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A comparative Analysis and Simulation of DSM and Energy Efficiency in Chinese and German Industry

Sino-German Energy Transition Project

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Executive Summary

The energy systems in China and Germany will undergo fundamental changes in the coming decades. Maintaining the security of supply and achieving greenhouse gas emission reductions are among the top priorities during these transitions. Adapting the use of electricity to these new circumstances can support these ambitions. Reducing electricity consumption by additional energy efficiency measures and a more flexible demand for electricity that can adapt to the time-dependent availability of renewable energy are promising options for achieving these goals.

This policy report provides expertise for Chinese and German policymakers, companies, and experts about the current state of energy efficiency and Demand Side Management (DSM) in four selected industries and an analysis of the current regulatory framework. These findings are accompanied by policy options for increasing DSM and energy efficiency for both countries.

The report is supported by a simulation tool. The tool allows users to explore potential interdependencies between energy efficiency and DSM and its effects on China's and Germany's current and future energy systems. Within this tool, users can change the technical parameters of the respective electricity markets and the energy efficiency and DSM potential of industrial processes in these countries. Furthermore, it allows the user to assess the effects of potential policy measures on market outcomes. The tool calculates the market price, average CO_2 intensity of the generated electricity, and potential economic savings of changes in energy efficiency and DSM in selected industries for the years 2030 and 2035 in Germany and China, respectively.

Energy efficiency and Demand Side Management

The report analyses energy efficiency from a techno-economic perspective and focuses on long-term energy savings. The discussion is restricted to electrical energy savings in the respective industry. Energy savings in the use of process heat or other energy carriers are beyond the scope of this report.

DSM comprises the targeted electricity demand management by shifting electric loads based on market signals or an agreed switching signal. This report considers four industrial sectors – the cement, paper, chlorine, and aluminium industries – and their most relevant technologies. We conduct a techno-economic analysis of load shifting and load shedding on a spot market in the corresponding simulation tool.

From a theoretical perspective, direct interdependencies between improvements in energy efficiency and DSM usage may exist. For instance, improvements in energy efficiency can reduce the achievable DSM potential by reducing the available electricity load that can be shifted in time. Empirical evidence for interdependent effects is scarce, mainly due to the low dissemination of DSM. Even with the increasing utilisation of DSM in the future, interdependencies are not expected to play a significant role in future energy systems. Nevertheless, the simulation tool allows for explicit modelling of these effects if additional evidence changes the assumptions.

Policy targets and regulatory framework

Increasing energy efficiency is a central pillar of **China's** energy security and climate change efforts. Since 2006 the central government has set ambitious targets to reduce the economy's energy intensity. Various regulations and standards combined with economic and financial incentives for different sectors have been introduced to reach these national targets. This primarily regulatory and target-driven approach has led to significant improvements in energy efficiency, especially in the industry.

Administrative DSM - such as ordered shutdowns - is utilised in China, and DSM has been on the central government's agenda for more than two decades. However, the country's market for DSM is still limited, as no regulatory framework for applying market-based DSM measures has yet been established.

In the past, the Chinese government has primarily focused on the supply-side for balancing electricity supply and demand. However, with China's power market reform still ongoing, market-based DSM is expected to become a focal point on the government's agenda for offering demand flexibility and enhancing power system stability.

German energy policy has implemented instruments for improving energy efficiency since the 1970s. In the last two decades, and increasingly in recent years, the European Union (EU) has strongly promoted the topic of energy efficiency. The European Commission has set ambitious binding targets on energy efficiency, and EU laws have been implemented in German regulations. Germany's energy efficiency policy builds on binding targets and standards, information services, and support measures.

The EU promotes ambitions in using industrial DSM, which Germany has implemented into national law. Hence several marketing options for industrial DSM exist. These range from specifically designed markets over balancing energy to responding to spot price signals. These options differ in their criteria for market entry and suitability for the considered industrial process, potentially limiting the use of DSM in Germany.

Challenges

With its power market reform, the **Chinese** government initiated important changes; however, the policies implemented could not remove some major difficulties for enhancing energy efficiency and incentivising voluntary DSM.

Nationally defined energy efficiency targets often do not consider the potential of individual companies. Moreover, the industrial electricity price is relatively low compared to international levels, potentially undermining energy efficiency efforts when energy costs are no major financial burden for companies operating on global markets. Furthermore, data availability, accuracy, and accessibility form administrative challenges for supervising and evaluating energy efficiency improvements.

Neither the establishment of incentivised DSM programs by power grid companies nor the use of DSM opportunities by electricity consumers is sufficiently rewarded in the current Chinese power market design. This is mainly due to a relatively stiff electricity pricing regime.

In **Germany**, high investment costs, long amortisation periods, and investment risks pose a challenge for further improvements in industrial energy efficiency. Apart from investment deficits, a lack of technical expertise and knowledge, particularly of optimised technologies and innovative processes, can limit the realisation of industrial energy efficiency potentials.

Furthermore, regulatory barriers prevent utilising the existing technical potential of DSM fully. Especially the current calculation method of network charges regarding individual network charges and atypical grid usage (§ 19.2 StromNEV) tends to create an opposing incentive to the price signal from the spot market.

Simulation tool analysis

We developed a simulation tool to calculate system-aggregate effects of energy efficiency and DSM on the Chinese and German energy systems. This report illustrates the merit order, the average electricity wholesale market prices, the average emission intensity of electricity, potential DSM savings, and energetic, environmental (CO_2) and economic savings for energy efficiency for selected industries.

Although the absolute values of the results vary significantly between China and Germany due to the different total installed capacities, we assume that the technical requirements in China and Germany are comparable in the default scenario so that the findings can be applied to both countries. In this report, the default scenario is presented.

The largest DSM potential was found in the cement industry for cement mills and raw mills in both countries. The technical prerequisites, especially the possibility of a relatively long load shift duration, are very advantageous for DSM marketing on the spot market.

The simulation tool shows economic and environmental savings than can result from improving the electricity energy efficiency or using DSM on the industrial level. Policymakers can use these results to prioritize support measures for industrial energy efficiency.

Options for policymakers

Based on the analysis of the current regulatory framework, prevailing challenges and results from the simulation tool, this report derives policy options for further improvements in DSM and energy efficiency. These are presented in the following boxes for both China and Germany.

Policy options for China

Energy efficiency

- An intensity-based carbon emission trading scheme, comparable to the existing ETS for the power sector, could be implemented for the industrial sector. This creates an economic incentive for improving energy efficiency.
- An increase in industrial electricity prices would incentivize further investments in energy efficiency.
- Local subsidies supporting relatively energy-inefficient companies should be abandoned.
- The Chinese central and provincial governments should promote programs supporting expertise and knowledge on industrial energy efficiency among decision-makers.
- Potential negative interdependencies between energy efficiency and DSM must be observed. For target achievement, possible decreasing efficiencies through DSM use and decreasing DSM potentials through energy efficiency gains must be considered.

Demand Side Management

- The regulatory framework of the power market should allow for short-term price signals or agreed switching signals, incentivising the use of DSM:

  Option 1: Implementation of an open spot market, where price spreads over time, incentivises companies to use their DSM potential.

  Option 2: Increase the price difference in a peak valley pricing scheme. Such a scheme provides incentives for an industrial company to shift production to more favourable market conditions, indicated by lower market prices.

  Option 3: In provincial electricity markets, a merit order based approach on industrial opportunity cost could indicate the shutdown with the lowest economic costs in case of a power shortage.

Policy options for Germany

Energy efficiency

- Introduction of an obligation to utilise identified energy saving potentials from regular energy audits.
- Obligation to use only the most energy-efficient technology in each new industrial installation.
- Introduction of shorter depreciation periods for investments in energy efficiency to shorten amortisation periods.

Demand Side Management

- Revision of § 19.2 StromNEV w.r.t. peak load time windows and the 7,000 h/a – rule. This lets industrial power prices more accurately reflect the actual market and grid conditions.

- Decrease high prequalification requirements for DSM marketing options. These limit the industrial DSM diffusion.
- Implementation of information campaigns and additional support measures can help reduce the cost of information and overcome knowledge gaps.

1 Introduction

The energy systems in Germany and China will undergo fundamental changes in the coming decades. Maintaining the security of supply and greenhouse gas emission reductions are among the top priorities during these transitions. The efficient use of electricity can support these goals. In particular, energy efficiency in electricity savings and the flexible use of electricity are suitable means.

The industrial sector already consumes a large share of electricity in both countries. About half of the yearly electricity generation is consumed by industrial processes in China. Increasing electrification of industrial processes resulting from decarbonisation efforts and growing production volumes will further raise the absolute industrial demand for electricity. Growing energy efficiency in the industry will contribute to a reduction in CO_2 emissions and cost savings. Therefore, the analysis also focuses on electricity savings.

The industrial electricity demand tends to be relatively inflexible and will meet a supply increasingly provided by volatile renewable sources. The electricity price will vary with renewable availability. DSM, where the industry adjusts its power demand based on the price of electricity, can make significant contributions toward bringing together security of supply and decarbonisation.

This policy report provides expertise for Chinese and German policymakers, companies, and experts about the current state of DSM and energy efficiency in the respective industries and analyses the applied regulatory framework. These findings are accompanied by policy options for increasing DSM and energy efficiency.

This report is supported by a simulation tool. The tool allows users to explore potential interdependencies between energy efficiency and DSM and its effects on China's and Germany's current and future energy systems. Within this tool, users can change the technical parameters of the electricity markets and the energy efficiency and DSM potential of industrial processes. The tool presents the market price, average CO_2 intensity of generated electricity, and potential economic savings of changes in energy efficiency and DSM in selected industries.

The policy report is structured as follows. In **chapter 2,** the basic concepts of energy efficiency and DSM are presented. Additionally, potential interdependencies between these measures are discussed. In **chapter 3**, current energy policy targets and the regulatory framework in China and Germany and the challenges for energy efficiency and DSM are described. **Chapter 4** introduces the simulation tool. First, the methodology behind the tool is described in detail. Second, necessary assumptions about the current and future energy system are illustrated. Third, results from scenarios calculated with the simulation tool are presented and analysed. In **chapter 5,** options for policymakers are discussed. These regulatory changes are expected to improve industrial energy efficiency and exploit the potential for DSM in China and Germany.

2 Energy efficiency, Demand Side Management, and interdependencies in selected industries

This chapter introduces the concepts of energy efficiency and DSM. Hereby, both measures are presented, and different potentials are defined. The chapter concludes with an overview of potential interdependencies between both measures.

Selected industries	Relevant processes for		Share in industrial electricity demand in 2019[1]	
	Energy Efficiency	Demand Side Management	China (estimated)	Germany
Aluminium	Entire process chain	Aluminium electrolysis	9.9 %	3.5 %
Chlorine	Entire process chain	Chlor-Alkali electrolysis	2.3 %	6.2 %
Cement	Entire process chain	Cement mill; raw mill	5.7 %	1.8 %
Paper	Entire process chain	Groundwood & TMP Refiner; paper recycling & pulp preparation	1.6 %	8.2 %

Table 1: Overview of selected industries and research focus on energy efficiency and Demand Side Management
Source: AG Energiebilanzen e. V. (2021), National Bureau of Statistics of China (2021), and own calculations

The analysis in this report and the accompanying tool focus on selected industries. These industries have been selected because they account for a large share of industrial electricity demand and are well suited for flexibility. Possible energy efficiency improvements are not constrained to specific processes but are applied to the total electrical demand. DSM is restricted to the most relevant processes within these industries. Selected industries, as well as the considered processes, are shown in Table 1.

[1] The total electricity demand of the industry in 2019 was 5,059 TWh in China (National Bureau of Statistics of China, 2021) and 218 TWh in Germany (AG Energiebilanzen e. V., 2021). The estimated share of the selected industries is based on own calculations regarding the electricity demand of the processes.

2.1 Energy efficiency

In the literature, energy efficiency and energy savings are often used synonymously. **Energy efficiency** refers to a decrease in relative energy demand due to an optimised process. However, if a measure also increases production capacity, absolute energy demand can still rise. **Energy savings** are typically defined as the absolute reduction of energy demand.

In the context of energy policy, a clear distinction between energy efficiency and energy savings is necessary. Most energy efficiency targets in Germany are formulated with the primary goal of permanent energy savings (BMWi, 2019). In China, policymakers tend to focus on the energy intensity of a process (Sandalow, 2019). Concerning grid efficiency and the potential savings in CO_2 emissions, an absolute reduction of energy consumption is more advantageous than a relative reduction. We refer to energy efficiency as long-term energy savings potential following this example. These savings can be achieved with technical or behavioural measures and structural changes; the policy report focuses on technical improvements (Pehnt *et al.*, 2011; Bundesstelle für Energieeffizienz (BfEE), 2018).

To define energy efficiency potentials, four different types must be considered (Figure 1).

- The **theoretical potential** gives an estimation of the theoretical energy efficiency potential. For example, the Carnot efficiency gives the upper bound on the potential efficiency for converting thermal into mechanical energy (Paschotta, 2022).
- For calculating the **technical potential**, restrictions of technical engineering for the respected measure are considered, for example, the minimum size for a plant.
- The **economic potential** takes an economic perspective, where lifetime and opportunity costs are considered.
- Last, the **achievable potential** describes a "realistic" penetration rate. Herby, non-technical and non-economic barriers like information deficits and organisational obstacles are considered.

Figure 1: Types of potential – relevant for energy efficiency and DSM

Source: own illustration based on BfEE (2018)

An overview of specific measures in the selected industries will be included in the Appendix.

Summary – energy efficiency

We analyse energy efficiency from a techno-economic perspective and focus on long-term energy savings. We restrict the discussion to electrical energy savings. Energy savings in the use of process heat or other energy carriers are beyond the scope of this report.

2.2 Demand Side Management

A stable power system and securing a supply of electricity are crucial for consumers. Future energy systems in Germany and China are mainly based on renewable energy sources (RES) (EWI, 2021a; IEA, 2021). Especially wind and solar power will provide a major share of electricity production. As this generation depends on fluctuating weather conditions, it is beneficial to adapt the power system to ensure the constant equality of supply and demand.

Flexibility, and thus system stability, can be provided by technical or demand-side options. Furthermore, the system's operation and market design can be adapted to a higher share of volatile renewable electricity. Table 2 gives an overview of flexibility options in the power system. Among these flexibility options, fields of application, technical prerequisites, and maximum potentials can vary greatly. A recent overview of the options mentioned can be found in the dena-report "Flexibility Technologies and Measures in the German Power System" (dena, 2021c). This policy report focuses on the flexibility provided by the demand side, more specifically from industrial processes.

Technical flexibility	Demand-Side flexibility	System Operation flexibility	Market Design flexibility
Conventional power plants (coal and natural gas)	Industrial and commercial Demand Side Management	Redispatch and curtailment	Increasing granularity in the power market
Biomass and biogas power plants	Residential Demand Side Management	Advanced forecasting of RE generation	Ancillary services
Pumped-storage power plants		Higher utilisation if the existing grid	Support schemes: RE and grid charges
Batteries (residential, BEV & large-scale)		Cooperation between DSOs and TSOs	
Power-to-X (e.g., water-electrolysis)		Cooperation and coordination between TSOs	
		Cross-border power exchange	

Table 2: Flexibility options in the power system

Source: dena (2021b)

Increasing the flexibility potential of electricity consumers can help match electricity demand to increasingly volatile renewable supply, e.g., by shifting from peak load to lower demand periods. DSM comprises the targeted management of electricity demand by increasing or decreasing electric loads in response to market signals or an agreed switching signal (Schenuit and Vogel, 2018).

Although any electricity consumer could apply DSM, energy-intensive industries are especially suitable from a system perspective, as they consume large amounts of electricity as a single entity and thus theoretically have higher DSM potentials. The DSM potential depends on multiple technical and economic requirements and the regulatory framework and differs between industrial processes.

The DSM potential can be divided into four different potentials analogous to energy efficiency (see Figure 1):

- **Theoretical potential** refers to the possible long-term flexibilisation of a process. This includes replanning production, investing in information and communication technology, and, if necessary, acquiring new operating resources.
- **Technical potential** corresponds to the available capacity of an existing process that can be flexibilised.
- **Economic potential** refers to the flexibility a company is willing to offer under current market conditions considering all marketing and opportunity costs.
- **Achievable potential** is the viable flexibility for marketing from the individual company's viewpoint. The achievable potential is different for each company and determined by company-specific factors like staff availability (Schenuit and Vogel, 2018; Vogel, Schenuit and Jian, 2019).

To increase energy system flexibility through DSM, it is important to maximise the achievable DSM potential of electricity consumers.

DSM measures consist of two different approaches: **load shifting** and **load shedding**. When load shifting is applied, the underlying goal is to balance a load increase or a load decrease over time by postponing (or preponing) electricity withdrawals such that the load occurs at a time when the grid is better prepared to accommodate it (dena, 2021b). For each industry, the potential time frame of load shifting differs. Load shedding refers to a load reduction without equivalent increase later in time. As for load shifting, there are process-specific technical restrictions for the maximum length of load shedding. The opportunity costs are typically higher for load shedding than load shifting since the corresponding loss of production is not compensated (Gruber, von Roon and Fattler, 2016).

Specific processes capable of DSM in the selected industries and their technical parameters and requirements are introduced in chapter 4.

Summary - DSM

Demand Side Management comprises the targeted management of electricity demand by switching electric loads based on market signals or an agreed switching signal. In this report, four industrial sectors and relevant technologies are considered. We conduct a techno-economic analysis of load switching and load shedding in the corresponding simulation tool.

2.3 Interdependencies between energy efficiency and Demand Side Management

Increasing the energy efficiency of a process can directly affect the feasibility of DSM and vice versa. One direct impact of increased energy efficiency on DSM is reducing peak and average loads. If the electricity load of a process is decreased permanently by improving electrical energy efficiency, the technical potential for DSM decreases. This can reduce profits from conducting DSM, as less electricity consumption can be shifted. We expect this to occur when a new process is installed, and the required capacity decreases. In contrast, a reduction in process-related electricity demand—with no change in installed capacity—would reduce the average load of a process, thereby increasing the DSM potential for increasing the load as part of load shifting.

Furthermore, conducting DSM can lead to a temporary decrease in the energy efficiency of a process. Load shifting and load shedding can distort the electricity load from its optimal level in an industrial process (Gruber, von Roon and Fattler, 2016). Increasing electricity demand often requires operating the process at a suboptimal load level, potentially decreasing energy efficiency.

Acknowledging these potential effects appears important when designing policy instruments. Policy targets like an improved integration of volatile renewable energy via DSM and progress in energy efficiency could be partly incompatible. Pursuing a reduction of CO_2 emissions by decreasing the demand for electricity from conventional power plants can obstruct efforts to integrate supply from variable renewables into the power system, as DSM potential can decrease with higher levels of energy efficiency.

However, these issues are less relevant in current practice. Interviews with German industry stakeholders conducted during this study revealed almost no practical implications at the industrial process level, as implications of the described effects are often too small to be quantifiable.

Following Gruber et al. (2016), relevant interdependencies were only found for aluminium electrolysis. For the interdependency between DSM and energy efficiency, the absolute number of hours per year in which flexibility is requested is decisive for the strength of the effect. The reason for this interdependency is the deviation from the optimal mode of operation and thus the most efficient mode. The optimal load is at 100 per cent; therefore, a provision of flexibility makes a permanent decrease of the load necessary. The provision of DSM by deviation from the optimal load level can lead to an energy efficiency decrease of up to 5 per cent for aluminium electrolysis.[2]

We do not expect the discussed interdependencies to be relevant at the system aggregate level for the industrial processes considered. This expectation is based on the existing empirical evidence and interviews with industry stakeholders. The simulation tool accompanying this study is based on current conditions and practices. Nevertheless, the tool gives the option to define

[2] Additional information on the analysis is provided in the Appendix.

interdependencies. This allows the user to address possible interdependencies that may become relevant in the future. Although we discuss potential direct and detrimental interdependencies between energy efficiency and DSM in industrial processes, we do not imply that policymakers should not pursue improvements in these areas. Our discussion is based on experience with individual processes and not on a comprehensive welfare analysis. We take the aggregate system view in chapter 4 and model implications of energy efficiency and DSM changes on electricity prices and CO_2 emissions.

Summary – Interdependencies between energy efficiency and DSM

From a theoretical perspective, direct effects between improvements in energy efficiency and conducting DSM exist. Empirical evidence for such effects is scarce, mainly due to the low dissemination of DSM. Even with the increasing utilisation of DSM in the future, interdependencies are not expected to play a significant role in future energy systems.

3 Energy efficiency and flexibility measures in China and Germany

The following chapter briefly introduces the regulatory framework for industrial energy efficiency and voluntary DSM in China and Germany. This chapter will give an overview of important national policies and measures for energy efficiency and DSM. For China, the climate targets and energy transition plans will be introduced, followed by an outline of the (industrial) energy efficiency strategies and policy measures and policies incentivising DSM utilization. The same discussion will follow for Germany, additionally including the relevant EU regulations and the existing DSM marketing segments.

Several case studies will show best practices of energy efficiency and DSM in China and Germany. After that, major regulatory, administrative, and financial challenges for industrial energy efficiency improvements and the utilisation of DSM potentials will be discussed in both countries.

3.1 Energy policy targets and regulatory framework

3.1.1 China’s policy framework

China’s energy transition targets

In 2020 China’s President Xi Jinping announced the country’s “dual carbon goals” and declared that China’s CO_2 emissions will peak before 2030, and the country aims to reach carbon neutrality before 2060. These targets stem from the core of the country's vision of a long-term transformation of its energy system and economy. In December 2021, China reaffirmed its climate target by publishing its updated nationally determined contributions (NDCs) targets (UNFCCC, 2021) with targets for 2030:

1) The country aims at reducing its emission by 65 % per unit of GDP compared to 2005 by 2030.
2) The share of non-fossil fuels in China's primary energy consumption should rise from 16 % in 2020 to 25 % in 2030.
3) The installed capacity of wind and solar power should reach 1,200 GW.

Additionally, China announced to limit the increase in coal consumption within its 14th Five Year Plan (FYP) period until 2025 and phase down coal consumption in the 15th FYP period (2026-2030) (IEA, 2021). In Figure 2 and Figure 3, these above-stated targets are visualised.

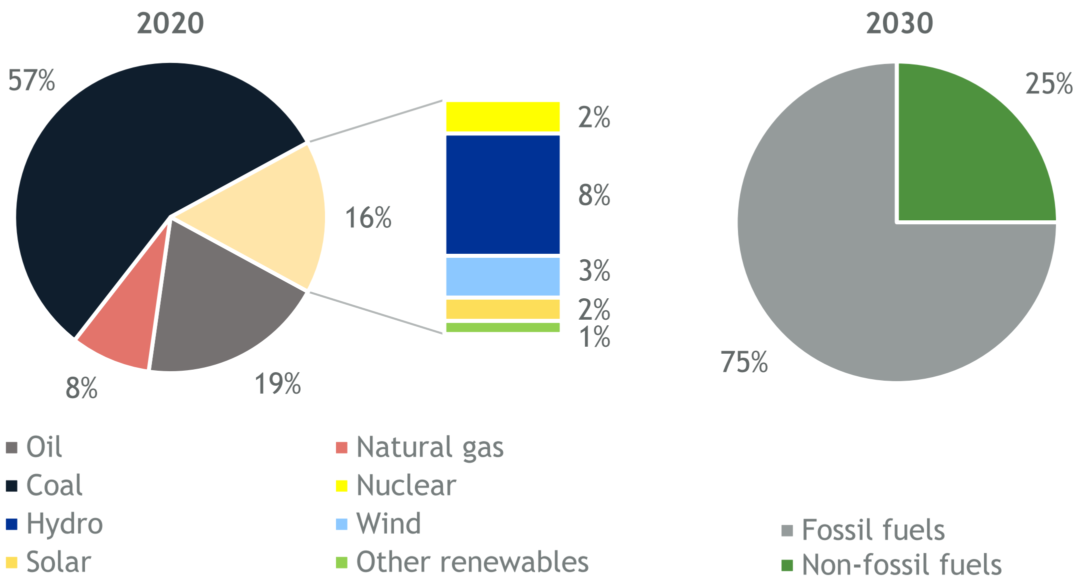


Figure 2: Share of energy sources in China's primary energy consumption in 2020 and targets for 2030
Source: bp (2021) (left side)

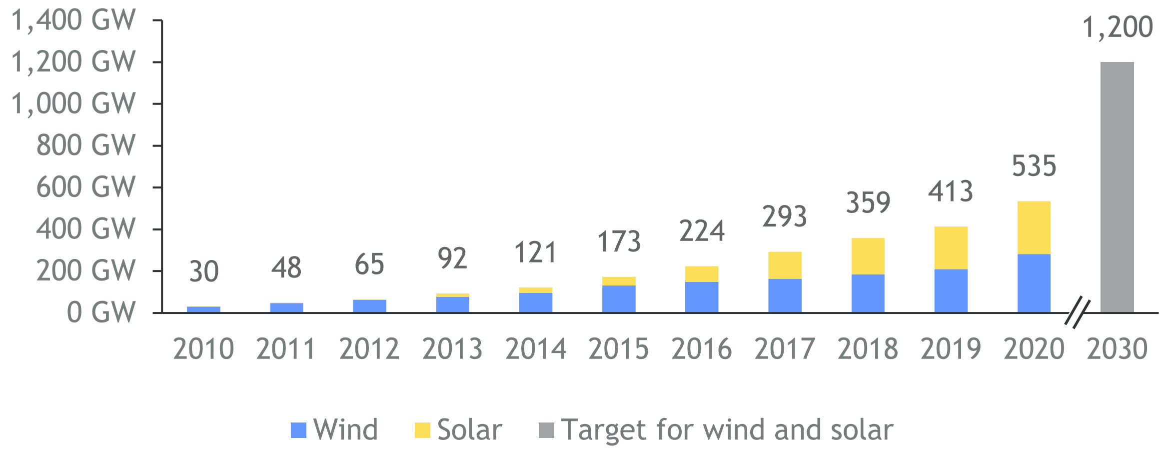


Figure 3: China's installed wind and solar capacity from 2010 to 2020 and target for 2030
Source: National Bureau of Statistics of China (2020)

China's energy efficiency policies

Energy efficiency and the expansion of renewable energy are the two central pillars of the Chinese "Energy Revolution", which aims at establishing a low carbon economy (IEA, 2021). Over the last decades, China achieved major improvements in energy efficiency. While the country's GDP grew, the energy intensity fell significantly. However, it remains above the global average (Enerdata, 2021). Since the late 1970s, energy efficiency and conservation have been central pillars in China's energy policy and became a national political priority in the 2000s (Andrews-Speed and Zhang, 2019). So far, the energy intensity of industrial sectors has been the initial focus of the country's energy conservation efforts since significant efficiency gains could be achieved at a relatively low cost (Andrews-Speed and Zhang, 2019).

China has developed a comprehensive framework of energy efficiency policies (World Bank Group, 2021), including an ambitious target-driven system. The key strategies are the FYPs, defining national and provincial-level energy intensity targets. The FYPs are complemented by additional national strategies, plans, and initiatives, providing additional incentives for energy efficiency improvements (Vïota, 2018; IEA, 2021). The energy and CO_2 intensity targets of the 11th - 14th FYP are summarised in Table 3. Additional national strategies and plans for industrial energy efficiency in China are listed in Table 4. China's national energy efficiency plans are detailed and adopted at the provincial and local levels (Vïota, 2018).

	11th FYP (2006-2010)		12th FYP (2011-2015)		13th FYP (2016-2020)		14th FYP (2021-2025)
	Target	Attained	Target	Attained	Target	Attained	Target
Reduction of energy intensity per unit of GDP	20 %	19 %	16 %	18.3 %	15 %	14 %	13.5 %
Energy consumption cap[3]			below 4 billion tce	4.3 billion tce	below 5 billion tce	4.98 billion tce	
Reduction of CO_2 intensity per unit of GDP[4]			17 %	20 %	18 %	18.8 %	18 %

Table 3: China's national energy intensity targets in the FYPs

Source: IEA (2021)

Strategy	Published by	Year	Implications on energy efficiency
Energy Conservation Law	Standing Committee of the National People's Congress of China	1998, latest updated in 2017	Establishes the legal framework for energy conversation and energy efficiency
Energy Supply and Consumption Revolution Strategy 2016-2030	National Development and Reform Commission (NDRC) & National Energy Agency (NEA)	2017	Long term outlook: energy intensity to reach the average global level
China's Nationally Determined Contribution		Latest update in 2020	Energy efficiency & conservation in power generation, industry, and cities
Strict Energy Efficiency Constraints to Promote Energy Conservation and Carbon Reduction in Key Areas	NDRC, Ministry of Ecology and Environment of the People's Republic of China (MEE), The State Administration for Market Supervision (SAMR) & NEA	2021	Focus on energy consumption accounted for a relatively high, relatively mature transformation conditions
Program for Improving the Double Control of Energy Consumption Intensity and Total Amount	NDRC	2021	Encouraging localities to exceed energy intensity reduction targets. Exemption of respective provinces from double control assessment of energy consumption in the current period of the five-year plan
Implementation Guide for Energy Saving and Carbon Reduction in Key Areas of High Energy-Consuming Industries	NDRC	Latest updated in 2022	Increased energy efficiency standards and targets for 2025 for 17 energy-intensive industry sectors

Table 4: Additional strategies concerning industrial energy efficiency

As part of the 11th FYP, which defined ambitious energy efficiency targets (see Table 3), a variety of instruments have been introduced (Andrews-Speed and Zhang, 2019), such as the Top-100-,

[3] In the 11th and the 14th FYPs no energy consumption cap is included. The 12th and the 13th FYPs introduced a dual control policy with targets for energy intensity and caps on total energy consumption. The goal to meet the dual control targets for the period 2016 to 2020 was a driver of electricity rationing in various provinces in 2021. For the current 14th FYP no energy consumption cap is set.

[4] A carbon intensity target first has been introduced in the 12th FYP in 2011.

1,000-, and 10,000-company program (see Case Study 1), the Top Runner Program for Energy Efficiency and the closure of plants. The Top Runner Program for Energy Efficiency identifies highly energy-efficient product models and sets efficiency benchmarks for the industry. The “top runners” receive financial support, and companies are thus competing to become the most energy-efficient company. In addition, the government started the closure of outdated and inefficient power and industrial plants (International Energy Charter, 2018; Nie, Wang and Chen, 2018; Vïota, 2018; Andrews-Speed and Zhang, 2019).

Chinese governmental bodies have introduced various standards and benchmarks and given recommendations for industrial energy efficiency, e.g. a comprehensive cross-sectoral guideline in 2014 (IEA, 2021) or the program National Recommended Catalog of Industrial Energy-saving Technology and Equipment in 2019 (UNFCCC, 2021).

Summary – China’s energy efficiency policies

Increasing energy efficiency is a central pillar of China’s energy security and climate change efforts. Since 2006 the central government has set ambitious targets to reduce energy intensity. Various regulations and standards combined with economic and financial incentives for different sectors have been introduced to reach these national targets. This primarily regulatory and target-driven approach has led to significant improvements, especially in industrial energy efficiency.

Case Study 1: Good practice on energy efficiency: The Top-1,000 Enterprises Energy Efficiency Program

The Top-100-, 1,000-, and 10,000-company program started in 2006. The program covers the largest companies with major energy demand, accounting for a significant share of the total industrial energy consumption and public buildings and large transport enterprises.

The program aims to push companies to realise energy efficiency improvements and allow China to reach its energy efficiency targets. The energy efficiency potential is assessed, mandatory targets for reducing energy consumption are set, and a system for progress monitoring, reporting and verification is established.

Provincial and local governments are responsible for meeting their assigned targets, introducing individual targets for each firm’s unit, conducting energy audits, and applying penalties. In addition, economic and financial incentives are set, e.g., a dedicated fund provides financial support and higher electricity tariffs for the least energy-efficient companies.

While the program’s costs are unknown, the energy performance level of the covered companies has improved significantly. This administrative approach has motivated the relevant local governments and companies to increase energy efficiency efforts. Energy efficiency improvements in all energy-intensive industry sectors, especially in the cement industry, have been achieved (Zhu, Bai and Zhang, 2017; International Energy Charter, 2018; Andrews-Speed and Zhang, 2019).

China's Demand Side Management policies

In China, DSM was introduced as an energy-saving strategy in the 1990s. Since then, administrative DSM measures, e.g., compulsory load shifting and power rationing, have been deployed. After 2010, plans and measures to support market-based DSM were made (see Table 5). DSM started to be supported by loans, and tax breaks for energy service companies (ESCOs) and subsidies for pilot projects were provided (Zhang, Jiao and Chen, 2017; Andrews-Speed and Zhang, 2019). Case study 2 gives an overview of the DSM Pilot City Program of 2012.

Measure / Program	Published by	Year	Implications for DSM
Demand-side Management Measures	NDRC	2010	Utility obligation and administrative load management
Guides on Improving Demand-side Management in Industrial Areas	Ministry of Industry and Information Technology (MIIT)	2011	Support for demonstration projects of DSM Establishment of energy service agencies
National DSM Platform		2014	Platform to offer support and technical services for decision-makers
Special Action Plan for Power DSM in the Industry Sector (2016-2020)	MIIT	2016	Guide for industry companies to deliver DSM
Measures for Administration of Electrical Power Demand Side	NDRC	2011 amended in 2017	Increasing the role of DSM and mobilising DSM participants
Interim Measures for the Promotion of Reference Products (Technology) for Power DSM in the Industrial Sector	MIIT	First published 2017	Support research, development, production, and application of DSM products
Guideline for Electricity Demand-side Management in Industry	MIIT	2019	Guideline for the establishment and improvement of DSM in the industry, energy management and energy efficiency

Table 5: National measures and programs promoting DSM in China

Case Study 2: DSM development in pilot cities

China launched a DSM Pilot City Program in 2012. The four cities, Beijing, Jiangsu, Foshan and Tangshan, tested comprehensive pilot schemes facilitating voluntary and incentive-based DSM. E.g. in Beijing, a special fund provided 100 CNY/kW for temporary peak load reduction (Zhang et al., 2017). The cities formulated power conservation and load shifting targets, while the central government provided financial incentives.

The city of Suzhou (Jiangsu Province) established the most ambitious plan with a load reduction target (2013-2015) of 1,000 MW (permanent: 800 MW; temporary: 200 MW). The targeted DSM participants were industries and municipal facilities. The DSM measures are based on a real-time pricing scheme and interruptible tariffs (Stern, 2015).

Although the 13th and 14th FYP stress the need to improve Demand Side Management capabilities, DSM is not yet a national priority. The available marketing options for DSM in China are limited due to a lack of a market- or rule-based institutionalised process for procuring load flexibility (IEA, 2021). In addition, the marketing of DSM is currently restricted by orderly power consumption and administratively defined peak-valley pricing.

Local governments are obliged by the administrative measures for **orderly power consumption** to manage the power consumption. Measures are taken in the following order: 1) peak shaving through power shifting, 2) peak avoidance through interruptible load, 3) power restriction, and 4) power rationing. These measures are implemented via bilateral agreements between grid operators and electricity consumers (Schenuit and Vogel, 2018).

A **peak valley** difference in electricity pricing introduces economic incentives for major electricity consumers to shift their load and balance electricity supply and demand. Peak and valley prices are set administratively in advance by provincial authorities. Thus, China’s peak valley pricing (until now) is not a market-based instrument (Schenuit and Vogel, 2018).

China started power market reforms in 2015 to ensure the stability of the power system, enhance further commercialisation of the electricity industry, and reduce energy consumption and emissions (Khalid, Amin and Chen, 2018). Market mechanisms, such as the liberalisation of electricity pricing, are gaining traction in the Chinese power system (IEA, 2021).

Electricity transactions are transitioning towards a higher share of mid- to long-term energy contracts. Mid- to long-term contracting is encouraged as the major form of market trading with various timescales (annually, quarterly, monthly, weekly, and day-ahead) and more technologies participating in the services markets, intended to increase the overall efficiency of the Chinese power system. In 2015, mid- to long-term contracting accounted for 2-10 % of Chinese power transactions, while the share increased to around 26 % in 2017 (IEA, 2019). In 2021 directly traded mid- and long-term contracts accounted for 35 % of the Chinese electricity consumption (China Electricity Council, 2021). The Chinese power market reform is important for paving the way for economic incentives promoting participation in DSM (GIZ, 2021a).

Due to the tight power supply and increased demand, the struggle to balance electricity supply and demand has resulted in power cuts in many Chinese provinces in late 2020 and 2021 (Meidan and Andrew-Speed, 2021). This case highlights the need for a more flexible power demand that can react to increased scarcity, ideally expressed by a price.

Summary – China's Demand Side Management policies

Although administrative DSM is utilised in China, and DSM has been on the central government's agenda for more than two decades, the country's demand response market is still limited. No regulatory framework for applying market-based DSM measures has yet been established.

China's power market reform is still proceeding. The Chinese government has focused on the supply-side for controlling load balancing in the past. Nevertheless, market-based DSM is expected to become a central point on the government's agenda for offering flexibility in the future and thus, enhancing power system stability.

3.1.2 Germany's policy framework

Germany's energy transition targets

In 2011 the German government decided to phase out nuclear power until 2022 and set ambitious climate targets. Coal will, by law, be phased out from the German primary energy mix at least until 2038 and ideally until 2030. As a member state of the European Union (EU), the union's European climate laws apply to Germany. The European Commission's Green Deal strategy launched in 2019 made climate action a priority for the EU, including the target of becoming the first climate-neutral continent by 2050.

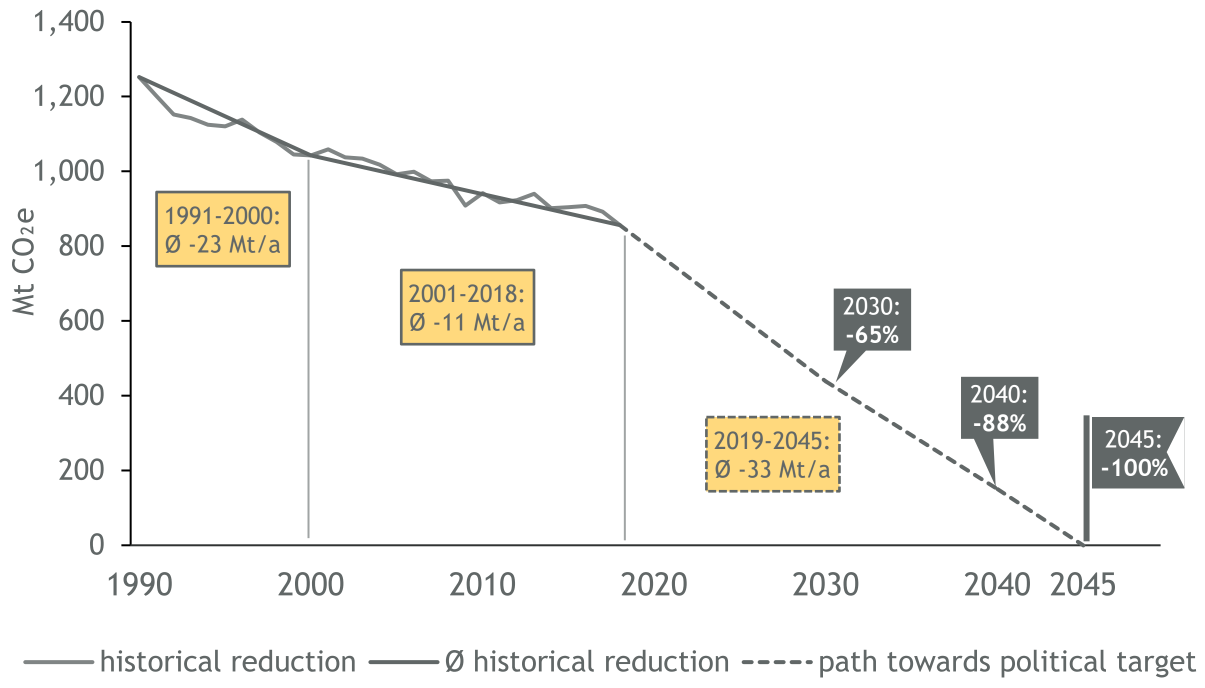


Figure 4: Development of German GHG emissions and national climate targets
Source: EWI (2021a)

In addition to the EU's targets, Germany has set more ambitious goals and included the target of climate neutrality by 2045 in its national law. The latest amendment of the German climate law from 2021 targets a 65 % reduction of GHG emissions until 2030 and an 88 % reduction by 2040 compared to 1990 (see Figure 4). Furthermore, the law determines annual allowed emissions for each sector (Bundesanzeiger, 2021).

The German government elected in September 2021 has announced even more ambitious targets for expanding renewable energy. Instead of 65 % of renewables in the electricity consumption, the new target is planned to be set at 80 % by 2030. Accordingly, the new government has increased the targets for expanding renewable capacity(SPD, Bündnis 90/Die Grünen and FDP, 2021). Figure 5 illustrates Germany's historical and targeted wind and solar capacities.

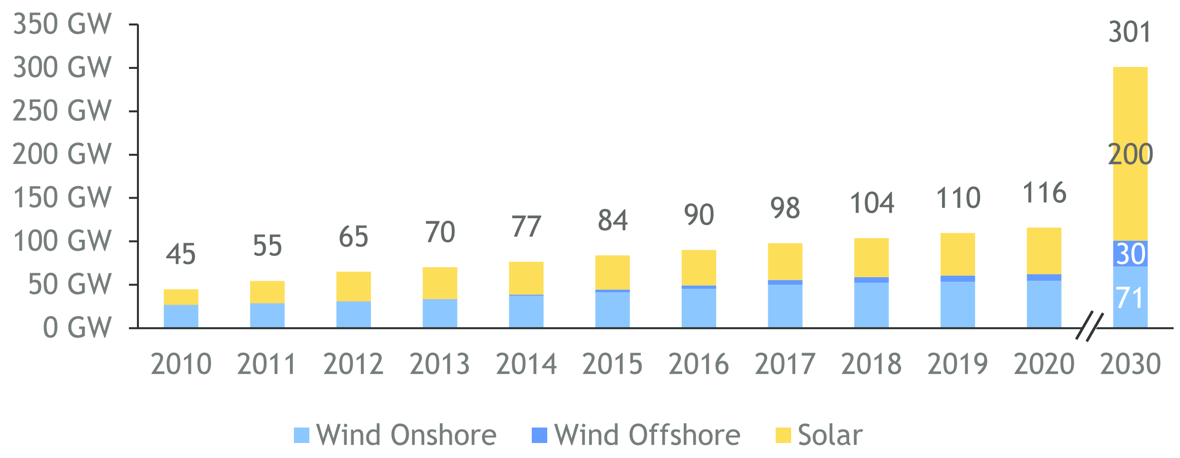


Figure 5: Germany's installed wind and solar capacity 2010-2020 and target for 2030
Source: BMWK (2021)

German energy efficiency policies

Since the oil crisis in 1973, Germany's efficient use of energy received major attention, and several laws and measures promoting energy efficiency have been released. The German Energy Concept 2010, a long-term energy strategy for the years up to 2050, included ambitious targets for reducing energy consumption and increasing energy efficiency. The German energy efficiency policy consists of support measures, information services and binding targets.

The European Union increasingly drives the German energy policies. The European Commission promotes the guiding policy principle "energy efficiency first" and gives recommendations to EU member states for the principle's national application (European Commission, 2021). The European Energy efficiency directive (EED), first launched in 2012 and amended in 2018, sets binding energy efficiency targets for 2020 and 2030. Within the European Green Deal, a new directive has been proposed under the "Fit for 55" package in July 2021, which targets a 32.5 % energy efficiency increase by 2030 compared to the EU's projected energy use in 2030. As Table 6 shows, energy efficiency plays a crucial role in several EU directives and regulations, which Germany has implemented in its national law.

EU law	Year	Implementation into German law	Energy efficiency measures
Energy Efficiency Directive	2012, amended in 2018	Energiedienstleistungsgesetz EDL-G	Energy audits for large companies every four years or implementation of an energy management system
Ecodesign Directive	2009	Energieverbrauchsrelevante-Produkte-Gesetz (EVPG)	Minimum energy efficiency requirements for products
European Industrial Emissions Directive: Best available techniques (BAT) reference documents	2010	(Direct applicability to German companies)	Reference for new large industrial installations
EU ETS Directive: Free allocation of emission allowances	2013 Revised in 2021	(Direct applicability to German companies)	Allocation of free allowances based on efficiency benchmark values and carbon leakage risk

Table 6: EU legislation on energy efficiency

In the German energy transition context and for reaching binding EU targets, the Energy Efficiency Strategy 2050 was published in 2019 (BMWi, 2019). The strategy sets targets of a 30 % reduction of primary energy consumption by 2030 and a 50 % reduction by 2050 compared to the level in 2008.

The National Action Plan Energy Efficiency (*Nationaler Aktionsplan Energieeffizienz*, NAPE 2.0) defines various measures to achieve energy efficiency improvements in the years 2021 to 2030. To increase energy efficiency in the German industry, standards in the framework of the minimum energy efficiency requirements of products (EU Ecodesign Directive) will be raised and the market surveillance supported.

The industry is committed to implementing energy audits and energy management systems measures. The government supports information exchange, consultancy services, and further qualifications of stakeholders. Industrial energy efficiency is financially supported, for example, by the Federal funding for energy and resource efficiency in the economy (*Bundesförderung für Energie- und Ressourceneffizienz in der Wirtschaft*) through subsidies and loans. The central government offers companies a subsidy of up to 50 % or a repayment bonus of up to 55 % for efficiency investments. Supported are measures optimising the utilisation of energy and other resources in industrial processes resulting in increased energy or resource efficiency or avoidance of fossil fuel consumption and CO_2 emissions (BAFA, 2021).

Summary – Germany’s energy efficiency policies

Energy efficiency has been a central pillar of the German energy policy since the 1970s. In the last two decades, increasingly in recent years, the EU has strongly promoted the topic of energy efficiency. The European Commission has set ambitious binding targets on energy efficiency, and EU laws have been implemented in German regulations. Germany’s energy efficiency policy builds on binding targets and standards, information services, and support measures.

Case Study 3: Energy efficiency networks in Germany

In 2014, the German government established the initiative energy efficiency network with multiple industry organisations technically and organisationally supported by the German Energy Agency (Deutsche Energieagentur, dena) to create 500 energy efficiency networks by the end of 2020. In March 2022, 336 energy efficiency networks are registered, covering 2,669 companies. The instrument will be extended and continued until 2025.

An energy efficiency network consists of eight to fifteen companies, running on average for two to three years. An energy management consultancy analyses the energy efficiency potential of the network and points out the potential for improvement. Companies then formulate their voluntary, non-binding energy saving targets and define measures.

The network supports the exchange of experience and best practices. This exchange can be combined with mandatory energy audits for large companies. Additionally, the energy saving in the network is monitored. While the costs for energy management services should decline due to shared resources, financial support is available (Initiative Energieeffizienz Netzwerke, 2019).

German Demand Side Management policies

The German DSM policies, promoting the voluntary management of electricity demand through market incentives, were initiated and are still mainly driven by EU efforts. By liberalising the electricity markets in the EU, the European Electricity Directive (2009) (Third Energy Package) created the opportunity to introduce DSM measures in Germany and the other EU member states.

The Energy Efficiency Directive from 2012 forms one step towards developing DSM in the EU. The directive aimed at enhancing the development of the flexibility of the demand side response and introduced the European Commission as the authority monitoring the national implementation of DSM. The German government has been promoting the DSM implementation over the last years with various instruments (Valdes *et al.*, 2019). The Electricity Market Act and the Act on the Digitalisation of the Energy Transition, both released in 2016, developed the electricity market further and formed the Electricity Market 2.0.

The European Commission launched the European Electricity Balancing Guideline (EBGL), which stresses the importance of additional DSM measures for system stability and governs the load balance mechanism. As a result, Germany has eased access to the balancing markets for demand side participants.

German regulations	Year	Description / relevant article
Energy Industry Act (EnWG)	2005 Amended in 2021	§ 13 responsibility of transmission system operators for the security of electricity supply system in their zone § 51a allows the regulator to conduct monitoring of load management
Ordinance Governing Interruptible Loads (AbLaV) (based on EnWG)	2012 Amended in 2016 in force until 1st July 2022	Promotes the use of industrial switchable loads for stabilising transmission grids
Electricity Network Charges Ordinance (StromNEV) (based on EnWG)	2005 Amended in 2021	Promotes balancing groups, e.g., § 19 reduction of network charges through atypical electricity consumption behaviour § 17 reduction of network charges through peak load reduction
DIN EN ISO 50001 international standard for energy management systems	Amended in 2018	Analysis of DSM potential of companies

Table 7: German regulations for establishing and regulating DSM

Case Study 4: DSM Bavaria Pilot Project

The pilot project DSM Bavaria (2013-2016) aimed to support companies by making their electricity demand more flexible. Companies from various industries located in the German province of Bavaria participated in this project.

The companies were supported in identifying their DSM potentials by defining flexible operatable production processes and marketing their existing DSM potentials. As part of the project, an analysis was conducted and learnings were made available for decision makers (Seidl, Schenuit and Teichmann, 2016b; Bayerisches Staatsministerium für Wirtschaft, Energie und Technologie, 2018).

In Germany, four marketing opportunities for DSM potentials have been established. Table 8 gives an overview of each market segment and a brief description. For a detailed discussion of these markets, please refer to the previous reports published by dena (Schenuit and Vogel, 2018; Vogel, Schenuit and Jian, 2019).

Marketing segment	Description
Spot market	Companies can market their DSM potentials on the spot market of the European Energy Exchange (EEX).
Interruptible Loads Ordinance (AbLaV)	The marketing of targeted loads for grid stabilisation is based on the Interruptible Loads Ordinance. Participants can be mandated to reduce consumption by the grid operator.
Balancing energy	Transmission system operators procure different control reserves through a tendering process on two markets to deliver balancing energy, the balancing power market (*Regelarbeitsmarkt*, RAM) and the control power market (*Regelleistungsmarkt*, RLM). Participants of the RAM and RLM previously must succeed in a prequalification process.
Balancing group management	Balancing group management utilises bilateral agreements and financial compensation for load balancing and forms the opportunity to market industrial DSM.

Table 8: Markets for industrial DSM potentials

Source: dena (2021c) and Schenuit & Vogel (2018)

The spot market is important for the marketing of industrial DSM. German companies can market their DSM potentials on the spot market by shifting their electricity demand depending on price signals. This marketing opportunity focuses on the analysis of DSM potentials following in chapter 4 of this study.

Apart from the spot market, the Interruptible Loads Ordinance (AbLaV) and balancing energy are relevant markets for industrial DSM but not the focus of the analysis in this report. The marketing opportunity offered through AbLaV will cease to exist after June 2022. At present, nothing has been officially announced regarding a potential follow-up regulation.

Summary – Germany's DSM policies

The EU actively promotes the use of DSM and pushes the expansion of DSM measures in Germany. Germany has implemented EU regulations into German law. As a result, several marketing options for DSM exist.

3.2 Current challenges for energy efficiency and Demand Side Management in China and Germany

3.2.1 Challenges faced by China

Transforming the Chinese energy system from a system relying on fossil fuels to renewables forms a significant challenge, especially from a regulatory perspective. Since the Chinese power market and energy policies are in transition, there is a lack of a stable long-term regulatory environment ensuring predictability for stakeholders and investors (Stern, 2015; GIZ, 2021a). With its power market reform, the Chinese government initiated important changes; however, the policies implemented could not remove some major difficulties.

Chinese provinces are still reluctant to extend electricity trading with each other. Due to the dominance of mid to long term electricity contracts instead of spot and regional transactions, the electricity market structure fosters provincial protectionism. This local protectionism - local decision-makers focusing on local outputs - results in China's negative economic and environmental effects. This problem applies to the Chinese energy sectors as well as to the industry.

China has a large territory with major regional disparities such as differences in economic development, energy generation and consumption, renewable energy potential, and industry structure. In addition, provinces and local bureaucracies differ in terms of human and financial capital (Zhu, Bai and Zhang, 2017; Khalid, Amin and Chen, 2018; Vïota, 2018). Nationally formulated policies and targets face local and regional policy implementation challenges. China has a complex bureaucracy with occasionally conflicting interests, which hinder policy implementation (Stern, 2015).

Regulatory and financial challenges for industrial energy efficiency in China

China faces challenges coordinating national energy efficiency targets and the local implementation of energy efficiency measures (GIZ, 2020). Defining energy efficiency targets through a top-down perspective poses economic efficiency problems, particularly for individual companies. It is difficult to efficiently allocate targets among companies while considering each company's individual energy efficiency potential (Zhu, Bai and Zhang, 2017). Local capabilities and the political will to implement national policies also differ among regions, resulting in constraints (Vïota, 2018).

The availability, accuracy, and accessibility of data, e.g., on energy consumption, form an administrative challenge in supervising and evaluating energy efficiency improvements in China. Relevant actors, such as local and provincial governments, national institutions, and enterprises, tend to refrain from sharing data. Authorities lack human, technical, and financial resources to conduct necessary monitoring, reporting, and verification processes of policy implications, e.g., the enforcement of energy efficiency standards (Zhu, Bai and Zhang, 2017; Vïota, 2018).

Besides these political and administrative challenges, economic and financial barriers exist to improve industrial energy efficiency in China further. The (industrial) electricity price is relatively low compared to international levels, potentially undermining public energy efficiency efforts when energy costs are no major financial burden to enterprises (GIZ, 2020). In particular, in the case of private companies, financing investments for additional energy efficiency measures is a challenge since these investments can exceed required payback periods (Vïota, 2018).

Regulatory and technical challenges for industrial DSM in China

Currently, there is no widespread use of voluntary DSM in China. To increase the diffusion of voluntary DSM, various policy, administrative, and financial obstacles need to be addressed. Significant regional disparities, the differing status of the implementation of energy market reforms and the application of DSM pose a challenge for establishing a comprehensive policy for DSM measures (Khalid, Amin and Chen, 2018).

Despite national goals to increase DSM and incentivise DSM measures, local governments continue applying mandatory administrative measures to control electricity demand (Zhang, Jiao and Chen, 2017). Although the national government aims to enhance the establishment and utilisation of DSM opportunities, it is not (yet) a political priority and local authorities are not explicitly instructed by the central government to promote DSM. In general, neither the establishment of incentivised DSM programs by power grid companies nor the use of DSM opportunities by electricity consumers is sufficiently rewarded by the Chinese government (Zhang, Jiao and Chen, 2017; Khalid, Amin and Chen, 2018; GIZ, 2021a).

Despite these challenges, several Chinese cities have established DSM pilot projects. The most important insight from these projects is that time-dependent differential pricing forms the basis for utilising market-based DSM measures. In some pilot projects, the price gap in time and thus the possible profit was too small for industrial DSM participants to recover the costs (Zhang, Jiao and Chen, 2017). In addition, there have been difficulties in some projects obtaining necessary real-time energy data. While implementing DSM measures requires supervision, some projects have faced limitations in the certification of participants and the supervision (Khalid, Amin and Chen, 2018).

It is necessary to invest in, e.g., demand side load control methods and management platforms. These methods and technologies require significant investment in DSM equipment and management software for the companies or the government (Energy Research Institute of the National Development and Reform Commission, 2020).

Summary – Challenges faced by China

With its power market reforms, the Chinese government initiated changes toward a liberalized electricity market; however, the policies implemented so far could not remove some major difficulties for enhancing energy efficiency and incentivizing DSM.

Nationally defined energy efficiency targets often do not consider the potential of individual companies. Furthermore, data availability, accuracy, and accessibility form an administrative challenge in supervising and evaluating energy efficiency improvements.

Currently, neither the establishment of incentivised DSM programs by power grid companies nor the use of DSM opportunities by electricity consumers is sufficiently rewarded by the Chinese government.

3.2.2 Challenges faced by Germany

The German electricity system is primarily based on market principles. Electricity prices vary with a (sub-)hourly pattern, providing incentives for market-based DSM and large-scale investments into energy efficiency improvements. However, financial and regulatory barriers to further steps remain.

Financial Challenges for industrial energy efficiency in Germany

In Germany, the most significant challenges to increasing industrial energy efficiency form economic barriers (Kube *et al.*, 2017). As well as in China, high investment costs and sometimes long amortisation periods and investment risks pose a challenge for further improvements in industrial energy efficiency. In the short term, energy efficiency investments might seem economically unattractive for companies since these investments often do not immediately pay back. Limited knowledge of the costs and benefits of energy efficiency investments increases this challenge (Ecofys, 2016; Brüggemann, 2018). However, investment costs and potential savings cannot be generalized for many innovative industrial energy efficiency measures since they depend on the individual application (Kube *et al.*, 2017).

Apart from investment deficits, a lack of technical expertise and knowledge of investment opportunities, particularly optimised technologies and innovative processes, can limit industrial energy efficiency potentials (Ecofys, 2016; Brüggemann, 2018). Limited knowledge of existing local- and national-level support measures, e.g. subsidies and loans for energy efficiency improvements, can reduce the potential positive effects of such support programs, as do complex application procedures and long approval periods (Kube *et al.*, 2017).

Regulatory and financial challenges for DSM in Germany

Several marketing options for DSM exist and are used by companies. However, regulatory barriers prevent utilising existing technical potential fully (Joint Research Centre, Institute for Energy and Transport, 2016; Stavenhagen, 2017).

The current calculation method of network charges for industrial consumers creates opposing incentives to the price signal from the spot market. Individual network charges (§ 19.2 StromNEV) incentivise time constant electricity consumption. Companies are rewarded for guaranteeing particularly well predictable load curves. For example, companies can agree on an individual network charge surpassing 7,000 full load hours per year. If the company falls below this threshold, it loses this privilege. This rule impedes DSM utilisation.

Another special case of network charge calculation is atypical grid usage (§ 19.2 StromNEV). The transmission grid operators define peak load time windows one year in advance. A company that can decrease the load in these specified time windows can benefit from a reduced network charge.

However, these windows do not necessarily reflect the actual market and grid conditions due to the long forecast horizon. Companies have a significantly reduced incentive to utilise DSM in these peak load time windows, even though actual market conditions might indicate a positive systemic value. A company loses the entitlement to reduced network charges if it increases its load in these time windows.

In addition, strong prequalification requirements for some DSM marketing options, especially in the case of balancing energy, form a significant market access barrier. These strict requirements reduce the number of companies offering their DSM potentials (Ecofys, 2016).

A lack of know-how among industrial companies restrains a broader application of industrial DSM measures. DSM and knowledge about DSM potentials remain relatively unknown in the energy-intensive industry sectors (Seidl, Schenuit and Teichmann, 2016a; Schenuit and Vogel, 2018). Furthermore, as the regulatory framework is frequently changing, companies have to often adapt to new circumstances, which forms a risk to companies' planning security (Ausfelder, Seitz and von Roon, 2018).

Summary – Challenges faced by Germany

High investment costs, long amortisation periods, and investment risks pose a challenge for further improvements in industrial energy efficiency. Apart from investment deficits, a lack of technical expertise and knowledge, particularly of optimised technologies and innovative processes, limits the realisation of industrial energy efficiency potentials.

Regulatory barriers prevent utilising the existing technical potential of DSM fully. Especially the current calculation method of network charges regarding individual network charges and atypical grid usage (§ 19.2 StromNEV) creates opposing incentives to the price signal from the spot market.

4 Simulation of energy efficiency and Demand Side Management in China and Germany

This chapter introduces the simulation tool accompanying the policy report. It presents the underlying methodology and functioning of the tool and explains how electricity market prices are calculated and how the CO_2 assessment is implemented. Furthermore, it discusses the implementation of energy efficiency gains and DSM in detail. For simplicity, the methodology for China and Germany is identical, even though fundamental differences still exist between the electricity markets today. We expect market design and regulation in the two countries to be more comparable in the future.

The second part shows the tools' framework, today's and future energy system. For Germany, most assumptions are based on an update of the *dena pilot study Towards Climate Neutrality* (EWI, 2021b). The Chinese framework is based on IEA's An Energy Sector Roadmap to Carbon Neutrality in China (IEA, 2021). The chapter then discusses the tools' results for the default scenario. All settings of the default scenario are included in the Appendix.

4.1 Efficient system optimum methodology

A simulation tool was developed within the project to quantify the effects of energy efficiency and DSM in China and Germany. This tool allows the user to assess the impact of a policy measure such as subsidies for energy efficiency investments or analyse the consequence of new technologies increasing DSM potentials.

To this end, an electricity market based on merit-order pricing was implemented. The electricity market simulation calculates an hourly price time series, including a heuristic for peak and negative prices. This heuristic provides the basis for applying and evaluating energy efficiency and DSM measures.

In the tool, the user can vary a wide range of assumptions regarding the energy system, the electricity market, and technical assumptions for the application of energy efficiency and DSM measures. The default settings of all parameters are based on in-depth literature research and interviews with companies in the relevant industries and researchers. Framework data for the energy system scenarios in 2030 and 2035 is based on EWI (2021b) and IEA (2021), respectively.

The tool's output includes an overview of the merit order, average electricity prices, and profits and emission savings from energy efficiency and DSM measures. The inputs and outputs can be set and calculated simultaneously for China and Germany. Figure 6 shows the overall concept of the tool. In the following, the tool's methodology is presented for different segments.

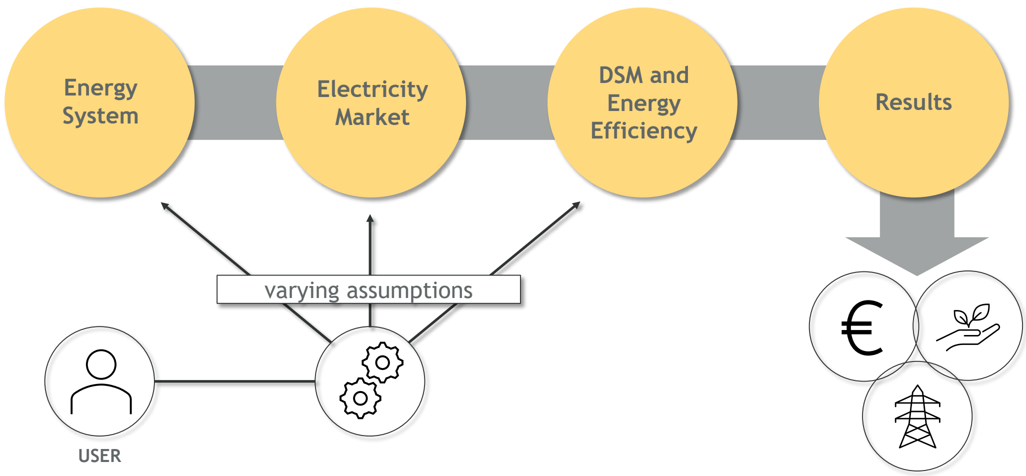


Figure 6: The main concept of the Energy Efficiency and Demand Side Management Tool

Calculation of market prices

The tool calculates hourly day-ahead market prices for China and Germany. The calculation is based on a merit order approach with a uniform price regime. Firstly, the residual load curve, i.e., the difference between demand and generation from renewable energies, is computed to derive hourly prices.

Current market pricing in China differs fundamentally from the merit order approach. For the simulation, however, it is assumed in a simplified way that the market forms electricity prices to enable a comparative analysis for both countries.

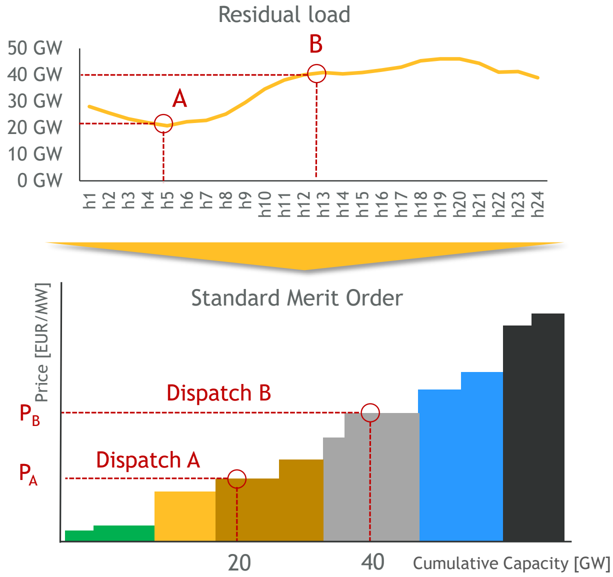


Figure 7: Exemplary illustration of residual load (top) and a standard merit order (bottom)

In general, the residual load must be covered by dispatchable power plants. The dispatchable power plant fleet is sorted ascending to each unit's marginal electricity generation costs.

Hourly prices can be derived by the hourly residual load and the ordered power plant fleet. The marginal costs of the last dispatched unit determine the market price of the respective hour. Hereby, market coupling, thus import from, or export to other electricity markets is not considered. The methodology is schematically illustrated in Figure 7.

Storage assessment - smoothing of residual demand

Storages and flexible demand will be highly needed in future energy systems to balance the volatility of RES. Due to its intertemporal characteristic, merit orders cannot account for flexibility. Although the tool's focus is the simulation of energy efficiency and DSM impacts, other flexibility measures (e.g., large-scale batteries) affect market prices and are therefore considered.

These additional flexibility measures are simulated by lowering the volatility of the residual load curve in predefined time intervals. In other words, hills and valleys of the residual load curve decrease in magnitude depending on the amount of available storage capacity. The power and storage size of these measures can be adjusted within the tool, while the time interval of load shifting by storage remains constant.

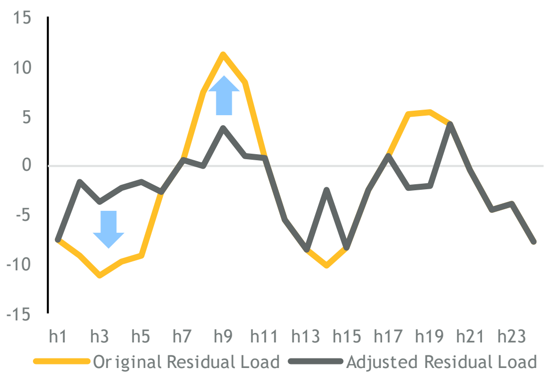


Figure 8: Illustration of flexibility assessment

Price adjustment – Peak pricing and negative pricing

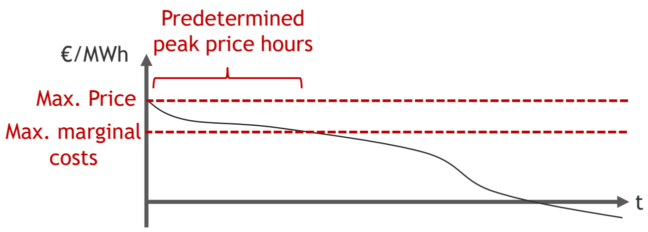


Figure 9: Illustration of the peak price heuristic

The merit order is calculated according to marginal power supply costs in the tool. In real-world energy markets, power plant operators put a surcharge on top of marginal costs when there are high energy shortages. Thus, electricity costs can surpass marginal costs – especially in times of shortages. To incorporate a more realistic simulation of **peak pricing,** the user can set an exogenous maximum price and the number of hours where peak pricing applies. The tool then non-linearly interpolates between the defined maximum price and the highest market price before the peak price adjustment. Figure 9 exemplarily illustrates the peak price heuristic.

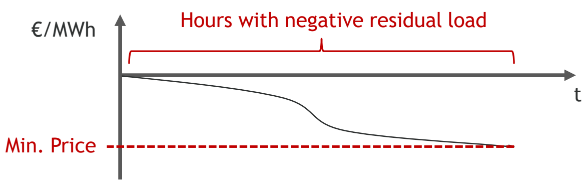


Figure 10: Illustration of the negative price heuristic

Energy systems with high RES-in-feeds are characterised by temporarily energy surpluses. Energy from renewable sources, which would be price-setting in these times, is assumed to have zero marginal cost. In real markets, the interplay of the inflexibility of some conventional generation units and subsidy mechanisms for RES can lead to negative market prices. Thus, the user can set an exogenous minimal price to incorporate **negative prices** in the tool. Then, negative residual loads are sorted, and negative prices are calculated - the more pronounced the negative load, the more pronounced the resulting negative price. The boundaries are determined by the minimal price and zero corresponding to the marginal power supply costs of RES. Figure 10 illustrates this process.

CO_2-Assessment

The tool calculates hourly CO_2 emissions of electricity supply based on the hourly emission intensity of the dispatched power plant fleet. The CO_2 emissions of foreign power plants (electricity imports) are assumed to equal zero.

It is expected that carbon capture technologies will be widely used in the Chinese power system by 2035, especially with coal-fired generation units. Accordingly, we apply a default emission reduction factor of 90 %. The emission intensity of each power supply technology is predetermined and can be adjusted by users.

Energy efficiency

Our discussion of energy efficiency is restricted to absolute electricity savings (see chapter 2.1). These potential savings are based on assumptions of a total yearly savings potential, leading to decreased energy intensity for the selected industries.

The user can make assumptions on the potential energy savings (in %) for Germany and China in 2030 or 2035, respectively, compared to the base year 2019. The potential energy savings can be set individually for the selected industry sectors. The tool calculates the average (net) economic savings[5] $P_{sav,sec}$ (in EUR) as well as indirect environmental savings $EM_{sav,sec}$(tons of CO_2).

The **economic savings** result from saved electricity. As gains in energy efficiency result in an absolute reduction of electricity consumption, market prices of electricity and taxes and levies must be considered to calculate economic savings. Therefore, a country-specific share of the market price for electricity from the end price an industry must pay for electricity MPS_{ctr} is considered. To calculate total economic savings over one year, the average market price MP_{avg} is multiplied by the sectoral efficiency gain EE_{sec} and the annual sectoral electricity demand D_{sec} and divided by the market price share (see the following equation).

$$P_{sav,sec} = (MP_{avg} * EE_{sec} * D_{sec}) / MPS_{ctr}$$

The indirect **environmental savings** ($EM_{sav,sec}$) are achieved by reducing overall load and thus a smaller CO_2 footprint from electricity generation. The indirect sectoral emission savings are calculated by multiplying the average emission intensity of the power supply EM_{avg}, the sectoral efficiency gain, and the annual sectoral electricity demand (see the following equation).

$$EM_{sav,sec} = EM_{avg} * EE_{sec} * D_{sec}$$

Demand Side Management

DSM is modelled by considering load shedding and load shifting. Multiple processes with different installed capacities and feasibility factors can be applied to each sector.

Load shedding applies if market prices exceed a predefined upper limit. The number of total load sheds per year is limited.

Load shifting applies if price spreads within rolling shift durations are high. These price spreads are calculated by the difference between the average price of the down ramping duration and the average price of the up-ramping duration. The total number of shifts per year is limited.

[5] In the tool, no investment or operating costs for the relevant measures are considered. The average economic savings are therefore net savings only.

Figure 11 illustrates the relevant technical assumptions necessary for simulating DSM. The potential of DSM is restricted by multiple technical aspects such as minimum and maximum load factors of the production process or the maximum time of ramping up/-down. The simulation tool complementing the policy report provides an overview of the assumptions for all technical parameters. Additionally, assumptions for considered processes are given. The underlying data has been determined by interviews with industry experts and is based on Fichter & Creutzburg (2019), FfE (2022), Godin (2019), Guminski et al. (2019), Hübner et al. (2019) and Steurer (2017) This data can be considered as default settings, adjustable by the user to identify and analyse effects of variations in technical assumptions.

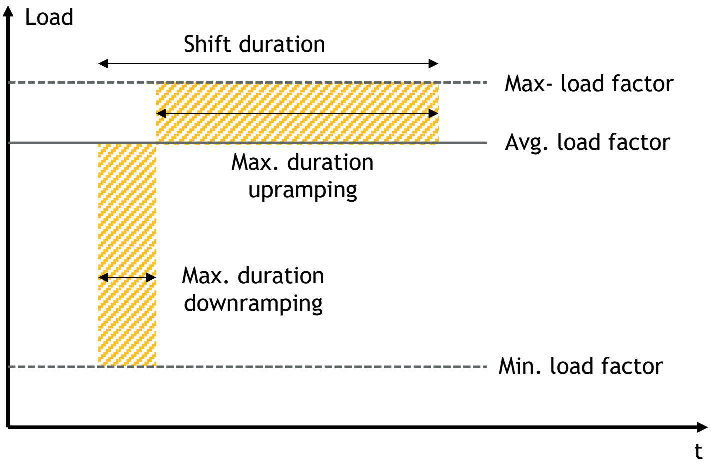


Figure 11: Exemplary illustration of load shifting

The (net) economic savings[6] by load shedding are equal to the market price when load shedding applies MP_t divided by the share of the market price from the end price an industrial customer pays for electricity consumption MPS_{ctr}. Economic savings by load shifting are calculated as the amount of load shifted E_{shift} multiplied by the mean price spread between the hours of ramping up and down $MP_{spread,t}$ (see the following equations).

$$P_{sav,shed} = MP_t / MPS_{ctr}$$

$$P_{sav,shift} = E_{shift} * MP_{spread,t}$$

4.2 Framework: Today's and future energy system

To simulate the effects of energy efficiency and DSM on the energy system, first, the framework of today's and future energy systems must be determined. In addition to basic technical assumptions presented in the methodology (chapter 4.1), assumptions must be made regarding the energy system and the industry.

In the following, central assumptions are shortly presented. These and further assumptions are set as default in the simulation tool. The user can adjust all described parameters. Thus, the assumptions developed in the tool and the framework described below can be changed in case of changing conditions.

[6] In the tool, no investment or operating costs for the relevant measures are considered. The average economic savings are therefore net savings only.

China

The energy system in China in 2019 was dominated by (unabated) coal-fired power plants with around 1,028 GW installed capacity (see Figure 12). RES made up 822 GW in total in 2019. Significant changes to the generation mix in China are expected until 2035 (IEA, 2021).

The installed capacity of coal-fired power plants is expected to increase by 130 GW to 1,158 GW, from which 40 % will be retrofitted with carbon capture technologies (abated coal). The installed capacity of RES is expected to increase by 2,140 GW to 2,962 GW in total in 2035. A large part of the installed capacity can be attributed to PV; by 2035, the installed capacity will increase from 206 GW to 1,478 GW. The second most important generation technology is Onshore Wind, whose installed capacity increases from 200 GW in 2019 to 850 GW in 2035.

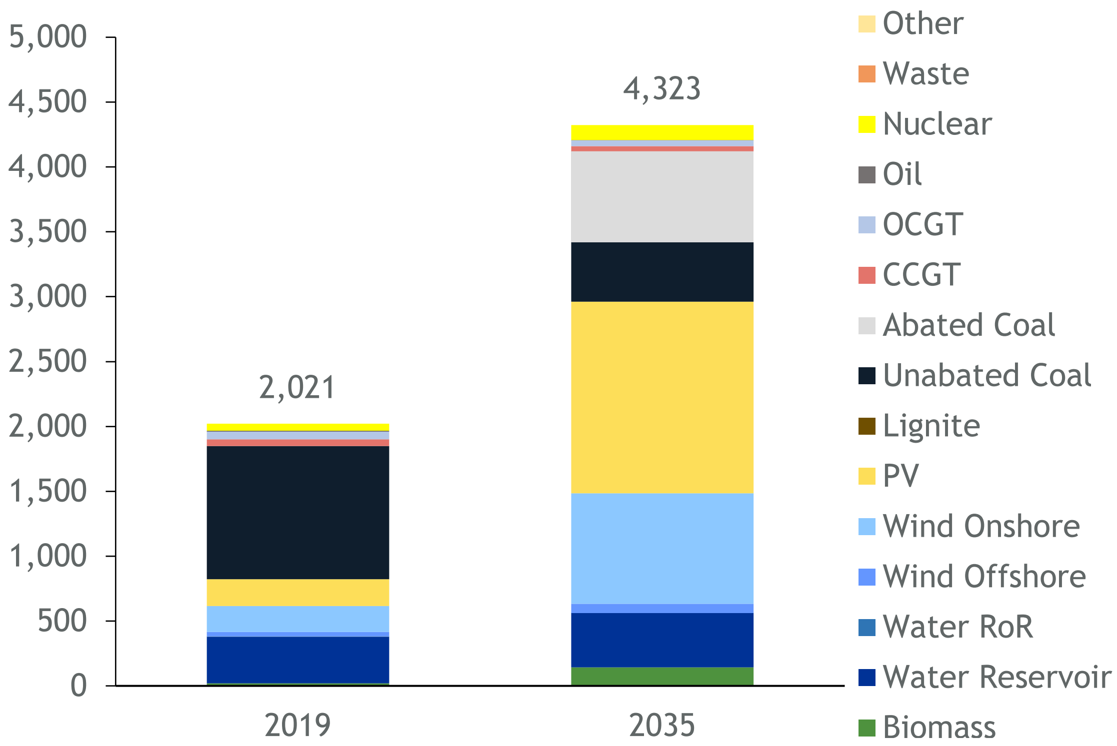


Figure 12: Installed generation capacity in China
Source: IEA (2021)

Volatile renewable energies dominate the future energy system in China. Thus, flexibility options become more critical with increasing renewable shares. Demand side flexibility options help balance supply and demand and maintain energy security.

Especially for DSM, the selected industries' production volumes and production capacities are essential inputs. The simulation tool calculates the production capacity and, thus, the technical DSM potential from production volumes and average load. Historical future production volumes and estimated future installed capacity for the selected industries are illustrated in Figure 13.

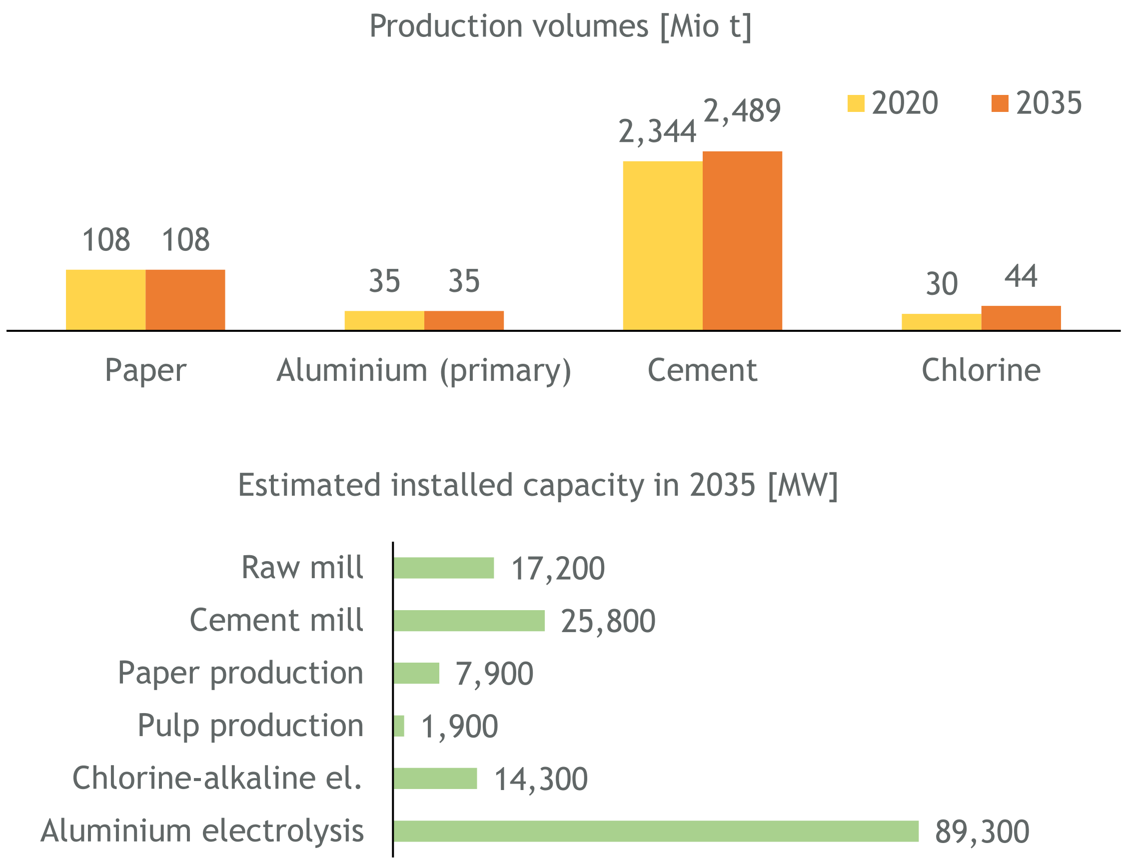


Figure 13: Industrial production volumes (top panel) and estimated installed capacity of DSM-processes (bottom panel) for China

Source: IEA (2021) and National Bureau of Statistics of China (2019)

Germany

Figure 14 shows the installed capacity in today's and future energy system in Germany. The installed capacity is based on EWI (2021b). In 2019 the German energy system had a balanced ratio of conventional power plants and RES concerning the installed capacity. For 2030 a target share of 80 % of RES in the energy system was set by the federal government, requiring a significant increase in installed renewable capacity.

Accordingly, the RES capacity is expected to double from 118 GW in 2019 to 337 GW in 2030. At the same time, the installed capacity of conventional power plants decreases from 99 GW in 2019 to 36 GW in 2030. These numbers are based on plans published by the German federal government (SPD, Bündnis 90/Die Grünen and FDP, 2021). As in China, Germany's increasing share of volatile renewable energy mandates utilising demand side flexibility options like DSM.

Especially for DSM, the selected industries' production volumes and capacities are essential inputs. The simulation tool calculates the production capacity and, thus, the technical DSM potential from production volumes and average load. Historical future production volumes and estimated future installed capacity for the selected industries are illustrated in Figure 15.

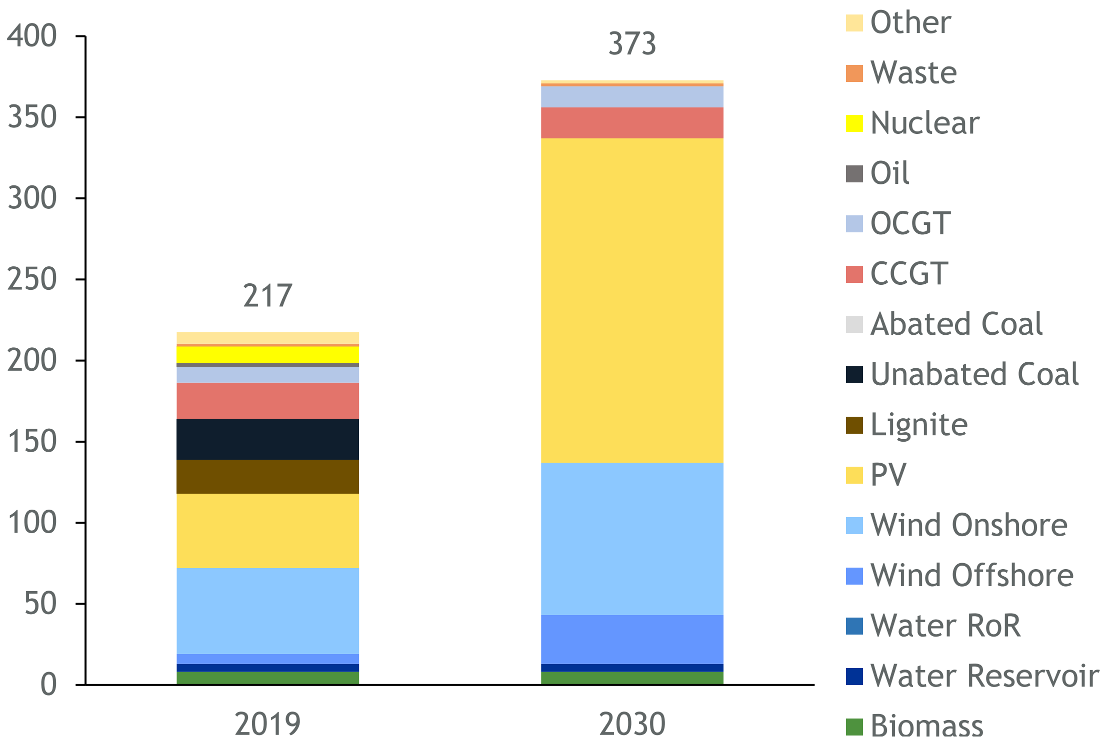


Figure 14: Installed generation capacity in Germany

Source: EWI (2021b)

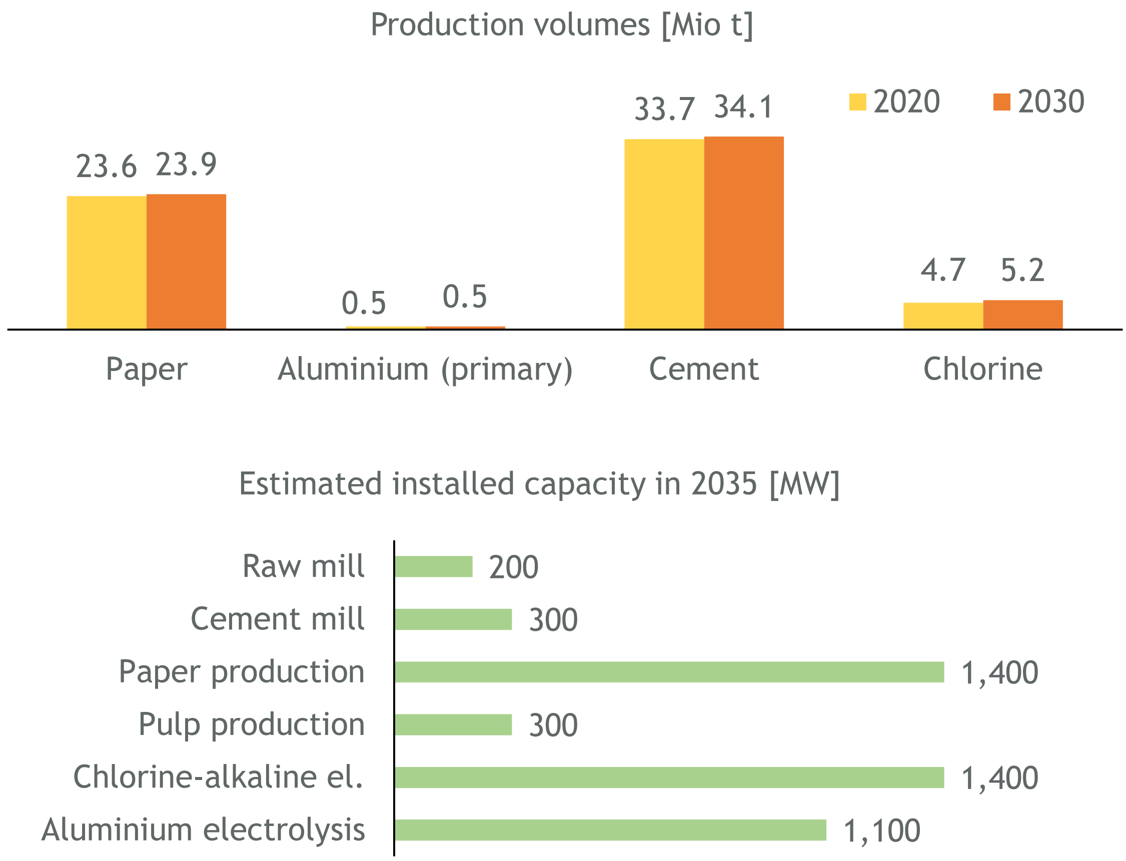


Figure 15: Industrial production volumes (top panel) and estimated installed capacity of DSM-processes (bottom panel) for Germany

Source: EWI (2021a)

4.3 Estimated potentials and effects on the energy market

In the following, first, the main results of the simulation tool are presented. Second, the estimated potentials of the considered industrial processes and their effects on the electricity market are discussed. The results in Figure 17 and Figure 19 correspond to the default scenario in the simulation tool. All underlying assumptions and the results are transparently displayed in the simulation tool and the Appendix.

China

Figure 17 shows the main results of the simulation tool for China. These results illustrate the merit order, the average electricity wholesale market price, the average emission intensity of electricity, potential DSM savings in 2030, and energetic, environmental (CO_2) and economic savings for energy efficiency.

The shown **merit order** directly results from the set energy system scenario and is the basis for the market simulation. The installed capacity of renewable and conventional power generation technologies, the emission price, fuel prices, transport costs, and other variable costs of power generation directly influence the merit order and resulting electricity prices.

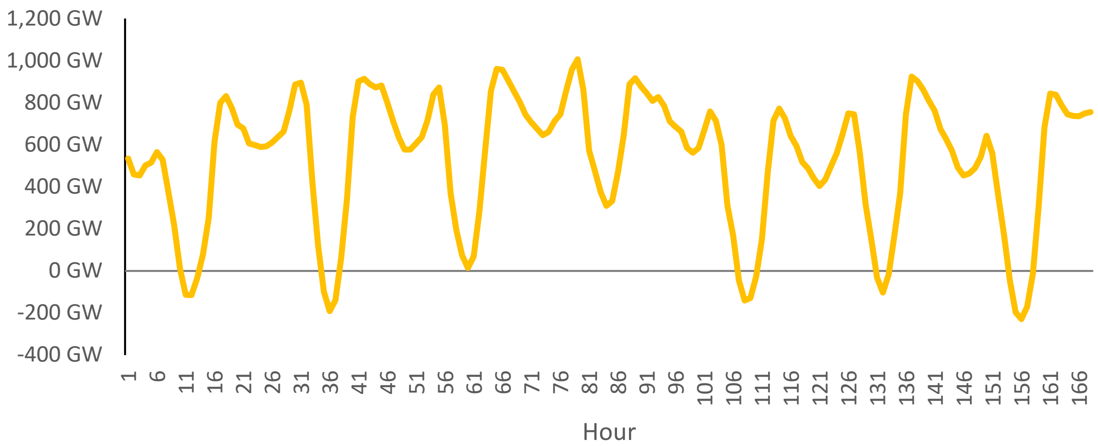
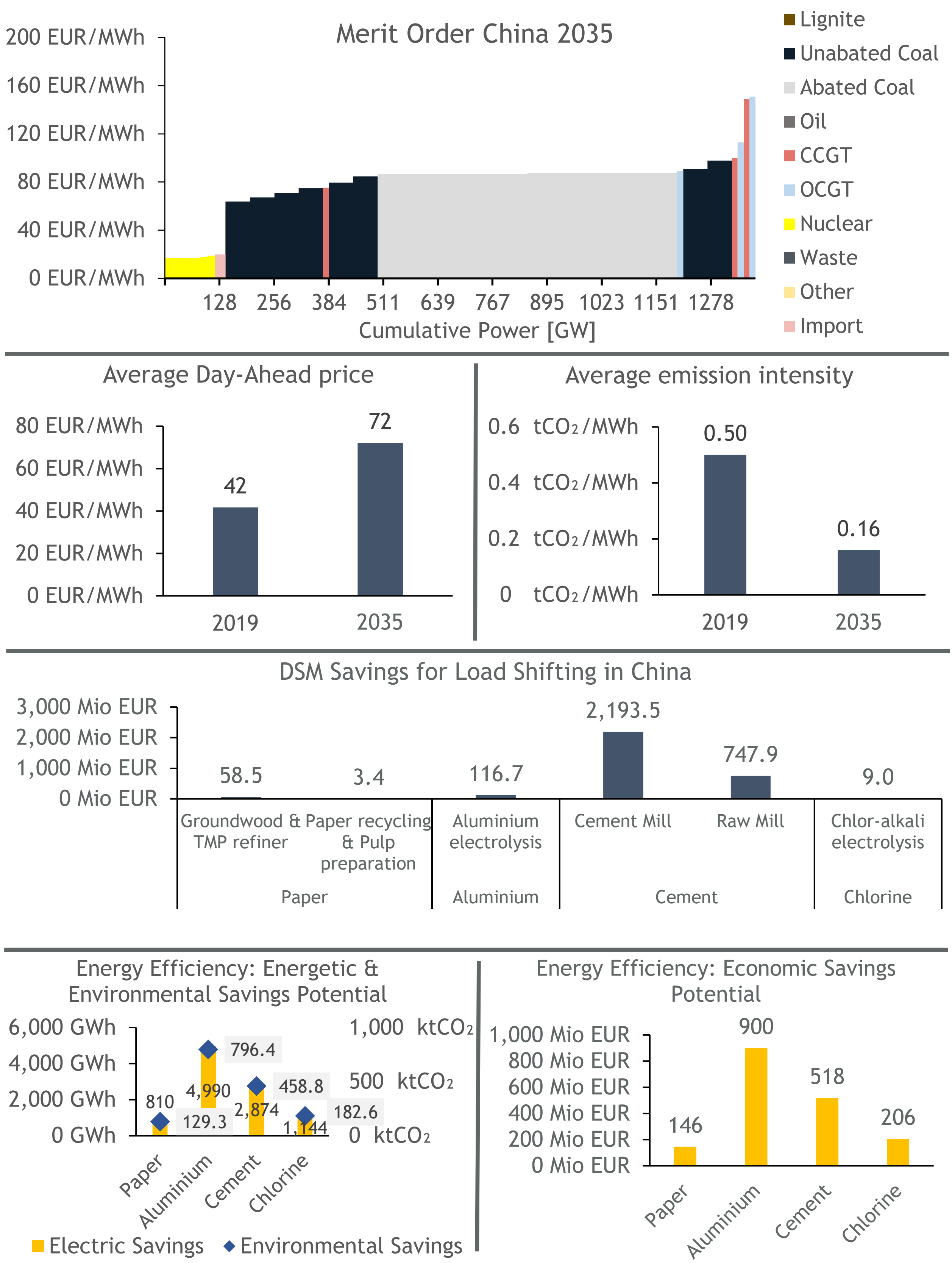


Figure 16: Hourly residual load in 2035 in China for one exemplary week (default scenario)

Figure 16 shows the hourly residual load for an exemplary week in 2035 as used in the default scenario. As explained in chapter 4.1, the residual load is the difference between demand and generation from renewable energy sources. In this example, the shape of the residual load curve follows the generation from solar panels. When the residual load is negative (e.g. in hours 11 and 36), the generation from renewables is larger than the demand. During these times, flexibility measures such as DSM can help stabilize the power system by increasing the electricity demand and decreasing it during times of higher residual load with less renewable production. Thus, DSM can help solve power grid congestion and prevent the otherwise necessary regulation of surplus renewable power, thereby decreasing CO_2 emissions.

In the default scenario for China, unabated and abated coal dominates the merit order up until around 1,300 GW of cumulative load and, therefore, mainly determines electricity prices. Renewable energies are not part of the merit order as only the residual load, calculated as total demand minus available renewables, must be covered by conventional power units with marginal costs greater than zero. The marginal costs of renewables are assumed to be zero.



Note: Exemplary calculation with energy efficiency gain set to 1 % for each industry.

Figure 17: Results for the default scenario of the simulation tool for China in 2035

With the merit order, the assumed electricity demand and load profiles of the end-use sectors, an **average electricity price** is calculated for 2035. In addition, the average **emission intensity** of power generation is determined, as described in chapter 4.1. While the average electricity price increases from around 42 to 72 EUR/MWh, the average emission intensity decreases from 0.50 to 0.16 tCO_2/MWh. The electricity price increases mainly due to a higher emission price: an increase from around 4 EUR/tCO_2 in 2019 to 47 EUR/tCO_2 in 2035 is assumed.

Additionally, marginal costs increase due to Carbon Capture and Storage (CCS) at coal-fired power plants. These abated coal power plants have higher marginal costs than unabated coal plants but save around 90 % of CO_2 emissions per unit of electricity, reducing the costs from the emission price. The decrease in emission intensity results from expanding abated coal and renewable energies. As the assumed marginal costs of abated coal-fired power plants are mostly lower than the marginal costs of unabated units, these plants are often ranked first in the merit order and are dispatched more often.

Potential **DSM economic savings** for 2035 show that some industrial processes cannot utilise their full DSM potential. For paper (recycling & pulp preparation) and chlorine, the potential DSM earnings range from 3 to 9 Mio EUR (net). Despite having a high installed electrical capacity of paper (7,900 MW) and chlorine (14,300 MW), the defined shift duration of a maximum of 2 hours limits the use of DSM in the simulation tool. This value was set as default following industry interviews.

This technical restriction indicates that these industries should instead specialise in shorter shifts (e.g., 15-minute intervals) and thus potentially have higher earning potential on other potential flexibility markets than the spot market (see Table 8). This highlights the need for regulators to design markets that take industrial circumstances into account. Other marketing options, such as balancing markets, where prices tend to be more volatile in the short term, can generate DSM profits for industries with a shorter shift duration. These markets are not included in this simulation.

Although aluminium electrolysis has the same technical restrictions as paper and chlorine regarding shift duration, the relatively large technical potential means that comparatively high DSM savings can be achieved – 117 Mio EUR (net) in 2035. Nevertheless, extending the shift duration, which is highly dependent on the underlying technology to produce aluminium, would also drastically increase the savings potential.

Industrial processes with longer shift durations like groundwood & TMP refiner and cement & raw mills can more successfully utilise their flexibility. In the default scenario, the groundwood & TMP refiner generate a profit of 59 Mio EUR (net). With an average electricity price of 72 EUR/MWh, this profit means that DSM allows saving roughly 9 % of expenses for electricity in this industrial process in 2035[7].

[7] The expenses without DSM utilisation can be calculated with assumptions from the simulation tool and the following formula:

$$\text{Average Day-Ahead price } [EUR/MWh) * \text{Load capacity } [MW] * (8760 * \text{Average load factor } [\%]) = \text{ Electricity costs } [EUR]$$

Due to a relatively lower total installed capacity, the potential profits in the paper industry are significantly lower compared to cement. In the raw and cement mill processes, 748 to 2,194 Mio EUR profits (net) are achieved in the scenario. These profits are realized by load shifting; thus, no loss of production would occur. Since these are net profits, the potential costs of implementing and operating DSM decrease these profits.

Our simulation analysis shows that the use of DSM can generate significant economic savings for the industrial firm. It can also support the transition towards a renewable energy system by shifting electricity demand towards periods with a lower CO_2 intensity and off-peak times. In the default scenario, load shifting as part of DSM reduces greenhouse gas emissions by 19,500 kt CO_2.

We simulate marketing the available DSM on a spot market for electricity. Industrial processes differ in the technical prerequisites for participating in this DSM-marketing option. Especially processes with a relatively long shift duration are suitable for reacting to spot price volatility. Other marketing options, where prices tend to be more volatile in the short term, such as balancing energy markets, can generate profits for industries with a shorter shift duration. These are not included in this simulation.

While load shedding is implemented in the simulation tool, it is not trivial to identify prices at which the selected industries would consider stopping their production. Load shedding is a business management decision and is expected to differentiate between companies since business relations with customers and opportunity costs must be considered. Therefore, a high price was set in the simulation tool, which exceeds the peak prices set in the default scenario. As a result, we see no profits from load shedding.

Energy efficiency's **energetic, environmental,** and **economic savings potential** directly follows from the default assumptions, most importantly, the available potential for improvement in the respective industry. As specific energy efficiency gains are hard to determine, the default scenario only gives an exemplary overview of different assumptions.

As energy efficiency targets and benchmarks are continuously adjusted, the simulation tool provides the opportunity to assess the impact of different efficiency gains in the selected industries. For example, in the paper industry, the energy efficiency gain is set to 1 % until 2035. This efficiency gain results in savings of 146 Mio EUR (net) by saving 810 GWh of electricity. Indirectly 129 ktCO_2 would be saved in the energy sector. The resulting net economic savings can be interpreted as an upper bound, as costs (mainly from investment) are not considered for achieving these efficiency potentials.

Germany

Figure 19 shows the main results of the simulation tool for Germany. These results include an illustration of the merit order, the average electricity wholesale market price, the average emission intensity of electricity, potential DSM savings in 2030, and energetic, environmental (CO_2) and economic savings for energy efficiency.

The shown **merit order** directly results from the set energy system scenario. The installed capacity of renewable and conventional power generation technologies, the emission price, fuel prices, transport costs, and other variable costs of power generation directly influence the merit order and hence electricity prices.

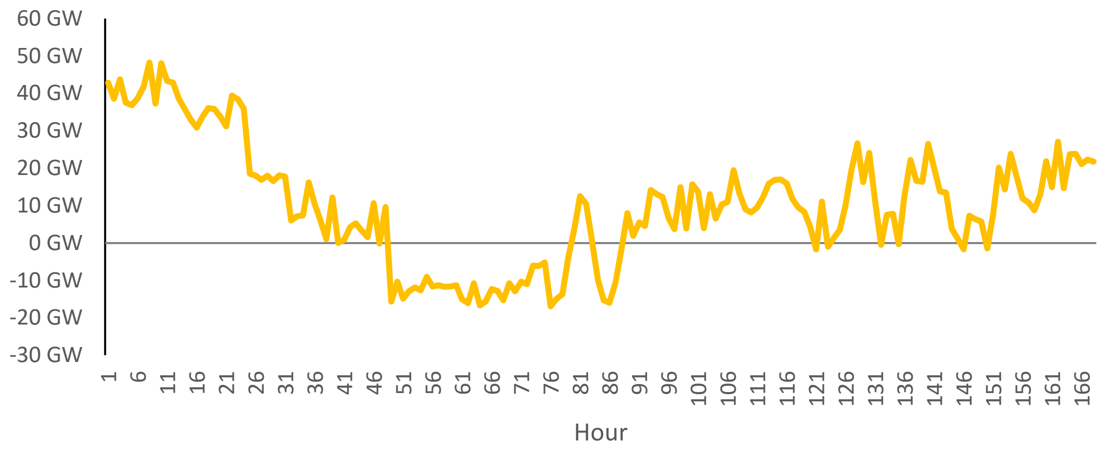


Figure 18: Hourly residual load in 2030 in Germany for one exemplary week (default scenario)

Figure 18 shows the hourly residual load for an exemplary week in 2030 as used in the default scenario. As explained in chapter 4.1, the residual load is the difference between demand and generation from renewable energies. Compared to China (Figure 16), more prolonged negative residual load times can be seen here. The peaks, both negative and positive, are also more smoothed. This is mainly due to the ability to trade electricity with neighbouring countries, export electricity at low prices, and import power at higher prices. DSM can help solve power grid congestion and prevent the otherwise necessary regulation of surplus power in this market.

In the default scenario for Germany, electricity imports, OCGT, and CCGT dominate the merit order from around 22 GW until around 52 GW of cumulative load. Renewable energies are not part of the merit order as only the residual load must be covered by conventional power units with marginal costs greater than zero. The marginal costs of renewables are assumed to be zero.

With the merit order, the assumed electricity demand and load profiles of the end-use sectors, an **average electricity price** is calculated for 2030. In addition, the average **emission intensity** of power generation is determined. While the electricity price increases from 46 to 62 EUR/MWh, the emission intensity decreases from 0.36 to 0.07 tCO_2/MWh.

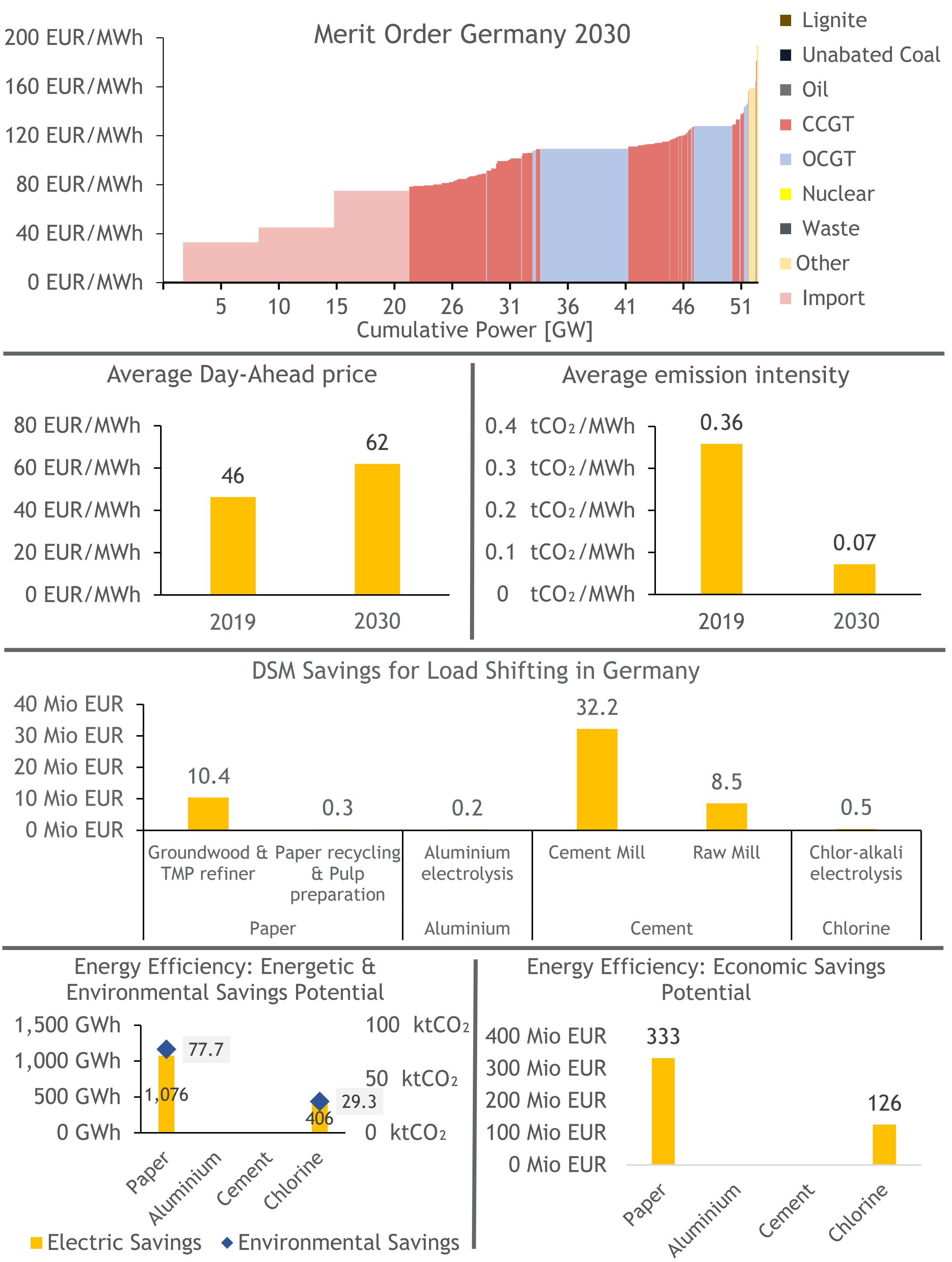


Figure 19: Results for the default scenario of the simulation tool for Germany in 2030

Due to several factors, the average electricity price increases: relatively inexpensive power generation from nuclear and coal-fired power plants will be phased out by 2030. Additionally, the CO_2 price is expected to increase until 2030, which drives the marginal cost of natural gas-fired power plants (CCGT and OCGT) upwards. The decrease in average emission intensity is a consequence of the heavy expansion of renewable energies and the relatively low CO_2-emission factor of natural gas compared to coal and lignite. Furthermore, Germany becomes a net importer of electricity. Since the emissions of imported electricity are not included in Germany's emission balance, only emissions in Germany are considered in the simulation tool.

Potential **DSM economic savings** for 2030 show that some industrial processes cannot utilize their full DSM potential. For aluminium, paper (recycling & pulp preparation), and chlorine, the DSM the potential earnings range from 0.2 to 0.5 Mio EUR (net). Despite having the highest installed electrical capacity of paper (1,400 MW), aluminium (1,080 MW) and chlorine (1,350 MW), the maximum shift duration of 2 hours limits the use of DSM in the simulation tool. This technical restriction indicates that these industries should instead specialise in shorter shifts (e.g., 15-minute intervals) and thus potentially have higher earning potential on other potential flexibility markets than the spot market see Table 8. Other marketing options, such as balancing markets, where prices tend to be more volatile in the short term, can generate DSM profits for industries with a shorter shift duration. These are not included in this simulation.

In contrast, industrial processes with longer shift durations like groundwood & TMP refiner and cement & raw mills can more successfully utilise their flexibility. These processes generate profits of 10.4 to 32.2 Mio EUR (net) in the default scenario. Firms with a groundwood & TMP refiner can save 6 % of their average annual electricity bill utilizing their available DSM potential.[8] These profits are made only by load shifting; thus, no loss of production would occur.

Since these are net profits, potential costs of implementing and operating DSM would lower these profits. In addition to reducing the electricity costs, using DSM also contributes to decreasing the CO_2 emissions in the electricity sector by shifting demand to periods with a lower emission intensity. Load shifting as part of DSM reduces greenhouse gas emissions by 134 kt CO2 in the default scenario.

The model shows relatively low DSM savings for the aluminium industry per installed capacity compared to China. This is based on the underlying assumption that production capacity in Germany is operated at a higher average load factor than in China, significantly decreasing the potential to increase electricity demand in times of relatively low electricity prices.

While load shedding is implemented in the simulation tool, it is not trivial to identify prices at which the selected industries would consider stopping their production. Load shedding is a business management decision and is expected to differentiate between companies since business relations with customers and opportunity costs must be considered. Therefore, a high price was

[8] The expenses without DSM utilisation can be calculated with assumptions from the simulation tool and the following formula:
$$\text{Average Day-Ahead price } [EUR/MWh) * \text{Load capacity } [MW] * (8760 * \text{Average load factor } [\%]) = \text{Electricity costs } [EUR]$$

set in the simulation tool, which exceeds the peak prices set in the default scenario. As a result, we see no profits from load shedding.

Energy efficiency's **energetic**, **environmental**, and **economic savings** potential directly follows the set assumptions, most importantly, the available potential for energy efficiency improvements in the industrial process. In interviews with industry companies, assumptions on energy efficiency potentials based on EWI (2021a) were discussed and adapted if necessary. Significant improvement potential in Germany was identified for the paper and chlorine industry. As a result, the paper industry would save around 333 Mio EUR (net) by saving 1,076 GWh of electricity. Indirectly 78 ktCO_2 would be saved in the energy sector as demand for electricity from this industry is reduced. Around 126 Mio EUR (net) in the chlorine industry would be saved by lowering electricity demand by 406 GWh. Indirectly 29 ktCO_2 would be saved in the energy sector.

The modelling results in no savings from energy efficiency in the aluminium industry. Interviews with industry experts revealed that there will likely be no additional investment into improving the energy efficiency of today's aluminium production process. This decision is based on the ongoing development and implementation of a new production technology.

Users of the tool can adjust the corresponding parameter to simulate the effects of additional energy efficiency investment until 2030. No further energy efficiency improvements are possible in the cement industry until 2030, as suggested by industry experts based on currently available technologies.

Modelling the future electricity markets in China and Germany, possible interdependencies between the effects of DSM and energy efficiency on the displayed variables are not explicitly considered. This decision is based on interviews with industry experts, suggesting no practical of these effects in the current setting. The simulation tool allows making these effects explicit if additional evidence emerges.

Summary – Estimated potentials and effects on the energy market in China and Germany

The presented results illustrate the merit order, the average electricity wholesale market prices, the average emission intensity of electricity, potential DSM savings, and energetic, environmental (CO_2) and economic savings for energy efficiency.

In the default scenario, it is assumed that the technical conditions in China and Germany are comparable, and the findings that can be derived can be applied to both countries.

The largest DSM potential was found in the cement industry for cement and raw mills. The technical prerequisites, especially regarding a relatively long shift duration, are very advantageous for DSM marketing on the spot market.

The results for energy efficiency are heterogeneous and depend on specific assumptions about the industry. The simulation tool shows how beneficial various savings can be in terms of electricity saved and indirect CO_2 emissions.

5 Options for policymakers – Encouraging energy efficiency and Demand Side Management

Both Germany and China are striving for climate- or carbon-neutral economies by 2045 or 2060, respectively. These goals entail large transformations both on the supply and demand side while maintaining the security of supply for all consumers. Increasing energy efficiency and demand flexibility in energy-intensive industrial processes are essential contributions toward achieving those goals.

Shifting electricity load in time as part of DSM can imply that the industrial process is operated at a suboptimal load level. DSM could negatively affect the energy efficiency of a process and potentially distort the progress achieved in this realm. On the other hand, increasing the energy efficiency of a process can reduce the absolute DSM potential, as less electricity can be shifted in time. Empirical evidence for such effects is scarce on the level of a single process. Hence, we do not simulate these effects explicitly. Such effects may occur if DSM is deployed at a large scale or major improvements in energy efficiency are achieved. Hence, acknowledging these potential effects appears important when designing policy instruments and should be monitored and considered when necessary.

This chapter provides specific recommendations and options for policymakers given the current state of regulation in the respective electricity market. The presented measures are expected to reduce the aggregate costs of the electricity system but are not based on a comprehensive welfare analysis. Distributional implications are not discussed.

5.1 Policy options for China

DSM and energy efficiency can play an important part in achieving China's energy transition and maintaining energy security. The future power system needs to incorporate flexibility measures and facilitate a high degree of energy efficiency.

Energy Efficiency

As presented in chapter 4.3, energy efficiency can positively impact direct energy demand and indirect CO_2 emissions. With the assumed electricity demand in 2035, an energy saving of 1 % in the selected industries would save around 10,000 GWh and thus nearly 800 $ktCO_2$ per year. The impact on an energy system with today's power plant fleet would result in even larger CO_2 savings.

Building on an effective administrative approach, economic incentives can provide an efficient way to promote industrial energy efficiency in electricity-intensive sectors further. Early experience with an ETS covering the power sector in Europe shows that such schemes can successfully achieve energy efficiency goals. A similar intensity-based trading scheme could be implemented for the industrial sector, creating an economic incentive to improve energy efficiency. An additional option is to increase electricity prices by taxation, favouring more energy-efficient companies.

Local subsidies supporting relatively energy-inefficient companies should be abandoned. This will increase incentives for investment into energy efficiency and shift production from less to more energy-efficient companies, reducing aggregate energy intensity without a loss of production. This price signal can be supported by dedicated programs and special loans from public sources.

The Chinese central and provincial governments should promote programs supporting expertise and knowledge on industrial energy efficiency among decision-makers (GIZ, 2020). This support can be provided, for example, in the form of information campaigns among (local) political and industrial decision-makers.

Demand Side Management

An increasing share of volatile renewable energies in the Chinese power system will require flexible options to balance supply and demand and thus maintain energy security. Energy storage capacities and voluntary DSM measures are promising options for achieving decarbonisation and energy security goals.

There is a large potential for industrial DSM, which is set to further increase with the electrification of even more industrial processes. China's DSM potential remains largely untapped, and a regulatory framework allowing for widespread market-based DSM does not exist.

The simulation tool's default scenario shows that around 39,400 GWh of electricity could be shifted from hours with high electricity prices to hours with lower electricity prices in the selected industries. As high prices indicate potentially high shares of conventional power generation and low prices high shares of renewable energies, DSM can supply flexibility to help secure electricity supply.

Various regulatory barriers must be removed to achieve this goal. The regulatory framework should allow short-term price signals or bilateral agreements, incentivising DSM. For a successful implementation of national goals, incentives for local implementation of policies are required.

To improve the regulatory framework for DSM in China, adequate compensation for DSM deployment needs to be established. For this, we present different options:

> **Option 1**: An efficient allocation of DSM potential could be achieved via an open spot market, where price spreads over time provide an incentive for companies to use their DSM potential. The Chinese power market reform introducing competitive areas in the power sector is important for establishing DSM market segments. Reforms such as (sub-)hourly and ancillary service markets will lay the foundation for market-based DSM (IEA, 2021).
>
> **Option 2**: Intermediate stages towards granular real-time markets can increase price-based incentives for DSM and tend to be relatively easy to implement. One promising option is to increase the price difference in a peak valley pricing scheme, which already exists in some regions in China. This will split a typical production day into two price regimes, where the

prices reflect fundamental differences in demand and supply. Such a scheme provides incentives for an industrial company to shift production to more favourable market conditions.

If no adequate compensation for DSM via market-based mechanisms can be implemented in the upcoming years, alternatively – in the short term - administrative measures can bridge this by allocating load shifting as efficiently as possible. An option is to establish an orderly manner (merit order) of power dispatch:

Option 3: Until now, the administrative reduction of loads have had high economic costs for companies and the Chinese economy. To reduce these costs, provinces should calculate a merit order containing industrial information, which is applied to coordinating targeted industrial load shifting with reduced economic costs in case of power shortage. Regulators should introduce merit order dispatch categories containing a strategy for orderly power consumption of major energy consumers. Such a merit order would increase transparency and predictability of the process, potentially increasing support for these measures.

Further support measures

While the significant barrier for DSM in China is the lack of a framework that ensures adequate compensation for DSM participants, other challenges - e.g., an information and financial gap - hinder the utilisation of industrial DSM potentials.

To facilitate the utilisation of DSM and investment in DSM in China, the availability and accessibility of data need to be improved for all stakeholders, including regulators, industry companies, and grid operators. Required data include real-time information on the availability of renewable electricity and - given a sophisticated market - spot power prices, such as intraday and day-ahead prices. In addition, information on industrial energy consumption is necessary. A well-functioning data collection and data sharing system forms the basis for applying demand response measures for electricity balancing. Besides, authorities need to establish a scheme for certification, reporting, and monitoring companies offering their DSM potentials.

Additional know-how and awareness for DSM at the provincial and local levels among authorities, policymakers, and companies can help promote the use of DSM across all Chinese provinces and industry sectors. The national government can support the uptake of DSM through technical support initiatives and qualification programs. Besides the information gap, the potential financial risk for companies should be addressed. Investment support for necessary DSM devices, such as software, can help release industrial DSM potentials where investment costs are a barrier. This report focuses on the industrial sector and provides options for policymakers to improve industrial DSM and energy efficiency. Progress in these areas can affect the power sector and other electricity consumers. Increased use of DSM will help integrate renewable capacity and higher levels of energy efficiency and reduce the average electricity price by lower demand.

Summary – Policy options for China

Energy efficiency

- An intensity-based trading scheme, similar to the ETS, could be implemented for the industrial sector, creating an economic incentive to improve energy efficiency.
- An increase in industrial electricity prices would incentivize further energy efficiency gains.
- Local subsidies supporting relatively energy-inefficient companies should be abandoned.
- The Chinese central and provincial governments should promote programs supporting expertise and knowledge on industrial energy efficiency among decision-makers.
- Potential negative interdependencies between energy efficiency and DSM must be observed, and potentially decreasing efficiencies through DSM use for target achievement should be considered.

Demand Side Management

- The regulatory framework of the power market should allow for short-term price signals or bilateral agreements, incentivising the use of DSM. Three options are recommended, which take into account different stages of electricity market reform

  Option 1: Implementation of an open spot market, where price spreads over time, incentivises companies to use their DSM potential.

  Option 2: Increase the price difference in a peak valley pricing scheme. Such a scheme provides incentives for an industrial company to shift production to more favourable market conditions.

  Option 3: Provinces should calculate a merit order containing industrial information, which is applied to coordinating targeted industrial load shifting with reduced economic costs in case of power shortage.

5.2 Policy options for Germany

Energy efficiency

Industrial companies in Germany are among the most energy-efficient in the world. However, significant potential for improvement still exists, and there are options for the government to support additional investments.

Besides various existing support measures, the German government could introduce more ambitious regulations. Although companies must conduct regular energy audits, there is no obligation to realise the identified energy saving potentials. Together with improved subsidy programs, energy efficiency in industrial processes can increase.

Further measures could require only the most efficient technology in each new industrial installation. Installations that are not climate-neutrality compatible (i.e., that cannot be used with renewable energy sources) should only be subsidised in exceptional cases.

Shorter depreciation periods should be introduced for investments to increase energy efficiency or reduce CO_2 emissions to shorten payback periods (BMWK, 2021; dena, 2021a)

Demand Side Management

Germany has established several marketing options for industrial DSM. Nevertheless, market access and regulatory barriers exist, and significant DSM potentials remain unused. To further facilitate industrial DSM potential utilisation, the German regulator can remove remaining market barriers and create a stable regulatory framework that allows stakeholders to predictability and planning security.

The simulation tool's default scenario shows that around 450 GWh of electricity could be shifted from hours with high electricity prices to hours with lower electricity prices in the selected industries. As high prices indicate potentially high shares of conventional power generation and low prices high shares of renewable energies, DSM can supply flexibility to help secure electricity supply.

While price signals for DSM from the spot market exist, calculation of grid fees often distorts this signal. Peak load time windows, which can be inaccurate forecasts of real market conditions and the 7,000 h/a – rule (§ 19.2 StromNEV) can penalise DSM efforts by industry, although the market price suggests the positive systemic value of such actions. Revising these rules to let grid fees more accurately reflect the actual market and grid conditions is a promising option for increasing the use of industrial DSM.

High prequalification requirements and stiff regulation at other marketing options limit industrial DSM diffusion. Decreasing prequalification standards in the balancing market and the AbLaV should increase the number of active participants and available DSM capacity and decrease prices. Unplanned deviations from the consumption schedule can be penalised within the AbLaV market, even though they can be beneficial from a system perspective. The regulatory framework should allow system-serving deviations to incentivise DSM.

Frequent changes to the regulatory framework of the additional markets create uncertainty about marketing opportunities for firms. A lack of knowledge and high cost of information often affect the willingness to offer DSM capacity. Information campaigns and additional support measures can help in overcoming these knowledge gaps.

Summary – Policy options for Germany

Energy efficiency

- Introduction of an obligation to utilise identified energy saving potentials from energy audits.
- Obligation to use only the most efficient technology in each new industrial installation.
- Introduction of shorter depreciation periods for investments in energy efficiency to shorten payback periods.

Demand Side Management

- Revision of § 19.2 Strom NEV w.r.t. peak load time windows and the 7,000 h/a – rule. Let grid fees more accurately reflect the actual market and grid conditions.

- High prequalification requirements and stiff regulation at flexibility marketing options limit industrial DSM diffusion.
- Implementation of information campaigns and additional support measures help reduce the cost of information and overcome knowledge gaps.

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List of abbreviations

AbLaV	Interruptible Loads Ordinance (in German “Verordnung zu abschaltbaren Lasten")
BAFA	Federal Office of Economics and Export Control (in German *Bundesamt für Wirtschaft und Ausfuhrkontrolle*)
BAT	Best available techniques
BEV	Battery Electric Vehicle
BMWi	Federal Ministry of Economics and Energy (in German *Bundesministerium für Wirtschaft und Klimaschutz*)
dena	German Energy Agency (in German *Deutsche Energie-Agentur*)
DSM	Demand Side Management
EBGL	European Electricity Balancing Guideline
EDL-G	Energy Services Act (in German *Gesetz über Energiedienstleistungen und andere Energieeffizienzmaßnahmen*)
EED	European Energy efficiency Directive
EEX	European Energy Exchange
EnWG	Energy Industry Act (in German *Energiewirtschaftsgesetz*)
ESCO	Energy Service Company
EVPG	Energy Consumption Relevant Products Act (in German *Energieverbrauchsrelevante-Produkte-Gesetz*)
EWI	Institute of Energy Economics at the University of Cologne (in German *Institut für Energiewirtschaft an der Universität zu Köln*)
FDP	Free Democratic Party of Germany
FYP	Five Year Plan
GDP	Gross Domestic Product
GHG	Green House Gases
GIZ	German Corporation for International Cooperation (in German *Gesellschaft für Internationale Zusammenarbeit*)
IASS	Institute for Advanced Sustainability Studies (Germany)
IEA	International Energy Agency
KFW	Reconstruction Credit Institute (in German *Kreditanstalt für Wiederaufbau*)

MEE	Ministry of Ecology and Environment of the People’s Republic of China
MIIT	Ministry of Industry and Information Technology (China)
NAPE	National Action Plan Energy Efficiency (in German *Nationaler Aktionsplan Energieeffizienz*)
NDC	Nationally Determined Contributions
NDRC	National Development and Reform Commission (China)
NEA	National Energy Administration (China)
OIES	Oxford Institute for Energy Studies
RAM	Balancing power market (in German *Regelarbeitsmarkt*)
RES	Renewable Energy Sources
RLM	Control power market (in German *Regelleistungsmarkt*)
SAMR	The State Administration for Market Supervision (China)
SPD	Social Democratic Party of Germany (in German *Sozialdemokratische Partei Deutschlands*)
StromNEV	Electricity Network Charges Ordinance (in German *Stromnetzentgelt-verordnung*)
TCE	Tons of coal equivalent
TMP	Thermomechanical pulp
UNFCCC	United Nations Framework Convention on Climate Change

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Appendix

Overview of promising energy efficiency measures (non-conclusive)

Industry	Measure	Potential efficiency increase [low-high]	Reference
Aluminium	Cathode improvements (graphitised or novel NSC cathodes)	medium	Haraldsson and Johansson (2018)
Aluminium	Anode improvements (use of slotted, perforated, or inert anodes)	medium - high	Haraldsson and Johansson (2018)
Aluminium	Performance improvements in electrolysis (suppression of anode effect, addition of aluminium oxide at several stages)	medium - high	Haraldsson and Johansson (2018)
Aluminium	For short transport distances: Delivery of molten aluminium	low	Haraldsson and Johansson (2018)
Aluminium	Vertical electrode cells	high	Haraldsson and Johansson (2018)
Aluminium	Low-temperature analysis	high	Haraldsson and Johansson (2018)
Cement	Cross-sectional technologies (variable-speed drives, high-efficiency motors)	low - medium	Price, Hasanbeigi and Lu (2009); Huang and Wu (2021)
Cement	High-pressure roller press and pre-grinding to ball mill **or** replacing a ball mill with a vertical roller mill (measure depends on the age of the mill)	high	Price, Hasanbeigi and Lu, (2009)
Cement	Use of high-performance roller mills for raw materials grinding	high	Price, Hasanbeigi and Lu (2009); Huang and Wu (2021)
Cement	Use of high-performance classifiers / separators	low - medium	Price, Hasanbeigi and Lu (2009); Huang and Wu (2021)
Chlorine	Switch to the membrane process with oxygen depolarised cathode (ODC). *Comment: Compared to the conventional membrane process, the by-product hydrogen is omitted. Therefore, the high-efficiency increase potential must be adjusted in cases where the hydrogen is used in subsequent applications.*	high	Geres *et al.* (2019)
Chlorine	Use of more efficient cross-sectional technologies	high	Geres *et al.* (2019)

Chlorine	Continuous incremental improvement of chlor-alkali electrolysis process efficiency	low	Geres *et al.* (2019)
Paper	High-efficiency refiners: The use of a more flexible refiner can minimise idle losses when switching to batch production	medium	Fleiter *et al.* (2012); GIZ (2021b)
Paper	Cross-sectional technologies (pumps, light, motors, etc.)	high	Kong *et al.* (2017)
Paper	Grinders: metal-modified grinding surfaces can increase efficiency instead of ceramic or stone surfaces.	low	Fleiter *et al.* (2012)

Table 9: Overview of promising energy efficiency measures (incomplete list)

Interdependencies between energy efficiency and Demand Side Management

In their analysis, Gruber, von Roon and Fattler (2016) researched different production processes and different states of the production to simulate load in- and decrease for different load states.[9] The analysis differentiated between two cases:

- Provision of positive load potential. In production times, the optimal load is maintained, and if needed, the production is switched to a partial load to supply a negative load.
- Provision of negative load potential. If the optimal load is lower than 100 %, the optimal load is maintained, and the production is increased to supply a positive load.

Table 10 displays the results of their analysis for aluminium-electrolysis and chlorine-alkaline-electrolysis. For TMP-refiner and cement mills, no impact of DSM on energy efficiency was found.

The authors point out that a variation of below 1 % is considered negligible since the accuracy of the measuring instruments is already lower than the efficiency deviation.

Process	Hold-back time*	Flexibility request (100 / 1,000 h/a)	
		negative	positive
Aluminium electrolysis	6,000 h/a	-0.5 % / -5 %	-0.05 % / -0.5 %
Chlorine-alkali electrolysis	7,000 h/a	+0.06 % / +0.6 %	-0.05 % / -0.5 %

* Holdback time is assumed to be equal to the annual production time.

Table 10: Interdependency between DSM and energy efficiency

Source: Gruber et al. (2016)

[9] For the aluminium electrolysis the following assumptions were made:7,000 full load hours, optimal load = 100 %, partial load = 75 %, Missing production volumes will be made up for (with a load of 100 %), Flexibility demand of 100-1,000 h/a.

Interviews conducted as part of the study

No.	Scope	Topic	Interview partners
01	Aluminium industry	Current and future potential of DSM and energy efficiency; Regulatory framework	Company
02	General overview	Dissemination of DSM and energy efficiency in China; Regulatory framework	Research
03	General overview	Dissemination of DSM and energy efficiency in China; Regulatory framework	Research
04	General overview	Dissemination of DSM and energy efficiency in Germany; Regulatory framework	Research
05	Chlorine industry	Current and future potential of DSM and energy efficiency; Regulatory framework	Company
06	Chlorine industry	Current and future potential of DSM and energy efficiency; Regulatory framework	Company
07	General overview	Dissemination of DSM and energy efficiency in China; Regulatory framework	Research
08	Cement industry	Current and future potential of DSM and energy efficiency; Regulatory framework	Company
09	Paper industry	Current and future potential of DSM and energy efficiency; Regulatory framework	Company

Table 11: Overview of the conducted interviews

Basic settings in the default scenario of the simulation tool

Renewables

Germany

Plant Type	2019	2030	Unit
Biomass	8	8	GWel
Water Reservoir	5	5	GWel
Water RoR	0	0	GWel
Wind Offshore	6	30	GWel
Wind Onshore	53	94	GWel
PV	46	200	GWel
Other	0	0	GWel

China

Plant Type	2019	2035	Unit
Biomass	20	144	GWel
Water Reservoir	361	418	GWel
Water RoR	1	1	GWel
Wind Offshore	34	71	GWel
Wind Onshore	200	850	GWel
PV	206	1.478	GWel
Other	0	0	GWel

Conventionals

Germany

Plant Type	2019	2030	Unit
Lignite	21	0	GWel
Unabated Coal	25	0	GWel
Abated Coal	0	0	GWel
CCGT	22	19	GWel
OCGT	10	13	GWel
Oil	3	0	GWel
Nuclear	10	0	GWel
Waste	2	2	GWel
Other	7	2	GWel

China

Plant Type	2019	2035	Unit
Lignite	0	0	GWel
Unabated Coal	1.028	457	GWel
Abated Coal	0	701	GWel
CCGT	50	40	GWel
OCGT	59	43	GWel
Oil	8	3	GWel
Nuclear	54	117	GWel
Waste	0	0	GWel
Other	0	0	GWel

Emission Price

Germany

	2019	2030	Unit
Price	25,00	96,00	EUR/tCO2

China

	2019	2035	Unit
Price	3,88	47	EUR/tCO2

Electricity Demand

Germany

	2019	2030	Unit
Demand	567	698	TWhel

China

	2019	2035	Unit
Demand	7.150	10.500	TWhel

Storage

Germany

Technology	Power	Size	Unit
Short-Term	10	40	GW, GWh

China

Technology	Power	Size	Unit
Short-Term	15	90	GW, GWh

Figure 20: Basic Settings - default scenario

Expert settings in the default scenario of the simulation tool

Fuel Prices

	Germany				China			
	Fuel Type	**2019**	**2030**	**Unit**	**Fuel Type**	**2019**	**2035**	**Unit**
	Lignite	3,10	3,10	EUR/MWhth	Lignite	3,10	3,10	EUR/MWhth
	Coal	11,28	9,59	EUR/MWhth	Coal	12,49	11,19	EUR/MWhth
	Gas	22,70	26,23	EUR/MWhth	Gas	24,55	34,30	EUR/MWhth
	Oil	32,92	48,67	EUR/MWhth	Oil	29,46	50,58	EUR/MWhth
	Nuclear	5,50	5,50	EUR/MWhth	Nuclear	5,50	5,50	EUR/MWhth
	Waste	0,00	0,00	EUR/MWhth	Waste	0,00	0,00	EUR/MWhth
	Other	32,92	32,92	EUR/MWhth	Other	32,92	32,92	EUR/MWhth

Transport Costs

Plant Type	2019	2030	Unit	Plant Type	2019	2035	Unit
Lignite	0,00	0,00	EUR/MWhth	Lignite	0,00	0,00	EUR/MWhth
Coal	1,25	1,25	EUR/MWhth	Coal	1,25	1,25	EUR/MWhth
Gas	0,50	0,50	EUR/MWhth	Gas	0,50	0,50	EUR/MWhth
Oil	0,30	0,30	EUR/MWhth	Oil	0,30	0,30	EUR/MWhth
Nuclear	0,00	0,00	EUR/MWhth	Nuclear	0,00	0,00	EUR/MWhth
Waste	0,00	0,00	EUR/MWhth	Waste	0,00	0,00	EUR/MWhth
Other	0,00	0,00	EUR/MWhth	Other	0,00	0,00	EUR/MWhth

Other Variable Cost

Plant Type	2019	2030	Unit	Plant Type	2019	2035	Unit
Lignite	1,70	1,70	EUR/MWhel	Lignite	1,70	1,70	EUR/MWhel
Unabated Coal	1,30	1,30	EUR/MWhel	Unabated Coal	1,30	1,30	EUR/MWhel
Abated Coal	1,30	1,30	EUR/MWhel	Abated Coal	43,33	60,00	EUR/MWhel
CCGT	1,50	1,50	EUR/MWhel	CCGT	1,50	1,50	EUR/MWhel
OCGT	1,00	1,00	EUR/MWhel	OCGT	1,00	1,00	EUR/MWhel
Oil	1,00	1,00	EUR/MWhel	Oil	1,00	1,00	EUR/MWhel
Nuclear	1,20	1,20	EUR/MWhel	Nuclear	1,20	1,20	EUR/MWhel
Waste	1,00	1,00	EUR/MWhel	Waste	1,00	1,00	EUR/MWhel
Other	1,00	1,00	EUR/MWhel	Other	1,00	1,00	EUR/MWhel

Emission Level

Plant Type	2019	2030	Unit	Plant Type	2019	2035	Unit
Nuclear	0,00	0,00	tCO2/MWhth	Nuclear	0,00	0,00	tCO2/MWhth
Lignite	0,40	0,38	tCO2/MWhth	Lignite	0,42	0,40	tCO2/MWhth
Coal	0,34	0,32	tCO2/MWhth	Coal	0,36	0,34	tCO2/MWhth
Gas	0,20	0,19	tCO2/MWhth	Gas	0,21	0,20	tCO2/MWhth
Oil	0,28	0,27	tCO2/MWhth	Oil	0,29	0,28	tCO2/MWhth
Waste	0,00	0,00	tCO2/MWhth	Waste	0,00	0,00	tCO2/MWhth
Other	0,21	0,20	tCO2/MWhth	Other	0,22	0,21	tCO2/MWhth

Outages

Plant Type	Rate	Unit
Lignite	7.0	%
Unabated Coal	7.0	%
Abated Coal	7.0	%
CCGT	6.0	%
OCGT	5.0	%
Oil	7.0	%
Nuclear	9.0	%
Waste	5.0	%
Other	5.0	%

Plant Type	Rate	Unit
Lignite	8.0	%
Unabated Coal	8.0	%
Abated Coal	8.0	%
CCGT	7.0	%
OCGT	6.0	%
Oil	8.0	%
Nuclear	10.0	%
Waste	6.0	%
Other	6.0	%

Price Adjustment

	2019	2030	Unit
Minimal Price	-60	-20	EUR
Maximal Price	95	220	EUR
Peaker Hours	1,200	450	#h

	2019	2035	Unit
Minimal Price	-	0	EUR
Maximal Price	-	150	EUR
Peaker Hours	-	0	#h

Market Premium

	2019	2030	Unit
Premium paid?	-	no	GWh

Import Capacity

	2019	2030	Unit
Import	-	20	GW

	2019	2035	Unit
Import	0	25	GW

Figure 21: Expert Settings - default scenario

Demand Side Management settings in the default scenario of the simulation tool

Inputs GER							
Sector	**Groundwood & TMP refiner**	**Paper recycling & Pulp preparation**	**Aluminium electrolysis**	**Cement mill**	**Raw mill**	**Chlor-alkali electrolysis**	**Unit**
Shift Duration	5	2	2	12	7	2	[h]
Applied number of Shifts p.a.	730	50	91	365	365	100	[#]
Feasability factor [%]	50	50	100	100	100	50	[%]
Loadfactor max.	0,95	0,95	1,00	1,00	1,00	0,95	[%]
Loadfactor avg.	0,73	0,85	0,97	0,65	0,78	0,87	[%]
Loadfactor min.	0,00	0,00	0,00	0,00	0,00	0,50	[%]
Loadshift delta	*0,73*	*0,10*	*0,03*	*2,60*	*1,10*	*0,08*	[Flh]
Hours down	*1*	*1*	*1*	*4*	*2*	*1*	[h]
Hours up	*4*	*1*	*1*	*8*	*5*	*1*	[h]
Installed Capacity	*334*	*1.406*	*1.082*	*283*	*188*	*1.351*	[MW]
Load shed price	500	500	500	500	500	500	[€]
Applied number of Sheds p.a.	*0*	*0*	*0*	*0*	*0*	*0*	[#]

Inputs CHN							
Sector	**Groundwood & TMP refiner**	**Paper recycling & Pulp preparation**	**Aluminium electrolysis**	**Cement mill**	**Raw mill**	**Chlor-alkali electrolysis**	**Unit**
Shift Duration	5	2	2	12	7	2	[h]
Applied number of Shifts p.a.	730	50	91	365	365	100	[#]
Feasability factor	50	50	100	100	100	50	[%]
Loadfactor max.	0,95	0,95	1,00	1,00	1,00	0,95	[%]
Loadfactor avg.	0,58	0,68	0,78	0,52	0,62	0,70	[%]
Loadfactor min.	0,00	0,00	0,00	0,00	0,00	0,50	[%]
Loadshift delta	*1,10*	*0,27*	*0,22*	*2,88*	*1,50*	*0,20*	[delta]
Hours down	*2*	*1*	*1*	*6*	*3*	*1*	[h]
Hours up	*3*	*1*	*1*	*6*	*4*	*1*	[h]
Installed Capacity	*1.886*	*7.941*	*89.312*	*25.847*	*17.152*	*14.287*	[MW]
Load shed price	500	500	500	500	500	500	[€]
Applied number of Sheds p.a.	*0*	*0*	*0*	*0*	*0*	*0*	[#]

Figure 22: Demand Side Management settings - default scenario

Energy Efficiency settings in the default scenario of the simulation tool

Efficiency gain to target year			
Sector	**GER 2030**	**CHINA 2035**	**Unit**
Paper	6	1	[%]
Aluminium	0	1	[%]
Cement	0	1	[%]
Chlorine	3	1	[%]

Electricity demand before efficiency assessment			
Sector	**GER 2030**	**CHINA 2035**	**Unit**
Paper	*17.925*	*81.000*	GWh_{el}
Aluminium (primary)	*7.556*	*498.960*	GWh_{el}
Cement	*3.938*	*287.410*	GWh_{el}
Chlorine	*13.520*	*114.400*	GWh_{el}

Share of market price of end electricity price			
Country	**GER 2030**	**CHINA 2035**	**Unit**
	20	40	[%]

Production volumes			
Sector	**GER 2030**	**CHINA 2035**	**Unit**
Paper	23,9	108,0	Mt
Aluminium (primary)	0,5	35,0	Mt
Cement	34,1	2489,0	Mt
Chlorine	5,2	44,0	Mt

Interdependence DSM and energy efficiency			
Process	**GER 2030**	**CHINA 2035**	**Unit**
Groundwood & TMP refiner	0,0	0,0	[%]
Paper recycling & Pulp preparation	0,0	0,0	[%]
Aluminium electrolysis	0,0	0,0	[%]
Cement mill	0,0	0,0	[%]
Raw mill	0,0	0,0	[%]
Chlor-alkali electrolysis	0,0	0,0	[%]

Figure 23: Energy Efficiency settings - default scenario

Website

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