Towards a climate neutral future with Deutsche Bahn: Analysis of company policy until 2050

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Abstract. The purpose of this paper is to analyze the state of current knowledge and tools needed to move the German company Deutsche Bahn AG towards climate neutrality. Both literary sources and statistical data were used in the preparation of the paper. The main questions addressed in the paper are: how the concept of climate neutrality applies to Deutsche Bahn AG, what experience the company has in planning carbon-neutral operation and what tools can be used. As greenhouse gas emissions rise, so does the need to find solutions for reducing carbon dioxide emissions. Deutsche Bahn AG is aiming for climate neutrality by 2050. To achieve this goal, it is primarily relying on the use of renewable energy to power overhead cables and train stations. In addition, alternative engine options are being developed to replace the existing fleet of diesel locomotives on non-electrified sections. Improving the energy efficiency of both rolling stock and railroad stations is also becoming increasingly important.

1 Introduction

Deutsche Bahn is following its targets as part of Germany's overall policy to reduce carbon dioxide emissions and achieve climate neutrality by 2050. Deutsche Bahn, as part of the German federal program to reduce greenhouse emissions, also plans to achieve climate neutrality by 2050. In the transport sector, transformative changes will need to occur by 2030. In the climate-neutral 2050 scenario, personal mobility does not suffer restrictions. Instead, people become more reliant on sustainable modes of transport, including public transit, bicycles, and walking. Goods will be increasingly transported by rail, and trucks that run on batteries, overhead lines, and fuel cells will cover nearly one-third of road freight mileage. [1] [2]

Deutsche Bahn set intermediate goals for itself by 2020 and even exceeded the plan: in the period from 2006 to 2020, the volume of specific CO2 emissions from the entire group was to be reduced by 30%. In effect, it was possible to achieve a reduction of more than 34%. The share of renewable energy sources among the sources of traction power supply for railways by 2020 was supposed to be 45%. In fact, the share of renewable energy sources was already 61% in 2020. [1] [3]

By 2030, it is planned to reduce CO2 emissions by half compared to 2006 and to increase

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the share of renewable energy sources among sources of traction power supply for railways to 80%. By 2038, the traction network must be completely converted to renewable power. [1]

However, increasing the share of renewables is not enough to achieve full climate neutrality. The plans also include the development of alternative engine options for rolling stock, improving the energy efficiency of both rolling stock and railway stations, as well as an energy-efficient driving way. [1] [3]

The principle of cold combustion is used in fuel cells to generate energy, that is, the direct conversion of chemical energy into electrical one. In an internal combustion engine, an intermediate conversion of chemical energy into thermal energy occurs first, which is then converted into mechanical energy and finally into electrical energy. With cold combustion, this intermediate stage is skipped, due to which, among other things, greater efficiency is achieved. [4] [5]

Fuel cells differ in reaction temperature or fuel type. The most common fuel is hydrogen, methanol, or propane, while hydrogen is commonly used in rolling stock. The following briefly explains the principle of the fuel cell operation: [5]

2 Materials and methods

Deutsche Bahn AG is the largest rail carrier in Germany and plays an important role in reducing carbon dioxide emissions. The company's goal is to achieve full climate neutrality by 2050. This article proposes to examine the factors that influence the reduction of carbon dioxide emissions in the transportation segment. The study uses both qualitative and quantitative approaches to collect primary and secondary data and information in order to identify success factors for Deutsche Bahn AG to reduce carbon dioxide emissions. The analysis is based on the data collected from online sources including previous academic research. Thus, it is necessary to examine the systems and procedures for reducing carbon dioxide gas emissions for the railroad industry, which is the purpose of the proposed study.

The German railway corporation Deutsche Bahn was chosen as an example to illustrate the organization of carbon dioxide reduction for a railway company. Deutsche Bahn AG is one of Europe's leading companies in the rail freight and passenger transportation market, but in terms of environmental perspective, it faces the problem of harmful industrial gas emissions (CO2) into the atmosphere and has to organize emission reduction strategy in the most efficient way to achieve the declared climate neutrality targets by 2050.

The concepts of “carbon neutrality” and “climate neutrality” are associated with the absence of human impact on the environment at the level of public consciousness. The German Federal Climate Change Act specifies the more precise term “net greenhouse gas neutrality”. This shall mean an equilibrium between the anthropogenic emissions of greenhouse gases from sources and the reduction in the volume of such gases by means of sinks. The term “greenhouse gases” itself means carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3), as well as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). “Greenhouse gas emissions” shall mean the anthropogenic release of greenhouse gases in tonnes of carbon dioxide equivalent, one tonne of carbon dioxide equivalent being one tonne of carbon dioxide or the volume of another greenhouse gas corresponding in its atmospheric warming potential to one tonne of carbon dioxide. Deutsche Bahn's 2050 CO2 Reduction Strategy sees "climate neutrality" in the same perspective - as a condition for reducing greenhouse gas emissions, which will ensure the achievement of the set goals. [6]

Looking at the goals of the German railway company Deutsche Bahn AG, the paper begins with an overview of hybrid trains and how they function, then looks at energy-efficient driving, and finally examines the climate-neutral operation of the rail infrastructure. This paper looks into the identified problems and outlines steps for the further improvement of the effective carbon emission reduction.

3 Hybrid trains

At present, approximately 60% of DB Netz AG's railway network more than 33,000 km long is electrified. The remaining 40% of the network is served by diesel trains, most of which are passenger transport. In total, at the moment, a third of passenger rail transportation is carried out using diesel traction. [7] [8]

The share of electrified lines should be increased to 70% by 2025. At the same time, equipping lines with overhead requires large financial and time costs. One kilometer of new overhead lines costs 1 million euros, which is not economically feasible, especially on secondary sections. This is why Deutsche Bahn will rely on alternative technologies in the future to ensure climate-neutral operation of non-electrified sections. Most often, a combination of two types of engines is used, therefore such rolling stock is called hybrid. [7] [8]

Hydrogen is supplied from the anode side (Fig. 1), which is oxidized and split into electrons and protons. Protons penetrate through the polymer-electrolyte membrane to the cathode. For electrons, the electrolyte is impermeable. For them, there is only one way past the electrolyte to the external circuit, where they do electrical work. This creates an electrical voltage that drives the electric motor. Oxygen from the ambient air is supplied from the cathode side. A combination of oxygen with hydrogen protons forms water. This redox reaction produces water and heat. [4] [5] [9]

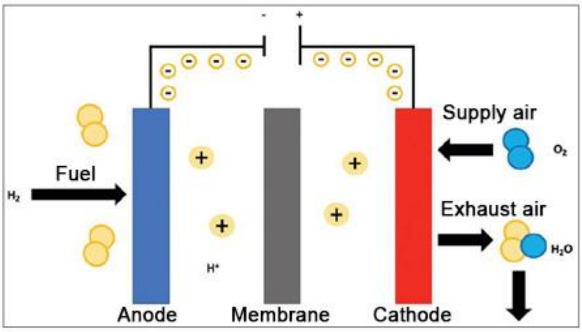

Fig. 1. Fuel cell operating principle.

A single fuel cell generates a voltage of about 1.2 V. Since, for example, this is not enough to set a train into motion, in practice several cells are connected in series, creating so-called “stacks” to achieve the useful power. To further increase the power, these stacks can be combined with other stacks as needed. [4] [5]

In rolling stocks, fuel cell engines are typically combined with batteries to smooth out power fluctuations and thus ensure efficient and balanced running. In addition, the restored energy is recovered during braking. [9]

3.1 Current fuel cell engine implementation examples

There are already specific examples of using such hybrid rolling stock with fuel cells and batteries:

3.1.1 Coradia iLint (Alstom)

The Coradia iLint train (Fig. 2) is based on the diesel Lint 54 and runs on hydrogen. It has a stack of fuel cells in each part of the car, gas tanks on the roof, and a large lithium-ion battery under the car body. [9]

Fig. 2. Coradia iLint train.

Commercial use began on 17 September 2018 on the Buxtehude-Bremerhaven-Cuxhaven section. This is the world's first example of the use of a hydrogen train in scheduled services. Other trains are due to be put into service in December 2022 in the Main-Taunus area. [10]

3.1.2 Mireo Plus H (Siemens Mobility GmbH)

The Mireo Plus H (Fig. 3) train is jointly developed by Siemens Mobility and Deutsche Bahn and is an improved version of the Mireo electric multiple unit. The train will run on hydrogen and at the same time will not be inferior in power to the electric one. The power reserve will be 600 km. A test run between Tübingen, Horb and Pforzheim in Baden-Württemberg is planned for 2024. [11]

Fig. 3. Mireo Plus H train.

3.2 Hybrid rolling stock using overhead cables and batteries

Hybrid trains using overhead cables and batteries have great potential. Currently, the so-called battery-powered multiple units (MU) are being developed, which on electrified sections can be used as full-fledged electric MU, while additionally equipped with lithium traction batteries for driving on non-electrified sections. Therefore, they are also called hybrid rolling stock using overhead cables and batteries. [7] [9]

One such new development is the Talent 3 MU from Bombardier. Talent 3 is an electric MU, additionally equipped with batteries or fuel cells for driving on non-electrified sections. In January 2018, the Talent 3 MU with additional battery power was presented at the InnoTrans exhibition in Berlin. This prototype is equipped with an additional battery system on the roof (Fig. 4), with a capacity of 300 kWh, providing a cruising range in battery mode from 30 to 40 km on level ground. For commercial purposes, the battery system can be easily extended, thereby increasing the cruising range in battery operation. In mass production, it is planned to achieve a cruising range of 100 km. [8] [9] [12]

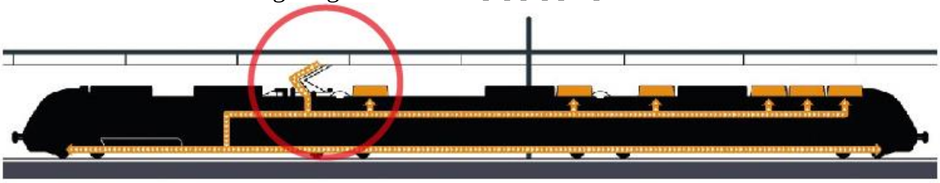

Fig. 4. The train is in loading mode.

On electrified sections, the MU receives the necessary traction current for movement and charging of batteries from overhead cables through the pantograph. Regardless of the mode of train movement, it is possible both during the movement and during the stop. When charging during the stop, for example, at electrified stations, the battery can be charged when the train arrives or when starting and accelerating. In addition, the batteries can also be recharged with recuperation during braking. When the MU leaves the electrified section, the pantograph goes down, and traction energy begins to flow from the battery (Fig. 5). [7] [8] [12]

Fig. 5. The train runs battery-electric.

A test run for passenger traffic was planned for 2019 in Baden-Württemberg. However, it had to be postponed as Bombardier first had to get the Talent trains approved for the Stuttgart regional network. [8] [12]

Due to the limited cruising range of battery-powered MU, it is necessary to take appropriate measures to prepare the infrastructure. However, an analysis of infrastructure and capabilities carried out by the Technical University of Berlin has shown that short-term operation of battery-powered MU is already possible without major infrastructure changes (see Fig. 6, left side). Small efforts, for example, the re-equipment of stops to change the direction of movement and intermediate stops, as well as the electrification of final and initial points will already significantly increase the share of such sections (Fig. 6, right side). [8]

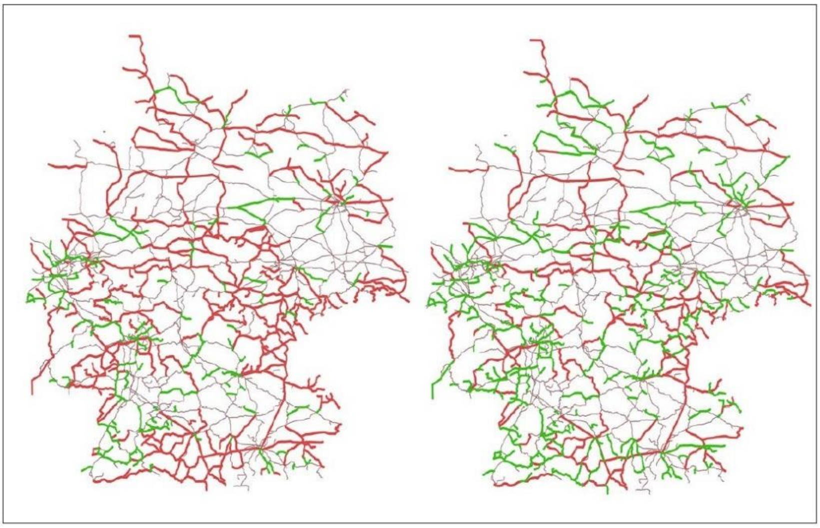

Fig. 6. Comparison of the areas already suitable for battery-powered MU (left, green lines), and after equipping all non-electrified terminals with charging stations (right, green lines) (the rest of the lines with diesel traction are red).

Additional measures should be taken to prepare the infrastructure on longer stretches that a battery train cannot pass without recharging, for example, overhead islands. Overhead islands are separated from the rest of the traction network and can be located both on railway sections and at railway stations. In terms of power supply, this means that in addition to the usual traction network (15 kV at 16.7 Hz), it is also possible to use a 25 kV at 50 Hz network. The choice of system depends on the planned rolling stock. Since it must be compatible, among other things, with the existing overhead infrastructure, only multi-system electric locomotives can be used with the 25 kV at 50 Hz system. The respective railway transport companies should choose their own electricity suppliers. In addition, overhead islands must meet the same technical and operational requirements as overhead cables on the rest of the DB Netz AG lines. [7]

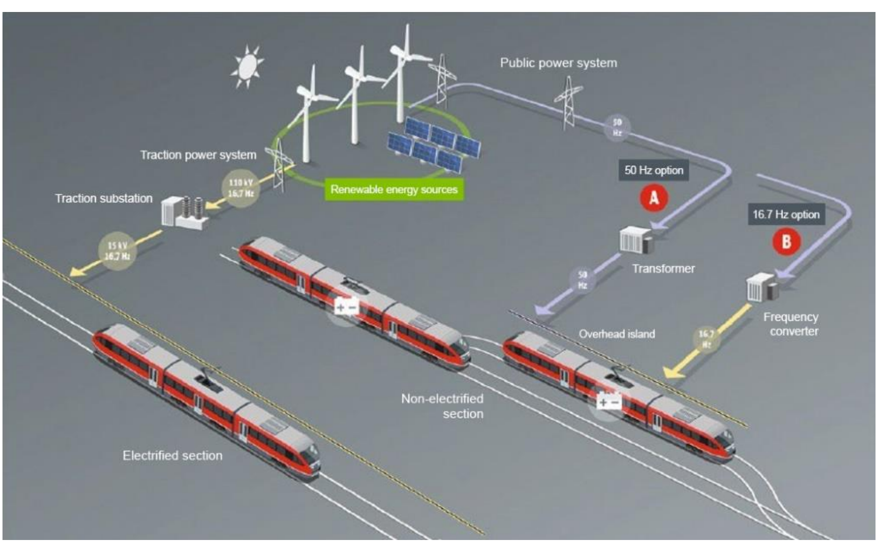

Fig. 7. Traction power supply system structure (1).

In general, there are three types of traction power supply:
- Supply from traction power plants, direct power supply to the 110 kV at 16.7 Hz traction power system, conversion of high voltage (110 kV) to medium voltage (15 kV) of overhead cables in traction substations (Fig. 7, left side),
- 50 Hz frequency current from public power system, conversion into a traction current with a 16.7 Hz frequency in central frequency converters, supplying energy to a traction power system at 110 kV at 16.7 Hz, conversion of high voltage (110 kV) into medium voltage (15 kV) of overhead cables in traction substations,
- 50 Hz frequency current from public power system, conversion into a traction current with a 16.7 Hz frequency in stand-alone frequency converters, direct power supply to overhead at 15 kV at 16.7 Hz.

The latter option is also applicable for overhead islands with a traction current of 15 kV at 16.7 Hz (Fig. 7, right side). [7]

3.3 Diesel hybrid rolling stock

The batteries can also be used in combination with diesel engines, such as the Prima H3 hybrid shunting locomotive by Deutsche Bahn (Fig. 8). It is a hybrid shunting locomotive with a diesel engine for freight transportation that has been used in the Westfrankenbahn regional network since April 2016. It accelerates to a certain speed using a battery, then the diesel engine is connected. As a result, fuel consumption is reduced by half compared to conventional shunting locomotives, and the volume of harmful emissions is reduced by 70%. [3] [9].

Fig. 8. Prima H3 hybrid shunting locomotive.

4 Energy efficient way of driving

Energy efficiency is gaining importance in addition to the development of new engine technologies for railway transport. Further improvement of modern rolling stock allows reducing energy consumption. For example, the new ICE 4 train is the most energy efficient per seat. Its energy consumption per seat is 22% lower than that of the ICE 1 train. This is primarily due to the fact that ICE 4, despite its very large passenger capacity (from 830 to 918 seats), has 670 t of empty weight, which is almost 120 t lighter than ICE 1. This weight reduction was achieved due to lighter trucks. Due to their narrow design, these can be aerodynamically clad on the non-powered end car. [13]

An energy efficient way of driving will further reduce energy consumption. To achieve this, Deutsche Bahn has been taking appropriate measures to improve drivers' qualifications since 2001. These measures include both theoretical basic training and practical exercises on the simulator. [3]

In addition, an energy consumption data information system has been introduced to analyze and optimize energy consumption during a train journey. Two main indicators are important in this case: the energy consumption of a particular train and the share of returned energy. Dynamic braking allows energy to be returned to the traction. If we subtract this share from the amount of energy received from the overhead lines, we will get the energy consumption of a particular rolling stock. At the same time, reducing the amount of energy coming from the network is more effective in terms of saving electricity than returning a large amount of energy. [3]

Power in and the amount of energy returned by the rolling stock are measured using electricity meters every five minutes. Since 2003, all electrically powered vehicles have been equipped with special meters for traction energy's measuring and accounting (TEMA). The resulting load profiles are analyzed and evaluated in the energy data information system. Drivers receive monthly data on the energy consumption of their trips and feedback on how the trips went in terms of energy consumption. [3]

5 Climate-neutral operation of railway infrastructure

According to the Deutsche Bahn report, the company successes to keep a positive dynamic (fig. 9) of increasing the percent of renewable energies used for traction. Including additionally purchased energy for all green DB products with 100% eco-power (for example S-Bahn (metro) Hamburg or DBeco plus) and taking into account a forecast based upon the Renewable Energy Sources Act subsidy [14]**.**

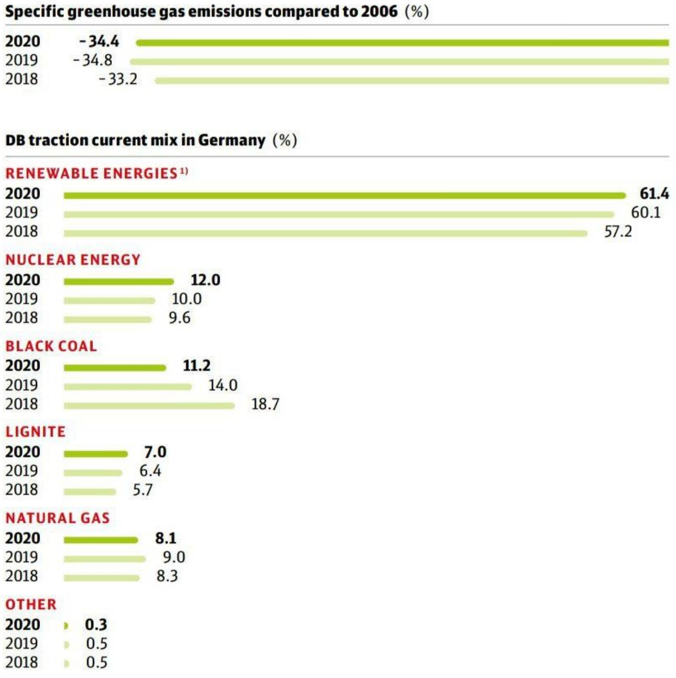

Fig. 9. Deutsche Bahn climate protection report 2020.

Based on the trend, Deutsche Bahn forecasts an increase in the share of renewable energy sources to at least 65 percent and aims to switch completely to climate-neutral sources by 2038 (fig.10) [14].

Fig. 10. Reported and forecasted share of renewable energies in DB traction current mix (%).

5.1 Railway stations

In order to achieve its climate goals, Deutsche Bahn must also ensure climate-neutral operation of its stationary facilities such as railway stations, technical and office buildings. They should be fully switched to renewable power by 2025. Since 2019, 33 Deutsche Bahn railway stations have been fully supplied with clean energy. However, to achieve full climate neutrality, further measures are needed, for example, conserving resources, increasing energy efficiency, and reducing emissions. [6] [13]

5.1.1 Green railway station in Horrem

Since 2014, the first CO2-neutral station in Europe has been operating in Horrem in North Rhine-Westphalia. Energy efficient technologies are implemented and natural resources are used at this station. The following is especially remarkable:
- Facade glazing amounts to 52% which allows the most efficient use of daylight,
- The rooftop photovoltaic plant with a collector area of 340 m2 generates 31,000 kWh of energy per year,
- The estimated annual energy requirement for heating, cooling, ventilation, hot water preparation, and lighting is fully covered by the solar power plant,
- The reduction of CO2 emissions compared to a conventional new construction according to the standard of the Energy Saving Ordinance is approximately 24 tons
- Geothermal heating and cooling: ground probes circulate water thus supplying the building with heat in winter and cooled air in summer,
- Locally produced and reproduced raw materials are used: production of the roof supporting structure from laminated veneer sheet, refusal of long-distance transportation,
- Landscaping of a 150 m2 roof allows rainwater infiltration to reduce the "heat island effect": the building and the surrounding areas heat up less, since the water is not drained away, but evaporates.
- Rainwater overflow is collected and used inside the building for flushing toilets [15]

5.1.2 Stationary fuel cell installations

Stationary fuel cell installations can be used to power route signs, sound warning systems, and lighting at rural railway stations. [5]

It is also possible to use stand-alone hybrid plants combining photovoltaic devices and fuel cells (Fig. 11). With good sunlight, solar energy is generated using a solar power plant. If the sunlight is insufficient, fuel cells are set up instead. In addition, a backup battery is used to store energy. A stand-alone unit can be used to power small consumers with a constant power of up to 100 W, for example, sensors or electronic displays. [5] [16]

Fig. 11. Stationary installation in Friedhausen (next to Giessen).

5.1.3 Reduction of energy consumption:

Lighting accounts for over 50% of the energy consumption at railway stations. Therefore, there are a lot of opportunities for savings. At the same time, LED equipment is an optimal alternative to conventional light sources. LED equipment reduces both the energy consumption of a specific facility and maintenance costs due to the longer lifespan of the lighting equipment. Gradually, LED equipment is being installed on lighting systems on platforms and in windows, as well as signs, information boards, and stair handrails. [15]

Elevators also consume a lot of energy, so the lighting in the elevator car switches off in standby mode. In addition, the station maintenance company DB Station&Service has been buying energy recovery elevators as standard since 2012. These elevators are equipped with an engine brake energy regeneration, thanks to which energy is returned to the network when the elevator moves down. [15]

5.2 Train safety devices

Alarm, interlocking, and control lock equipment must be equipped with standby power installations. They are necessary to keep the railway running in case of a power outage. According to the current regulations, fuel cell backup systems can also be used in this case. Until now, diesel generators have usually been used, which have many disadvantages due to their noise and pollutant emissions as well as the high space and maintenance requirements, which can be eliminated with a fuel cell.

In September 2018, Deutsche Bahn AG commissioned a fuel cell backup power plant in Sömmerda. Such a fuel cell backup installation consists of the following components: [5]

- Fuel cell module:

It converts reactive gases (usually hydrogen and oxygen) into electrical energy,

- Bypass battery system:

This system overlaps the start phase of the fuel cell (approximately 20 seconds),

- Current converter:

Since the fuel cell can only provide direct voltage, an inverter is necessary to convert the direct voltage into three-phase alternating voltage,

- Control unit:

It is responsible for recognizing situations in which backup power is needed. If such a need arises, the control unit disconnects the device connected after it (for example, an alarm, interlocking, and control lock equipment) from the public system and turns on the stand-alone power supply. After that, depending on the required power, additional fuel cells are started or turned off,

- Gas system/hydrogen storage tank:
Supplies the fuel cell with the required reactive gas. As a rule, gas cylinders or cylinder blocks are used as fuel tanks.

In the future, it is planned to digitize the entire track infrastructure as part of the railway digitalization program in Germany. Digital control and safety technology (DLST) are important elements of this process, in which new technologies (ETCS, European Train Control System) are to be connected to a new digital alarm, interlocking, and control lock equipment (DSTW). The equipment will be self-powered. In order to improve reliability and ensure operability in the event of malfunctions, a large number of emergency power systems will also be necessary in the future. [5]

6 Conclusions

To achieve its climate neutrality goals, Deutsche Bahn relies on the use of renewable energy sources to power its traction. By 2038, the traction network should be completely converted to renewable power. At the same time, the German railway network is electrified by only 60%. The process of railroad electrification should continue in the coming years. But equipping lines with overhead cables is costly and economically impractical, especially on secondary lines, therefore Deutsche Bahn is betting on the development of alternative engine technologies for railway rolling stock. These alternative technologies are most commonly used in hybrid forms that combine two drive technologies. Three variants are currently being developed: fuel cell battery hybrid vehicles, catenary battery hybrid vehicles, and diesel hybrid vehicles. Some of these trains are already used in regular services today, and others will be added in the coming years.

Fuel cells can also be used as stationary power supplies for railway infrastructure. These include, for example, train destination indicators, public address and lighting systems for rural stations, and emergency power supply systems for signal boxes.

In addition, improving the energy efficiency of both rolling stock and stations is becoming increasingly important. Energy efficiency is improved by, on the one hand, the weight reduction of modern trains and, on the other hand, by the energy efficient way of driving. At the railway stations, energy savings are achieved primarily through the targeted use of sunlight and the use of LED lighting. In addition, locally produced and sustainable materials are used in the construction of stations.

To summarize, climate neutrality requires the entire value chain, not in a single operation, but from production to disposal.

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