RACE TO ELECTRIFICATION  
– NORWAY IN  
POLE POSITION

EIRIK HORDNES
IMAGINE AN ELECTRIFIED FUTURE. NOISE AND POLLUTION ARE GONE. THE AIR YOU BREATHE IS CLEAN. HEALTH-RELATED SOCIETAL COSTS ARE REDUCED – FREEING UP RESOURCES FOR OTHER INVESTMENTS THAT WILL BRING MEANING AND JOY TO PEOPLE’S LIVES IN THE CITY.
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Electrification is one of our best tools to mitigate climate change. By replacing fossil energy used today with renewable electricity we can substantially reduce carbon emissions, decreasing the rate of global warming. The Intergovernmental Panel on Climate Change (IPCC) has highlighted electrification of transport and industry as a central element in achieving a pathway compatible with the 1.5°C target.

It is of little doubt that electricity is set to become the dominant energy carrier in the future. After all, electricity is the only energy carrier that can be generated and distributed to the end user in large quantities and over long distances in a split second, with relatively small losses. It can be produced centrally in large power plants, but can also be easily produced locally — for example, with photovoltaic panels on the end user’s own rooftop. Electricity is also extremely flexible and can be converted into other energy carriers, such as hydrogen, to be stored and used at a later time.

Norway is one country that is leading this trend and has already come quite far with electrification. Nearly all (98 per cent)\(^1\) of the country’s power generation is produced from renewable hydroelectric power. Norway also has a head start in the rollout of electric vehicles, which by 2025 are likely to comprise 100 per cent of all vehicles sold. In 2015 Norway commissioned the world’s first electric ferry and fishing boat. Norway will also have the world’s first electric container ship ready for operation by 2020 and has set a goal of electrifying all domestic air travel by 2040. Norway accounts for around 40 per cent of the global battery-powered ship fleet.\(^2\) Power generation in Norway is also a regulable energy source, making it easier to adapt production to varying consumption patterns and enabling electrification of different sectors without the need for extensive new storage solutions.
Many other European countries are largely dependent on a mix of coal, gas, oil and nuclear power production for their electricity generation. Fossil fuel combustion accounts for a large share of global carbon emissions, contributing to global warming. In addition to electrifying energy end use, other countries need to phase out fossil fuels and adapt their energy systems to utilise a larger share of renewable energy sources in order to reduce their carbon emissions and ecological footprint.

All of these factors put Norway in a leading position to become the world’s first fully electrified country. But what do we actually mean by “fully electrified”? Is this achievable, or even necessary? Will it make goods and services more expensive? And what issues does Norway face, as compared with other countries?
2. DEFINING ELECTRIFICATION
Becoming fully electrified ("electrification") is the process of converting a machine, process, system or sector to use electricity where it did not do so before. Examples include going from a petrol- or diesel-driven passenger vehicle to an electric vehicle, and using electricity (rather than coking coal) to produce hydrogen from water as a reduction agent in steel production.

The term "electrification" can be quite ambiguous in the sense that it does not specify the source from which the electricity is being produced. We therefore need to talk about beneficial electrification, rather than electrification per se. In this report, electrification refers to a conversion that replaces fossil fuel use with electricity in a way that reduces overall emissions. Electrifying the transport sector would be one such beneficial electrification. Becoming fully electrical involves phasing out fossil fuels in all sectors wherever possible (and where it is meaningful to do so). This report does not focus on the energy source producing the electricity, as this has been addressed in a previous Urban Insight report.3 Our focus is on electrifying the end use, since the generated electricity should come from renewable sources in a truly “fully electrified” journey.
We can subdivide electrification in two main categories: direct and indirect electrification.

- In this report, direct electrification means directly converting a previously fossil-driven process into an electricity-driven process. When talking about indirect electrification, things can get a bit more complicated.

- Indirect electrification can refer to using electricity to produce or refine other energy carriers used to phase out fossil fuels. This is done in processes where it is difficult or simply not meaningful to use electricity directly. Electricity can be used, for example, to produce hydrogen to power ships with hybrid drivetrains (combination of hydrogen fuel cells and electrochemical batteries), since batteries take up too much space and are too heavy to be used as the sole power source on long-distance routes. Indirect electrification can also be used in processes such as producing hydrogen used for direct reduction in the steel industry for the manufacture of e.g. wind turbines, or to produce hydrogen for ammonia manufacturing.
3. WHY AND WHAT DO WE NEED TO ELECTRIFY?
The main reason for electrifying our various sectors is to reduce CO₂ emissions as a means of preventing climate change. This can be achieved by electrifying processes that are currently dependent on fossil fuels. According to the IPCC, electrification of the transport and industry sectors is a central element in achieving a pathway compatible with the 1.5°C target.

Electrification can also be a sound economic choice, since it often leads to greater efficiencies than the alternatives. This can reduce energy demand and costs, although in many cases electrification may require greater initial investments since the new green value chain and technology are not as mature as conventional alternatives. This is changing rapidly, however, as more and more businesses are investing in new and more efficient production lines, making their businesses “Paris-proof”.

In addition to reducing climate gas emissions, electrification will also produce less noise and localised air pollution, which is positive for citizen wellbeing. As a result, it also provides urban development opportunities in areas previously dominated by noise and pollution, making these areas attractive for new residential areas and businesses.

But electrification is not a silver bullet that will solve all problems in achieving a decarbonised society. Electrification is one of several efforts to bridge the gap between the society of yesterday and the society of the future. The road to decarbonisation can be categorised into three main areas. This report will focus on decarbonisation technologies, with particular focus on electrification.

III. 4: Electrification is a key factor on the road to decarbonisation.
“Energy”, as a term used in everyday speech, is a relatively familiar concept for most people. Two other energy-related terms – exergy and entropy – are not as familiar. Exergy is a measure of the energy’s quality. Exergy can do “anything”. Energy cannot, because every process creates what is called entropy, often illustrated in the form of chaos or disorder. Entropy is low-quality energy that is not useful for doing things. When buying electricity from the utility company, you are buying what can be considered pure exergy (since electricity can do “anything”), but for every process exergy is being destroyed and entropy is created. This can be illustrated with a toothpaste tube. When squeezing the tube (doing a process) the paste (exergy) fills your toothbrush with good usable toothpaste to clean your teeth with. The paste cannot be put back into the tube, and when squeezed enough times, the only thing you’re left with is the squeezed tube (entropy) which cannot be used for “anything”.

This can also be illustrated with the electric radiator heating your home. When doing this, pure exergy (electricity) is converted to low-quality energy (low-temperature heat), which cannot be used for much else than keeping your house warm for a while. This can be compared to throwing away a half-used toothpaste tube. It is better to use a heat pump, which uses only some electricity to heat your home, or to use a solar collector, which saves you money and reduces the grid’s peak load while also satisfying the physicist in the family.
WHICH SECTORS DO WE NEED TO ELECTRIFY?

To understand what we need to electrify, we need to take a closer look at all of the processes in our society that use fossil fuels and identify where it is possible (and meaningful) to electrify them. This analysis shows that the major areas with the greatest potential for CO₂ emission reduction are the transport and industry sectors, and building utilisation and operation. This report will therefore focus on these sectors in Norway.

![Graph showing share of CO₂ emissions in Norway, 2017.](image)

**SHARE OF CO₂ EMISSIONS IN NORWAY, 2017**

- **Industry, 58%**
- **Transport, 29%**
- **Buildings, 2%**
- **Others, 11%**

![Graph showing breakdown of CO₂ emissions from various sources in Norway, 2017.](image)

**EMISSION-INTENSIVE SECTORS IN NORWAY**

- **Passenger vehicles: 36%**
- **Process emissions: 67%**
- **Stationary combustion: 99%**

III. 6: Share of CO₂ emissions in Norway in 2017 from targeted sectors, which account for approximately 90 per cent of Norwegian CO₂ emissions.

III. 7: Breakdown of CO₂ emissions from various emission sources in Norway, 2017.
THE TRANSPORT SECTOR
The transport sector comprises road transport, inland air transport, inland shipping and rail transport. This accounts for 29 per cent of total CO₂ emissions in Norway. Within this sector, road transport is the greatest source of emissions in Norway (68 per cent), while passenger cars and light vehicles account for approximately 36 per cent of transport-related CO₂ emissions.

In an electrification scenario, the use of batteries will be essential for shorter journeys, while a combination of hydrogen fuel cells and batteries will be necessary for longer journeys for heavier vessels and vehicles. It should be noted that heavy road transport, shipping and aviation are notoriously difficult to decarbonise through electrification or other means.

THE INDUSTRY SECTOR
The industry sector comprises a wide range of industries, responsible for around 60 per cent of Norway’s total CO₂ emissions. Industrial segments include upstream and downstream oil and gas extraction and production, metal production, chemical industries and cement production.

Industries such as the cement, steel and chemical industries are particularly difficult to electrify due to the nature of the processes involved. These industries also have a high level of process-related emissions.

THE BUILDINGS SECTOR
The buildings sector is referred to as the “40 per cent sector” on the global level, as it typically uses 40 per cent of all energy consumed, accounts for 40 per cent of greenhouse gas emissions and uses 40 per cent of the world’s materials. The sector includes residential properties, public and municipal buildings, and commercial, retail and other buildings. In Norway, emissions from buildings during the operational phase are quite low, as Norway relies mainly on hydropower for electricity production and uses a lot of electricity and very little fossil fuels to fuel the buildings.

“THE BUILDINGS SECTOR IS KEY IN THE ELECTRIFICATION OF NORWAY.”

Buildings can play a key role in the electrification of Norway, without involving additional electrification in this sector. For heat production, for example, direct electric heating can be substituted by water-based heating using heat pumps. This will reduce buildings’ electricity demand and free up electricity for other uses in sectors that depend entirely on electricity for decarbonisation, while at the same time reducing the need for new electricity production.
INTRODUCING THE E-DAY
Some helpful indicators can be useful for forming an overview of where we are regarding the electrification of our society. To do this, we will introduce the “E-day”. This is the theoretical day of the year by which all electricity has been used. All energy used after this day will not come from electricity, but from other sources such as coal, gas, oil and bio. (This will never be the case in real life, since we will always have electricity available and the use of electricity is distributed across the year.) To calculate when the E-day will occur, we take all energy used in one year and divide this by 365 (the number of days in a year). We then know how much energy we use on average each day. We then tally the amount of electricity we use every year and assume that we only use electricity to meet our daily energy needs, starting from January 1st. At some point – the E-day – the electricity will have been used up, which means that from that day on, through the end of the year, we use something other than electricity to meet our energy needs.

This gives us a general indication of how electrified our society is and how far away we are from a 100 per cent electrified society. If your country has a lot of electric vehicles, for example, it will need to use more electricity to fuel cars, but less fossil fuel. If that’s the case, the E-day will occur later in the year than it would if your country’s cars were fuelled solely by fossil fuels.
The diagram below, based on data from 2016, shows that Norway will have used up all of its electricity by July 7th, while the corresponding date for Great Britain is as early as March 12th. Norway, in other words, is more electrified than the UK. This translates to a share of electrification of around 52 per cent when comparing fossil fuels and other energy carriers with electricity. Compared with other European countries we see that Norway is in the pole position to achieve this — “becoming fully electrical.”

III. 9: E-day for various European countries, based on end use of energy in 2016. Figures from Eurostat.

III. 10: With a large part of the country situated above the Arctic Circle, Norway is obviously dependent on having electricity all year round. The E-day shows that Norway is currently dependent on other energy sources to complement electricity.
4. CASE STUDY: MEET THE ELECTRON
The electron is an essential part of the electrification process. The electron flows through conducting power cables into factories, buildings, vehicles, vessels, batteries, and water to produce hydrogen. The electron enables electrification.

Norway in winter. The largest of Norway’s 1,600 hydropower plants is located approximately 4 hours southeast by car from Bergen, Norway’s second largest city. The water level in the dam at the Kvilldal hydropower plant is now at a record low due to a combination of a hot summer and high energy exports to Europe, followed by a cold winter. The plant, completed in 1981, has a power production capacity of 1.24 gigawatt (GW) and an annual energy production of 3.6 terawatt hours (TWh), corresponding to the energy needs of approximately 240,000 homes for an entire year. 260 cubic metres of water falls 536 metres per second from the dam, through a pipe and down to a turbine that rotates when the massive amounts of water hit the runner blades of the Francis turbine. The turbine is coupled to an electric generator through a shaft with large magnets surrounded by coils of copper wire. The electrons in the wire starts moving when the magnets spin.

Meanwhile, in Bergen. Approximately 200 kilometres from the Kvilldal hydropower plant at the home of the Nesses, a family of three, the electron arrives the moment Merete (the mother of the house) plugs in the family’s electric vehicle. Merete is a bit late getting home from work due to rush hour queues. Her husband Bjarne is already home with their two-year-old son Marius, putting finishing touches on the family’s dinner. It is the peak hour of the year. It is freezing outside. The induction stove, the electric vehicle, the lights, the water heater and the electric radiators are all making the meter spin. It is for this hour, this day of the year, that the cables running all the way from the power plant to the house have been sized to accommodate this maximum demand. Electricity consumption is not always this demanding in the Nesse household, but it is typically high at this time of the day when all appliances are “on”, and the electricity transmission and distribution system needs to be able to accommodate this peak demand.

Bjarne and Merete are both engineers and are interested in new technology. They also have their son Marius’s future in mind and are constantly trying their best to make environmentally sound choices. Even though Bergen is not the sunniest place around, they recently filled part of their southwest facing roof with photovoltaic (PV) solar panels. The 20-square-metre PV system produces a maximum of 4 kilowatts, giving the family 3,000 kilowatt hours (kWh) of electricity each year. This covers around 20 per cent of their yearly electricity consumption, including electricity for their electric vehicle.
Electric heating: good efficiency, bad efficiency

Like many Norwegians, the Nesse family heats their house with electricity through wall-mounted electric radiators. Approximately 60 per cent of their electricity bill goes towards heating. Bjarne and Merete have decided they want to switch to an electric heating system with water-based radiators fuelled by a ground source heat pump, which will save them about a third off their electricity bill. Doing so will also help the grid reduce its peak load. The capital investment will be quite high, but the Nesses have saved up and think this investment will reduce their heating bill quite a lot – particularly since it appears that Norway, like Sweden, is planning to amend energy tariffs to include power tariffs, which will result in higher costs for using a lot of power during peak load periods. It is also bad energy economics to waste a high-quality product like electricity in exchange for a low-quality product like heat. In other words, it’s like washing the floor with champagne.

Holiday for the rich?

The Nesse family are going on holiday this summer and have decided to travel to Belgium to visit an old family friend. They considered taking the boat to Denmark and then the train from Denmark to Belgium, but due to time limitations they decided to fly to get the most out of their holiday. Merete was concerned about the greater climate impact of aviation. After a quick internet search she learns that, according to an EEA report comparing various means of transportation, planes are the worst, emitting 285 grams of CO₂ per passenger per kilometre. This is 20 times more than train emissions. Emissions from other greenhouse gases and the formation of contrails that trap heat in the atmosphere also have a negative effect.

III. 12: Overview of various means of transportation and related CO₂ emissions per passenger kilometre.

Note: The figures have been estimated with an average number of passengers per vehicle. The addition of more passengers results in fuel consumption – and hence also CO₂ emissions – penalty as the vehicle becomes heavier, but the final figure in grams of CO₂ per passenger is obviously lower. Inland ship emission factor is estimated to be 245 gCO2/pkm but data availability is still not comparable to that of other modes. Estimations based on TRACCS database, 2013 and TERM027 indicator.

Source: European Environment Agency.
With her suspicions confirmed, Merete feels even worse and starts thinking that there must be something that can be done to decarbonise air travel. She’s thinking that traveling by plane provides so many opportunities to get places in no time, and she wants her son to be able to travel the world as she has done. But still, she does not want him to grow up in a world with constantly rising temperatures.

She continues browsing the internet, hoping to find a solution somewhere. She finds an article on the website of Norwegian state-owned firm Avinor, owner and operator of the national network of civilian airports, specifying Avinor’s goal to electrify all Norwegian domestic flights by 2040 in collaboration with aviation industry partners. She thinks this is great news, but still thinks it’s too far off, thinking once again about her son Marius’s future. In a BBC article that offers more details on Norway’s plans to electrify its inland fleet of planes, she learns that Avinor is planning to introduce electric planes with 25–30 seats by 2025.

Currently, there is only one electric plane in Norway, the first fully electric two-seater in the world approved for commercial use. The Alpha Electro G2 has a range of 130 kilometres and can remain airborne for 1 hour per charge. But more electric planes are on the horizon. A 2018 report from Roland Berger, Electric Propulsion Ushers in New Age of Innovation Aerospace, found that around 100 different electric aircraft programmes are in development worldwide, a 30 per cent increase over 2017. Seventy per cent of these programmes are looking at all-electric propulsion, with the rest looking at hybrid propulsion using traditional fuels. This is quite promising, although the development of all-electric propulsion is strongly correlated with the development of battery energy density, since the energy-to-weight ratio is crucial for planes. Jet fuel (kerosene) has, in comparison, approximately 40 times greater energy density than batteries. To make all-electric aviation commercially available for longer distances, battery energy density needs to be around 4 times higher: from today’s 250 watt hours per kilogramme (Wh/kg) to 800 watt hours per kilogramme. This will make it possible for aircrafts to move about 150 passengers up to 1,100 kilometres, replacing half of global aircraft departures.
Achieving 800 Wh/kg cannot be done with lithium-ion batteries, which now dominate the propulsion market, due to their expected fundamental limits of 350–400 Wh/kg. It is likely that battery energy density up to 500 Wh/kg will be available by 2025–30, but it is not known whether density can be doubled within a few years subsequent to that, since battery energy density has historically been doubling only every 20th year. Charging this all-electric aircraft fleet would increase global electricity demand by 110–340 TWh (0.6–1.7 per cent), the equivalent of what you could produce by placing PV panels over the entire city of Hamburg or an area twice the size of Barcelona. Several experts believe that battery- or hydrogen-powered flights may become feasible for planes of up to 100 seats flying 300–500 km. But energy-dense fuels are needed for international flights, and this is currently only available with liquid hydrocarbon fuels. Another hope is appearing on the horizon, however: biofuels can have the same characteristics as conventional jet fuels and can be used in existing engines. Currently the most critical factor for reducing CO₂ emissions is the continuing improvement of jet engine efficiency, since fuel consumption is one of the most significant costs for airlines. However, the improvements of around 2 per cent per year are cancelled out by the 4.5 per cent annual growth in air travel. All this makes Merete want to cancel their airline tickets. She’s thinking, if I’m not changing habits, who will?
5.
CAN TRANSPORT IN NORWAY BECOME FULLY ELECTRICAL?
As we have seen, Norway is in a leading position to become fully electrified, with its E-day arriving as late as July 7th, corresponding to a 52 per cent share of its energy end use being electric. We will now take a closer look at the different sectors and consider what it would take to fully electrify them in Norway — and whether it would be meaningful or realistic to do so.

The figure below shows primary energy use in Norway in 2017, distributed between fossil fuels and electricity. Other energy carriers (e.g. bioenergy) are not included in the figure. The figure shows the amount of electricity needed to fully electrify the various sectors, and the amount total energy use is reduced by going fully electric, from fossil fuels to electricity. A total electricity production of approximately 200 TWh will be needed to fully electrify Norway; 121 TWh is already being used and an additional 79 TWh of electricity will be needed for new purposes. This would produce a 65 per cent increase in electricity demand, but would at the same time reduce overall energy use by 25 per cent due to efficiency gains achieved by changing energy carrier from fossil fuels to electricity.16
THE TRANSPORT SECTOR CAN BE HIGHLY ELECTRIFIED

To reduce emission levels quickly and significantly, the Norwegian government has set ambitious goals for transport. These goals are formulated in the National Transportation Plan 2018–2029. As part of the plan, all new ferries will use low- or zero-emission technology and all new passenger vehicles and small vans will be zero-emission vehicles by 2025.16 All new city buses will be zero-emission or biogas-fuelled by 2025. By 2030 distribution of all goods in the largest cities will produce close to zero emissions. Public institutions will almost exclusively use biofuels or low- or zero-emission technology for owned and leased vehicles, and by 2050 all transportation modes will be close to zero-emission/climate neutral.

To achieve this, as well as full electrification, massive investments are needed in charging infrastructure at ports, in cities and along main transport hubs, and at airports. This infrastructure will also need energy storage solutions such as batteries to ease the power grid in areas with low capacity. Ports will function as energy hubs in supplying electricity, hydrogen and biogas to ships. Let’s take a look on how this can be done in various transport subsectors.
PASSENGER CARS/LIGHT VEHICLES

It is entirely possible for passenger vehicles to become fully electrical. Passenger cars, for example, are already being rapidly electrified in Norway, where nearly every second passenger car sold in 2018 was electric. The share of electric vehicles sold in Norway was more than 58.4 per cent in March 2019. If hybrid electric vehicles are included, more than 3 of every 4 cars purchased can be charged with electricity. Even more impressive: According to the Norwegian Electric Vehicle Association’s own forecast for 2025, it seems highly probable that all new sold private cars in Norway will be electric by then.

The Institute of Transport Economics in Norway estimates that the share of zero-emission passenger cars in relation to the total number of passenger cars in Norway may be 62 per cent in 2030 and 100 per cent in 2050. This would reduce Norway’s total CO₂ emissions by 10 per cent by 2050, compared to 2017 levels. This forecast is based on implementation of the Norwegian policy of allowing only zero-emission cars to be sold as new cars by 2025. Private passenger cars have received massive government incentives to stimulate and incentivise the market. The same uptake has not been seen for commercial vehicles due to reduced market incentives for business purposes. In 2017, 1 per cent of the approximately 480,000 small vans in Norway were electric, and only 0.7 per cent of the other 450,000 light vehicles were electric.

In total it is estimated that a full electrification of passenger cars and light vehicles in Norway will increase electricity demand by approximately 5 per cent.
BUSES, TRUCKS AND VANS

Larger, heavier vehicles are not as easy to electrify as passenger cars and other light vehicles. The market is not as mature, and vehicles in this category are heavier and drive longer distances with little time for charging. They therefore require larger battery capacity, which is counterproductive due to the increase in size and weight. It is, however, highly likely that buses and smaller vans and trucks will become fully electrical due to shorter journeys and lighter axels. Bus lanes can be electrified directly with batteries and/or supercapacitors using various charging strategies (induction, fast charging at each stop, fast charging at end stop, slow overnight charging), or by using overhead wires typical for trolleybuses. Some bus lanes and some trucks and vans that travel longer distances will need to be electrified indirectly using e.g. hydrogen or biogas.

Electric buses are experiencing a massive breakthrough globally, fuelled by China’s huge appetite for clean transport. According to Bloomberg New Energy Finance, in 2017 China was home to around 99 per cent of the world’s 386,000 electric buses, and electric buses had a 22 per cent market share of all new buses in the country. In the Chinese megacity of Shenzhen, all 16,000 buses are fully electric. The UK is the European country with the most electric buses in absolute terms, although less than 1 per cent of their total municipal bus fleet is electric. Norway is taking a European leading position on electric buses. According to the National Transportation Plan 2018–2029, all new city buses will be zero-emission or biogas-fuelled by 2025. Bergen, Norway’s second largest city, has ordered 80 electric buses to be ready for operation by the end of 2020, which will make Hordaland County’s 700-strong bus fleet approximately 12 per cent electric. The capital of Oslo will have 76 electric buses in operation in 2019. Oslo Municipality has an explicit ambition to become Europe’s number one city for electric buses.

The electric truck market lags behind the rapidly growing e-bus market. This is especially true for heavy-duty and long-haul trucks. Light- and medium-duty trucks appear more promising, as they travel shorter distances and carry less weight. Hydrogen fuel cell-based propulsion may be a good alternative for manufacturers that are developing electric longer-range heavy-duty trucks. US manufacturer Nikola Motor Company (NMC) has, for example, developed several heavy-duty truck models using this technology and has laid out a plan to install 700 hydrogen fuelling station across the US, with the capacity to deliver 8 tonnes of hydrogen from each station per day. NMC plans to build its first demo heavy-duty station during 2020 and to begin constructing its 700-station infrastructure in 2022. NMC is doing some of its testing in Norway in collaboration with its Norwegian partner NEL, and has a number of pre-orders from Norwegian customers. The manufacturer has given one of its semi-truck models a Norwegian name – TRE (“three”) – as acknowledgement of Norway’s pole position in electric transport.

It is estimated that the full electrification of buses, trucks and vans in Norway will increase electricity demand by approximately 4 per cent.
RAIL TRANSPORT

Electric rail propulsion has several advantages over the diesel alternative: no local pollutant emissions, greater efficiency and momentum, and lower operational costs. Energy produced from braking is also harnessed, recovering 10–20 per cent of electrical energy needed to drive the train. The main drawback to electrification is high initial investment costs.

Rail transport in Norway is already highly electrified, with 2,500 of the 3,900 kilometres in service using electrical contact wires. In terms of passenger kilometre, the electrification share is as high as 90 per cent. Rail is also highly electrified on the global level (approximately 70 per cent of all passenger kilometres), as seen in the bar chart below.

To increase the share of electrification in Norway, several ongoing projects are focused on converting diesel trains to electric ones using conventional solutions with overhead power lines. Conversion costs are high, however. As an example of this, electrification of the Meråker and Trønder lines was only recently re-started after having been put on hold due to high investment costs.

In 2015, Bane NOR (the Norwegian Railway Directorate) commissioned a report on how to best electrify the remaining non-electrified 1,400 kilometres. According to the report, implementation of several alternative zero-emission propulsion methods is feasible by 2021. These methods include propulsion based on battery-electric, hydrogen fuel cells, or biodiesel. By 2027, the report concluded, battery-electric and hydrogen fuel cells may be the preferable alternatives based on several criteria. It is highly likely that all rail transport in Norway will be fully electric by 2030 and that several of the alternative solutions will be used. This clearly demonstrates that electrification is not a straightforward solution and that alternative pathways must be mapped to identify the most viable decarbonisation strategy given the specific sector and local conditions.

It is estimated that the full electrification of rail in Norway will increase electricity demand by approximately 0.5 per cent.

### Table: Passenger Rail Transport Activity by Fuel Type

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Source: IEA. All rights reserved.
SEA TRANSPORT

Norway has a long tradition of shipping and a coastal landscape dominated by passenger ships, offshore supply ships and fishing vessels. Norway has about 140 ferry routes, many of which are well suited for conversion to battery-electric operation due to relatively short distances and fast-charging opportunities on both sides of the fjords when loading passengers. MF Ampere, the world’s first fully electric battery-powered passenger and car ferry, was put into service in 2015 and services the Lavik–Oppedal route across the Sognefjord. After some initial problems the ferry now runs with very good regularity, and passengers hardly notice the difference between this ferry and other more conventional ones – except for much less noise.

Due to low-capacity power grids in the rural areas where such ferry routes are typically located, innovative solutions that avoid major power grid investments are a key success factor. For MF Ampere, the solution was to have batteries on both sides of the fjord to serve as energy storage. This reduces peak load demand, charging the batteries slowly from the grid while the ferries are at sea. When the ferry arrives for charging and loading, the battery storage capacity can handle the maximum load needed for charging the batteries onboard the ferry. The Norwegian Public Roads Administration estimates that two-thirds of Norwegian ferries will be electric by 2030.

A recent report by DNV GL concluded that only passenger ships (<1,000 gross tonnage) are suitable for electrification using batteries. All other vessel types can be electrified with batteries to some degree (1–36 per cent of fuel use), depending on category and size. Hydrogen and fuel cells, working with or without batteries, will make it possible to indirectly electrify almost every vessel type with gross tonnage (GT) less than 10,000. It will be extremely important to offer both hydrogen and electricity to ships docked at harbour. Ports therefore need to serve as “energy hubs”, supplying the energy required by incoming ships. This is a new market for the ports: developing a production line and sufficient capacity to supply the ships, and serving as the energy hub for land-based functions within or outside the port.

In addition to supplying electricity for charging a ship’s propulsion system, shore power will be needed to reduce emissions when the ships are docked. An ongoing programme in Norway focuses on providing charging facilities and electricity to power the ships in “hotel mode” when docked. To date, approximately 90 of these systems have been installed in Norwegian ports.
Norway also dominates the global scene in terms of the share of ships with batteries (42 per cent, 137 of 325 ships) and number of shore power facilities in absolute numbers.\textsuperscript{30}

It is estimated that the full electrification of inland sea transport in Norway will require approximately 7 TWh of electricity, increasing demand by nearly 6 per cent while reducing primary energy demand by around 4 TWh.

In international shipping, 90,000 ships are trafficking the oceans to supply everything from chemicals, coffee, electronics, clothes and so on. These ships use around 300 million tonnes of heavy oil\textsuperscript{31} and account for approximately 3 per cent of global CO\textsubscript{2} emissions. The world’s 20,000 largest ships (over 25,000 GT) use around 80 per cent of this fuel, so it is essential to identify decarbonisation strategies for this transport category.\textsuperscript{32}

These ships travel vast distances over long periods, making this type of shipping entirely different from the MF Ampere’s 5-km route. In the short and medium term, Liquified Natural Gas (LNG) and biofuels are viable alternatives to heavy oil. But in identifying sustainable long-term solutions for long-distance shipping, electrification can play a key role indirectly through production of the promising fuels hydrogen and ammonia (NH\textsubscript{3}).

In early 2018, a Dutch consortium that includes Norwegian fertiliser company Yara launched a project to evaluate options for using ammonia produced from electricity as a fuel in shipping. The 2-year project involves theoretical and laboratory work culminating in a pilot-scale demonstration. C-Job naval architect Niels de Vries, who is involved in the project, says that “an internal combustion engine can be used to burn the ammonia.” He adds, “The technology exists – in fact, the first ammonia-powered car dates back to 1935.” As related to shipping, he says that “it just needs to be applied in much larger engines with modern techniques.”\textsuperscript{33}

“INTERNATIONAL SHIPPING COULD BE FUELED BY AMMONIA (NH\textsubscript{3}) – A PROMISING FUEL THAT IS INDIRECTLY LINKED TO ELECTRIFICATION.”
Interestingly, Norway is now putting legislative pressure on the maritime sector by demanding that cruise ships and ferries that traffic the West Norwegian Fjords, a UNESCO World Heritage Site, use zero-emission technology as soon as technologically possible and by 2026 at the latest.

**AIR TRANSPORT**

Inland air transport emits around 1.2 million tonnes of CO₂ annually, and Norway wants to reduce this amount as part of its climate commitments. Energy efficiency measures and demand management have only limited effect. The use of alternative fuels such as biofuels can have problematic side effects, including competing with land use for food production. As a consequence, Avinor, the state-owned operator of Norwegian airports, announced in 2018 that it “aims to be the first in the world” to make the switch to electric air transport. All of Norway’s short-haul airliners could become entirely electric by 2040, setting an ambitious goal which would require substantial technical development. “We think that all flights of up to 1.5 hours can be flown by aircraft that are entirely electric,” the company’s CEO said, noting that this would cover all domestic flights and flights to neighbouring Scandinavian capitals. Much has already happened in Norway since that announcement. Norwegian airline Widerøe, having jumped on the bandwagon, predicts that the first electric commercial airlines will be in service in Norway by 2025. Rolls Royce has established a department for electric flight engines, and OSM Aviation recently signed a contract to purchase 60 electric airplanes, to be delivered in 2021, for use in pilot training in Norway.

The technical maturity of electric planes was described in the case study presented earlier in this report. Norway has several features that make it well suited to take a pole position in the electrification of aviation. In addition to the high share of renewables in power production and a generally strong power grid, Norway has a relatively dense and country-wide network of small airports. Together with a relatively small population, this makes the country a near perfect match for the battery- and hybrid-electric planes now under development that will carry relatively few people over short distances. This may very well change the way we think about air transport and transform the entire infrastructure for this transport sector. Finnmark County in northernmost Norway has been
highlighted by Avinor as a region where short-range electric planes may be particularly useful. This region with several small towns has no rail-based transport and is spread out over a large area. With hybrid-electric solutions that combine a jet-fuelled electric generator with batteries, partially electrified flights could be implemented as early as the 2020s.

Electrifying all inland flights in Norway would require only 5 TWh of electric energy per year, corresponding to a 4 per cent increase in total Norwegian electricity demand.

**BATTERIES – ESSENTIAL FOR ELECTRIFICATION OF TRANSPORT**

Batteries are essential for electrification of the transport sector. Electrifying the various vehicles will require a lot of batteries, and many new battery factories will need to be constructed. How many batteries and battery factories do we need? Several large battery factories are currently being planned in Europe, including Northvolt in Northern Sweden and LG Chem in Poland. In Norway, two battery factories have recently been built: one in Trondheim, owned by Siemens, and one in Bergen, owned by Corvus Energy. Each factory will have an annual production capability of around 400 MWh, the amount required to serve 150–200 Norwegian ferry lines. Several other major new battery production facilities are being planned in Norway. As with the electrification of several other sectors, the high share of renewables in Norway’s power production is a strong argument for locating battery production there.

The worldwide market for lithium-ion batteries is booming and is forecast to jump from 85 GWh in 2016 to 550 GWh in 2025, an increase of over 500 per cent over 10 years. Electrification of the global car and truck fleet will require an estimated 660 TWh, so production capabilities must be expanded extremely rapidly to meet future requirements.

With electric vehicles roaming the streets and, most importantly, being parked for around 98 per cent of the time, there are tremendous opportunities for improving electric power availability by using the vehicles’ batteries. There will eventually be enormous amounts of power available in the total number of electric cars, buses, ships, etc. The Norwegian
Water Resources and Energy Directorate estimates that, if Norway has 1.5 million electric vehicles in 2030 (a realistic scenario), this would equate to a theoretical potential of 100 GW of power. Norway’s highest recorded use was registered in January 2016 at a power need of 24.5 GW. The future electric vehicle fleet will therefore have 4 times more power available than the amount generated by installed hydropower and can in theory function as an enormous energy storage facility. Practical limitations may reduce the amount of this theoretical power, although good planning from the outset can mitigate these limitations.38

Batteries used in various means of transport have defined life spans for propulsion operation. When battery capacity is reduced over time to 80 per cent of original capacity, the battery is thought to have served its purpose in a vehicle.39 So what should we do with the enormous amount of batteries that have ended their useful life in automotive applications? We can reuse these batteries in buildings, for fast-charging, to increase self-consumption, and to help regulate the grid with storage services and frequency control. This is a perfect match for use of second-life batteries in an energy system with a lot of intermittent energy production (e.g. wind and solar), presenting an opportunity for Norway to export its used electric vehicle batteries.

Ill. 26: Using the vehicle’s battery to feed energy back into the grid is a promising technology helpful in future demand and production scenarios.
6. INDUSTRY – A “HARD-TO-ABATE” SECTOR
The Norwegian industry sector (excluding the oil and gas extraction and production segment) has reduced its greenhouse gas emissions by nearly 40 per cent since 1990 while increasing production by some 37 per cent. Despite this incredible performance, further emission reductions need to be made in coming years. Electrification of different industries is an essential solution for reducing emissions, but some segments of industry (such as cement, steel and plastic production) remain extremely difficult to electrify due to process-related emissions generated in the specific industrial processes that are currently used.

Greenhouse gas emissions for oil and gas extraction and land-based industry in Norway in 2017.

Greenhouse gas emissions from the industry sector in Norway in 2017 for the targeted industries.
OIL AND GAS EXTRACTION
The oil and gas industry accounts for roughly 30 per cent of Norwegian climate gas emissions, 99 per cent of which come from combustion in gas turbines to power oil platforms. In theory, these emissions are easy to eliminate by supplying power via cables from land or by installing offshore wind turbines, possibly in combination with solar panels and hydrogen and/or battery storage to handle the intermittency problems associated with wind. Today, five oil and gas platforms on the Norwegian continental shelf have been fully or partially electrified. Commercially available in technological terms, the full electrification of oil and gas platforms is indeed possible.

It is assumed that full electrification of the Norwegian platforms will require approximately 33 TWh of extra electric energy, increasing electricity demand by 27 per cent. Compared with pre-electrification energy need, this actually substantially reduces energy use due to the efficiency gains from going electric. However, construction of a permanent infrastructure to electrify oil and gas platforms is a hotly debated topic in Norway. Critics say that electrification will indeed reduce Norwegian climate gas emissions but not global emissions, since it is thought that gas normally burned on the platforms will instead be exported to other European countries and burned there. Supporters of this approach believe that onshore gas turbines are more efficient than offshore turbines and that, overall, energy is better used by exporting the gas to land rather than burning it on the platforms. In any event, within Norway’s borders it is possible to strive towards increasing electrification and reducing emissions locally.

METAL PRODUCTION
The Norwegian metal production industry already has a very high share of electrification: approximately 83 per cent in 2017. This sector uses about 26 TWh of electricity, 4 TWh of coal and 1 TWh of gas. One reason for the high share of electrification is that one of the main metals produced in Norway is primary aluminium, which is produced via electrolysis – a very energy-intensive process that uses large amounts of electricity. The remaining challenge is the process emissions.

Norway is also one of the world’s largest producers of ferroalloys, essential in the production of steel and iron. The global production of steel, aluminium, solar panels and electronic devices will continue to drive the need for more ferroalloys. Steel, iron and ferroalloys are produced in relatively similar ways. Currently, approximately 95 per cent of primary steel is produced in blast furnaces using coking coal as a heating source and as the reduction agent in removing impurities such as oxygen in the steel. The remaining new steel is produced using direct reduction combined with electric arc furnaces (EAF), with syngas (a combination of CO and H₂) used as a reduction agent. Decarbonised production can be achieved using EAF, which is commercially available, and reduction agents such as hydrogen. The Norwegian metal industry is also equipped for the production of materials essential in battery production. The HYBRIT project – a collaboration in Sweden between companies SSAB, LKAB and Vattenfall – is trying to achieve this. Construction of a pilot plant for fossil-free steel production began in 2018 in Luleå, Sweden. The goal is to have a solution commercially ready by 2035. In other words, electrification, in direct and indirect form, will then become central to the decarbonisation of the metal production industry.

It is estimated that the full electrification of metal production in Norway would increase electricity demand by 6 TWh, a 5 per cent increase, and increase total energy end use by 1 TWh.
CHEMICAL INDUSTRY
The chemical industry in Norway accounts for roughly 15 per cent of Norwegian climate gas emissions and uses 8 TWh of electricity and 8 TWh of fossil fuels, with an electrification share of around 50 per cent.\textsuperscript{44}

The petrochemical industry in Norway produces the petrochemical building blocks ethylene and propylene from natural gas. Ethylene is used as a raw material in the production of the plastics polyethylene and PVC, used to produce e.g. plastic bottles. Propylene, the second most important starting product in the petrochemical industry after Ethylene, is used as a raw material to produce a wide variety of end-use products such as piping, ropes, textiles, cars, etc. Both can be used to produce materials for renewable energy technology, such as wind turbine rotor blades. Although some of these products save energy and reduce climate gas emissions relative to other materials, the industry itself needs to become decarbonised. This is most likely to happen if the current fossil fuel-based feedstock is converted to use biomass in plastic production – as Norwegian company Borregaard is doing, using biomass from wood-based products to produce plastics. Potential electrification technologies – furnace electrification and new electrochemical processes – for the production process are expected to reach commercial maturity at a later stage than that necessary to achieve the 1.5°C target.\textsuperscript{45}

The fertiliser industry in Norway has two factories owned by Yara, which export 90 per cent mineral fertiliser.\textsuperscript{46} The main products produced at the factories are ammonia (\(\text{NH}_3\)), made from a reaction between hydrogen from natural gas (\(\text{CH}_4\)), and nitrogen from the air fuelled by electricity. Ammonia is not only a key ingredient in fertilisers used for food production, but is also promoted as a fuel and energy carrier for the future, particularly for use in international shipping. Here, the fertiliser industry can play an expanded role as a fuel producer. Electrification of the fertiliser industry would involve production of hydrogen through electrolysis rather than from natural gas, which is already an established technology.

Full electrification of the Norwegian chemical industry would increase electricity demand by 8 TWh, a 7 per cent increase over 2017. This would not reduce or increase energy demand, but would rather shift demand from other fuels to electricity.\textsuperscript{47}

CONSTRUCTION
Emissions from the construction industry are directly related to the use of fossil fuels for machines used at construction sites and for various heating purposes, including dehumidification during the building phase. After some ambitious building developers began demanding emission reductions at construction sites, Norway quickly emerged as a testing ground for zero-emission solutions and electrification of construction site machines and processes. This has spread to construction sites throughout the country and facilitated new national legislation. The use of fossil oil for heating and dehumidification at construction sites will, for example, be prohibited as from 2022 in Norway. Volvo CE is the world’s first construction equipment manufacturer to announce the launch of a range of electric compact excavators and wheel loaders (scheduled for mid-2020), and will discontinue development of new diesel engine-based models. Two Norwegian companies are working on electrifying earth-moving equipment.\textsuperscript{48} One of these companies, Pon Equipment, has already delivered a 25-tonne caterpillar to Oslo Munici-pality, rebuilt from diesel-drive to electric and with batteries that last for 7 hours of use.
Full electrification of the Norwegian construction sector would increase electricity demand by around 2 TWh, nearly 2 per cent more than in 2017.49

CEMENT PRODUCTION
Cement is the most widely used man-made material in the world and is an essential input in the production of concrete used to construct buildings, bridges, dams, airports, tunnels and roads. At the same time, decarbonising the cement sector is one of the most difficult challenges on the road to a low-carbon economy. The Energy Transitions Commission names cement production as one of the “harder-to-abate” sectors, since emissions are largely an imbedded part of the process of making the product itself.50

Globally, cement production accounts for approximately 7 per cent of CO2 emissions.51 These emissions arise mainly from two aspects of the production process. Firstly, the burning of fossil fuels (pulverised coal or coke, natural gas, lignite, and fuel oil) required to heat the raw materials to around 1,600°C. Decarbonisation can be achieved using alternative fuels for heating, with electrification playing a direct or indirect role. The second major issue is emissions derived from the chemical reaction in the production process. This stage in the production of Portland cement (currently the predominant cement type) involves heating ground limestone to produce calcium oxide (CO), with CO2 released as a by-product.52 Electrification has no obvious role in reducing process emissions from cement production, but can be achieved by making clinker-free cement (new cement chemistries) or using Carbon Capture and Storage/Use (CCS/CCU) to capture and store or use the process emissions.

The Norcem facility in Breivik, Norway, has initiated a project with the Heidelberg Cement Group under which four different technologies for separating CO2 from combustion exhaust gases were tested in 2015. Based on the preliminary study, the Norwegian government decided to conduct a feasibility study for construction of a large-scale CO2 separation facility at Breivik. The study will investigate the possibility of separating 400,000 tonnes of CO2 annually using an amine scrubber and storing the CO2 underground, equivalent to annual emissions from around 180,000 fossil-fuelled cars. If successful, this would be the first major CCS plant in the cement industry and a key solution in a future low-carbon economy.53
7. THE BUILDINGS SECTOR – NORWAY AS AN OUTLIER
The buildings sector is comprised of households and other buildings such as offices, hospitals, schools, factories, etc. The buildings sector in Norway uses around 65 TWh of electricity, 1 TWh of natural gas, 4 TWh of oil and 4 TWh of other sources, mainly biofuels. Energy use in this sector accounts for only 2 per cent of Norway’s CO₂ emissions, a stark contrast to the buildings sector’s global emissions.

In other words, buildings sector emissions are not a major issue in Norway. However, the buildings sector can indirectly help decarbonise the economy by reducing its electricity need, thereby releasing electricity required in other sectors where increased electricity need is anticipated (e.g. transport and industry). Norwegian households use the second most electricity in the world per capita, after the Gulf State of Kuwait. According to Statistic Norway’s most recent household survey, electricity is the main source of heating in 73 per cent of Norwegian households.\(^5\)

Full electrification of the Norwegian buildings sector would require only around 2 TWh of extra electricity, phasing out around 6 TWh of fossil fuels if converted to electric heating using heat pump technology. This would increase the electricity demand by nearly 2 per cent, compared to the electricity used in 2017.

![Diagram: Share of CO₂ emissions from the buildings sector in Norway in 2017, for various energy use purposes.](image)

![Diagram: Legislation regulating fossil fuel use for heating purposes in buildings has been tightened in Norway in recent years, resulting in a total ban from 2020 in most buildings.](image)
The amount of electricity used in buildings in Norway stands in sharp contrast to the amount used in most other European countries. It also indicates that, in many countries, electrifying buildings is not an easy task. The main barriers for this are the limited supply of electricity from renewable sources and regional and local weaknesses in the power grid. Building electrification is also not an obvious choice when it is not supported by the building’s technical systems (e.g. when natural gas is used as the main energy source for producing heat). This means that there will be a need for decarbonisation pathways in the buildings sector that are adapted to national, regional and local conditions. Electrification is only one of the tools in the toolbox.

**ELECTRICITY CONSUMED PER PERSON IN HOUSEHOLDS, 2017**

![Elecricity Consumption Graph](image)

Source: Eurostat
8. CONCLUSIONS AND RECOMMENDATIONS
Norway is in the pole position to become the first fully electrical country in the world, fully electrifying its transport and buildings sectors, and electrifying what is possible to electrify within the industry sector. This is also illustrated by the E-day for different countries, as mentioned previously in this report. Although further electrification will involve initial costs, the positive implications of energy efficiency improvements, reduced noise and air pollution, and lower operational costs are likely to outweigh the initial investments. Norwegian companies may also gain a competitive advantage in the green economy, with opportunities to further increase exports of climate-friendly metals, technology, transport services, fuels, batteries and a skilled workforce.

With electricity representing 22 per cent of EU energy use, there is substantial potential for electrification in many European countries. Norway leads the way in the electrification of many sectors, and other countries may take advantage of the resulting technological breakthroughs and leapfrog Norway in the electrification game. Some of Norway’s advantages, however, indicate that the country will maintain its pole position in further electrification. A large share of renewables in the power sector, good conditions for using new renewable energy sources, and a strong power grid are advantages that are likely to continue playing to Norway’s advantage.

Although electricity is the fastest-growing means of using energy, the pace of development of electrification on the global level is moving too slowly. We need to step up our game, look to leading nations and increase our efforts in the spirit of John F. Kennedy’s famous words: “We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard.” We need to work on several things in parallel: electrifying different sectors and increasing the share of electric and hydrogen vehicles, buses, ships, aircraft, rail, buildings and industries. Ambitious policies and European and global co-ordination are essential to achieving this, as most of the required technology is available for mass deployment.

Additional efforts and more government attention are needed to bring to market electrification of the heavy goods road transport fleet and improve the rollout of electrified buses to replace old stock.

**“ELECTRIFICATION WILL PLAY A MAJOR ROLE IN ALL SECTORS AND INDUSTRIES THAT ARE CURRENTLY HEAVILY RELIANT ON FOSSIL FUELS.”**

Electrification – in either direct or indirect form (e.g. via hydrogen) – is relevant and will play a major role in all sectors and industries that are currently heavily reliant on fossil fuels. Alongside electrification, measures for achieving energy efficiency and demand reduction mentioned earlier in this report will always be relevant, since increased electricity production always involves extra resource use and has environmental consequences.
Direct electrification will be most dominant for lighter road vehicles, rail, and shorter ship routes, while hydrogen or ammonia will dominate for heavier and long-distance vehicles, rail and ships. Direct and indirect electrification will both be relevant in decarbonising oil and gas extraction, metal production, portions of chemical production, and the construction sector. Direct electrification, particularly through use of heat pumps, will be dominant in electrification of the buildings sector.

But electrification cannot solve everything. Biomass will be essential for long-distance aviation and for plastic and polymer production. Biomass must be used with special care to avoid unwanted consequences of overuse and conflict with food production land areas, and should only be used in industries with no other available options for decarbonisation (aviation and plastics in particular). Carbon Capture and Storage/Use (CCS/CCU) will also be essential but will play a relatively limited role (5–8 GtCO₂ per annum). If no new cement chemistries are developed, CCS/CCU will be necessary for decarbonising cement production.

“ELECTRIC TRANSPORT WITH PLANES, SHIPS AND CARS WILL CREATE A QUIETER, MORE PLEASANT JOURNEY FOR PASSENGERS AND TRANSPORT EMPLOYEES, IMPROVING COMFORT WHILE TRAVELLING.”

THE FUTURE IS QUIETER AND CLEANER
Imagine an electrified future. You can hear the birds in the city, the street musicians playing even in the midst of construction work with electric excavators and cement mixer trucks. Noise and pollution from ships, cars and trucks are gone. The air you breathe is clean. People with asthma can live more safely in cities, and many health-related societal costs are reduced – potentially freeing up resources to invest in better libraries, education, cultural activities and other things that bring meaning and joy to people’s lives.
INCREASED COSTS, BUT NOT IN THE LONG RUN
But electrification and decarbonisation will have some economic consequences. According to the Energy Transitions Commission, it will cost society less than 0.5 per cent of global GDP to decarbonise the hard-to-abate sectors and around 1 per cent of GDP if the lighter-to-abate sectors are included. The end consumer will see increased product prices in different sectors, which can be illustrated as follows:

**TRANSPORT**

### Aviation:
- Cost to industry: +€0.27–0.53 per litre of jet fuel equivalent (+50–100 per cent increase)
- Cost to end user: Ticket prices for zero-carbon international flights will increase 10–20 per cent, resulting in a €35–70 ticket price increase for a 6,500-km economy class flight

### Shipping:
- Cost to industry: + €3.5 million for a typical bulk carrier voyage, cost per annum (+110 per cent increase)
- Cost to end user: <1 per cent increase for a €54 pair of jeans = +€0.27

### Trucking:
- Cost to industry: No price impact
- Cost to end user: None

**INDUSTRY**

### Steel industry:
- Cost to industry: +€107 per tonne of steel (+20 per cent increase)
- Cost to end user: +1 per cent on car price = +€160

### Chemical industry (plastics):
- Cost to industry: +€445 per tonne of ethylene (+50 per cent increase)
- Cost to end user: Zero-emission plastic would increase the price of a litre of soft drink by less than €0.09

### Cement industry:
- Cost to industry: +€89 per tonne of cement/+€27 per tonne of concrete (+100 per cent/+30 per cent increase)
- Cost to end user: +3 per cent on a €445,000 house = +€13,000

Source: Adapted from Energy Transitions Commission

But we need to ask another question before concluding our analysis of decarbonisation-related price increases. What are the economic consequences of continuing with business as usual, or allowing a 2°C temperature increase to occur? A recent study in *Nature*, an international science journal, concluded that it would be more economically advantageous to make the investments necessary to achieve the 1.5°C target, rather
than those required for a 2°C target. Doing so could save us €18 trillion. The study does not quantify the potential savings as compared with the business-as-usual trend, which culminates in a 4.3°C temperature increase by 2100. We can only imagine the economic and physical consequences of going down this road. It seems far wiser to start investing in the future and a massive electrification of our society.

Today, many people are willing to pay more for products of superior quality, such as children’s clothing made from ecological cotton or wool that reduces exposure to chemicals. Some are willing to pay 50–100 per cent more than they would pay for similar non-ecological clothes. This is a good parallel to increased decarbonisation costs, where the largest end-use cost increase (for aviation) is only 10–20 per cent. Isn’t it worth doing this to create a better future for our children and grandchildren?

CHANGING THE DESIGN OF THE CITIES AND COMMUNITIES WE LIVE IN

A massive societal electrification will generate additional demand for electricity by phasing out fossil fuels. This will create a need for new charging and fuelling infrastructure development in cities, along highways, at people’s homes, in ports and at airports. Increased electricity demand will also increase the peak load. This will require resizing of transmission lines and investment in new transformers, and will spur growth of energy storage technologies such as batteries, hydrogen, flywheels, vehicle-to-grid (V2G) and pressurised air to reduce grid infrastructure investment needs.

The electrified future – with huge fleets of electric cars, e-buses, ferries and short-haul aircrafts, along with hydrogen production and an increasingly electrified industry – will put a strain on the grid. Norway, with its hydropower characterised by excellent regulating capabilities, will need fewer new energy storage solutions and less local energy production to handle these extreme situations than other countries with less favourable natural resources. Solar and wind, central to the future energy system, will be dominant in many countries. Because these energy sources have intermittent production patterns, many countries will need large amounts of new energy storage and become more reliant on smart energy systems, which is likely to increase infrastructure costs as compared with Norway, Sweden and other countries with a lot of hydropower potential.

The need for electric liquid fuels such as hydrogen (H₂) and ammonia (NH₃) are also likely to create a need for pipelines to transport the fuels from producer to fuelling stations, if the fuel is not generated locally. For hydrogen pipelines in Europe, this would add to the existing 1,500-km H₂ pipeline infrastructure. Ports can be a major player, functioning as an “energy hub”, supplying and/or producing both electric liquids (H₂ and NH₃) in addition to delivering shore power and battery charging.

Industries that are early to adopt a high degree of electrification will be able to market themselves to consumers and other downstream actors with more climate-friendly products – an essential factor for remaining competitive in the market.

Ultimately, citizens in more electrified cities and communities will experience changes in their everyday lives. Some changes will involve accommodating a changing infrastructure, such as adapting to the regular charging stops associated with electric vehicles. But most electrification-related changes will only involve changes to the supporting infrastructure and will be hardly noticeable to the average citizen.
9. ABOUT THE AUTHORS
EIRIK HORDNES holds a degree in Energy Technology and is a part of the Energy and Environment group of Sweco’s Technical Installations Department in Bergen, Norway. He and his team specialise in energy-related topics in planning and designing infrastructure for e-mobility, decentralised energy production and storage, buildings and industry, focused on achieving cross-sectoral synergy effects. He and his team are often involved at the early design stage, developing new solutions and combining existing technologies in innovative ways. Eirik collaborated with Sweco experts from across Europe to gather insight and perspectives on electrification and decarbonisation from different countries for this report.

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