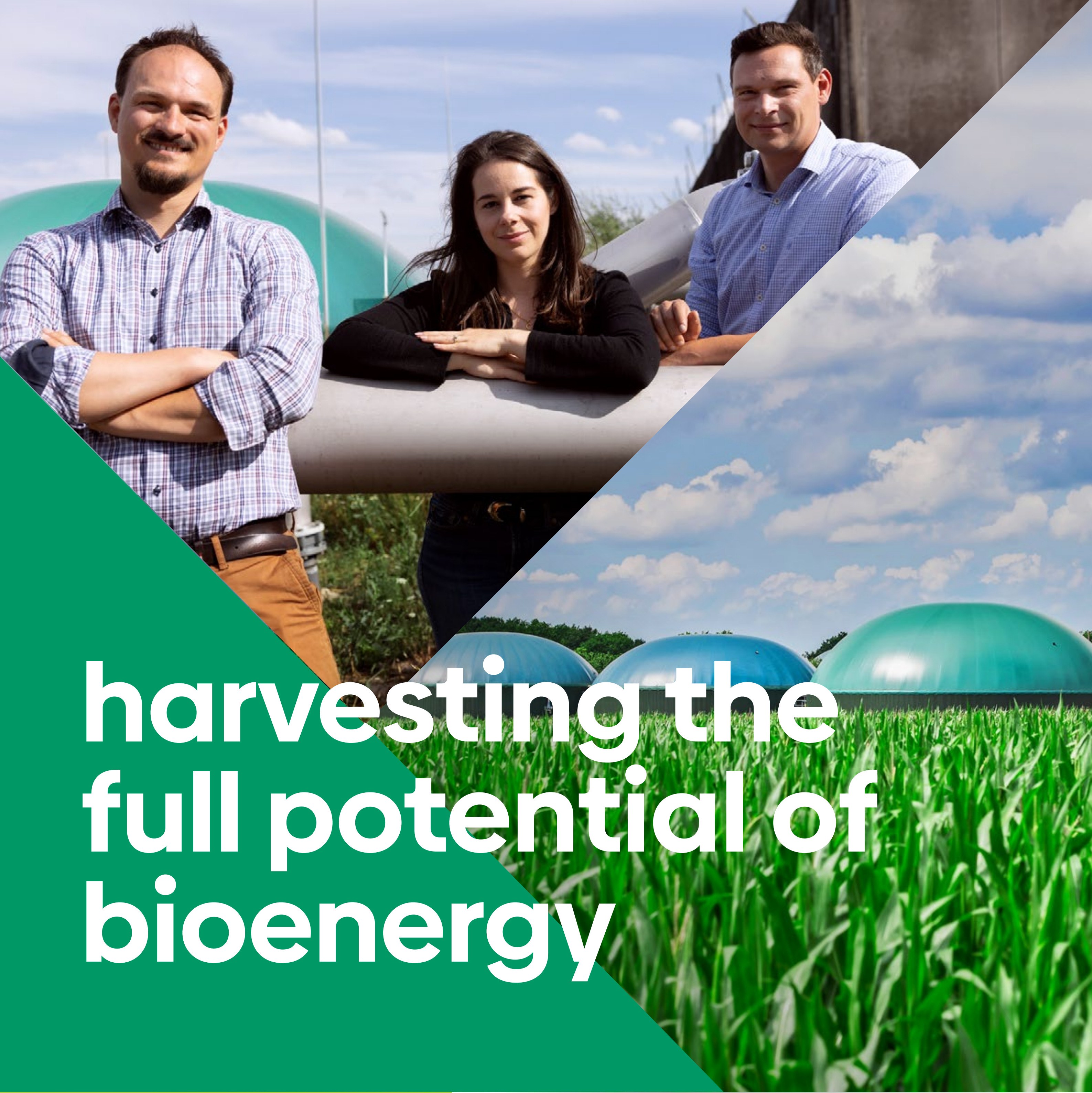

harvesting the full potential of bioenergy

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foreword

The world is changing at unparalleled speed. To remain fit for the future, we need to position ourselves in a resilient and sustainable way. This also applies to our energy supply.

The biogas sector plays a vital role in this. Energy production in biogas plants offers a sustainable alternative to fossil fuels. Agricultural residues and organic waste, together with renewable raw materials, become valuable sustainable energy sources. These help to reduce our dependence on fossil fuels and thus on geopolitical upheavals.

At the same time, bioenergy can be used flexibly for base load requirements and can be stored. Thanks to its controllability and the ability to store the gas produced, it is possible to react to fluctuations in output from wind and solar energy in a targeted manner. This not only contributes to a high level of supply security, but also reduces the load on the electricity grids.

With the expiry of subsidies under the "Erneuerbare-Energien-Gesetz" (Renewable Energy Act), the biogas sector is facing a phase of development and transformation. To ensure that bioenergy plants can continue to make their contribution to the energy transition and security of supply in the future, it is necessary to develop economically viable concepts and implement them promptly. Technological innovations are needed here. After all, they are indispensable when it comes to efficiently developing the bioenergy sector and successfully positioning it for the future.

The following report "Potential of technological innovations in the bioenergy sector" shows the great untapped potential of bioenergy as a decentralized, load-flexible, grid-balancing and potentially climate-neutral energy source.

We, the German Agricultural Bank, support the transition to a sustainable energy supply with a broad range of funding and advisory services.

NIKOLA STEINBOCK
Chairwoman of the Management Board,
Rentenbank

foreword

Structural change is often just a thought away. Innovation is the catalyst that transforms yesterday's impossibilities into tomorrow's essential solutions. Extantia approaches all challenges with this pioneering spirit. This study is further proof that daring to think in new ways can bring forth unimagined potential.

For a long time, energy production from the countryside was dismissed by the state as a hidden subsidy whose substance was questioned. This was particularly true for the production of biogas.

This study aims to contribute to the debate and showcase new possibilities to decision-makers - possibilities that enable a green and fair energy supply, free of power lines and protests but with a clearly efficient infrastructure that saves Germany a significant amount of euros and CO_2 budget.

Our country is the greatest treasure we have the privilege of managing. Technological progress enables us to use this treasure in an economically and ecologically responsible way. Alongside other domestic resources such as wind, water, sun or geothermal energy, bioenergy can make a relevant contribution to the energy mix of the future, paving the way for a resilient energy market, not only in Germany but in many other countries around the world.

With this study, we want to show that a sustainable and more efficient future is possible through innovative approaches and the conscious use of our natural resources. We invite you to join us in being a pioneer and to explore the potential that a prudent and future-oriented energy policy can offer with technology "Made in Germany".

SEBASTIAN HEITMANN

Partner, Extantia

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Executive summary

With the urgent need for an energy transition to mitigate climate change, the role of bioenergy - through biogas and biomethane – can be significant, benefiting the power system and optimizing the energy transition cost. The EU is targeting net-zero emissions by 2050, with Germany aiming for 2045, aligning with the Paris Agreement to keep the global temperature rise below 2°C. This transition requires significant investment in renewable energy, electrification, and energy efficiency, with projected climate finance needs rising to USD 9 trillion annually. Transitioning to renewables is crucial for climate mitigation, economic growth, and job creation, as renewable energy becomes more cost-competitive. The energy crisis following Russia's invasion of Ukraine highlights the need for energy affordability and security, pushing the EU to hasten renewable adoption and reduce fossil fuel dependency. Increased electrification is anticipated, with renewables projected to dominate power generation by 2050, necessitating flexible energy solutions.

Bioenergy can significantly enhance energy supply security and sustainability. Germany's power demand is set to rise, requiring extensive renewable capacity. Flexible solutions like biogas and biomethane can provide reliable, dispatchable power, utilizing existing gas grids and reducing new infrastructure needs. This enhances energy security by decreasing fossil fuel imports. Biomethane also supports local economies, providing opportunities for farmers and waste management sectors. In hard-to-abate sectors, biomethane can replace natural gas, leveraging existing infrastructure for decarbonization. Liquid biofuels offer alternatives to fossil fuels in transportation, supporting emission reduction without major infrastructure changes, thus fostering local economic development and reducing fossil fuel dependence. The report identifies feedstock availability as crucial for bioenergy scalability, highlighting anaerobic digestion, biomass combustion/gasification, and liquid biofuels. EU regulations promote sustainable, advanced feedstocks, focusing on efficiency to maximize bioenergy potential. Technological improvements in anaerobic digestion could significantly boost output.

Enhancing bioenergy competitiveness is essential for an efficient energy transition. Innovations in the bioenergy value chain are expected to reduce costs by 10-50%. Anaerobic digestion offers significant cost-reduction potential, with fuel cells potentially enhancing biogas-to-power efficiency, making biomethane a competitive zero-carbon power source.

Various incentives, such as feed-in tariffs, mandates, and tax credits, are crucial for bioenergy adoption. Examples include Germany's feed-in tariff system and the US Renewable Fuel Standard, which support local economies, reduce fossil fuel dependence, and promote carbon-negative solutions via biomethane. Including biomethane in carbon contract for difference schemes and providing financial support can further boost sector growth and competitiveness.

In conclusion, efficiency is critical for sustainable energy systems. Effective subsidies should target high-efficiency technologies and support innovations to reduce costs and enhance scalability. Biogas/biomethane, with its cost-reduction potential and availability in Germany, is positioned to play a pivotal role in the energy transition. Policy measures should incentivize technological breakthroughs, making biomethane a competitive renewable energy source, facilitating a transition to a more sustainable and efficient energy system.

Chapter 1

The energy transition is needed to mitigate climate change – Europe aims for net-zero by 2050

The need for an energy transition to limit climate impacts and global warming is widely recognized by scientists and global leaders. The burning of fossil fuels for energy is a major contributor to greenhouse gas emissions, which trap heat in the atmosphere and lead to global warming. To mitigate the effects of climate change, it is essential to transition to renewable energy sources that emit significantly less greenhouse gases.

Achieving these targets will require significant investment in alternative energy sources, such as solar, wind and bioenergy, as well as electrification and energy efficiency measures. The Climate Policy Initiative estimates that annual climate finance will need to increase to USD 9 trillion from USD 1.3 trillion in 2021/2022 (Climate Policy Initiative, 2023).

Germany aims for climate neutrality by 2045

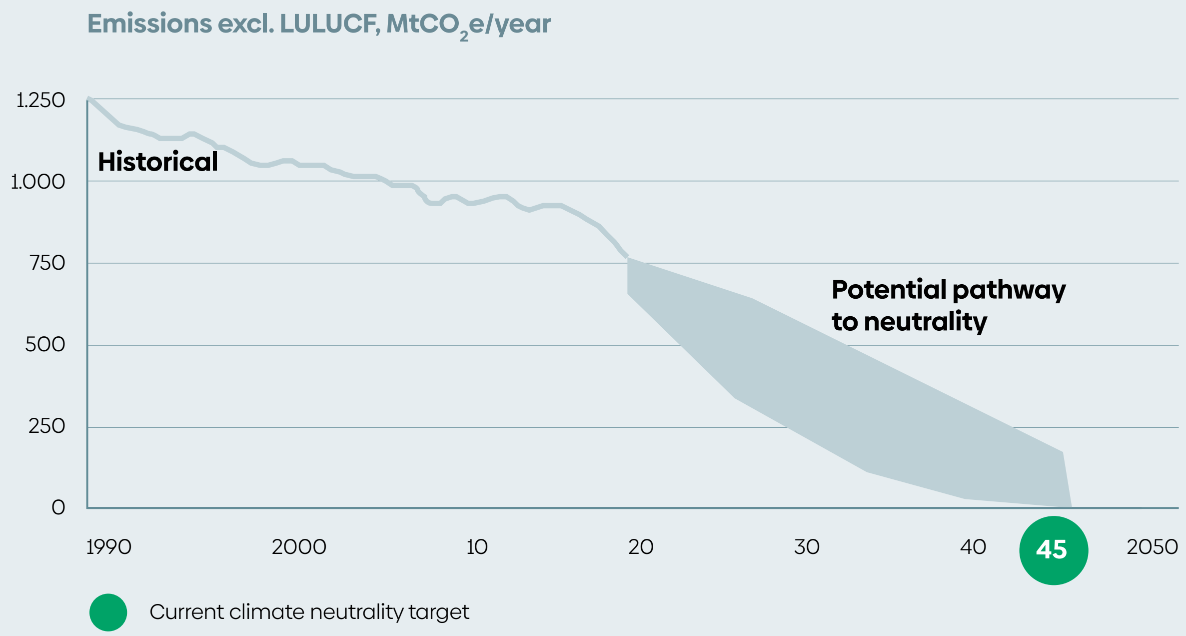

Figure 1. Emissions excl. LULUCF, MtCO$_2$e/year. (Climate Policy Initiative, 2023), Extantia estimate

The transition to renewable energy sources will not only help mitigate the effects of climate change but also create new economic opportunities and jobs. Renewable energy sources are becoming increasingly competitive with fossil fuels, and the cost of renewable energy has decreased significantly in recent years. This makes it more attractive for countries to invest in renewable energy sources and transition away from fossil fuels.

In addition to sustainability, the energy crisis following the Russian invasion of Ukraine has highlighted the importance of affordability and energy security. Prices of fossil fuel imports have skyrocketed, and many countries have invested in additional infrastructure to diversify their energy supply, such as new liquefied natural gas terminals. European Union countries have accelerated their targets on renewables and domestically produced energy such as bioenergy to reduce their dependence on fossil fuel imports. The cost of renwable energy has decreased significantly in recent years, making it more competitive with fossil fuels. However, some countries may still face challenges in transitioning to renewable energy, due to the higher initial investment required.

Ensuring an efficient energy transition requires the prioritization of decarbonizing the growing power supply, and electrification is one of the main levers to achieve this. Increasing electrification means that power demand is expected to grow by 80-100% by 2050, according to IEA (IEA, World Energy Outlook, 2023) (IEA, Renewables 2023, 2023). Renewables have become so cheap that solar and wind energy are the most cost-efficient option to build new capacities in most markets. As a result, renewables are expected to account for 70-89% of the power generation mix by 2050 (IEA, World Energy Outlook, 2023) across IEA World Energy scenarios.

Despite the increasing dominance of renewables, their intermittent nature requires flexibility and dispatchable load in the system. This means that there is a need for flexible generation, storage, and management of energy. Balancing the fluctuations in energy demand and intermittent renewable power supply, especially in times of peak demand, is critical to ensure a reliable and stable energy system. The integration of flexible solutions will be crucial to achieving a sustainable and efficient energy transition.

In hard-to-abate sectors where electrification is not a technically and/or economically viable option, clean alternatives to fossil fuels will be needed. Sustainable fuels using (waste and residue) biomass or hydrogen as feedstock can be used to decarbonize existing fleets of aircrafts, trucks, and maritime vessels, as well as replacing natural gas in existing grids for energy use in buildings and industry.

Chapter 2

Bioenergy can help increase supply security and sustainability

Chapter 2.1 Bioenergy in the power system – significant implications beyond the power grid

Power demand in Germany is expected to grow significantly in the next two decades. While many sources agree on the significant growth, the range of the projections varies. The German Federal Government assumes that electricity demand will rise to 750 TWh by 2030, reaching over 1,000 TWh by 2045 according to the government's 2023-2037/2045 scenarios (Bundesnetzagentur, 2022). Fraunhofer on the other hand estimates 2030 demand at 580-715 TWh across scenarios (Fraunhofer-Institut für System- und Innovationsforschung ISI, 2023). This growth is due to increasing electrification in the industrial and private sectors, the increase in electromobility and the development of electrolyzer capacities.

As of 2030, Germany is to source 80% of its electricity from renewable sources, aiming for fossil-free supply by 2045

Net electricity consumption and generation, TWh

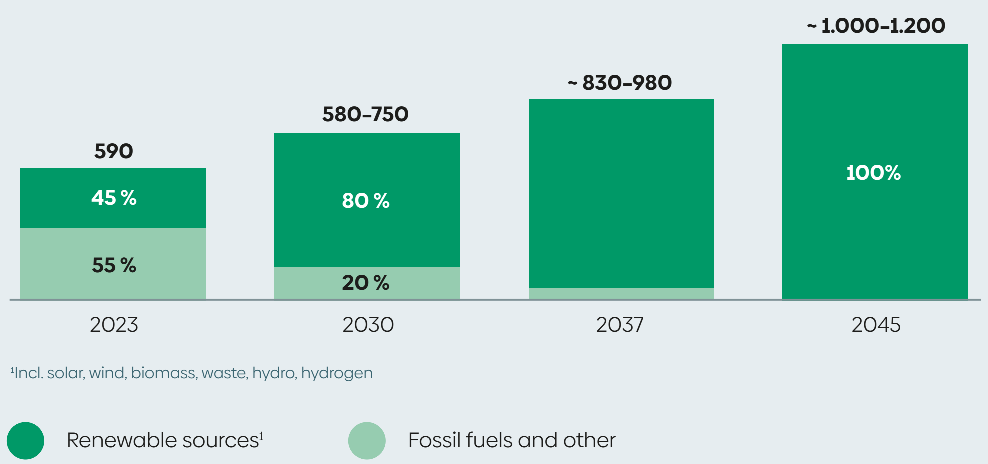

Figure 2. Net electricity consumption, TWh (IEA, World Energy Outlook, 2023) (Bundesnetzagentur, 2022) (Fraunhofer-Institut für System- und Innovationsforschung ISI, 2023) (Energiewende, 2023) (dena-Leitstudie, 2021) (Netzentwicklungsplan, 2024)

To supply this substantial power demand at reduced carbon intensity, a massive build-out of solar and wind power capacity is required. The German Federal Government expects 80% of power supply to come from renewable sources by 2030 (BMWK - Bundesministerium für Wirtschaft und Klimaschutz, 2022). To meet this ambition, the government expects over 500 GW of solar and wind power capacity will be installed in Germany by 2035. In an alternative scenario highlighted by Handelsblatt, optimization of the total system cost could lead to a more conservative renewables build-out with a higher contribution from dispatchable sources (Handelsblatt, 2024). In such a scenario, the role of dispatchable power would be higher.

Substantial build-out of renewables capacity is required – an optimized system could minimize the required investment

Electricity generation capacity mix in 2035, GW

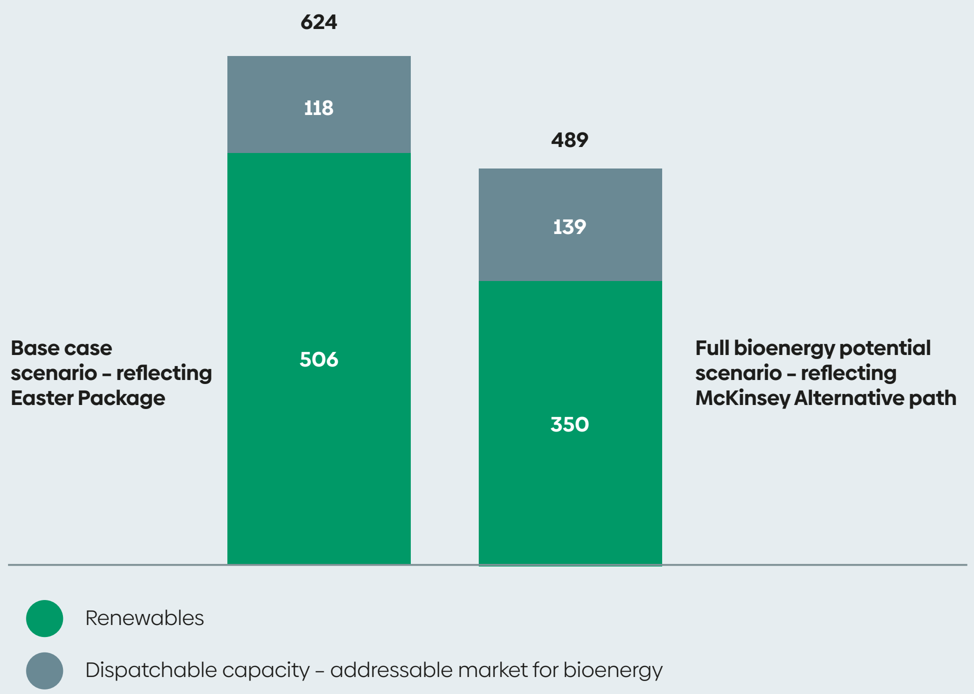

Figure 3. Electricity generation capacity mix in 2035, GW. (Handelsblatt, 2024) (McKinsey&Company, 2024)

There are various technologies and solutions that contribute to dispatchable flexible energy. Gas turbines and engines can be cost-competitive flexibility solutions complementing other technologies such as, hydropower, batteries or flexible load from electric vehicles. Biogas or biomethane as well as clean hydrogen are renewable alternatives to natural gas for gas turbines and engines. The recently announced power plant strategy of Germany includes at least 10 GW of hydrogen-ready gas power plant capacity, which can provide dispatchable power to balance the grid.

This report evaluates the potential role of biogas and biomethane in the power supply mix and refers to biogas/biomethane as bioenergy throughout the report. To consider the future of dispatchable power in Germany, we have investigated two scenarios to assess the potential of bioenergy. In order to assess the potential outcomes, we examine two different scenarios based on the current plans announced by the German government, as well as a more conservative approach to the expansion of renewable energy sources:

The base scenario considers current expectations on cost developments around biogas, biomethane, hydrogen and batteries, as alternatives to gas OCGT (Open-cycle gas turbine) usually used in peak- demand-hours and/or at times of lower renewable generation, providing flexibility in the power supply mix. The base scenario evaluates the competitiveness of these options over time, taking into account emission reduction potential, expected technology learning rates that reduce costs over time, as well as the availability of feedstock and technology scale-up. This scenario reflects the current government's ambition for renewables build-out (EEG 2023 as part of the Easter Package (BMWK - Bundesministerium für Wirtschaft und Klimaschutz, 2022)) and corresponding need for dispatchable power.

The full bioenergy potential scenario considers an accelerated technology learning curve using some recent technology innovation examples as a proxy. These could lead to much more competitive costs and thus a faster uptake as well as faster growth of the biogas and biomethane industry. The key to improved competitiveness would be improving energy efficiency and overall costs of bioenergy. This could be unlocked by regulatory signals in order to create a flexible energy source with low-carbon-intensity and reduced import dependence. This scenario assumes an optimized power supply mix with lower system costs, a slightly lower uptake of wind and solar than the current governmental ambition, and a higher share of flexible generation sources without carbon emissions.

The role of bioenergy in power generation could grow from a stable contribution to a major zero-carbon flexible power supply

Non-intermittent and dispatchable electricity generation, TWh

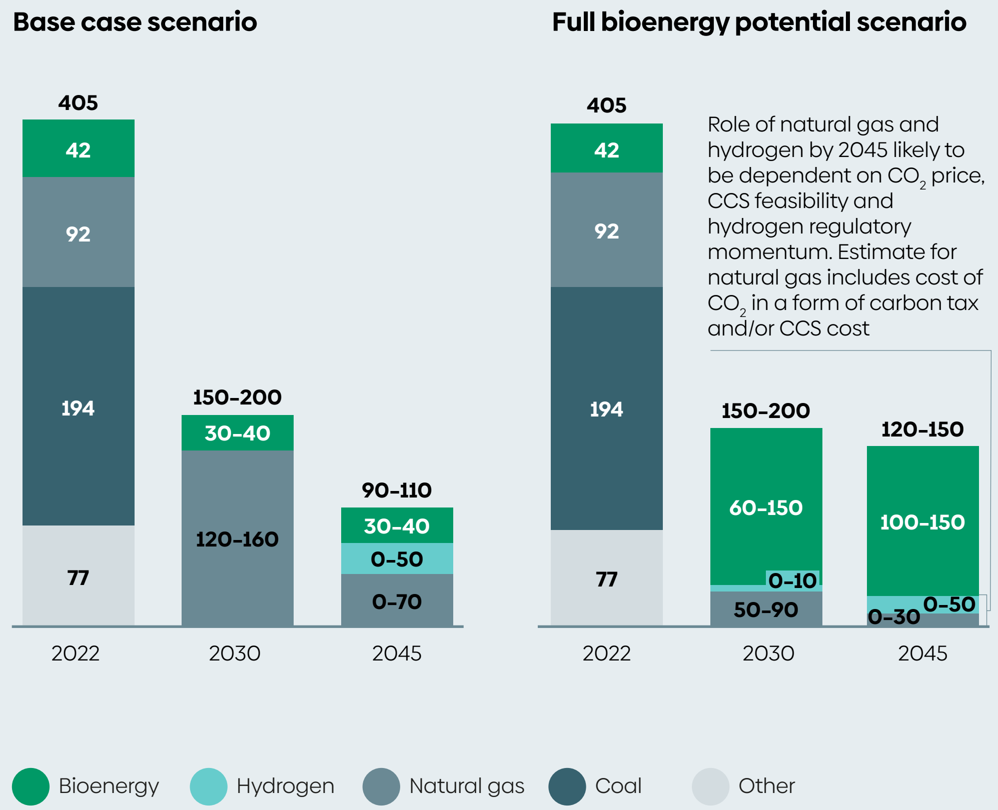

Figure 4. Non-intermittent and dispatchable electricity generation, TWh. (IEA, World Energy Outlook, 2023) (BMWK - Bundesministerium für Wirtschaft und Klimaschutz, 2022) (Fraunhofer-Institut für System- und Innovationsforschung ISI, 2023)

The implications of these scenarios, where biomethane is used as a replacement for natural gas along with hydrogen, are significant beyond the power grid. One major advantage is that it allows for higher utilization of existing gas grids, reducing the need for new infrastructure specifically designed for hydrogen. This is important because building new hydrogen-suited infrastructure can be costly and time-consuming – transmission system operators estimate the cost of hydrogen network at EUR 19.8 billion (BMWK - Bundesministerium für Wirtschaft und Klimaschutz, Wasserstoffnetz für die Energiewende – wichtige Weichen für koordinierten und privatwirtschaftlichen Aufbau sind gestellt, 2024).

By using biomethane as a replacement for natural gas, the existing gas grid can be repurposed to transport and distribute renewable gas. This can help maximize the use of existing infrastructure and minimize the need for additional investment in new pipelines and storage facilities. It also allows for a smoother transition from fossil fuels to renewable energy sources, as the infrastructure is already in place.

Additionally, using biomethane as a replacement for natural gas can reduce dependence on imports of fossil fuels. Many countries rely on imported natural gas to meet their energy needs, which can pose risks to energy security and increase vulnerability to price fluctuations, as the European energy crisis following the Russian invasion of Ukraine has painfully shown. Both as a response to the crisis and to diversify the European Union's gas supply as part of the REPoweEU Plan (European Union, 2022), the Union has outlined an ambition for 35 bcm of yearly biomethane or biogas production by 2030. By producing biogas or biomethane domestically, a country can reduce its reliance on imported fuels and increase its energy resilience and security.

Furthermore, the use of biomethane offers a local value-chain. Biomethane can be produced from organic waste, agricultural residues, and energy crops, among other feedstocks. This creates opportunities for local farmers, waste management companies, and other stakeholders to participate in the production and supply of biomethane. This can contribute to the development of local economies and the creation of jobs. The full system investment needed for this transition will be significant.

Following the German government's 2022 Easter Package ambition for renewables build-out requires substantial investment in additional new renewable capacity as well as transmission and distribution network expansion. According to the McKinsey report Zukunftspfad Stromversorgung (McKinsey&Company, 2024), a power system optimized for the lowest cost of energy transition that relies less on new intermittent sources of renewable power and more on dispatchable capacities would allow for EUR 150 billion lower investment needed between 2023 and 2035. A higher need for dispatchable power could then be met with a cost-efficiency biogas/biomethane supply providing reliable zero-emission power at a lower system cost.

Required investments in the German electricity system will largely depend on the mix of renewables and dispatchable capacity

Investment required between 2023–2035, billion EUR

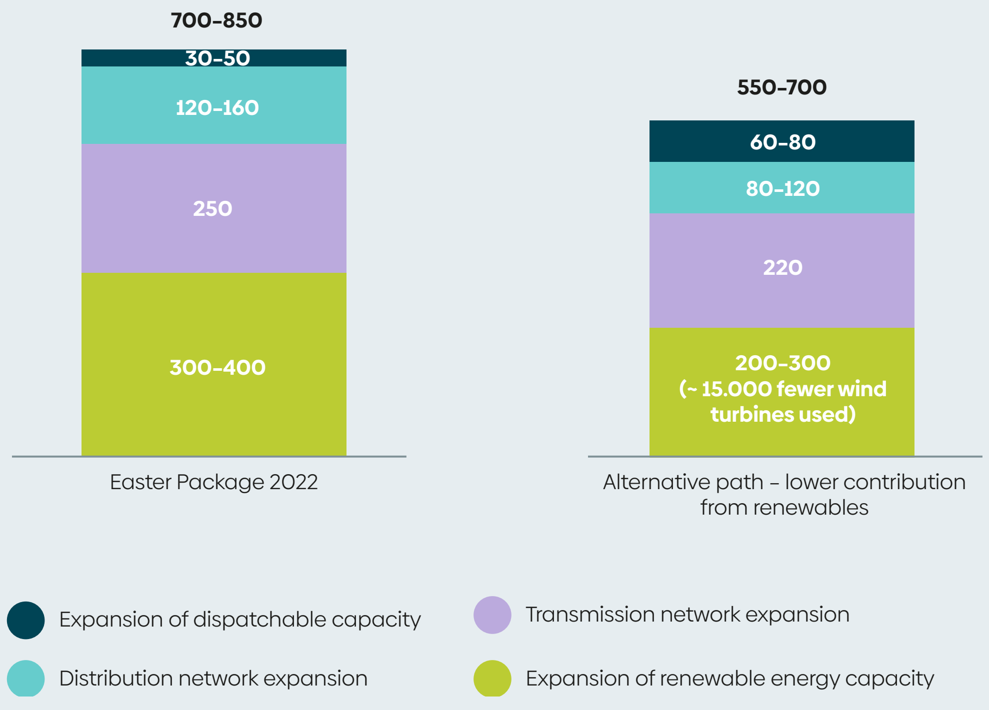

Figure 5. Investment required between 2023-2035, billion EUR. (Handelsblatt, 2024) (McKinsey&Company, 2024)

Chapter 2.2 Bioenergy in hard-to-abate sectors

Beyond power, methane will continue to play a significant role in other sectors such as buildings, industry, and transportation (road transport and maritime shipping). In these sectors, biomethane can be used as a drop-in replacement for natural gas, allowing for the decarbonization by using existing infrastructure including the grid, LNG and CNG fueled vehicles/vessels, and boilers.

In addition to biomethane, liquid biofuels can also be used as a replacement for liquid fossil fuels in major transportation sectors such as aviation, maritime, and trucks. These biofuels can be produced from a variety of biomass feedstocks, including agricultural crops, forestry residues, and oils. The production process typically involves converting. the feedstocks into a liquid fuel through processes such as transesterification or hydrotreatment.

One of the key advantages of liquid biofuels is that they can be used in existing engines and infrastructure without the need for significant modifications. This makes them a viable option for reducing greenhouse gas emissions in the transportation sector without requiring a complete overhaul of the existing infrastructure. Additionally, liquid biofuels have the potential to reduce dependence on imported fossil fuels and support local economies through the production of domestic feedstocks.

Bioenergy potential varies across sectors and can reach 15% to 20% of energy consumption

Bioenergy as share of total energy consumption in full bioenergy potential scenario, TWh

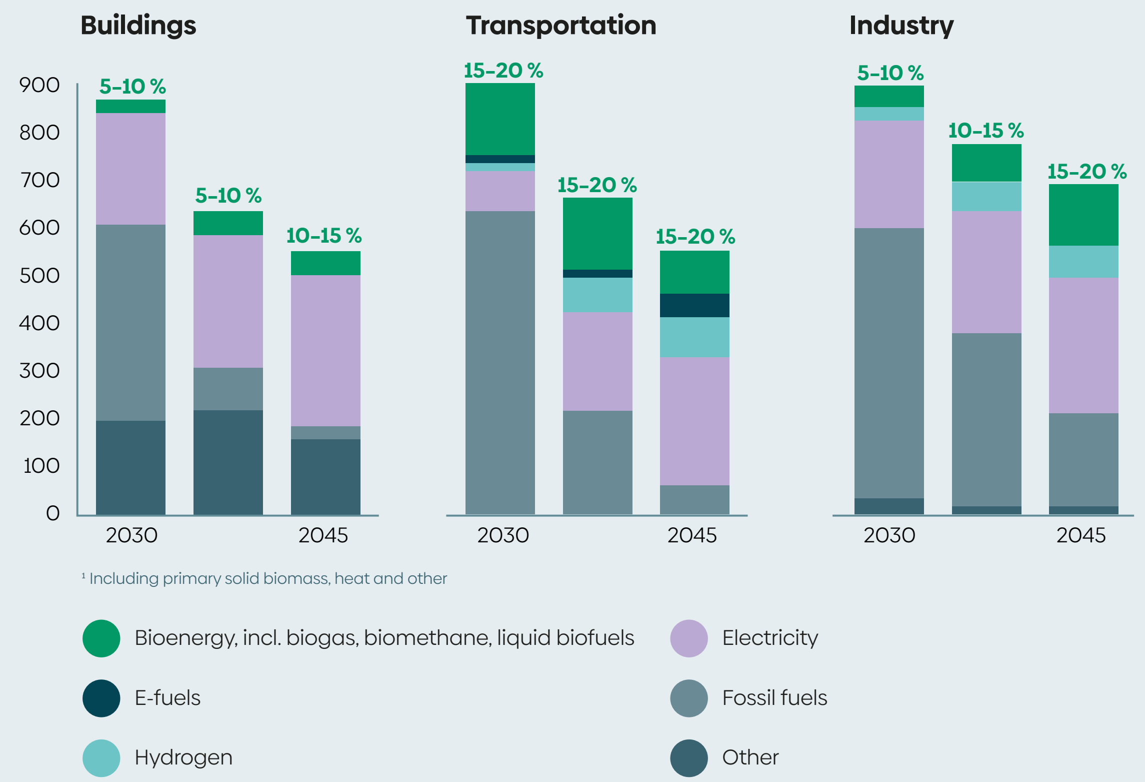

Figure 6. Bioenergy as a share of total energy consumption in full bioenergy potential scenario, TWh. (IEA, World Energy Outlook, 2023) (Bundesnetzagentur, 2022) (Hydrogen Council, 2023) (Gas For Climate, 2023) Extantia estimate

Chapter 2.3 Feedstock for bioenergy

When evaluating the potential for bioenergy, it is important to consider the availability of feedstock resources. The amount of feedstock available will determine the scale and feasibility of bioenergy production. Factors such as land availability, crop yields, and the availability of waste and residue streams will all impact the potential for bioenergy production. There are three main routes of bioenergy: anaerobic digestion, biomass combustion with gasification, and liquid biofuels. Each of these routes utilizes different core feedstocks.

1. Gaseous biofuels: Biomethane production involves the use of feedstocks such as manure, agricultural residues, the organic fraction of municipal waste, sewage sludge, and other organic materials. These feedstocks are processed through anaerobic digestion to produce biogas, which is then upgraded to biomethane.

2. Solid biomass through combustion & gasification: This route involves the use of wood and other lignocellulosic materials, as well as organic materials with a high dry matter content. These feedstocks can be used for both combustion and gasification processes. Combustion involves the direct burning of biomass to produce heat or electricity, while gasification is a special form of "incomplete combustion" that converts biomass into a gas (syngas) that can be further processed for various energy applications. The choice between combustion and gasification depends on factors such as flexibility requirements, desired energy product (gas, heat, electricity, or complex molecules), and available infrastructure.

3. Liquid biofuels: Liquid biofuels are produced from oils and other waste and residue liquids. These feedstocks can be converted into biofuels through processes such as transesterification or hydrotreatment. Liquid biofuels have applications in transportation and can be used as a substitute for fossil fuels.

In the European Union, there are regulations in place to ensure the use of sustainable feedstocks for bioenergy production. Sustainable feedstocks are those that do not contribute to food scarcity or have negative impacts on the agricultural industry. The EU Renewable Energy Directive limits the use of first generation feedstock for fuels used in the transportation sector to the 2020 level +1% with a max. of 7% of all transport energy, while advanced feedstocks listed in Annex IX Part A of the Directive, including for example agricultural residues or lignocellulosic waste, are required. Specifically for biogas/biomethane production, the use of straw after harvest instead of energy crops is encouraged. Given the scarcity of the feedstock, its efficient use will be critical. Focusing on energy efficiency will be needed to maximize the potential of bioenergy. On the biogas and biomethane side, improvements in the yield of anaerobic digestion, as well as a switch from technology converting biogas to electricity, could increase electricity output by up to +140% (European Biogas Association, 2023) (Gas For Climate, 2023).

Novel tech can enable higher biogas yields from available feedstock and improve electricity generation efficiency, maximizing bioenergy potential

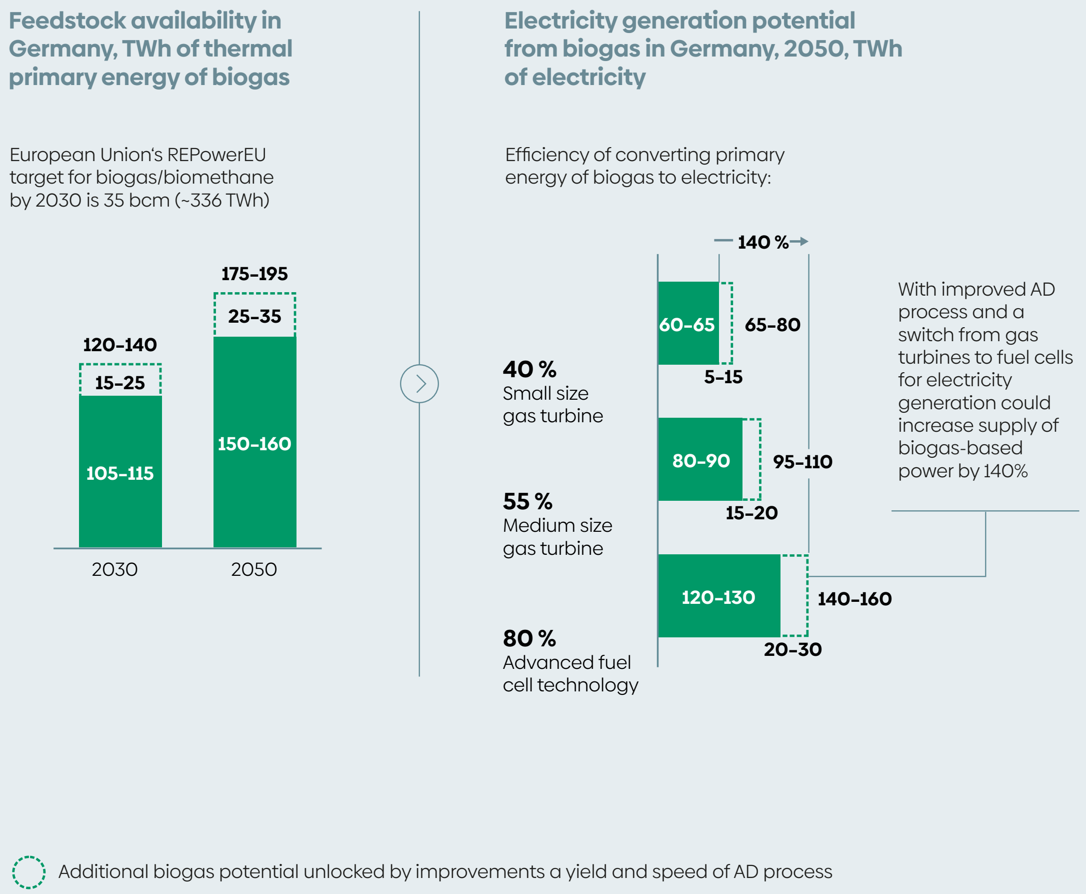

Figure 7. Feedstock availability in Germany, TWh in thermal primary energy of biogas; Electricity generation potential from biogas, TWh of electricity. (Gas For Climate, 2023) (European Biogas Association, 2023) (European Union, 2022)

Chapter 3

To optimize the energy trilemma, bioenergies will need to enable competitiveness. Innovation will be required to bring costs down

An efficient energy transition must ensure affordability and enable competitiveness. As the need for decarbonization increases and carbon dioxide prices rise, fossil energy sources will become more expensive. At the same time, continued innovation will drive down the costs of new energies (Hydrogen Council, 2023).

By 2040 bioenergy has the potential to become the most cost-competitive source of flexible carbon-neutral power

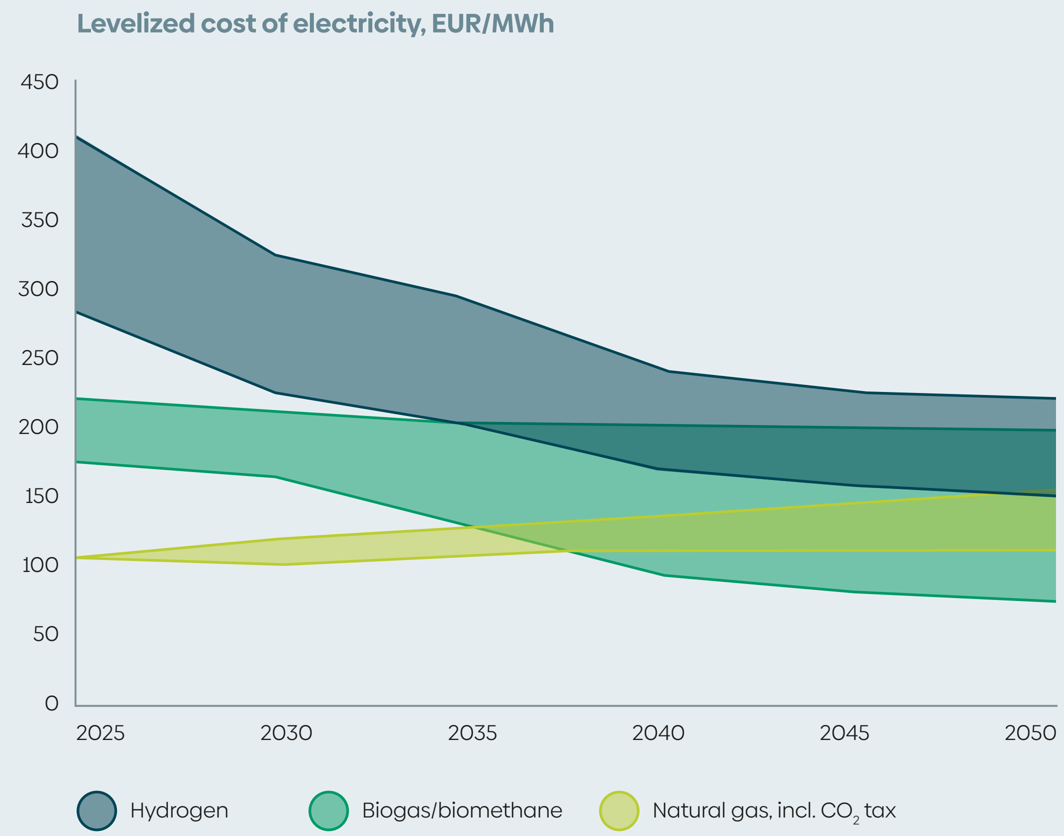

Figure 8. Levelized cost of electricity, EUR/MWh. (Hydrogen Council, 2023) (IEA, World Energy Outlook, 2023) Extantia estimate

For bioenergies specifically, we expect a cost decline of 10-50% over the next few years based on efficiency improvements and innovations across the entire value chain, including biomass collection, more efficient plant configurations and better utilization of the energy potential of the respective feedstocks. The full cost-stack of bioenergies includes the cost of feedstock, transportation, processing, and distribution. Innovations in each of these areas can help reduce the overall cost of bioenergies. On the other hand, the cost of fossil fuel usage increases with the cost of carbon, as many countries and regions have implemented carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, to incentivize the reduction of greenhouse gas emissions.

Bioenergy cost decline expected over time

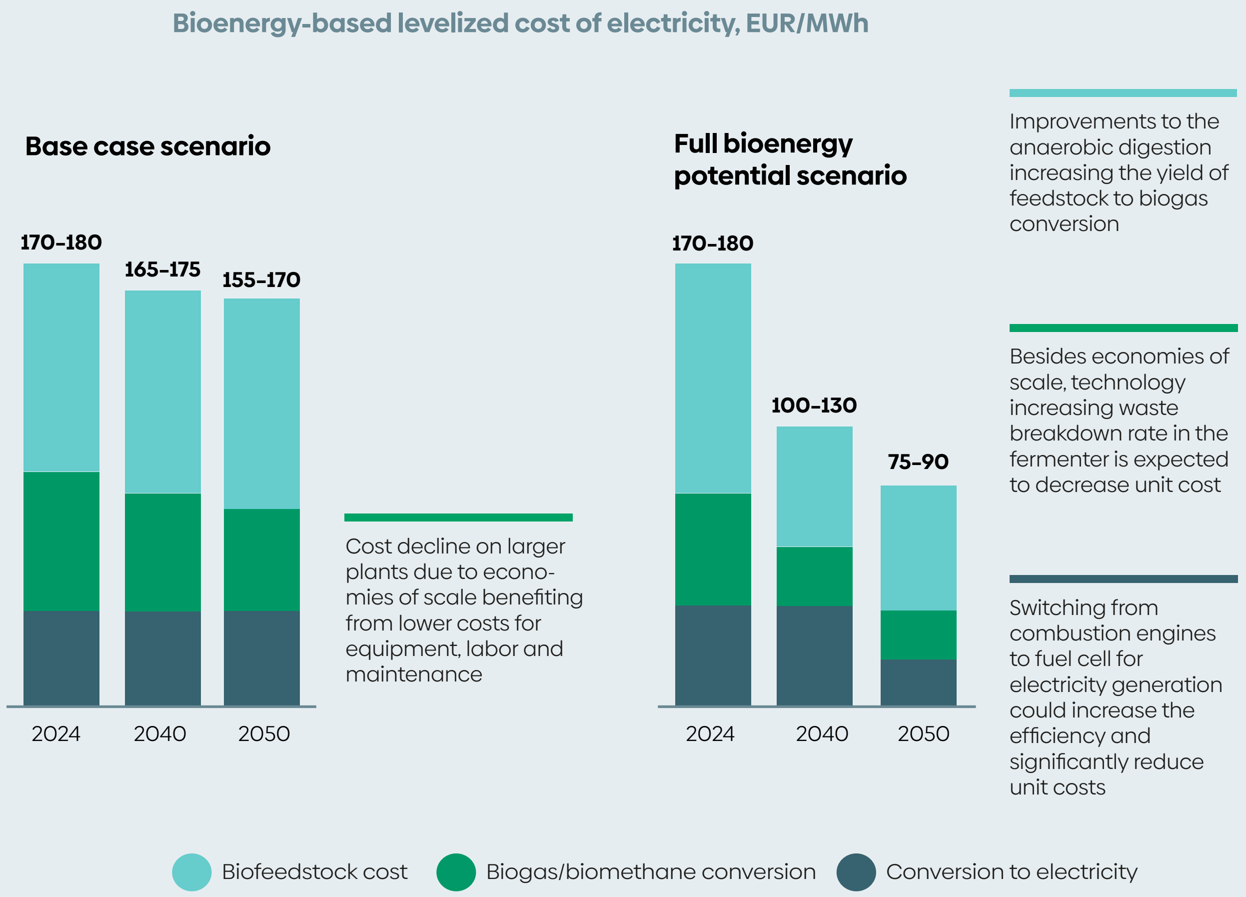

Figure 9. Bioenergy-based levelized cost of electricity, EUR/MWh. (Engie, 2021) (Gas For Climate, 2023) (European Biogas Association, 2023) Extantia estimate

Improvements in the bioenergy value chain can help reduce costs and increase efficiency. Anaerobic digestion is a well-established technology that has been used for many years to convert organic waste into biogas. In the next decades there is potential for cost-out with scale effects on larger plants due to economies of scale, where larger plants can benefit from lower costs for equipment, labor, and maintenance. In addition to cost-out potential with scale effects, there is also potential for improved balance of plant efficiency and better collection of feedstocks and digestate through aggregators. This can help optimize the performance of the anaerobic digestion plant and improve the quality of the biogas produced. However, there is also the potential for higher feedstock prices due to increased competition. As more plants are built and demand for feedstocks increases, the price of feedstocks may rise. This could potentially offset some of the cost-out benefits of scale effects. It is important to note that the impact of higher feedstock prices will depend on the specific market conditions and the availability of alternative feedstocks. Overall, the estimated effect of cost-out potential with scale effects on larger plants is around 5-10% of today's average biomethane cost, corresponding to approximately 10-15 EUR/MWhthermal (Engie, 2021).

The Main improvement areas in anaerobic digestion technology include maximizing the full biomass potential, accelerating the digestion process, and enhancing the efficiency of biogas to power conversion. These improvements can be achieved through various strategies and technologies:

- **Yield improvements to anaerobic digestion** - One key area of improvement is maximizing the biomass potential. Improvements to anaerobic digestion can increase the efficiency of converting feedstock into biogas (either improving methane yield per ton or feedstock, increasing the methane content in the raw gas or extracting remaining energy from the digestion residue) by better understanding, controlling and influencing/stimulating the fermentation process. New technologies and process elements can also speed up the anaerobic digestion process and the time required in the fermenter by 2-3 times. In recent years, multiple scientific papers have been published on improved and advanced fermentation process studies in various countries and for different feedstock types. Several companies (both established biomethane producers and start-up newcomers to the market) have presented innovations that could lead to substantial efficiency improvements in the fermentation process compared to today's standards. Examples of such companies are WASE, SGTech, Vertus Energy and Aquature.

- **Improvements to the efficiency of biogas to power** – current biogas combustion offers 30-40% efficiency. Improvements to conversion could significantly reduce costs while adding a new solution to existing 30TWh electricity generation from biogas plants in Germany whose subsidies run out after a 20-year period could be a way to prolong their lifetime. A promising pathway is the application of fuel cells instead of combustion units to convert biogas to power, potentially increasing electricity conversion efficiency to 80% (with some residual heat). Fuel cells have reached a certain level of technical readiness, but there is still efficiency and cost-out potential from scaling up production, reducing the cost of materials, improving the efficiency of the manufacturing process and waste heat recovery.

With improvements to the biogas process and a switch to more efficient power generation, bioenergy-based power can halve in cost by 2050

Bioenergy-based levelized cost of electricity, EUR/MWh

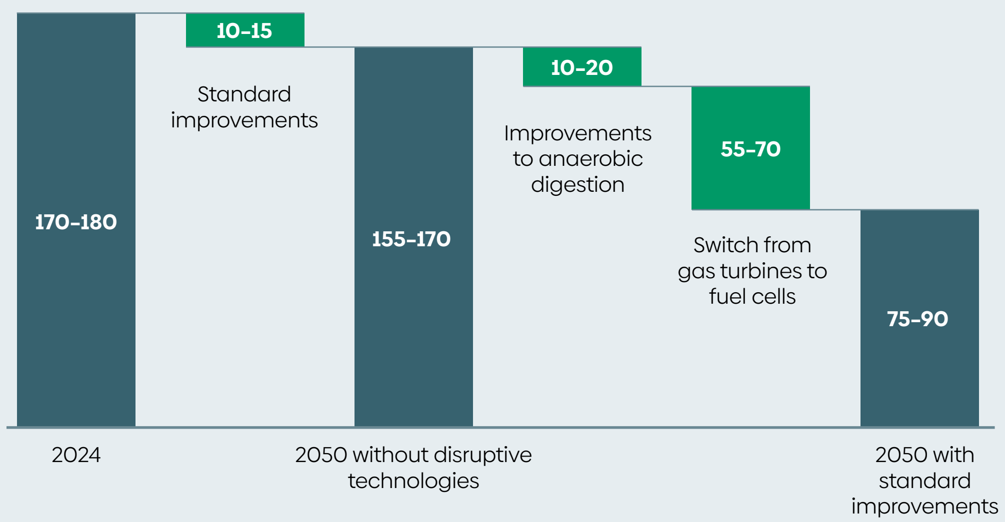

Figure 10. Bioenergy-based levelized cost of electricity, EUR/MWh. (Engie, 2021) (European Biogas Association, 2023) (Gas For Climate, 2023) Extantia estimate

At reduced costs, bioenergy, specifically biogas and biomethane, can become a competitive source of zero-carbon power in the energy system (DNV, 2023). This is especially true when considering the cost of firming intermittent sources of power, such as wind and solar. Firming refers to the process of ensuring a stable and consistent supply of electricity from intermittent sources through the addition of batteries or other long-duration energy storage (LDES), which can be challenging and costly. Biomethane, on the other hand, can provide a stable and reliable source of power that can be dispatched on demand, making it an attractive option for meeting energy demand. Furthermore, at reduced costs, biomethane can compete with alternative flexible power sources, such as natural gas or coal. This can help to reduce greenhouse gas emissions and promote the transition to a more sustainable energy system.

At the lowest cost, bioenergy could compete with alternative power sources also beyond dispatchable power need

Levelized cost of electricity by technology, 2030-2050, EUR/MWh

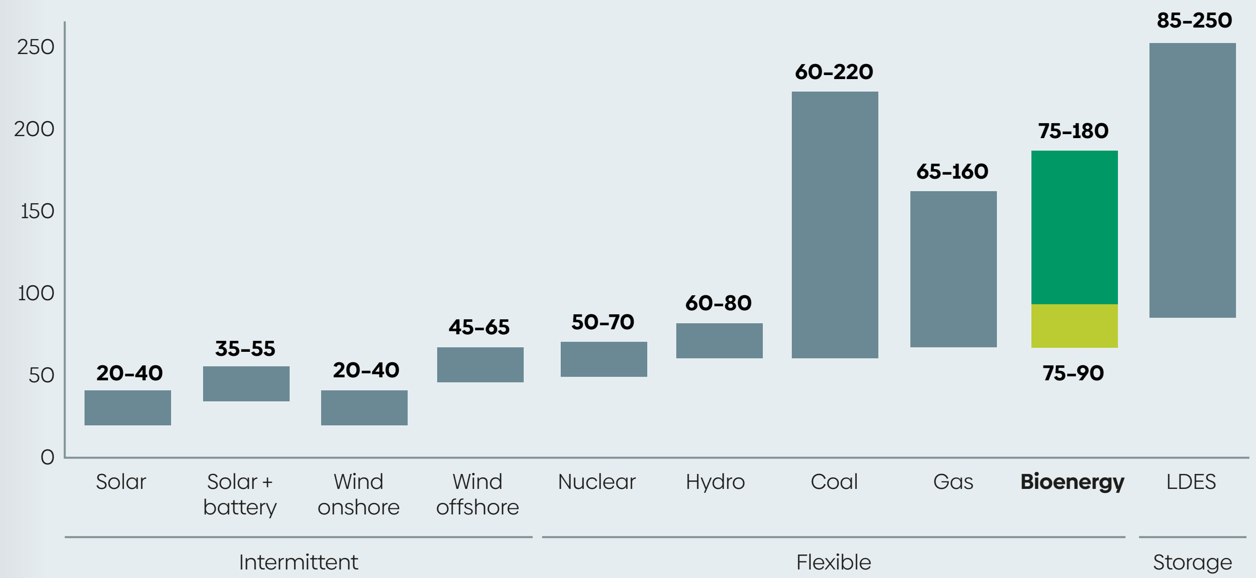

Figure 11. Levelized cost of electricity by technology, 2030-2050, EUR/MWh. (DNV, 2023) (Afry, 2022) (Engie, 2021) Extantia estimate

In conclusion, improvements in the bioenergy value chain can help reduce costs and increase efficiency. Upstream improvements in feedstock, process improvements in unit capital expenditure and operating expenses, and downstream improvements can all contribute to making bioenergy more affordable and even competitive with or cheaper than alternatives.

Chapter 4

To accelerate some of the technical improvement potential, regulatory signals and enablers have been used across the EU and beyond

Incentives and schemes supporting various bioenergy products are crucial for their widespread adoption and growth. These incentives can take various forms, such as feed-in tariffs, mandates, and tax credits.

Feed-in tariffs are one of the most common incentives used to support renewable energy sources, including bioenergy. Feed-in tariffs are policies that require utilities to purchase renewable energy at a fixed price, often above market rates, to incentivize the development of renewable energy sources. This can help offset the higher costs associated with developing and deploying new bioenergy technologies.

Mandates are another type of policy that can be used to support bioenergy products. These policies require a certain percentage of energy to come from renewable sources, which can drive demand for bioenergy products. This can help create a market for bioenergy products and encourage investment in the sector.

Tax credits are also commonly used to incentivize the development and use of bioenergy products. These credits provide financial benefits to companies and individuals who invest in bioenergy technologies.

These incentives and schemes are implemented across the globe, with varying degrees of success, for example:

Germany has been successful in promoting the use of bioenergy through its feed-in tariff system, which has led to significant growth in the biogas sector. The feed-in tariff system in Germany provides financial incentives for renewable energy production, including biogas. The feed-in tariff system guarantees attractive feed-in tariffs for a 20-year period, which has incentivized the production and use of biogas in the country. As a result, Germany has experienced a 13-fold increase in renewable energy production between 2004 and 2014. However, recent policy changes, such as the replacement of the feed-in tariff system with a tender system for larger installations, have slowed down the historic growth of biogas and biomethane production in the country. The shift to a competitive tender system has created uncertainty for planning, and selected biogas production sites are expected to be decommissioned once they drop out of the 20-year guaranteed feed-in tariff period.

In Denmark, the positive development of the Danish biogas market, especially gas feed-in, is due, among other things, to the feed-in tariff system introduced in 2012 and the lifting of the funding cap (construction of large biomethane plants, for example by Orsted and E.ON). Since 2020, a new funding regime in the form of capacity auctions has been applied for cost reasons. The new regime is limited to climate-neutral gases in the form of biomethane or e-methane; Due to the capacity cap, a slight reduction in growth is expected

The Renewable Fuel Standard (RFS) in the United States is a policy that mandates the use of biofuels in transportation, which has driven demand for biofuels in the country. Under the RFS, a certain percentage of transportation fuels must come from biofuels, and this requirement has created a market for biofuels in the United States. The RFS includes mechanisms such as the Blenders Tax Credit (BTC) to incentivize the production and use of biofuels.

Subsidizing the biomethane sector not only supports the development of this industry, but also indirectly benefits the local agricultural sector. This is because biomethane is typically produced from organic waste materials, such as agricultural residues and manure, which are sourced from farms. By providing subsidies to the biomethane sector, farmers can receive additional income from selling their waste materials for use in biomethane production. Additionally, the development of the biomethane sector can replace or build on existing support for the agricultural sector, providing farmers with new opportunities for revenue generation.

Furthermore, biomethane has the potential to act as a carbon abatement technology. This is because the biomethane upgrading process involves capturing biogenic carbon dioxide, which is a greenhouse gas that is produced naturally through biological processes. By capturing this carbon dioxide and storing it, the process can result in a carbon negative solution. This means that the production and use of biomethane can actually result in a net reduction of greenhouse gas emissions, making it an attractive option for reducing carbon footprints and mitigating climate change.

Chapter 5
Conclusions and next steps

Efficiency is a crucial factor in promoting sustainable energy systems. High efficiency and high energy recovery can maximize the benefits of energy systems and ensure their sustainability in the long term. Subsidies and incentives should be targeted towards improving the efficient use of materials to reduce waste and promote sustainability. This approach can help to reduce the environmental impact of energy systems and promote the transition to a more sustainable energy system.

Effective subsidies are the ones that are not required forever. By providing financial support to innovations that require significant investment in the short term but enable cost decline with scale and adoption over time, subsidies can help drive their adoption and market penetration as the technology becomes more efficient and cost-effective, ultimately leading to a more sustainable and efficient energy system.

Biogas/biomethane is a promising renewable energy source that is already cost-effective in many cases, with an LCOE price range in Germany of around 80-90 EUR/MWht, equivalent to 170-180 EUR/MWh_e. Further developments and technology improvements increasing the efficiency of the digestion process for biogas production, as well as the usage of new solutions like fuel-cells for electricity production instead of combustion engines, resulting in higher electricity yields from the process and less system losses, could bring the LCOE cost down significantly, potentially reaching 50-60 EUR/MWht, equivalent to 85-95 EUR/MWhe.

This cost potential makes biogas/biomethane a highly attractive option for the transition to a more sustainable energy system. Biogas/biomethane is also broadly available in Germany, with an upper limit of 150 TWht (15 bcm), and there is upside potential from land uses currently used for energy crop purposes. This means that biogas/biomethane has the potential to play a significant role in meeting Germany's energy needs in the future.

Based on our models and price forecasts of alternatives, biomethane has the potential to become the most competitive renewable energy source. However, to fully realize this potential, energy transition strategies should incentivize technology breakthroughs and improvements through various means. These include:

Capex investment grants, which are subsidies or funding provided to support capital expenditure (capex) investments in various projects or initiatives. These grants aim to incentivize and support the development and implementation of new technologies or infrastructure. In the context of biogas/biomethane, capex investment grants could be used to provide financial support for the construction and establishment of biogas/biomethane production facilities, such as anaerobic digesters or fuel-cell set-ups for power generation. These grants can help offset the initial high costs associated with setting up biogas/biomethane production infrastructure, making it more financially viable for investors and project developers.

Innovation subsidies and funding which are financial incentives or support mechanisms specifically targeted at promoting and fostering innovation. These subsidies and funding are designed to encourage the development and adoption of new ideas, products, or processes that can bring about positive changes or advancements in a particular industry or sector. In the case of biogas/biomethane, innovation subsidies and funding could be used to support research and development efforts aimed at improving the efficiency, cost-effectiveness, and scalability of biogas/biomethane production technologies. This could include funding for pilot projects, demonstration projects, or collaborative research initiatives that explore new methods or technologies for biogas/biomethane production.

Offtake support/feed-in premiums which refer to mechanisms or incentives that ensure a guaranteed market for the output or production of a specific project or industry. Feed-in premiums, on the other hand, are additional payments or incentives provided to producers of renewable energy for the electricity they generate and feed into the grid. These mechanisms aim to support the viability and profitability of renewable energy projects. In the context of biogas/biomethane, offtake support/feed-in premiums could be used to provide financial incentives for biogas/biomethane producers, ensuring a stable and predictable revenue stream for their production. This can help offset the higher costs associated with biogas/biomethane production compared to conventional fossil fuels, making it more economically attractive for producers.

Proactively including biomethane in carbon contract for difference schemes, potentially linked to innovations, which refers to the inclusion of biomethane in carbon contract for difference (CfD) schemes. CfD schemes are mechanisms that provide financial support to low-carbon electricity generation projects. Including biomethane in these schemes incentivizes the production and use of this renewable gas, potentially leading to innovations in the biomethane sector. This inclusion could involve providing financial incentives or subsidies to biomethane producers based on the difference between the market price of biomethane and a predetermined strike price. This can help bridge the cost gap between biomethane and conventional fossil fuels.

In conclusion, capex investment grants, innovation subsidies and funding, offtake support/feed-in premiums, and proactively including biomethane in carbon contract for difference schemes are all options that can be used to support the development and adoption of biogas/biomethane as a renewable energy source. These options provide financial incentives and support mechanisms that can help overcome the initial high costs associated with biomethane production, encourage innovation in the sector, ensure a stable market for biogas/biomethane producers, and make biomethane more competitive in the energy market. By implementing these options, governments and policymakers can contribute to the transition to a more sustainable and efficient energy system.

Lastly, promoting efficiency and supporting bankable technology are crucial factors in promoting sustainable energy systems. Subsidies and incentives should be targeted towards high efficiency and high energy recovery systems, and investment in research and development can help to drive innovation and improve the scalability and cost-effectiveness of energy technology. By adopting these approaches, we can maximize the benefits of energy systems and contribute to the transition to a more sustainable energy system.

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