Transport Systems and Renewable Energy Sources. Critical role in achieving climate change mitigation

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Critical role in achieving climate change mitigation

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Abstract

Transport systems are linked with a wide range of environmental considerations from the global to the local. Environmental impacts are related to transport modes, their energy supply systems, their GHG emissions, and the infrastructures over which they operate. In recent years the automotive landscape is undergoing an electrifying transformation, with electric vehicles (EV) accelerating towards mainstream adoption. However, a crucial challenge remains – while EVs hold the key to a more sustainable future, the high costs associated with battery technology have cast a shadow over profitability for most vehicle manufacturers. In the last decades transport systems emit, approximately, 2,5% of global greenhouse gas emissions but contribute 4% in the climate change because of the type of pollutants emitted.. By combining electric vehicles and renewable fuels, we can substitute more than 50% of global crude oil use in transportation. Other solutions such as green hydrogen, renewable fuels and bio--fuels can contribute to a further replacement. It is clear that developed countries need to make the change from fossil fuels to renewable solutions in the various forms of transport, whether renewable electricity, renewable hydrogen or renewable bio-fuels. Many experts agree that the electrification of the transportation sector will be vital in our efforts to mitigate and control climate change. Electric vehicles (EVs) thanks to incredible technological innovation are replacing fast conventional vehicles. Developing countries have made switching to electric cars a priority in their plans to reach their climate goals. In 2022, nearly 66,000 electric buses and 60,000 medium- and heavy-duty trucks were sold worldwide, representing about 4.5% of all buses sales and 1.2% of truck sales worldwide. China continues to dominate production and sales of electric (and fuel cell) trucks and buses. Railways make an important contribution to environmentally friendly mobility. Most trains in Europe's railway network use electric traction. 60% of the European rail network is already electrified. Railway electrification dates back to the late 19th century when the first electric tramways were introduced in cities like Berlin, London, and New York City. World railway electrification continued to expand throughout the 21th century, with technological improvements and the development of high-speed electrical trains. The International Maritime Organisation (IMO) estimates that between 2007 and 2012, on average, the world's marine fleet consumed between 250 and 325 million tonnes of fuel annually, accounting for approximately 2.8% of annual global greenhouse gas emissions. However, compared to other modes of transport, shipping produces the lowest emissions of carbon dioxide (CO2) per tonne per kilometre travelled. The aviation sector accounts for 2.5% of global CO_2 emissions. But it has contributed around 4% to global warming to date. Because aviation flights are emitting CO_2 from burning fuel, but also affect the concentration of other atmospheric gases and pollutants. Planes generate a short-term increase in GHG but a long-term decrease in ozone (O_3) and decrease of methane (CH_4) in the atmosphere.

Introduction: transportation systems, global goal for future renewable energy use

Climate scientists and energy experts are thinking for the future use of renewable energy sources (RES) for most of the transportation systems on a global scale. Recent advances for the production of electricity by renewable energy sources are very promising. 2022 was a record year for renewable electricity capacity additions, with annual capacity amounting to about 340 GW [gigawatt (GW) is equal to one billion watts or 1,000 megawatts].

Fossil fuels still account for over 60% of global energy production, but renewable energy sources of energy now (2022) produce 29% of global electricity. In 2022, renewable energy sources made up 41% of gross electricity consumption in European Union countries. It is hoped that a global transition to a higher percentage (approaching 100%) of renewable energy across all sectors (electricity, heat, transport, desalination, farming) will be feasible before 2050. Already, renewable energy sources are now cheaper in most countries (photovoltaic solar panels, wind turbines, etc), and generate three times more jobs than fossil fuels.

In 2010, passenger and freight vehicles emitted 7.0 gigatonnes of carbon dioxide equivalents (CO_2-eq) of GHGs into the atmosphere or 23% of the world's anthropogenic GHGs (Intergovermental Panel on Climate Change, 2014). The relative contributions of transportation-related GHGs between countries depend upon many regional factors (population size, travel demand, fuel sources, and levels of economic activity), where the overall trend is that the developed world (e.g., Organization for Economic Co-operation and Development, OECD countries) emit a higher amount of GHGs than developing countries on a per capita basis. Vehicle fuel efficiency which influences the majority share of vehicle life-cycle GHG emissions, depends heavily on both vehicle design and key powertrain characteristics. Across passenger and freight modes, light weighting and downsizing, thermodynamic cycle improvements, hybridization, and aerodynamic improvements represent proven technological strategies for reducing fuel usage and thereby the GHG intensity of vehicles. However, the adoption of fuel-saving technologies within vehicle fleets depends on many regional factors, including income, geography, climate, and culture.[1]

Fuel efficiency improvements are critical steps toward curbing the GHG intensity of personal mobility and goods movement, but there are other pathways to GHG reductions in the transport sector. Scientific studies suggest that mode-switching and alternative fuel (e.g., electricity from RES and cleaner bio-fuels) adoption strategies offer many potential climate benefits. For example, electric vehicles and other means of transport under new and renewable energy sources in the future will substantially contribute to reduce emissions of GHGs and limit global warming in the future.

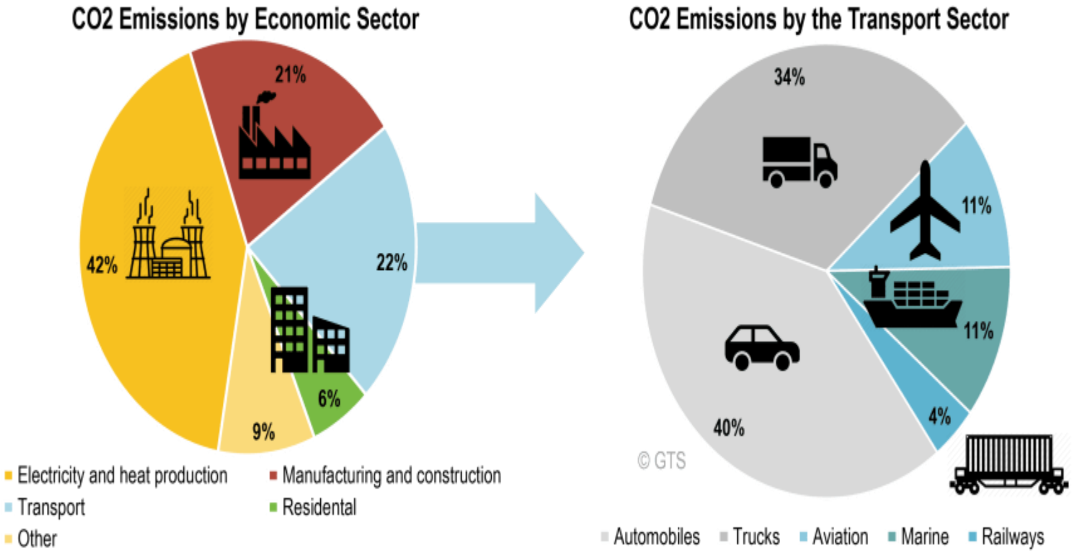

Figure 1. Global carbon dioxide, CO_2, emission by economic sectors, and CO_2 emissions by transport sector systems (vehicles, trucks, rail, aviation, marine vessels). Transportation accounts for about 20-24% of greenhouse gas emissions, with road transportation accounting for 3/4 of this share. Aviation and maritime transportation account for 11%, respectively. Each of the main transportation modes requires its own mitigation strategy. [https://transportgeography.org/contents/chapter4/transportation-and-environment/greenhouse-gas-emissions-transportation/].

Transportation systems (automobile, buses, trucks, train, aviation, marine vessels) are linked with a wide range of environmental considerations from the global to the local. Environmental impacts are related to transport modes, their energy supply systems, their emissions, and the infrastructures over which they operate. While consuming large quantities of energy, especially petroleum oil, vehicles emit numerous pollutants such as carbon dioxide (CO_2), nitrogen oxide (NOx), ozone (O_3), suspended particulate matter (PM) and noise. Transport infrastructures are considered to have high potential to damage many ecological systems with their toxic pollutants. Several environmental impacts of transport systems have been externalized, implying that a few realize the benefits of mobility while the whole society assumes the costs. The spatial structure of economic activities, notably their land use, is also increasingly linked with environmental impacts. The sustainability of transport systems has become one core issue in the provision of mobility, particularly decarbonization.

Most means of transport (vehicles, trucks, rail transport, maritime-shipping, aviation) use until now the conventional energy fuels (petroleum, coal, natural gas). Greenhouse gas (GHG) emissions from transportation account for about 29% of total U.S. greenhouse gas emissions, making it the largest contributor of U.S. GHG emissions. Transport in other industrial countries (OECD) accounts for around 22-25% of CO_2 emissions.[1,2]

GHGs from transport feature prominently in mitigation pathways that limit warming to well-below 2^oC or 1.5^oC (of preindustrial level), which would be in line with the Paris Agreement's targets. It was adopted by 196 countries-Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015 (entered into force on 4 November 2016).

The overarching goal of the Paris agreement was to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels (before 1750)." In recent years, world experts have stressed the need to limit global warming to 1.5°C by the end of this century. Because crossing the 1.5°C threshold risks unleashing far more severe climate change impacts, including more frequent and severe weather events , droughts, heatwaves, floods and excessive rainfalls.

IPCC (Intergovernmental Panel on Climate Change)l uses pre-industrial levels (1750) as a baseline to evaluate the Earth's warming due to human activities. This comparison helps scientists, policymakers, and the public to better understand the magnitude of climate change and the urgency of mitigation strategies to limit global warming by reducing GHG emissions to meet these temperature targets.

The role of the transport systems to climate change mitigation

The transport sector has a critical role to play in achieving climate change mitigation targets and Sustainable Development Goals (SDGs). The Paris Agreement (2016) on climate change and the 2030 Agenda for Sustainable Development provide a useful framework for sustainable transport measures. New and emerging technologies, from electric cars and buses to zero-carbon producing energy sources,

Demand for sustainability in the maritime industry grows, there is an increasing focus on alternative fuels such as liquefied natural gas (LNG), biofuels, Hydrogen, liquid at low temperature (H_2), and ammonia to reduce the sector's reliance on fossil fuels and the carbon footprint of vessels.

Hydrogen fuel, in the future, is considered a potentially revolutionizing fuel in the Aerospace Industry. Hydrogen is a clean-burning alternative with a remarkable 0% emission rate. It is considered the leading sustainable fuel options, generating electricity to power aircrafts, but has many problems and challenges. Also, alternative fuels, such as biodiesel, ethanol, n-butanol, 70% NH_3–30% H_2, and CH_4 are evaluated in the last decade, demonstrating comparable temperatures to conventional jet fuels. The NH_3-H_2 blend, while exhibiting lower thrust, limits the aircraft range due to reduced thrust compared to kerosene-gasoline fuels.

There are numerous new ideas for policy innovations and new cleaner fuels, which are critical for combating climate change, but to be effective, they must ensure that transport strategies benefit everyone, including the poorest member-countries of the world. According to a new United Nations multi-agency report launched in October 2021 that provides a guide to achieving sustainable transport. New and emerging technologies, from electric cars and buses to zero-carbon producing energy sources, as well as policy innovations, are critical for combating climate change, but to be effective, they must ensure that transport strategies benefit everyone, including the poorest, according to a new United Nations multi-agency report for sustainable transport.

According to the new report, there is urgent need for transformative action that will accelerate the transition to sustainable transport globally. Transport solutions exist that can help achieve the Sustainable Development Goals and the Paris Agreement, although the report cautions that without the right policies and investments, they will not bring change to where it is needed most, particularly to people in developing countries. The report, launched just before the second UN Global Sustainable Transport Conference begins in Beijing, China, on 14 October 2021, was prepared by the United Nations Department of Economic and Social Affairs in close collaboration with 14 other UN agencies.[3]

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Second United Nations Global Sustainable Transport Conference
14-16 October 2021, Beijing, China

Recent studies showed that the world is well off course in efforts to limit climate change to 1.5°C. With 70% of the world's transport energy still coming from burning fossil fuels, the transport sector produces 25% of all energy-related emissions and without major changes, are expected to increase. The increasing emissions and rising temperatures are causing more extreme weather events, which in turn are also highly disruptive to transportation infrastructure. Energy experts (2021) suggest that it will take significant investments to ensure that transport infrastructure is upgraded to become climate resilient. A recent study found that the cost of adapting 53 ports in the Asia-Pacific region could range from $31 to $49 billion. However, the World Bank estimates suggest that the overall net benefits of investing in resilient infrastructure in developing countries could amount to $4.2 trillion over the lifetime of new infrastructure—a $4 benefit for every dollar invested in resilience. A low-carbon pandemic recovery could decrease expected emissions in 2030 by 25%, as a result of changes in the shipping, aviation and lifestyle sectors.[4]

The case of electric vehicles (EVs) is very interesting. While no greenhouse gas emissions directly come from EVs, they run on electricity that is, in large part, still produced from fossil fuels in many parts of the world. Energy is also used to manufacture the vehicle – and, in particular, the battery. Here, in response to recent misleading media reports on the topic, Carbon Brief platform provides a detailed look at the climate impacts of EVs. The report established that EVs are responsible for considerably lower emissions over their lifetime than conventional (internal combustion engine) vehicles across Europe as a whole. In countries with coal-intensive electricity generation, the benefits of EVs are smaller and they can have similar lifetime emissions to the most efficient conventional vehicles – such as hybrid-electric models.[5]

However, as countries decarbonise electricity generation by renewable are progressing to meet their climate targets, car driving emissions will decrease for existing EVs and is expected that manufacturing emissions for new EVs will fall. In the UK in 2019, the lifetime emissions per kilometre of driving a Nissan Leaf EV were about three times lower than for the average conventional car, even before accounting for the falling carbon intensity of electricity generation during the car's lifetime. Comparisons between electric vehicles and conventional vehicles are complex. They depend on the size of the vehicles, the accuracy of the fuel-economy estimates used, how electricity emissions are calculated, what driving patterns are assumed, and even the weather in regions where the vehicles are used. There is no single estimate that applies everywhere. There are also large uncertainties around the emissions associated with electric vehicle battery production, with different studies producing widely differing numbers. As battery prices fall and vehicle manufacturers start including larger batteries with longer driving ranges, battery production emissions can have a larger impact on the climate benefits of electric vehicles.[5]

Transport is leading sector for socio-economy development

Transport is one of the leading sectors that play fundamental role in achieving socio-economic development in any country. It enhances the mobility of individuals and goods and creates employment opportunities. It is also one of the main reasons for suburbanization among cities.[6]

Transportation systems and their efficiency become a yardstick for the development status of a country. The more efficient the transportation system of a country the more economic and social welfare development and positive effects on increased investment opportunities and access to new markets. The opposite, deficient transportation system can hinder the development targets and quality of life. On the financial front, the contribution of transportation sector to GDP (Gross Domestic Product) accounts for 6%–12% in developed countries. Worldwide, there are around 57 million people employed in 2020 in transport directly and other relevant interconnected economic sectors, and this number is expected to reach 143 million by 2050. Despite its great contribution to economic progress of a country, the transport sector is also the second-largest carbon dioxide emitter (CO_2), after the production of electricity by fossil fuels.[7]

According to extensive measurements the total transport sector worldwide accounted for 23% of CO_2 emissions and approximately 27% in industrial countries of OECD (Organization of Economic Co-operation and Development). Most of the CO_2 emissions are attributed to the road transport sector. World transport energy use is projected to grow at 2% per year, especially in emerging economies, and total transport energy use and CO_2

emissions are projected to be about 80% higher in 2030. It is estimated that about 3/4 of all transport sector energy is used by road vehicles.[8]

The high volume of energy usage and the resulting continuous increase of transport-based CO_2 emissions attract the attention of researchers and policymakers. Atmospheric pollution and toxic suspended particulate matter (PM) contribute to environmental degradation, and negative development in sensitive ecosystems. Also, transport and vehicle air pollution in urban areas have adverse effects on human health, especially in urban populations and in megacities. In recent decades the trend is to develop "sustainable transport systems" or greener transport with the use of renewable energy sources and cleaner biofuels. Sustainable transport simply means the capacity to meet the mobility needs of a community today without jeopardizing the sustainability of the environment and the mobility needs of the future generation.[9,10]

Scientific studies have established that the main driver of air pollution by transport services is urbanization. In the last 20 years, the number of urban populations substantially increased from 34% to 55% in 2022. World urban population for 2021 was 4,454,013,147 (out of 8 billion total population).

With the rise in urban population, the transport mobility needs increase substantially and the demand for personalized motor-based vehicles increases additionally. It has been reported that the global registered number of vehicles has grown sharply to 1.430 billion in 2018 worldwide, which results in high energy use and carbon emissions. Another estimation for 2024, the number of cars (vehicles) in the world has grown to **1.475 billion**. This is one car for every 5.5 humans, or 182 cars per 1000 humans. [https://www.whichcar.com.au/news/how-many-cars-are-there-in-the-world].

Problems and challenges facing electric vehicles (EVs)

Transportation can play a significant role in a person's day-to-day life. Although awareness of Electric Vehicles (EVs) is high, nearly 65% of Americans have never driven an EV or known anyone who owns one.

Many experts agree that the electrification of the transportation sector will be vital in our efforts to mitigate and control climate change. Electric vehicles (EVs) have been around for more than 120 years. Now thanks to incredible technological innovation and advances, the electric vehicle industry is growing at an unprecedented rate. Research and development brought substantial improvements in battery life and lowered overall manufacturing and purchase costs. With more EVs on the road every year, people understand that electric cars are better for the environment than oil or gas-powered ones.

Most industrial countries (OECD) and developing countries have made switching to electric cars a priority in their plans to reach their climate goals. In 2022, 17 countries have announced 100% zero-emission vehicle targets or to phase-out internal combustion engine vehicles by 2050. The world's most powerful economies (US, UK, Germany, France and China) are racing against each other to become leaders in the EV market, with the latter making remarkable progress in expanding the EV industry. In 2020, China has sold more than 3 million passenger EVs, In the USA the equivalent number is 1,5 million EVs. China also has over 400 registered brands in the New Energy Vehicle (NEV) industry and over 500,000 electric buses, accounting for a staggering 98% of the global figure. But the future of EV sector looks equally promising in the USA and other western European countries. In the USA EV car sales have climbed by more than 40% a year since 2016 and the number is expected to rise as President Joe Biden's plan to reach carbon neutrality involves making sure that 50% of all new vehicle sales in the country will be zero-emission cars. While the US government is doing its part by boosting consumer tax credits for purchasing a new EV, as well as financing new public charging infrastructure, US states are also taking action by adopting credit programmes and tougher emissions standards. In California, fuel demand for EVs has sparked a race to build 1.2 million chargers by 2030, as the California Energy Commission predicts that in 2030, there will be approximately 7.5 million EVs on the US roads.

For the United Kingdom (UK), the government introduced a ban on new petrol and diesel cars from sale after 2030 in a bid to reach zero-emissions by 2050. To fuel the transition, the government will invest nearly £12 billion to accelerate the roll-out of charging points across the country, boost mass production of EV batteries as well as support consumers' purchases with grants that will allow them to save up to 42%.[11]

The most important challenges facing EVs

Electric Vehicles (EVs) adoption is accelerating rapidly worldwide in the last decade, driven by the rising cost of fossil fuels (for conventional cars), longer ranges due to improved EV battery performance, reduced battery cost, and federal and state incentives for buying EV. Despite the positive trends, the EV industry faces many pressing challenges. The most important 10 issues are listed below. [12]

Purchase cost. Electric vehicles (EVs) are more expensive than gasoline-powered ones, primarily because of battery technology. EV batteries use expensive raw materials and must hold a massive charge to provide the minimum range for most car models. In the USA, massive supply of gas-powered vehicles are comparatively cheaper. There are very few EV models on the US market with a price of less than $30,000 (not including government tax credits). According to the U.S. Dpt of Energy's National Renewable Energy Laboratory (NREL) EVs save their owners between $4,500 and $12,000 on operating costs, compared to conventional cars.

Range anxiety. EV drivers are worried how-far they can travel in an EV car before finding a charging station and having to wait through a long charging session in a charging electricity station. In 2020 a range of 250 miles (1 mile =1.609 Km) was considered excellent, but in 2024 EVs can do more than 500 miles.

There are now many more EVs with 300 miles or more of range on the market. Achieving longer range in electric cars requires continuous technological advancements with significant innovation in battery technology.

Improvements in battery chemistry, such as using higher energy density materials like lithium-ion batteries, have greatly increased the amount of energy that can be stored. In 2024, 26 EVs in the UK offered a range of 300 miles or more.

Charging Infrastructure. The scarcity of charging stations in many countries increase the range anxiety. In many industrial countries the governments are working to improve the number of EV charging stations and related infrastructure. **EV Charging Speeds in stations.** Charging electric cars can be a problem for drivers who have trouble adjusting to the EV lifestyle, which can dictate a slower pace of life.

Limited Selection. Ten years ago, EV models in the U.S. were limited to the Nissan Leaf 24kWh, Tesla Roadster 1.0, and the Mitsubishi iMIEV. Selection is rapidly increasing, in 2022, there are now 28 EV models available in the USA from 18 different manufacturers.

Difficulty finding a technician. Most EV car owners find that having their vehicle serviced by a dealer can be significantly more expensive than using a qualified independent maintenance and repair shop.

Grid capacity. Changing to EVs means millions of people will rely on the electric grid in new ways, and grid capacity will need to increase to avoid strain. Experts vary on how much additional power is needed, as the number of EVs is increasing substantially.

Charging station financing and ownership. Public EV charging stations can be expensive to install, with components ranging in cost from**. Charging price structures**. EV charging includes several different pricing structures, unlike gasoline which is always priced by the gallon. This difference can result in inconsistent pricing and inflated charging costs.[12]

In 2023 were more than 40 million electric cars in use globally, and this is growing quickly. In 2022, this figure was just 26 million. Electric car sales, including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), exceeded 10 million in 2022, up 55% relative to 2021. In the course of just 5 years, from 2017 to 2022, EV sales jumped from around 1 million to more than 10 million.

Market of electric buses, medium and heavy duty trucks

The global market for electric trucks is expanding due to increased consumer awareness of electric cars. The electric truck market is estimated to be at 135,632 units in 2023, and it is expected to grow by 34% during 2024-2030 to reach one million units by 2030. The conventional fuel-based trucks have high operating and maintenance cost, as compared to the EV trucks.

In 2022, nearly 66,000 electric buses and 60,000 medium- and heavy-duty trucks were sold worldwide, representing about 4.5% of all buses sales and 1.2% of truck sales worldwide. China continues to dominate production and sales of electric (and fuel cell) trucks and buses. In 2022, 54,000 new electric buses and an estimated 52,000 electric medium- and heavy-duty trucks were sold in China, representing 18% and 4% of total sales in China and about 80% and 85% of global sales, respectively. In addition, many of the buses and trucks being sold in Latin America, North America and Europe are Chinese brands.[13]

European and North American electric buses and trucks makers rely heavily on Asian battery makers. Given China's dominance in lithium iron phosphate (LFP) battery chemistries, China produces the vast majority of batteries for trucks. However, spurred on by industrial policies – the European Union's Green Industrial Plan and the United States' IRA – truck makers have already begun to build or are announcing investments in new production facilities for heavy-duty battery packs (such as Volvo's 2.7 GWh plant, which opened in Sweden in 2022). Truck makers have also entered collaborations with major battery cell makers, seeking to secure further opportunities for vertical integration. Development of battery technology is making battery electric heavy duty trucks technically and commercially viable and several manufacturers have introduced battery electric trucks recently.[14]

Battery electric trucks have not been a viable option to replace heavy duty trucks because of the high energy requirements and low energy density of batteries. However, recent developments in battery technology are making electric heavy duty trucks technically and commercially viable as mild and full hybrid and battery electric. As battery prices are expected to decrease significantly, the life cycle costs of heavy duty electric trucks are expected to become lower than those of heavy duty diesel trucks, making electrification of heavy duty trucks an interesting research area.

Figure 2. Volvo Trucks is aiming for 50% its sales in Europe to be electric by the end of the decade as truckmakers increasingly move away from diesel towards battery power. The Swedish Volvo is the world's second-largest, battery-powered vehicles. Volvo leads the booming market for electric trucks.

AB Volvo Trucks have now sold more than 4,300 electric trucks globally in more than 38 countries. In Europe, Volvo Trucks is the market leader with a 32% share of the market for heavy electric trucks, and in North America (USA, Canada), nearly 50% of all heavy electric trucks registered in 2022 were Volvo trucks. [Volvo Group, 2023 https://www.volvogroup.com/en/news-and-media/news/2023/feb/news-4474482.html]. As a result of the improved batteries, the Volvo FL Electric now has a range of up to 450 km, while Volvo FE Electric has a range of up to 275 km. With a range of up to 450 km, Volvo electric trucks are ready to replace entire fleets of diesel city trucks. Volvo Trucks starts serial production of heavy battery electric trucks at the Ghent factory in Belgium.

Alternative fuels for buses, medium & heavy-duty vehicles

The world is living in the midst of a global transition in the commercial vehicle market. This is a period where all commercial vehicles, buses, vans, trucks and off-road vehicles, are powered by fossil fuels to a point in 15 or 20 years where a large majority will be alternatively fueled, either by alternative bio-fuels, electricity, or hydrogen. This transition will have a huge impact across the entire value chain. A rapid uptake of battery electric trucks and buses is going to reduce demand for diesel fuel, but as market adoption accelerates to 2030 the reduction in demand will become prominent in certain markets. Compressed natural gas (CNG, CH_4) and propane (C_3H_8, $CH_3CH_2CH_3$), also known as liquefied petroleum gas (or LPG) are at present the most popular alternatives to gasoline and diesel fuel for transport trucks, heavy duty and school buses.

School buses in the USA, hybrid electric buses and plug-in hybrid electric buses can use renewable or cleaner energy sources. CNG, propane, hybrid electrics, and fuel cells are potential options for shuttle buses and large passenger vehicles that provide transportation on standard routes. Hybrid transit buses, along with those powered by CNG or liquefied natural gas (LNG), are available. Fuel cell use demonstrations are also in progress. Many fleets, like refuse trucks use CNG engines, and they can even run on landfill gas where bio-methane processing facilities are in operation. Regular routes and stop-and-go operation make refuse haulers a good application for hybrid operation as well. Hydraulic hybrid systems are well suited to refuse service. Diesel electric hybrids offer fuel-saving operations with the convenient availability of diesel. City transport and delivery vans that service a set route, such as a package delivery service, may find all electric battery operation an effective alternative to conventional vans. CNG, LNG, propane, all-electric, and hybrid vehicles operate in a variety of roles, from beverage delivery to utility boom trucks, paint striping trucks, and merchandise delivery.[15]

In 2021, 68% of all new buses registered in the European Union ran on diesel. Electrically-chargeable buses posted strong growth, resulting in their market share increasing from 6.1% in 2020 to 10.6% last year. Alternative fuels powered 10.5% of all new buses sold, while hybrid electric vehicles accounted for 10.1% of the market. Together, all alternatively-powered vehicles made up 31% of the EU bus market in 2021. Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU. This Regulation establishes mandatory national targets leading to the deployment of sufficient alternative fuels infrastructure in the European Union for road vehicles, trains, vessels and stationary aircraft.

Rail infrastructure, electrification and hydrogen fuel cells

Railways make an important contribution to environmentally friendly mobility. Most trains in Europe’s railway network use electric traction. Regarding main lines, 60% of the European rail network is already electrified.

Railway electrification dates back to the late 19th century when the first electric tramways were introduced in cities like Berlin, London, and New York City. World railway electrification continued to expand throughout the 21th century, with technological improvements and the development of high-speed electrical trains.

Today, many countries have extensive electrified railway networks with 375,000 km of standard lines in the world, including China, India, Japan, France, Germany, Spain and the United Kingdom. Electrification is seen as a more sustainable and environmentally friendly alternative to diesel or steam power and is an important part of many countries' transportation infrastructure.

Thanks to the use of modern vehicles with three-phase AC drive systems, the railway is the only mode of transport capable of recovering large amounts of the energy used during operation and feeding it back into the grid. Rail transport is currently by far the most electrified transport mode in Europe. Especially in urban areas, rail almost exclusively runs on electricity already today. There are no technical obstacles to further electrification. On busy railway lines electrification makes most sense economically and from a carbon savings perspective. On low-density lines there is today no proven cost-efficient solution to replace diesel-powered trains. Further electrification of railways could be explored considering its economic viability.

Hydrogen fuel cells for rail applications

Hydrogen (H_2) could be considered an interesting alternative for passenger and freight rail in isolated areas and islands or other parts of the network that are difficult to electrify. In this respect, the possible technological developments emerging from EU joint activities on research and synergies between them (e.g., Shift2Rail and FCH JUs) should be considered.

It was at InnoTrans 2016 in Berlin that Alstom presented the Coradia iLint for the first time. The launch of the CO2-emission-free regional train that represents a true alternative to diesel power positioned us as the first railway manufacturers in the world to develop a passenger train based on hydrogen technology. And just two years later, at 2018, the iLint entered into commercial service in Germany.

The hydrogen (H_2) train was introduced by Alstom in 2016, the Coradia iLint™ is the world's first and only operational passenger hydrogen train. It has successfully operated in regular passenger service in Germany and Austria and covered more than 220,000 kilometers. In addition, it has been successfully shown in the Netherlands, Sweden, France, Poland, Czech Republic and Slovakia.

Figure 3. Successful trial operation of the world's first two hydrogen trains was officially completed at the end of February. Two pre-series trains of Alstom's Coradia iLint model have been in passenger service since September 2018. [https://www.alstom.com/press-releases-news/2023/10/alstom-concludes-successful-demonstration-first-commercial-service-hydrogen-powered-train-north-america].

Alstom's Coradia iLint hydrogen-powered train transported more than 10,000 passengers in a demonstration project in Quebec from June to September

2023. Using Alstom's green hydrogen-powered train on this route helped save approximately 8,400 litres of diesel and averted 22 tonnes of CO_2 emissions during this pilot. Alstom has laid the foundation of a comprehensive, safe and efficient H2 ecosystem for the heavy transportation sector in North America, from production to refuelling to operation. They welcomed 34 commercial, governmental and regulatory delegations from all over North America looking to witness this hydrogen-propulsion technology and capture the requirements for wider implementation across North America.

Maritime industry, shipping transport and trading

The maritime and shipping industry are the backbones of global trade and a lifeline for island communities, transporting approximately 90% of the tonnage of all traded goods (estimated by the International Chamber of Shipping, ICS). Shipping is the life blood of the global economy. Without shipping, intercontinental trade, the bulk transport of raw materials, and the import/export of affordable food and manufactured goods would simply not be possible. Seaborne trade continues to expand, bringing benefits for consumers across the world through competitive freight costs. Thanks to the growing efficiency of shipping as a mode of transport and increased economic liberalisation, the prospects for the industry's further growth continue to be strong. There are over 50,000 merchant ships trading internationally, transporting every kind of cargo. The world fleet is registered in over 150 nations, and manned by over a million seafarers of virtually every nationality.

Ships are technically sophisticated, high value assets (larger hi-tech vessels can cost over US $200 million to build), and the operation of merchant ships generates an estimated annual income of over half a trillion US dollars ($) in freight rates.
[International Chamber of Shipping, ICS, Overview, 2024. https://www.ics-shipping.org/shipping-fact/shipping-and-world-trade-world-seaborne-trade/].

UNCTAD's (United Nations Conference of Trade and Development) Review of Maritime Transport 2023 calls for a "just and equitable transition" to a decarbonized shipping industry. The sector, whose greenhouse gas emissions have risen 20% over the last decade, operates an ageing fleet that runs almost exclusively on fossil fuels. [16]

The global shipping tonnage loaded annually increased from 2.6 billion to 9.5 billion tonnes between 1970 and 2013. At the end of 2023, there were around 68,000 vessels in the world trading fleet, with a total deadweight tonnage of 2,224 million. The world fleet has almost doubled in size since 2007 and growth remains linear, increasing by 3% in the latest year.

The demand for shipping is predicted to grow further, owing to the changing configuration of global production, the increasing importance of global supply chains and the expected growth in many economies. Also for the foreseeable future, seagoing ships will continue to carry the bulk of that trade. The energy source for the propulsion of ships has undergone significant transformations over the last 150 years, starting with sails (renewable energy) through the use of coal to heavy fuel oil and marine diesel oil, now the dominant fuel for this sector. The consumption of these fuels has been increasing over the years in line with rising demand for transport by shipping.[17]

The International Maritime Organisation (IMO) estimates that between 2007 and 2012, on average, the world's marine fleet consumed between 250 and 325 million tonnes of fuel annually, accounting for approximately 2.8% of annual global greenhouse gas emissions. However, compared to other modes of transport, shipping produces the lowest emissions of carbon dioxide (CO2) per tonne per kilometre travelled. Still, emissions are expected to rise with shipping demand and could triple by 2050 if left unchecked. Emissions from the shipping sector must be curbed in order to reduce air pollution and climate change impacts.

Prevention of pollution from ships and use of cleaner fuels

The International Convention for the Prevention of Pollution from Ships (MARPOL) has stipulated mandatory technical and operation measures, which require more efficient maritime energy use and, less CO_2 emissions. These regulations came into force in 2013. The industry itself has set targets to reduce carbon dioxide emissions by 20% by 2020 and 50% by 2050. Ship operators, therefore, need to consider cleaner fuel and power options, including the use of renewable energy sources (RES), to meet these targets. Furthermore, the globally volatile energy markets, provide another compelling reason to scale up modern shipping solutions based on renewable energy sources and technologies.

Renewable energy can transform the global shipping fleet at all levels and in varying magnitudes, including: international and domestic transport of goods, people and services; fishing; tourism and other maritime pursuits. Renewable power applications in ships of all sizes include options for primary, hybrid and/or auxiliary propulsion, as well as on-board and shore-side energy use. Potential renewable energy sources for shipping applications include wind (e.g. soft sails, fixed wings, rotors, kites and conventional wind turbines), solar photovoltaics, biofuels, wave energy and the use of super capacitors charged with renewable energy sources.

These cleaner energy solutions with lower emissions can be integrated through retrofits to the existing fleet or incorporated into new shipbuilding and design, with a small number of new ships striving for l00% renewable energy or zero emissions technology for primary propulsion. The transition to a clean energy shipping sector requires a significant shift from fossil fuel-powered transport to energy-efficient designs and renewable energy technologies. The contribution of renewable energy sources to the energy mix of the shipping sector is limited in the near and medium terms. Nevertheless, developers are increasingly enhancing ship designs and proof-of-concept pilots demonstrating major savings in some applications. The development of renewable energy solutions for shipping has been hampered by over-supply of fossil fuel-powered shipping in recent years and the related global depressed investment market.

The main barriers to increased penetration of renewable energy solutions for shipping remain: At first, there is the lack of commercial viability of such systems; and, second the existence of split incentives between ship owners and operators, resulting in limited motivation for deployment of clean energy solutions in the maritime sector. Ultimately, market forces working within a tightening regulatory regime will govern the speed of uptake of renewable energy technology for shipping, although this will also be tempered by infrastructure lock-in and other nonmarket factors. Therefore, a set of organizational and structural, market and non-market barriers needs to be removed before renewable energy sources can make meaningful contributions to the energy needs of the shipping sector.

Shipping, decarbonisation, green biofuels, certification

Shipping accounts for 2.5-3% of global greenhouse-gas (GHG) emissions. At the same time maritime and shipping sectors contribute to the 90% of traded goods travel the Earth’s oceans. The International Maritime Organisation (IMO) has set a decarbonisation target of reducing annual GHG emissions from international shipping by at least 50% by 2050, with higher targets specifically for carbon-intensity reduction.

For the decarbonising of shipping experts agreed that a variety of cleaner fuels and technologies of decarbonisation options exist for the shipping community, but that these efforts remain fragmented and many will require market drivers to move forward. In the absence of clear regulation, working together across ports, vessels, shipping companies, shipping-dependent businesses and other key maritime industries can help unify and ultimately accelerate decarbonisation of shipping.[18]

Figure 4. A Japanese consortium is designing a prototype of an all electric oil carrier ship powered by a 3500 Kwh battery. This ship, smaller than a typical cargo liner, would be 62-metres in length and have a payload of 1300 cubic metres of oil. This would serve as a proof of concept prototype before Japan embarks on full sized oil tankers. [https://www.team-bhp.com/forum/commercial-vehicles/228455-cargo-ships-powered-renewable-energy-sources.html].

On the technology side, the shipping giant **MAERSK,** which is one of the biggest shipowner all over the world, is a Danish shipping and logistics company founded in 1904. Maersk operates shipping containers and ports through subsidiaries and affiliates. Maersk transports dry cargo, refrigerated cargo, special cargo and conducts used container sales and supports intermodal transport.

Maersk started using 'green fuels' as fuels with low (65-80%) to very low (80-95%) GHG emissions over their life cycle compared to conventional fossil fuels. The fuels and the supply chain are verified by the International Sustainability and Carbon Certification (ISCC). It is an independent multi-stakeholder initiative and certification system supporting sustainable, fully traceable, deforestation-free and climate-friendly supply chains. The ISCC certification system covers all sustainable feedstocks, including biomass from agriculture, forestry and aquaculture, biogenic waste and residues, non-biological renewable materials and recycled carbon-based materials and products. With currently over 7,000 valid certificates in more than 100 countries, ISCC is among the world's largest certification systems. As a no-deforestation standard with a strong commitment to protect forests, high-carbon stock lands and biodiversity, ISCC strives for a world where biomass and other raw materials are produced in an environmentally, socially and economically sustainable manner.

Maersk has an ambitious goal to become a climate-neutral company by 2024. The 660,000 standard containers transported on green fuels in 2023 equal 3% of global ocean transport volume and show that the low emission movement is taking large steps year-on-year. Integrated logistics company Maersk has finalized an agreement with Amazon for 2023-2024 for the transport of 20,000 FFE containers using green biofuel. The deal, which is part of Maersk's ECO Delivery ocean product offering, is the fourth consecutive year the two companies have arranged container shipping using low greenhouse gas fuel options. The ECO Delivery offering provides customers with emissions reductions with verified greenhouse gas savings.

Maersk's eco solution replaces conventional fossil fuels with "green fuels" such as biodiesel and green methanol (CH_3OH). The biodiesel is solely sourced from waste streams and can lead to GHG emission reductions of above 80% on a well-to-wake basis. With the deployment and naming of the world's first methanol-enabled container vessel in September 2023, Danish shipping giant introduced "green methanol" as a low-emission fuel in container shipping. A few months later, the world's first large methanol-enabled container vessel was named in Ulsan, South Korea.

Monitoring decarbonisation in maritime systems. The created Zero Carbon Fuel Monitor is based on evidence from a wide range of sources, assessed by the Maritime Decarbonisation Hub and LR. LR, Lloyd's Register is a leading provider of classification and compliance services to the marine and offshore industries, helping clients design, construct, operate, extend and decommission their assets safely and in line with environmental expectations.

Figure 5. Maersk's 2030 targets include: **All The Way to ZERO**. To reduce greenhouse gas emissions by 30% by2030. Maersk commits to reach net zero greenhouse gas emissions by 2040.

The results are regularly updated in line with the latest developments and are used to identify research, development and deployment projects that will advance solution readiness and accelerate a safe and sustainable transition to zero. The zero carbon marine fuels landscape is constantly evolving, and the content reflects expert's views and priorities. Insight-based assessment of the readiness of zero carbon fuel fuels for maritime applications and industry wide comparisons of alternative solutions across the entire fuel supply chain. (ammonia, E-ammonia, bleu-ammonia, biodiesel, electrification, hydrogen, methane, methanol, nuclear). [19]

In response to the urgent need for reducing greenhouse gas emissions in the maritime sector, the IMO has introduced regulations that include energy labels for seagoing ships. These labels provide a clear indication of a vessel's energy efficiency and environmental impact. The Carbon Index Monitoring platform empowers ship operators to measure, monitor, and optimize their vessels' carbon performance, enabling compliance with the IMO's stringent regulations.[https://www.sirimarine.com/carbon-index-monitoring/?gclid=....].

Aviation sector, renewable energy sources and decarbonisation

The aviation sector accounts for 2.5% of global CO_2 emissions. But it has contributed around 4% to global warming to date. Because aviation flights are emitting CO_2 from burning fuel, but also affect the concentration of other atmospheric gases and pollutants. Planes generate a short-term increase but a long-term decrease in ozone (O_3) and methane (CH_4), and increased emissions of water vapor (H_20), soot, sulfur aerosols, and water contrails. While some of these impacts result in warming, others induce a cooling effect. But overall, the warming effect from aviation is stronger.

Flying is one of the most carbon-intensive activities. But as global incomes rise in most countries and the middle class increase, travelling by air has increase**.** A combination of increased demand and technological improvements has driven the change in aviation emissions over the last half-century. In 2023, there were 16.3 million air flights on a global scale. According to the Transportation Security Administration, 2023 was also the busiest year for air travel ever.

The aviation sector produced globally 915 million tonnes of carbon dioxide (CO_2) in 2019. The sector's emission contributes about 2% of the world's CO2 emissions and about 12% of all transport emissions. Non-CO_2 emissions from aviation also have a significant climate impact, contributing almost 2/3 of net radiative forcing. This is projected to double by 2050 in a business-as-usual scenario. Although the COVID-19 pandemic has affected the sector's emissions, the industry is likely to recover, reaching and exceeding preCOVID emissions within a few years. The international aviation accounts for 60% of the energy consumption, while remaining 40% for domestic aviation. Aircraft typically use jet kerosene, refined from crude oil. This counts to almost all (99.9%) the energy consumption for aviation, with aviation gasoline and sustainable aviation biofuels (SAFs) being the rest of the consumption.[20]

According to energy experts there are several options for the decarbonising of the aviation sector. But it needs major transitions in several components; such as the reduction of aviation demand and accelerated fuel efficiency improvements, a robust mixture of low-carbon fuels in the form of bio-jet fuels and synthetic kerosene, and the commercialisation of new electric and hydrogen aircraft.

An aviation biofuel (also known as bio-jet fuel or bio-aviation fuel , BAF)) is a biofuel used to power aircraft and is a sustainable aviation fuel (SAF). The International Air Transport Association (IATA) considers it a key element in reducing the environmental impact and emissions of GHG of aviation.

Achieving deep GHG emission reductions will require new technologies, including modifications to existing aircraft, new propulsion systems such as electric and hybrid aircraft (likely most suitable for small aircraft/short haul and a limited numbers of passengers), and the use of hydrogen (likely most suitable for short and medium haul and medium-sized aircraft). In addition, reduced demand for flying could also have an impact on emission reductions. Although the first commercial aircraft using alternative propulsion systems will soon become available, due to the relatively long life expectancy of aircraft (20-35 years) it will be several decades before these alternatives achieve large-scale penetration in the sector and lead to significant emission reductions.

Currently most biojet is produced via the hydrotreatment of fats, oils and greases (FOGs) such as used cooking oils. These oleochemical/lipid feedstocks are also known as HEFA (hydrotreated esters and fatty acids) or HVO (hydrotreated vegetable oils). Small volumes of alcohol-to-jet is currently available and this technology, as well as others such as gasification and Fischer-Tropsch synthesis, will provide greater volumes in the longer term. • Current biojet production is about 140 million litres/year (2019), and although production has increased significantly (up from only 7 million litres in 2018), commercial volumes remain small (less than 1% of fuel currently used by the aviation sector). This is due to several factors such as the slow rate of technology development and the high cost of these fuels. [21]

The fuel efficiency performance for airlines has improved on average 2% annually between 2009 and 2019. This was largely the results of new generation aircraft and operational improvements. While improvement in fuel efficiency can curb carbon emissions in the short term, decarbonising the sector requires additional measures including new aircraft technologies (including electricity and hydrogen-powered aircraft), participation of sustainable aviation fuels (SAFs), the use of synthetic fuels supported by market-based measures, some of which was echoed by the International Civil Aviation Organization's (ICAO) commitment to address climate change4. Several options powered by renewable energy can be discerned: electric batteries and green hydrogen (both for short-haul flights only); synthetic fuels produced from green hydrogen (made from splitting water molecules into hydrogen and oxygen using renewable electricity) — also known as electrofuels or e-fuels; and biofuels (IRENA, 2022).[22]

Airlines can only fly with fuels that have been approved by the industry under the auspices of US-based standards organisation ASTM International (American Society for Testing and Materials). American-Internation organization with over 12,000 standards covering a wide range of materials, **ASTM** safety standards empower for scientists and technologists to find the perfect match for every material and project.

Figure 6. The aviation industry is undergoing a transformative shift towards sustainable practices, notably through the adoption of renewable energy sources such as aviation biofuel. [https://www.travelandtourworld.com/news/article/transforming-aviation-industry-with-renewable-energy-sources/].

So far, these have been limited to biofuels and e-fuels (also known as powerfuels). SAF (Sustainable Aviation Fuels) production covers less than 1% of the global jet fuel demand with around 100 million litres of SAF produced in

2021. Sustainable aviation fuel, including biojet, has recently increased its production as more countries and airlines commit to reduce their CO2 emission through use of SAFs. They are commonly used as drop-in fuels, blended with fossil fuel jet kerosene, up to a maximum of 50%. Majority of the SAFs produced today are HEFA-SPK7, while the other SAFs approved by ICAO (International Civil Aviation Organisation) have not yet reached commercialisation.

Aviation Biofuels. The use of bio-jet fuels in aviation would comprise of 47% of the total fuel consumption, or around 204 billion liters of bio-fuels produced annually in the IRENA's 1.5°C scenario. To date, nine pathways have received ASTM certification, which allows bio-jet fuel to be blended with petroleum derived jet fuels or co-processed, but only one is said to be technically mature and commercialized. The process that uses vegetable oils, waste oils and fats (often used cooking oil) as its feedstock, known as HEFA-SPK (hydroprocessed esters and fatty acids synthetic paraffinic kerosene). More than 95% of biofuel flights to date have used HEFA-SPK fuel. Global biofuels production totalled 150 billion litres in 2018, but just 17 million litres of advanced biof-uels for aviation was produced, all from a single plant in California. Thus, rapid upscaling of bio-fuel for aviation is needed, and the share of aviation fuel in total biofuel must increase rapidly for a meaningful contribution. To significantly scale up production, alternative feedstocks such as lignocellulosic biomass, and technologies such as gasification with FischerTropsch (FT) and/or pyrolysis or hydrothermal liquefaction will be required.[23]

Future alternative fuel options for substituting fossil oil in transport systems

In the last decades expert groups on Future Fuels for Transport have studied extensively and produced numerous reports on cleaner and more environmentally friendly for future transport fuels.

The main alternative fuels for propulsion in transport are the following:

a. Electricity/hydrogen, and bio-fuels (liquids) as the main options,

b. Synthetic fuels as a technology bridge from fossil to biomass based fuels

c. Methane (natural gas, CH_4, and bio-methane) as complementary fuel

d. Liquefied Petroleum Gas (LPG) as supplement. A mixture of liquefied gases butane and propane,

e. Methanol, these chemicals are sulphur-free, so use of methanol and ethanol fuels (as mixtures) would ensure compliance with the European Commission Sulphur Directive. The European Maritime Safety Agency (EMSA) commissioned studies to gain more information about the benefits and challenges associated with methanol-ethanol fuels and to evaluate their potential for the shipping industry. Methanol has been proven safe and cost-competitive marine fuel for the commercial shipping industry that can meet or exceed current and planned emissions regulations.

f. Ethanol doesn't have exactly the same characteristics as gasoline. Engines may need to be adjusted. Ethanol has a range of negative practical issues that make it less economical or inconvenient to be used as alternative fuel.

Energy transport experts support various options of alternative fuels for the different transport modes in the future.

a. **Road transport** could be powered by electricity for short distances, hydrogen (H_2) and methane (CH_4) up to medium distance, and biofuels/synthetic fuels, LNG and LPG up to long distance.

b. **Railways** should be electrified wherever feasible, otherwise use biofuels.

c. **Aviation** should be supplied from biomass derived kerosene.

d. **Martine or shipping transport** could be supplied by biofuels (all vessels), hydrogen (inland waterways and small boats), LPG (short sea shipping), LNG and nuclear (maritime).

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