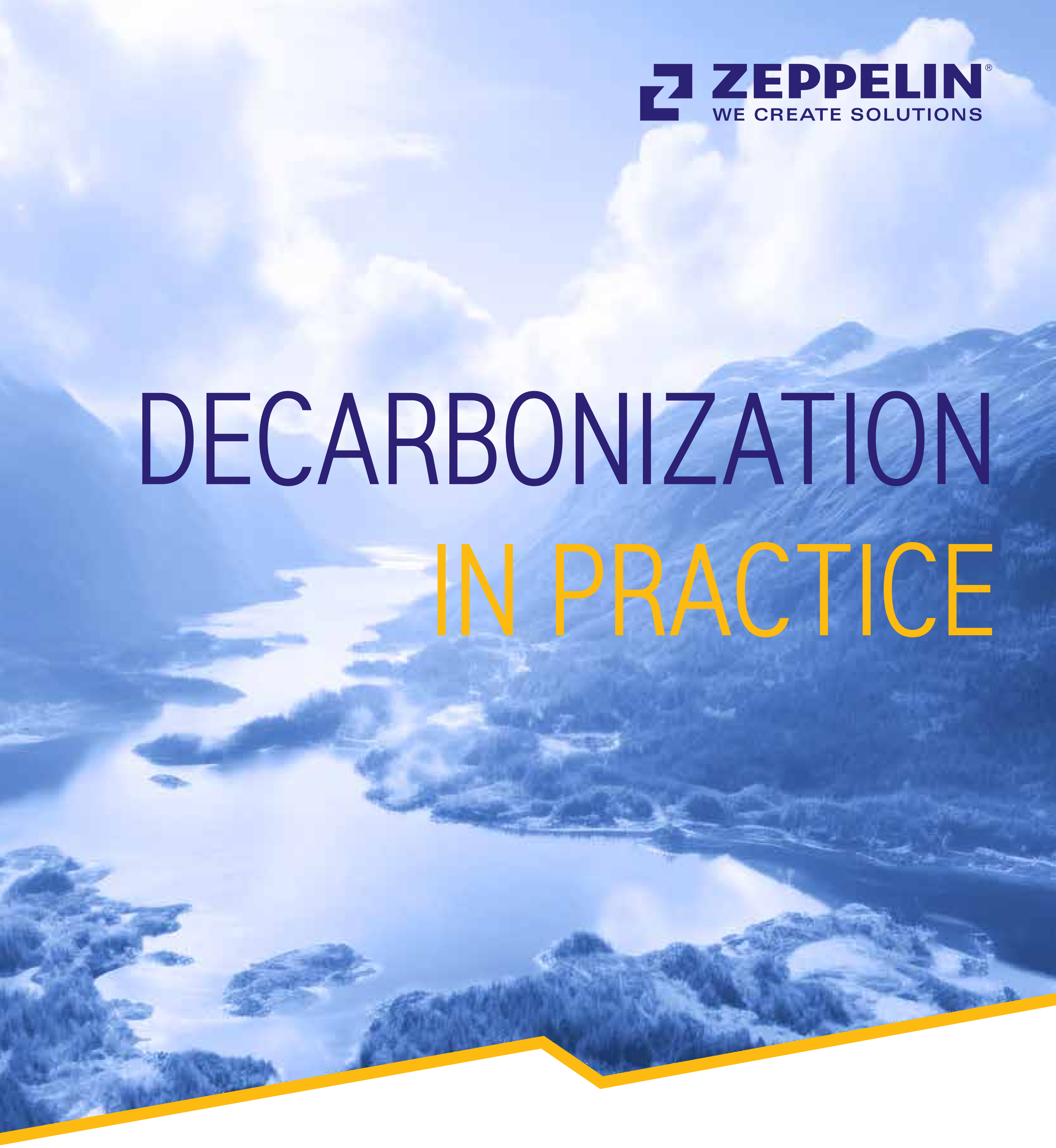


ZEPPELIN
WE CREATE SOLUTIONS

DECARBONIZATION IN PRACTICE

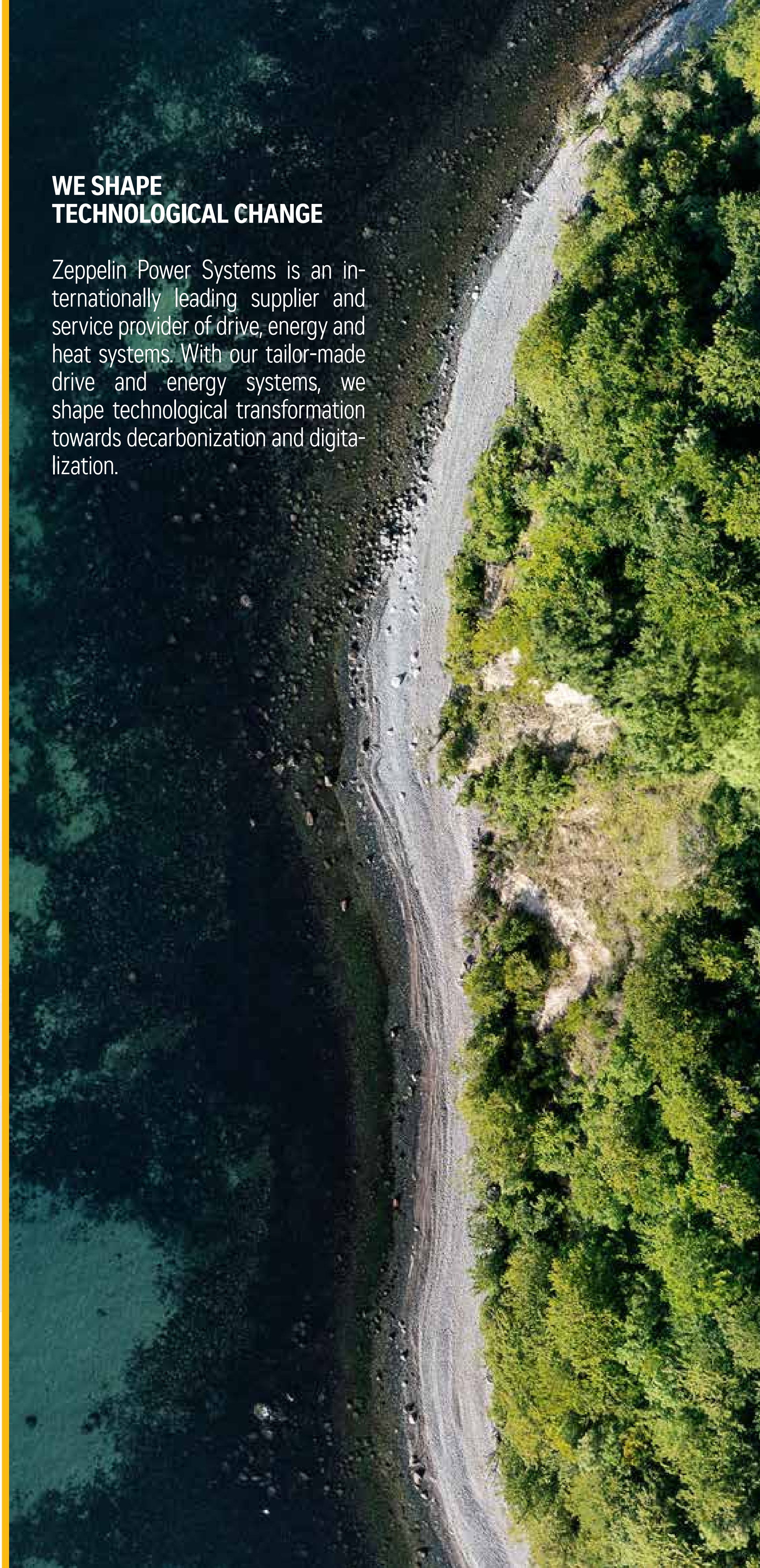
A GUIDE TO IMPLEMENTATION IN THE MID-SIZED INDUSTRY

TABLE OF CONTENTS

Please note:
To access the specific content, please click on the relevant chapter.

WE SHAPE TECHNOLOGICAL CHANGE

Zeppelin Power Systems is an internationally leading supplier and service provider of drive, energy and heat systems. With our tailor-made drive and energy systems, we shape technological transformation towards decarbonization and digitalization.



FOREWORD

Decarbonization is a key challenge for companies and entire industries worldwide. Especially in Europe and Germany, reducing CO_2 emissions plays a crucial role in achieving the ambitious targets set in the Paris Agreement and the European Green Deal.[1] To achieve the transformation to a climate-neutral economy by 2050, companies must rethink their production processes, supply chains and energy use and develop and implement innovative solutions to reduce emissions.

In addition to the diverse challenges of decarbonization, it also offers potential for **cost savings** and a **long-term increase in competitiveness**. Companies that embrace decarbonization at an early stage can reduce their operating costs and benefit from first-mover advantages by implementing innovative technologies and digitalized processes.

Small and mid-sized enterprises in particular have the potential to improve their market position, attract new customer groups and enter new niches through **innovative decarbonization strategies**. While end customers and private consumers are already demanding climate-neutral services today, large companies and public contracting authorities are increasingly expecting their suppliers to adhere to established environmental standards, which they explicitly outline in their tender criteria.

This whitepaper is designed to help companies identify the first steps to decarbonize their own assets and highlight potential strategies for action.

Have fun reading!

Your team from Zeppelin Power Systems

[1] https://www.bmz.de/de/service/lexikon/klimaabkommen-von-paris-14602

REGULATIONS AS PACESETTERS FOR DECARBONIZATION

All policies and laws to reduce greenhouse gas emissions are based on the **2015 Paris Agreement**, which was adopted by 195 countries. The aim is to limit the rise in global temperature to 1.5°C if possible, but to a maximum of 2°C.[2] The concrete implementation of the agreed targets is the responsibility of the individual countries. Every five years, a global inventory is held to review progress and ensure targets are met.[3]

In line with the Paris Agreement, the **European Green Deal** represents the European Union's comprehensive strategy whose objective is to achieve climate neutrality by 2050. The **EU Commission** has set an interim target of reducing emissions by 55% by 2030 compared to emissions in 1990.[4] These targets are enshrined in the EU Climate Law of 2020, making the aim of climate neutrality legally binding. In order to implement the necessary measures, the **Fit for 55 package** was launched.

[2] https://www.bmz.de/de/service/lexikon/klimaabkommen-von-paris-14602
[3] https://www.bmwk.DE/Redaktion/DE/Artikel/Industrie/klimaschutz-abkommen-von-paris.html
[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119&from=FR.

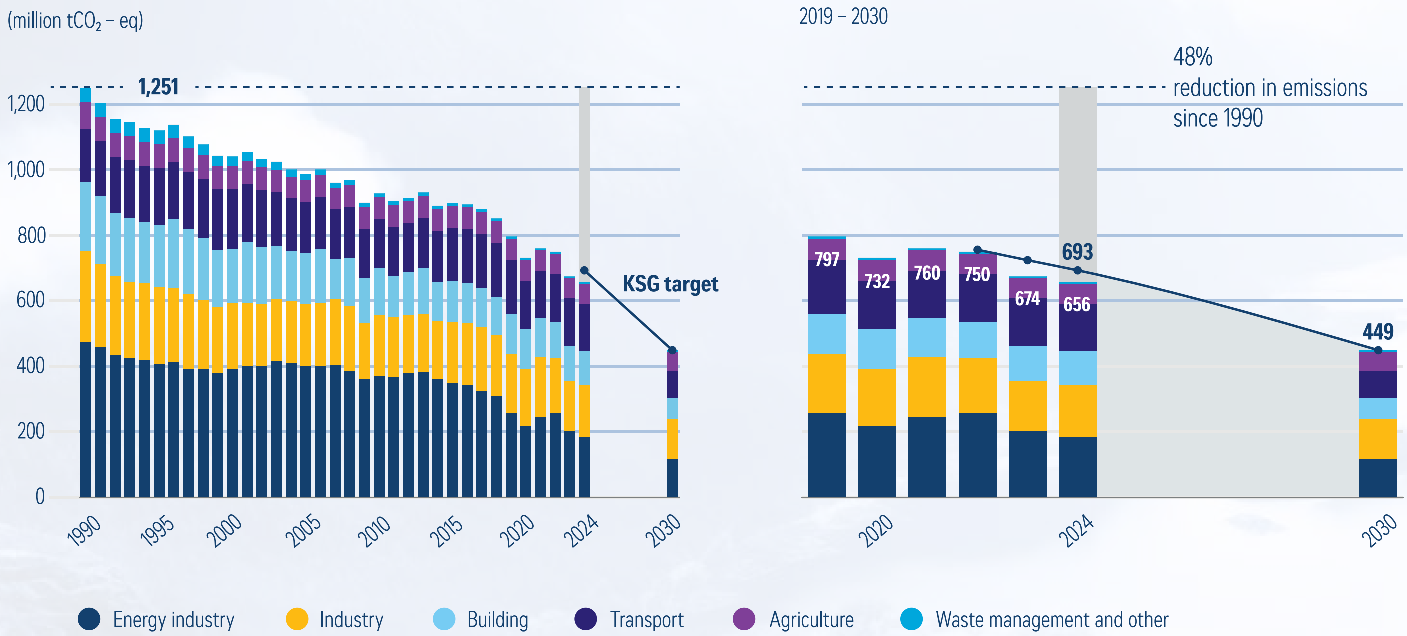
Selection of concrete measures from the Fit for 55 package

MEASURES OR GUIDELINES	DESCRIPTION
Renewable Energy Directive (RED II or RED III)[5]	The aim is to increase the share of energy from renewable sources in the overall energy mix. This is done, among other things, through sectoral sub-targets in areas where progress is slow, such as transport, building and industry. Under RED III, 42.5% of the EU's total energy consumption is expected to be renewable energy in 2030.
Energy Efficiency Directive (EED)[6]	The Energy Efficiency Directive (EED) requires EU Member States to take measures to increase energy efficiency and to draw up national energy efficiency action plans. The aim is to reduce energy consumption and promote the use of energy-efficient technologies in various sectors.
FuelEU Maritime[7]	FuelEU Maritime sets limits for the annual greenhouse gas intensity of ships above 5,000 GT calling at EU ports. The intensity is to be reduced by 2% in the first step from 2025 and by 80% by 2050. From early 2030, passenger and container ships in European ports will also need to use shore power or other emission-free technologies, and monitoring of GHG intensity began on January 1, 2025.
Reform of the EU Emissions Trading System (EU ETS)[8]	The EU ETS is a CO_2 market where emission allowances for energy-intensive industries and the electricity sector are traded. A gradual reduction and possible cessation of the free allocation of allowances are planned, as well as an expansion to include emissions from maritime transport.
Carbon border adjustment mechanism (CBAM)[9]	CBAM aims to protect competitive conditions for European companies. To this end, the limit compensation system charges a price on CO_2 emissions for imports of certain goods. The measure prevents companies from relocating their production to non-EU countries where emission limits and climate protection measures are less ambitious. It is also intended to stimulate more climate-friendly production outside Europe.

[5] https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules
[6] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules
[7] https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime
[8] https://eur-lex.europa.eu/EN/legal-content/summary/eu-emissions-trading-system.html
[9] https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

The **Climate Action Plan 2050** represents the long-term climate policy strategy of the Federal Republic of Germany and has been developed in line with the Paris Agreement. The **Federal Climate Action Act (KSG)** forms the core of national climate policy and has since been adapted and tightened several times. A reduction rate of at least 65% of greenhouse gas emissions is set for the target year 2030. Emissions are to be reduced by at least 88% by 2040. In addition, Germany is aiming for net greenhouse gas neutrality by 2045, which would have been five years earlier than required by the EU.[10 11]

Development of greenhouse gas emissions in Germany by sector since 1990



Agora Energiewende (2024) according to UBA (2024a) – 2024: estimate of Agora Energiewende based on AGEB (2024a). Target path derived from the German Climate Action Act (KSG).
Exclusive land use, land use change and forestry.

Image source: https://www.agora-energiewende.de/publikationen/die-energiewende-in-deutschland-stand-der-dinge-2024

[10] https://www.gesetze-im-internet.de/KSG/KSG.pdf#
[11] https://www.bundeswirtschaftsministerium.DE/Redaktion/DE/Downloads/klimaschutz/20231004-klimaschutzprogramm-der-bundesregierung

Selection of concrete measures from the 2023 climate protection program

MEASURES	DESCRIPTION
Renewable Energy Sources Act (EEG 2023) [12]	By 2030, at least 80% of electricity consumption in Germany is to come from renewable energies. The law creates incentives for the use of solar, wind and bioenergy, thus promoting the expansion of renewable energies in Germany.
Combined Heat and Power Act (KWKG) [13]	The KWKG promotes the simultaneous generation of electricity and heat in order to increase energy efficiency and reduce CO_2 emissions. It provides financial incentives and feed-in tariffs for cogeneration producers to improve their profitability and support the use of renewable energy.
Updating the national hydrogen strategy [14]	By 2030, 30 to 50% of Germany's hydrogen demand is to be met locally. In addition, the construction of a hydrogen core network is planned by 2032, as is the development of a comprehensive hydrogen filling station network.
Heat Planning Act (WPG) [15]	The WPG obliges all municipalities in Germany to draw up heat plans to make the local heat supply more sustainable and climate-neutral. In addition, all heating networks must be operated climate-neutral by 2045 by being fed exclusively from renewable heat sources and unavoidable waste heat.

Companies are increasingly required not only to address sustainability issues and decarbonization, but also to publish comprehensive information about them. The **Corporate Sustainability Reporting Directive (CSRD)** significantly expanded reporting obligations at EU level. The obligations no longer only concern large enterprises of public interest, but now also include small and mid-sized capital market-oriented enterprises as well as all large enterprises within the meaning of accounting law. It is estimated that the number of companies affected in the EU will increase from around 11,600 to around 49,000. The new reporting obligations have applied to larger companies since financial year 2024, while small and mid-sized enterprises (SMEs) will be included in the scope of the CSRD from 2026. These developments aim to increase transparency and accountability in the area of sustainability and encourage companies to actively contribute to the implementation of sustainable practices. [16]

[12] https://www.bundesregierung.de/breg-de/schwerpunkte/klimaschutz/novelle-eeg-gesetz-2023-2023972
[13] https://www.eon.de/de/gk/energiewissen/kwkg-2023.html
[14] https://www.bmftr.bund.de/DE/Forschung/EnergieKlimaUndNachhaltigkeit/Energie/WasserstoffUndSynthetischeKraftstoffe/wasserstoffundsynthetischekraftstoffe.html
[15] https://www.bmwsb.bund.de/SharedDocs/gesetzgebungsverfahren/DE/kommunale-waermeplanung.html
[16] https://www.csr-in-deutschland.de/DE/CSR-Allgemein/CSR-Politik/CSR-in-der-EU/Corporate-Sustainability-Reporting-Directive/corporate-sustainability-reporting-directive-art.html

CHALLENGES AND OBSTACLES IN IMPLEMENTATION

To implement targeted decarbonization measures within the company, it is essential to first accurately identify the sources of emissions in own operations. The company's CO_2 footprint, also known as the **Corporate Carbon Footprint (CCF)**, plays a central role here. This provides information on how many greenhouse gases are generated and in which areas they occur. The Greenhouse Gas Protocol is considered the most commonly used standard for calculating companies' greenhouse gas balances. It distinguishes between direct and indirect greenhouse gas emissions and divides the emissions into three "scopes". [17] [18]

Scope 1

includes all **direct emissions** that a company **causes itself** and can control. These include, for example, emissions from production processes, the combustion of fossil fuels in own plants or emissions from own vehicles. Scope 1 emissions can be reduced comparatively easily, as they are under the direct control of the company. Clear reduction potentials can be identified, in particular through a reduction in fossil fuel consumption and the switch to renewable energies.

Scope 2

includes **indirect greenhouse gas emissions** resulting **from the purchase of energy in the form of electricity, heat or cold**. Scope 2 emissions are more dependent on local conditions and can only be influenced by the company to a limited extent. However, emissions-intensive energy purchases and consequently emissions can be reduced through energy-saving measures, enhanced energy efficiency, and the procurement or in-house production of renewable energy.

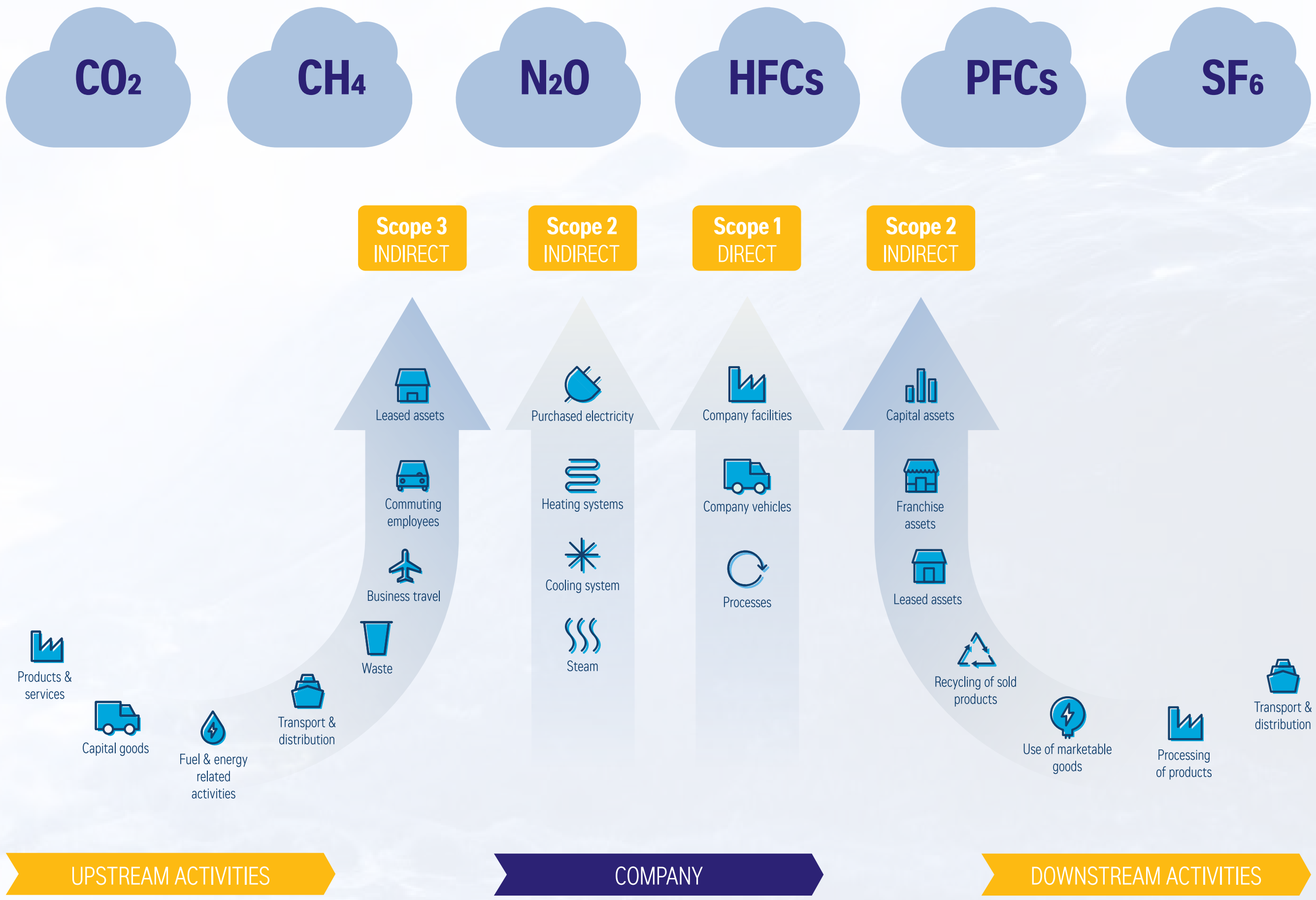
Scope 3

includes **indirect greenhouse gas emissions** that occur **throughout a company's upstream and downstream value chain**. Emissions include, among other things, those arising from the mining and production of procured raw materials, components and materials, as well as from the upstream and downstream transport of goods. Emissions arising from waste and its disposal as well as from the use of manufactured products by end customers are also included in this area. Scope 3 emissions are diverse and more difficult to capture and influence as they depend on partners, suppliers and customers along the entire value chain.

[17] https://www.epa.gov/climateleadership/scope-3-inventory-guidance

[18] https://saim.de/content-hub/blog/scope-1-scope-2-scope-3-emissionen-beispiele-123/#:~:text=mittelbaren%20Einflusses%20relevant%3A%20Scope%201,und%20Lassen%20der%20Wertsch%C3%B6pfungspartner%20abh%C3%A4ngig.

Three scopes when considering direct and indirect greenhouse gas emissions



CO_2	Carbon dioxide	HFCs	Hydrofluorocarbons
CH_4	Methane	PFAS	Per- and Polyfluoroalkyl substances (synthetic chemicals)
N_2O	Nitrous oxide	SF_6	Sulfur hexafluoride

Implementing new technologies presents numerous challenges that affect both technical and economic aspects. One of the main obstacles is **technological integration and maturity**. Many decarbonization technologies have made different progress as to their stages of development.

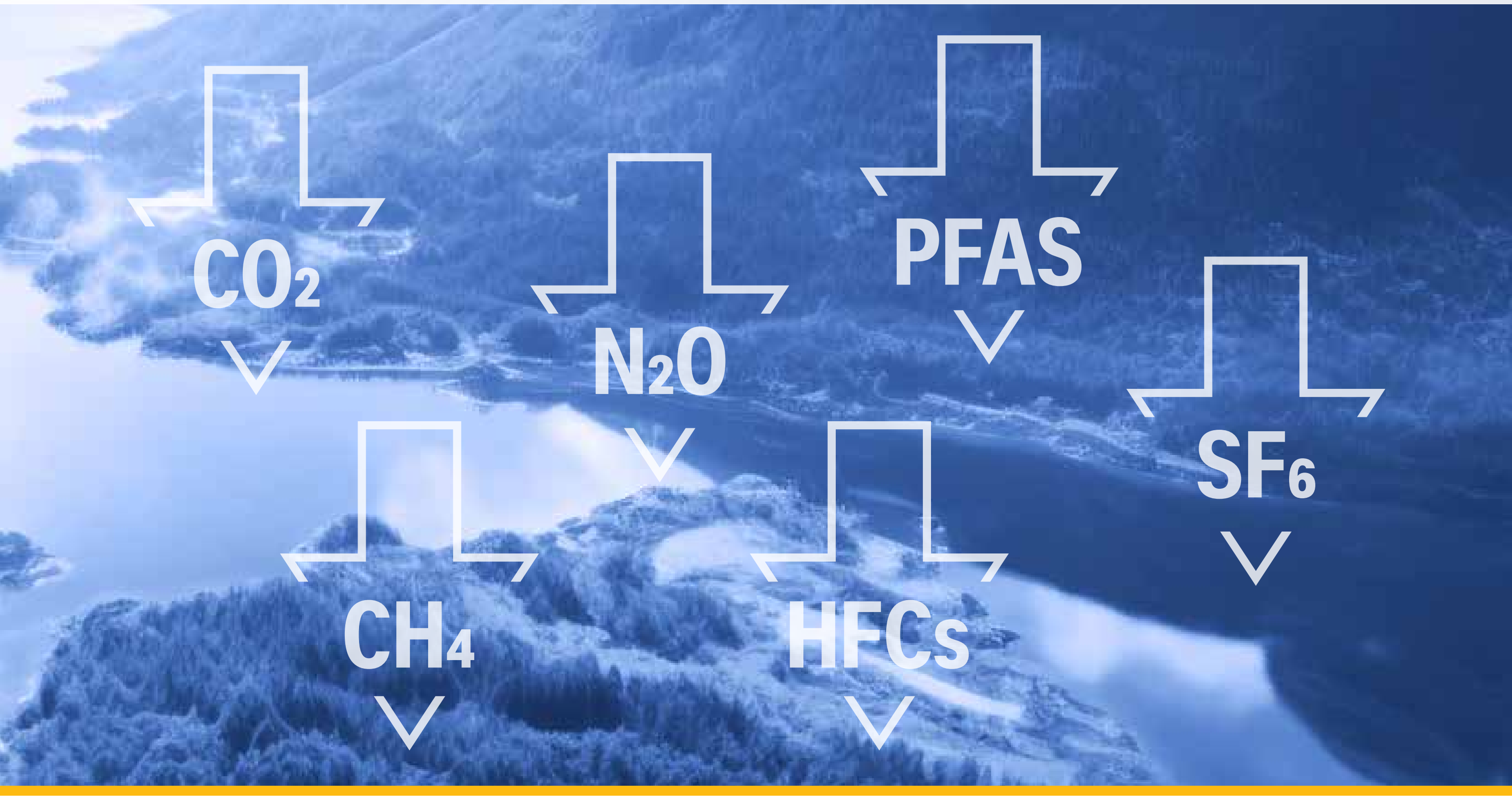
The **infrastructure** also plays a crucial role in the implementation. New technologies not only need to be developed, but also embedded in existing infrastructures. This requires significant adjustments and investments, as existing systems are often not designed to take advantage of advanced decarbonization technologies.

Another challenge is the **cost** and **financing** of new technologies, especially for small and mid-sized enterprises. In addition, the return on investment (ROI) can often only be realized after a long period of time, which makes many companies hesitate. However, there are various funding options available to companies that can help alleviate financial obstacles.

In addition, the **shortage of qualified professionals** hampers implementation. New technologies require specialized professionals to ensure installation, operation and maintenance.

Inconsistent or **unclear rules** for recording emission reductions further complicate the achievement of climate neutrality. For example, all emissions along the entire life cycle (including Scope 3 emissions) must be considered. However, different actors often disagree on the implementation of these standards.

After all, a key challenge is the **uncertainty about future developments**. Technological progress is often hard to predict, which hinders forecasts regarding market development, user acceptance, and environmental impact. Furthermore, the lack of long-term data can complicate the assessment of life cycle costs and impacts.



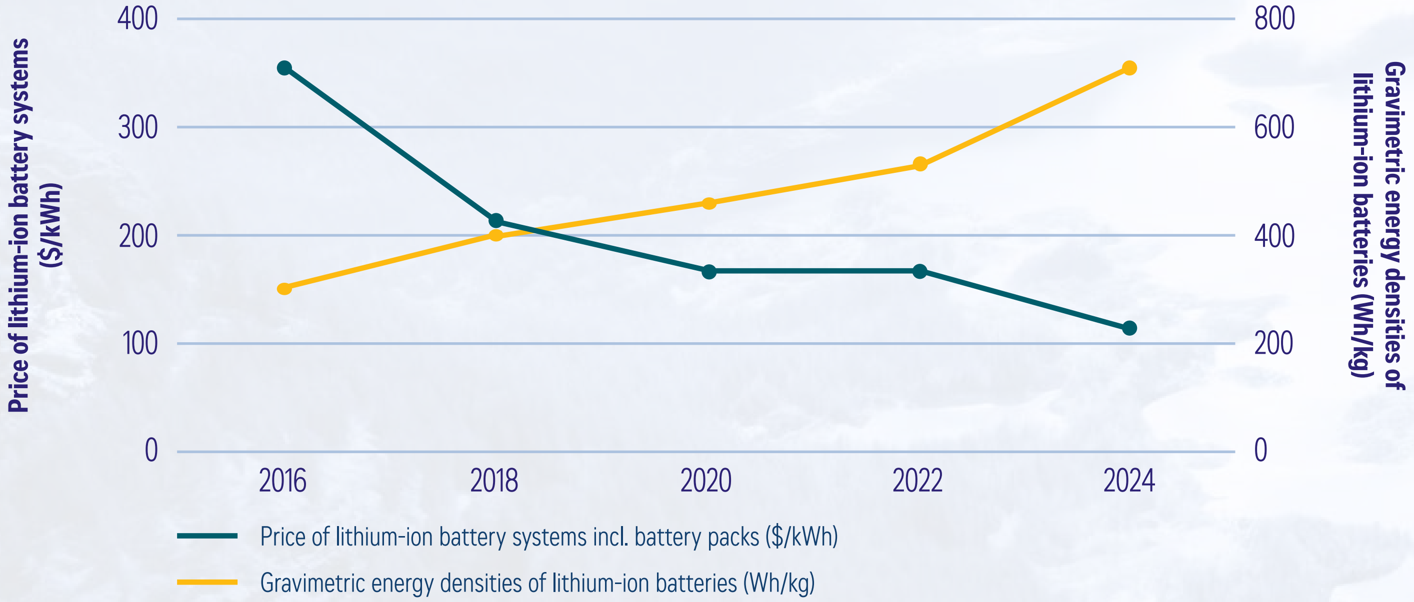
DECARBONIZATION TECHNOLOGIES FROM ELECTRIFICATION TO E-FUELS

LATEST-GENERATION BATTERY STORAGE: THE ROLE OF LITHIUM-ION BATTERIES IN DECARBONIZATION

Battery storage represents a key technology for the transformation of modern energy systems and is considered an essential building block for achieving decarbonization goals in mobile as well as stationary applications. Technological advances in the automotive sector in particular could significantly increase both the energy density and the efficiency of battery systems. Already today, batteries are increasingly replacing the combustion engine or acting as a primary energy storage solution – especially in applications with low to medium energy and power requirements (<300 kW).

In addition to the particularly energy-dense NMC batteries (nickel manganese cobalt), LFP batteries (lithium iron phosphate) are increasingly used, which have a lower energy density, but also result in lower costs. In addition to developments in volumetric energy density, first of all, one of the biggest drivers of the technologies are the **falling production costs**. For example, prices for both battery cells and complete battery systems have fallen steadily in recent years, with the exception of a short period around 2022. For large projects in the MWh range, especially for stationary applications, the costs of complete battery systems are now $100-200/kWh, of which the battery cells account for around half of the costs (as of 2024).

Price development and energy densities of lithium-ion batteries over time



Prices: BloombergNEF report from 12/2024
https://about.bnef.com/insights/commodities/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/

Energy density: https://physicsworld.com/a/lithium-ion-batteries-break-energy-density-record/

For stationary and mobile non-automotive applications, the costs for the packager are also added. This integrates the universal cells into a complete system, including power electronics and control – ready for deployment in locomotives, marine applications, or stationary setups. As volumes here are still small but steadily increasing, costs for end users are expected to continue to fall in the coming years and batteries will be suitable for an ever-increasing number of applications.

The feasibility of a solely battery-powered energy system depends largely on the specific requirements and framework conditions of the respective application:

- Cycle of possible charging processes
- Total energy required
- Energy system volume and weight requirements
- Available infrastructure
- Regional and application-specific requirements for CO_2 emissions
- Available investment volume

The variety and complexity of the influencing factors illustrate the need for an upstream feasibility analysis for each project that considers the use of a battery-electric drive or energy system.

Exkurs – Cat® battery for off-highway applications

Find out more about stationary and mobile battery solutions for industrial use.

Contact:

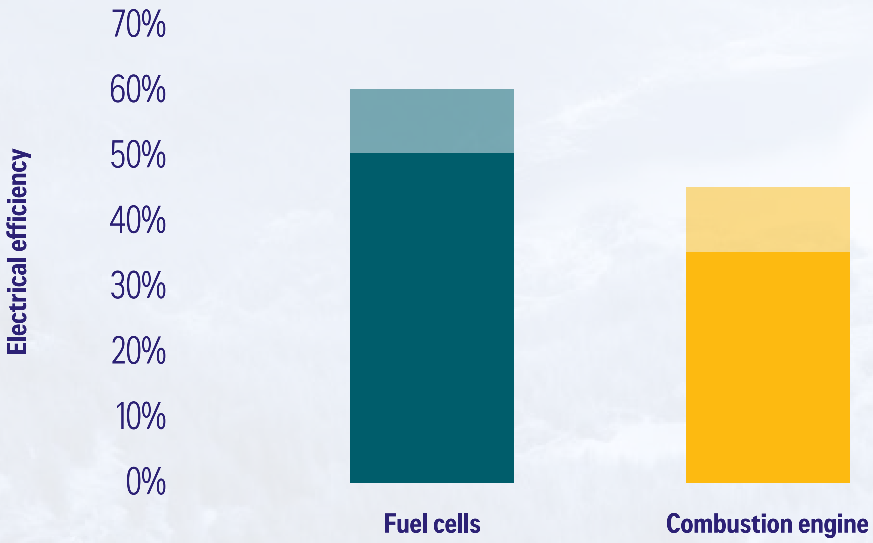
zps.hamburg@zeppelin.com

FROM PRODUCTION TO APPLICATION: FUEL CELLS IN A GROWING HYDROGEN ECONOMY

Fuel cells are a promising solution for decarbonizing many sectors and applications that cannot be directly electrified due to the low energy density of batteries. When operated with hydrogen, they convert chemical energy directly into electrical energy, with water being the only by-product. Fuel cells offer an **emission-free alternative** to conventional diesel and gas drives and are suitable for applications where high energy density and long operating times are required, such as in **ships**, **trains** and **stationary energy systems**.

With increasing efforts to use fuel cells in heavy-duty transport, there are more and more suppliers on the market offering fuel cells for both automotive and non-automotive applications. Again, fuel cells benefit from the economies of scale generated and standardizations that are expected to reduce the cost of fuel cell components such as bipolar plates, membranes and catalysts by more than 50% over the next few years.[19] In addition, these economies of scale are driven by developments in electrolysers, which have a large number of components in common with fuel cells.

Electrical efficiency of fuel cells compared to conventional combustion engines



[19] https://hydrogencouncil.com/en/path-to-hydrogen-competitiveness-a-cost-perspective/

Hydrogen Council. (2020). Path to hydrogen competitiveness: A cost perspective. Press release January 20, 2020.

The biggest challenge in the introduction of fuel cells is the availability of cheap and green hydrogen. While there is currently only a very limited amount of green hydrogen in Germany and Europe, the planned and ongoing projects indicate that the amount of hydrogen available will increase significantly in the coming years. There are a large number of projects, especially in Central and Western Europe. However, many of these are currently still being planned or undergoing a feasibility study.

Overview map of ongoing and announced hydrogen production projects in Europe

Image source: https://www.iea.org/data-and-statistics/data-tools/hydrogen-production-projects-interactive-map

Exkurs – Fuel cell power generator from Zeppelin Power Systems

Whether a fuel cell is a sensible option for decarbonizing the respective application depends on various factors, where the Total Cost of Ownership (TCO) should always be considered. Fuel cells have made major leaps in efficiency and power density in recent years, which have an increasingly positive impact on TCO. In addition, the falling cost of hydrogen will make the fuel cell a viable alternative for applications that collect high operating hours per year.

At Zeppelin Power Systems, we are working to shape **technological change** with our customers. To demonstrate our expertise, we constructed a demonstrator of an electricity generator based on a PEM fuel cell. The demonstrator is a **hybrid energy system** consisting of a 50 kW fuel cell and a 36 kWh high-voltage battery as well as an integrated hydrogen storage system. The demonstrator is designed to be particularly robust, allowing it to be tested in a wide variety of applications – from the construction site to festival. The insights gained from the operation of the demonstrator will contribute to the development of another hybrid energy system that will be more compact, more powerful, and the first commercial fuel cell product of Zeppelin Power Systems.

The fuel cell power generator developed by Zeppelin can be operated with hydrogen and offers an emission-free and low-noise type of power generation. The hybrid fuel cell and battery system is suitable for numerous construction site or industrial applications and can be used in stationary, marine or rail applications, among other things.

Contact:

Zeppelin Fuel Cell Competence Center:
Keno Leites, Head of Fuel Cell Competence Center,
E-mail: keno.leites@zeppelin.com

OPPORTUNITIES AND LIMITATIONS OF LOW-CARBON FUELS

In addition to direct electrification or the use of hydrogen, **alternative, low-carbon or carbon-free fuels** are already being used today. This means that these fuels are almost CO_2 neutral throughout production and use. These include biofuels and synthetically produced e-fuels. These are primarily used where direct electrification is not possible due to power and space requirements. Each fuel has advantages and disadvantages and is therefore more or less suitable for certain areas of application.

While fuels such as **methanol, methane** and **ammonia** require changes to the energy converter, biofuels such as **biodiesel** and **HVO** can be used without major conversions. Most engines are already approved for biofuels, so these fuels, known as drop-in fuels (alternative fuels that can be used at any time and without technical changes), can be used without problems. However, as the availability of biofuels is limited, not all applications can be decarbonized by them. It has been projected that global production capacities will cover only 2.5% of global consumption by 2028. There is also a constant conflict between the use of cultivated land for biofuels and its use for food production. The use for the respective applications (aviation, automotive, industry, heat generation) is also discussed for existing capacities.[20][21][22]

E-fuels, on the other hand, are not subject to any restrictions attributable to the availability of cultivated land. They are produced by methanol or Fischer Tropsch synthesis based on CO_2 and hydrogen from electrolysis. Due to the large number of process steps required, it is assumed that the production of e-fuels per kilowatt-hour is significantly more cost-intensive than the direct use of electrical energy in battery storage systems or the use of **hydrogen**.

Caterpillar Hydrogen Gensets

[20] https://de.statista.com/statistik/daten/studie/198562/umfrage/verbrauch-von-otto-und-dieselkraftstoffen-in-deutschland/

[21] https://www.chemanalyst.com/industry-report/diesel-market-2925#:~:text=The%20global%20Diesel%20market%20stood,internal%20combustion%20engines%20(ICE)

[22] https://www.argusmedia.com/en/news-and-insights/topical-market-themes/hvo

"Well-to-tank" fuel costs in euros per liter diesel equivalent for 2030 [23]

2030 (euros/liter diesel equivalent)	Diesel reference	CGH_2	LH_2	$PtCH_4$ as LNG	PtL-methanol	PtL-diesel
Power generation, transport and distribution		1.21	1.19	1.29	1.52	1.70
H_2 production		0.21	0.12	0.14	0.14	0.17
H_2 storage incl. compressor		0.22	0.22	0.03	0.03	0.17
H_2 liquefaction, hydrogenation LOHC			0.19	0.21	0.26	0.33
CO_2 capture and storage				0.05	0.16	0.21
Methanization, synthesis					0.05	0.16
Gas network					0.03	
Large-scale gas storage incl. compressor				0.04		
Fuel distribution by truck			0.14		0.08	0.04
CH_4 liquefaction				0.19		
Filling station		0.44	0.10	0.06	0.02	0.02
Total	0.55	1.85	1.96	2.03	2.21	2.64

Overall, the use of e-fuels can be beneficial if the application in which they are utilized has only a limited number of operating hours. As a result, CAPEX would be the decisive factor for the Total Cost of Ownership (TCO), while operating costs (OPEX) would be negligible. However, this must be considered from application to application in a TCO analysis.

[23] https://www.now-gmbh.de/wp-content/uploads/2020/09/now_studie-ship-fuel-1.pdf (p.93)

Cat® C13D

Engine of the future and platform for future hydrogen solutions

Exkurs – low-carbon fuels at Caterpillar

With decades of experience in the field of alternative fuels, Caterpillar relies on hydrogen as a pioneer of a greener future. This means that a large number of gas engines can already be operated today with up to 25% hydrogen. A Caterpillar pilot project also confirmed the use of the 3516H generator with 100% hydrogen. In addition to the developments in the gas engine sector, Caterpillar has announced a three-year program to demonstrate hydrogen hybrid solutions based on the new C13D engine platform.

Robust, compact and with an enormous power range: The Cat® C13D achieves the highest power density of all diesel engines in the 13 liter segment. Like all Cat® engines, the Cat® C13D is compatible with alternative fuels such as HVO or biodiesel. It is also the platform for future hydrogen solutions.

Learn more about the new Cat® C13D.

Contact:

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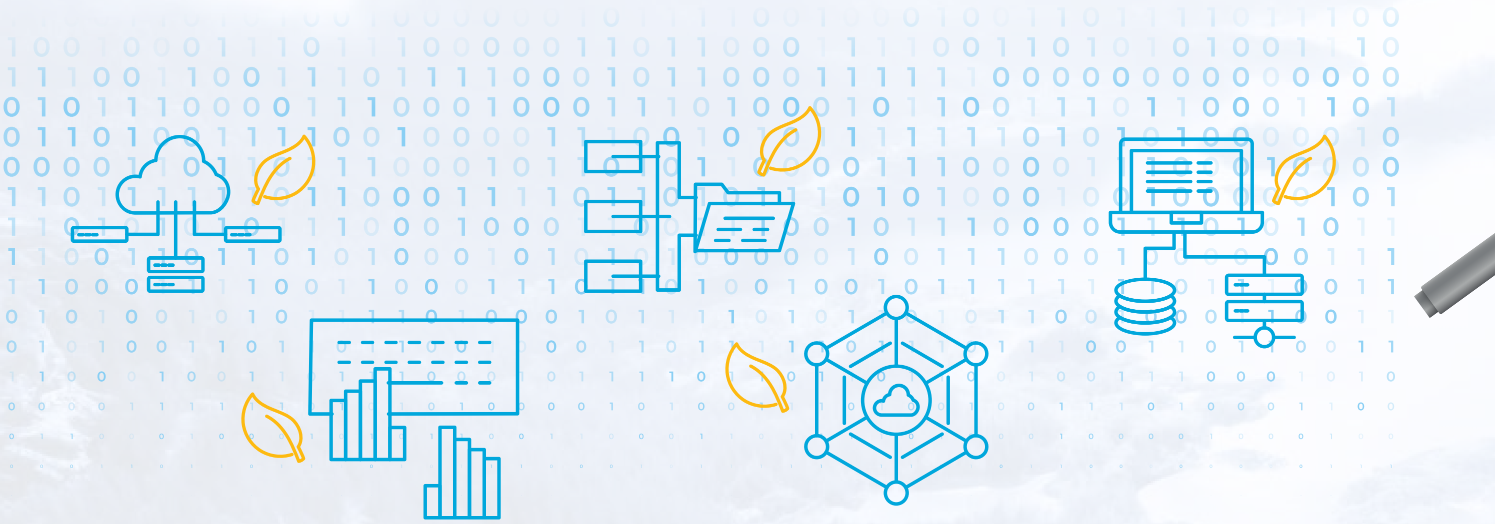
DIGITALIZATION AS AN ENABLER OF DECARBONIZATION

Digitalization plays a key role in supporting and optimizing decarbonization efforts in various sectors. The transition to alternative energy systems always begins with the design of the energy system and the simulation of different operations in a **digital twin**. In order to do this as realistically as possible and thus get the maximum efficiency from the configuration, various data on the applications and the respective operating profiles are required. In addition to the number of data points, the data resolution and quality are also of great importance.

Using this data, a design is feasible, particularly in the **combination of multiple energy converters or energy storage systems**. Incorrect design can lead to both higher investment costs and higher operating costs, thereby reducing the profitability of the application. It is therefore advisable to collect as much operating data as possible before deciding on an alternative energy system, in order to have a comprehensive data foundation ready when planning a conversion or new construction.

In addition, the data can already today help to support the primary processes and increase the service life of the application through **predictive maintenance**, as well as facilitate troubleshooting.



Exkurs – digital solutions from Zeppelin Power Systems

Zeppelin Power Systems' digital solutions allow you to control and manage motor and system data. A telematics module connects the engines and collects all operating, status and location data in real time. The IoT platform offers secure data processing and evaluation. Your information is made available from anywhere in a viewer portal via a customized configurable dashboard.

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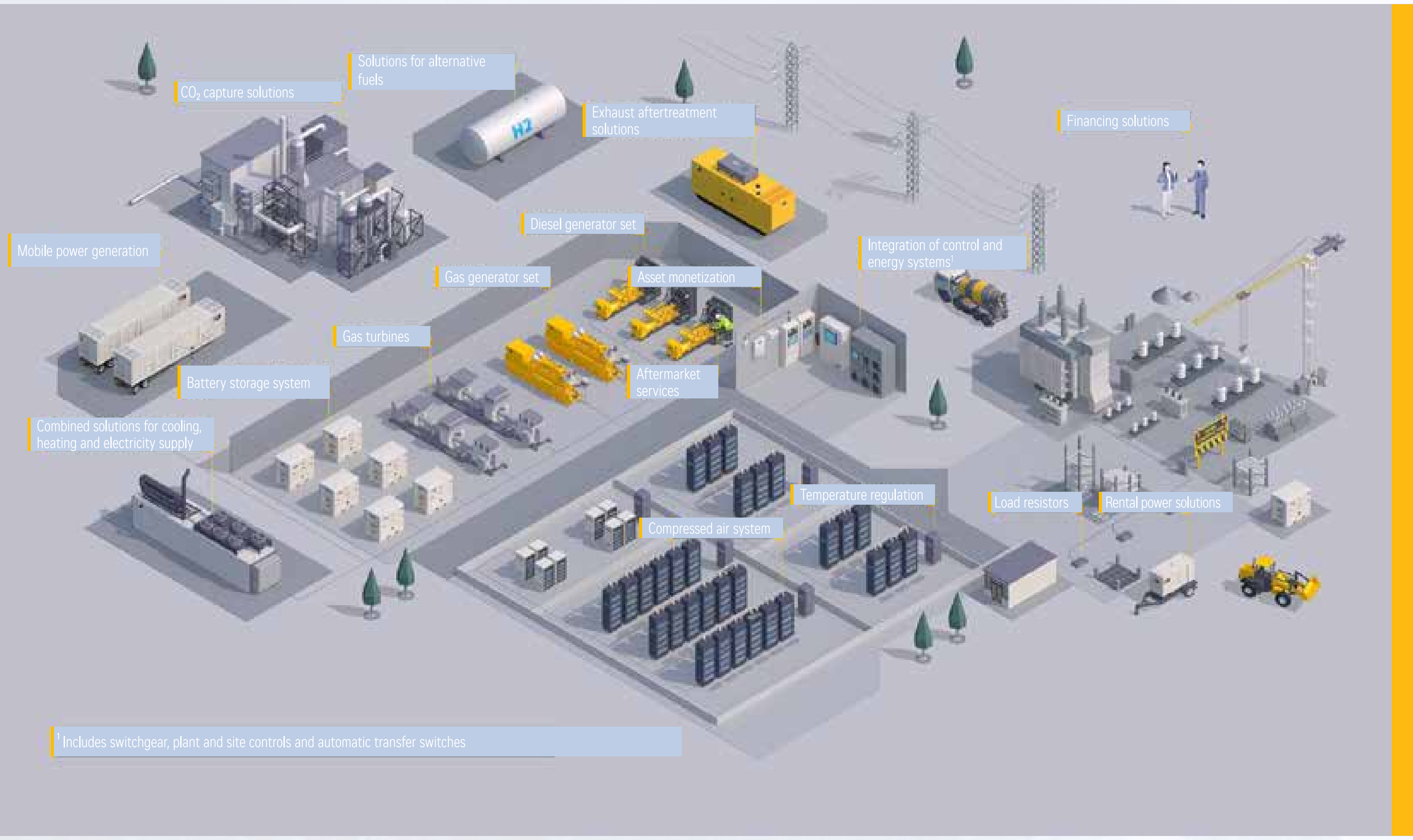
MEASUREMENT CRITERIA FOR SELECTING SUITABLE TECHNOLOGIES

In order to measure technologies holistically, the four categories of **technology, economy, system aspects** and the **environment** must be considered. The technology category examines the technical availability and maturity of the technology, as well as the system safety and compatibility with existing systems. In the economy category, the focus is on cost efficiency, both in terms of capital expenditure (CAPEX) and operating costs (OPEX).

The system aspects take into account possible path dependencies, regional dependencies as well as regulatory requirements and infrastructure dependencies that can influence the use of the technology. Finally, the environment category includes energy efficiency and greenhouse gas (GHG) efficiency, as well as the impact of technology on emission control. These dimensions provide a comprehensive basis for evaluating decarbonization technologies in all their complexity.



Source: Caterpillar

Choosing the right measurement criteria plays a key role in the success of a technology measurement. These criteria determine which aspects are included in the analysis and thus influence how a technology is assessed overall. Careful selection of these benchmarks is therefore crucial to obtain a comprehensive and accurate picture of the technology.

Measurement of decarbonization technologies against various criteria[24]

Technology

- Technical availability & maturity
- System security
- Compatibility

Economy

- Cost efficiency (CAPEX & OPEX)

Environment

- Energy efficiency
- GHG efficiency
- Effects on immission control and waste generation

System aspects

- Creating path dependencies
- Regional dependencies
- Regulatory requirements
- Infrastructure dependency

[24] https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/05_2024_cc_dekarbInd_tb1.pdf

METHODS FOR THE COMPARISON AND MEASUREMENT OF DIFFERENT TECHNOLOGIES

The methods for the measurement of technology are diverse and should be carefully adapted to the respective measurement objectives and issues. Essentially, these methods can be divided into qualitative and quantitative approaches, which are often used in combination to ensure a comprehensive analysis.

Quantitative methods include, among other things, the analysis of the **Total Cost of Ownership (TCO)**, which relates to the total cost of a project over its entire life cycle. This includes not only one-off expenses such as investments in technical infrastructure (CAPEX), but also ongoing operating, maintenance, disposal and dismantling costs (OPEX). As the recording of these costs is often based on estimates and assumptions, this method can be challenging, yet it provides a comprehensive picture of the financial burden. It should also be noted that the cost structure is shifting with new technologies, making the TCO more complex. For battery-electric applications, for example, CAPEX is often higher than for conventional technologies such as combustion engines. This is primarily due to the high cost of battery storage. However, operating costs (OPEX) are often lower. The reasons for this are the high energy efficiency of batteries and electric motors, which leads to lower overall energy consumption, as well as reduced maintenance expenditure due to the lower number of mechanically loaded components.

Another quantitative method is **cost-benefit analysis**, which compares the costs of a technology with the expected benefits, such as energy savings or **emission reductions**. In addition, simulations and **digital twins** play an important role, especially when it comes to modeling the performance of a technology under different conditions or in potential future scenarios.

In addition to quantitative methods that focus on measurable variables, qualitative approaches such as **scenario analysis** also play an important role. It can be used to show different possible development paths and their potential impacts. Technology ratings and benchmarking procedures allow a systematic measurement of the performance of technical solutions against established standards or the best available technology. Point systems or scorecards are often used, which allow multidimensional measurement based on defined criteria.

8 STEPS TO THE FIRST DECARBONIZATION PROJECT

If you are a small or mid-sized company facing the task of decarbonizing individual systems or applications, we recommend the following guide. A **systematic approach** creates the best conditions for successfully overcoming the diverse challenges of decarbonization. We are happy to help you find the right strategies and solutions for your business.

1 Collect data and analyze load profiles

Collecting and analyzing operational data and load profiles is essential for successful decarbonization as it enables accurate decisions and optimizations. Data on load profiles, consumption patterns and operating conditions are the basis for optimal dimensioning of energy systems, avoiding over- and under-dimensioning and reducing costs. Using high-resolution and high-quality data, digital twins can be used to simulate operating scenarios and exploit efficiency potentials.

2 Review regulatory requirements

Reviewing regulatory requirements is a crucial step in decarbonization, as regulatory requirements and standards set the framework for the planning, implementation and operation of energy systems. Regulations at international, national and regional levels have a significant impact on which technologies, procedures and funding options can be used in a particular application. It is therefore essential to gain a comprehensive overview of the applicable regulations at an early stage. An important aspect are emission limits, which are becoming stricter, especially in energy-intensive industries, and which require the use of low-emission technologies.

3 Check infrastructure

A thorough review of the existing infrastructure is essential to effectively implement decarbonization measures. This includes the analysis of the energy supply, grid connections, storage and transport capacities as well as the structural conditions. Especially when switching to battery-electric applications or to hydrogen, extensive testing is necessary, but also for new fuels such as methanol or ammonia, the infrastructure measures that need to be taken must be examined in detail.

4

Develop a rough concept

Creating a rough concept is a decisive step in laying the foundation for implementing a decarbonization measure. The most important framework conditions, objectives and technical solution approaches are defined. The rough concept initially provides an overview of the required technologies, the dimensioning of the energy system and the integration into existing structures.

5

Create a digital twin and simulate different concepts

A digital twin can help in finding the optimal design, especially for more complex energy systems, by presenting a simulation that is as realistic as possible, based on real operating data. This results in lower investment costs as components are not over-sized and reduced operating costs as components can be designed for their real optimum operation. In addition, changes to the energy system can be tested on the digital twin before being implemented in reality.

6

Perform an economic measurement of the concepts

Once the rough concept has been defined and different variants have been simulated, the total cost of ownership can be examined, in which the different variants are analyzed and optimized with regard to their costs. This provides the basis for the ultimate decision on a final design. This will also include opportunities to use public funding.

7

Select and finalize a concept

The selected concept is then finalized and elaborated in detail. This includes precise technical specifications, more precise costing and consideration of interfaces to existing systems.

8

Start and implement a project

Project initiation marks the transition from the planning phase to the implementation phase and lays the foundation for the successful rollout of the decarbonization project. In this step, the necessary resources are provided, responsibilities are defined and a detailed project plan is created. This includes milestones, schedules, and budgets that allow for structured execution.

Zeppelin Power Systems

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