

3. Road charges, tolls and fuel taxes are key drivers of lower carbon trucking. The EU will propose an amendment to its tolling directive (Eurovignette) in 2017. 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.

4. Zero-emission freight strategies for cities need to be adopted across Europe. Currently the Netherlands is one of the few countries that explicitly aims to phase out combustion engine trucks and buses from cities in between 2020 and 2030. Other countries, e.g. the Nordics, should follow so as to increase bottom up pressure on truckmakers to invest in zero emission trucks and buses.

5. Building the right infrastructure. Battery electric, e-highway or hydrogen trucks all require infrastructure to operate. Based on current knowledge, battery charging in cities and e-highway infrastructure on highways appear to be the most promising investments. A starting point would be to finance cross-border trials of e-highway trucks. The EU should use its post-2020 transport budget lines to co-finance such projects but the Nordic countries too could initiate such trials, and avoid spending on technologies which do not have the potential to decarbonise.

6. Zero-emission liquid fuels cannot be a stand-alone solution to decarbonising transport but could play a complementary role in a fully decarbonised transport system (e.g. powering an e-highway truck going off the highway to the warehouse). The EU renewable energy directive is a key tool to boost the supply of sustainable and advanced fuels. Its reform is currently under discussion. In addition to focussing on advanced biofuels – which can only make a limited contribution - the directive should be amended to require fuel suppliers to also supply renewable electricity and (renewable and sustainable) power-to-liquid to the road transport sector.

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List of acronyms

BAU	Business-as-usual
BEV	Battery electric vehicle
CCS	Carbon capture and storage
EC	European Commission
EFSI	European Fund for Strategic Investment (*Juncker plan*)
ESR	Effort sharing regulation
EU	European Union
EUTRM	European transportation roadmap model
EV	Electric vehicle
FAME	Fatty acid methyl ester
FCEV	Fuel cell electric vehicles
GDP	Gross domestic product
GHG	Greenhouse gas
GTRM	Global transportation roadmap model
HDV	Heavy duty vehicle (includes trucks and buses)
HHGV	Heavy heavy goods vehicles (in EUTRM refers to trucks above 16t)
HGV	Heavy goods vehicle (includes only trucks)
HVO	Hydrotreated vegetable oil
ICCT	International Council for Clean Transportation
ICE	Internal combustion engine
ILUC	Indirect land use change
IM	Rail infrastructure manager
ITS	Intelligent transport systems
LDV	Light duty vehicle (includes cars and vans)
LHF	Low-hanging fruit
LNG	Liquefied natural gas
MCV	Medium commercial vehicle
MHGV	Medium heavy goods vehicles (in EUTRM refers to trucks below 16t)
MRV	Monitoring, reporting and verification
NO	Norway
PES	Primary energy supply
PHEV	Plug-in hybrid electric vehicle
PtG	Power-to-gas
PtL	Power-to-liquid
RED	Renewable energy directive
RU	Railway undertaking (operator of the trains)
TEN-T	Trans-European transport network
TTW	Tank-to-wheel (tailpipe emissions)
VECTO	Vehicle energy consumption calculation tool
WTT	Well-to-tank (upstream emissions including the extraction, refining and transport of the fuel)
WTW	Well-to-wheel (whole life cycle, combination of WTT and TTW)
ZEV	Zero-emission vehicle

1. Introduction

1.1. Background

In Europe, transport is the largest emitter of greenhouse gases (GHG)[i] and thus the biggest contributor to climate change. In order to curb and bring to zero these emissions, a strategy for the transport sector must be rapidly adopted to efficiently adopt the latest carbon free technology. In the case of light duty vehicles, battery electric vehicles are now widely seen as the fastest and most cost-effective pathway towards decarbonisation. In fact, Norway's ambitious pro-electric vehicles (EV) policies have contributed significantly to this with 29% new sales share of PHEVs and BEVs in 2016[ii]. For heavy vehicles the pathway is far less clear, as batteries aren't dense enough to work on this scale yet.

In 2017, Norway is holding the Nordic Council[1] presidency. The Norwegian Ministry of Climate and Environment commissioned a paper from Transport & Environment on zero GHG trucking and heavy duty vehicles (HDV), including buses, the purpose of which is to inform discussions under the Nordic Council of Environment Ministers in 2017.

This research report outlines the state of play, options and policy recommendations needed to achieve zero GHG HDV transport in the European Economic Area by 2050, with a focus on Nordic countries.

1.2. Required efforts under agreed climate targets (2030)

The EU as a whole agreed to reduce its GHG emissions by 40% by 2030 compared to 1990.[iii] In order to achieve this, EU leaders agreed to reduce its emissions outside the emissions trading system (EU ETS), including surface transport, buildings, agriculture and waste, by 30% compared to 2005. The Effort Sharing Regulation (ESR), still in negotiation between the European Parliament and the European Council, will establish the exact target for each country for its ESR sectors. Nordic countries have ambitious targets compared to the EU average, as can be seen in the table below, and Norway[iv] also agreed to participate in the system, despite not being an EU member:

Member state	Effort-sharing target (vs. 2005) by 2030
EU	-30%
Denmark	-39%
Finland	-39%
Iceland	-30-40% [2]
Norway	-40%[3]
Sweden	-40%

Surface transport is responsible for 35% of the emissions in the EU within the ESR sectors. It is by far the largest sector when it comes to emissions, only followed by buildings with 25% of the emissions.[v] Road transport, both in the EU and in Nordic countries, accounts for more than 90% of the transport emissions. Within road transport, heavy duty vehicles represent more than 25% both in the EU and in the Nordic countries, and its importance is expected to increase.[vi]

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[i] Transport accounts for 26% of all GHGs, the next highest sector being electricity production at 24%. Roman numerals refer to endnotes while ordinary numbers refer to footnotes; for the full list of endnotes, please see the final pages of this report.

[1] The Nordic Council unites Denmark, Finland, Iceland, Norway and Sweden. Note that in this report, Iceland transport emissions are not computed. Iceland, due to its unique location and energy grid, is excluded from this study. In addition, our transport model does not include Iceland. Thus unless stated explicitly, 'Nordic countries' refers to the Nordic council countries without Iceland.

[2] Iceland intends to join the Effort Sharing Regulation, but at the date of writing is still discussing the details with the European Commission.

[3] Norway is still discussing with the EU the details of its participation in the system.

1.3. Required efforts under the Paris Agreement

The Paris Agreement establishes that parties will take action to hold the global temperature increase to 2ºC, and pursue efforts to limit it to 1.5 ºC.[vii] A recent study calculated the targets needed in effort sharing sectors in the EU by 2050 in order to stay within the Paris limits.[viii] It concluded that to avoid catastrophic climate change, GHG emissions in the effort sharing sectors, where transport is included, should be, in 2050, 95% below 2005 levels. Given that some of the included sectors, such as agriculture, cannot fully decarbonise, road transport should fully decarbonise in order to reach this target. This report utilises this basic assumption, and investigates different ways to reduce GHG emissions from trucks and buses to zero by 2050.

1.4. Past GHG emission trends in road transport

Between 1990 and 2014, road transport emissions in the EU+NO have increased by 15%[ix], despite the efforts to make light duty vehicles (LDVs) more efficient. Emissions increased steadily until 2007, when they started to decrease, mostly due to the economic crisis, i.e. from reduced demand for road transport, not efficiency. However, for the last two years in a row, road transport emissions have increased in the EU+NO. Similar trends have been observed for road freight emissions. HDVs represent around 30% of all road transport emissions, but their share is expected to grow if no measures are taken, as the rest of the road transport sector decarbonises.

In the Nordics, the trend is less acute, and GHG road transport emissions have only increased by 6% in 2014 compared to 1990. Since 2007, they have steadily decreased, including the last few years, in contrast to the general EU trend. However, this can be partially explained by the use of biofuels in Sweden and Finland. Although the overall (life-cycle) emissions associated with the use of biofuels can be worse for the climate than their fossil counterpart[x], biofuels are assumed to be zero-emissions in national GHG inventories.[4] The same trends are observed in road freight emissions. However, future demand for trucking is likely to continue growing: in Norway, for example, freight transport activity is expected to grow by 35-40% by 2040.[xi]

1.5. Vehicle stock and vehicle mileage trends

The EU28 heavy duty vehicle (HDV) fleet was approximately 6.3 million vehicles in 2014, an increase of 1% over 2005 numbers. New registrations were 326,000 in 2015 in the EU. [xii] The HGV fleet size in the Nordic countries was 385,000 in 2014[xiii], representing a little over 6% of the total EU fleet. Except for Denmark which had largely a static fleet size, fleet sizes in the Nordic countries have all increased significantly more than in the EU, recording an 8-14% increase over the same period. Exceptionally, the Finnish fleet increased by almost 60%. In terms of new registrations, the Nordic countries were responsible for 5.7% of the market. The Icelandic HDV fleet is the smallest of the Nordic countries at approximately 10,000 and unique in Europe owing to its distance to the continent and population distribution, with two thirds of the population living in Reykjavik.

HGV mileage travelled each year is strongly dependant on the truck type and country. As for passenger cars, the annual mileage of HGVs reduces with the age of the vehicle. In general, mileage for new HGVs has on average increased from 2005 to 2010[xiv] to about 110,000 km for the EU for the 40-50t category. In the EU, the average age of the HGV fleet was 10 years old in 2010, up from 8 years old in 2005.

The Nordic countries generally follow these trends, however geographical reasons change the absolute values. For example in the case of Sweden, the mileage of a new HGV in the 40 – 50t category in 2010 was considerably above than the EU average whereas it was 30,000 km in Iceland. Trucks are, on average, a year younger in Sweden and a year older in Finland and Norway compared to the EU. The average age of the

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[4] In 2014 more than 13% of all energy used in surface transport in Sweden was biofuels (without policy multipliers), after a doubling in just four years. Similar trends were observed in Finland (Eurostat, SHARES database). All biofuels are zero-rated, even in those cases when their life-cycle might be worse than the fossil alternative.

Danish fleet was 6 years in 2010. In terms of infrastructure, the EU motorway network is approximately 75,000 km.[xv] The Nordic motorway network is 4,500 km.

1.6. Policy developments

There are some on-going or planned policy developments in the EU with the objective to reduce emissions from HDVs, briefly summarised here:

Monitoring, reporting and verification (MRV)

On 31 May 2017 the European Commission made a proposal to monitor and report truck CO_2 emissions. To date truck CO_2 emissions have not been monitored and reported in a systematic way. The Commission has developed VECTO, a simulation tool to measure truck CO_2 emissions. With the upcoming MRV proposal, truck CO_2 emissions are required to be certified, reported and monitored. Such an MRV scheme will bring more market transparency and enable truck buyers to compare the fuel efficiency of different vehicles. It will also be the foundation of the planned truck CO_2 regulation.

Review of Eurovignette Directive

The European Commission published a draft proposal to review the Eurovignette Directive also on 31 May 2017. The Directive currently regulates how member states can charge (toll) trucks and buses (heavy duty vehicles, or HDVs) when using their roads. The Commission proposes that toll charges be amended "taking into account reference CO_2 emissions values and the relevant vehicle categorisation". After the Commission defines "the reference values of CO_2 emissions, together with an appropriate categorisation of the HDVs concerned", member states would have one year to revise the toll charges applied within their territories. The proposal further provides that "zero-emission vehicles shall benefit from infrastructure charges reduced by 75% compared to the highest rate". Additionally, the Commission has proposed that the Directive be extended to cars and vans.

Fuel efficiency standards for Heavy Duty Vehicles

The European Commission committed in its Low Emissions Mobility Strategy (July 2016) to introduce a truck CO_2 standard as it has done for cars and vans in the past. This proposal is expected to come in the first half of 2018. The European Commission is currently performing an impact assessment to determine the baseline vehicles and which cost-effective technologies are currently on the market to improve truck fuel efficiency. Furthermore the EC still needs to decide what kind standard they will introduce (whole vehicle standard, engine standard, whole vehicle and engine standard …). The proposal will be issued in 2018, and would be adopted in 2019/2020. The standards will likely kick in from the mid-2020s. The Commission is also considering a zero emission vehicle mandate for urban buses.

EU post-2020 multi-annual budget communication

A draft post-2020 Multiannual Financial Framework or "EU Budget" will be finalised by the European Commission before 01 January 2018. The current seven year budget that runs from 2014-2020 and earmarks approximately 100 billion euros for transport infrastructure (under different funds such as CEF, ESI, and Horizon 2020). The EU's transport budgets can be used to build (cross-border) infrastructure that is needed to fuel battery, hybrid or hydrogen vehicles. In addition to this budget, the EU is finalising the second part of the European Fund for Strategic Investments which aims at attracting private investment into Europe.

Review of the Renewable Energy Directive

The renewable energy directive proposed by the European Commission sets out an advanced biofuels target for fuel suppliers of 3.6% by 2030, inside an advanced alternative fuels target of 6.8% in 2030 for fuel suppliers. The advanced alternative fuels are advanced biofuels, renewable electricity, waste-based fossil fuels and renewable fuels of non-biological origin (for example hydrogen or Power-to-X). Hence there is an option for fuel suppliers to blend PtX into their fuel mix. The electricity needs to be of renewable origin, excluding biomass, for PtX to be considered as a part of the blending obligation. The inclusion of the different fuels and the target levels may still change during the political process.

1.7. Market developments

There are several promising on-going market developments to reduce the emissions from the sector. This report reviews many different alternatives on how to reduce GHG emissions from HDVs. The main ones are battery electric trucks and buses, hybrid trucks powered by catenary lines, fuel cell hydrogen, and power-to-liquids, and are all discussed in detail in their specific sections.

2. Methodology and business-as-usual scenario

HDV GHG emissions are calculated by T&E's in-house model, the European Transportation Roadmap Model (EUTRM). EUTRM is based on the ICCT's Global Transportation Roadmap Model (GTRM)[xvi], and adapted to include the 28-EU member states plus Switzerland and Norway. As the GTRM was first released in 2012, the EUTRM makes use of the most recent available data as well as detailed European-specific data (such as member state electricity grid mix and transfers of second hand vehicles). This section aims to briefly discuss the EUTRM and the business as usual scenarios, particularly focused on road freight and to a lesser extent, bus passenger transport.

In this report, four modes of transport are considered. Rail freight refers to both electrified and diesel trains that move freight. HGVs are divided into two categories: trucks greater than 3.5 tonnes and less than 16 tonnes (medium heavy goods vehicles, MHGVs) and trucks that are greater than 16 tonnes (heavy heavy goods vehicles, HHGVs). We also consider passenger movements by bus, which include vehicles longer than 12 metres and more than 16 passenger capacity. Freight movements are mostly measured in tonne-kilometres (t-km).

The EUTRM at a glance

The EUTRM is a demand driven model that can compute GHG emissions in five year intervals. Transport and freight demand are based on purchasing power parity (PPP) adjusted GDP, which is determined by historical and projected gross domestic product (GDP), population, and fuel price for each country. All transport demand is then met with effectively unlimited transport capacity. The relationship between freight transport and GDP has been observed historically[xvii], and this assumption is carried forward in time (passenger transport demand shows a slight decoupling with GDP). Thus, an increase of per capita GDP over time will result in an increase of demand for transport and freight. In lieu of policy decisions, this new demand is only met by increasing the fleet size with new vehicle sales.

The EUTRM is initialised with historical data, whereby for the example of trucks, the vehicle stock and number of new vehicles (both in number and in category), mileage, fuel consumption, and load factor are considered. Vehicle renewal / purchasing is based on retirement curves and freight demand. In a business-as-usual (BAU) case, with the exception of legislated policies, all of the aforementioned parameters are assumed constant for future years. The only 'predictions' made in the model are based on GDP, population estimates and electric grid composition (i.e. external estimates). Only policy decisions will change mode specific parameters. Thus, in the case of trucks, these can include policy driven modal shift (moving freight from road to rail), engine technology uptake (hybrid, electric, hydrogen), and fuel efficiency (efficiency standards). Therefore, the strength of the EUTRM is in its ability to combine multiple policy decisions and show their effect on the BAU case, and to quantify the relative importance of policies on GHGs.

2.1. Defining the BAU case

The BAU case can be a contentious issue and is rarely the same between independent studies. Careful consideration of GDP projections must be taken into account as it is the key parameter to predict transport demand, as well as the implementation of legislated policies. In the EUTRM, GDP and population estimates are based on the lowest of the Commission's Reference Scenario[xviii], OECD and IMF WEO; oil prices are kept constant. Table 1 summarises the inputs and projections of the GDP driven freight activity. Despite Brexit, the UK is retained within the "EU 28" model for calculation purposes.

Table 1: Main socio-economic assumptions to the EUTRM

	2000	2010	2020	2030	2040	2050
Population (millions)	484	500	510	516	521	522
GDP (billions)	11459	13155	14849	17023	19824	22980
Freight Activity* (billion tkm)	2274	2157	2388	2855	3390	3928

Figure 1 shows the EU28 and Nordic emissions for heavy duty vehicles (HDVs, i.e. HGVs and buses) and rail freight from 2000 to 2050. Europe and the Nordic countries have a similar modal contribution of GHG emissions. Notably, the freight rail share in the EU is typically 3 times the share in the Nordic countries. Otherwise, in 2050 the HHGV share in EU is projected to be 66% whereas in the Nordic countries the share is expected to be 71%. The figure shows that direct freight transport carbon dioxide equivalent emissions (tank-to-wheel [TTW] CO2e – i.e. tailpipe emissions) increases by 116 million tonnes (Mt) in the EU and by 5.4 Mt in the Nordic countries. Rising transport demand, and thus growth in BAU emissions, means that more ambitious policy decisions are required to obtain a target of zero - as well as higher investment in technology and infrastructure. The main assumptions for each of the options considered in the BAU are described in its specific section below. Without additional policy measures, emissions are expected to grow as the economy, and therefore transport activity, continue to grow.

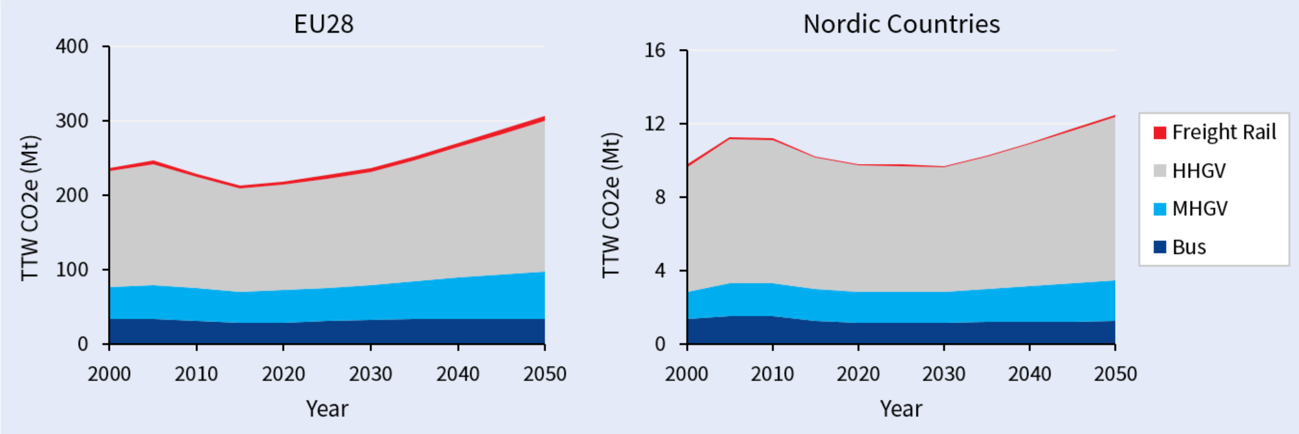

Figure 1: GHG emissions from heavy goods vehicles, rail freight and buses in the EU and in the Nordics, under a business-as-usual scenario

One last noteworthy assumption used in the EUTRM relates to the member state electricity mix changing over time, as this will ultimately affect the well-to-wheel (WTW) emissions for electric vehicles. The Commission's Reference Scenario has been used for this purpose. For the Nordic countries this assumption will not be a hindrance to cutting carbon as their grids are currently mostly composed of low carbon intensity technologies (see section 3.2.1). The additional demand in freight activity will result in 5.4 million more HHGVs in 2050 compared to 2015, and the consumption of 0.6 Mboe/day of liquid fuels for HDVs. These increases are similar in scale to modelling undertaken by the ICCT and the EU Reference scenario.

The results in Figure 1 are within the same order of magnitude as similar studies used in other models. For instance, Ricardo[xix] estimated the same emissions under a business-as-usual scenario to be under 300 Mt for the EU as a whole, and it is also the case for the Commission's reference scenario.[xx]

3. Roadmap to zero GHG HDVs

In this section we describe the different alternatives to reach zero-GHG HDV transport in the EU by 2050. Vans (commercial vehicles less than 3.5 t) are excluded from the scope of the study. Section 3.1 describes options to reduce emissions with existing deployable technology (low hanging fruit), and Section 3.2 describes how to reduce emissions in the remaining gap after all low hanging fruit measures have been implemented.

3.1. Low hanging fruit

HDVs have great potential to significantly reduce their GHG emissions with existing technology, both through improving the efficiency of vehicles and through increasing the efficiency of the transport system. The following sections describe the main assumptions for each option both under BAU and maximum untapped potential scenarios, and show how much they could contribute towards reaching the final goal of zero GHG by 2050.

3.1.1. Increased efficiency in trucks and buses

Road freight transport is a unique sector in Europe and this is reflected in the vehicle fleet. Five manufacturers[5] account for nearly 100% of the market, where for cars the top 7 car manufacturers capture < 50%. The Commission has fined all truck makers – except Scania – penalties totalling almost €3 billion for operating the EU's largest ever cartel between 1997 and 2011. There has been a stagnation in fuel efficiency since 2000 [xxi] and only very limited penetration of alternatively fuelled vehicles (hybrid, electric, hydrogen, LNG). However, progress was made on pollutant emissions. A typical Euro VI HHGV now emits less NO_x than a typical Euro VI diesel car – mainly because the typical diesel car doesn't meet the legal limits.[xxii]

A CO_2 vehicle standard, if accompanied by reliable emission testing, has proven to be a very strong driver in bringing fuel efficient technologies to the market for cars and vans in Europe but also for trucks in other regions in the world. Countries such as the US, Canada, China and Japan already successfully implemented a truck CO_2 standard but so far Europe is lagging behind.[xxiii] A truck fuel efficiency standard would require European truck manufacturers to improve the efficiency of new vehicles to a certain level; otherwise manufacturers would be fined.[xxiv]

Improving the fuel efficiency of new trucks is one of the most effective ways to curb their GHG emissions. Different studies show that there is still great potential in increasing vehicle efficiency. The efficiency of trucks can be improved by applying cost-effective fuel efficient technologies to the vehicle.

Contrary to cars, there are many different truck types and categories which all have different driving cycles ranging from long-haul highway trucks, to urban delivery, construction vehicles and waste collection trucks. Different technologies have different potential depending on the truck category. In general aerodynamic improvements to the tractor and the trailer, low resistance tyres and engine efficiency improvements have the biggest potential. All together, the adoption of these currently available technologies could reduce fuel consumption of trucks by 30-50%.[xxv]

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[5] Daimler, MAN, Scania, IVECO, Volvo-Renault.

Tractor-trailer trucks use a trailer to move freight around Europe. They are also known as articulated trucks. The use of tractor trailers increased since 2009 and is now the truck type with the biggest share in Europe. Rigid trucks are mostly smaller trucks where the body that carries the payload is fixed and cannot be removed or decoupled as is the case with tractor-trailer trucks. There is some uncertainty regarding the contribution of HHGVs in the freight segment.[xxvi] [xxvii] [xxviii] In any case, tractor-trailer trucks are the main source of emissions within HGVs, and their importance is increasing.

The EU's VECTO simulation tool and its MRV proposal will increase the transparency of the truck market but will only curb truck CO_2 emissions to a very small extent. We can expect the forthcoming truck CO_2 standard (expected early / mid 2018)[xxix] to be more effective in curbing such emissions – once testing and overall implementation is robust.

BAU: the uptake of fuel efficient truck technologies has been very limited so far. Different studies show that the truck fuel efficiency has been stagnating for the past 15 years which is a clear indication that these technologies are not finding their way into the market.[xxx] An important reason for this is that fuel efficient technologies are not standard on the vehicle and only can be purchased at extra cost - a so called 'eco-package'. Haulage companies run most of the time on very small margins and have limited access to finance which partly explains the low uptake of fuel efficient technologies.[xxxi] Without targeted policy measures, the vehicle efficiency of long haul and regional delivery trucks would only gradually improve by 10% in the 2010-2030 period. Smaller trucks would only improve by 6%.[xxxii]

Untapped potential: a 2013 study for the European Commission found that based on technologies available in 2011 trucks could already achieve cost-effective fuel use reductions of 35% that would pay back within 3 years.[xxxiii] The latest ICCT study estimates a 40% by 2030 by applying state-of-the-art technologies, also with a short payback period of 2-3 years. For smaller trucks, the potential was estimated at 25% improvement by 2030 compared to 2010, with fuel efficiency technologies already on the market combined with technologies soon to be on the market in the coming years.[xxxiv] [xxxv]

For the tractor the biggest reduction potential lies in the engine. Engine technologies are, for example: waste-heat recovery, engine friction reduction and combustion optimization. Hybridization, driveline optimization, low resistance tires and cab aerodynamics also have great potential. For the trailer, low resistance tires and aerodynamics such as side skirts and boat tails can reduce fuel consumption.[xxxvi] Engine improvements are a better guarantee for long term efficiency improvements over time because they are less likely to be replaced compared to other technologies such as aerodynamic devices or tyres.

For buses, we estimated that the maximum potential they could develop would be a fuel use improvement of 25% by 2030 through technologies such as serial hybridisation.[xxxvii]

Improvements in vehicle efficiency translate directly to reductions in TTW (tailpipe) CO_2 equivalent emissions, as shown in Figure 2 for both the EU28 countries and Nordics alike. By 2050, emissions are 32% and MHGVs 18% less compared to BAU for both the EU and Nordic countries. In the EU, this corresponds to absolute decrease of 65 Mt CO_2e and 12 Mt CO2e annually respectively, and for the Nordics, 3 Mt CO_2e and 0.5 Mt CO_2e yearly reductions respectively, by 2050. Buses see a 22% reduction in annual emissions by 2050, equivalent to 7 Mt CO_2e for the EU and 0.3 Mt CO_2e for the Nordics per year.

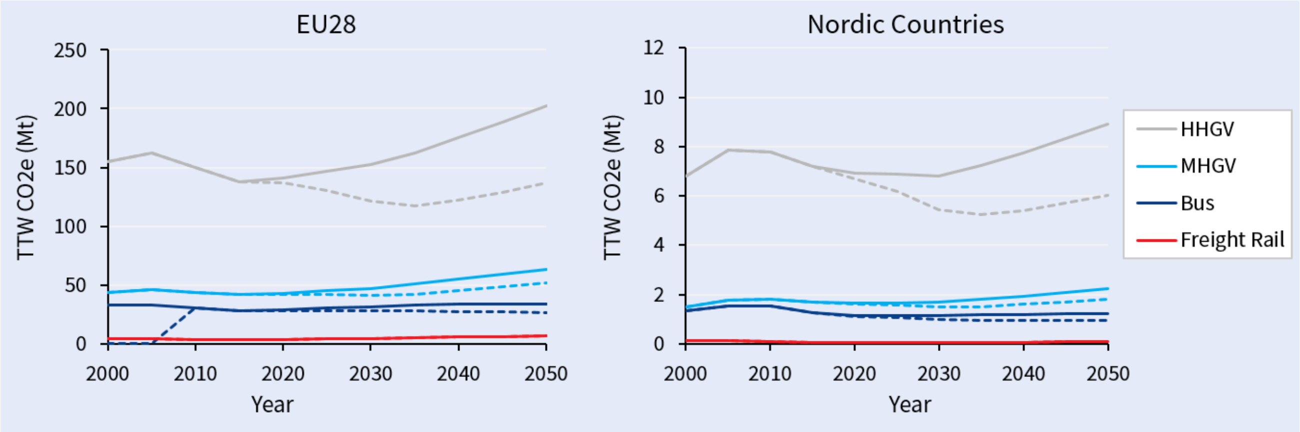


Figure 2: GHG emissions from heavy goods vehicles, rail freight and buses in the EU and in the Nordics. Solid lines show the BAU emissions, dashed lines are the emissions after applying untapped truck efficiency potential

3.1.2. Increased electrified rail freight

Modal shift has long been lauded as *the* way to decarbonize freight transport as the railway network in Europe is largely electric and far more energy efficient than today's truck transport. In 2011, 86% of train-km for freight were performed on electric traction in the EU.[xxxviii] However, only 60% of freight railway total energy consumption is performed by electric traction.

Waterways, especially in certain Nordic countries, can be an alternative to reduce emissions in long-haul road transport when rail infrastructure is not in place. However, they are outside the scope of this study.

Rail currently transports 18% of freight in Europe. Sweden and Finland are both well over this EU average (at 33% and 30% respectively) while both Denmark and Norway fall short (at 11% and 13% respectively).[xxxix] Iceland has no railway infrastructure. Rail is highly dependent on the type of goods being transported in the country. Rail is more common for bulk commodities.

The distance of 200km and below is where road transport is typically superior to rail in terms of cost and feasibility. This is because road transport is flexible to the customer's needs and that there are low operational costs (i.e. infrastructure charges, loading costs, fuel taxes, driver costs, and capital costs for purchase of equipment). Furthermore, road transport is comparatively trouble-free when crossing borders.[xl]

The prior notification needed to get goods onto rail make it inflexible. Track access needs to be granted for a train over 12 months in advance in most cases.[xli] This doesn't work well in most markets where demand is rarely guaranteed. The more actors necessary for rail freight make the service more complex.

In Europe, there are several actors involved in rail. The rail infrastructure manager (IM) and the operator of the trains (rail undertaking RU) is owned by the same holding company in many European countries. This holding company is normally a public company so the state is the ultimate owner of both. This market structure does not favour competition. The Commission has, through its legislative packages on rail (the fourth of which was finalised in December 2016[xlii]), ensured a certain level of independent decision-making by IMs so that they are less able to unjustly favour the incumbent company. The restriction of competition in rail means that existing growth opportunities are not being fully realised.

BAU: The completion of the TEN-T network will be beneficial to rail as it may lead to rail achieving a further modal share of international freight traffic[xliii]. This network, along with the integrated Rail Freight Corridors, aim to remove cross border bottlenecks so that freight can be more easily transported over long distances in Europe. If successful, this will improve the attractiveness (reliability and speed) of the service so more shippers will choose to use this mode. However, rail also needs to make up for declining markets, the transport of coal and mineral oils for example. If no additional measures are taken to boost rail (infrastructure investment and policy to internalise external costs in all transport modes) it is assumed rail will likely maintain 18% market share In Europe. This is an input to the model. The share of diesel locomotives is unlikely to decline in a business-as-usual scenario (beyond marginal improvements). The renewal of these locomotives will take decades as the lifecycle of locomotives is approximately 30-40 years. The likelihood of road tolls that are high enough to boost modal shift to any significant extent is unlikely in the foreseeable future.

Untapped potential: Whatever potential growth that is possible for rail is unlikely to materialise without improvements in rail capability and greater customer service by rail freight operators. This shift in business model (i.e. a more customer-orientated and international vision) will come from a better environment for competition whereby more train operators can compete fairly with the state-owned operators. The cost of road has to increase significantly so that the external costs of road transport (such as air pollution, GHG emissions and infrastructure costs) are internalised.[xliv]

Switzerland is often referenced as a success story for modal shift. The country has a clear policy in place to shift goods from road to rail. They spend billions on rail infrastructure that is largely funded through charging trucks to use road infrastructure. The Swiss introduced a toll in 2001 and it generates approximately one billion euro every year. The railways increased their volume of freight by 25%. There is also a night-time driving ban on trucks in Switzerland and a full ban on trucks being driven on Sundays.

The German Environmental Agency saw a doubling of transport volumes on rail as possible before 2025[xlv], achieving a modal share of 23% by 2030.[xlvi] To get there, it required differentiated pricing to increase capacity, improvement of trackside infrastructure, improved planning and services, as well as speedy harmonisation to remove bottlenecks.

For this study, we assumed that the potential modal share for rail in Europe is an increase from 18 to 23% of the freight market.[xlvii] This was an input to the model. Even if the value might not seem that high, this is within a context of increasing freight demand, meaning that the total freight volumes transported by rail would considerably increase.

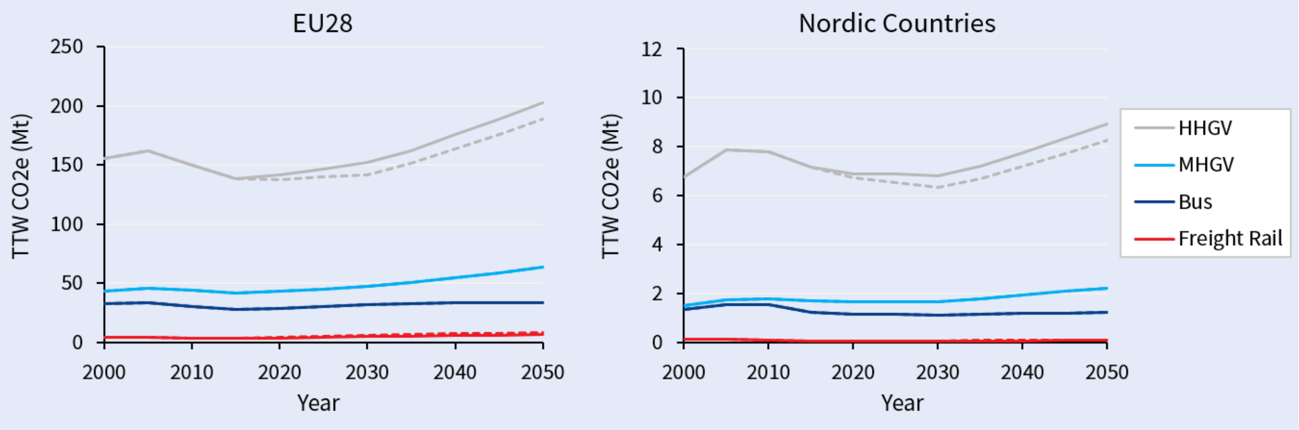


Figure 3: GHG emissions from heavy goods vehicles, rail freight and buses in the EU and in the Nordics. Solid lines show the BAU emissions, dashed lines are the emissions after reaching modal shift potential.

The results of modal shift are shown in Figure 3. For both the EU and Nordics there is a 7% reduction in HHGV emissions by 2050 and a respective increase in freight rail emissions of 32% and 12%. Although these percentages are significantly larger than the reduction for road freight movements, as rail is significantly more energy efficient than HHGVs, this translates to a net reduction in annual final energy expended of 140 PJ in the EU and 11 PJ in the Nordic countries.

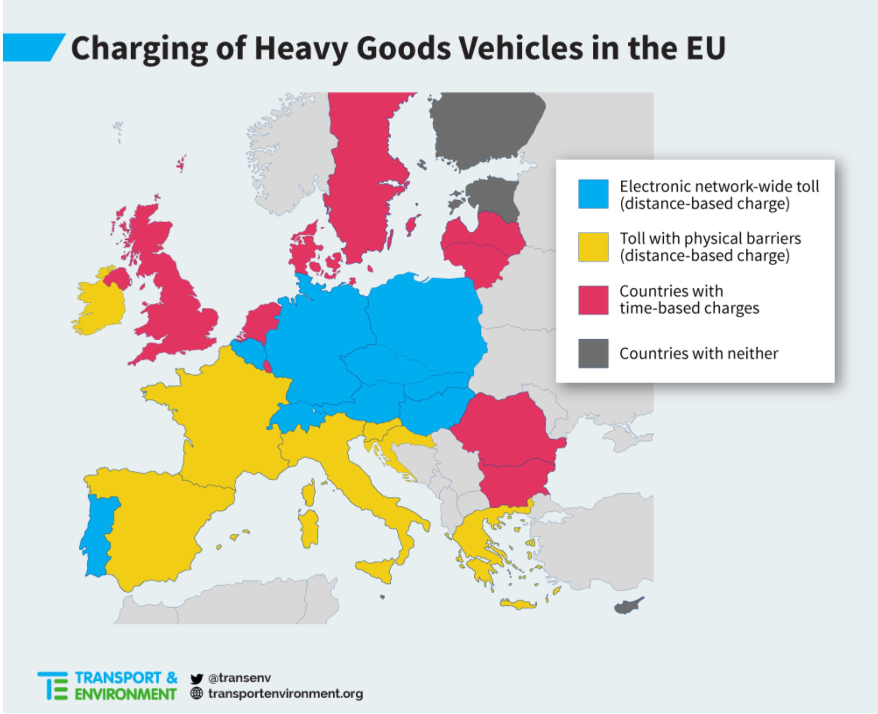
3.1.3. Improved logistics efficiency

In theory there exists a lot of potential to make the manner in which goods are transported in Europe far more efficient than it is today. The logistics sector is underperforming in Europe as 20% of trucks run empty and, although there is no reliable statistical evidence, partially loaded vehicles are also very common.[xlviii] The inefficient use of trucks has a negative effect on how many trucks are on European roads and unnecessarily increases the externalities of such vehicles.

One key reason for today's logistic inefficiency in Europe is the price of road transport. A truck can operate in Germany for about 1.1 euro per vehicle km. This cost is a lot lower in Eastern Europe (72 cents per vehicle km in Poland and 58 cents per vehicle km in Lithuania).[xlix] The operational cost of a truck is artificially low if we consider the externalities of the vehicle and the "polluter pays" principle. Increasing the price of road transport is a way to improve the efficiency of road haulage[l], the uptake of cleaner vehicles (through CO2 differentiation of road charging), and the attractiveness of cleaner modes. Pricing pressure forces companies to be smarter in how and when they use trucks. A truck will operate empty or suboptimally far less often if they're being charged to do so. This price increase (achievable by means of a toll or through fuel taxation) has no recognisable impact on the economy or trade[li]. In fact, tolls can be beneficial to state economies as a means for securing public revenue. A number of solutions exist to making today's logistics more efficient:

Road charging

Directive 2011/76/EU, known commonly as the "Eurovignette" Directive, is the European legislation that establishes how EU Member States can toll trucks for their use of infrastructure. There is no EU obligation on Member States to introduce a road toll for trucks but, if they choose to do so, then the toll has to be in accordance with this Directive.



Fifteen EU countries have distance-based road charging: Austria, Belgium, Czech Republic, Germany, France, Greece, Hungary, Croatia, Ireland, Italy, Poland, Portugal, Slovakia, Slovenia and Spain. However, only Germany, Poland, Hungary, Austria, Czech Republic, Slovakia, Portugal and now Belgium have a km-based system. The Netherlands, Luxembourg and France are the only centrally located EU countries that have no km-based road charging (although France does have many tolled highways).

Sweden has a time-based[6] (or "vignette") system in place with tolls also in place on some bridges. Denmark also has a vignette system with limited tolls on the E20 motorway and some bridges. Norway has some tolled roads, Iceland has one single tunnel tolled, while Finland has no toll roads at all.

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[6] Unlimited access is granted in daily, weekly, monthly, or yearly periods

Time-based systems (such as those in Denmark and Sweden) are an inferior means of charging trucks compared to distance-based system because they don't reflect actual use of infrastructure or incentivise the efficient use of trucks.[lii]

Fuel taxes

Fuel tax prices and fuel tax rebates contribute to the low cost of road transport. An increase in diesel fuel taxes to at least that of petrol could help to improve the efficiency of road haulage, as well as motivate truck owners to buy cleaner vehicles/cleaner vehicle technologies. Trucks should pay the external costs that they cause to society. An example of progress is Finland: back in 2010, the country had one of the lowest diesel excise duty in Europe. However, since then they have made progress to considerably increase excise and benefit from the advantages of high fuel taxes. By 2014, they had gone up to 46 cents per litre, more in line with the EU average in that year.
Truck diesel tax rebates totalled around €4.5 billion in 2014, up from €0 in 1999. The number of countries giving fuel tax rebates to hauliers (whereby truck users can apply for tax back on fuel) has gone up from only one in 2000 to eight today.[liii] The Nordic countries do not offer such rebates.

Digitalisation

In addition to pricing pressure, technology can play a role in making transport more efficient. The flow of real time information regarding cargo space and arrival time is underutilised in road haulage. Internet applications are being developed and increasingly used, enabling road haulage companies to be more aware of goods 'available' to be transported near their trucks. These tools can help to eradicate dead mileage and reduce empty legs. Increasing the cost of road transport will increase the uptake of such technologies as road is currently too cheap for this technology to be adopted at the extent necessary to have an impact on logistic efficiency.

BAU: if member states improved their road tolls and fuel taxation systems then there could be an increase in efficiency of the system, which would bring GHG reductions. The likelihood of this in a business-as-usual scenario is unlikely as the current cost of road transport is artificially low. Therefore, no GHG reductions are expected without additional policy.

Untapped potential: fuel tax is increased to disincentivise the use of fossil fuels. Road charging will be used as the tax system to replace lost revenue from such a decline in fuel use. It would also be an enabler for modal shift to rail. To reflect improvements in logistics efficiency, it was assumed that empty headings would be reduced by one quarter and freight demand would be reduced by 5% from 2030 due to pricing policies.

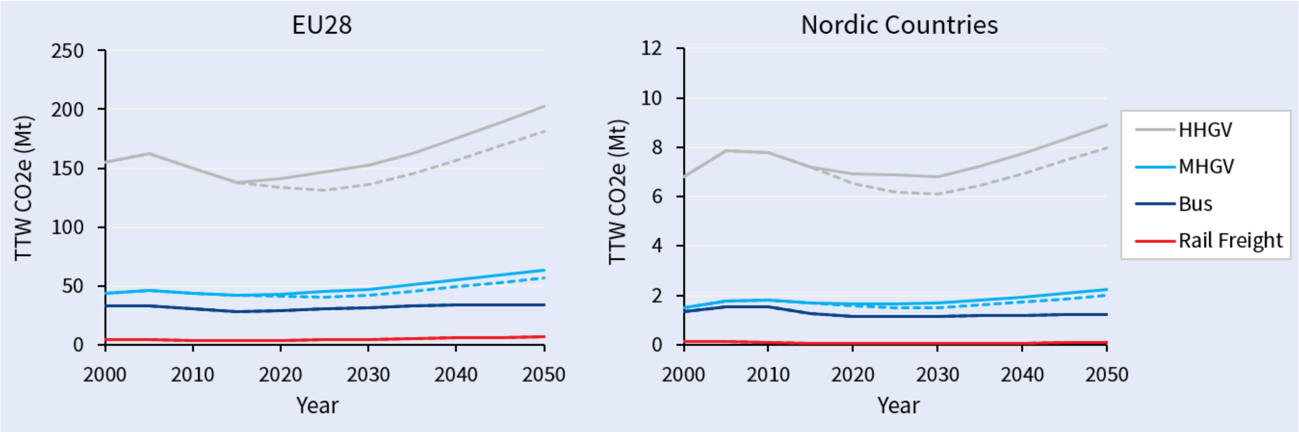

Figure 4: GHG emissions from heavy goods vehicles, rail freight and buses in the EU and in the Nordics. Solid lines show the BAU emissions, dashed lines are the emissions due to logistics improvement potential

Figure 4 shows the effect of logistical measures compared to the BAU trajectory. Logistics could result in a 10% reduction in emissions by 2030 for both HHGVs and MHGVs, owing to the technology being readily available and applicable on current fleets.

3.1.4. Summary of low hanging fruit options

By combining all of the low hanging fruit measures, significant reductions in GHG emissions can be achieved. Figure 5 shows the total cumulative effects of these policies. For both regions, buses reduce emissions by 22%, MHGVs by 28%, and HHGVs by 44%, by 2050. Combining these modes, a 111 Mt CO2e net reduction in emissions can be achieved in the EU and 5 Mt CO2e in the Nordic countries. Although significant progress can be secured, the trajectory shows that the low hanging fruit measures alone will not achieve full decarbonisation, and by 2035 emissions begin to rise again due to ever increasing demand. Evidently, new and ambitious policy is required above and beyond currently employable technology to achieve full decarbonisation.

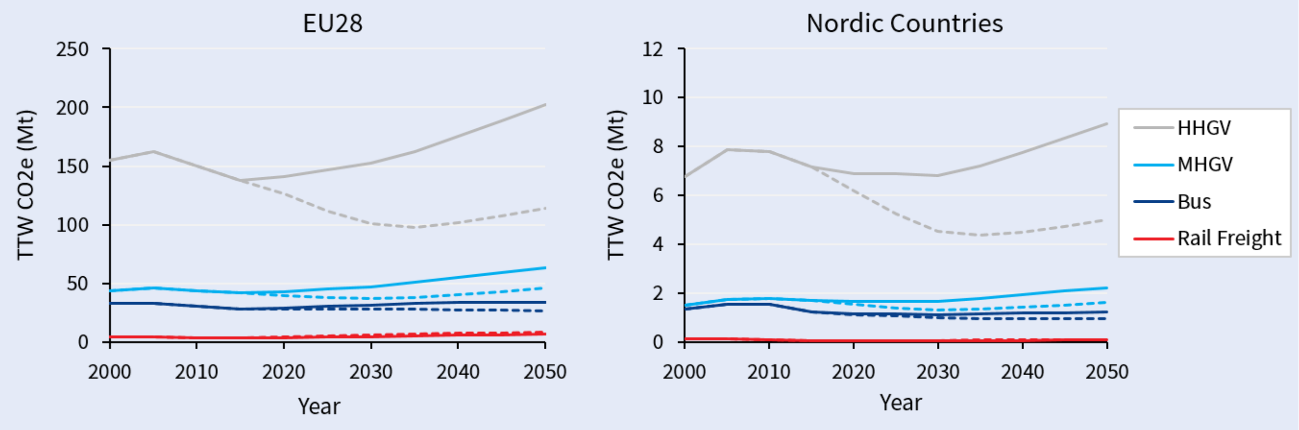

Figure 5: GHG emissions from heavy goods vehicles, rail freight and buses in the EU and in the Nordics. Solid lines show the BAU emissions, dashed lines are the emissions after adoption of all LHF policy options

3.2. Pathway to zero

Figure 4 above shows that even if those options are implemented, it would not be enough to reduce the climate impact of the sector to Paris compatible levels. The authors looked at several alternatives to reach that goal. After analysing the efficiencies of different technologies (explained in more detail in Section 3.2.3), it became clear that electricity should be used as much as possible as a fuel, due to its inherent efficiencies compared to internal combustion engines. For this reason, this study looks into what could be considered the maximum potential to use electricity in road freight and buses. Section 3.2.1 looks into clean electricity, an enabler to reduce the climate impact through the use of it by large trucks (3.2.1.1) in catenary lines and by smaller trucks and buses (3.2.1.2) using batteries. Finally, the study looked into how the remaining needs of liquid fuels for internal combustion engines could be covered, first reaching the potential of sustainable advanced biofuels (analysed in Section 3.2.2.1.) to then analyse how the remaining energy needs could be supplied through potentially zero GHG fuels such as power-to-liquids (3.2.2.2) and hydrogen (3.2.2.3).

3.2.1. Clean electricity

Renewable electricity is an enabler for the solutions proposed in this section. Multiple large scale decarbonisation options rely on electricity for their propulsion system, either directly, in the case of batteries or catenary lines, or indirectly such as in the production of hydrogen, or other gases or liquids, which are discussed in more detail in the sections below. Electricity based options are scalable, and some could be theoretically used to power all HGVs. The production of fuel with electricity can be done with grid electricity or with power plants only supplying the fuel production. For modelling purposes, the grid GHG emissions from the production of electricity is calculated on the technology mix and JEC emission factors.[liv] Renewable energy can be split to intermittent energy sources (wind, solar, hydro) and on demand technologies (bioenergy[7], geothermal). The potential of intermittent energy sources and geothermal are dependant strongly on the local conditions of the location where energy is produced.

The development of renewables has enabled the power sector to take a steep trajectory of decarbonisation. The Nordic countries have significantly higher shares of renewable electricity in their grid, with the exception of Finland. Renewables and nuclear both provide zero GHG electricity.

Table 2: Current share of renewable and zero GHG electricity

	Share of renewable electricity of gross consumption in 2014 (%)[lv]	Share of zero GHG electricity (including nuclear) in 2015 (%)[8]
EU28	27.5	55.5
Denmark	48.5	58.3
Iceland	97.1	-
Finland	31.4	76.3
Norway	109.6	-
Sweden	63.3	98.6

BAU: The electricity grids will continue to decarbonize and the high level of Renewable electricity will remain in the Nordic countries. EU wide, the share of renewable electricity will reach over 40% by 2030 and the amount of zero GHG electricity will reach about 65%. Nordic countries in the EU will be doing better than the EU, and Iceland and Norway will continue to have almost fully renewable grids. Finland has a policy to ban coal use by 2030, and Sweden is planning (but has not yet legislated) to be a fossil free society in 2050. Denmark will continue to increase energy production from wind, and develop storage. Norway will continue to have an oversupply of renewable electricity and export electricity to the other Nordic countries. Iceland has near 100% geothermal power, and there are no policies to change from this. The table below[lvi] was used as an input to the EUTRM.

	Renewable electricity of gross consumption in 2030 (%)	Share of zero carbon electricity in 2030 (%)	Renewable electricity of gross consumption in 2050 (%)	Share of zero carbon electricity in 2050 (%)
EU28	42.9	64.9	55.0	73.1
Denmark	81.5	81.5	80.4	80.4
Finland	45.9	76.8	49.4	90.7
Sweden	64.7	93.2	63.4	94.4

Untapped potential: The maximum potential is a completely carbon neutral grid in 2050 in the EU and in the Nordics. This is needed if the bloc is to commit to the objectives set out in the Paris agreement. As road transport will be more and more electrified (either directly or indirectly), demand for electricity will increase, hence overall electricity generation capacity needs to increase. In the next sections we calculate what the additional demand would be for different scenarios.

3.2.1.1. E-highways for HHGVs

One of the possible technologies to achieve low carbon long-haul trucking are hybrid trucks powered by overhead power lines on key arterial freight corridors. In the so called 'e-highway' system catenary wires

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[7] Bioenergy for power plants mostly refers to solid biomass. The carbon intensity can exceed that of coal when the whole life cycle and concepts such as carbon debt are incorporated. Default zero rating of biomass should be avoided.
[8] Includes renewables and nuclear.

transmit energy to the hybrid truck via the pantograph[9] that is mounted on top of the truck as is the case with trams, trains and trolleybuses today. When connected to the powerline, trucks can run fully electric. Once driving off the powered track, the vehicle will run on the diesel or electric engine via on-board battery capacity. The catenary system ensures a reliable energy supply for the e-highway truck.[lvii]

The technology is currently in a test phase, with different pilot projects being run in Europe. Since 2011 the e-Highway concept has been developed on a test track north of Berlin in a cooperation between Scania and Siemens - the so-called ENUBA 1 research project.[lviii] In the summer of 2016 a first two-kilometre electric highway was opened in Sweden. This project fits into the national goal of having a fossil fuel independent transport sector in Sweden by 2030. A similar trial is underway in California.[10] The German Environment Ministry announced that in 2018 they will open two e-highways to test this technology on the ground.[lix] According to the German Environment Agency e-higways are the most cost-effective way to decarbonise the road freight sector.[lx]

BAU: without specific and targeted policy measures, the uptake of this technology will be very limited. So far catenary trucks have only been tested on very small scale with government support and private sector involvement (Siemens and Scania). Given the high upfront investment costs (energy and road infrastructure and vehicle costs), a clear timeline with guaranteed policy support is needed to push the deployment of this technology and avoid a chicken and egg problem[11]. In the BAU, we assumed zero-uptake of this technology.

Untapped potential: by 2050 38% of EU highways could be electrified with overhead powerlines.[lxi] In a 2016 study the French Ministry for Environment and Energy calculated the effects of electrifying 2 860 km of their highways with overhead powerlines. It is estimated that 34% of the HGV traffic could be running on the e-highways by 2050.[lxii] A study in Germany looks at the potential of electrifying 4,000 km of the highway network by 2030, which means 60% of the total truck traffic would be running on this infrastructure.[lxiii] According to the study, the first catenary trucks will find their way into the market as from 2025. By 2050, 90% of all new long-haul registrations would be catenary trucks. As an input to the EUTRM, we have assumed that a progressive uptake of the technology to reach maximum potential by 2050. The relative share of electricity used by these hybrid trucks would also increase over time. In the EUTRM, these inputs apply only to HHGVs, above 16 tonnes.

3.2.1.2. Fully electric MHGVs and buses

The technology for full electric battery trucks and buses is comparable with the one for cars. The battery pack is the most important electronic component and accounts for most of the costs. Batteries have improved significantly over the past years to provide an acceptable range for light duty applications and studies expect BEVs to reach price parity with their conventionally fuelled-counterparts within the next years.[lxiv] Until now, full electric truck applications range from 3.5 up to 19 tonnes vehicles.[lxv]

Because of their weight and higher energy consumption HDVs need a bigger and heavier battery pack compared to passenger cars. Limited range is only a problem if the truck is not going back to the depot

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[9] A pantograph is a pole mounted on the roof of an electric train, tram, truck or bus to collect power through contact with an overhead catenary wire

[10] http://www.siemens.com/press/en/feature/2015/mobility/2015-06-eHighway.php?content[]=MO#event-toc-2

[11] A stalemate where manufacturers require policy and infrastructure certainty to invest and policy makers want proof of concept.

overnight. While heavy battery packs tend to reduce the payload of the truck, a lighter engine and the absence of a gearbox compensate for this to a large extent.[lxvi]

MHGVs

Different studies agree that full electric trucks are seen as a potential technology for smaller delivery trucks given that these vehicles can be charged overnight.[lxvii] At the moment battery trucks are deployed on a small scale but with a reduction of battery costs due to higher level of production, further development of battery technology, and energy charging structure, there is definitely future potential for longer distance pure battery trucks.

There are several pilot projects under development over the few past years, with manufacturers increasingly starting to build electric trucks. For example, Renault[lxviii] presented at the COP21 a 16 tonne fully electric truck which is currently being tested and Tesla announced that it will start developing electric trucks.[lxix] Many projects are underway in different cities, such as in Paris, where Guerlain and Renault are testing a 16 tonne truck operated by Speed Distribution Logistique,[lxx] or in London, where UPS and TEVVA Motors are running an electric delivery vehicle. Furthermore FREVUE[12] (Freight Electric Vehicles in Urban Europe) is organising different electric freight vehicle projects in eight cities in Europe with over 70 electric freight vehicles in Europe. The FREVUE vehicles range from 3.5 up to 19 tonnes.

In 2016, Mercedes presented its full electric Urban eTruck. This is a 26 t truck, with a battery pack consisting of three lithium-ion battery modules with a range of up to 200 km – enough for a typical daily delivery tour.[lxxi] But also MAN is entering the market with full electric battery trucks ranging from 12 to 26 t. This was announced in February 2017. Serial production will start as from 2021.[lxxii] At the same time BYD, the big Chinese bus manufacturer that already put more than 10 000 ebuses on the market is investing in electric trucks. The company is already offering box and refrigerated trucks including a US Class 6 trash collection truck and Class 8 tractors designed for the short-haul goods movement industry.[lxxiii]

Many projects are on-going in Norway. Last year the country introduced its first electric food delivery truck, driving from the storage facilities on Oslo's outskirts to nearby towns and Oslo city center. Despite its initial purchase prices being double that of a conventional truck, it results in savings amounting to half a million euro during its lifespan, while delivering significant CO_2 and air pollutant cuts. In addition, the municipality of Sarpsborg in Norway last month introduced two fully electrified waste collection trucks, which will be in operation from September 2017.

In California, the government has established a target to "deploy over 100,000 freight vehicles and equipment capable of zero emission operation and maximize near-zero emission freight vehicles and equipment powered by renewable energy by 2030".[lxxiv]

BAU: 5% of the MHGV market could be fully electric in Germany by 2026.[lxxv] CE Delft estimates that in a conservative BAU scenario, electric delivery trucks will not penetrate the market until 2050.[lxxvi] Otherwise, current battery powered vehicles in this category are kept constant. For modelling purposes of the BAU, we assumed the conservative scenario, except for Germany.

Untapped potential: a study notes[lxxvii] that only 60% of the MCV market could run full electric. The other 40% are vehicles such as construction and waste collection that need more power. In an ambitious scenario, battery electric trucks will already enter the market after 2020. They could reach their maximum potential by 2050. This is an input in our model.

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[12] FREVUE is an European project with the aims to prove that the current generation of electric vans and trucks can offer a viable alternative to diesel vehicles, particularly when combined with state of the art urban logistics applications, innovative logistics management software, and with well-designed (local) policy.

Buses

A battery electric bus (BEV) is fully driven by an electric motor and powered by batteries. All power is derived from the batteries and these buses have no internal combustion engine. Electric buses can be charged overnight at the depot or multiple times a day (in 5 to 10 minute bursts between journeys). Therefore they may have reduced route flexibility and will require charging infrastructure at route end points. Because of the limited distance they have to cover and opportunities to charge buses have evolved from a pilot phase towards fully electrified bus-lines in different cities.[lxxviii] It is expected that electric buses will reach market maturity soon depending on the charging pattern. In the Nordics, there are examples in Copenhagen, Stockholm, Turku and Ängelholm.[lxxix] A study for Oslo concluded that if Oslo's bus fleet were to be converted to fully electric, the municipality would save EUR 80 million over 10 years, compared to today' diesel buses.[lxxx] California has a zero emission bus program for large transit agencies[lxxxi], which can be used as an example for the implementation of purchase programmes.

BAU: The majority of the buses are still diesel powered, with 50% of buses across the EU of Euro III standard or older. The uptake of electric buses has so far been rather limited (1.2%).[lxxxii] As many cities have plans to uptake electric buses in urban areas[lxxxiii], we have assumed 5% of market share by 2030, and 20% by 2050.

Untapped potential: The untapped potential is to switch all urban buses in Europe to BEVs.[lxxxiv] This is an input in our model. Coaches, travelling inter-city, are not included in this assumption.

3.2.1.1. Projected emissions savings from the electricity pathway

Figure 6 shows the effect of converting the current fleet of buses and MHGVs to battery electric vehicles and the roll-out of e-highways against the BAU scenario. Compared to the BAU emission trajectory, electrification can result in a 71% reduction in GHGs for HHGVs, 63% reduction for MHGVs, and 36% reduction for buses by 2050. Respectively, this corresponds to reductions of 144 Mt CO2e, 40 Mt CO2e, and 12 Mt CO2e in the EU, and 6.3 Mt CO2e, 1.4 Mt CO2e, and 0.5 Mt CO2e in the Nordic countries, compared to the BAU scenario. Importantly, against the low hanging fruit options, by 2050 HHGV and MHGV emissions are reduced by a further 49%, and buses by a further 19%. The uptake of this technology does not achieve full decarbonisation, however, and thus further measures are required to achieve this target, explained in the following sections.

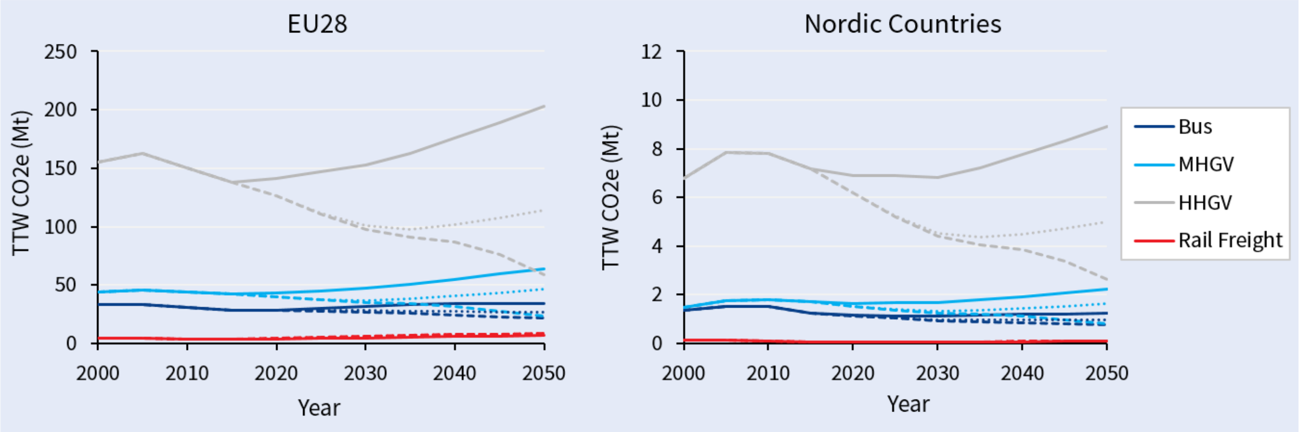

Figure 6: GHG emissions from heavy goods vehicles, rail freight and buses in the EU and in the Nordics. Solid lines show BAU emissions, and dashed lines show emissions adopting low hanging fruit measures and electric alternatives. Dotted lines show the low hanging fruit emissions trajectories for comparison.

3.2.2. Additional fuels

As can be seen if figure 6 above, even with the ambitious implementation of current and future technology, both the low-hanging fruit and the electric alternatives, there would still be approximately one third of the sector that would depend on internal combustion engines in 2050. Therefore, in the next sections we assess how much each different option could contribute to achieve the final goal of achieving a free GHG HDV sector.

3.2.2.1. *Advanced sustainable biofuels*

Biofuels according to the current EU legislation are "liquid or gaseous fuels produced from biomass".[lxxxv] A biofuel can be ethanol, methanol, fatty acid methyl ester (FAME), hydrotreated vegetable oil (HVO) or biomethane (either compressed or liquefied)[13]. These biofuels can also be split into generations of biofuels, first generation (or conventional) being produced from sugars, starch crops, or vegetable oils, and advanced biofuels that are produced from wastes, residues or novel feedstocks such as algae. Biofuels were first introduced in the hope of reducing carbon intensity of fuel, as in a simplistic sense the CO_2 generated by combustion is absorbed by the regeneration of the crops used to make it, and because they can be blended into fossil fuels without the need to modify engine technology.

For HDVs the drop-in options that can be used in current vehicles are different types of biodiesel. First generation vegetable oil based biodiesel is not a decarbonisation option for the transport sector as when both direct and indirect emissions are taken into account, all biodiesels have higher greenhouse gases than fossil derived diesel.[lxxxvi] This is due to indirect land-use change (ILUC) emissions. Vegetable oil based biodiesels have significant ILUC emissions, making their emissions 'savings' insignificant or worse in terms of well-to-wheel overall GHG emissions. Palm oil, for instance, is the second largest feedstock for biodiesel in the EU (31%)[lxxxvii], and has significant ILUC emissions due to deforestation and peatland drainage. Energy crops (e.g. maize or sugar beet) are typically grown on agricultural land for the production of biomethane, also resulting in ILUC.[14]

BAU: the European Commission's proposal caps the amount of food and feed based biofuels to 3.8%. As there is no target for food and feed biofuels, we assume they will no longer be supported, and market demand will be limited. Different member states are at different levels of uptake of biofuels in transport, Finland and Sweden with the highest proportions in the EU.

Advanced biofuels will be developed and blended into fossil petrol and diesel. There will be no preference, but from a technology perspective lignocellulosic material will be more likely produced into ethanol than diesel, as the ethanol pathways are more developed and closer to maturity. HVO technology is mature, but there the issue is the sustainable feedstock supply of lipids and oils. The EU will have 3.6% of advanced biofuels on the market in 2030, and 1.7% of animal fat and used cooking oil based biofuels as proposed by the European Commission in the recast of the renewable energy directive. In the Nordic countries, the level of advanced biofuels will be significantly higher. For instance Finland is adopting a 30% blending mandate for 2030 and Norway just announced a 20% biofuel target for 2020.

Untapped potential: as sustainable advanced biofuels are based on wastes and residues, their potential contribution is finite. The maximum potential of advanced biofuels in heavy duty transport is very much dependant on the other sectors potentially using the same raw materials or fuels. It is difficult to say exactly what is going to happen in each sector, but one could presume that the energy sector would decrease biomass consumption in 2030-2050 due to lower energy demand/higher biomass prices/lower prices of other renewables. The chemical sector and material sectors are likely to increase consumption of low quality biomass with the development of bio-based products.

The amount of biomass in the EU that could be used for advanced biofuels is difficult to measure owing to biomass covering a broad range of materials, whether primary raw material or from wastes and residues.

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[13] Biomethane is further discussed in the natural gas section.

[14] In short, first generation biodiesel is an inefficient land intensive solution, removing land from food production, which in the longer term is needed to feed the planet's growing population. In T&E's view a policy of crop based vegetable oil biodiesel should not be sought.

The industries that typically contribute the most to advanced biofuels are agriculture and the food industry (through residues such as organic waste sludges, manure or straw) and forestry industries especially in the Nordics (from saw and pulp mills). Biomass resources are also already well utilised. In the case of wood at EU level, 52% is for industrial use (paper + materials), 24% domestic heat and 24% for heat plants, electricity and combined heat and power.[lxxxviii] However, the availability of wood is lower in the EU than in Norway, Finland, and Sweden.

At EU level in 2030, if the current consumption of the competing sectors is assumed to continue, we can assume a maximum contribution of 23 Mtoe[lxxxix] liquid fuels production which could contribute to 8.5% of all road transport. If all is used in the heavy duty sector, it would cover around 27.5%. However we cannot assume all will be used in the road freight sector. The aviation and shipping industry also claim that they will use it, hence we considered a maximum of 8.5%. This is an increase from the 5.3% included in the baseline. In the Nordics, for countries with higher targets, we assume the same values as in the baseline.

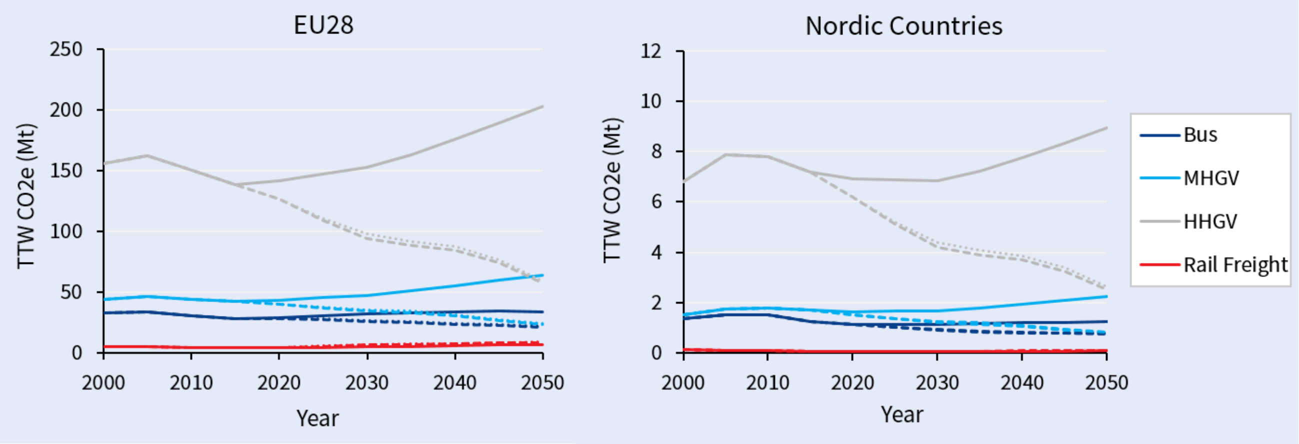

Figure 7: GHG emissions from heavy goods vehicles, rail freight and buses in the EU and in the Nordics. Solid lines show BAU emissions and dashed lines show emissions adopting low hanging fruit measures and electric alternatives. Dotted lines show the emissions trajectories of the low hanging fruit and electrification potentials for comparison

Figure 7 shows what effect the additional uptake on bio-fuels will have over the BAU case. As can be seen, only a slight cut on emissions can be observed, equating to around 4% savings across all modes by 2050 for both the EU and Nordic countries. Due to the insufficient amount of advanced biofuels to bridge the gap to zero emissions in 2050, other advanced fuels are explored as shown in the following sections.

3.2.2.2. Power-to-X

Power-to-X (PtX) refers to Power-to-liquids (PtL) and Power-to-gas (PtG). This means using electricity to produce a gaseous or liquid fuel. PtX is only a zero carbon option if it is produced only from renewable electricity. If that would not be the case, PtX would not be an option for a pathway to zero.

PtG generally refers to the production of methane (CH_4), but can also mean the production of hydrogen or injecting hydrogen into biogas to upgrade it to biomethane. Power-to-gas can be also called syngas (synthetic gas) or windgas. In this section we do not consider hydrogen as PtG, as it is analysed in its own section below, and power to methane is a follow-up step from electrolysis.

The end-product of PtL is either methanol, or gasoline, diesel, and kerosene fuels from Fischer-Tropsch (FT) synthesis. It is an additional step from PtG. Hence if the Fischer-Tropsch synthesis pathway is used, the fuel is a drop-in fuel and could be used directly in diesel engines. As with hydrogen, renewable electricity is needed for it to be beneficial compared to fossil fuels.

The overall system efficiency is a problem in the production of PtX, and the longer the production chain the lower the efficiency. Also the source of the CO_2, which is needed in the process, will affect the overall efficiency. A concentrated source of CO_2 such as a steel mill, or combustion power plant can be used as a source for CO_2. If CO_2 is captured from the air, it adds another highly energy intensive process to the chain, decreasing overall efficiency. The system efficiency is extremely significant especially if non-renewable electricity is used, as the emissions from electricity production will be added to the fuel. Overall the GHG benefit of PtX exists only if produced from renewable electricity. However, in terms of land use PtL is far more efficient compared to conventional and advanced biomass-based fuels.[xc]

PtX technologies are being explored, mainly linked with excess renewable power to keep electricity costs low. The capital costs however are high, as the amount of operating hours with excess power is very low. The main consumption areas are aviation and heavy duty sectors. The main focus is in ensuring low cost renewable electricity. Currently PtX trials are ongoing. For example, Audi has a PtL trial producing synthetic diesel using CO_2 from a biogas reactor and renewable electricity.

BAU: without targeted policy measures, it is assumed that PtL would not be developed in the decades to come.

Untapped potential: in this report we only explored PtL, as PtG would also require the development of gas infrastructure and gas vehicles, which is further explored in the costs section. PtL has the theoretical potential to decarbonise completely the freight sector, but the amount of renewable electricity needed for this is quite considerable (see Figure 8). The most likely pathway is that PtL has initial use as a blended fuel and then eventually deployed as a fuel to power the ICE of hybrids. PtL technologies will be developed to act as drop in fuels for the aviation and heavy duty sectors. Renewable electricity plants will be built in ideal locations for electricity production and e-fuels will be produced at large scale.

3.2.2.3. Hydrogen

Hydrogen is not an energy source but an energy carrier (like electricity) that stores and delivers energy in a usable form. Hydrogen therefore needs to be produced, usually by separating hydrogen from other elements with which it is found. This can be achieved via thermal, electrolytic, or photolytic processes, of which steam methane (natural gas) reforming is the most commonly used today where hydrogen is extracted from natural gas. However in the future, if hydrogen is to be used as a zero GHG transport fuel, it should be produced through electrolysis using exclusively renewable electricity. The GHG impacts of hydrogen use is therefore tied to the decarbonisation of our electricity grid. If the grid is not decarbonised and it is not produced from water, it would not be a pathway to reach zero.

Hydrogen is already a well-established chemical commodity in various industrial sectors, and can also be used as a transport fuel in Fuel Cell Electric Vehicles (FCEV). However, currently it is not being produced through electrolysis using renewable electricity. FCEV are hybrid vehicles powered by both fuel cells and a battery, as a purely fuel cell truck without a battery would have insufficient acceleration and power with current technology. The TTW efficiency of fuel cell systems in trucks is around 50-60%, significantly higher than for diesel engines.[xci] The process theoretically only releases water and heat, making fuel cells zero emissions vehicles from the tailpipe, but it would only make sense if produced through electrolysis using renewable electricity only. Although some tests have been made in internal combustion engines, the efficiency has proven to be very low. As such, hydrogen as a combustible fuel is still in a conceptual stage and is not included in the analysis herein.

Hydrogen has many disadvantages as a fuel, such as the high pressure needed for storage in tanks (700 bars) which combined with the small size of H_2 results in leakage. Hydrogen poses safety risks of the same order of magnitude as gasoline or natural gas[xcii], so they should be manageable. Storage of hydrogen also poses problems, and needs to be stored cooled (-253ºC), compressed, physically or through chemical absorption. The different storage options take up to 40% of the energy in the fuel (liquefying compressed hydrogen), and need to be considered when evaluating the well-to-tank performance. The storage space in the truck is large enough to ensure daily operation range, but the pressurised storage tank adds about 1200kg to the weight of the vehicle compared to a full diesel storage tank. The fuel cell itself is around 150kg lighter than an ICE engine, but the electric motors and batteries will add weight. Hence the propulsion technology is expected to add conservatively at least 1 tonne more weight compared to a diesel truck.

There has been no commercial vehicles launched yet by major manufacturers. Nikola has announced a commercial long haul hydrogen truck in USA and production will begin in 2020. [xciii] Some European manufacturers have been testing hydrogen technologies. For instance, Asko (Norway's largest convenience wholesaler in Norway), is testing trucks with an electric powertrain powered by hydrogen.[xciv] Most hydrogen and fuel cell technologies are still in the early stages and are currently too costly (both vehicle and infrastructure) for wide-scale use.[xcv]

BAU: no serious uptake of hydrogen in the HDV sector is happening in Europe. Regarding hydrogen refuelling infrastructure the Alternative Fuels Directive does not set EU wide requirements on the refuelling network for hydrogen, and the cost of vehicles remain high.[xcvi] Therefore, in the baseline we assume zero-uptake of hydrogen.

Untapped potential: under this option, hydrogen breaks through as an energy carrier and heavy duty vehicle manufacturers invest in the technology properly and start selling models for all uses at competitive prices. Cross EU freight travel would be possible with hydrogen trucks, and the amount of fuelling stations would be sufficient. Hydrogen would be produced both locally at the refuelling stations and in centralised plants, through electrolysis linked to renewable electricity only. Hydrogen would be also used as energy storage and balancing power. The overall WTW emissions can theoretically be reduced to zero if the compression and storage energy is done also with renewable electricity. Otherwise this option would not contribute to a pathway to zero. Considering that the whole fleet would need to be renewed, all new trucks sold after 2035 would need to run on hydrogen for the fleet to be decarbonised by 2050. However, for a policy such as this it is important to analyse the costs, discussed in the section below.

3.2.3. Additional electricity demand from pathways to zero

All pathways to zero GHG emissions use electricity to power the surface freight fleet, either directly through batteries and catenary wires, or indirectly through the production of PtL or Hydrogen. This section aims to quantify the additional electricity demand, i.e. the primary energy supply (PES) requirement, and the assumptions used.

First, we consider the additional electricity supply required from the E-highway and BEV options as discussed in section 3.2.1. The electricity isn't transformed from one form to another, but there are losses in charging the batteries (or delivery over catenaries), losses in the inverter, and small inefficiencies of the electric motor itself. In total, we approximate that the efficiency of the electrified vehicles – both catenary and battery powered, are 73%. The PES demand split for HHGVs and the MHGVs and buses are shown in Figure 8. In the EU, 0.1 x10^6 GWh are required for HHGVs alone, approximately 3% of the total EU supply in 2015.

Next, to bridge the remaining gap between electrification and zero GHG emissions by 2050, the additional fuel efficiencies are calculated. For PtL, the conversion of electricity supply to a usable fuel is 44%[xcvii], and the efficiency of an internal combustion engine is taken to be 30%, resulting in a final efficiency of 13% (see figure 9 below for more details). Similarly for Hydrogen, the electrolysis and compression/liquefaction is 52% efficient, a fuel cell is taken to be 50% efficient in producing electricity, and the motor efficiency is assumed to be 90% (as was the case for the electric options), resulting in a final efficiency of 22%. This demand is also presented in Figure 8. Making a similar comparison as before, PtL amounts to 1.1 x10^6 GWh for all HDVs (including rail freight), which is 33% of the total EU supply of electricity in 2015 and 114% of total EU renewable supply[xcviii]. Section 4 discusses which option would be more viable from a cost perspective.

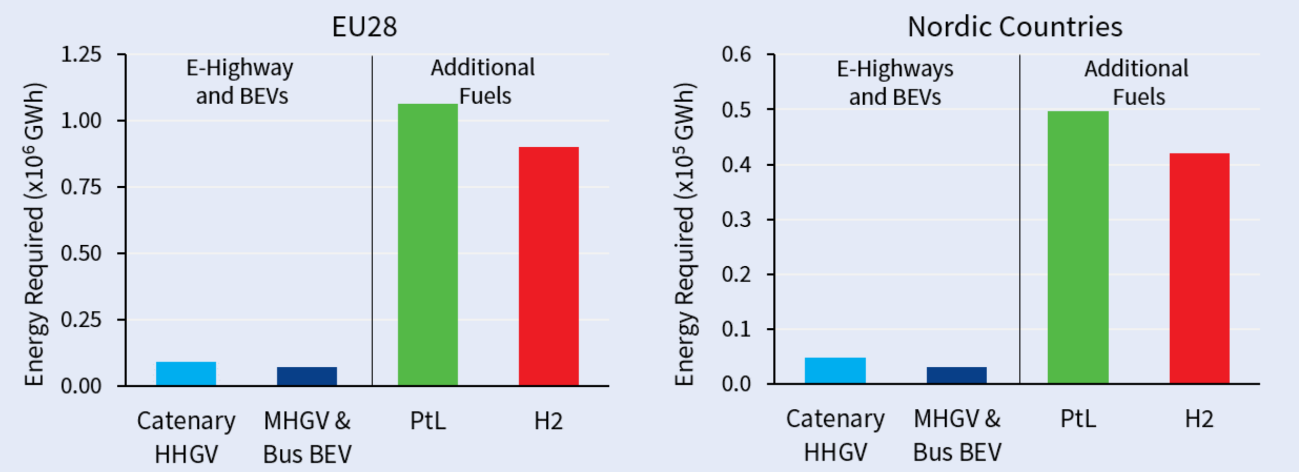

Figure 8[15]: Primary Energy Supply (PES) of electricity for: catenary for E-highways for HHGVs and electric MHGVs & buses, as described in Section 3.2.1; for PtL, and; for hydrogen options, for remaining energy needs of additional fuels to reach zero GHG emissions by 2050 in the EU and in the Nordics.

As both hydrogen and power-to-liquids require massive amounts of renewable electricity, other options would need to be considered as well beyond the assumptions considered in this study, for example reduced freight transport demand, higher modal share, or invest in innovation in order to ensure that large trucks can run on batteries when off the catenary lines. For illustration purposes, figure 9 below summarizes the efficiency of the different pathways.

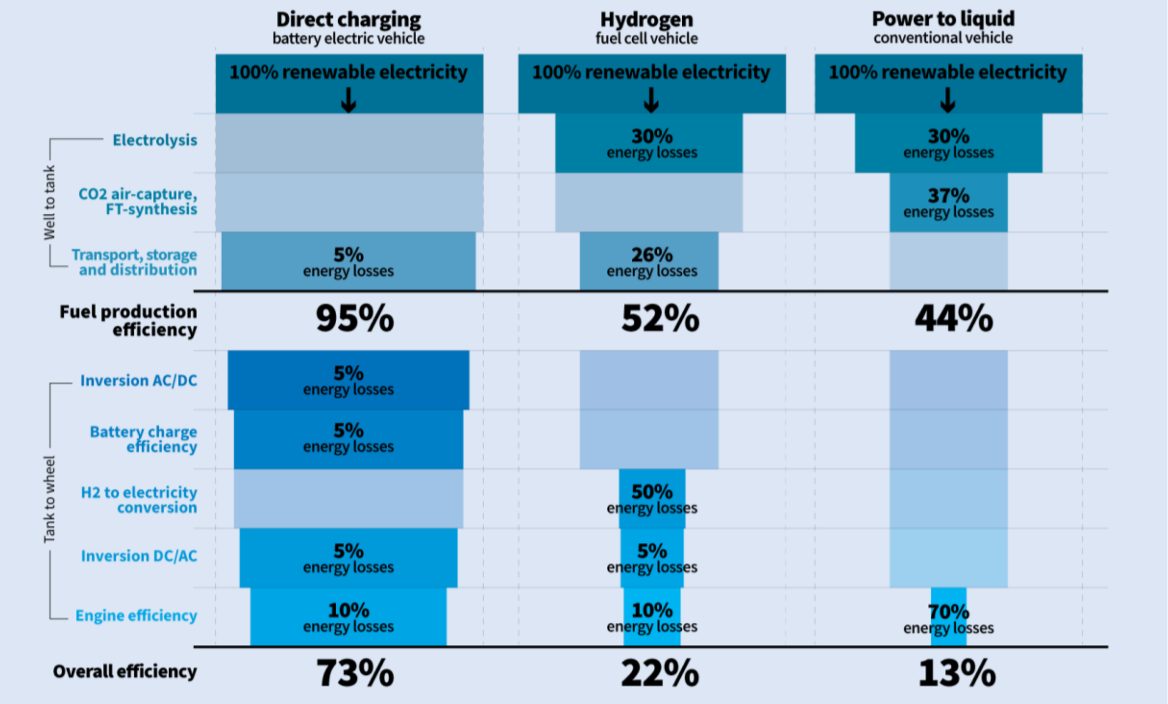

Figure 9: Energy efficiency of different technologies

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[15] Figure 8 and appropriate text has been modified compared to an earlier version of this document, to correct for the energy required for the HGV electrification.

3.3. Options disregarded

Some options were initially considered within the scope of this report. However, after analysing them in more detail, they were not included in the modelling because they could not contribute to make freight zero GHG. They are explained below. Waterways, as explained in Section 3.1.2, were also outside the scope of the study.

3.3.1. Natural gas

HGVs can run on natural gas in the form of Compressed Natural Gas (CNG) or Liquefied Natural Gas (LNG), a fossil fuel composed of mostly methane, a greenhouse gas thirty times more potent than carbon dioxide in a 100 year perspective. Currently, two main types of trucks can run on natural gas: dedicated natural gas vehicles and dual-fuel vehicles, operating on both diesel and natural gas.

Methane has the lowest carbon intensity of any hydrocarbon, but natural gas vehicles are typically up to 15% less fuel efficient than their diesel counterparts.[xcix] Real driving tests in the UK showed that dual fuel vehicles are on average 7% less energy efficient, while dedicated gas vehicles are 24% less efficient than diesel vehicles.[c] As a result, TTW (tailpipe) emissions are, at best, 5% better, and at worst, 15% higher than diesel in dedicated natural gas vehicles. When considering the whole life cycle, the so called WTW emissions, both dual-fuel and dedicated gas vehicles are as high as for diesel or worse.[ci] Only if high shares of sustainable biomethane are used could these vehicles deliver some climate benefits.

When using natural gas, vehicles can run both on the fossil derivative or on biomethane, which is produced by removing impurities from biogas. Biomethane can be produced from landfill gas or from anaerobic digestion of different plant materials (crops, food waste, sewage sludge, etc.). There are concerns about how much biomethane can be produced in the EU in a sustainable way.[cii] Moreover, biomethane competes with biomass and biofuels for mostly the same sustainable sources.

Natural gas vehicle engines could become more efficient. However, diesel vehicles engines are also expected to improve. It is estimated that natural gas vehicles will remain 10% less fuel efficient than equivalent diesel vehicles.[ciii]

If natural gas vehicles remain less efficient than equivalent diesel vehicles, promoting natural gas vehicles will not improve the climate impact of equivalent diesel vehicles. The only option where it would make sense to switch to natural gas vehicles from a climate perspective would be a scenario with a high availability of sustainable biomethane. Although Denmark has a high biomethane capacity due to its large swine industry, this is a unique case in the EU and not a recommended pathway for the EU as a whole. Studies suggest that there will not be high availability of biomethane in the EU from sustainable sources.

4. Costs, barriers

Previous sections described different pathways to reach zero GHG in surface freight and buses. This report's main focus was not to analyse the costs of the different alternatives, but on how to reach zero. Costs are currently beyond the scope of what EUTRM can model. However, it is fundamental to look into the costs and barriers of different alternatives if they are to be implemented in the real world.

When analysing the costs of different alternatives, it is of paramount importance to follow a holistic approach. For instance, looking into only the direct costs of building catenary lines for HHGVs on e-highways, is incomplete. If only the additional cost of new infrastructure is analysed, it might look expensive in comparison to, for instance, using hydrogen, where no new road infrastructure is needed. But in that example, hydrogen needs to be produced at a higher cost than electricity.

Research on this direction is still limited. However, the German Environmental Agency (UBA) commissioned a study to look at different alternatives in Germany[civ]. Ideally this would be done for the EU as a whole, but for this study we will use it as a main reference.

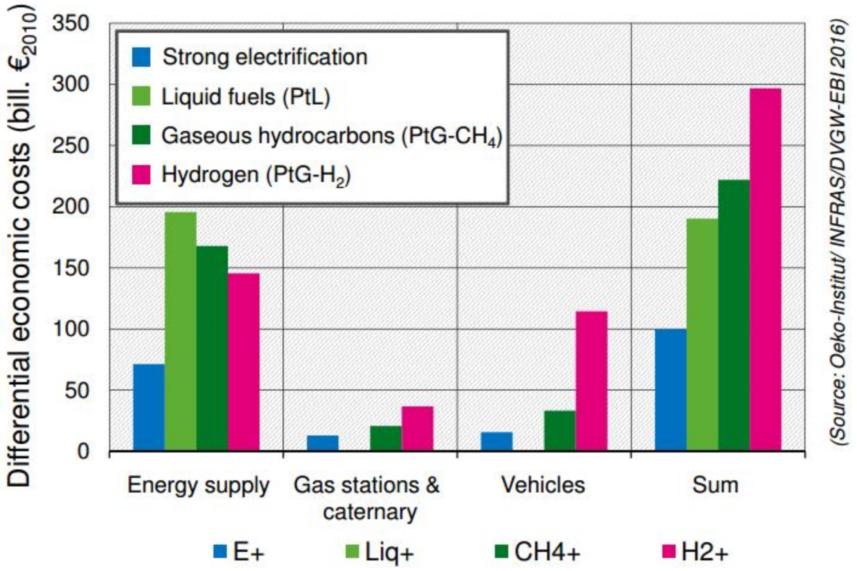
The UBA study looked into four different scenarios to reach zero GHG emissions in transport by 2050:

- E+: further electrification of trucks, electric buses and overhead catenary lines.
- Liq+: further use of liquid hydrocarbons (mostly PtL)
- CH4+: change to gaseous hydrocarbons when possible (mostly PtG).
- H2+: change to hydrogen when possible.

It looked at costs to reach carbon neutrality within three categories:

- Energy supply: producing the energy needed in transport.
- Additional gas stations and catenaries: infrastructure needed to supply the energy.
- Vehicles: additional costs compared to existing vehicles.

The graph below shows the main result for long haul transport (trucks and buses):



(Source: Oeko-Institut/ INFRAS/DVGW-EBI 2016)

Figure 10: differential economic costs of different alternatives to reach carbon neutral long haul transport in Germany by 2050

The graph above shows that the options selected in this study also make sense from an economic perspective. Whenever possible, electrification is the cheapest alternative possible. In cases where that might not be an alternative, implementing PtL is cheaper than using PtG and hydrogen, the most expensive option considered. However, it must be highlighted that this is decarbonisation option only if alternative fuels are produced from 100% renewable or zero emission electricity.

When analysing costs, it is also key to mention the co-benefits that would be a consequence of this transformation: energy independence, improved air quality, and job creation. There is evidence that improving transport efficiency and switching to domestic energy sources for vehicles could contribute to Europe’s key objectives of stimulating economic growth and mitigating climate change.[cv]

There is one main barriers to the introduction of the E+ scenario: the construction of the catenary lines. There is also one main precondition that needs to be met in order to make trucks and buses zero GHG: decarbonisation of the grid and enough supply of renewable energy to meet additional demand from the transport sector. In the section below we address how to overcome these two issues.

5. Policy recommendations & main results

In order to unlock the potential needed to reach zero GHG in HGV and buses, policy is needed on the EU-, national- and local levels. This section gives some key policy recommendations in the short term, mostly focusing on EU level measures, as the potential GHG savings from each policy. It also includes the percentage reduction that it could deliver compared to the business-as-usual.

5.1. Low-hanging fruit

Low hanging fruit options are those that are the most feasible in terms of technology and cost. Despite the relative ease in implementing these policies and their significant reductions in CO_2 emissions, a range of policies are required to unleash their potential.

Increased efficiency of HDVs

- Implement an ambitious CO_2 standard for trucks. This can be a whole vehicle standard or a whole vehicle standard combined with a separate engine standard. A separate engine standard would not bring the savings modelled. For truck categories not included in VECTO, a stringent engine standard is needed. Trailers should be included in VECTO as soon as possible.

The implementation of this measure could untap the potential described in Section 3.1.1, reducing 84.8 Mt compared to BAU (28%) in the EU.

Increased electrified rail freight

- Invest in infrastructure so trains can cross borders easily and transhipments can be faster and cheaper.
- Open national/international EU markets to competition, including separating the financial accounts of infrastructure manager and railway undertaking and creating an independent regulator to ensure fair competition in the European railway market.
- Improve management of tracks to allocate more capacity to freight trains, while maintaining passenger kilometres).

The implementation of this set of measures could untap the potential described in Section 3.1.2, reducing 12 Mt compared to BAU (4%) in the EU.

Improved logistics efficiency

- Implement a distance-based road charge for trucks across Europe.
- Ensure that fuel taxes reflect the external costs of trucks.
- Invest in smart infrastructure to allow for ITS and advanced road tolling, while possible obliging data sharing (with strong data protections in place) so that internet applications can optimally improve the efficiency of freight transport.

The implementation of this set of measures could untap the potential described in Section 3.1.3, reducing 18 Mt compared to BAU (9%) in the EU. Combining all low hanging fruit options would amount to a reduction of 112.8 Mt compared to BAU (36%).

5.2. Pathway to zero

Clean electricity

- Establish high renewable energy targets.
- Ensure that carbon has a high price, either through the ETS or other tools.

This is an enabler for the options below, not a pathway by itself.

E-highways for HHGVs

- Take a decision to push this alternative as soon as possible to start developing the infrastructure.
- Use road charging revenues to finance infrastructure and vehicle costs and other pilot projects (eg LKW Maut in Germany). It can be complemented with EU funding.
- Develop a common EU strategy to avoid bottlenecks, reduce prices and incentivise investments in catenary truck technologies.

Fully electric MHGVs and buses

- Establish an e-vehicle mandate for trucks below 16 tonnes, helping to decrease price.
- Invest in infrastructure and R&D for battery technologies.
- Guarantee that green public procurement schemes, such as the currently ongoing revision of the Clean Vehicles Directive, promote the uptake of these technologies.

The implementation of this set of measures to promote electricity in trucks and buses could untap the potential described in Section 3.2.1.1 and 3.2.1.2, reducing 83 Mt compared to the low hanging fruit pathway (42%) after the implementation of all other measures described above.

Additional fuels

Advanced sustainable fuels

- Establish stable policy to promote industry's confidence, ensuring proper sustainability from the beginning.
- Focus on efficiency measures in the EU. The biomass available for the transport sector is dependant significantly on the heating and electricity sector.

The implementation of this measure could untap the potential described in Section 3.1.1, reducing 4 Mt compared to the case where the low hanging fruit and electrification options have been adopted (3%), when used in addition to the low hanging fruit measures.

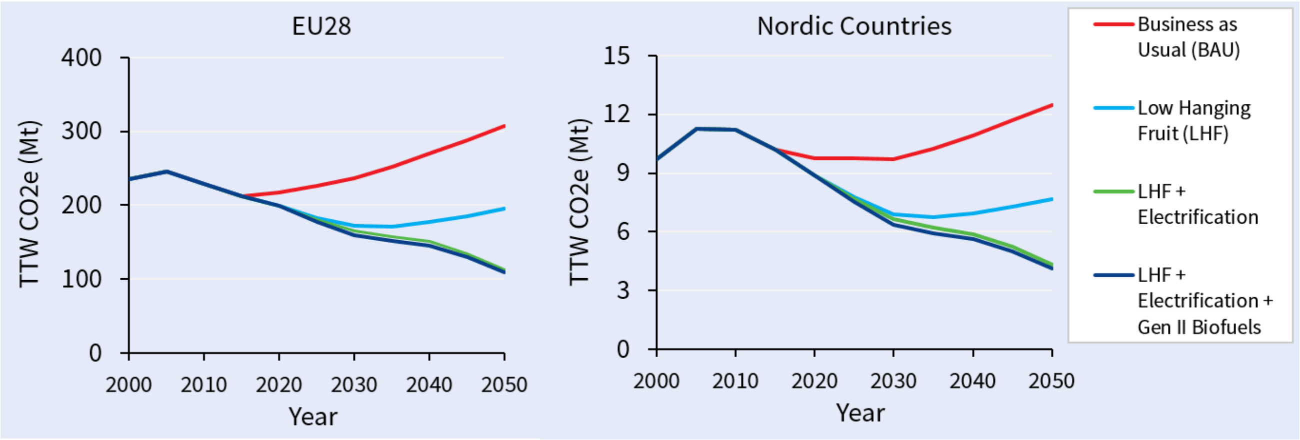


Figure 11: The cumulative effects of the low hanging fruit, electrification, and biofuel options for decarbonizing road freight transport in the EU and in the Nordic countries.

Power-to-X

- Establish clear incentives to promote uptake of PtL to make it more cost-competitive, beyond the incentives established in the Renewable Energy Directive.

Hydrogen

In the case this option would be promoted (when it seems there is no economic case based on Section 4), some policy recommendations would be:

- Strong support for zero carbon freight.
- Developing pan European fuel production and refuelling infrastructure for hydrogen trucks if the technology is taking off.

Both PtX and hydrogen, if done through electrolysis and only using renewable electricity could do the final effort to bring HDV emissions to zero by 2050. However, important amounts of additional renewable electricity would be needed for each alternative, as explained in Section 3.2.3.

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