A CO$_2$-Neutral Chemical Industry in 2050 – A Roadmap for the Future?

An analysis about perception and use of technologies fostering a CO$_2$-neutral chemical industry within the industrial park Höchst
This study is part of the EIT Climate-KIC funded Re-Industrialise Flagship initiative. The Flagship initiative is focussing on decarbonising industrial business models and operations in high-carbon industry regions in order to comply with European and international climate policy targets for 2050.

It is an explorative study and provides first insights on how CO₂-neutral technologies proposed by literature and various studies are currently used or could be implemented in practice by using the industrial park Höchst as a “real-life” case study.

**Due to the explorative character of the study, further research is necessary to analyse possible transformation strategies and in which particular context they are applicable. Therefore, we invite all scientists, practitioners, and interested readers to provide feedback to the authors.**

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## Table of contents

1 Background and objectives of the study ................................................................. 5
  1.1 Methodology ........................................................................................................ 6
  1.2 The climate debate and the chemical industry .................................................... 7
  1.3 The industrial park Höchst and local CO₂ emissions ........................................... 8

2 Levers for a carbon neutral chemical industry .................................................... 12
  2.1 Lever I: Measures and technologies for energy management and supply .......... 12
      2.1.1 Energy efficiency ......................................................................................... 12
      2.1.2 Power plants with fossil fuels and gases ..................................................... 12
      2.1.3 Virtual power plants .................................................................................... 12
      2.1.4 Biomass ........................................................................................................ 13
      2.1.5 Waste-to-energy ........................................................................................... 13
      2.1.6 Power-to-X ................................................................................................... 13
  2.2 Lever II: Selected changes in production processes ............................................. 14
      2.2.1 Example I: Chlorine Electrolysis ................................................................. 14
      2.2.2 Example II: Plastics recycling ................................................................. 14
      2.2.3 Example III: Carbon Capture and Storage .............................................. 14
  2.3 Lever III: Changes in policy .................................................................................. 14

3 Insights from industry expert interviews: Current developments and perspectives for a carbon neutral chemical industry at the industrial park Höchst ........................ 15
  3.1 Lever I: Potential measures and technologies for energy management and supply 15
      3.1.1 Energy efficiency ......................................................................................... 16
      3.1.2 Thermal (steam) and electrical (electricity) energy generation: Coal phase-out and build-up of new gas turbine ....................................................... 16
      3.1.3 Electric steam generator ........................................................................... 18
  3.2 Lever II: Potential changes in production processes and products ..................... 18
      3.2.1 New electricity-based production processes ............................................. 19
      3.2.2 Green feedstock ......................................................................................... 19
      3.2.3 Secondary emissions ................................................................................... 20

4 Conclusions for the industrial park Höchst .......................................................... 20
  4.1 Industrial park Höchst as a space for demonstration projects ............................ 22
  4.2 Findings for Re-Industrialise .............................................................................. 22

5 References .............................................................................................................. 25
List of tables
Table 1: Differences between combined heat and power (CHP) and power generation. .................. 17

Table 2: Key questions for company decision makers regarding 1) innovation and technology, 2) Industry and business, and 3) Regulation and policy. ................................................................. 24

List of figures
Figure 1: Three different steps of the study approach. ................................................................. 7

Figure 2: Emissions of Infraserv Höchst in CO₂ equivalents for 1) direct emissions from energy production, 2) indirect (secondary) emissions, and 3) indirect emissions from industrial processes. ......................................................................................................................... 9

Figure 3: Combined heat and power (CHP) generation at industrial park Höchst with indication of the origin of 1) direct emissions from energy generation and 2) indirect emissions from the purchase of electrical energy from the local power grid. ................................................................. 11
1 Background and objectives of the study

Recently, reports like the “Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry” have been published laying out the transformation of European heavy industry towards a climate-neutral industry.¹ In addition, further industry-specific studies have been published that discuss different (technological) scenarios how the chemical industry can reduce greenhouse gas emissions (GHG) and CO₂ emissions to meet the goals for 2050, which have been set by policy. The chemical industry must achieve CO₂ emissions reduction by 80-95% compared to 1990.²

Different scientific and industry associations like the association of the German Chemical Industry (VCI), the German Society for Chemical Engineering and Biotechnology (DECHHEMA), or the European Chemical Industry Council (Cefic), but also by private consultancies like McKinsey have published studies, which describe different pathways for a CO₂-neutral chemical industry.³ These pathways - built on macro-economic assumptions - describe what is, in theory, technically feasible. This explorative study investigates how technologies proposed are currently used or could be implemented in practice by using the industrial park Höchst as a “real-life” case study. In doing so, the study provides a reality check for the discussion around a climate neutral chemical industry. Based on six qualitative interviews with industry experts, it offers an explorative overview of how carbon neutral technologies are currently discussed and used by companies, which are located at the industrial park Höchst, and how these discussions may lead to locational changes. In addition, it investigates which economic and political conditions on a regional and European level are necessary for the transition of the local chemical industry to a CO₂-neutral production.

Therefore, key questions of the study are:

- Which technologies are already in discussion and (will be) implemented at the industrial park Höchst?
- What are the locational effects and key challenges that prevent the scaling of low carbon technologies so far?

The first chapter continues with a description of the methodological approach for this explorative qualitative study. Subsequently, an overview on the climate debate and the chemical industry is given. Then, the industrial park Höchst and areas of local emissions are presented. In the second chapter, levers for a carbon neutral chemistry are provided, and technologies for the chemical industry are presented. In the third chapter, the insights from the industry expert interviews on current developments and perspectives for carbon-neutral chemical industry will be presented. Finally, key issues and recommendations for a carbon-neutral chemical industry 2050 at the industrial park Höchst will be given for practice and policy in the last chapter.

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¹ Cf. Material Economics (2019)
² Cf. European Commission (2019a)
1.1 Methodology

In this study, we combine a literature review with insights from six qualitative interviews with industry experts. The methodology followed for this explorative study will be explained in detail below.

First, a literature review was conducted on levers and relevant technologies for the topic under research. In addition, experts within the Re-Industrialise consortia were involved for the selection of relevant technologies. In doing so, technologies were identified, which are highlighted by various studies to reduce CO₂ emissions to meet the CO₂-emission goals for 2050. In addition, it was investigated in which areas the industrial park Höchst has the highest CO₂ emissions. Based on the literature review and relevant areas identified, an open and semi-structured questionnaire for qualitative interviews with industry experts at the industrial park Höchst was developed. The objective of the questionnaire was to obtain insights from industry which technologies and economic and political conditions could support the transition to a carbon-neutral chemical industry. In this context, qualitative interviews were considered to produce the most promising results for this explorative study since they offer deep insights into the topic and can identify connections between economical, technological and political conditions.

Second, industry experts relevant for the study were identified and approached, whether they would like to participate and provide their experiences and insights on this topic. These industry experts serve as key informants since they possess broad experience concerning energy management as well as changes in production and the related implications on business activities of the respective companies. Besides, they are familiar with the current technologies used in different areas. Therefore, they can help to identify levers for the application of measures and technologies plus the necessary economic and political conditions which support or inhibit the application of technologies required for a CO₂-neutral chemical industry. In total, five experts from companies were interviewed, who are located at the industrial park. For the complementation of the companies’ perspective, one expert from an industry association was also interviewed, which is located in Frankfurt and has recently published a study concerning the topic under research. Thus, all experts had a local connection to industrial activities at the industrial park Höchst. A brief description of the interviewees’ background can be found below:

1) Companies perspective:
   - Interviewee 1: responsible for energy management
   - Interviewee 2: responsible for new technologies
   - Interviewee 3: responsible for business development
   - Interviewee 4: responsible for continuous improvement of industrial processes
   - Interviewee 5: responsible for energy & utilities

2) Industry association perspective:
   - Interviewee 6: responsible for energy & climate
The interviews were semi-structured as questions varied according to the interviewee’s function. The duration of the interviews was 60 minutes, but one was only 45 minutes due to the availability of the interviewee. Three interviews were conducted over the phone and three were face-to-face. The interviews were not recorded. No quotations from these interviews will be used in this study to ensure confidentiality.

Third, the qualitative expert interviews were analysed and compared with the technological pathways and scenarios from other studies to derive implications and recommendations for the industrial park Höchst how CO₂ emissions may be reduced.

Figure 1 summarises the three different steps of the study approach.

Figure 1: Three different steps of the study approach.

1.2 The climate debate and the chemical industry

In 2017, the chemical industry was a significant energy-consuming sector with 10.4 % of total GHG emissions in Germany. The share of the energy intensive energy sector (e.g. the steel industry) accounted for 14.3 % of total emissions. However, the European chemical industry has reduced GHG emissions by nearly 61% between 1990 and 2017, although production increased by 83%. Indeed, further large reductions in CO₂-emissions are necessary since the EU has agreed to reduce emissions to 80 to 95 % below 1990 levels to limit global warming. In Germany, the federal government aims also at the reduction of CO₂-emissions level by 80 to 95% compared to 1990.

In this context, the role of the chemical industry is multifaceted. It is not only a contributor to GHG and CO₂ emissions, but also a solution provider for many downstream sectors and end consumer areas. The use of chemicals and materials (e.g. insulation materials, efficient lighting, lighter materials for transport, and advanced materials for renewable technologies) can make substantial contributions to reducing energy demand and emissions across many sectors. A study demonstrated the positive impact of chemicals, in which several life-cycle

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4 Cf. VCI (2019)
5 Cf. Cefic (2019)
6 Cf. European Commission (2019a)
7 Cf. Gatzen et al. (2019)
analyses (LCAs) showed that for every unit of carbon emitted in 2005, they could reduce up to 2.6 units of CO₂ equivalent savings during their lifetime.⁸

The multifaceted role of the chemical industry is also reflected in the results of the survey conducted by the CHEMonitor in Germany, in which 46% of the managers see chances in national climate protection plans. In the chemical industry, managers are increasingly alerted by the effects climate change may have on their business model in the future. The same survey showed that 78% of managers in Germany think that their company will be affected by climate risks and more than 50% say that they already feel the consequences of climate change.⁹

Cefic defines climate change mitigation and adaptation as key focus areas for the European chemical industry. Climate change will cause more and more frequent and powerful droughts and storms which will lead to a changing environment for companies and increasing numbers of climate refugees. Climate change may affect the water level of rivers (low or high waters) for transportation of resources and products, but also for cooling of production facilities. Hence, companies must reconsider their operations strategy by investing in flood control measures and reducing their reliance on rivers.¹⁰

For instance, BASF had significant extra costs in 2018 due to a long dry spell and very low levels of the rivers in Germany. Less products could be transported to the plants and production had to be reduced because cooling water was not sufficient and too warm, which is normally taken from rivers.¹¹

Therefore, Cefic calls for selective and productive use of virgin fossil carbon. For the scale-up of cost effective low-carbon, it is assumed that the next ten years will be crucial since all scenarios proposed by the European Commission predict a relatively stable rate of reduction in emissions by industry until 2030 and a subsequent steep decline.¹²

In the following, the industrial park Höchst will be presented as a “real-life” case study for an explorative approach to qualitatively assess potential opportunities to reduce CO₂ emissions and to identify possible local pathways towards a CO₂-neutral chemical industry.

1.3 The industrial park Höchst and local CO₂ emissions

The industrial park Höchst is one of Europe’s leading locations for research and industrial production and is located close to Frankfurt in Germany. On an overall area of 460 hectare, the park comprises more than 90 companies with 22,000 employees in the sectors of chemistry, pharma and biotechnology in more than 980 buildings. The industrial park itself is operated by Infraserv, which is a service provider, who grants access to infrastructure, energy, storage capacities, and waste/wastewater treatment.¹³

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⁹ Cf. CHEMonitor (2019)
¹⁰ Cf. Cefic (2019)
¹¹ Cf. Handelsblatt (2018)
¹² Cf. Cefic (2019)
¹³ Cf. Infraserv (2019a)
In general, emissions result from three different areas within the industrial park Höchst: 1) direct emissions from energy production, 2) indirect (secondary) emissions, and 3) indirect emissions from industrial processes. Figure 2 provides an overview about the total annual amount of these three different types of emissions from Infraserv Höchst at the industrial park Höchst. Direct emissions caused by energy production have the largest share of the total emissions. This can also be observed at international level.\(^{14}\) Indirect emissions do not result from activities within the industrial park, but are based on the purchase of electrical energy from the local power grid. The third contribution to emissions is related to the activities of the local companies, which also includes the emission profile of purchased raw materials of the local companies. Therefore, it is important to differentiate between the various causes of emissions.

![Diagram of emissions](image)

**Figure 2: Emissions of Infraserv Höchst in CO\(_2\) equivalents for 1) direct emissions from energy production, 2) indirect (secondary) emissions, and 3) indirect emissions from industrial processes.**\(^{15}\)

In general, the companies of the industrial park Höchst have a high demand for energy. The energy, which companies require for their production processes, is differentiated into thermal (steam) and electrical (electricity) energy. Infraserv as the industrial park operator takes care of local power generation. The use of combined heat and power (CHP) enables a significantly higher degree of efficiency compared to conventional power plants. A schematic illustration of the production and use of CHP at the industrial park Höchst is depicted in Figure 3.

Local energy generation causes the largest amount of emissions within the activities of Infraserv Höchst with 73.5%. Thermal energy is an important source of energy for the chemical industry. The high efficiency (around 90 \%) of local energy production is achieved by using CHP at the industrial park. As a result of the use of CHP, the carbon footprint of electrical energy generated as a “by-product” of the thermal energy production within the

\(^{14}\) Cf. Umweltbundesamt (2019)

\(^{15}\) Cf. Infraserv (2017a)
industrial park was already significantly lower than that of the public power grid in 2010. The electrical power supply of the industrial park by Infraserv Höchst had a carbon footprint of 0.394 kg CO$_2$/kWh, while that of the public German electrical power supply was 0.502 kg CO$_2$/kWh. By 2017, a further reduction to 0.293 kg CO$_2$/kWh had been achieved. The total energy supply of Infraserv Höchst to its customers at the industrial park Höchst was 5210 GWh in 2017. This demand is divided into a consumption of about 3750 GWh thermal energy (65%) and 1460 GWh electrical energy (35%) as indicated in figure 3. This is comparable to the energy consumption of 670,000 households for electricity and the heat demand of 170,000 single-family houses.$^{16}$

Based on this energy demand, Infraserv identified four core strategies for climate protection: 1) increasing energy efficiency, 2) increasing the amount of energy from waste incineration, 3) decreasing energy demand and 4) decreasing emissions of GHG. In total, the amount of GHG emissions were about 1,584,149 tons CO$_2$ equivalents for the production of energy and industrial processes at the industrial park Höchst in 2017. This represents 0.18% of the total German GHG emissions in 2017.$^{17}$

DECHEMA identified that nine raw materials such as ammonia, methanol and chlorine are responsible for more than half of the chemical sector’s energy demand and CO$_2$ emissions.$^{18}$ However, only chlorine as one of these basic chemicals is produced at the industrial park Höchst in the course of chlorine-alkali electrolysis. This is due to the fact that the companies located on-site are predominantly specialised in the production of higher added value products and source their production input resources outside of the industrial park. The production and transport of the basic chemicals studied by DECHEMA are thus included in the balance sheet as secondary emissions of the companies. At the industrial park Höchst, chemical production processes are already largely optimized in terms of energy efficiency because of cost reasons. Therefore, the main potential for the reduction of CO$_2$ emissions lies in the type of energy production.

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$^{16}$ Cf. Infraserv (2017b)
$^{17}$ Cf. Infraserv (2017a); Umweltbundesamt (2018)
$^{18}$ Cf. DECHEMA (2017)
In this context, one way of reducing CO\textsubscript{2} and other GHG emissions is to change the primary energy source for energy generation. Therefore, Infraserv is currently building a new gas turbine to achieve the switch from coal to natural gas as primary energy source. Natural gas has a lower CO\textsubscript{2} balance. In doing so, Infraserv is currently modernising its existing CHP power plant until 2020, extending it with an additional gas turbine, which will be finished in 2022. By building the highly efficient gas turbine (efficiency >90 \%) and phasing out coal-fired power generation, it will be possible to reduce CO\textsubscript{2} emissions by one million tons per year which is around two-thirds of the current overall CO\textsubscript{2} emissions of the industrial park Höchst.\textsuperscript{20}

\textsuperscript{19} Cf. Umweltbundesamt (2019)
\textsuperscript{20} Cf. Infraserv (2019b)
2 Levers for a carbon neutral chemical industry

In the next section, different levers including energy management and supply technologies, selected changes in production processes and policy will be presented that can contribute to a climate-neutral chemical industry. Therefore, the aim of this study is not to identify new technologies, but to examine their potential application and technical feasibility at the industrial park Höchst. In addition to the brief description of the technologies, the technical feasibility and their saving potentials for the reduction of CO₂ emissions are assessed.

2.1 Lever I: Measures and technologies for energy management and supply

In the context of energy generation and energy management, various key technologies have been identified from other studies. The technologies listed below can be assigned to the reduction of direct emissions.

2.1.1 Energy efficiency

This technology field refers to the improvement of energy use in production processes to an economically reasonable maximum. An increase in energy efficiency, however, has always been the core ambition of manufacturing industries because an increase in energy efficiency leads to the reduction of production costs and improves the company’s competitive advantage. Nevertheless, expectations exist that digitalisation (e.g. Industry 4.0) will provide and raise new saving potentials in terms of energy use. In addition, the complete implementation of energy efficiency technologies to all kind of technologies will hold potential for future CO₂ emission reductions since energy demand can be reduced (e.g. for pumps, compressors, ventilators). Therefore, it is important to clarify to what extent the potential for energy efficiency improvements has already been exhausted at the industrial park Höchst.²¹

2.1.2 Power plants with fossil fuels and gases

Fossil fuels and gases, in particular coal, are still a commonly used primary energy carrier for the generation of electrical energy. Since these fuels have different energy densities and carbon footprints, even changing the fuel can lead to a significant reduction in CO₂ emissions. The industrial park operator Infraserv Höchst is already completely phasing out coal-fired power generation. The primary energy source in the future will be then natural gas for the new gas turbine since natural gas has a lower carbon footprint than coal.²²

2.1.3 Virtual power plants

This term refers to the combination of different power plants at distinct locations into one (decentralized energy generation). On this basis, a more flexible capacity can be provided.

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²¹ Cf. Gatzen et al. (2019)
²² Cf. Gatzen et al. (2019)
also ensures security of supply.\textsuperscript{23} This implementation has already taken place at the industrial park Höchst.

2.1.4 Biomass

The use of biomass refers to the production of energy sources or chemical raw materials by using cells (e.g. bacteria). For this purpose, biological waste or, in the case of the industrial park, chemical residues are processed by fermentation. Depending on the cells used, a range of products can be produced.\textsuperscript{24} This process is already widely used in the pharmaceutical industry. Based on this type of technology, Infraserv Höchst operates a biogas plant to recycle biological and chemical waste. From a balance sheet point of view, this type of recycling represents a CO\textsubscript{2} sink since waste becomes a valuable resource to produce energy or other products. The capacities of the biogas plant would have to be increased to expand this sink. For this reason, however, waste from outside of the industrial park would have to be collected. Since the primary purpose of the plant is to treat waste water and waste, the current capacities would not allow the industrial park to extend the supply.

2.1.5 Waste-to-energy

Biodegradable waste could also be used for energy generation through incineration. Infraserv Höchst already operates a residue incineration plant. Here, an extension is limited as well since the share of energy produced depends on the availability of waste and the capacity of the current plant.\textsuperscript{25}

2.1.6 Power-to-X

The term Power-to-X covers a wide range of technologies. In general, it is defined as the use of electrical energy to produce valuable materials by means of energy-intensive processes. Core technologies in this field are Power-to-Gas, Power-to-Liquids and Power-to-Chemicals. With the exception of Power-to-Hydrogen, which is part of the Power-to-Gas technology, these technologies are based on the utilization of CO\textsubscript{2} as an input raw material in the course of hydrogenation. Therefore, Power-to-Hydrogen represents the basis for the feasibility of the other technologies. Since the chlorine-alkali electrolysis at the industrial park Höchst already produces large quantities of hydrogen today, this technology could represent an option for future developments. Currently, the hydrogen is primarily used for energy production.\textsuperscript{26}

\textsuperscript{23} Cf. Gatzen et al. (2019)
\textsuperscript{24} Cf. Klass (1998)
\textsuperscript{25} Cf. Kothari, Tyagi, Pathak (2010)
\textsuperscript{26} Cf. Varone & Ferrari (2015)
2.2 Lever II: Selected changes in production processes

Based on the results of DECHEMA (2017), possible developments in production processes will be presented below that are in interest of policy and may be relevant and could be implemented in the industrial park Höchst.27

2.2.1 Example I: Chlorine Electrolysis

One of the most energy intensive production processes in the industrial park Höchst is the chlorine-alkali electrolysis. The energy demand of this process was already reduced by 30% in 2015 through a process improvement by the introduction of a new membrane process. This new membrane process represents the most environmentally friendly process at the current state of the art. Hence, no further large saving potentials are expected here.28

2.2.2 Example II: Plastics recycling

At present, the production of plastics is still predominantly based on fossil raw materials. At this point, saving potentials can only be achieved through recycling. Against this background, the European Commission decided that all plastic packaging should be recyclable by 2030. Since only about 30% of plastic packaging is currently recycled, a great potential to reduce CO₂ emissions exist.29 However, no plastic is currently recycled at the industrial park Höchst. For the chemical recycling of plastics, a suitable company must be settled at the industrial park Höchst.

2.2.3 Example III: Carbon Capture and Storage

Carbon Capture and Storage (CCS) is a technology field that can be used to separate carbon dioxide from gas streams. An example for this technology is classic flue gas scrubbing. With the separation of CO₂, industrial processes can be treated as carbon neutral in the balance sheet. However, it must be taken into account that this technology requires a high degree of energy for the overall process and there is also a need to store the separated CO₂.30

2.3 Lever III: Changes in policy

The European Commission introduced the EU Circular Economy Package in 2018 and put this topic on the political agenda.31 Although the aspect of a circular economy is not regarded as a core issue in the studies under consideration, it offers a supplementary approach to positively influence the carbon footprint of a production site. Here, the potential lies in the reduction of secondary emissions. On the one hand, transportation of raw materials and products could be reduced and on the other hand, by-products and waste is utilized as a raw material for other production processes. In addition, the recycling of materials can be a good starting point to reduce resources and also CO₂ emissions. A good example is the purification

27 Cf. DECHEMA (2017)
29 Cf. Hopewell et al. (2009); Europäisches Parlament (2018)
31 Cf. European Commission (2019b)
and reuse of used solvents. However, these aspects of a circular economy are widely implemented at the industrial park Höchst in terms of industrial synergies by closing resource loops on-site and using by-products of one production process as an input resource for another production process.

3 Insights from industry expert interviews: Current developments and perspectives for a carbon neutral chemical industry at the industrial park Höchst

In the following, the results from the qualitative industry expert interviews for this explorative study will be presented to gain practical insights and perspective on the technologies, which are currently in discussion to foster a CO₂-neutral chemical industry at the industrial park Höchst and to better understand the local needs and necessary involvement of relevant stakeholders.

3.1 Lever I: Potential measures and technologies for energy management and supply

One interviewee stated that the industrial park Höchst represents around 0.6% of the whole energy demand of Germany. Thus, the companies at the industrial park require a huge amount of energy. In case new companies will settle at the industrial park, the energy demand will even increase. All interviewed industry experts stated that the substitution of large amounts of energy from fossil-based resources and nuclear power to renewable energy represents a big challenge to ensure energy supply.

From their perspective, renewable energy is locally neither sufficiently available nor is there enough space to produce renewable energy (e.g. solar, wind or geothermal energy) to meet the energy demand in Germany. Thus, renewable energy must be imported. For instance, some companies currently purchase certificates for “green” electricity produced in Norway to reduce their environmental footprint.

In general, many energy carriers, such as natural gas, are imported. For this reason, renewable (“green”) energy could be considered as a commodity in the future, which will be imported as well. Indeed, the transportation of electricity with power lines is not very efficient. While transporting electricity via power lines, certain energy losses occur which is detrimental. Therefore, it rather makes sense to use renewable energy on-site to produce synthetically CO₂-neutral feedstock like hydrogen and to store the energy materially. Subsequently, the energy stored can be transported in existing or new pipelines, or shipped to Germany. Besides, more energy quantity can be transported in form of materials through pipelines than electricity via power lines since pipelines have a larger diameter. Finally, the existing infrastructure in terms of power grid and pipelines must be extended to deal with an increased amount of energy in the future.
3.1.1 Energy efficiency

Most industry experts indicated that energy efficiency measures will only slightly contribute to additional reductions of CO₂ emissions. Energy efficiency is not considered as a significant leverage for the reduction of CO₂ emissions. Only a few further percent points in terms of energy and thus CO₂ emission savings can be achieved. Only one interviewee mentioned that energy efficiency will be a big lever for CO₂ emission reductions. Here, digitalisation will play a crucial role since data allow transparency and a better understanding of production processes. The combination of several measures could lead to energy savings in double-digit percentage points. However, all (especially large) companies are already monitoring and constantly improving their energy efficiency to reduce production costs.

3.1.2 Thermal (steam) and electrical (electricity) energy generation: Coal phase-out and build-up of new gas turbine

Flexible energy production and production processes are becoming increasingly important to compensate and react to lows and peaks in energy demand in a changing energy system. For the compensation of lows and peaks, the industry experts interviewed do not consider battery technology as an adequate technology to store energy. From their perspective, energy from renewables should be stored materially. For instance, green hydrogen that was produced by electrolysis with renewable energy could be combusted in turbines to produce steam/heat and electricity to ensure a constant energy supply.

In 2022, the new gas turbine under construction will replace the hard coal power plant of Infraserv Höchst, which will result in the phase-out of coal for energy production at the industrial park Höchst.

In general, gas turbines are used for the production of steam, which combine heat and power (CHP) generation. The regular lifetime of a gas turbine is around 15 years (normally 120,000 equivalent working hours (EOH)) as indicated by one interviewee. Then, a gas turbine must be renewed or retrofit solutions must be integrated. Thus, the current gas turbine under construction can be rather considered as a transition technology. However, with future retrofit solutions many new opportunities will be possible. For instance, the use of other gases instead of natural gas for the operation of gas turbines is likely (e.g. hydrogen). Indeed, other synthetically produced gases with green electricity, must be sufficiently available and at competitive prices to ensure the supply and continuous operation of gas turbines. Currently, small shares of other gases together with natural gas can be combusted as well in the new gas turbine.

Table 1 summarises the differences between energy-intensive and electricity-intensive processes, which are both relevant in industrial parks. However, most production processes within an industrial park are heated with steam from gas turbines, which combine heat and power (CHP) generation and thus represent energy (thermal)-intensive processes. Electricity is mostly used for production processes, or for manufacturing equipment (e.g. stirrers), ventilation, lighting or heating of (production) facilities. In CHP generation plants, steam is the main output and electricity is “rather” a by-product.
Table 1: Differences between combined heat and power (CHP) and power generation.\textsuperscript{32}

<table>
<thead>
<tr>
<th></th>
<th>CHP generation</th>
<th>Power generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Gas turbine</td>
<td>Coal-fired power plants, photovoltaic, solar, geothermal, water or wind power plants</td>
</tr>
<tr>
<td>Current input resource</td>
<td>Natural gas (synthetically produced gases)</td>
<td>Depending on the respective technology (e.g. coal, natural gas, renewables)</td>
</tr>
<tr>
<td>Price of current input resource in 2019</td>
<td>Ca. 2 cent/kWh</td>
<td>Ca. 4 cent/kWh (if companies are exempt from the renewable energy apportionment, otherwise price is around 15/16 cent/kWh)</td>
</tr>
<tr>
<td>Output</td>
<td>Steam + Electricity</td>
<td>Electricity</td>
</tr>
<tr>
<td>Use for</td>
<td>Steam: Industrial processes</td>
<td>Industrial processes, lighting and heating of facilities, ventilation, etc.</td>
</tr>
<tr>
<td></td>
<td>Electricity: industrial processes, lighting and heating of facilities, ventilation, etc.</td>
<td></td>
</tr>
</tbody>
</table>

Currently, the CO\textsubscript{2} footprint of Infraserv is around 1.5 mt CO\textsubscript{2} equivalents.\textsuperscript{33} Once the new gas turbine is in operation, Infraserv could reduce its CO\textsubscript{2}-footprint by around 1.0 mt CO\textsubscript{2} equivalents. In total, this represents the reduction of CO\textsubscript{2}-emissions by around two-thirds by 2022. A further reduction of another two-thirds is necessary to reach the goals for 2050.

For the achievement of these goals and to reduce carbon emissions in total by 90\% until 2050, significantly more electricity from renewable sources is needed – either to substitute the energy currently produced by the gas turbines, or to produce synthetically fuels with green electricity from renewables to operate the current or new gas turbines (e.g. with green hydrogen). In addition, the use of biogas for the gas turbines could be increased. In the following the different roadmaps are explained in more detail.

Green hydrogen could be used to operate gas turbines, which could be produced at suitable locations, where sufficient renewable energy is available. Suitable locations may be in the

\textsuperscript{32} Cf. Own representation
\textsuperscript{33} Cf. Infraserv (2017a)
South of Europe or North of Africa. The production and use of green hydrogen strongly depends on the context and purpose.

For instance, for the operation of gas turbines, purified methane is not attractive. Methane is a first base chemical, which can be produced with hydrogen. However, the production of methane represents an additional production step, which requires extra energy and thus, the additional invested energy is lost when combusting the methane. This is not economically reasonable. However, synthetic methane could be used for a transition period to use existing (natural gas) pipeline networks for the transport.

For the combustion of synthetically produced gases in the gas turbine, the following main questions remain:

- Which synthetically produced gases are relevant and which ones can be produced with green energy at competitive prices?
- Is it realistic that excess energy (and in which quantities) is available to produce “green” gases on-site or must green synthetically produced gases be imported to the industrial park Höchst (e.g. green hydrogen)?

3.1.3 Electric steam generator

For the production of steam, electric steam generators can also be used. Electric steam generators are already widely used in practice. They are flexible in operation and can be quickly operated with full load (in 1-2 minutes). However, they require a high amount of electricity for their operation (several 100 MW). Thus, a prerequisite for their application is that the power grid can provide sufficient electricity. In case, the grid cannot provide sufficient energy supply, it must be extended which would generate additional costs when applying this technology. At the moment, the application of electric steam generator is not economically feasible with current electricity price at the German energy stock exchange in Leipzig, which are about twice as high as of natural gas, if companies are exempt from the renewable energy apportionment (§24 EEG 2014, cf. table 1). Otherwise, the costs for electricity are even higher and cannot compete with the low costs of natural gas. Hence, electric steam generator could play a crucial role in reducing CO$_2$ emissions since the technology already exists. Yet, this technology will only be applied and can contribute to the reduction of CO$_2$ emissions, if the electricity price will be equal or below the price of natural gas and is produced with renewable energy sources. Possibly, this technology could be applied more broadly around 2040 if the variable costs for the production of electricity will approach zero.

3.2 Lever II: Potential changes in production processes and products

Some companies have set themselves climate goals for each decade, which are regularly monitored to adapt measures. However, most companies have only formulated concrete goals until 2030 and thus, lack concrete measures and goals until 2050. For the reduction of CO$_2$ emissions, companies have different opportunities to change their production processes
(e.g. switch to electricity-based production processes or use synthetically produced CO\textsubscript{2} neutral feedstock).

3.2.1 New electricity-based production processes

In principle, production processes could be changed from steam- to electricity-based processes. This is technically feasible. However, this would require large amounts of additional electricity. The association of the German chemical industry assumes that the switch from steam-based to new electricity-based production processes requires 628 TWh more electricity from the mid-2030s on, what is equal to the current annual demand of Germany.\textsuperscript{34}

In addition, the switch to electricity-based processes is difficult since most production processes are heated with steam. Electricity-based production processes would require the retrofitting or build-up of new production facilities. Besides, most production processes in the industrial park Höchst are steam-based and hence, would require the development of new production processes or even new products. In consequence, large investments are necessary for the switch from steam-based to electricity-based production processes. An advantage of the current production facilities in the industrial park Höchst is that they are already depreciated, are running very reliably and delivering products of high quality. Therefore, it is unlikely that companies will invest in completely new production processes, if not necessary.

3.2.2 Green feedstock

Fossil-based resources can also be substituted by synthetically produced feedstock. However, the production of this feedstock requires large amounts of energy – and this energy needs to come from renewable sources to ensure that the substitute is CO\textsubscript{2} neutral.

Methanol can be produced with CO\textsubscript{2} and hydrogen. This is however not economically viable yet and needs adequate framework conditions. In addition, several key questions remain:

- Is sufficient (green) hydrogen and energy available?
- Who will produce the hydrogen required?

The current amounts of hydrogen being produced at the industrial park Höchst are by far not sufficient to serve the energy demand of the whole industrial park. It is unlikely that hydrogen will be produced at the industrial park Höchst on larger scale since a special partner or company must be found, which will settle and produce hydrogen on-site. Besides, the production of hydrogen requires large amounts of electricity, which is associated with high costs. Thus, a production is probably not economically feasible on-site. In consequence, green hydrogen must be imported. For the production of methanol, a partner would also be necessary. It is likely that methanol will be further produced outside of the industrial park, where renewable energy is sufficiently available and subsequently imported for the production like many other base chemicals, which are imported by the companies at the

\textsuperscript{34} VCI (2019)
industrial park Höchst. Furthermore, the activation of \( \text{CO}_2 \) requires a large amount of energy. Thus, it is likely that the production of methanol will be conducted at locations where energy is cheap.

3.2.3 Secondary emissions

In general, companies must differentiate between three different types of emissions:

- **Scope 1** – direct emissions of company
- **Scope 2** – emissions from external sourced energy
- **Scope 3** – emissions related to business operations but not under the direct control of the company (e.g. emissions from suppliers, service providers or employees)

One interviewee mentioned that only 10% of total emissions can be reduced by the companies themselves. 90% of the emissions of their products come from scope 2 and especially scope 3 emissions. Therefore, an analysis and categorisation of their supplier portfolio is necessary, whether the respective suppliers contribute to the achievement of the goals set. Besides, they have started discussions for an internal \( \text{CO}_2 \) emission pricing system to enable a comparison between different potential locations for future investments.

In addition, transport of goods accounts for a large share of emission. Hence, companies plan to increasingly switch from road to water transport.

4 Conclusions for the industrial park Höchst

This explorative study provides a first qualitative overview on the status quo on the use and application of relevant technologies to reduce \( \text{CO}_2 \) emissions at the industrial park Höchst.

The interviews showed that the transition to a carbon neutral chemical industry is of utmost importance to the interview partners and their respective companies. While the goal is not questioned by the companies, a lot of insecurity can be observed with regards to the technological, economic and policy dimensions of the transition pathway resulting in the following questions:

- When will which type of technology be ready and economically viable?
- What are new business models for chemical companies and industrial parks?
- Who is the decision maker with regards to the regulatory framework (EU, national, regional policy makers)?
- Who influences the decisions and in which way?
- Are policy decision makers sufficiently aware of the economic and technological consequences of their decisions?
- Is there a shared vision of all stakeholders with regards to a carbon neutral chemical industry?

Currently, most companies have only formulated measures until 2030 and have no concrete (climate) roadmap until 2050 yet. Some interviewees and studies stated that most
technologies mentioned will be ready and applied between 2020 and 2035. In addition, the interviews showed that all companies have a company specific transformation pathway.

In general, communication and exchange among different companies and stakeholders becomes increasingly important since many production facilities are aging and must be refurbished, or new ones must be installed to remain competitive in Europe on a global level. Until enough alternatives have been developed, natural gas represents an energy carrier for the transition period towards a CO₂-neutral chemical industry. If the price in Germany will reach 2 cent per kWh, many technological opportunities are possible. This will rather be the case, if energy will be imported. Policy must set stable frame conditions, which allow long-term planning. Electricity must become cheaper for industry to stay competitive on a global level. The power grid must be expanded better and faster. Distinct grids and infrastructure of different industrial parks must be connected. At the moment, rather fragmented and isolated grids exist. Apportionments must be also reduced. For instance, the revenue from the CO₂-emission certificate scheme could be used to subsidize energy prices and support the use of environmental friendly technologies.

In contrast, renewable and green feedstock will be available very late (around 2030, rather 2040) because of high energy prices for the production. Currently, oil is too cheap. Hence, regulation must support renewable and green feedstock.

The role of an industrial park operator could change in the future and new business models must be developed. A key question is how the role will change, if the main share of energy is produced outside of the industrial park (e.g. renewable energy), or imported (e.g. green hydrogen from the South of Europe). Currently, a large share of an industrial park operator’s revenue comes from the sales of energy. Energy amounts also for the highest cost of the companies.

Change may be also caused by changing product demand and request by customers since customers are increasingly asking for green energy and sustainable products. However, this is still no main decision criteria. “Sustainable” products must be relevant for customers. Then, extra costs can be charged, or additional cost can be transferred to the respective customer or end consumer.

Finally, base chemical production has only a limited future in Germany. Previously, it moved to locations where oil was sufficiently available and cheap. In the future, base chemical production may move to areas where electricity is sufficiently available and cheap. Therefore, the German chemical industry must increasingly focus on speciality chemicals and on providing solutions instead of merely offering products to remain competitive on a global level.

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35 Cf. Cefic (2019)
36 Cf. Cefic (2019)
4.1 Industrial park Höchst as a space for demonstration projects

The interviews have shown that all companies have a company specific transformation pathway, but the transformation requires a joint effort of a variety of stakeholder (policy, company, academia, civil society). Policy must provide subsidies for the development of new relevant technologies. These technologies can be tested in demonstration projects, implications of new technologies on business models need to be elaborated, and workers need to be up- and reskilled.

The industrial park Höchst represents a suitable “real-life” testing area for the transformation towards a carbon neutral chemical industry. The so-called “Reallabore”-concept (“regulatory sandboxes”) of the German Federal Ministry for Economic Affairs and Energy is considered as very promising and this approach should also be followed by other governmental institutions to support the development of new technology and to reduce bureaucracy. Here, the term regulatory sandboxes refers to a testing environment for the development and application of new technologies under real-life conditions, which are merely partially compatible with the existing legal and regulatory framework. The aim of regulatory sandboxes is to quickly gather experiences with new technologies and to assess the opportunities and risks of them to derive the appropriate regulatory framework for their application. This could be a promising approach since for many technologies no experiences exists, although they have a high technology readiness level (TRL). Indeed, the companies within an industrial park have plenty of experience in developing and testing demonstration projects. Local and national policy should provide sufficient subsidies to support technologies, which have a low TRL, but are promising and not profitable yet.

In doing so, Power-2-X technologies could be developed and tested in demonstration projects in in the industrial park Höchst. For the application and scale-up of these technologies, they can be sold to partners in the South of Europe or North of Africa to operate them with renewable energies and to produce green feedstock and energy carriers like a “Desertec 2.0” (e.g. hydrogen or methanol). In this context, long-term frame contracts are necessary that guarantee the purchase of the produced feedstock and energy carriers while providing benefits for both sides. For this kind of projects, a pan-European solution is necessary to ensure energy and feedstock supply. Thus, the involvement of a high number of partners and stakeholders is necessary. Indeed, this approach could cause cartel-related issues.

4.2 Findings for Re-Industrialise

The industrial park Höchst represents a landmark for industry transformation with its history of 160 years. It represents as well an ideal location for working on the transformation to a carbon neutral chemical industry in Germany, at which the different aspects of technology,

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37 BMWI (2019)
38 Handelsblatt (2019)
business, academia, policy could be combined in order to learn how to realise the desired goal of carbon neutrality.

So far, there is no joint road map of the different stakeholders. A systematic transformation-related exchange among different companies and other actors is missing.

The industrial park operator should be the leading organisation to initiate these exchanges since it may have the data and transparency concerning the needs and energy demand of the member companies of the industrial park Höchst. The industrial park operator has also the aim to provide cheap energy, which is carbon-neutrally produced to keep the industrial park Höchst attractive for further investments and to improve its image regarding sustainability.

Interaction with local authorities is necessary to identify synergies between the industrial park and its close environment (e.g. district heating). In doing so, industrial parks and municipalities could achieve their climate goals together and the industrial park could contribute to the energy supply of cities.

In this context, a platform organisation could act as a facilitator to connect relevant stakeholders from different areas (e.g. university or municipality). Local policy could also organise networking and exchange events for local stakeholders, which deal with large amounts of energy (e.g. airport and industrial park). Besides, stakeholders with different backgrounds from distinct industries must participate in these exchanges to enable sharing of best practices and learning from each other.

Finally, table 2 provides an overview and key questions for the top three areas to help the local chemical industry to reduce its CO₂ emissions at the industrial park Höchst. These questions need to be further elaborated in a multi-stakeholder exchange and approach to achieve the goals for 2050.
Table 2: Key questions for company decision makers regarding 1) innovation and technology, 2) Industry and business, and 3) Regulation and policy.

<table>
<thead>
<tr>
<th>Area</th>
<th>1) Innovation and technology</th>
<th>2) Industry and business</th>
<th>3) Regulation and policy</th>
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<tbody>
<tr>
<td>Key questions for company decision makers</td>
<td>• When is which technology at what price level available?</td>
<td>• How do business models of companies change?</td>
<td>• Who develops the regulatory framework? How are business and societal aspects integrated by decision makers?</td>
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<td></td>
<td>• How can “green” energy be locally produced or imported to comply with changing customer or legal requirements?</td>
<td>• What will be the locational effects of different scenarios (combination of energy-price and technological options)?</td>
<td>• Do policy makers, companies and civil society have a shared understanding of the expected and desired transformation path?</td>
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<td>• How can an industrial park operator develop and apply new storage systems for energy, if energy consumption and demand will change, or to balance fluctuations in the power grid?</td>
<td>• What is the future business model of an industrial park operator (central vs. decentral energy generation)?</td>
<td>• Who is paying the price for energy/electricity?</td>
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<td>• What are the time periods for return on investment (ROI) for new technologies?</td>
<td>• Does the industrial park operator generate energy or only transmits energy?</td>
<td>• How does policy organise the reallocation of costs?</td>
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<td>• Which kinds and forms of collaboration and subsidies are most promising to develop suitable solutions (e.g. regulatory sandboxes)?</td>
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5 References


