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Chapter

Energy Efficiency Management: State of the Art and Improvement Potential Analysis with Regard to Cargo Transport by Air and Rail

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Abstract

This review article summarizes the state of the art in energy efficiency (EE) management in air and rail cargo transportation. After an introduction, explanations and definitions follow around the topic of energy efficiency. The political framework conditions of the European Union (EU) as well as the associated European Union Emissions Trading System are described. In particular, the drive technologies, CO_2 emissions, and fuel-saving options are reviewed.

Keywords: energy efficiency, cargo, air, rail

1. Introduction

The effects of climate change are global. For many years now, polar ice caps and glaciers have been melting, sea levels are rising, and storms and floods are destroying people's habitats. Therefore, it is particularly important to reduce anthropogenic greenhouse gas (GHG) emissions through energy efficiency (EE) [1].

Energy efficiency [2] is gaining more and more attention in the society. The term energy efficiency means using less energy to guarantee the same benefits of output [3].

The reasons for the increasing interest in energy efficiency are the persistent climate change, depletion of fossil fuels, and rising energy prices. The production as well as the use of energy based on fossil fuels is one of the biggest drivers of climate change. The sustainable use of energy or "green energy" is playing an increasingly important role in various decision-making processes for companies and other organizations [4].

The application and implementation of energy efficiency is often the cheapest way to reduce fuel costs and carbon dioxide (CO_2). Of course, the needs of the present are to be satisfied, but future generations should not be disadvantaged. The most important sectors in terms of energy efficiency include industry, buildings, and transport. Year after year, countless institutes and corporations are researching new technologies to ensure that energy efficiency can be continuously optimized, alongside decarbonization [4, 5].

The European Union (EU) has adjusted its policy framework based on annual CO_2 emissions. In 2005, the EU introduced an emissions trading system for all member states to reduce CO_2 emissions (for details, see **Figure 2**, purchase and sale

of emission certificates) [6–9]. This chapter deals with the current state of the art of freight trains and cargo aircraft.

Energy efficiency means using less energy to provide the same level of utility. It is therefore one method to reduce anthropogenic (human) greenhouse gas emissions [3].

EE is a universally applicable concept relevant for consumers and industry alike that can be achieved by a more efficient technology, an improved process, or a change of individual behavior. Energy efficiency can, according to the International Energy Agency's (IEA) World Energy Outlook (IEA WEO), "close the competitiveness gap caused by differences in regional energy prices" [10].

In November 1974, the International Energy Agency, an autonomous agency, was founded. Its main mission is to promote energy security among its 29 member countries.

Energy efficiency is the key to ensure a safe, reliable, affordable, and sustainable energy system for the future. It is the one energy resource that every country possesses in abundance and is the quickest and least costly way of addressing energy security and environmental and economic challenges. While energy efficiency policies are becoming a key part of the global energy market, there remains vast untapped-into potential [11].

Energy efficiency means using the same amount of energy to achieve the same utility level. The term energy efficiency itself is therefore very clear and self-explanatory [12].

"Energy intensity" looks at how much energy was needed to get a certain result. The units of energy intensity used are usually given by the primary energy consumption per inhabitant or by the primary consumption per unit of gross domestic product (GDP). Measuring energy efficiency as an energy intensity is basically possible at the macroeconomic level [4]. As an indicator of energy efficiency, the energy intensity of a country is often used for the assessment. This is because at a high level it is a proxy measure of energy needed to provide the used energy service (the energy intensity measures the energy needed to provide units of economic value). Moreover, it is very readily available as an indicator, and it is easier to rate or compare countries. If a country has a low energy intensity, it does not necessarily mean that the energy efficiency of that country is also high. Conversely, it should be noted that lower-intensity trends are not necessarily due to efficiency improvements. Energy efficiency contributes to

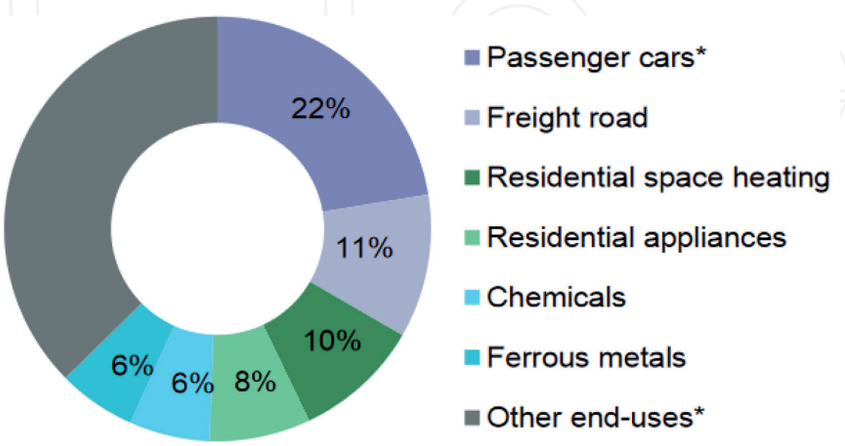


Figure 1.
Top six CO_2-emitting end uses in IEA countries in 2013. Reproduced with permission from [13].

the definition of intensities and trends. However, other factors play a major role, e.g., the structure of the economy, the presence of large energy-consuming industries, the passenger car density, and the specific housing sector. Globally, passenger cars, together with road haulage vehicles, account for about one-third of energy-related CO_2 emissions and consume approximately as much energy as the entire housing sector [13]. Canada, the USA, Australia, and New Zealand are among the regions in which transport is currently the highest consumption sector. The manufacturing sector has the largest share of energy in Japan and Korea. In particular, the subsectors' ferrous metals and chemicals have a high energy demand. The residential sector is the highest in most European countries. This stems very much from the consumption for space heating and heaters. For the IEA countries, emissions for residential heating were higher for household appliances as well as for each subsector of the manufacturing sector. Especially in countries such as the UK and Germany, the heating of the rooms was the largest emitting end use (see **Figure 1** for 2013 data) [13].

2. Political framework operations in the EU

The European Union has adopted a wide range of legal instruments to improve energy efficiency. For EU directives, it is up to the member states how they transpose the directives into national law. In the official journal of the European Union, directive 2009/28/EG promoting the use of energy from renewable sources and amending and subsequently repealing directives 2001/77/EG and 2003/30/EG are binding and non-binding guidelines for an efficient energy use in the EU. All member states have to give their best to implement those improvement measures [6].

The main targets of the directive 2009/28/EG are the so-called 20-20-20 targets. This means that, as target, renewable energies account for 20% of the final energy consumption across the EU, the greenhouse gas emissions have to be reduced by 20%, and the energy efficiency should be increased by 20% in the EU referring to 1990 as base year. Furthermore, the directive 2009/28/EG stipulates that biofuels must account for 10% of total fuel consumption by 2020 [7].

There are also some long-term objectives of the EU. The proportion of renewable energies in energy consumption and the energy efficiency should increase to at least 27% by 2030. In 2020, the goals should be reviewed to see whether an increase of 30% is possible. In 2030 the greenhouse gas emissions must be reduced by almost 40% (base year 1990) [8].

2.1 European emissions trading system (EU ETS)

The European Union Emissions Trading System was introduced in 2005 for the regulation of greenhouse gas emissions in energy-intensive industries. The relevant system operators concerned must have a certificate for each tonne of CO_2 emitted and submit it to the regulatory authority. The system enables trading in carbon certificates under a defined overall framework for all participants—a so-called "cap-and-trade" system. These allowances are freely tradable, which means that participants who emit more greenhouse gases can purchase emission certificates from other participants with lower greenhouse gas emission needs. In order to reduce overall emissions, the proportion of allowances is reduced by 1.74% per year by 2020 [9]. **Figure 2** illustrates the EU ETS scheme.

The principle of the "cap-and-trade" system is easy to recognize in **Figure 2**. In this example, issuer A generates more emissions than issuer B, thus exceeding the authorized amount of CO_2. In order to solve the problem, issuer A can purchase the unused certificates from issuer B (which has very low CO_2 emissions in this example).

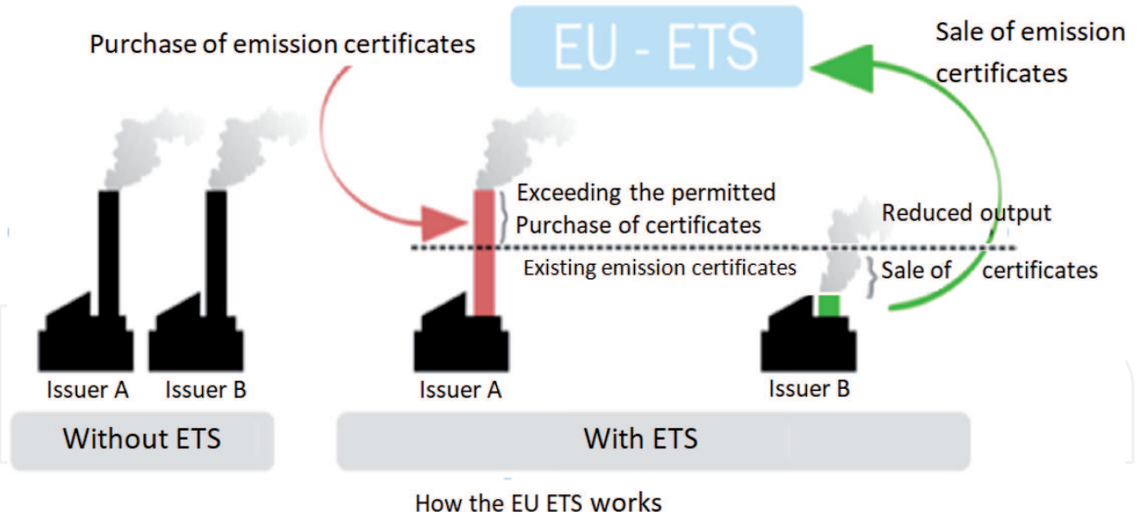


Figure 2.
Purchase and sale of emission certificates. Reproduced with permission from [9].

3. Energy analysis

In the transport sector, mainly fuels based on crude oil are used, so there is a high dependence on fossil fuels. While diesel fuel showed a steady growth in Europe for several decades, gasoline fuel is now becoming more important again, according to the European Automobile Manufacturers Association (ACEA) [14]. Recently, dual-fuel gasoline/diesel engines were presented [15]. Electric vehicles are strongly on the rise and are expected to replace cars with internal combustion engine in future [16, 17].

The movements of goods and people are very different transport processes and are also recorded differently. It is customary to specify the transport performance in the freight sector in tonne kilometers (tkm) or in person kilometers (pkm). The transport service refers to the distance covered in the respective territory.

The steady growth of online commerce has and will continue to have a major impact on the transport sector in future [18].

Large online mail order companies promote the digitization of trade and thus the amount of goods that have to be transported to the end users. In Germany alone, freight traffic has risen by about 120% since 1990 [19]. Thus, the traffic volume takes up about 26% of the traffic-related energy consumption [20]. The strongest increase is recorded in road and rail transport. For the transport sector, energy intensity indicators are collected on the basis of energy consumption and the transport performance provided.

These energy intensity indicators are used as a statistical measure of energy efficiency. In order to support the sustainable development of economic and livelihood models, indicators in the transport sector should include resource efficiency. Due to the large increase in freight traffic in recent years, the objective within freight transport should be to decouple growth in terms of increased transport performance and CO_2 emissions. Energy consumption in freight transport related to rail and aviation is around 15% in aviation and 2% in rail transport, respectively [4].

Overall, it can be summarized that the energy consumption has increased less than the transport performance. Thus, it can be concluded that energy efficiency in freight transport has increased, but growth is neutralizing the efficiency gains achieved [4].

As it can be seen in **Figure 3**, aviation has the highest specific energy consumption. Low oil prices encourage the (continued) use of older, less energy-efficient cargo aircraft, making them economically viable again or extending their useful

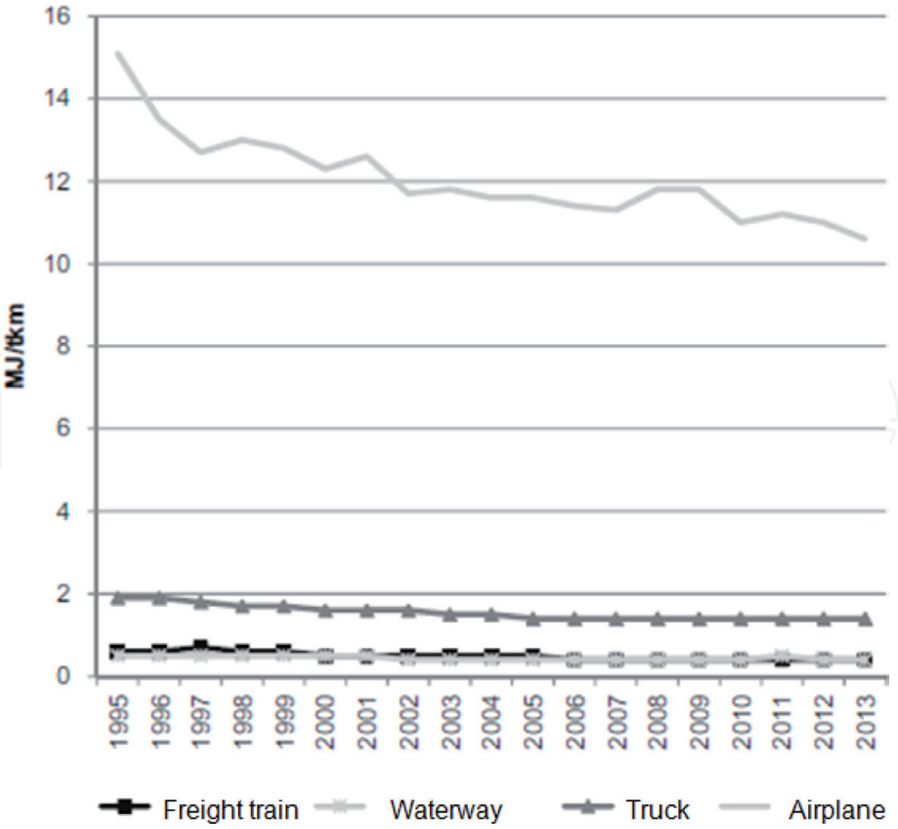


Figure 3.
Development of specific energy consumption in freight traffic by mode of transport from 1995 to 2013 (modified from [21], p. 246).

lifetime. This could have an impact on indicator development. In the second place is the use of trucks, which are logistically almost inevitable due to the infrastructure in most countries, particularly for "last mile" delivery.

4. CO_2 emissions

Atmospheric CO_2, which stands at ~400 ppm, is both harmful and vital. Without the significant greenhouse gas CO_2 and other natural greenhouse gases, the Earth's average surface temperature would be sub-zero, and life would not be possible. This natural balance is disturbed by excessive and increasing anthropogenic CO_2 emissions. These disturbances lead to global warming, which has developed since the Industrial Revolution (~1750) and increased significantly in recent years [3, 22].

The steadily growing globalization is making a significant contribution to the greenhouse gas effect. Carbon dioxide is also produced in combustion processes of engines and other equipment, with most of the artificial and harmful CO_2 emissions caused by the industrialized countries. In addition to carbon dioxide, e.g., methane (CH_4) and nitrous oxide (N_2O) contribute to the environmental impact. These gases have a higher global warming potential (GWP) than CO_2 [23]. All greenhouse gases can be converted into CO_{2eq} (CO_2 equivalents) [3].

4.1 Natural and anthropogenic greenhouse effect

Natural greenhouse gases act as a kind of filter that lets the (short wavelength) sun's rays through and captures the heat radiation (long wavelength) from the Earth's surface, thereby enabling regulated global warming. The functioning of a greenhouse is also used, for example, in plant breeding. Colloquially, the term greenhouse

gas effect is used for global warming [22]. The presence of gases with GWP results in an increase in temperature and thus the greenhouse gas effect. Many scientific predictions suggest that the Earth will continue to warm without a reduction in CO_2 emissions [23], e.g., by 2°C when the atmospheric CO_2 concentration can be kept at or below 650 ppm, and significantly higher if it cannot [10]. In August 2018, the IPCC has released a special report, pledging to limit global warming to 1.5°C [24]. "Limiting global warming to 1.5°C compared with 2°C would reduce challenging impacts on ecosystems, human health, and well-being," said Priyadarshi Shukla, Chair of the Global Centre for Environment and Energy, Ahmedabad University, India, and the co-author of the report.

Under the 2015 Paris Agreement [25], countries have agreed to keep global temperatures increase below 2°C, which might not be enough to avoid exceeding dangerous tipping points.

4.2 The Kyoto Protocol

The Kyoto Protocol [26] is an agreement made in 1997. It regulates the United Nations Framework Convention on Climate Change (UNFCCC) and focuses on climate protection. In doing so, an international and joint agreement was achieved, which should gradually reduce CO_2 emissions worldwide. The Kyoto Protocol is designed to slow down the progressive effects of greenhouse gases and, if possible, to halt artificial global warming [23].

The statistics in **Figure 4** shows the 10 largest CO_2-producing countries by share of global CO_2 emissions in 2016. With a very high proportion of over 28% of global carbon dioxide emissions, China was the world's largest CO_2 emitter in 2016. Second only in the list of climate sinners come the USA with almost 16%. In addition to carbon dioxide, the Kyoto Protocol includes another five greenhouse gases: methane (CH_4), nitrous oxide (N_2O), "F-gases" hydrofluorocarbons (HFCs), perfluorocarbons (PFC), and sulfur hexafluoride (SF_6). Nitrogen trifluoride (NF_3) must be additionally included since 2015. In 2015, Germany was able to reduce almost all greenhouse gases compared to the year 2000 (with the exception of hydrofluorocarbons) and thus already meets the requirements of the Kyoto Protocol [27].

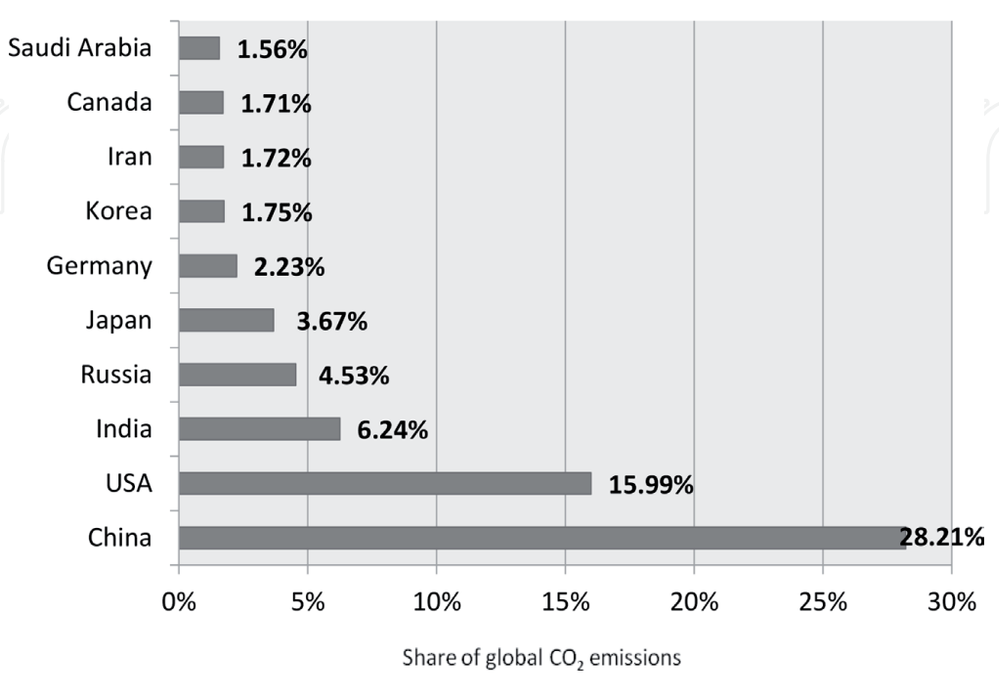


Figure 4.
The 10 countries with the largest share of CO2 emissions worldwide in 2016. Modified from [27].

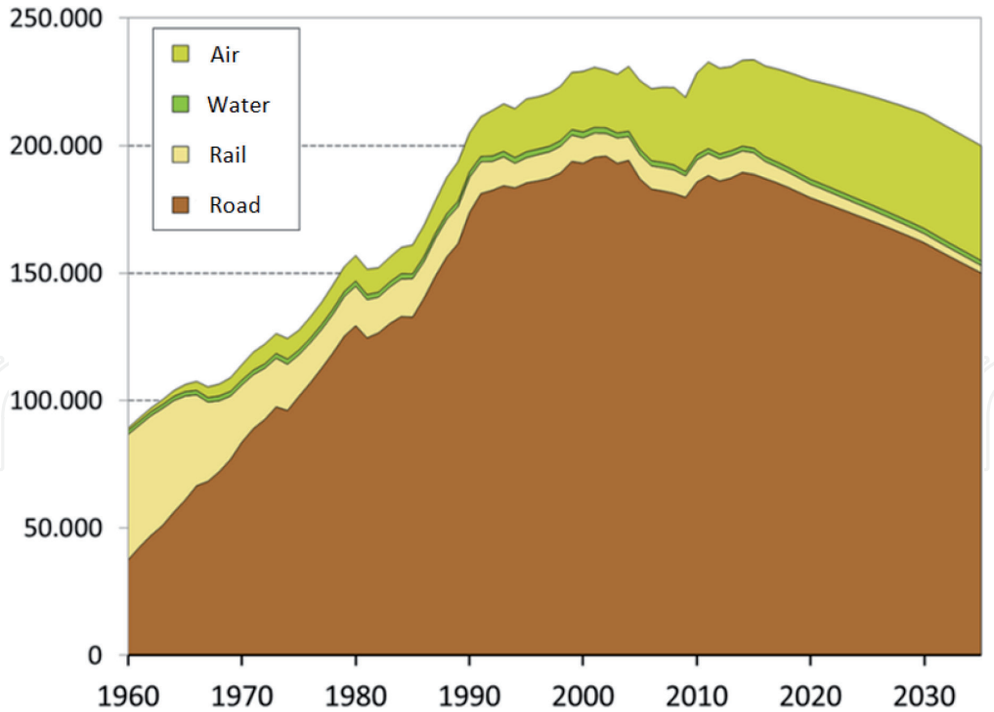


Figure 5.
Carbon dioxide emissions of transport (in kt) in Germany in 1960–2014 and in the trend scenario until 2035 [30].

Nearly two-thirds of global carbon dioxide emissions are caused by 10 countries, around a quarter or one-sixth by China and the USA alone, respectively. Germany ranks sixth in that list. For the total emissions of a country, both the number of inhabitants and the per capita emissions are relevant. In short, an American causes almost twice as much carbon dioxide as a German and about 10 times as much as an Indian citizen. Worldwide, the carbon dioxide emissions and the carbon dioxide concentration in the atmosphere are steadily increasing. Energy-related carbon dioxide emissions have more than doubled worldwide since 1970 and increased more than 15 times since the beginning of the last century. Since 2013, however, emissions have grown significantly more slowly. This gives a little hope that a stabilization and then a trend reversal can be made possible [28].

The Transport Emission Model (TREMOD) [29] is a commonly used method of determining CO_2 emissions. The TREMOD takes into account direct emissions from vehicles, evaporative emissions, and total emissions with the energetic upstream chain [4] (compare **Figure 5**).

In the transport sector, not only the specific energy consumption but also the development of CO_2 emissions is an important indicator of energy efficiency. Concerning CO_2 emissions, very different information is given in the transport sector, mainly because of the increased use of specific energy sources and significant differences in the CO_2 balance among the individual modes of transport [4].

5. Rail freight

According to a study by SCI traffic "Rail Transport Markets-Global Market Trends 2016–2025," global rail freight traffic fell by 4.4% in 2015 [31]. Thus, the rail freight traffic has recorded negative growth for the first time since many years. The reason for this is the slowdown in the transport of coal and steel due to weaker production activity and also the decline in international trade growth. In the face

of growing protectionism, transport demand is expected to be negatively impacted worldwide. Coal transport in North America has declined significantly as a result of the change in the energy mix [31].

In Asia, above all, the Chinese transport market, which is shrinking in rail freight transport [31], dominates. The rising tariffs in rail freight traffic are the cause of the reduction. The strong expansion of road infrastructure with highways, which has made road transport more attractive, also led to a decline in rail traffic. However, there is a desire in the Chinese area for a sustainable improvement in air quality, which can also be achieved by shifting the modal split in favor of greener rail. However, it is still unclear whether and to what extent the corresponding political decisions will take place and whether they will be able to compensate for the declining coal transport by rail [31] (compare **Figure 6**).

The basis for rail freight transport is freight wagons in regular or special design. These are coupled to wagon groups (half trains or block trains). Newer trains have a total length of up to 700 meters. Each wagon has a payload of 25–62 tonnes. The first railways were driven with the power of steam engines. However, this technique is no longer used today due to the low efficiency. At present, mainly internal combustion engines and electric motors are used for the drive. Here the drive is in locomotives or in the railcar. While a railcar carries the goods to be transported, a locomotive pulls wagons with the goods to be transported [32].

Freight trains are divided into different types of trains:

Block trains: Carriage of goods or a shipment from one customer to another one; between the departure station and the destination station, the whole train remains unchanged. The wagons of the same design are put together. This favors standardized loading processes for consignors and consignees as well as equipment that is specially tailored to the type of wagon [33].

Mixed freight wagonload/single wagonload freight trains: Individual wagons are used to build trains for different customers, which must be dismantled and reassembled in shunting yards [33].

Mixed block trains: Mixed block trains stand for trains that consist of several blocklike segments that carry different goods and/or have different routes. This is intended to combine the flexibility of wagonload traffic with the efficiency of block train traffic [33].

In internal combustion engines (as in everyday traffic), typically commercial diesel fuel is used. By the invention of the electric motor (1837) and generators

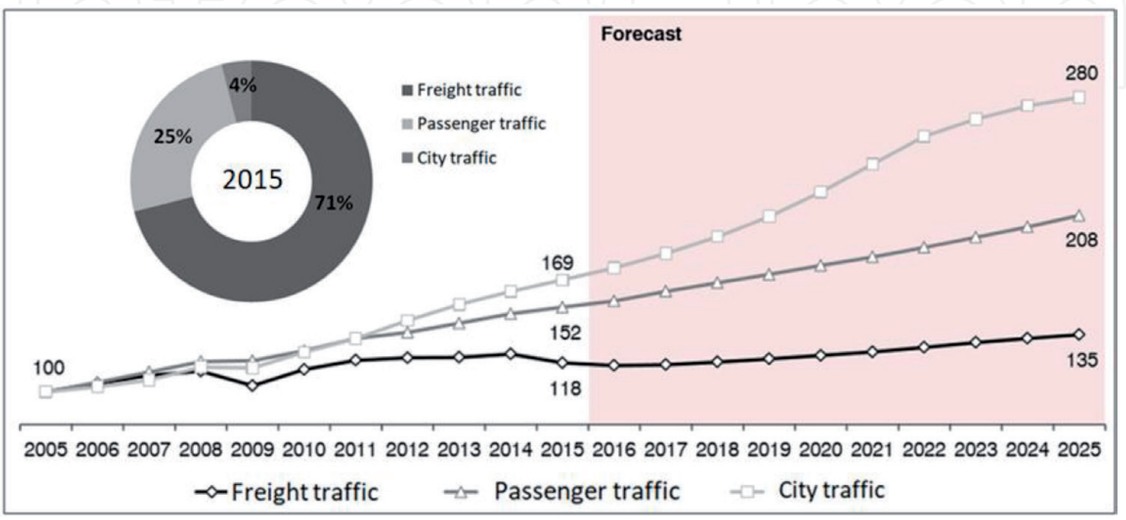


Figure 6.
Worldwide rail services; index 100 (average) = 2005, pkm (person kilometers), tkm (tonne kilometers). Reproduced with permission from [31].

and transformers (1866), it was possible to develop the first electrically operated railways. The energy required was initially supplied directly via batteries or via the tracks. AC motors or DC motors are used [32] (AC = alternating current, DC = direct current).

In order to increase energy efficiency, unnecessary transport routes must be avoided. Traffic avoidance can be achieved by means of dynamic route planning by telematics systems. It uses information technologies and communication technologies as well as up-to-date traffic information for tour planning and tour control. Data streams from location, navigation, data and voice communication, and vehicle data are transmitted, collected, processed, and sent back in real time to the vehicles for their control. This relieves traffic infrastructure and the environment [32].

Apart from that, measures to optimize capacity utilization are important, since the means of transport are mostly only moderately utilized and empty trips (trips without goods to be transported) are not uncommon. This includes, for example, bundling. In "time bundling," future requirements of a target area are combined to transport blocks, while in "spatial bundling," orders from neighboring customers, e.g., by transshipment point or cross-docking, are pulled together [32].

5.1 Existing and emerging fuel-efficient locomotives

At the 2012 American Society of Mechanical Engineers (ASME) Joint Rail Conference, technology options for use in new rail systems, retrofits, or system-wide energy efficiency gains were assessed as being proven and highly promising. Among other things, it was recognized that the most important factor in improving energy efficiency is the modernization of the traction and propulsion system. The modernization of the heat, ventilation, and air conditioning (HVAC) system control for railcars allows further system-wide energy efficiency gains [34].

The focus here is on integration:

- Variable fans or dampers.
- Frequency converters for refrigerant compressors, which save energy for heating and ventilation (saving potential can reach up to 70%).
- Permanent magnet motors, which increase the efficiency. They also reduce the size and weight of compressors/pumps.

Improved rail and facility efficiency lighting system options (including stations, depots, and rails, as well as multimodal terminals) include daytime lighting, automatic ambient light sensors, and motion detectors. Furthermore, incandescent lamps and fluorescent lamps are being replaced by long-lasting, low-power, light-emitting diodes (LEDs) [34].

Regenerative braking can be used to store and reuse generated electricity. The electricity is gained by dynamic braking; the electric motor is driven backward and should slow down the train. The electric motor can act as a generator with the aid of dynamic braking. Currently, most of the trains used to convert this dynamic braking energy and deploy resistance bridges. The resistance bridges heat up during this process. Usually, a cooling grid is arranged at the top of the locomotive for the braking resistors. The use of electronically controlled pneumatic (ECP) brakes is increasing, but energy savings can only be realized here, as long as all railcar brakes are connected. For regenerative braking to be used, an onboard rechargeable energy storage system (RESS) is required. Only with the RESS, the recovered kinetic energy can be stored and returned if needed. Normally, this kinetic energy converts

to frictional heat and is thus lost. The recovered braking energy can be redirected back into the system or used for peak load requirements such as accelerating or uphill driving. Modern or newer electric train systems are able to save and reuse 10–20% of energy consumption with the aid of the regenerative braking function. For rail freight traffic with numerous stops, this is particularly interesting in terms of energy efficiency [34].

5.2 Energy efficiency for high-speed rail

Freight railways deserve a lot of attention as they require about 90% of the energy of domestic rail transport. In 2011, the American Public Transportation Association (APTA) cited some UIC data in a report stating that the high-speed trains achieved about 106 mi (170 km) per kWh of energy. In comparison, planes only get 13 mi (21 km) and cars 34 mi (55 km) per kWh [35]. High-speed rails (HSR) and maglev (magnetic levitation) systems have many advantages over conventional rail, highway, and air, especially in terms of air quality and sustainability. CO_2 emissions from HSR operations are significantly lower (0.1–0.3 lb of CO_2/passenger-mile or 0.03–0.08 kg/passenger-km) than other modes of transport such as aircraft (0.6 lb./p-mi or 0.17 kg/pkm) or cars (0.5 lb/p-mi or 0.14 kg/pkm). An up-to-date life cycle analysis of HSR versus traditional rail, air, and highway modes found that system-wide comparisons of rail infrastructure construction and operation, high load and occupancy factors, maintenance and fuel, and clean electricity must be supplied with renewable energies (instead of, e.g., coal-fired power stations) [34].

5.3 Diesel multiple units (DMUs) and electric multiple units (EMUs)

Self-propelled diesel railcars can be diesel-electric, diesel-hydraulic, or diesel-mechanical units. These traction vehicles (including powered wheels) can accelerate much faster and have a shorter braking distance than locomotive trains and are thus also more energy-efficient than these. As long as the powered vehicles are connected by cable or radio link, they can be used in the decentralized power configuration. Another form of self-propelled railcars are electric multiple units (EMUs). EMUs are individually powered by direct current (DC) from a third rail, but there is also the option of being powered by a vehicle pantograph in contact with the AC overhead line system (OCS). EMUs are more costly than DMUs but are more environmentally friendly and more energy-efficient and can achieve higher speeds [34].

5.4 Dual power hybrid locomotives

A **hybrid train** is a locomotive, railcar, or train which uses an onboard rechargeable energy storage system (RESS), placed between the power source (often a diesel engine) and the traction transmission system connected to the wheels. An example is the hybrid locomotive ALP-45DP with dual drive developed by Bombardier. It is designed as a diesel and electric locomotive. The hybrid locomotive can reach a speed of 160 km/h under diesel drive and up to 200 km/h under electric drive. For a higher efficiency, it can be switched from the diesel drive to the purely electrical operation with just a button push [34].

5.5 Efficient and ultraclean diesel-electric locomotives and repower kits

General Electric (GE) Evolution Series is a diesel-electric locomotive with 12-cylinder engine. It is currently considered the most fuel-efficient and technologically advanced. This product is viewed to be particularly environmentally friendly and

currently has about 3700 locomotives in 10 different countries in use [34]. It has the advantage over other clean locomotives that no urea additive for selective catalytic reduction (SCR) is needed to reduce NO_x emissions. There are no expensive infrastructure upgrades to store and deliver urea for denitrification. New locomotives are very expensive to buy, so a cost-effective option to achieve energy efficiency would be to retrofit existing locomotives with repower kits that reduce fuel consumption and emissions. Progress Rail Service (PRS) acquired in 2010 is a Caterpillar division, Electro-Motive Diesel (EMD), which has long been producing locomotives. The goal of the acquisition was to switch low-power, regional, and high-performance long-range mid-power locomotives to cleaner operation through repowering and achieving more efficient traction. The 710ECO Repower locomotives significantly reduce fuel consumption. Up to 25% of fuel and even 50% of lubricating oil can be saved. This is highlighted by the manufacturer as one of the most important advantages for railways, which are constantly confronted with rising fuel costs [34].

5.6 Distributed power management and control technologies for freight rail

Unlike the traditional push-pull configuration, decentralized power supplies place locomotives in the middle and at the ends of the trains. Distributing the locomotive power along the train can achieve about 5% more energy efficiency (compared to the push-pull configuration). This is increasingly being used by freight trains. Due to the power distribution, there is an increase in safety, as the trains are less susceptible to derailment [36]. The wear of wheels and tracks as well as the braking distance can be significantly shortened by the distributed power. To achieve a desired speed curve, distributed energy control and power management software is used. Various companies such as Canac and Wabtec offer solutions for the decentralized electricity market. Norfolk Southern saved nearly 30% on fuel with a combination of electronically controlled pneumatic (ECP) brakes that communicate with GE's Locotrol over the network with the LEADER train management and control system [34].

5.7 Alternative fuels for environmental sustainability

5.7.1 Hydrogen fuel for fuel cell hybrid locomotives

Hydrogen has been considered for use in rail transportation [37, 38]. Alternative fuels for locomotives are particularly important for environmental improvement in the rail sector. With the use of hydrogen fuel cells, a reduction of particulate matter pollution and greenhouse gases emitted into the atmosphere can be achieved. The dependence of the iron webs on fossil fuels is reduced to a minimum with the hydrogen fuel cell [34].

In the hydrogen hybrid locomotive, the following components are used:

- Batteries for driving electric traction motors, which are charged by a Ballard fuel cell stack with 240 kW
- Hydrogen tanks storing 70 kg of hydrogen at 350 bar on the roof
- Corresponding power electronics
- Battery ventilation systems

The batteries that drive the electric motor are charged by the fuel cell. To ensure sufficient traction between rails and wheels, the locomotive carries 900 kg of

ballast. In the case that the temperatures of the batteries are too high, a pressure relief device can be activated. This process ventilates the batteries as well as the hydrogen fuel cells. With this model, the air pollution and the noise pollution at the stations are reduced. The problem with this variant is the limited range between the fueling and the hydrogen storage capacity [34].

5.7.2 Natural gas locomotives using liquefied natural gas (LNG)

Liquefied natural gas (LNG) is an interesting alternative fuel for locomotives [39, 40]. Westport Innovations is working with Caterpillar to develop a natural gas fuel system for locomotives [34]. This project uses high-pressure direct injection technologies for combustion. The main objective was defined as the production of emission compliant long-haul locomotives with interchangeable tender vehicles. With this technology, 95% of the diesel fuel is replaced by natural gas and thus only 5% diesel fuel used for combustion to bring the locomotive to full capacity. Energy Conversions Inc. is working with Burlington Northern Santa Fe (BNSF) to develop a convertible engine with a dual-fuel system. This system uses low-pressure direct injection (LPDI) with no pump being required. The NO_x emissions caused by premixed combustion are reduced. This system can save up to 1.1 million liters of diesel per year per locomotive, equivalent to a possible replacement of 92% [34]. According to BNSF, the economy and technology have been improved so much that natural gas in long-haul locomotives becomes operationally feasible [34].

5.7.3 Biofuels and blends with petrodiesel

Biofuels are derived from renewable and (in principle) non-exhaustive sources of energy. To produce biofuels, biological (plant or animal) materials are converted into liquid fuel composed of fatty acid methyl esters (FAME). Instead of fossil fuels, organic waste (e.g., waste cooking oil) can also be used for production [41, 42]. Biodiesel fuel is obtained from transesterification of fatty acids. In this chemical process, glycerol is separated from fat or vegetable oil, and methanol is consumed. Biodiesel is made from a variety of products, such as animal fat, vegetable oil (rape seed, soy bean, palm oil, etc.), or recycled restaurant fat. Petroleum diesel can be blended with biodiesel to any percentage. In these biodiesel blends, the percentage of biodiesel is always clearly marked. For example, B10 contains 10% of biodiesel, with the remaining 90% being made from fossil sources. Pure biodiesel is known as B100. Blends containing more than 20% biodiesel require special handling or even modifications of the equipment. Biodiesel is biodegradable and nontoxic, reduces air pollutants, and provides better lubricity due to its viscosity. The high cetane number facilitates combustion in compression ignition engines [34].

For two recent reviews on biodiesel, see [43–45] for biodiesel in railway use. Bioethanol is more a fuel of choice for smaller (gasoline) engines.

Other biofuels are, e.g., biobutanol and biomethanol [3, 46].

6. Airfreight

The steadily growing world trade is the reason for the rapid increase in air cargo volume in recent decades. This transport method offers many advantages such as speed, safety, and reliability. The short transport times over long distances are particularly attractive for goods with a high urgency and high value. Airfreight records the highest growth worldwide compared to other modes of transport [47]. Another advantage is the precisely planned organization in air traffic. Flight plans

are minutely adhered to under very high safety standards, thus ensuring a smooth supply chain. Compared to other transport methods, the transport costs, due to the high fuel consumption, are relatively high. Aircraft consume about 12 times more fuel than, for example, seagoing vessels [48] per tonne kilometer.

Based on the assessment basis for specific CO_2 emissions, air traffic is a significant contributor to climate change. In most cases, energy consumption is related to transport performance, such as passenger kilometers or tonne kilometers. This includes the consumption from the departure terminal to the arrival terminal and therefore also the movements that take place on the ground. Between 1990 and 2011, freight transport services quadrupled in Germany, and on a global scale, a future annual growth rate of ~7% is expected on average [4, 47].

In December 2017, the International Air Transport Association (IATA) published updated data for the global airfreight market. It showed that demand (measured in freight tonne kilometers, FTK) increased by 5.9% compared to the previous year. Freight capacity, measured in available freight tonne kilometers (AFTKs), also increased by 3.7% compared to 2016 [49].

Alexandre de Juniac (IATA Director General and CEO) said: "Demand for air freight increased by 5.9% in October. And tightening supply conditions in the fourth quarter should be the air cargo industry delivering its strongest operational and financial performance since the post-global financial crisis rebound in 2010" [49].

In the Asia-Pacific region, airlines increased their cargo volumes by 4.4% and capacity by 3.9%. Freight demand exceeds the record high reached in 2010 by around 3%.

Airlines in North America recorded an increase in cargo volume of 6.6% in 2017 compared to 2016. The increase in capacity was 3.8%. In recent years, the market for inbound freight transport has increased due to the strength of the US economy and the US dollar.

In Europe, the 5-year average of 4.9% was exceeded, and freight demand rose by a total of 6.4%. Capacity grew by 2.5%. Compared to other continents, European export orders have been rising fastest for more than 7 years [49].

Middle Eastern carriers' freight volumes increased 4.6%, and capacity increased 3.4% in 2017 [49].

In the last half of 2017, seasonally adjusted international freight volumes continued to rise at a rate of 8–10%. Airlines in Latin America, like all other major regions, posted positive growth in freight demand (7.2%) and capacity (4.4%). By far the largest increase over the previous year was seen by African carriers. Freight demand rose by 30.3% and capacity by as much as 9.2% [49].

Decarbonization attempts in aviation concern passenger and freight transport alike. Engine improvements have a very strong leverage on energy efficiency. There is a trade-off between NOx emissions and turbine energy efficiency [50].

6.1 Solar energy systems: solar kerosene

For many years countless research activities have been dealing with the topic of solar energy and where it can be used. The EU Commission announced in 2014 that an experiment had succeeded in producing kerosene with the help of sunlight [51]. In the process, synthesis gas is generated under the action of sunlight, which consists of hydrogen (H_2) and carbon monoxide (CO). Andreas Sizmann from the Bauhaus Luftfahrt (participant in the research project) explained two major advantages of this method. First, the harmful climate gas CO_2 would be used and not fossil hydrocarbons such as oil. Although the kerosene produced in this way will also release CO_2 through combustion, CO_2 can be obtained directly from the air over the long term. Therefore, the process is on the whole potentially CO_2 neutral,

according to Sizmann. Second, the energy for the entire process is generated from solar energy. The process is very efficient and does not compete with food production as opposed to the production of other (mainly first-generation) biofuels [52].

6.2 Electric motors: environmentally friendly flying

The use of electric motors is already well advanced in parts of the transport sector. Soon, electric flying should become possible. In this regard, Siemens and Airbus announced a development cooperation in 2016 in which hybrid technology is used. In the presented test aircraft, the jet engine was replaced by a 2 megawatt electric motor (produced by Siemens), which drives the large air impellers. The 2 megawatt electric motor is only 30 centimeters long and weighs 175 kilos. To get power from the electric engine, several steps are necessary. With a gas turbine burning kerosene, an electric generator is powered, which feeds the power into a 2 tonne lithium-ion battery. Finally, the lithium-ion battery supplies the built-in electric motor. Since starting up an aircraft requires a great deal of energy, the lifting can be supported by generator and battery. During the descent, the engine blades, which work like small windmills, can be used to generate electricity. This principle is similar to that of electric cars or locomotives, which carry power back into the battery while braking. The representatives of this project are of the opinion that with their concept they can reduce the consumption of kerosene by double-digit percentages compared to conventional jet engines. Flying would therefore also become more environmentally friendly and more quiet [53, 54]. Electric power for a two-seat aircraft is discussed in [55]. The more electric aircraft (MEA) concept is discussed in [56]. Light pure-electric and hybrid-electric aircraft are presented in [57]. The MEA concept essentially aims at replacing conventional non-electric power (pneumatic, hydraulic, and mechanical) by electric power to drive aircraft subsystems more efficiently. An all-electric 180-passenger commercial aircraft is discussed in [58].

6.3 Aerodynamics: winglets and riblets

In aviation, aerodynamics focuses on two main forces: lift and drag. The power of lifting makes an airplane fly. This is caused by the uneven pressure on a wing's top and bottom. The drag represents the resistance that arises during movement through the airflow. Due to the high pressure under the wings, air flows over the wing tips upward and rolls off in the form of a vortex. This vortex is also called induced drag and can be so strong that it disturbs other planes. Wake turbulence can become a safety concern particularly for small aircraft. Induced air drag degrades performance and reduces the range and speed of the aircraft [59].

Winglets are more than just a striking and aesthetic design feature; they are among the most visible fuel-saving and performance-enhancing technologies in aviation introduced in recent years. According to Whitecomb, winglets can reduce induced drag by about 20% and improve carrying capacity by 6–9%. The design of the winglets can be very different. Aviation Partners Boeing (APB) has developed a special form: the Blended Winglet. The Blended Winglet's design fuses the wing into a smooth upward curve. Other winglets are shaped more like a fold or kink. Through this smooth transition, optimal efficiency can be achieved [59].

Riblets are micro- and nanostructured surface structures that cause drag reduction. This technology comes from the field of bionics, which works by transferring phenomena from nature to technology. Riblets resemble the skin of a shark and are characterized by fine grooves on the surface. The so-called shark-skin effect causes a reduction of the friction resistance of up to 8% compared to aircraft without this coating [60].

In the research project FAMOS (management system for the automated application of multifunctional surface structures) of Lufthansa Technik, Airbus Operations GmbH, BWM GmbH, and the Fraunhofer Institute for Production Technology, it has been possible to develop an automatic guidance system for the application of riblets to the outer shell of the test aircraft [61]. Tests from this research project have shown that riblets, despite minor wear of the microstructures, significantly reduce the frictional drag in the air. For riblets, lacquer is first applied to a UV-transparent mold or matrix. This matrix contains the negative impression of the riblet shape. The resulting negative mold is then pressed into fresh paint and thus cured with UV light. After removing the negative mold, the positive of the sharkskin structure stops at the surface. The application of the riblets is possible on any aircraft models; they are attached in the form of strip tracks on the surfaces parallel to the flow direction. In the laboratory of the project FAMOS, the longevity as well as the efficiency of the sharkskin structure was confirmed. Depending on the area applied, airlines can use this technology to save about 1.5% of fuel [61].

6.4 Composite materials to optimize fuel consumption and CO_2 emissions

The processing of composite materials is becoming increasingly important for aircraft construction. Even though planes are themselves tonnage heavy, every single kilogram counts. The manufacturing and processing costs of carbon fiber-reinforced plastics (CFRP) in aircraft far exceed the costs of traditional metal construction. In the long term, however, the cost advantage outweighs due to the low weight and the resulting reduced fuel consumption. Nowadays, fuel consumption is a top priority for airlines because less fuel means less CO_2 emissions and lower operating costs. Thus, something good is done for the environment while saving money, too. For many years CFRP has been installed on models such as the Airbus A380 (28%) or the Airbus A350 XWB (53%). Predecessors, such as the A330, weigh almost 10 tonnes more and consume more fuel than the Airbus A350 XWB with comparable payload capacity and range [62, 63].

CFRP consist of hair-thin layers of carbon fibers, which are embedded in a resin matrix (thermoset). The material scores with a very high specific strength and low weight. Mechanically, this composite material is extremely difficult to deal with, so millimeter-thin CFRP tapes have to be stacked on top of each other for the outer hull of the skin in a day-long process and then baked together under pressure and heat. Due to the extreme hardness of the material, particularly high-quality and expensive cutout drills and cutters (e.g., for external connections, doors, windows, and holes for rivets) must be used. Because of the high abrasion when drilling, even modern tools with diamond-like coating last on average only half as long as tools in metalworking [62].

6.5 Aircraft engines: current technology and energy-efficient developments

Aircraft engines must be reliable and efficient. The technology behind them is explained quickly and easily. Engines work in a similar way as rockets: The intake air is compressed and fuel is injected. The combustion of the fuel creates an exhaust gas jet, which emerges at the back. The exhaust jet drives the actual turbine (a wheel with blades). The turbine finally generates the drive for the compressor at the engine entrance. The compressor increases the pressure of the air and consists of several stages. Each of these stages includes a rotor and a stator wheel. The turbine part is also constructed like that. Depending on the engine, between 8 and 14 stages are used today. Particularly modern engines achieve compressions of 45 times the input pressure. The developments in aircraft engines initially focused on sending

part of the air through the compressor and the combustion chamber, rather than around the engine. The first stage of the compressor, also known as a fan, works like a giant blower. The fan accelerates this circulating mantle air. The so-called turbo-fan engines are the current state of the art [64].

The shroud flow ideally requires a relatively low speed for the large fan and high speed in the high-pressure range. This created the two-shaft engines. The axles of these engines can rotate counter-wise. One of them is the slow-speed low-pressure shaft, which is driven by the rear turbine stages just before the exhaust outlet. At the same time, the first compressor stages are rotated. The other one is the very fast-rotating high-pressure shaft. The high-pressure shaft is operated by the turbine stages behind the combustion chamber and thus moves the high-pressure part of the compressor.

Optimization of the engine concept has been in progress for many years. First and foremost, the approach is followed to change the amount of air that has passed through. The difference in speed should not be too big between thrust and airspeed. Ideally, a very large amount of air is pushed back very slowly from the engine. Another approach for increasing efficiency is the turbine including the combustion chamber. The hotter the combustion is, the more efficient the process becomes. Here, the materials are pushed to their limits. The first stage of the turbine is under most stress because it gets the full heat of the combustion chamber. Other developments are heading back in the direction of the classic propeller. Ideas in this area run under the slogan "open rotor concept." However, the mounting size, which makes mounting on the wing difficult, as well as the noise, proves to be problematic. Aircraft could look completely different in the future, for example, with a huge propeller engine on the roof of the fuselage.

6.6 Continuous descent operations: CDO

Continuous descent arrival (CDA) is an aircraft operating technique designed to reduce aircraft noise, fuel consumption, and emissions. In this method, an incoming aircraft sinks with minimal engine performance and largely avoids horizontal flight phases. Ideally, this happens at idle. Without the use of CDA, an airplane goes down step-by-step. When performing CDA, the aircraft lingers high up in the air for extended periods of time, operating at a low engine thrust. This causes a reduction

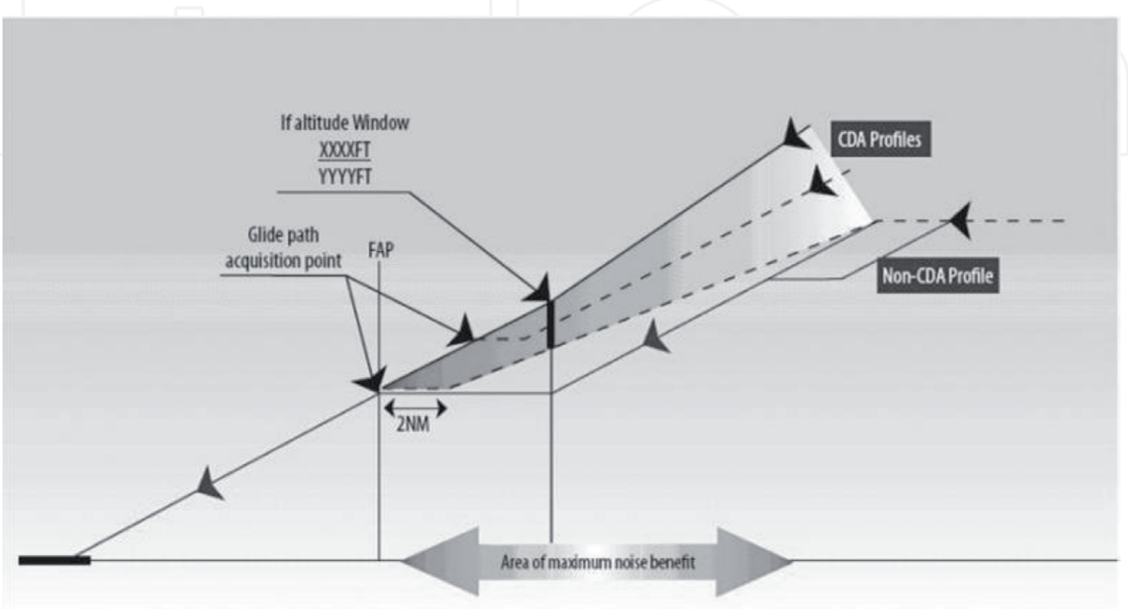


Figure 7.
Visual representation of CDA [65]. NM = nautical mile; FAP = final approach point; FT = foot.

in fuel consumption, emissions, and noise during the descent profile. The most optimum CDA starts at the top of the descent and ends as soon as the plane starts the last approach and follows the glide path to the runway [54] (compare **Figure 7**).

7. Conclusion

To sum up, energy efficiency management should always be used and aspired to because of the overwhelming economic and ecologic benefits in the transport sector. One of the most important advantages is, above all, the potential for saving fuel, since low fuel consumption leads to cost savings and consequently to reduced CO_2 emissions. The application of energy-efficient technologies and methods therefore not only has economic aspects but is also good for the environment. This chapter shows that there are already several propulsion technologies and developments in the areas of rail freight and airfreight, but they are not yet completely revolutionized and provide room for further improvements.

Rail freight currently has mainly internal combustion engines and electric motors in use. In particular, the invention of electrically powered railroads has been a significant advance in improving energy efficiency. By using modern drive technologies and methods in rail freight transport, many potential savings can be achieved. In the field of electric locomotives, regenerative braking can be used, for example, with rechargeable energy storage systems (RESS). This allows the current generated during dynamic braking to be stored and reused, and it offers a potential of 10–20% of energy consumption to save. Other powertrain technologies such as the dual power hybrid locomotive as well as diesel multiple units (DMUs) and electric multiple units (EMUs) are particularly effective and efficient. The dual power hybrid locomotive convinces with the advantage that the diesel engine can be converted to a purely electric drive with just a single push of a button. Although EMUs prove to be a high financial burden, they are considered to be very environmentally friendly and energy-efficient. The most fuel-efficient and advanced engine in this regard is the highly clean diesel-electric locomotive with repower kits. Compared to other locomotives, this model has the advantage of not requiring urea additives to reduce NO_x emissions. Since the purchase of a completely new diesel-electric locomotive is extremely expensive, repower kits are a cost-effective option that can also reduce fuel consumption and emissions. This can save up to 25% on fuel and about 50% on lubricating oil. To optimize energy efficiency, the use of energy management and control technologies should be promoted. It has been proven that the distributed power controller is 5% more efficient than the traditional push-pull configuration. In conjunction with electronically controlled pneumatic brakes, it is possible to achieve fuel savings of almost 30%. Rail freight transport should focus on natural gas locomotives in terms of renewable energy. With this technology hardly more diesel fuel is needed. Only 5% of the diesel fuel is needed to reach full power, with the remaining 95% being replaced by natural gas. Natural gas locomotives can save over 1 million liters of diesel per locomotive per year.

Airfreight is extremely attractive as a transport method. The aircraft as a means of transport brings many benefits. The reliability, safety, and speed ensure steady growth in this sector. It should be noted, however, that fuel consumption, as measured by effective numbers, is highest. Due to the specific CO_2 emissions, airfreight drives global warming. All the more important are the technologies and opportunities that contribute to improving energy efficiency. The potential here is in different areas. Propulsion technologies, aerodynamics, composites, as well as flight behavior itself can have a huge impact on the energy efficiency of freighters. The solar energy systems announced by the EU for the production of "solar kerosene" act primarily as an optimal way to supply clean fuel to aircraft, but in this process, CO_2 is also

produced by combustion. Electric motors in aviation are currently still in the development phase but could become very relevant in terms of energy efficiency in the future. The developments in the field of aerodynamics have proven to be effective and operational for many years. With the help of winglets and riblets, air resistance can be reduced by 20% and load capacity increased by almost 9%. This technology can be applied to any aircraft and offers around 1.5% fuel savings.

In aircraft construction, the processing of composite materials can result in optimized fuel consumption and a reduction in CO_2 emissions. A disadvantage of carbon fiber-reinforced plastics is the high manufacturing and processing costs. In the long term, however, these investment costs are offset by the respective savings. Composites are particularly interesting because of their high specific strength. Changing the flight behavior can result in a reduction in fuel consumption, emissions, and aircraft noise. This aircraft operating technique is called continuous descent arrival. The state of the art is currently the turbofan engine. The developments have shown that ideas in the direction of the classic propeller cannot be ruled out.

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Conflict of interest

There is no conflict of interest.

List of abbreviations

AC	alternating current
ACEA	European Automobile Manufacturers Association
AFTK	available freight tonne kilometer
APB	Aviation Partners Boeing
APTA	American Public Transportation Association
ASME	American Society of Mechanical Engineers
BNSF	Burlington Northern Santa Fe
CDA	continuous descent arrival
CDO	continuous descent operation
CFRP	carbon fiber-reinforced plastic
CH_4	methane
CO_2	carbon dioxide
CO_{2eq}	CO_2 equivalents
comb.	combustible
DC	direct current
DMU	diesel multiple unit
ECP	electronically controlled pneumatic
EMD	electro-motive diesel
EMU	electric multiple unit
EPA	Environmental Protection Agency
EU	European Union
EU ETS	European Emissions Trading System
FRA	Federal Railroad Administration

FTK	freight tonne kilometer
gas	natural gas
GDP	gross domestic product
GE	general electric
GHG	greenhouse gas
GJ	gigajoule (10^9 joules)
GWP	global warming potential
H_2	hydrogen
HFC	hydrofluorocarbon
HSR	high-speed rail
HVAC	heat, ventilation, and air conditioning
IATA	International Air Transport Association
IEA	International Energy Agency
LED	light-emitting diode
LNG	liquefied natural gas
LPDI	low-pressure direct injection
LPG	liquefied petroleum gases
m^2	square meter
MJ	megajoule (10^6 joules)
N_2O	nitrous oxide
NAZCA	non-state actor for climate action
NF_3	nitrogen trifluoride
PFC	perfluorocarbon
PJ	petajoule (10^{15} joules)
pkm	person kilometers
PRS	progress rail service
RESS	rechargeable energy storage system
SCR	selective catalytic reduction
SF_6	sulfur hexafluoride
tkm	tonne kilometers
TREMOD	transport emission model
UNFCCC	United Nations Framework Convention on Climate Change
VA	value added
WEO	World Energy Outlook
WESS	wayside energy storage system

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