Development of a novel highly efficient energy supply system
for energy autonomous multi-family buildings
based on biomass gasification coupled with an SOFC and a PV system

Grant Agreement No 101083409

D8.7: Final environmental and socio-economic impact assessment

Deliverable Factsheet	
Full title	Final environmental and socio-economic impact assessment
Deliverable number	D8.7
Work package	8
Work package leader	Thomas Götz (WIKUE)
Related Task(s)	Task 8.3 – Impact assessments
Lead beneficiary	WIKUE
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Project coordinator	Ingwald Obernberger (BIOS)
Nature of document	R – Document, report
Dissemination level	PU - Public
Version	1.0
Date	30.03.2026

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Preface

The document **D8.7 - Final environmental and socio-economic impact assessment** consists of two parts:

The **first part (Part I)** comprises the

Final environmental performance analysis and impact assessment

The **second part (Part II)** of this document comprises the

Final analysis of the relevant policy framework

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This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101083409.

This document has been prepared by the Micro-Bio-CHP project partners as an account of work carried out within the framework of the EC-GA contract no 101083409.

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Executive Summary

To meet the defined climate protection targets, building heating in Germany and Austria needs to become climate-neutral by 2045. On this basis, it can be assumed that current fossil-fuelled heating systems will be replaced by low-emission or renewable alternatives by that time (German Federal Government, 2024; National Council Austria, n.d.).
Based on the premise that all fossil fuel-based heating systems must be converted by 2045, it can be assumed that efficient and low-emission solid biomass systems will be considered as an alternative energy source primarily for current heating systems using heating oil. In order to ensure a sustainable electricity and heat supply, not only the available biomass potential within the EU needs to be considered, but also other relevant environmental impacts. In addition to optimising fuel consumption, improving overall efficiency and reducing GHG emissions, it is therefore crucial to explore ways to reduce other air-quality-related emissions of such systems. In this context, Micro-Bio-CHP is an EU Horizon Europe project with the aim of developing a novel highly efficient energy supply system for (nearly) energy self-sufficient multi-family buildings, providing electricity, space heating and domestic hot water (DHW) with almost zero greenhouse gas (GHG) and other emissions. For true energy autonomy, a year-round equilibrium between supply and demand, with storage considered, is paramount. Comparing alternative systems is therefore a complex task, particularly as the different systems are designed according to diverging priorities.

As a result of the technical system design and the techno-economic evaluations (Task 8.2) system performance data such as envisaged emission factors for particulate matter (PM), carbon monoxide (CO), organic gaseous compounds (OGC), and nitrogen oxides (NO_x) or efficiencies of the new technology have become available after the last phase of the Micro-Bio-CHP project. This final impact assessment compares the key technical, environmental and economic parameters of the new technology with selected state-of-the-art reference systems. Based on final measurement results, techno-economic evaluations and scenario-based stock modelling, the assessment examines the potential contribution of the technology under different market development pathways. The analysis focuses on system performance, pollutant emissions, greenhouse gas mitigation, costs and policy relevance.

The key findings of this assessment are as follows. Micro-Bio-CHP already represents a significant advance in biomass technology, especially for significantly reduced specific emissions of PM, CO, OGC and NO_x. Further optimisation potential is found especially in reducing fuel consumption and increasing overall efficiency of the Micro-Bio-CHP technology. Together with reductions in capital costs, this could also make the Micro-Bio-CHP technology cost-competitive with the other two biomass-fuelled technology options analysed. Addressing the transition from fossil-based heating systems to renewable energies before 2040 therefore also depends on clear political incentives. Another focus of future policy incentives should be to avoid potential bottlenecks in supply and installer capacities as a large number of installed old systems in the stock needs to be replaced in a very short period of time to achieve climate protection targets.

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1 Introduction: Setting the scene

Micro-Bio-CHP is an EU Horizon Europe project with the aim of developing a novel highly efficient energy supply system for (nearly) energy self-sufficient multi-family buildings, providing electricity, space heating and domestic hot water (DHW) with almost zero greenhouse gas (GHG) emissions. The micro combined heat and power (mCHP) system runs on conventional high-quality wood pellets and is based on biomass gasification for use in a biomass boiler coupled with an SOFC and a state-of-the-art PV system, integrating a water buffer storage for heat and bi-directionally chargeable e-vehicles serving as electrical storage.

The capacity is 23.5 kW (fuel power) at nominal load, with 18 kW nominal heating capacity, 2.5 kW gross electric capacity and a 39.3 kW_p nominal power PV system. The novel compact SOFC system with its highly efficient durable stack units shall achieve an electric stack efficiency of 44.7%. It integrates a HCl and H_2S removal reactor and is flexibly coupled with a 14 kW gasifier. The flexible partitioning of product gas supplied to the SOFC and the gas burner is designed to cover the overall heat demand and to maximise SOFC operation at the same time. That way, overall efficiencies of close to 90% shall be achieved. As the biomass conversion unit comprises a low-emission updraft biomass gasifier, a low-emission burner and a novel gas cleaning unit (GCU) with a combined thermal and catalytic tar reformer, the Micro-Bio-CHP system shall further distinguish itself by virtually zero emissions of CO, OGC and dust as well as 40% to 45% reduced NO_x emissions compared to other biomass CHP technologies. Apart from its technological advantages, the system shall be economically highly attractive for future users, so that it helps to increase the penetration of renewable energies (RES) on the multi-family house (MFH) level and has the potential to significantly contribute to reaching the EU climate and clean air goals.

As a result of the technical system design and the techno-economic evaluations (Task 8.2), system performance data such as envisaged emission factors for PM, CO, OGC and NO_x, as well as efficiency values, became available in the last phase of the project. The preliminary impact assessment was therefore updated and refined on the basis of these final measurement and analysis results. Using an in-house stock model developed by WIKUE, the final assessment compares the new Micro-Bio-CHP technology with selected state-of-the-art reference systems under different development scenarios. The aim is to assess the technical, environmental and economic performance of the technology and to derive conclusions for its further development and for the relevant EU policy framework. The assessment was carried out by WIKUE with data inputs from BIOS and the other project partners.

This report (D8.7) provides the final impact assessment for one particular application case, based, among others, on input data from the techno-economic analysis as well as extensive further research, including an evaluation of the market potential for the new Micro-Bio-CHP technology.

1.1 Application case A1

The exemplary application case A1 chosen by the consortium for this final impact assessment is a normally insulated multi-family house with nine apartments and a floor area of approximately 600 sqm, which is very typical for the German and Austrian building stock. Respective system performance data is available from the techno-economic evaluations (Task 8.2) of the Micro-Bio-CHP project. The total annual heat demand is 51,007 kWh/year for space heating and domestic hot water. The electricity demand is 23,201 kWh/year plus 4,414 kWh/year for domestic hot water production in summer and an additional 24,759 kWh/year for e-mobility, yielding a base electricity demand of 52,374 kWh/year. In addition, 175 kWh/year are required for SOFC start-up heating, which is accounted for separately in the techno-economic analysis. The photovoltaic system provides 40,089 kWh/year to cover the major part of the demand. For the comparative analysis in this final impact assessment, the remaining electricity demand as well as the heat demand are supplied by four different technology options, which are briefly described below. More detailed technical data can be found in Table 3.

- **Micro-Bio-CHP using biomass (Micro-Bio-CHP)**

  The new combined heat and power generation in micro-scale using wood pellets in a biomass updraft gasifier to fuel a 2.5 kW_{el} SOFC, as developed in the Micro-Bio-CHP project.
- **Boiler using biomass (Biomass_boiler)**

  Traditional biomass boiler running on wood pellets for heat generation only, while electricity is sourced from the grid.
- **CHP using biomass (Biomass_CHP)**

  Traditional biomass combined heat and power generation with external combustion engine (Stirling engine) at 0.6 kW_{el} capacity using wood pellets as fuel.
- **Solid oxide fuel cell using natural gas (NAT_GAS_SOFC)**

  High temperature fuel cell running on conventional natural gas for combined heat and electricity generation at 0.7 kW_{el} capacity.

2 Market potential

2.1 Multi-family building stock in Germany and Austria

Overall, multi-family buildings with 7–12 apartments are most interesting for the new Micro-Bio-CHP technology, which can be adapted to the different energy demands of all such buildings. For this final impact assessment, the selected exemplary application case A1 with 9 residential units and its specific energy requirements are considered for the detailed analysis. In order to estimate the market potential, it is first necessary to know the overall and relative numbers of such multi-family houses in Germany and Austria. Furthermore, information on the main energy carrier used for heating in these buildings is relevant. However, data on the heating structure of residential buildings by energy carrier are not available in this resolution, i.e. specifying the residential units in the building. Therefore, it is assumed for simplicity that the distribution of energy carriers in the selected group of buildings corresponds to that of the entire residential building stock.

According to data for Germany from Statistisches Bundesamt (Federal and state statistical offices Germany, 2022), 4.6% (921,714) of the 19,957,268 residential buildings counted on 15th May, 2022 were multi-family houses in the range of 7–12 apartments. Assuming a respective equal distribution (1/6) in terms of the number of apartments in this range, around 153,600 of the 921,714 multi-family houses in Germany would have exactly 9 apartments. In Austria in 2023, there were 281,493 residential buildings with three or more apartments (Federal Statistical Office Austria, 2025). Combining these data with those from Kleine Zeitung (2016)[1], it can be concluded that around

[1] In the absence of more granular official data on apartment-count distribution, this estimate draws on media-reported summary statistics.

194,000 multi-family houses with 3-10 apartments existed in Austria in 2023. Assuming again an equal distribution in terms of the number of apartments (here 1/8), around 24,200 of the 194,000 multi-family houses in Austria would have exactly 9 apartments.

2.2 Status quo and development of heating systems in Germany and Austria

2.2.1 Current heating structure by energy carrier

Looking at the heating structure of residential buildings by energy carrier for Germany and Austria, it is possible to estimate the number of heating systems in the selected group of buildings that use fuel oil or biomass. According to BDEW (2019), 30.4% of the residential buildings in Germany in 2019 were heated using heating oil and 3.3% using wood and/or pellets. In Austria, the shares for heating oil and biomass were 14% and 18% respectively, on average over the years 2017 to 2022 (Federal Ministry of Climate Protection, Environment, Energy, Mobility, Innovation and Technology, 2022). The available data on building structure and heating type refer to different reference years. Since the purpose of this analysis is to provide an indicative estimate of the market potential rather than a precise stock calculation, the resulting inaccuracy is considered acceptable. It should also be noted that application case A1, with 9 residential units, was chosen as a representative example for the broader stock of multi-family buildings with 7–12 apartments. Therefore, the overall market potential (as shown in the section before) and emissions saving potential of the new Micro-Bio-CHP technology in all building categories combined is much higher. However, while the absolute emissions of buildings with less or more than 9 apartments may differ in absolute numbers, the general pattern is the same as for the analysed example. For the purpose of this final impact assessment, this aspect is also addressed partly by a sensitivity analysis with different assumptions and scenarios with assumed high ambition levels for the Micro-Bio-CHP market development. The key data for the exemplary application case A1 is therefore presented in Table 1 and the following Figures and Tables of this final impact assessment.

Table 1: Estimated building and heating system stock for the analysed application case A1

	Germany	Austria
Total multi-family houses (MFH) with 9 apartments	153,619	24,215
Stock oil heating systems	43,781	3,148
Stock biomass heating systems	5,069	4,331

2.2.2 Replacement and renewal rates for the heating system stock

Since building heating in Germany and Austria needs to be climate-neutral by 2045 in order to achieve the defined political climate protection targets, it can be assumed that current fossil-fuelled heating systems will have been replaced by that time (German Federal Government, 2024; National Council Austria, n.d.). According to BDEW (2019), existing buildings with gas heating systems that are to be converted have generally been connected to district heating in recent years. Oil heating systems, on the other hand, were more frequently converted to diverse other energy sources such as electricity, district heating and natural gas. Based on the premise that all fossil fuel-based heating systems must be converted by 2045, it can be assumed that biomass will be considered as an alternative energy source primarily for current heating systems using heating oil. Given the age of the systems as in the BDEW study (2019) and a maximum lifetime of 25 years, the replacement and renewal rates for fuel oil- and biomass-fired heating systems can be summarised in Table 2.

Table 2: Expected replacement and renewal rates for fuel oil- and biomass-fired heating systems, based on BDEW (2019)

	Oil heating replacement/renewal rate	**Biomass heating replacement/renewal rate**
Until 2025	34.4%	24.0%
2025-2030	15.6%	12.0%
2030-2035	13.5%	13.3%
2035-2040	10.2%	15.0%
After 2040	*26.3%*	*35.8%*

Furthermore, it can be assumed that the new systems installed as replacements by 2025 and 2030, respectively, will have reached the end of their technical lifetime after 20 years. Against this background, they will be included in the market potential starting in 2045 and 2050, respectively. The 20-year timeframe is consistent with the technical lifetime used in the Final Assessment when comparing the innovative Micro-Bio-CHP technology with state-of-the-art systems.

2.3 Sales and stock modelling for application case A1

2.3.1 Three differently ambitious scenarios for the fossil heating phase out

Starting from the described assumptions, three differently ambitious scenarios are formulated for the potential development of the biomass heating market:

1) The total installed stock of biomass heating systems will double by 2045 relative to today's level.
2) Of the existing fuel oil heating systems, 50% will be exchanged for biomass-based ones until 2045.
3) Of the existing fuel oil heating systems, 90% will be exchanged for biomass-based ones until 2045.

2.3.2 Modelling of technology innovation diffusion for application case A1

Before the sales figures and, based on them, the stock development can be modelled, a suitable assumption must be made for the diffusion of the new technology. Given a logistic growth and an initial share in 2030 of 5% of Micro-Bio-CHP systems in all new biomass heating systems, an increase of this rate to 25% in 2040 and a maximum threshold value of 75%, the curve shown in Figure 1 results for the assumed share of the new technology. Compared to the preliminary assessment, a later market entry with a faster increase of the share is assumed. This is based on an assumed greater market readiness at the time of market entry, which is likely to be driven by increased pressure to act in light of the goal of achieving climate neutrality by 2045. According to the described development, in 2045, 43 per cent of the systems for this market segment would be a Micro-Bio-CHP system.

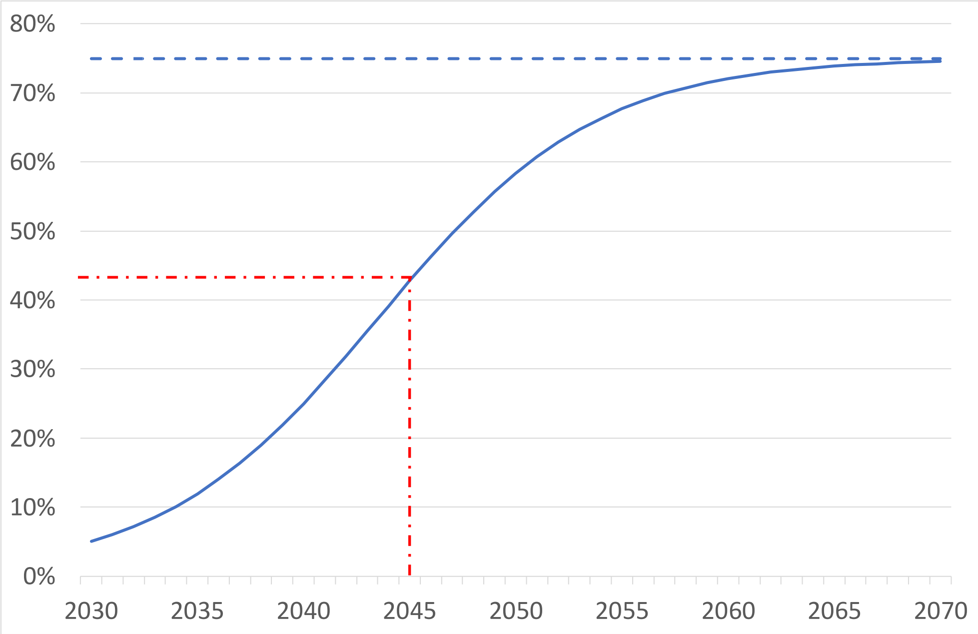

Figure 1: Assumed share of Micro-Bio-CHP systems in sales

2.3.3 Sales modelling for application case A1

Now, the sales development in Germany and Austria can be modelled for the three scenarios mentioned above (see Figure 2). The different starting conditions in the two countries are clearly reflected, as the share of biomass-fired heating systems in the initial year is already twice as high in Austria as in Germany. This leads to scenario 1 being the most ambitious one in Austria and the least ambitious one in Germany at the same time.

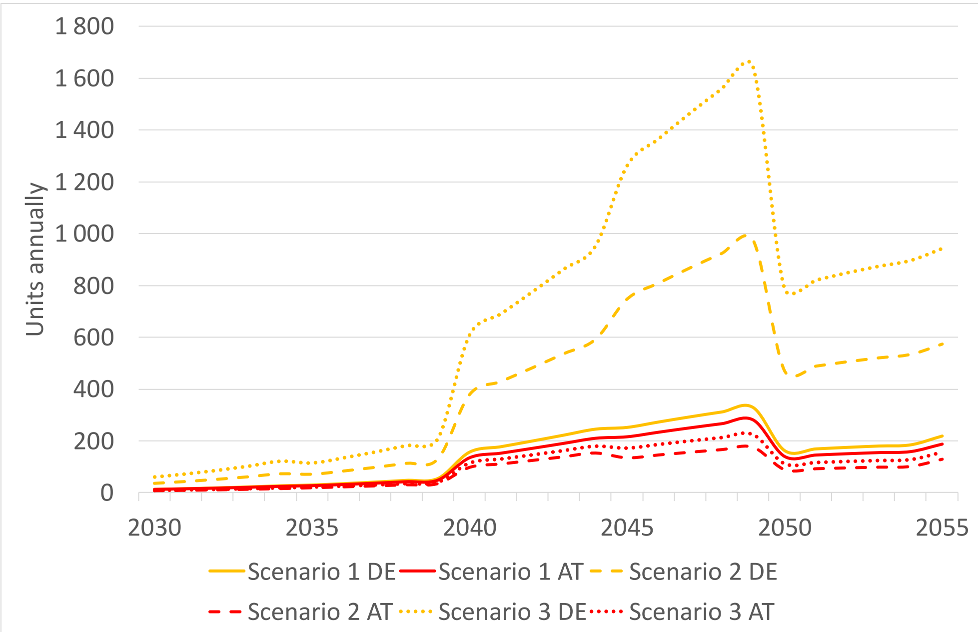

Figure 2: Modelled sales development in Germany and Austria for the three different scenarios

The pronounced increase in the sales trajectories shown in Figure 2 reflects the high replacement rates required after 2040 to meet current climate policy targets. In the model, fossil-fuelled heating systems are assumed to be phased out by 2045. Sales dynamics beyond that point are still shaped by earlier replacement cycles, since systems installed during periods of high replacement activity will themselves require renewal after approximately 20 years, as shown in Table 2. Conversely, the comparatively low replacement rates between 2025 and 2030 are expected to translate into a temporary decline in sales around 20 years later. If low replacement rates persist into the 2030s without adequate policy intervention, bottlenecks in both sales and stock may emerge, as illustrated in Figure 2, most prominently in the German scenarios. Policy measures are therefore needed in both countries to smooth the demand curve and support a timely transition to a climate-neutral heat supply.

2.3.4 Stock modelling for application case A1

Starting from the modelled sales development and taking into account a typical lifetime of 20 years for the Micro-Bio-CHP system, the stock can be modelled for the selected scenario 2 (see Figure 3).

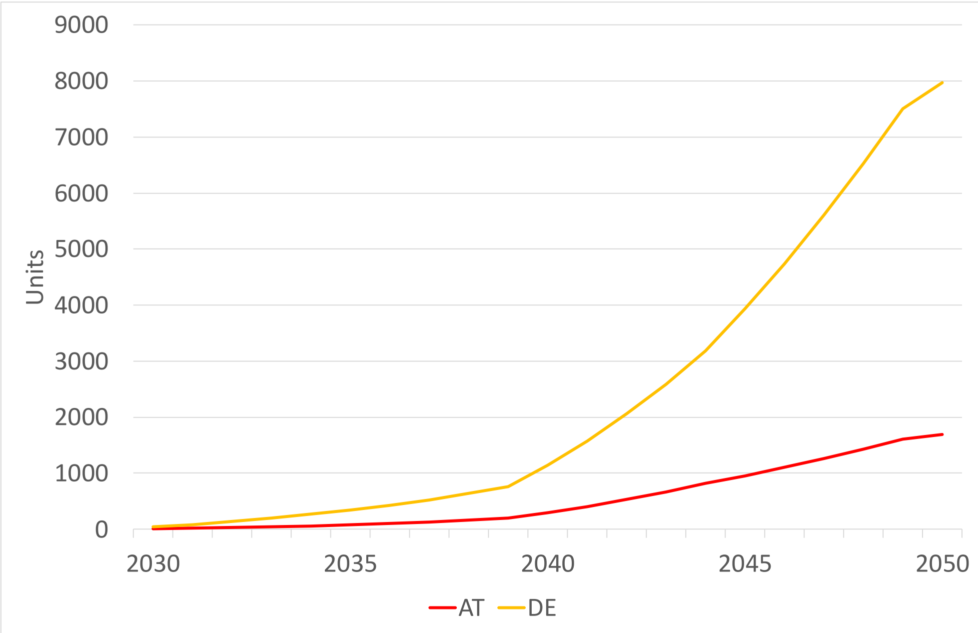

Figure 3: Stock development of Micro-Bio-CHP systems in Germany and Austria in scenario 2 (50% of oil heating systems converted to biomass)

By 2050, the stock reaches 1,690 units in Austria and almost 8,000 units in Germany. This implies that the stock is expected to more than double between 2045 and 2050 in Germany, while the increase in Austria during that period will exceed 75 percent.

3 Technology alternatives

3.1 Technical specifications

To investigate the impact of the described roll-out of the Micro-Bio-CHP technology on air pollutant emissions in Germany and Austria, the new system is compared with three alternative systems, which are traditionally used in the same power range. The technical details of the alternative systems provided by project partner BIOS from the techno-economic analysis are summarized in Table 3, while a more detailed version can be found in Table 5 in the ANNEX.

Table 3: Technical specifications of the heating (and power) systems compared (summary; see Table 5 in ANNEX for complete data)

Technology		**Micro-Bio-CHP**	**Biomass_ boiler**	**Biomass_ CHP**	**NAT_GAS_ SOFC**
Fuel		Wood pellets	Wood pellets	Wood pellets	Natural gas
Nominal heating capacity (at the beginning of operation without degradation)	[kW]	18.0	18.0	18.0	18.0
Gross electric capacity (at the beginning of operation without degradation)	[kW]	2.5	-	0.6	0.7
Nominal power photovoltaic system	[kW_p]	39.3	39.3	39.3	39.3
Operating hours system	[h/year]	5,952	5,952	5,952	5,952
Full load operating hours CHP/boiler	[h/year]	2,810	2,864	2,864	2,845
Full load operating hours electricity production SOFC/CHP	[h/year]	3,813	-	2,864	5,952
Heat demand (space heating + DHW)	[kWh/year]	51,007	51,007	51,007	51,007
Electricity net production CHP	[kWh/year]	7,085	-	1,583	2,565
Auxiliary electricity consumption	[kWh/year]	1,021.1	134.6	136.1	0.7
Electricity demand	[kWh/year]	52,374	52,374	52,374	52,374
Electricity consumption SOFC electricity	[kWh/year]	7,084.6	-	1,582.5	2,565.3
Electricity consumption PV electricity	[kWh/year]	40,089.2	40,089.2	40,089.2	40,089.2
Electricity consumption grid electricity	[kWh/year]	5,375.2	12,419.4	10,702.3	9,719.5
Total energy production (heat and electricity)	[kWh/year]	99,844.4	91,646.4	93,365.0	95,098.6
Annual thermal efficiency	[%]	77.1%	94.3%	98.0%	86.2%
Annual gross electrical efficiency	[%]	12.3%	-	3.3%	5.8%
Annual net electrical efficiency	[%]	10.6%	-	3.0%	4.3%
Total annual efficiency	[%]	87.7%	94.3%	101.0%	90.5%
Fuel demand	[kWh/year]	66,900	59,793	52,595	54,674

Note: The total annual efficiency slightly exceeding 100% reflects potential rounding and the fact that fuel input is referenced to the net calorific value (NCV). If part of the latent heat of water vapour in the flue gas is recovered, useful energy output can exceed the NCV-based input – analogous to condensing boiler technology. This does not imply a violation of thermodynamic principles.

3.1.1 Total annual efficiencies

Based on the input data from techno-economic analysis, the Micro-Bio-CHP system generates more power and less heat than the alternatives and has a comparatively high fuel demand as well as, resulting from this, a relatively lower total annual efficiency as also illustrated in Figure 4. However, it shall be noted that also the electricity net production of the analysed systems differs sharply. Because grid electricity consumption and fuel demand are not directly comparable, the underlying assumptions strongly influence the resulting key figures.

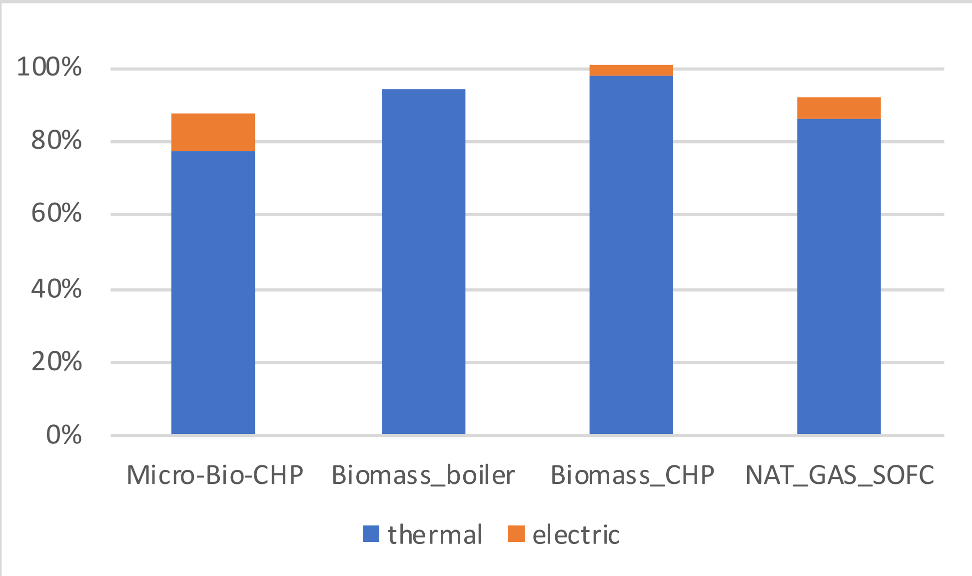

Figure 4: Total annual efficiencies of the compared systems

3.1.2 Specific emissions

The specific emissions, related to **fuel (energy) input** (as typically reported for biomass and other heating systems), can be seen in Figure 5. The specific emissions shown include the emissions associated with grid electricity consumption of the respective system.

In direct comparison with the analysed three alternative technologies, the Micro-Bio-CHP technology causes very low emissions in all categories for a biomass-based system and can even compete with the natural gas fuel cell. In this respect, the new Micro-Bio-CHP technology represents a large improvement and a clear step forward, especially compared to current biomass technologies.

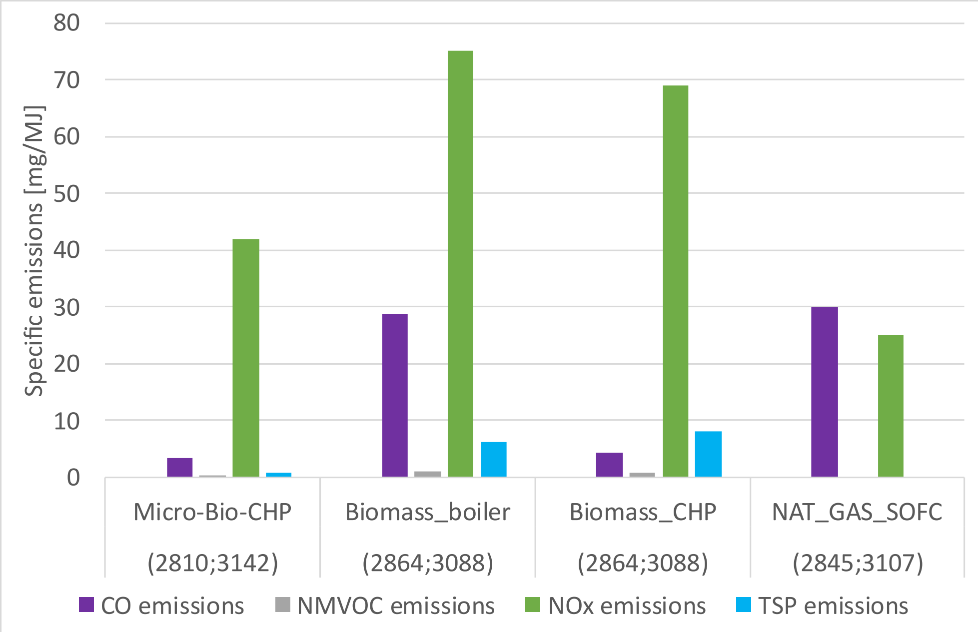

Figure 5: Specific emissions of the compared systems, related to fuel input (full-load and partial-load hours are given in brackets)

3.1.3 Influence of grid electricity displacement

The air pollutant emission effects associated with grid electricity displacement differ across pollutants and across national electricity mixes. In general, the emission factors of grid electricity are expected to decline over time as the share of renewable electricity generation increases. This development is illustrated in Figures 6 to 9, which show the modelled evolution of CO, NMVOC, NO_x and TSP emission factors for grid electricity in Germany, Austria and the EU average, together with the corresponding modelled values for the Micro-Bio-CHP system.

For grid electricity, the emission factors are expressed in g/kWh. For the Micro-Bio-CHP system, the values shown in Figures 6 to 9 are also reported in g/kWh, consistent with the current model output. However, these values are not explicitly normalised to electrical output and should therefore not be interpreted as electricity-specific emission factors in g/kWh_{el}. It should also be noted that the Micro-Bio-CHP system simultaneously provides useful heat, which is not separately represented in these values.

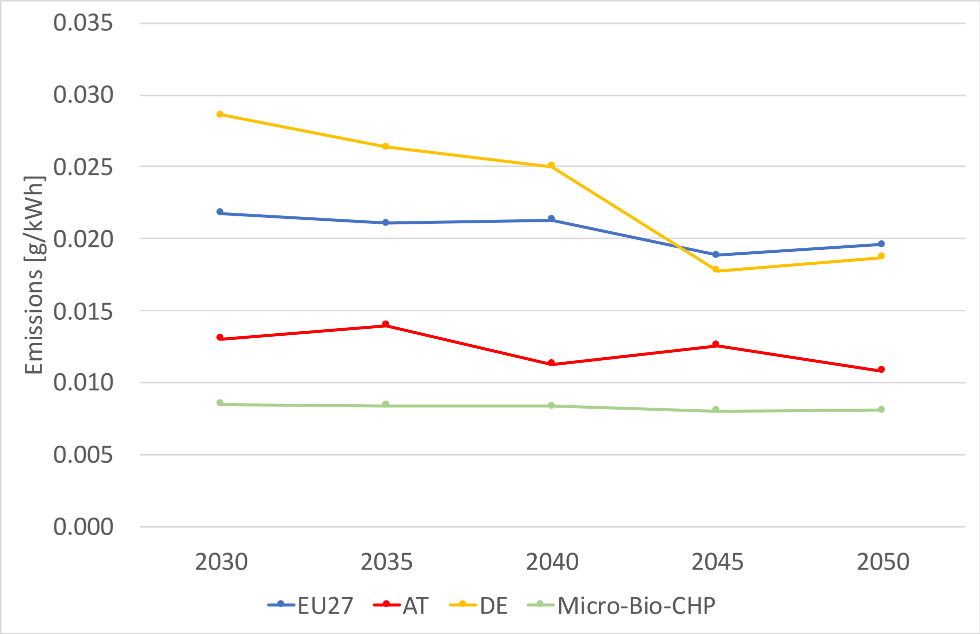

Figure 6: CO emission factors for grid electricity and Micro-Bio-CHP over time (g/kWh, total system basis); own estimates based on PRIMES REF2020 (E3Modelling, 2021) and EMEP/EEA (2023).

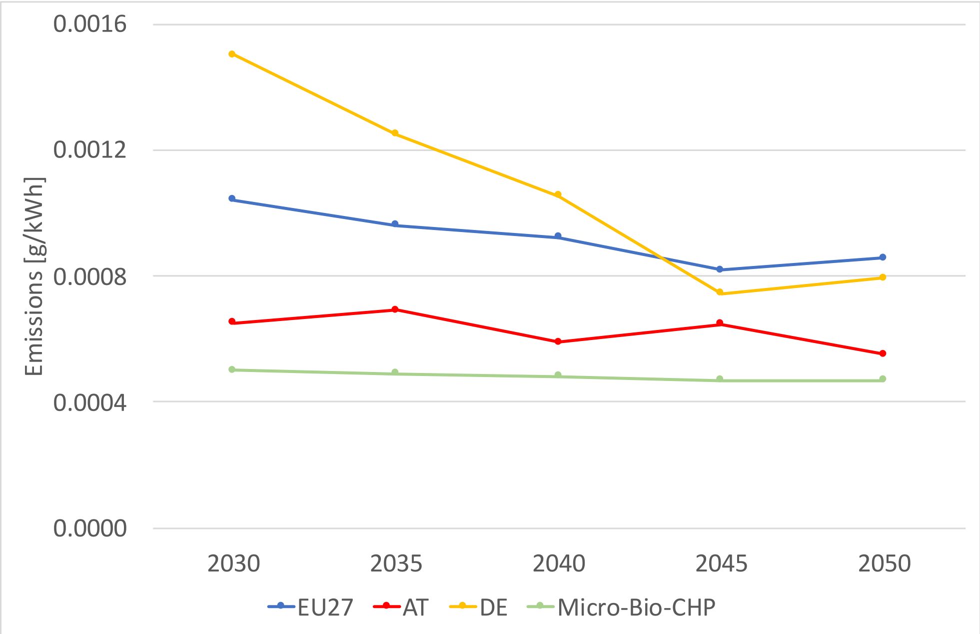

Figure 7: NMVOC emission factors for grid electricity and Micro-Bio-CHP over time (g/kWh, total system basis); own estimates based on PRIMES REF2020 (E3Modelling, 2021) and EMEP/EEA (2023).

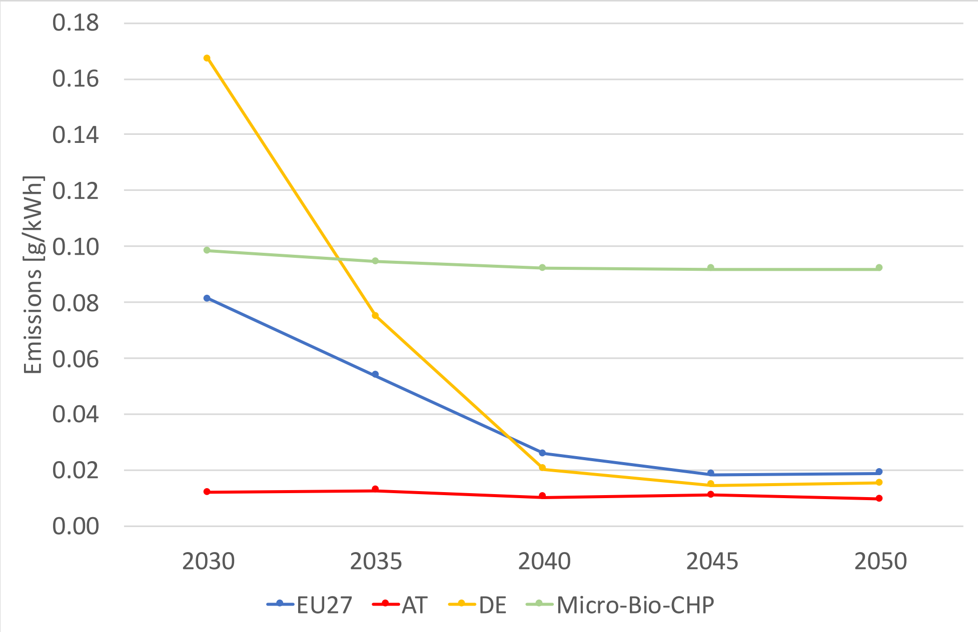

Figure 8: NO_x emission factors for grid electricity and Micro-Bio-CHP over time (g/kWh, total system basis); own estimates based on PRIMES REF2020 (E3Modelling, 2021) and EMEP/EEA (2023).

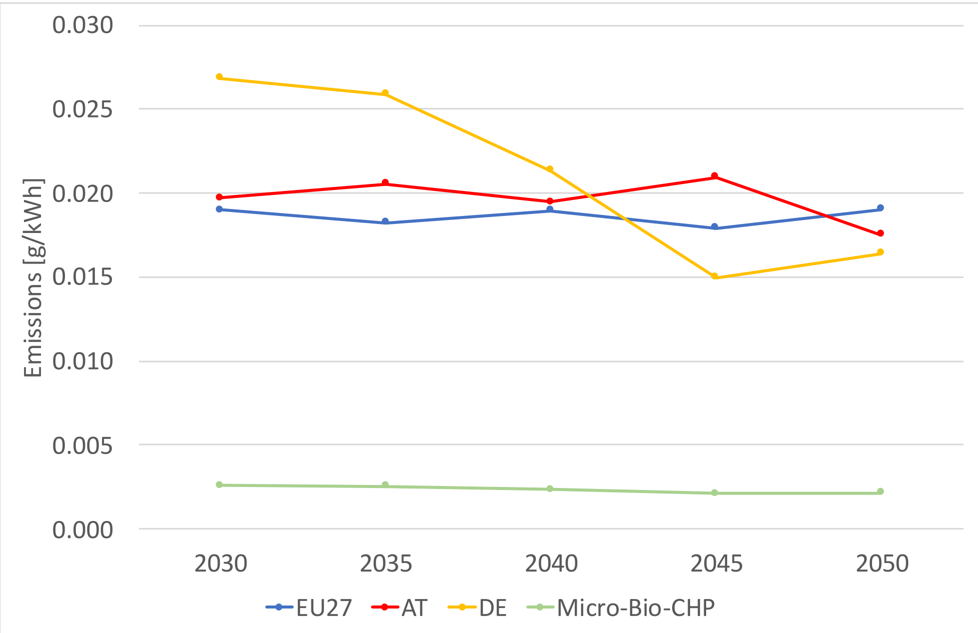

Figure 9: TSP emission factors for grid electricity and Micro-Bio-CHP over time (g/kWh, total system basis); own estimates based on PRIMES REF2020 (E3Modelling, 2021) and EMEP/EEA (2023).

Note that the EMEP/EEA air pollutant emission inventory guidebook (2023) is primarily intended for emission inventory compilation rather than for modelling future technological progress or tightening emission standards. In the present assessment, the guidebook-based emission factors for the individual energy carriers are therefore kept constant over time. As a result, potential future reductions in air pollutant emissions due to technological improvements or stricter standards are not

explicitly captured. This applies both to grid electricity and to the Micro-Bio-CHP system. Changes in the emission factors of grid electricity therefore result solely from changes in the assumed electricity mix.
The electricity mix assumptions used here are based on PRIMES REF2020 and therefore reflect the scenario framework applied in this assessment. More recent policy and market developments could lead to a faster decline in fossil-based electricity generation than shown in this trajectory.
Within this modelling framework, Germany's grid electricity emission factors remain comparatively high up to 2045, reflecting the continued role of fossil-based generation assumed in the scenario. By contrast, Austrian emission factors are already relatively low, consistent with Austria's high share of renewable electricity generation, mainly hydropower. An exception is TSP, where comparatively high values may partly reflect the assumed stock composition, in particular a relatively large share of older biomass-based energy systems. For the EU average, it should also be noted that nuclear energy accounts for a larger share of electricity generation than in the German and Austrian national contexts.

3.2 Total air pollutant emissions

The total annual emissions presented in this section are calculated by combining the modelled stock development (Section 2.3.4) with the system-specific operating parameters and emission factors described in Section 3.1. For each year, the modelled stock is combined with the annual energy demand, operating profiles and the respective emission factors to derive total annual emissions for each technology option and pollutant.
Combining the stock model from Figure 3, the operation parameters from Table 3 and the specific emissions for the technology alternatives from Figure 5, the total annual emissions for the stock volume can be calculated for application case A1. Figure 10 to Figure 13 show the respective emissions with focus on the application case A1 and scenario 2 in Germany. The emissions for this setup in Austria are illustrated in Figure 24 to Figure 27 in the ANNEX. The general trends for Austria are identical to Germany, while the stock is smaller and, consequently, so are the absolute emission values.

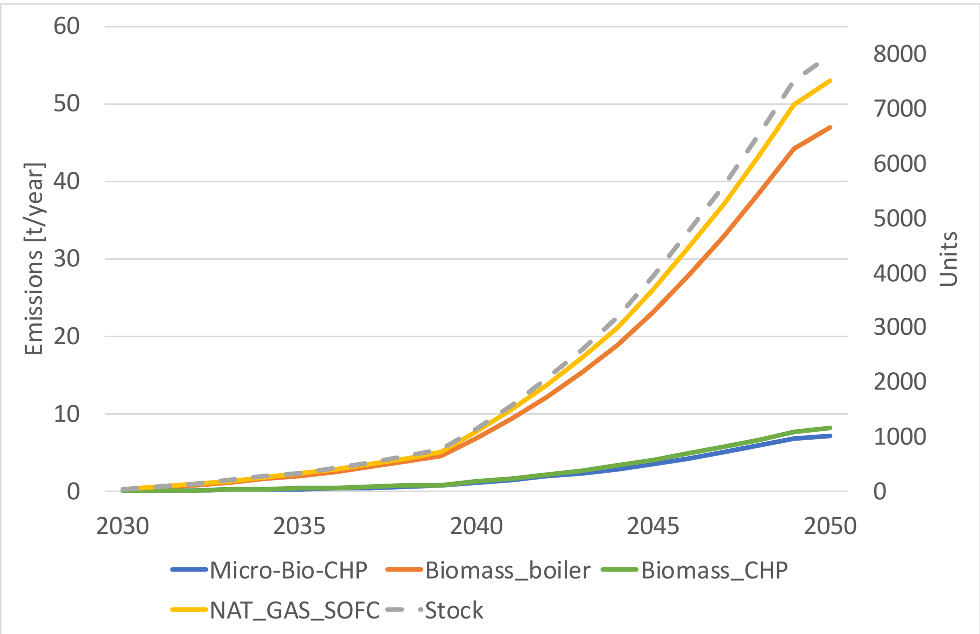

Figure 10: Total annual CO emissions and stock volume for application case A1 and scenario 2 in Germany

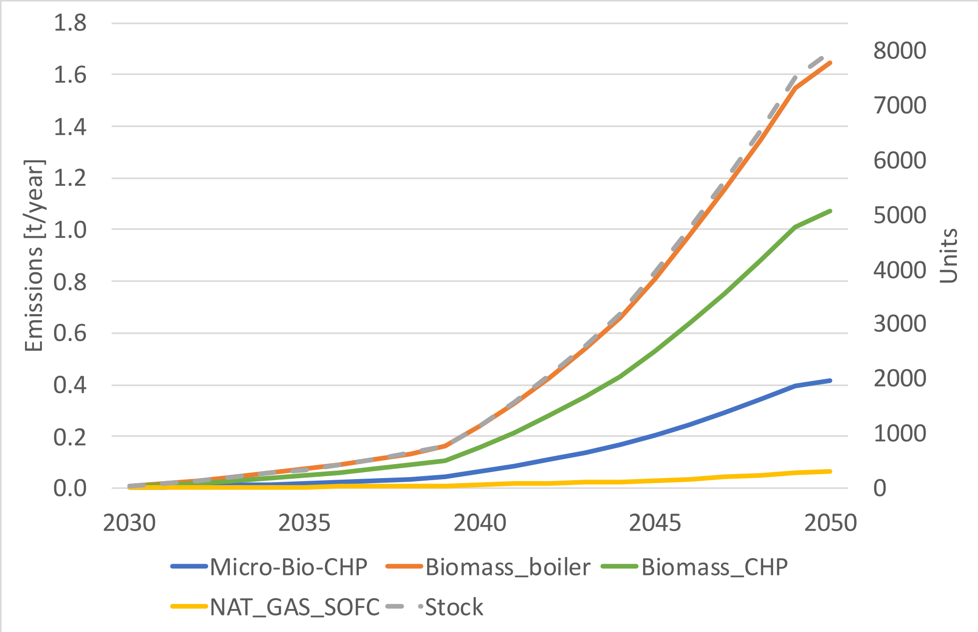

Figure 11: Total annual NMVOC emissions and stock volume for application case A1 and scenario 2 in Germany

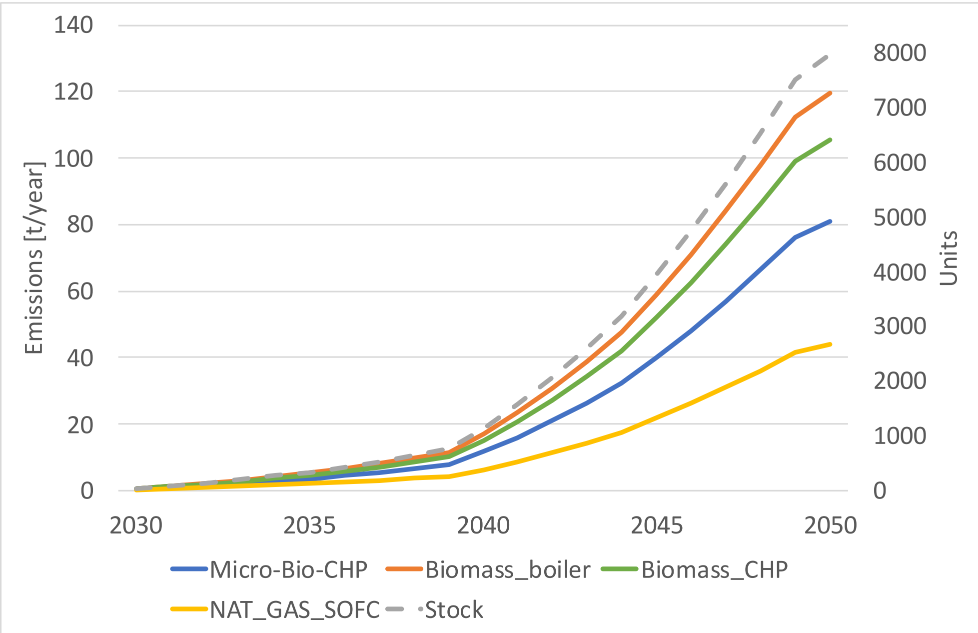

Figure 12: Total annual NO_x emissions and stock volume for application case A1 and scenario 2 in Germany

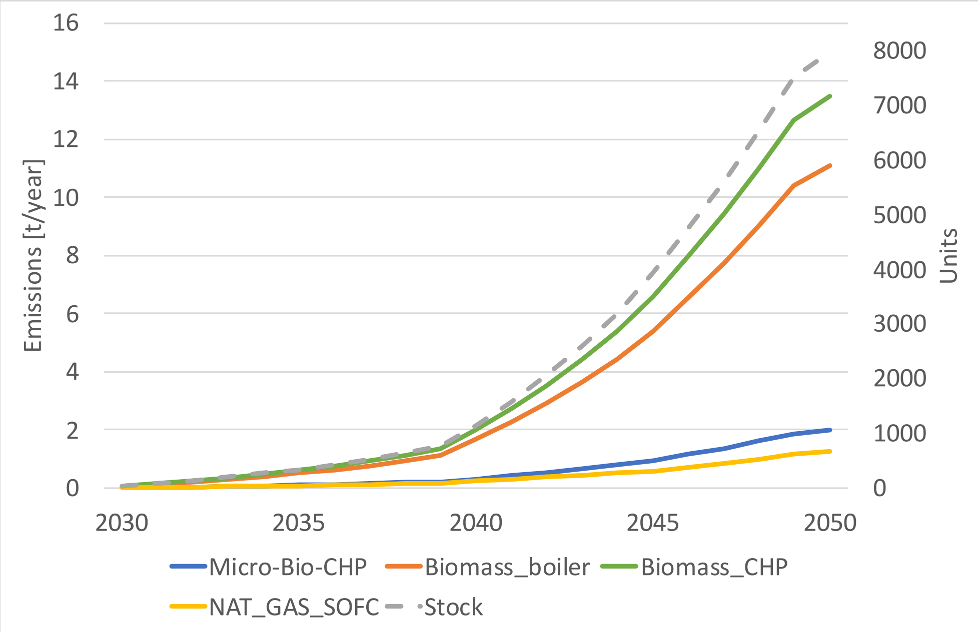

Figure 13: Total annual TSP emissions and stock volume for application case A1 and scenario 2 in Germany

While the respective emissions differ between the systems fuelled by biomass, the total GHG emissions of all technologies running on wood pellets are quite similar, as depicted in Figure 14. The fossil natural gas-fired SOFC causes significantly higher GHG emissions in comparison.

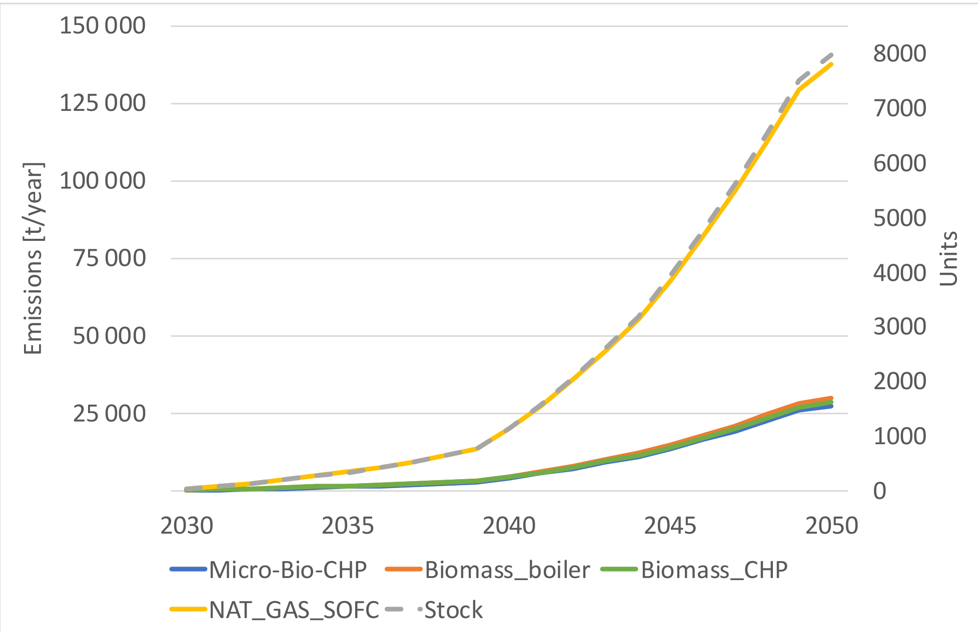

Figure 14: Total annual GHG emissions and stock volume for application case A1 and scenario 2 in Germany

Based on the modelling assumptions described in Section 3.1.3, and taking into account the avoided emissions associated with grid electricity displacement, Micro-Bio-CHP and the natural gas SOFC achieve net negative TSP emissions as shown in Figure 15, the magnitude of which increases with the stock.

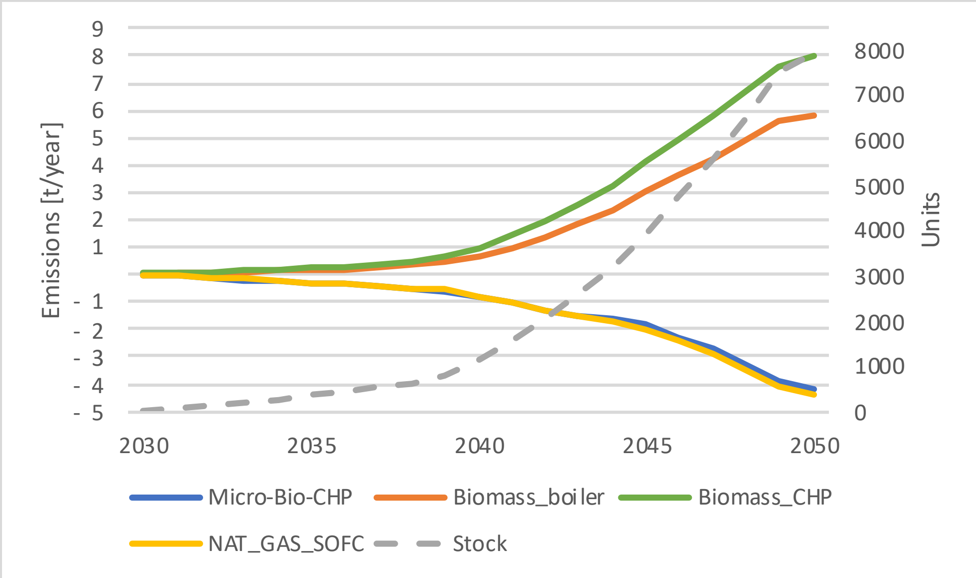

Figure 15: Net annual TSP emissions and stock volume for application case A1 and scenario 2 in Germany

Likewise, but as the only one of the four technology options analysed, the Micro-Bio-CHP system achieves net negative GHG emissions by the displacement of grid electricity as shown in Figure 16. This result is based on the convention that biogenic CO_2 from sustainably sourced wood pellets is treated as climate-neutral, consistent with EU inventory accounting rules. The net negative balance reflects avoided fossil CO_2 from displaced grid electricity exceeding the system's remaining non-CO_2 GHG emissions.

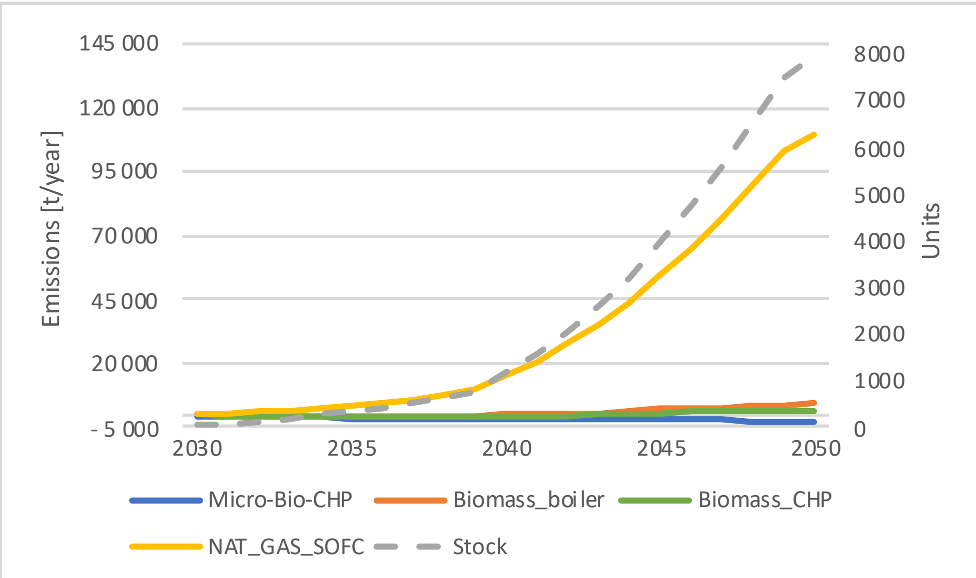

Figure 16: Net annual GHG emissions and stock volume for application case A1 and scenario 2 in Germany

3.3 Total expenditures

This section presents the total expenditures associated with each technology option. This includes investment and installation costs, maintenance costs as well as operating costs, which include fuel costs, costs from grid electricity consumption, and other consumables. If a component (e.g., a SOFC stack) of the whole system has to be replaced before the lifetime of the heat generation unit is up, these costs are included in the investment costs of the respective year. Based on the project partners' inputs, the values shown in Table 4 are assumed as investment costs, installation costs and maintenance costs of the four technology options. In this case, only machinery-related costs are included under investment costs. The maintenance costs encompass operating costs other than fuel or grid electricity costs (including other consumables). It is assumed that future general increases in prices of goods and services (i.e., the inflation rate) will equal future cost reductions due to, for example, economies of scale, so that the costs shown in Table 4 will be constant in real terms.

Table 4: Investment, installation and maintenance costs of the systems compared

Technology		**Micro-Bio-CHP**	**Biomass_boiler**	**Biomass_CHP**	**NAT_GAS_SOFC**
Fuel		Wood pellets	Wood pellets	Wood pellets	Natural gas
Investment costs (incl. Building and Engineering)	[€/lifetime]	140,400	121,700	143,100	129,500
Maintenance costs	[€/year]	1,600	1,170	1,400	750

The assumptions for future natural gas and grid electricity price development are based on a five-year mean of Eurostat prices for household consumers[2]. Current prices for wood pellets are based on data by C.A.R.M.E.N. e.V. in the case of Germany and input by BIOS in the case of Austria. The assumptions on future increases in real prices are based on Öko-Institut et al., (2022) in the case of Germany as well as Anderl et al. (2021) and Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (2023) in the case of Austria. The price for natural gas includes a rising CO_2-price based on assumptions in the studies named before. Figure 17 shows the assumed development of the prices of energy carriers in Germany in $€_{2025}$. The price of grid electricity first decreases in real terms up to 2040, then increases again close to the initial level. For natural gas, a substantial rise of real prices is assumed, not least due to increasing CO_2-prices. The price for wood pellets, too, increases in real terms, but more slowly.

[2] Data code nrg_pc_202 and band D2 in the case of natural gas, and data code nrg_pc_204 and band DD in the case of grid electricity. The electricity band reflects the annual grid electricity consumption at building level after accounting for on-site electricity generation from CHP and PV.

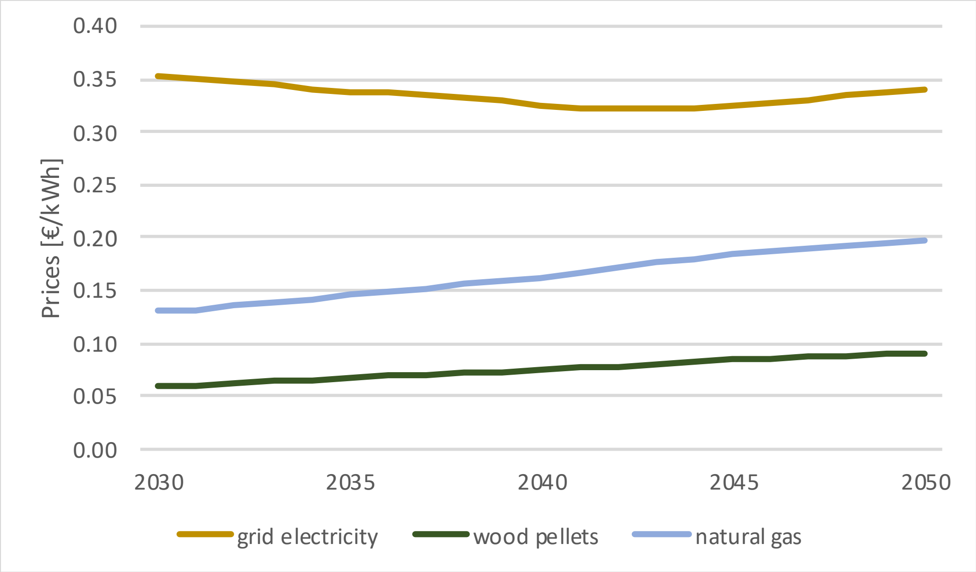

Figure 17: Assumed development of prices of energy carriers in Germany

Figure 18 depicts the yearly investment costs based on the number of sales in scenario 2. The two micro-CHP technologies lead to higher investment costs than the other technology options with the biomass boiler-based system having the lowest annual investment costs. Investment costs in 2049, the year with the highest number of sales, are about 136 million €$_{2025}$ for the Micro-Bio-CHP technology and about 117 million €$_{2025}$ for the biomass boiler technology option.

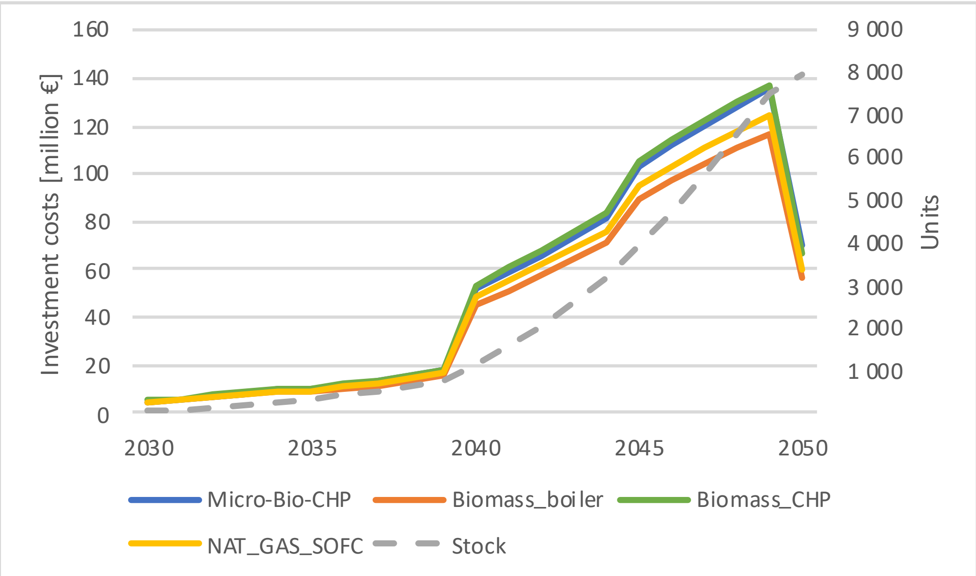

Figure 18: Total annual investment costs (including installation costs) and stock volume for application case A1 and scenario 2 in Germany

When looking at maintenance costs, one finds a similar picture (Figure 19). With almost 13 million €$_{2025}$, the Micro-Bio-CHP technology option yields the highest maintenance costs in 2050, the year with the largest stock. This is more than twice the annual maintenance costs for the natural gas SOFC technology option, which amount to less than 6 million €$_{2025}$.

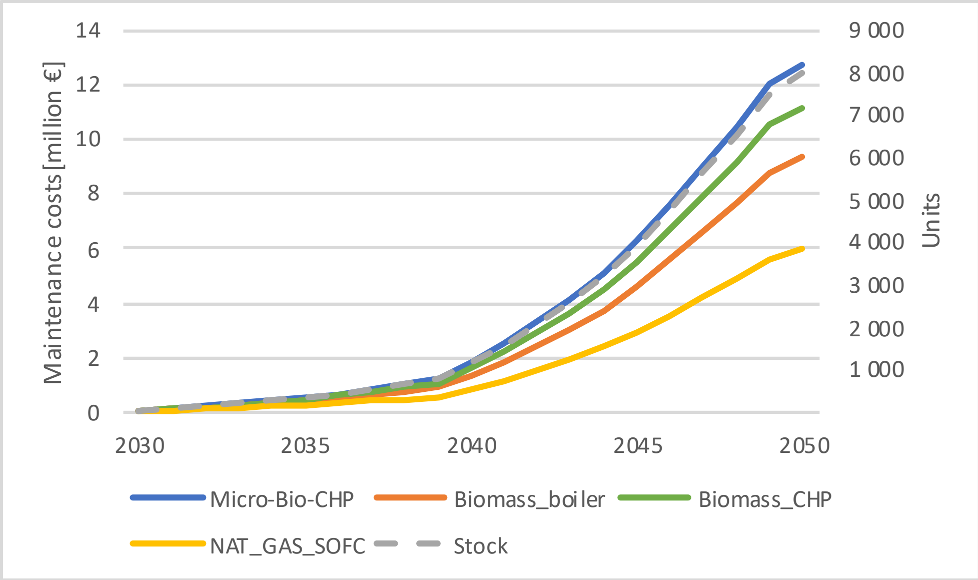

Figure 19: Total annual maintenance costs and stock volume for application case A1 and scenario 2 in Germany

This picture is reversed when looking at operating costs including costs for fuel and grid electricity (Figure 20). The operating costs of the natural gas SOFC technology option, with about 121 million €$_{2025}$, are higher than 1.7 times the average operating costs of the biomass-fuelled technology options. This is mainly due to the disproportionate increase in natural gas prices. With about 71 million €$_{2025}$ in 2050, the Micro-Bio-CHP technology option has second-lowest operating costs. It is second to the Biomass-CHP technology, which has operating costs of 68 million €$_{2025}$ in 2050.

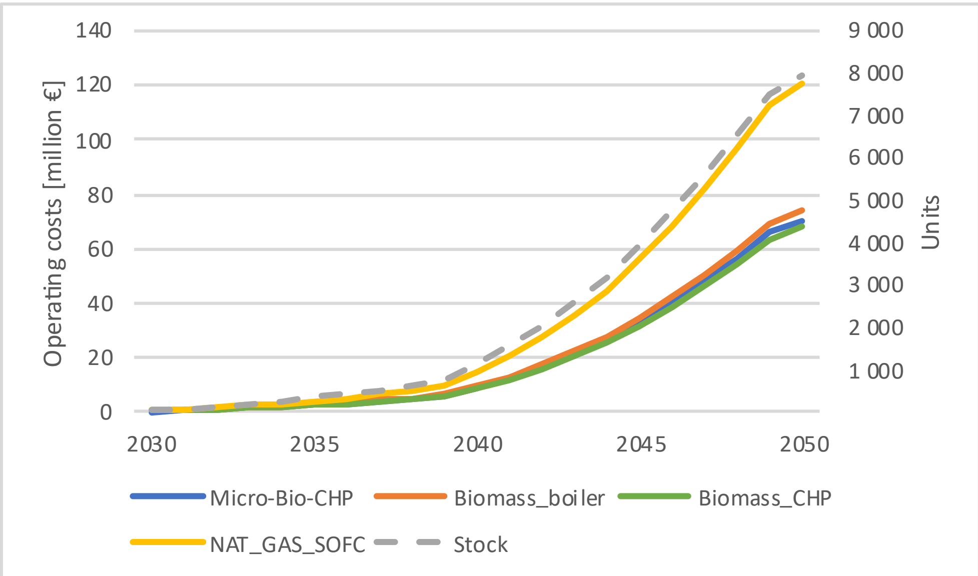

Figure 20: Total annual operating costs and stock volume for application case A1 and scenario 2 in Germany

Figure 21 and Figure 22 show the total annual fuel and grid electricity costs for the four technology options, respectively.

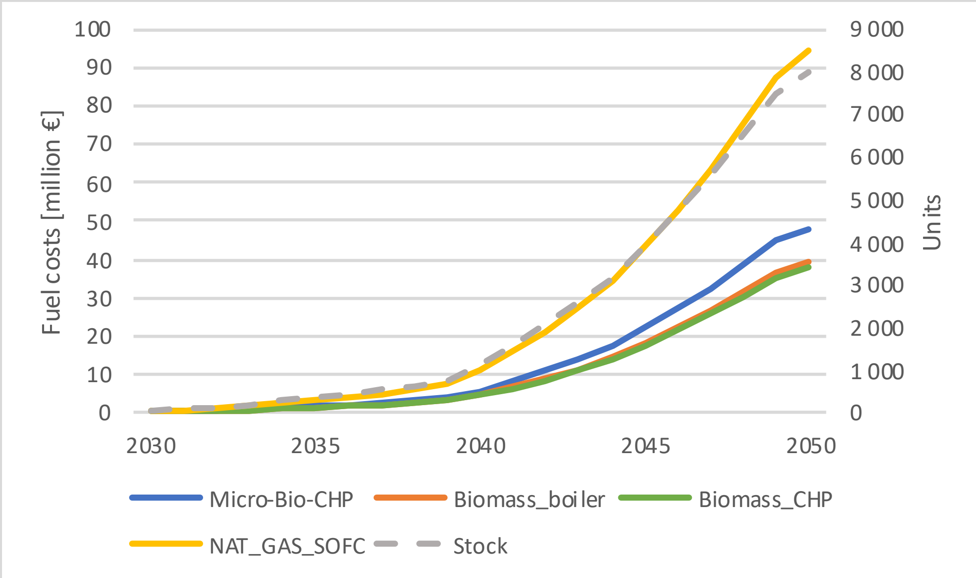

Figure 21: Total annual fuel costs and stock volume for application case A1 and scenario 2 in Germany

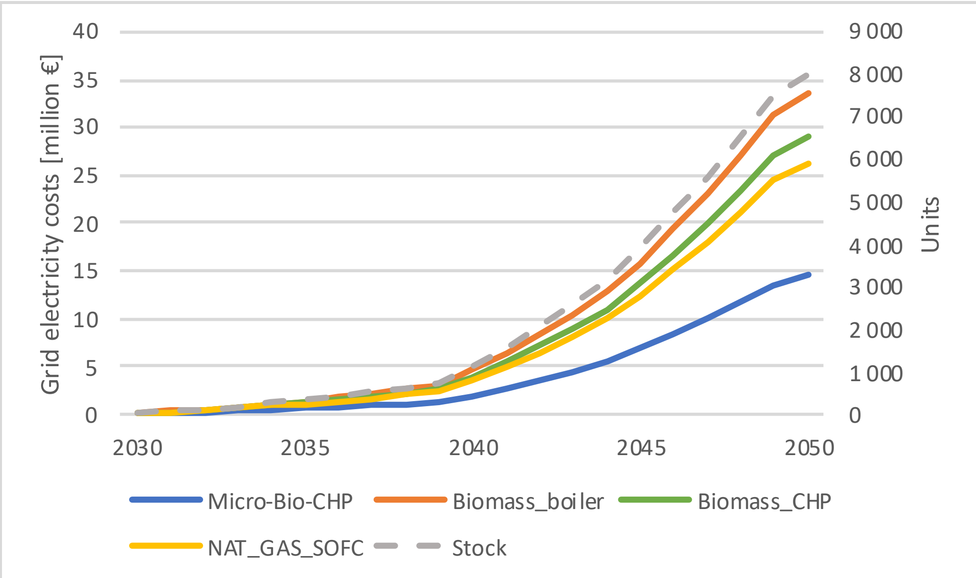

Figure 22: Total annual grid electricity costs and stock volume for application case A1 and scenario 2 in Germany

Taking all costs together leads to the picture shown in Figure 23. The natural gas-fired SOFC is the technology option with the highest annual total costs, while the biomass micro-CHP technologies are close together in between the SOFC and the biomass boiler. Compared to the latter, total costs for the Micro-Bio-CHP technology are 9% higher in 2050. This suggests that even small increases in efficiency and reductions in capital costs could make the Micro-Bio-CHP technology option cost-competitive with state-of-the-art biomass boilers. The importance of adequate, i.e. sufficiently high, CO_2 pricing for promoting climate-friendly technology options is also evident from these results.

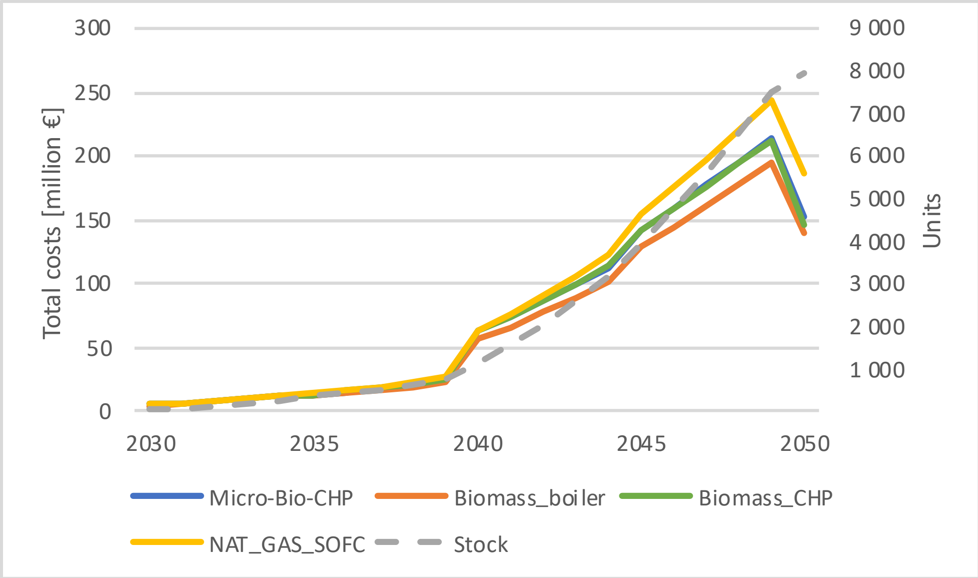

Figure 23: Annual total costs and stock volume for application case A1 and scenario 2 in Germany

4 Conclusions for the final assessment

In both Germany and Austria, addressing the overall energy transition from fossil-based heating systems before 2040 hinges clearly on political incentives. As can be seen in the presented results for sales and stock developments, one primary political aim should be to prevent potential bottlenecks in supply and installer capacities, as a massive stock of old existing systems with low performance has to be replaced by renewable energy-based systems in order to achieve the politically defined climate protection targets. However, an evaluation of the specific impacts of the alternative heating and CHP systems also highlights important differences between the technologies, particularly because the Micro-Bio-CHP system generates more electricity than its counterparts due to its autonomy-oriented design. This is because true energy autonomy requires a year-round balance between supply and demand, taking into account also storage.

Following the completion of the technical system design and the techno-economic analyses (Task 8.2), final economic and system performance data (such as emission factors for PM, CO, OGC and NO_x or efficiencies) of the new technology have become available after the last phase of the project. Based on the technical, energy efficiency, economic and environmental parameters, the most relevant parameters have been analysed within this final impact assessment and compared with the respective data from other state-of-the-art systems in order to evaluate and quantify the expected improvement potential of the new technology. Using an in-house stock model developed by WIKUE, the assessment compared different scenarios to quantify improvement potentials and derive recommendations for the further technology development and the EU policy framework. The assessment was carried out by WIKUE with data inputs from BIOS and the other project partners.

This report presents the results of the final impact assessment, based on, inter alia, input data from the techno-economic analysis and extensive further research, including a final assessment of the market potential for the new Micro-Bio-CHP technology. Based on these results, Micro-Bio-CHP represents a clear step forward for biomass technology especially in terms of significantly reduced particulate matter (dust) emissions. Besides PM, also the specific CO, OGC and NO_x emissions can be reduced by the Micro-Bio-CHP technology to a large extent. Due to the naturally higher nitrogen content of the fuel, all biomass-based systems still emit higher levels of NO_x compared to the SOFC using natural gas, so further research is needed to explore the full potential for reduction as far as possible with biomass fuels. However, even in this challenging context, Micro-Bio-CHP already outperforms other state-of-the-art biomass technologies and even rivals the natural gas-based system in many environmental aspects. In terms of total emissions, optimisation potential is mainly found and recommended in reducing fuel consumption by further increasing the overall efficiency of the Micro-Bio-CHP technology. Furthermore, reductions in capital costs can make the Micro-Bio-CHP technology option also cost-competitive with simpler state-of-the-art biomass boilers. Adequate, i.e. sufficiently high, CO_2 pricing would strengthen the cost advantage over the natural gas-based system.

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ANNEX

Table 5: Detailed technical data on the heating systems compared

Technology		**Micro-Bio-CHP**	**Biomass_ boiler**	**Biomass_ CHP**	**NAT_GAS _SOFC**
Fuel		Wood pellets	Wood pellets	Wood pellets	Natural gas
Nominal heating capacity (at the beginning of operation without degradation)	[kW]	18.0	18.0	18.0	18.0
Gross electric capacity (at the beginning of operation without degradation)	[kW]	2.5	-	0.6	0.7
Electricity consumption boiler at nominal load	[W]	92.0	47.0	47.5	49.0
Electricity consumption boiler at part load	[W]	73.0	-	-	-
Electricity consumption gas cleaning unit	[W]	-	-	-	-
Electricity consumption CHP	[W]	200.0	-	-	100.0
Nominal power photovoltaic system	[kW_p]	39.3	39.3	39.3	39.3
Operating hours CHP/boiler	[h/year]	5,952	5,952	5,952	5,952
Full load operating hours CHP/boiler	[h/year]	2,810	2,864	2,864	2,845
Operating hours electricity production SOFC/CHP	[h/year]	4,368	-	5,952	5,952
Full load operating hours electricity production SOFC/CHP	[h/year]	3,813	-	2,864	5,952
Operating hours electricity production PV	[h/year]	4,380	4,380	4,380	4,380
Full load operating hours electricity production PV	[h/year]	1,021	1,021	1,021	1,021
Heat demand (space heating + DHW)	[kWh/year]	51,007	51,007	51,007	51,007
Electricity gross production	[kWh/year]	8,198	-	1,719	3,452
Electricity net production	[kWh/year]	7,085	-	1,583	2,565
Share of auxiliary electricity consumption	[%]	14.4%	-	8.6%	28.6%
Auxiliary electricity consumption	[kWh/year]	1,021.1	134.6	136.1	0.7
Electricity demand multi-family house	[kWh/year]	23,201	23,201	23,201	23,201
Electricity demand e-mobility	[kWh/year]	24,759	24,759	24,759	24,759
Electricity demand	[kWh/year]	52,374	52,374	52,374	52,374
Electricity consumption SOFC electricity	[kWh/year]	7,084.6	-	1,582.5	2,565.3
Electricity consumption PV electricity	[kWh/year]	40,089.2	40,089.2	40,089.2	40,089.2
Electricity consumption grid electricity	[kWh/year]	5,375.2	12,419.4	10,702.3	9,719.5
Total energy production (heat and electricity)	[kWh/year]	99,844.4	91,646.4	93,365.0	95,098.6

Technology		**Micro-Bio-CHP**	**Biomass_ boiler**	**Biomass_ CHP**	**NAT_GAS _SOFC**
Fuel		Wood pellets	Wood pellets	Wood pellets	Natural gas
Annual thermal efficiency	[%]	77.1%	94.3%	98.0%	86.2%
Annual gross electrical efficiency	[%]	12.3%	-	3.3%	5.8%
Annual net electrical efficiency	[%]	10.6%	-	3.0%	4.3%
Total annual efficiency	[%]	87.7%	94.3%	101.0%	90.5%
Fuel power input at nominal load related to NCV (net calorific value)	[kW]	23.5	19.1	18.4	20.3
Fuel demand	[kWh/year]	66,900	59,793	52,595	54,674

Note: The total annual efficiency slightly exceeding 100% reflects potential rounding and the fact that fuel input is referenced to the net calorific value (NCV). If part of the latent heat of water vapour in the flue gas is recovered, useful energy output can exceed the NCV-based input – analogous to condensing boiler technology. This does not imply a violation of thermodynamic principles.

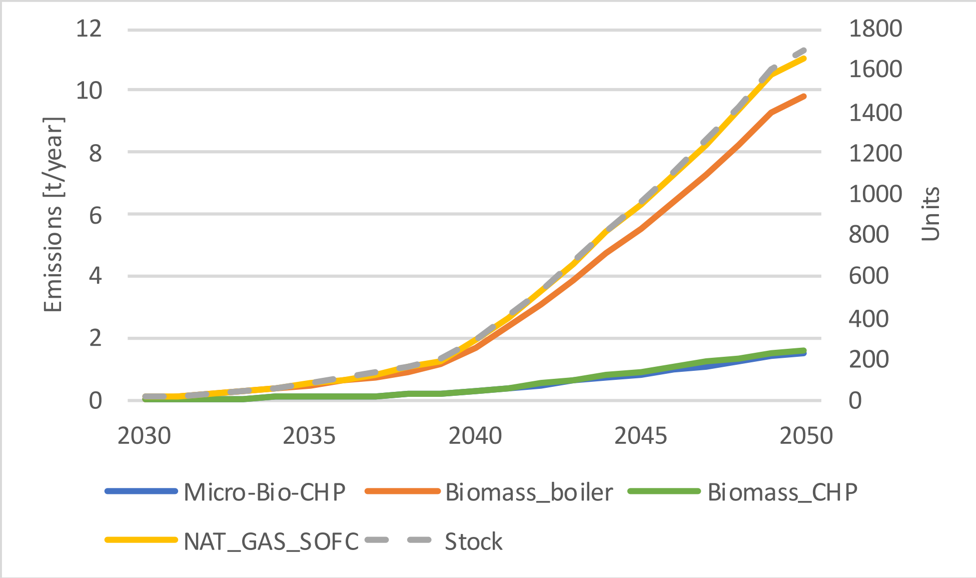

Figure 24: Total annual CO emissions and stock volume for application case A1 and scenario 2 in Austria

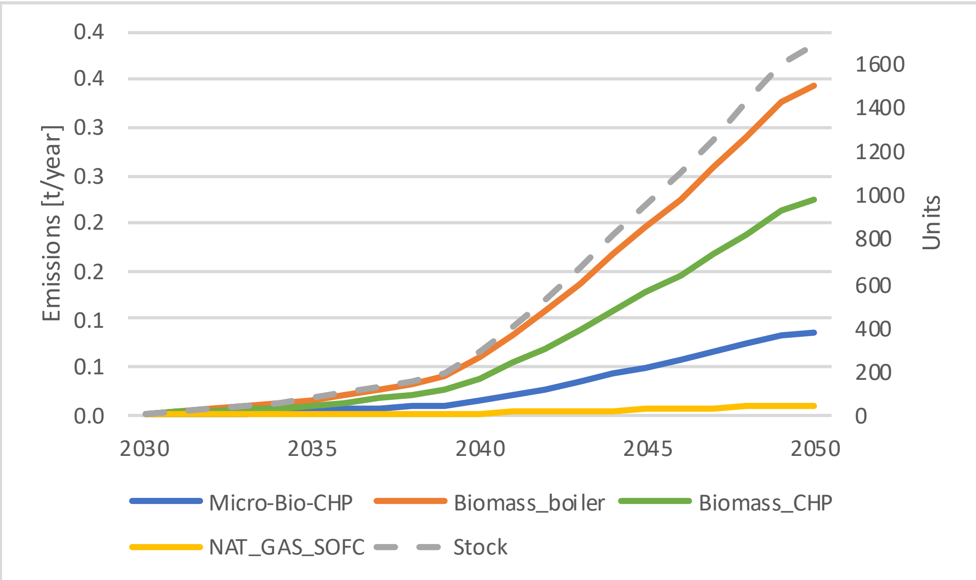

Figure 25: Total annual NMVOC emissions and stock volume for application case A1 and scenario 2 in Austria

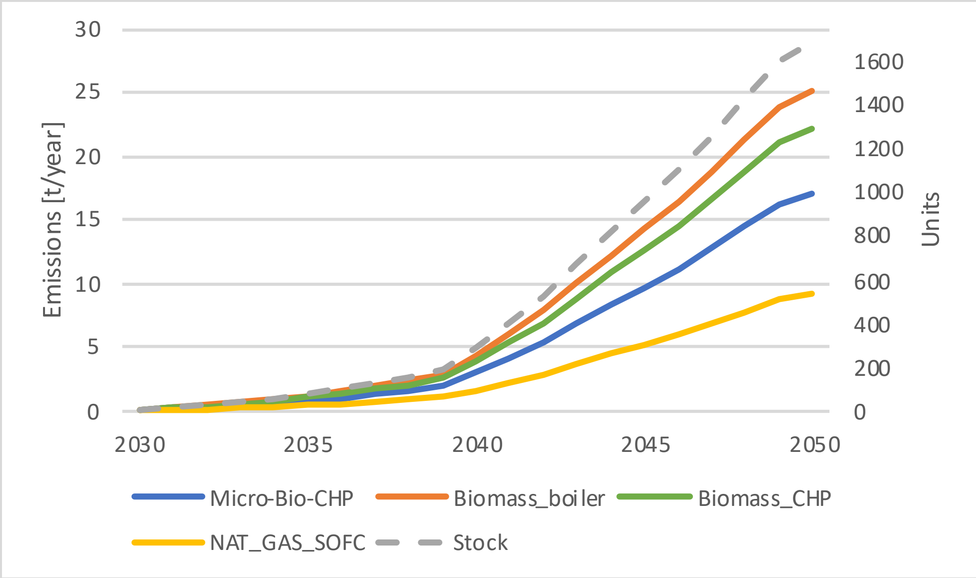

Figure 26: Total annual NO_x emissions and stock volume for application case A1 and scenario 2 in Austria

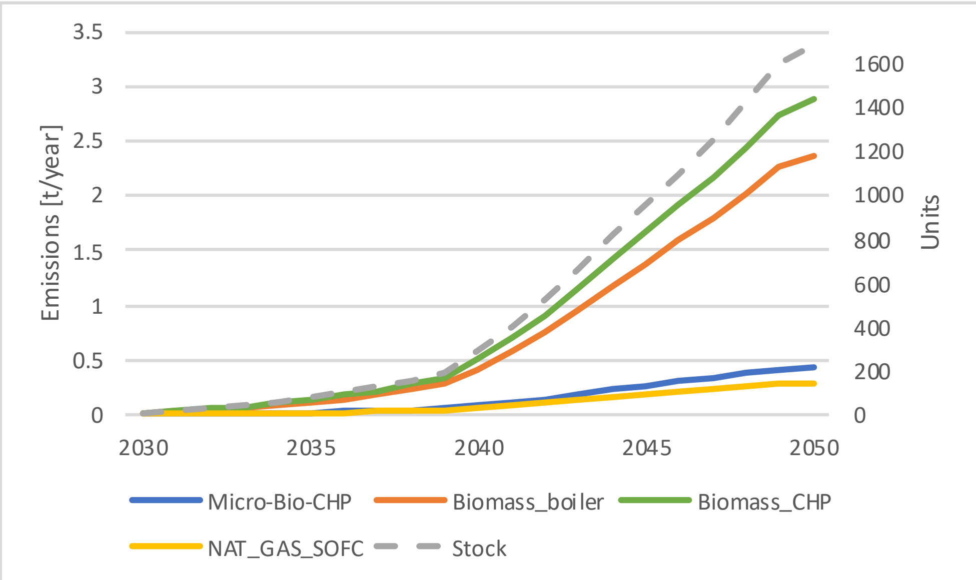

Figure 27: Total annual TSP emissions and stock volume for application case A1 and scenario 2 in Austria

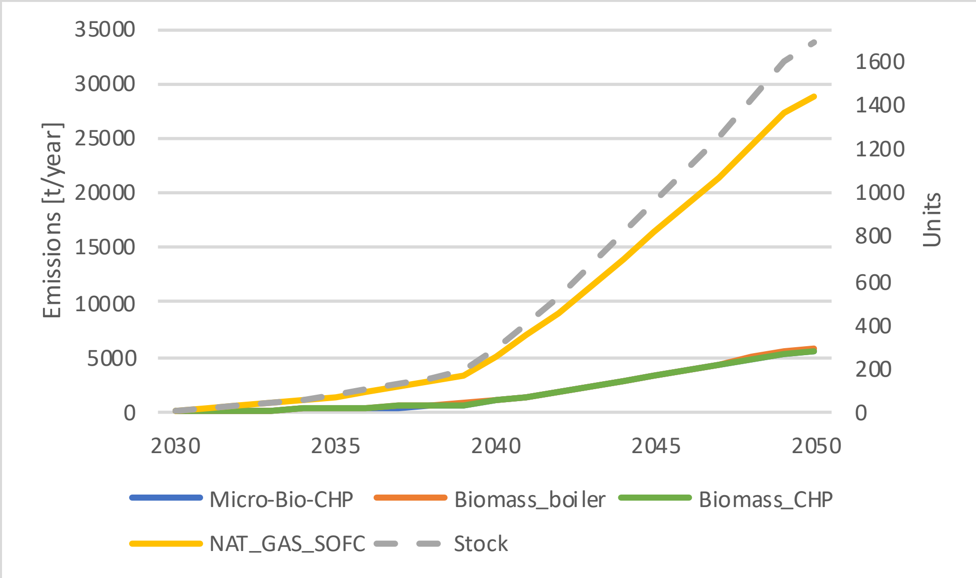

Figure 28: Total annual GHG emissions and stock volume for application case A1 and scenario 2 in Austria

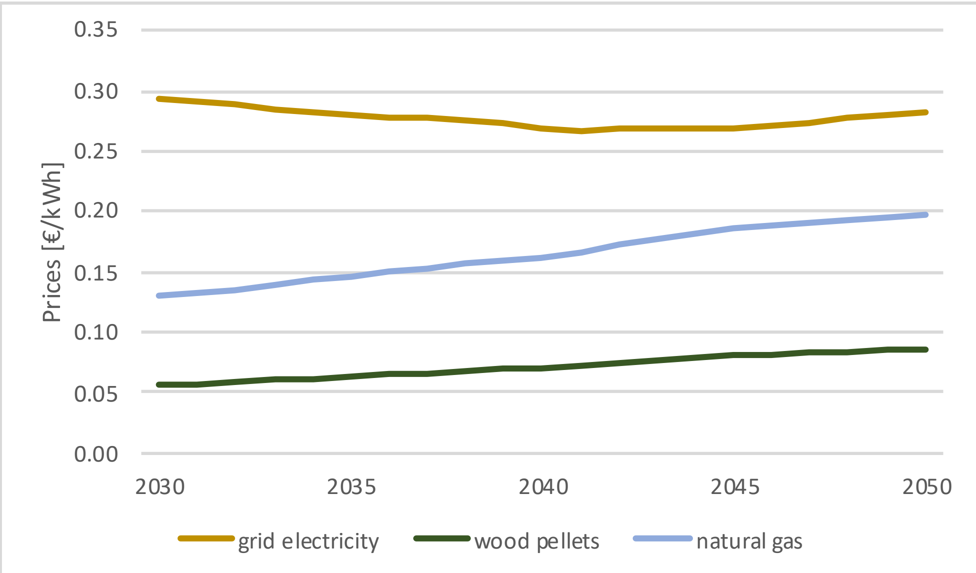

Figure 29: Assumed development of prices of energy carriers in Austria

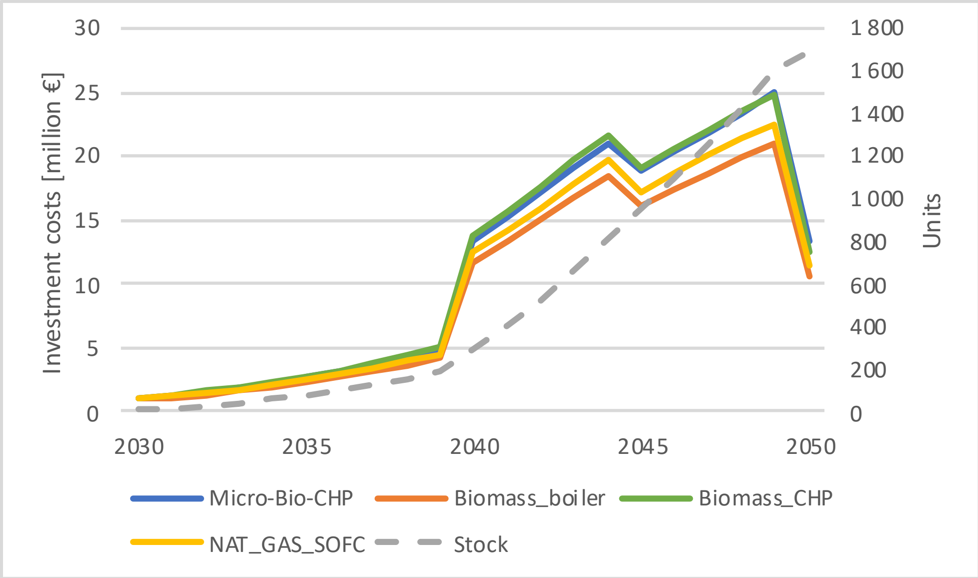

Figure 30: Total annual investment costs (including installation costs) and stock volume for application case A1 and scenario 2 in Austria

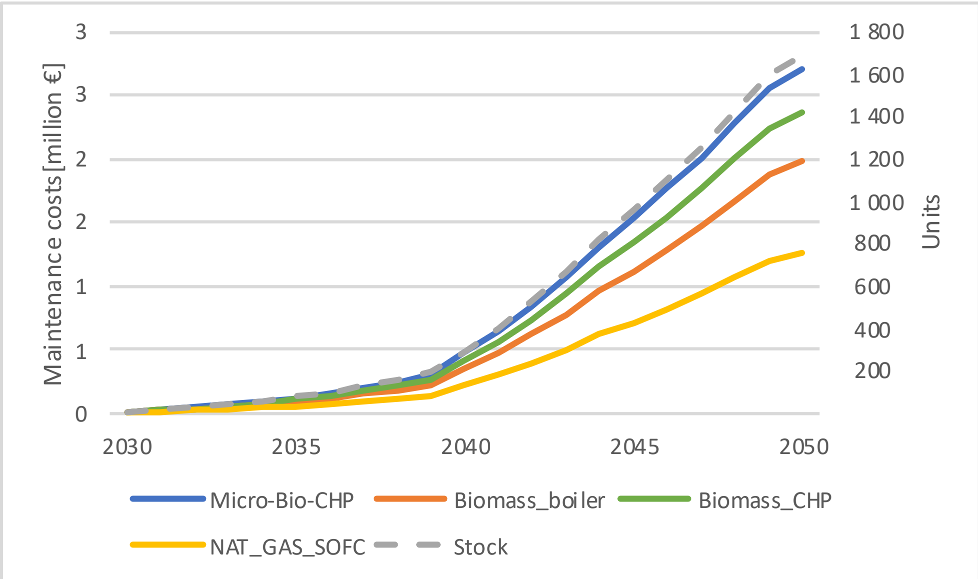

Figure 31: Total annual maintenance costs and stock volume for application case A1 and scenario 2 in Austria

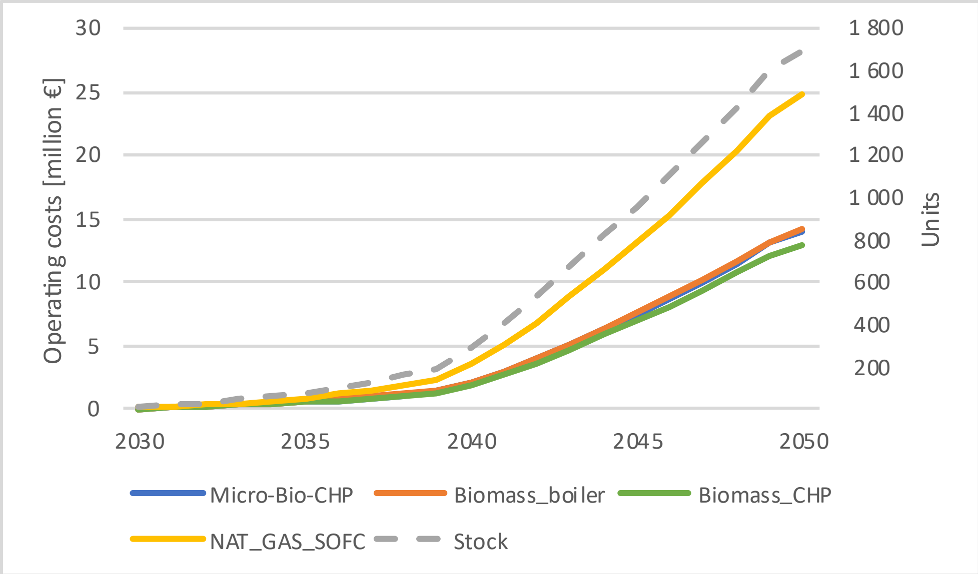

Figure 32: Total annual operating costs and stock volume for application case A1 and scenario 2 in Austria

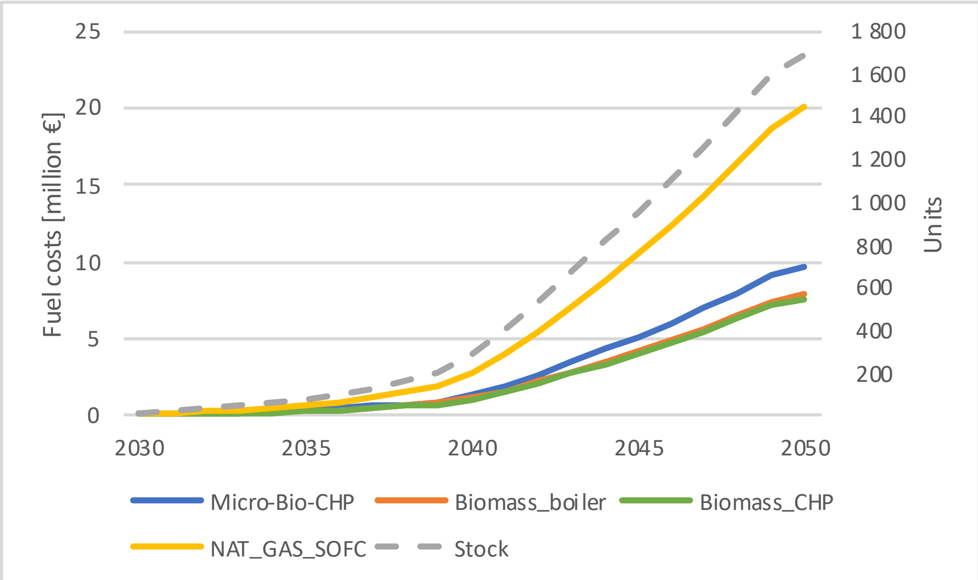

Figure 33: Total annual fuel costs and stock volume for application case A1 and scenario 2 in Austria

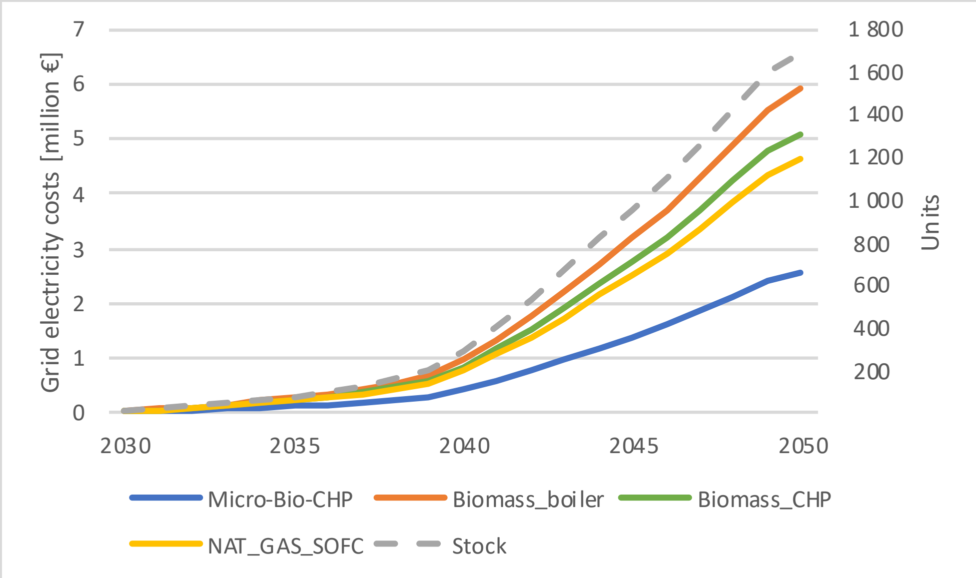

Figure 34: Total annual grid electricity costs and stock volume for application case A1 and scenario 2 in Austria

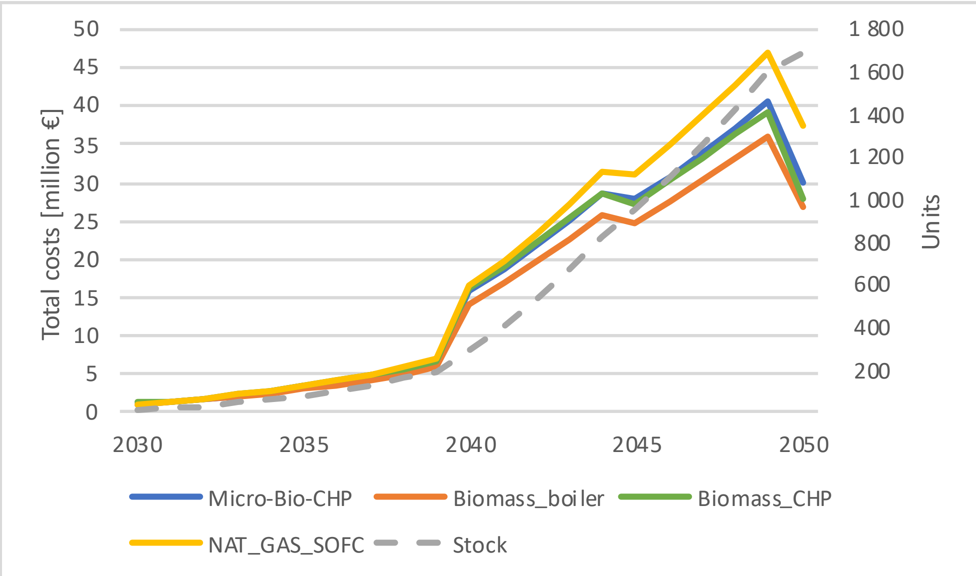

Figure 35: Annual total costs and stock volume for application case A1 and scenario 2 in Austria

Development of a novel highly efficient energy supply system
for energy autonomous multi-family buildings
based on biomass gasification coupled with an SOFC and a PV system

Grant Agreement No 101083409

D8.7: Final environmental and socio-economic impact assessment – Part II

Final analysis of the relevant policy framework

Deliverable Factsheet	
Full title	Final environmental and socio-economic impact assessment Part II – Final analysis of the relevant policy framework
Deliverable number	D8.7
Work package	8
Work package leader	Thomas Götz (WIKUE)
Related Task(s)	Task 8.3 – Impact assessments
Lead beneficiary	WIKUE
Author(s)	Lena Tholen (WIKUE) Thomas Götz (WIKUE)
Project coordinator	Ingwald Obernberger (BIOS)
Nature of document	R – Document, report
Dissemination level	PU - Public
Version	1.0
Date	30.03.2026

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or of the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

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This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101083409.

This document has been prepared by the Micro-Bio-CHP project partners as an account of work carried out within the framework of the EC-GA contract no 101083409.

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1 Problem definition

The Micro-Bio-CHP project develops a novel highly efficient energy supply system for (nearly) energy self-sufficient multi-family buildings, combining biomass gasification, a solid oxide fuel cell (SOFC) and a photovoltaic system. While the overall concept also includes thermal storage and electricity-storage interactions linked to e-mobility in order to support (near-)autonomous building supply, this Part II focuses on the policy framework most directly affecting the biomass-based heating and CHP component and its interaction with energy, climate and air-quality policy. Part I of this impact assessment documents the technical, environmental and economic performance of the Micro-Bio-CHP system in quantitative detail; this Part II is self-contained and can be read independently.

1.1 Significance of the topic

Heating and cooling remains one of the most difficult parts of the energy transition. According to Eurostat, renewable energy accounted for 25.2% of the EU's gross final energy consumption in 2024 (Eurostat 2025) and for 26.7% of heating and cooling consumption (Eurostat 2026). Under Directive (EU) 2023/2413, the Union target for 2030 is at least 42.5% renewable energy, with an additional 2.5% indicative top-up for achieving a target of 45%. This makes the decarbonisation of the heating sector strategically important for the achievement of EU climate and energy targets. Biomass continues to play an important role in this transition, especially in buildings and local or district heating contexts. Its policy role has, however, become more conditional. Biomass is no longer assessed only through the lens of renewable energy supply; it is increasingly judged by feedstock sustainability, overall system efficiency, local air-quality effects and compatibility with competing material uses of woody biomass.

Air quality is the key environmental qualification issue for solid biomass systems. The European Environment Agency (EEA) notes that $PM_{2.5}$ particles are emitted mainly from the combustion of solid fuels for domestic heating, industrial activities and road transport (EEA 2025b). In parallel, the recast Ambient Air Quality Directive, Directive (EU) 2024/2881, introduces stricter 2030 air-quality standards and strengthens the planning, monitoring and access-to-justice framework. This means that any future role for biomass in urban or peri-urban heating depends on verifiable low-emission performance in real operation, not only on the renewable character of the fuel.

In this policy context, the relevance of Micro-Bio-CHP depends on whether it can combine renewable heat and power supply with high system efficiency and clearly lower pollutant emissions than conventional biomass boilers and stoves. The technology is therefore assessed simultaneously under energy, climate and air-quality policy. The health basis for this ambition is well-established. The WHO global air quality guidelines (2021) set an annual mean guideline value of 5 µg/m³ for $PM_{2.5}$, substantially below both the current EU annual limit value of 25 µg/m³ and the stricter 10 µg/m³ limit that will apply from 2030 under Directive (EU) 2024/2881. The EU Zero Pollution Action Plan (COM(2021) 400) set a target to reduce premature deaths from air pollution by 55% by 2030 compared to 2005, with residential solid-fuel combustion identified as a remaining challenge (European Commission 2021). The Plan's mid-term review in January 2026 confirmed mixed but overall encouraging progress, while also calling for stronger implementation of pollution laws (European Commission 2026b). This strengthens the policy case for technologies that demonstrably outperform conventional biomass combustion.

As shown in Part I of this impact assessment, Micro-Bio-CHP already represents a significant advance over other biomass-based reference systems, particularly with regard to specific emissions of particulate matter (PM), gaseous organic carbon compounds (OGC), carbon monoxide (CO) and nitrogen oxides (NO_x). Part I also points to further optimisation potential, especially in reducing fuel consumption, improving overall efficiency and lowering capital costs. Part II therefore examines whether the current policy framework supports the market uptake of such high-performance low-emission systems.

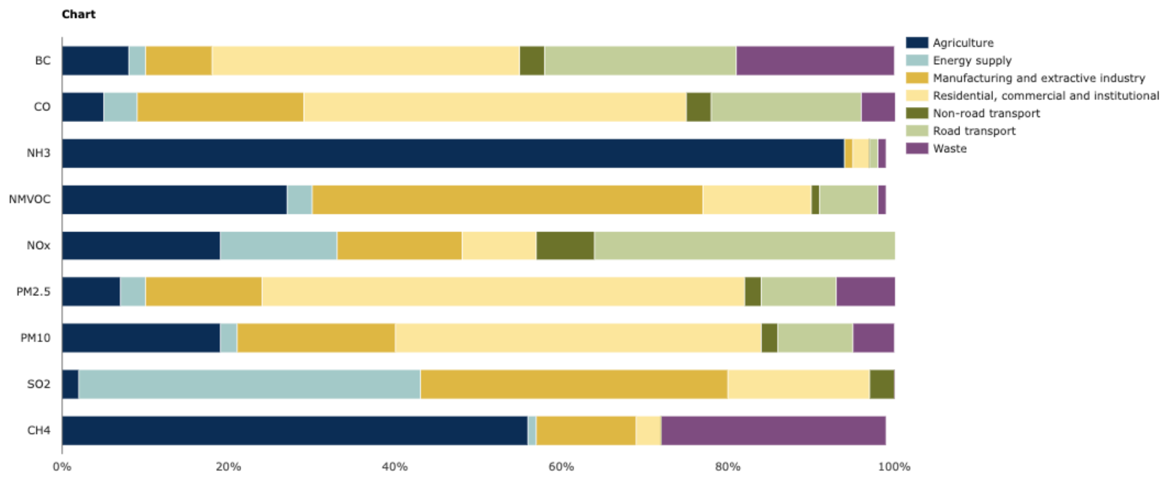

Figure 1: Contributions to EU-27 emissions of major air pollutants by main source sector (2020), Source: European Environment Agency (2024)

2 Barriers for efficient, low-emission solid fuel systems

Despite the existence of EU-wide product law and environmental legislation, several barriers still hinder the diffusion of highly efficient and very low-emission biomass systems. For innovative concepts such as Micro-Bio-CHP, the main barriers are not only technical but also informational, organisational and regulatory.

2.1 Insufficiently transparent performance information

End-users, planners and investors often lack comparable information on seasonal efficiency, pollutant emissions, maintenance needs and fuel-quality requirements.

A further barrier is the compliance-performance gap: even where appliances formally meet ecodesign requirements under laboratory test conditions, actual in-use performance still depends on installation quality, hydraulic integration, settings, exhaust design, fuel quality and maintenance. In particular, real-life problems may refer to insufficient adaptation of the whole system (e.g. wrong dimensioning compared to actual building conditions), inadequate exhaust systems (e.g. as consequence of a change between different heating systems), the quality and selection of the fuel used (e.g. too wet fuels, contaminated or generally other fuels than recommended by the manufacturer), incorrect control or wrong settings of automatic control systems, and insufficient maintenance (e.g. cleaning of the grate and de-ashing). This concern is reinforced by an EU-organised market-surveillance campaign published in January 2026: in a sample of 10 solid fuel boilers, 9 failed performance and energy-labelling requirements (European Commission 2026a). Although this is only a small sample, it clearly demonstrates that formal regulation alone does not guarantee compliant market outcomes.

2.2 Real-life measurement and testing challenges

Type-testing under harmonised conditions remains necessary, but it does not fully eliminate uncertainty about real-life operation across different fuels, load profiles and building contexts. In addition, current product and test standards do not always fully reflect the performance advantages of the most innovative systems in terms of efficiency and emissions. This can slow market diffusion where regulatory recognition depends mainly on standardised type-testing rather than broader evidence on real-life performance.

2.3 Installer and operator competence

Low emissions require proper dimensioning, control strategies, combustion settings, chimney design and regular maintenance. Innovative systems cannot realise their technical advantages if they are poorly installed or badly operated.

2.4 Economic and organisational barriers

Advanced systems usually face higher upfront costs, limited installer familiarity, and split incentives between building owners, investors, tenants and users. In addition, there is a lack of qualification and of economic incentives for wholesalers, retailers and installers who advise end-users on technology choices. Physically limited energy efficiency improvement potentials mean that too high incremental investment costs often cannot be quickly compensated by fuel savings, particularly because additional emission reductions and the respective external costs (e.g. health costs from air pollution) are currently not monetised in the investment decision.

2.5 Regulatory fragmentation and local constraints

Market prospects depend not only on EU rules but also on national support schemes, municipal heat planning, local air-quality plans and, in some cases, stricter regional or local requirements.

For Micro-Bio-CHP, these barriers mean that technical superiority alone is not enough. Market uptake depends on evidence, certification, installation quality, fuel-chain reliability and a policy environment that rewards both decarbonisation and clean combustion.

3 Influence of existing policies and legislation

The policy framework affects the technology through both direct and indirect channels. Direct rules govern product design, installation conditions and support eligibility. Indirect rules tighten air-quality and decarbonisation obligations for Member States, which in turn shape national markets. For analytical clarity, the following review distinguishes these functions.

3.1 EU level

3.1.1 Renewable Energy Directive (RED)

Directive (EU) 2023/2413 (RED III) is the main EU framework for renewable energy deployment. It sets a binding Union target of at least 42.5% renewable energy by 2030, with an additional 2.5% indicative top-up for achieving a target of 45%. It also strengthens sectoral requirements for heating and cooling and sets an indicative 49% renewable share in buildings by 2030. For heating and cooling, Member States must increase the renewable share by at least 0.8 percentage points annually from 2021 to 2025 and by at least 1.1 percentage points annually from 2026 to 2030.

For biomass, RED III is relevant in two ways. First, it improves the strategic position of renewable heating in the EU policy mix. Second, it tightens sustainability and greenhouse-gas saving criteria. According to the Commission's biomass overview and the legal text, these criteria now apply to heat and power installations with a total rated thermal input of 7.5 MW or more for solid biomass fuels. In addition, national support schemes must respect the cascading principle for woody biomass.

The implication for Micro-Bio-CHP is supportive but conditional. RED III strengthens demand for renewable heating and decentralised renewable supply, but biomass is no longer treated as automatically beneficial regardless of feedstock origin, efficiency and alternative material uses. For a small building-scale Micro-Bio-CHP system, the main effect is therefore strategic rather than direct legal compliance with the 7.5 MW threshold.

3.1.2 Energy Performance of Buildings Directive (EPBD)

The recast EPBD, Directive (EU) 2024/1275, is one of the most important market-shaping instruments for heating technologies in buildings. It requires a transition towards a zero-emission building stock by 2050. New buildings owned by public bodies must be zero-emission from 1 January 2028 and all new buildings from 1 January 2030. For the residential building stock, Member States must reduce the average primary energy use by 16% by 2030 and by 20–22% by 2035.

A particularly important immediate provision is Article 17(15): from 1 January 2025, Member States may no longer provide financial incentives for the installation of stand-alone boilers powered by fossil fuels. The European Commission issued guidance on this requirement in October 2024 (European Commission 2024b).

EPBD does not prescribe one specific heating technology at EU level. Instead, it changes the decision environment within which national building law and support schemes operate. For Micro-Bio-CHP, this is potentially positive where the system helps to deliver low operational emissions, high efficiency and renewable on-site or near-site energy supply. However, any biomass option in dense urban settings remains constrained by local air-quality considerations and by national implementation choices.

3.1.3 Energy Efficiency Directive (EED)

The recast Energy Efficiency Directive, Directive (EU) 2023/1791, strengthens energy efficiency as a core principle of EU policy. It sets a binding EU-level target corresponding to an additional 11.7% reduction in energy consumption by 2030 compared with the 2020 reference scenario. The Directive also extends the 3% annual renovation obligation to public buildings at local, regional and national level and reinforces planning and support for efficient district heating and cooling.

For Micro-Bio-CHP, the relevance of EED lies in its system-efficiency logic. The Directive favours technologies that deliver reliable energy savings and efficient energy services, not only renewable input shares. This is relevant for micro-cogeneration concepts that can demonstrate high overall efficiency under realistic operating conditions. Conversely, if a biomass-based CHP system underperforms in part-load operation or in unsuitable buildings, EED logic weighs against it.

The EED also progressively tightens the definition of efficient district heating and cooling in Article 26. From 1 January 2028, systems must meet more demanding combinations of renewable energy, waste heat and high-efficiency cogenerated heat. From 2035 onwards, the criteria tighten further, and from 2050 an efficient system must use only renewable energy, only waste heat, or only a combination of renewable energy and waste heat. Today, the share of renewable energies in district heating in the EU is dominated by biomass, and with increasing requirements, the pressure on biomass demand is likely to increase further (Braungardt et al. 2022). This trajectory increases long-term pressure to decarbonise heat networks and may, depending on local economics and infrastructure rollout, strengthen the case for decentralised solutions such as Micro-Bio-CHP in buildings beyond the economic reach of district heating infrastructure.

3.1.4 Ecodesign and energy labelling rules for solid fuel boilers

The most direct EU product rules for the biomass heating component are Commission Regulation (EU) 2015/1189 (ecodesign) and Commission Delegated Regulation (EU) 2015/1187 (energy labelling) for solid fuel boilers up to 500 kW. These requirements have applied since 2020 and set harmonised rules for seasonal space-heating efficiency and pollutant emissions, including particulate matter (PM), gaseous organic carbon compounds (OGC), carbon monoxide (CO) and nitrogen oxides (NO_x). According to the EU Ecodesign preparatory studies, energy consumption and emissions of solid fuel small combustion installations are concentrated mainly on the use phase, accounting for up to 99% of the product's total energy use over its lifetime and 43% to 98% of the product's total emissions of particulate matter, depending on the product type (European Commission DG TREN 2009). The broader Ecodesign for Sustainable Products Regulation, Regulation (EU) 2024/1781, provides a new horizontal framework, but the technology-specific solid fuel boiler regulations remain the operative product regime at present.

In principle, this framework supports the phase-out of inefficient and highly polluting products. In practice, however, compliance and enforcement remain an issue. In January 2026, the Commission reported the results of an EU-organised market-surveillance campaign in which 9 of the 10 solid fuel boilers tested failed performance and energy-labelling requirements (European Commission 2026a). The sample is small and cannot be interpreted as a full market estimate, but it clearly demonstrates that ecodesign compliance should be treated as a minimum baseline rather than as sufficient proof of environmental superiority.

For Micro-Bio-CHP, this means that conformity with ecodesign rules will be necessary but not sufficient. Independent evidence on very low dust emissions, stable performance and reliable control under real-life conditions will remain essential for credibility and market access.

3.1.5 National Emission Reduction Commitments Directive (NEC)

Directive (EU) 2016/2284 is an indirect but important driver. It requires Member States to limit annual anthropogenic emissions of SO_2, NO_x, NMVOC, NH_3 and $PM_{2.5}$, with stricter obligations from 2030 onwards. According to the Commission's 2025 evaluation, Member States met 90% of their emission reduction commitments in 2023 (European Commission 2025c).

For building-scale biomass, NEC matters because residential and commercial combustion remains a relevant $PM_{2.5}$ source in many Member States. The Directive therefore creates pressure for national measures to limit emissions from solid fuel combustion, including tighter product requirements or restrictions in air-quality hotspot areas. The NEC Directive and the AAQD jointly increase pressure on Member States to address emissions from solid-fuel combustion through national, regional or local measures; however, the exact design of such measures differs substantially across Member States.

3.1.6 Ambient Air Quality Directive (AAQD)

The recast Ambient Air Quality Directive, Directive (EU) 2024/2881, complements the NEC Directive by regulating ambient pollutant concentrations rather than national emissions. It entered into force in December 2024, must be transposed within two years, and requires compliance with stricter 2030 limit values. In particular, the annual limit value for fine particulate matter ($PM_{2.5}$) has been reduced from 25 $\mu g/m^3$ to 10 $\mu g/m^3$ from 2030 onwards, and the daily PM_{10} limit value has been lowered to 45 $\mu g/m^3$, with a maximum of 18 exceedances per year. The Directive also strengthens air-quality roadmaps, monitoring, modelling, public information and access to justice, including the possibility for individuals to seek compensation in cases of violations of EU air quality rules.

The relevance for biomass heating is considerable. Even highly efficient biomass systems may face acceptance problems in local hot-spot areas if they contribute to winter particulate peaks. In areas with persistent winter PM hot spots, stricter local restrictions on solid-fuel combustion remain a plausible policy response under future air-quality planning. For Micro-Bio-CHP, this means that a low-emission profile is not just an advantage but may become a precondition for deployment in urban and suburban markets.

3.1.7 MCP Directive

Directive (EU) 2015/2193 on medium combustion plants covers plants from 1 MW to less than 50 MW thermal input and sets emission limit values and monitoring requirements, including for dust. This means that the Directive is normally not directly applicable to building-scale micro-CHP concepts below 1 MWth.

Even though building-scale Micro-Bio-CHP systems normally remain below this scope threshold, the MCP Directive is still relevant as part of the broader regulatory continuum between Ecodesign requirements for smaller appliances (below 500 kW) and IED rules for large combustion plants (above 50 MW). It therefore provides policy context for possible upscaling, aggregation or application in larger building and district-energy settings. For the present project, the importance of the MCP Directive is mainly contextual rather than immediate, but it illustrates the EU's broader trend towards tighter combustion-emission governance across the entire capacity range.

3.2 National level

3.2.1 National implementation and the role of supplementary policies

EU rules alone do not determine market outcomes. National transposition, building law, subsidy design, carbon pricing, municipal heat planning and local air-quality management determine whether advanced biomass systems are actually investable and socially acceptable. National policy is, in effect, the main route through which EU objectives become concrete market signals. Yet Member States retain considerable discretion in how they translate these overarching objectives into building, heating and support rules. This means that the market position of advanced biomass systems can depend strongly on whether national frameworks differentiate sufficiently between technologies with very different emission profiles, fuel pathways and renewable contributions.

National rules shape the relative economics of competing energy carriers – electricity, gas, oil, district heat and biomass-based options – and determine whether low-emission biomass is explicitly eligible, conditionally eligible or politically discouraged for financial support. Municipal or regional heat planning further influences whether decentralised solutions remain viable or whether buildings are expected to connect to future district heating networks.

Training, documentation and installer requirements are set or shaped at national level and are therefore a decisive factor for real-life performance. Local air-quality plans can justify stricter conditions in pollution hot spots even where EU product law is formally satisfied.

Germany illustrates this particularly well, because it combines a binding building-law framework, municipal heat planning, targeted subsidy instruments and an active political debate about future reform.

3.2.2 Case study Germany

At the time of writing, the binding legal framework remains the amended Building Energy Act (Gebäudeenergiegesetz, GEG) together with the Heat Planning Act (Wärmeplanungsgesetz, WPG). Under Section 71 GEG (Gesetze im Internet 2026a), new heating systems must generally supply at least 65% renewable energy. This requirement already applies to new buildings in new development areas. For existing buildings and for infill buildings, longer transition periods apply and are linked to municipal heat planning: in municipalities with more than 100,000 inhabitants after 30 June 2026, and in smaller municipalities after 30 June 2028 (BMWSB/BBSR 2026).

Germany is, however, currently in a period of regulatory debate. In February 2026, the governing coalition agreed official key points for a proposed Gebäudemodernisierungsgesetz (GMG). According to the Bundesministerium für Wirtschaft und Energie (BMWE 2026), the proposal would abolish the 65% renewable quota and again allow modern gas and oil boilers, subject to future low-carbon fuel shares from 2029 onward. However, these are political reform proposals and not yet binding law. Accordingly, the existing GEG/WPG framework remains legally applicable until changed by legislation.

Germany's support framework remains highly relevant for market deployment. For private owner-occupiers in existing residential buildings, KfW programme 458 provides a 30% basic grant for a climate-friendly heating system and can reach up to 70% of eligible costs through additional bonuses.

Biomass systems may additionally receive a flat emissions-reduction bonus of EUR 2,500 if they meet a dust limit of 2.5 mg/m^3 under the KfW programme conditions (KfW 2026a). For companies and other investors in residential and non-residential buildings, the relevant KfW programmes generally provide grants of up to 35% of eligible costs (KfW 2026b; KfW 2026c). Official guidance also shows that support eligibility for biomass is narrower than for some other technologies: as a rule, centrally fed biomass heating systems are eligible, whereas single-room solid-fuel appliances are generally not (Energiewechsel 2024).

In addition, Germany's national fuel emissions trading system increases the economic risk of new fossil heating. From 2026, certificates in the national emissions trading system (nEHS) move from fixed prices to auctions in a price corridor of EUR 55 to EUR 65 per tonne of CO_2 (DEHSt 2026a); for certain statutory cost-sharing calculations, the relevant 2026 carbon price is EUR 60 per tonne of CO_2 (DEHSt 2026b). This underlines the policy signal away from purely fossil heating, even if the regulatory architecture is politically contested.

Overall, the German framework is mixed for Micro-Bio-CHP. On the one hand, demand for low-carbon heating in existing multi-family buildings, the continued relevance of public support and the search for technology-open solutions may create openings for the concept. On the other hand, stricter air-quality expectations, narrow biomass-specific subsidy criteria and current regulatory uncertainty during the debate over a future GMG remain important constraints. Under current conditions, the concept is likely to be most relevant in building segments where district heating is unavailable or uneconomic and where fully electric solutions face technical, economic or acceptance-related constraints. For market uptake, the key conditions will be very low dust emissions, integration as a central building system and credible economic evidence.

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