Expectations on flexible bioenergy in different countries

IEA Bioenergy: Task 44 Flexible Bioenergy and System Integration

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Executive summary

There is a wide agreement on the dramatically increasing importance of variable renewable energy (VRE) like wind and solar photo-voltaic (PV) to expand energy access and enable electrification based on clean energy, driven by market opportunities, substantial cost reductions, and a favourable policy environment. In energy systems of many countries, bioenergy is a more and more important option in fields where alternative renewable energy sources are difficult or costly to provide. Those fields of use for bioenergy are for example seen in the aviation and maritime sectors, heavy duty road transport, in high-temperature industrial heat, but also in enhancing renewable energy supply systems for residential heating during cold seasons or for electricity, especially if it comes to balancing electricity supply and demand in systems with high shares of VRE like wind and PV. To fulfil those demands climate-efficiency and cost-effective flexibility of bioenergy is key, for example when providing flexible electricity. Bioenergy also is expected to serve as an accelerator for green hydrogen production as well as being an attractive enabler for carbon capture and utilisation and/or storage options.

However, to unlock the enormous potential of flexible bioenergy's contribution to the transformation of the energy system, favourable policy conditions are necessary (as they are for the whole energy system transformation). With this report on the expectations of flexible bioenergy in different countries we analyse the developments in flexible bioenergy implementation in 14 countries and the European Union.

The report is mainly based on questionnaires completed by bioenergy experts in the countries, who were contacted through the IEA bioenergy network. Even though all surveyed countries are OECD members, the status, policy framework and examples are heterogeneous and give different priorities to short-term flexible bioenergy, multiproduct systems and longer-term flexibility services.

All investigated countries as well as the European Union target to reach net-zero Greenhouse gas (GHG) emissions by 2050 or at least 2053 as in the Paris Agreement, while some countries, namely Finland, Austria, Sweden, and Germany have set more ambitious targets, the most ambitious target being net-zero GHG emissions by 2035 in Finland. The US has also set a net-zero target for the electricity sector by 2035. Linked to net-zero GHG emissions further national targets are of importance as for example Italian National Energy Strategy of 2017 confirming the political commitment to phase-out coal from power generation in 2025 and Austria targets 100% renewable electricity by 2030. Furthermore, EU countries have set overall renewable energy targets for 2030, following the EU 42.5% target.

Flexible bioenergy is identified as a key contributor to energy security, particularly in supporting the transition from fossil-based to renewable energy systems. E.g., countries like Denmark and Austria emphasize its role in buffering uncertainties and maintaining electricity supply amidst increasing reliance on variable renewable energy (VRE). Bioenergy is also expected as a key factor for decarbonizing hard-to-abate sectors, with Canada, the UK, and others highlighting its importance for industrial heat, heavy transport, and the integration with carbon capture and storage (CCS) technologies (Bioenergy with carbon capture and storage, BECCS). Despite its potential, flexible bioenergy is inconsistently addressed in national strategies, often overshadowed by broader renewable energy targets or limited by biomass resource availability. Overall, international cooperation and clear policy frameworks are necessary to unlock bioenergy's flexibility benefits at scale.

The survey explored the role of policies in advancing flexible bioenergy, focusing on national and international frameworks, synergies, and contradictions. Respondents agreed that both national regulations and international strategies, such as EU-wide targets, are critical, with countries like Austria and Canada highlighting the benefits of policy alignment and financial incentives. However, challenges such as regulatory barriers in Germany and public resistance in the Netherlands demonstrate that contradictions between policies can hinder progress. While some countries, such as Denmark and Sweden, recognize the importance of flexibility in their energy strategies, explicit references to flexible bioenergy remain limited in most policy documents.

The strongest drivers for flexible bioenergy identified by most countries are climate neutrality targets, energy prices, and energy security, while factors like specific flexible energy targets and fossil fuel phase-out strategies are less influential. Countries like Denmark and Türkiye emphasize energy security and reducing dependency on fossil fuels, with Denmark boosting biogas deployment and Sweden focusing on local base load power. Energy prices are viewed variably, with countries like the Netherlands and the European Commission for the European Union seeing them as weak drivers, while others consider them significant. Germany, through its Renewable Energies Act, is one of the few with specific instruments for promoting flexible bioenergy. Phase-out strategies, such as for coal in Finland, are seen more as weak or neutral drivers rather than primary motivators for bioenergy expansion.

Countries identified key opportunities for flexible bioenergy systems over two timeframes. For 2020–2030, priorities include utilizing biogenic residues, complementing renewables usage, and supporting industrial energy needs. For 2030–2050, the focus shifts to hydrogen synergies, CCUS, and e-fuels, highlighting their role in decarbonizing heavy industry and enhancing renewable energy storage. Providing sustainable fuels remains crucial across both periods, while biogenic residue valorisation diminishes in relevance by 2050. Overall, the shift reflects a move from short-term adoption to long-term integration within broader decarbonization strategies.

Synergies between flexible bioenergy and green hydrogen are expected in many ways: Value chains, improving technical performance as well as new business models are seen as top areas for the strongest synergies. Also, better Greenhouse gas balances are mentioned, which are an important issue when reaching net zero energy systems over the next 10 to 25 years.

Thus, flexible bioenergy is considered a crucial element and key enabler in the transition toward net-zero energy systems. However, uncertainties in biomass availability make its potential impact unclear in many countries. Additionally, the sectors expected to benefit most from flexible bioenergy remain uncertain, particularly in the long term. Differences in energy transition progress exist between countries, compounded by uncertainties around competing technologies such as electric mobility for heavy transport, bi-directional charging in the electric vehicle sector, and high-temperature heat pumps for industry. These challenges highlight significant knowledge gaps regarding the need for flexibility options and the specific role of flexible bioenergy compared to other flexibility solutions across various energy sectors. They also emphasize the importance of increased collaboration both within and between countries. To address these challenges, coordinated actions at both national and international levels are crucial. This includes clarifying biomass potential, enhancing energy system modelling to better understand the need for flexibility in energy and material systems, determining how flexibility can be provided, developing supportive policies, and aligning technological advancements across sectors.

1. Introduction

Achieving least-cost, reliable and sustainable energy systems under the framework of the Sustainable Development Goals (SDGs) is a global challenge. Renewable energy sources are key for the energy sectors to realise a climate neutral energy supply until the mid of the current century at the latest. There is wide agreement on the need to dramatically increase the share of variable renewable energy (VRE) like wind and solar photo-voltaic (PV) to expand energy access and enable electrification based on clean energy, driven by market opportunities, substantial cost reductions, and a favourable policy environment. This essentially affects the structure and operation of power systems, but also influences the heat and transport sectors (Thrän et al. 2021).

Bioenergy is a key option in fields where alternative renewable energy sources are difficult or costly to provide and where sufficient sustainable biomass is available. Those fields of use for bioenergy are for example seen in the aviation and maritime sectors, heavy duty road transport, and high-temperature industrial heat, but also in enhancing renewable energy supply systems for residential heating during cold seasons or for electricity, especially if it comes to balancing electricity supply and demand in systems with high shares of VRE like wind and PV (Schildhauer et al. 2021 and Thrän et al. 2024). To fulfil those demands, climate-efficiency and cost-effective flexibility of bioenergy is key.

Flexible bioenergy is not the only option to provide flexibility to the energy system, in particular for providing flexibility to a variable renewables based electricity grid it is part of a set of technologies, including e.g. hydropower as well as hydrogen and various storage technologies. Beyond providing flexible electricity, additional chances are seen for bioenergy to provide different energy system services such as biofuels, renewable heat as well as carbon capture and utilisation and/or storage options and the reduction of grid operation costs (Millinger 2023). Moreover, potential synergies of flexible bioenergy with hydrogen are reported (Mäki et al. 2024).

Energy flexibility is the ability to effectively cope with variations in the supply or demand of energy and provide dedicated options to support the energy transition by providing flexible energy in different energy system services. In this context, flexible bioenergy is defined as deployment of sustainable biomass to provide multiple services and benefits to the energy system under varying operating conditions and/or loads contributing to energy security (Schipfer et al. 2022). The definition of flexible bioenergy includes:

- Utilisation of sustainable biomass feedstocks of varying types and qualities depending, for example, on feedstock availability or accessibility due to meteorological or seasonal conditions or the impacts of climate change;
- Trade and storage of bioenergy carriers such as wood pellets, biomethane and bioethanol over longer periods;
- Flexible generation of power for grid stability and ancillary services for power systems;
- Flexible and/or poly-generation of power, heat and fuels, according to market demand and trends, for example, matching seasonal demand patterns between power and heat or continuous changes in output shares of heat for residential heating and biofuels;
- Flexible provision and processing of biogenic CO_2, converted to synthetic fuels or other products (with for example hydrogen from PV or wind surpluses) or captured and stored (i.e. bioenergy carbon capture and storage (BECCS)).

Additionally, the possible contribution of flexible bioenergy goes even beyond the energy sector, when it is provided in integrated biorefineries or Power-to-X-systems for chemicals and/or materials production, and when by-products, such as CO_2, bio-sludge, digestate or biochar are used to remove CO_2 from the atmosphere (carbon dioxide removal, CDR).

However, to unlock this enormous potential of flexible bioenergy's contribution to the transformation of the energy system, favourable policy conditions are necessary (as they are for the whole energy system transformation). With a first overview of the flexible bioenergy status in different countries, published in March 2021 (Thrän et al. 2021), we were able to show that technological barriers are not seen as a major challenge, but that an economically feasible integration of the technologies in the overall energy system is a major hurdle. Coherent policy support to integrate flexible bioenergy in the energy system is considered necessary.

With this report on expectations on flexible bioenergy in different countries we provide further insights in the ambitions concerning the energy system transformation and the possible contribution of flexible bioenergy to accelerate this transformation. Therefore, we have asked the national experts from different countries about the national goals on flexible bioenergy as well as whether and how flexible bioenergy is considered in national energy scenarios. In addition, we also collected expectations on benefits for different energy sectors, but also outside the energy system. Taking this into consideration, the expectations on policy instruments driving flexibility were assessed as well as the potential synergies with currently discussed and developed hydrogen strategies and their implementation. The first report (Thrän et al. 2021) also concluded that a promising way to unlock the potential benefits from flexible bioenergy is through a stronger link between flexible bioenergy and other options for flexibility, such as demand side management, energy storage, power-to-X and green hydrogen (Thrän et al. 2021). So, we have also included this topic in our second survey.

This report, called "Expectations of flexible bioenergy in different countries" is part two of our latest analysis, following the report on "Implementation of flexible bioenergy in different countries" (Thrän et al. 2024). Here, we provide an update of the situation in 2021-2022 and analyse the developments over the last three years, also including more countries and the European Union as an additional player. We included the "lessons learned" of the first analysis (Thrän et al. 2021) in our study design, so that questions were asked more specifically and the experts were better aware of the different dimensions of flexibility. A summarizing synthesis report as part three will follow soon.

2. Method

This report is based on a questionnaire with 44 different questions on flexible bioenergy and was answered in written form by bioenergy experts from 14 countries (Austria, Australia, Brazil, Canada, Denmark, Finland, Germany, Italy, the Netherlands, Sweden, Switzerland, Türkiye, United Kingdom, United States of America, and the European Commission for the European Union of 27 Member States (which we also refer to as "country" in the report in order to simplify our writing). For engaging experts from the countries, we used the IEA bioenergy network and especially the expertise of the members of Task 44 Flexible Bioenergy and System Integration. Unfortunately, we were not able to engage more countries from Asia or the Global South to participate.

The questionnaire was conducted between February and August 2023 and builds upon the first round of analysis published in the report "Expectation and implementation of flexible bioenergy in different countries" (Thrän et al. 2021). Questions from the initial survey were refined where needed, and further questions were added to address topics that were mentioned but not fully explored previously. Most countries that participated in the first round contributed again, allowing for comparative analysis over time.

The questionnaire consisted of a mix of open and closed questions designed to gather insights into policies, technologies, synergies, and challenges associated with hydrogen and bioenergy integration. It addressed multiple dimensions, including technical performance, infrastructure, GHG balance, sustainability, value chains, and business models. Responses were enriched with information from national strategies, policy documents, and ongoing research projects shared by the respondents. The data was

analysed to identify common themes, country-specific challenges, and best practices. To aid interpretation, key findings were summarized through visualizations such as charts and figures, facilitating cross-country comparisons. The assessments and opinions presented in the report are primarily derived from the analysed questionnaires, directly reflecting the input of experts from the respective countries, and do not represent the authors' own statements. Detailed individual responses and additional supporting information are included in the annexes for reference.

Given the extensive evaluations and diverse questions addressed, the analysis was divided into two parts. The first part of the report, “Implementation of flexible bioenergy in different countries” (Thrän et al. 2024), was published in May 2024 and focused on the current status and implementation efforts across participating countries. The structured questionnaire used for data collection is provided in the annex of the first report (Thrän et al. 2024). This report, “Expectations on flexible bioenergy in different countries”, represents the second part of the analysis. A summary document covering both reports will follow.

The answering of the questionnaire has been done by a broad range of stakeholders. The experts from different countries had different backgrounds – including i.e. technology experts, energy market experts, policy officers and energy system analysts. The number of respondents varied by country, with some countries contributing multiple perspectives and others relying on a single expert. This heterogeneity is reflected in the depth and quality of the assessments. Additionally, not all respondents had expertise in every area covered by the survey, and some questions were not fully answered by all countries. As a result, there are data gaps and incomplete responses, which should be considered when interpreting the report.

The report is structured as following:

- The way forward: National targets to net zero GHG emissions (Chapter 3)
- National needs and goals for flexible bioenergy in different energy sectors (Chapter 4)
- Policy instruments driving flexibility (Chapter 5)
- Drivers for flexible bioenergy implementation (Chapter 6)
- Opportunities for flexible bioenergy systems (Chapter 7)
- Synergies between hydrogen and bioenergy (Chapter 8)
- Conclusion (Chapter 9)

3. The way forward: National targets to net zero GHG emissions

Most of the countries have set up national targets to reach net-zero GHG emissions with varying timeframes (Figure 1). All investigated countries as well as the European Union target to reach net-zero GHG emissions by 2050 or at least 2053 as in the Paris Agreement, while some Member States, namely Finland, Austria, Sweden and Germany have set more ambitious targets, the most ambitious target being net-zero GHG emissions by 2035 in Finland. The US has also set a net-zero GHG emissions target for the electricity sector by 2035, while the 2017 Italian National Energy Strategy confirmed the political commitment to phase-out coal from power generation in 2025 and Austria targets 100% renewable electricity by 2030. In a short run, by 2030, the EU links the climate target of reducing net GHG emissions by at least 55%, compared to 1990 levels, with the binding renewable energy target at least 42.5% and the EU energy efficiency target, making it binding for EU countries to collectively ensure an additional 11.7% reduction in energy consumption by 2030, compared to the projections of the EU reference scenario 2020. Regarding climate action to reach binding net-zero GHG emissions, the EU has committed to planting 3 billion additional trees before 2030. This pledge is part of the plan to tackle the protection and restoration of nature but also close to biomass availability.

Some countries have recently increased the ambition of their net-zero GHG emissions targets compared to the first edition of the report[1]. These countries include Finland, Austria, and Germany, which have moved the target from 2050 to 2035, 2040, and 2045, respectively. In Denmark, the advancement of the carbon neutrality from 2050 to 2045 and being carbon negative (110% GHG emissions reduction) by 2050 are under governmental discussion. Denmark's climate goals are ambitious, reflecting its role as one of the leaders in climate action within Europe. Since Italy did not indicate a specific target in the survey for the 2021[1] report, there is no basis for comparison.

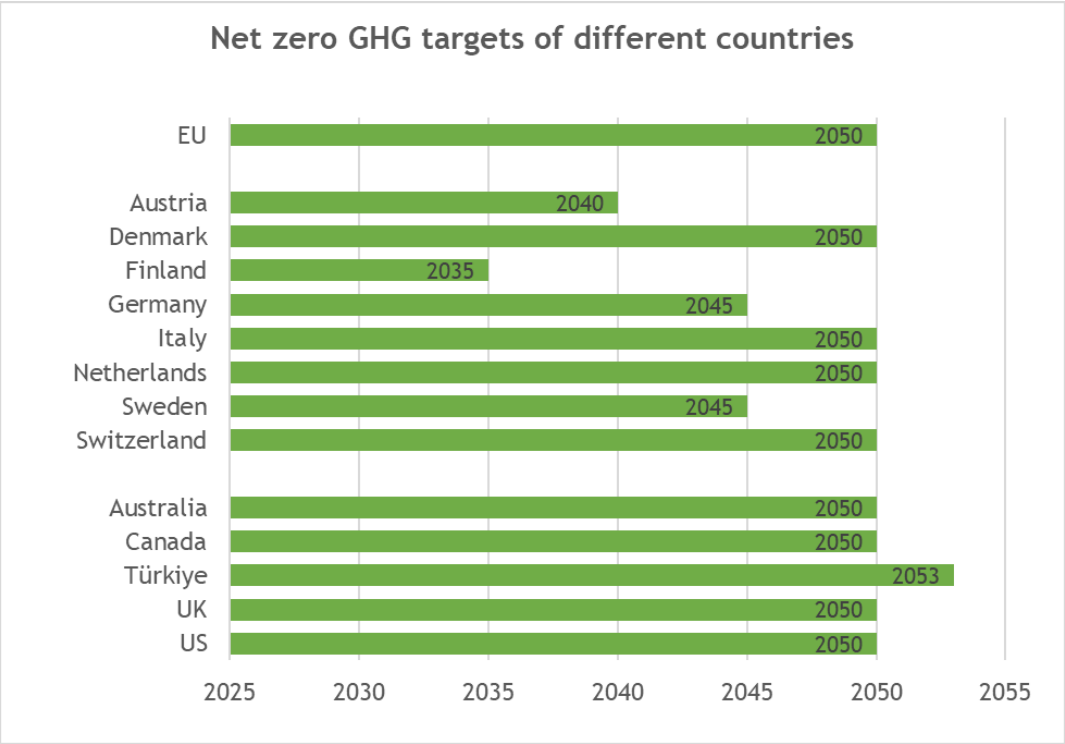

Figure 1: Carbon neutrality targets in respondent countries. Brazil not included.

[1] https://task44.ieabioenergy.com/wp-content/uploads/sites/12/2021/04/IEA-Task-44-report-Expectation-and-implementation-of-flexible-bioenergy-in-different-countries.pdf

Some countries have already developed different roadmaps, pathways/scenarios, and strategies to achieve the net-zero GHG emission target, while other countries are in the development phase. For instance, the Netherlands has an intermediate target of 55% GHG emissions reduction by 2030 compared to 1990 level, which is in line with the overall European Fit-for-55 goal. The European Climate Law which entered into force on 29 July 2021 establishes a legal objective for the European Union to reach climate neutrality by 2050 and sets an ambitious 2030 climate target of at least 55% reduction of net emissions of GHG as compared to 1990. Switzerland has three scenarios under political debate. In Canada, the legislation sets five-year emissions reduction milestones, starting with Canada's 2030 Emissions Reduction Plan[2]. The Plan aims to reduce emissions by 40-45% from 2005 levels by 2030 and includes a roadmap to meet the targets.

In governmental discussions, numerous issues are analysed, proposed, and expected to evolve in terms of pathways, strategies, and measures for climate action. In Sweden, for example, support is being implemented for BECCS (Bioenergy with Carbon Capture and Storage) and other negative emissions solutions, such as re-wetting drained land and using biochar. Sweden has also clearly defined its net-zero target: it excludes the LULUCF (Land Use, Land-Use Change, and Forestry) sector, includes negative emissions, and allows for international collaboration, while mandating at least an 85% reduction in domestic emissions. Türkiye, on the other hand, is transitioning from setting climate targets to developing the specific policies and action plans needed to achieve them.

4. National needs and goals for flexible bioenergy in different energy sectors

EXPECTATIONS ON SECTORS: WHERE FLEXIBLE BIOENERGY IS NEEDED

In the questionnaire we asked the country experts "Where do you see strongest needs for flexible bioenergy? Where does this need come from?". The specific answers for the different countries are given in Figure 2 (background information and references to find in Annex). Strongest needs for flexible bioenergy are seen in providing security of supply especially due to expected large-scale integration of variable renewable energy (VRE), in balancing the VRE, and decarbonizing hard-to-abate sectors including industry and transport.

Security of supply in energy transition and resilience

At EU level, flexible bioenergy is expected to increase security of supply when substituting fossil fuels and base-load capacity. For example, in Denmark, bioenergy is considered as a key in maintaining electricity supply security in the energy transition from dispatchable power production to considerable solar and wind power production. Austria mentions flexible bioenergy as a resilience measure to buffer different types of uncertainties related to, e.g., climate, supply, demand, trade, political, trends, overproduction (e.g., sudden residues emergence through extreme events), and undersupply (e.g., seasonal changes in heat demand).

In the UK, diversifying and increasing the supply of biomass are seen to increase energy security in a situation of increased concern due to geopolitical changes. The phase out of coal is mentioned as a vehicle for increased capacity of bioelectricity from solid biomass and signs of governmental will to increase bioenergy use exist. However, it remains unclear whether this will come along with flexible bioelectricity.

[2] https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/plan.html

While some parts of Canada have extensive hydropower capacity, other regions rely heavily on fossil fuels (e.g., natural gas, coal) to generate electricity. Gaseous and solid biofuels provide drop-in ready and co-firing potential that could support both the energy transition in regions of Canada as well as provide net-negative electricity if paired with BECCS.

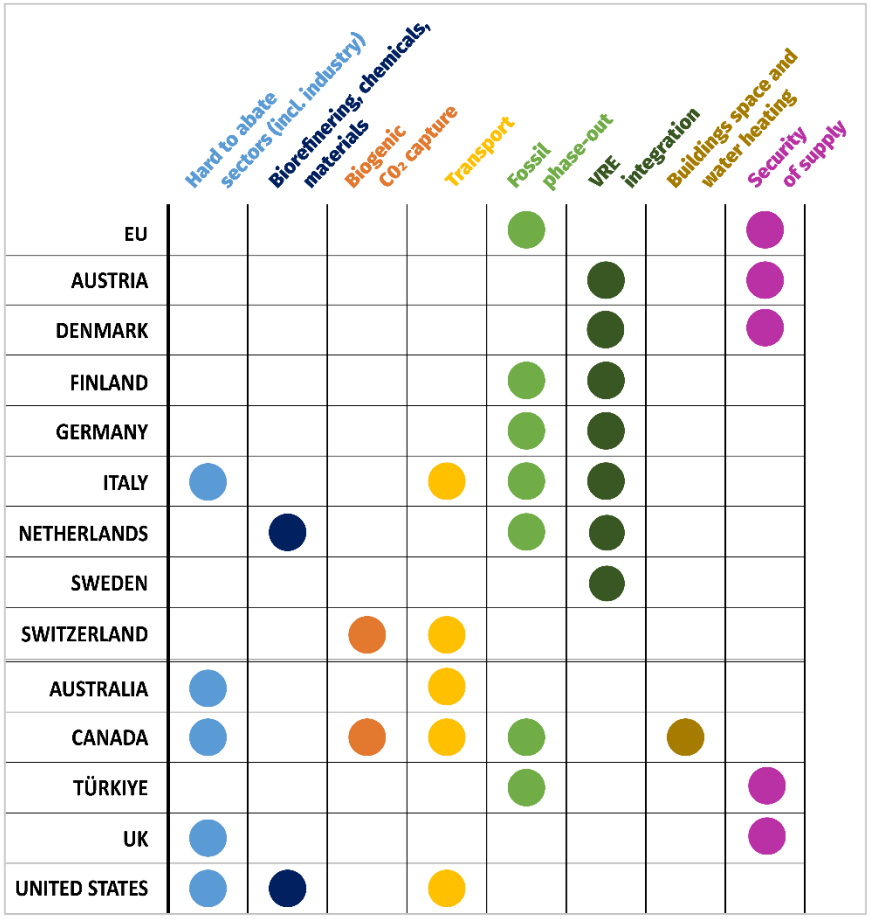

Figure 2: Strongest needs for flexible bioenergy in respondent countries. Brazil not included.

Balancing VRE – resulting in need for security of supply

The large-scale integration of variable renewable energy and the phase out of fossil fuels, that have been considered as balancing components in conventional energy systems, are mentioned as main drivers for flexible bioenergy by many respondents. Austria mentions the need for flexible bioenergy as a controllable technology to compensate for the volatile nature of most renewable alternatives – this is connected to the security of supply. Denmark foresees significant changes in the energy system by 2030 through political agreements and ambitions also on EU level to increase VRE production and electrify large parts of the energy system, while a significant amount of dispatchable power capacity will be phased out. As a result, bioenergy will be key to guarantee security of electricity supply. Finland and Sweden mention flexible bioenergy as a measure to complement increasing wind power production capacity. Also in Germany, there is demand for peak power production as coal-fired power generation capacities will phase out until 2038. Furthermore, flexible bioenergy is expected in the heating sector to support heat pumps during cold spells.

The gradual phase out of conventional sources of flexibility supply (notably fossil coal and gas plants) and the increasing need for (back-up) dispatchable CO_2-free power generation capacity were mentioned as drivers in the Netherlands. Given the existing power infrastructure and the plans to stop coal-firing,

converting the coal-fired power stations to 100% biomass firing is proposed as the most straightforward measure. According to the feedback from the Netherlands, given the current perspectives on biomass policy, it is unlikely that the Dutch government will actively support or subsidize this development.

Decarbonizing hard-to-abate sectors

Generally speaking, the countries' responses are not so much about flexibility, but rather about using "all suitable renewable energies" to replace fossil fuels as much as possible, insofar as this is economically feasible. Substituting fossil fuels in energy production and decarbonisation of industrial heat and heavy transport are seen as a driver for bioenergy. The change is driven by climate action and related legislation (e.g., in Finland there is an act banning the use of coal for energy generation in 2029). There are also concerns related to energy dependency, which has led to the need to find a substitute for fossil fuels (e.g. in Türkiye). But there are also exceptions, such as Sweden, where substitution no longer plays a major role, as fossil fuels have already been replaced in heat and power generation and in large parts of industry.

In the UK and Canada, flexible bioenergy is needed for providing emission reductions in energy-intensive, "difficult-to-decarbonize" industries, like in steel and cement production, where other renewables cannot offer what is required. Canada mentions also BECCS in conjunction to biomass use for industry as a possibility to further reduce emissions. Capturing biogenic CO_2 for negative emissions is mentioned also by Switzerland. Depending on how the transition of the refinery/chemicals sector will be shaped in the Netherlands, it may also involve a substantial increase in biofuels production. The US mentions the need for flexible bioenergy in the chemical sector.

Canada foresees liquid and gaseous biofuels to provide drop-in ready alternatives to fossil fuels in heavy-duty and long-haul transportation, providing immediate emission reductions. This is particularly important given Canada's land mass and reliance on long-haul transportation for services and goods across the country. The United States mentions a strong need for flexible bioenergy in the heavy-duty fuels sector. Australia and Italy foresee biofuels to support hard-to-abate sectors and transport, e.g., aviation (sustainable aviation fuels, SAF), maritime, and rail.

NATIONAL GOALS AND MECHANISMS TO IMPLEMENT FLEXIBLE BIOENERGY

None of the countries mention flexible bioenergy as a specific target in their national net-zero energy strategies. As explained in the previous chapter, expectations for flexible bioenergy vary significantly across countries and sectors. For example, the discussion on flexible bioenergy in the UK focuses on the issue of biomass imports versus domestic production. Detailed country responses regarding their national goals and mechanisms to implement flexible bioenergy can be found in Appendix 1 – Goals and mechanisms for the implementation of flexible bioenergy by the respondent countries. In the following, a few examples from Annex 1 are given for each country to describe their status. However, it can be seen that in some countries there are specific mechanisms that support the flexible provision of electricity in particular, but also of heat in some cases.

- **Australia** has no strong focus on bioenergy but on hydrogen.
- In **Austria**, there are policies and support mechanisms in place and planned, but delays have led to unsuccessful implementation and even to shut down of biomass CHP plants.
- **Canada** supports the deployment of bioenergy through various policies and explores the feasibility of a bioenergy strategy that optimizes the use of agricultural, forestry and municipal waste resources to support a transition to net-zero energy.

- In **Denmark** it has been decided to phase out gas for heating. However, this should not lead to higher biomass consumption.

- On **European Union's** level, a non-binding target has been set to produce 35 billion cubic meters (bcm) of biomethane by 2030 as a part of REPowerEU plan, to reduce the reliance of fossil gas imports from Russia.
- In **Finland**, the need for flexibility and its implementation through steering mechanisms have been recognized in national energy and climate strategy launched in autumn 2022 (Carbon neutral Finland 2035 – national climate and energy strategy (valtioneuvosto.fi)).

- Within the REA (Renewable Energies Act, EEG, Erneuerbares Energien Gesetz) bioenergy plants in **Germany** are forced to become more and more flexible and it is planned to ensure 8.4 GW installed capacity in 2030.

- **The Netherlands**: Biomass co-firing, which has been the main flexible bioenergy option for the power sector over the last decade and continues to be so in the Netherlands, has clearly been influenced by the planned phase-out of coal. However, given the current biomass policy views, it is not likely that this will continue to be actively supported/subsidized by the Dutch government.

- In **Sweden** the government launched an electrification strategy, emphasizing the need to increase power production from biobased combined heat and power (CHP). However, the potential remains underutilized. While fossil fuels in CHP have been phased out, many cities and regions still require additional local power capacity, particularly during winter months with low wind conditions, typically occurring during high-pressure periods and cold spells.

- **Switzerland**: Three different scenarios are under discussion of which one sees a stronger role of renewable gases incl. biomethane. Gas industry promised to cover 30% of domestic heating with renewable methane by 2030, e.g. by import of biomethane and some support for Power-to-Methane. Generally, the PV and hydropower way is more dominant in discussions.

- The main driver for the development of bioenergy in **Türkiye** has been the Renewable Energy Resources Support Mechanism (YEKDEM). This mechanism provides a foreign currency (USD) based purchase guarantee and within this, there has been a significant increase in the installed power of renewable energy power plants including bioenergy-based ones.

- **UK**: The phase out from coal has clearly been a vehicle for the increased capacity of bioelectricity from solid biomass (conversion and new establishment of biomass power plants). Latest Government strategies (e.g. Net Zero Strategy) will require an increase of bioenergy, but these have not been clearly described or quantified.

- There are no "flexible bioenergy" specific goals nationally in the **United States**. The major bioenergy goal in the US is the Sustainable Aviation Fuel Grand Challenge, which targets 3 bn gallons of SAF by 2030 and 35 bn gallons by 2050.

We conclude that strategic energy policymakers expect flexible bioenergy mechanisms to emerge more significantly from other areas of action and likely to appear as market-driven initiatives. However, there remain substantial gaps in flexibility expectations between various energy sectors, highlighting the need for greater cooperation both within individual countries and at an international level. Notably, the IEA took initial steps in this direction in the summer of 2024 by launching the IEA TCP collaboration activity, particularly establishing a working group focused on flexibility.

FLEXIBLE BIOENERGY IN NATIONAL ENERGY SCENARIOS

According to 57% of the questionnaire respondents, flexible bioenergy is integrated into national energy scenarios (Figure 3). Several countries, however, have noted that the term 'national scenarios' often lacks a clear definition. Official energy strategies, including targets and measures, are often based on several different scenarios. For example, in the Netherlands, a range of organizations conduct energy transition scenario studies up to 2050, though the broad range and complexity of bioenergy technologies are only addressed to a limited extend. In contrast, countries like Sweden rely less on detailed scenarios and targets; instead, their energy policies are largely driven by incentive-based approaches.

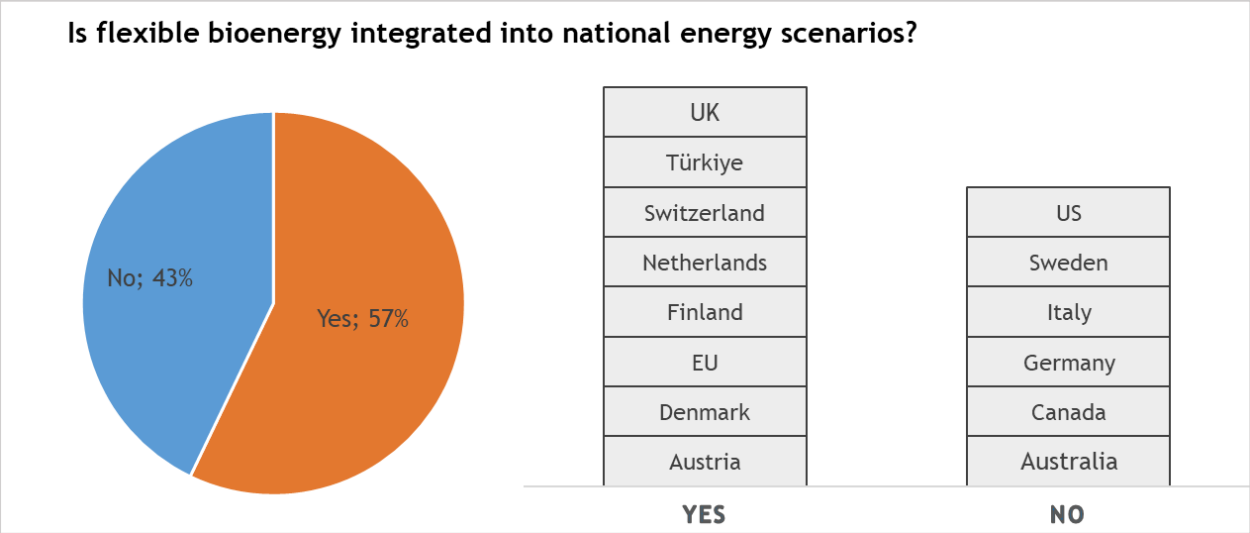

Figure 3: Share of flexible bioenergy integrated into national energy scenarios. Brazil not included.

In many of the countries, bioenergy is considered as well developed as it is already and it is seen that it will be exploited to cover energy demand flexibly (e.g. Austria, Finland). For example, heat demand is covered flexibly with wood fuel and renewable gases contribute to energy flexibility when injected to the grid and stored in large existing storage facilities in Austria. Biomass-fired generation with CCS (BECCS) is projected to be a significant source of flexible bioenergy for the net-zero scenario in Canada.

On the other hand, in some of the national scenarios (e.g., Germany, Italy), biomass does not play a significant role as a flexibility option in the future. In long-term-scenarios for Germany provided by Fraunhofer[3], it is stated that biomass resources are limited and will be needed for hard to electrify applications in the heat and transport sector. In Italy, the role of bioenergy in the power sector is often seen as somehow slowly declining[4], while to some extent its possible role in the balancing market is recognized[5]. In the UK, there are several national strategies that integrate bioenergy, but not necessarily under a flexibility umbrella, since it is uncertain whether biomass resources are available to the UK and which sector(s) biomass can be used most efficiently to meet the net zero target (according to UK's response).

The demand for flexible energy is included in scenarios of many countries (e.g., due to energy security in Australia), but means do not necessarily focus on bioenergy. Flexible bioenergy is often not explicitly or

[3] https://www.langfristszenarien.de/enertile-explorer-wAssets/docs/LFS3_T45_Webinar_Angebot_Nov_2022_final_webinarversion.pdf
[4] https://dgsaie.mise.gov.it/pub/sen/relazioni/relazione_annuale_situazione_energetica_nazionale_dati_2021.pdf
[5] https://download.terna.it/terna/Piano_Sviluppo_2021_8d94126f94dc233.pdf

adequately addressed by the national energy scenarios. In Finland, the flexibility characteristics of technologies have been integrated into a background model generating the scenarios at least to an extent and thereby, into scenarios presented in the background study of the national climate and energy strategy[6], but not all the flexible bioenergy options that can be envisaged have been integrated there. The EU strategy on energy system integration[7] addresses, in the broader sense, all the items listed in this report, but lacks in presenting specific business models with flexible bioenergy systems and their large-scale impact on the EU27.

5. Policy instruments driving flexibility

RELEVANCE OF NATIONAL AND SUPRANATIONAL INTERNATIONAL POLICIES

An important question is **how best to improve the political framework—whether through national regulation or through overarching legislation, such as supranational or international regulations**. We posed this question to the countries surveyed. The majority view internal and external influences as equally significant (see Figure 4).

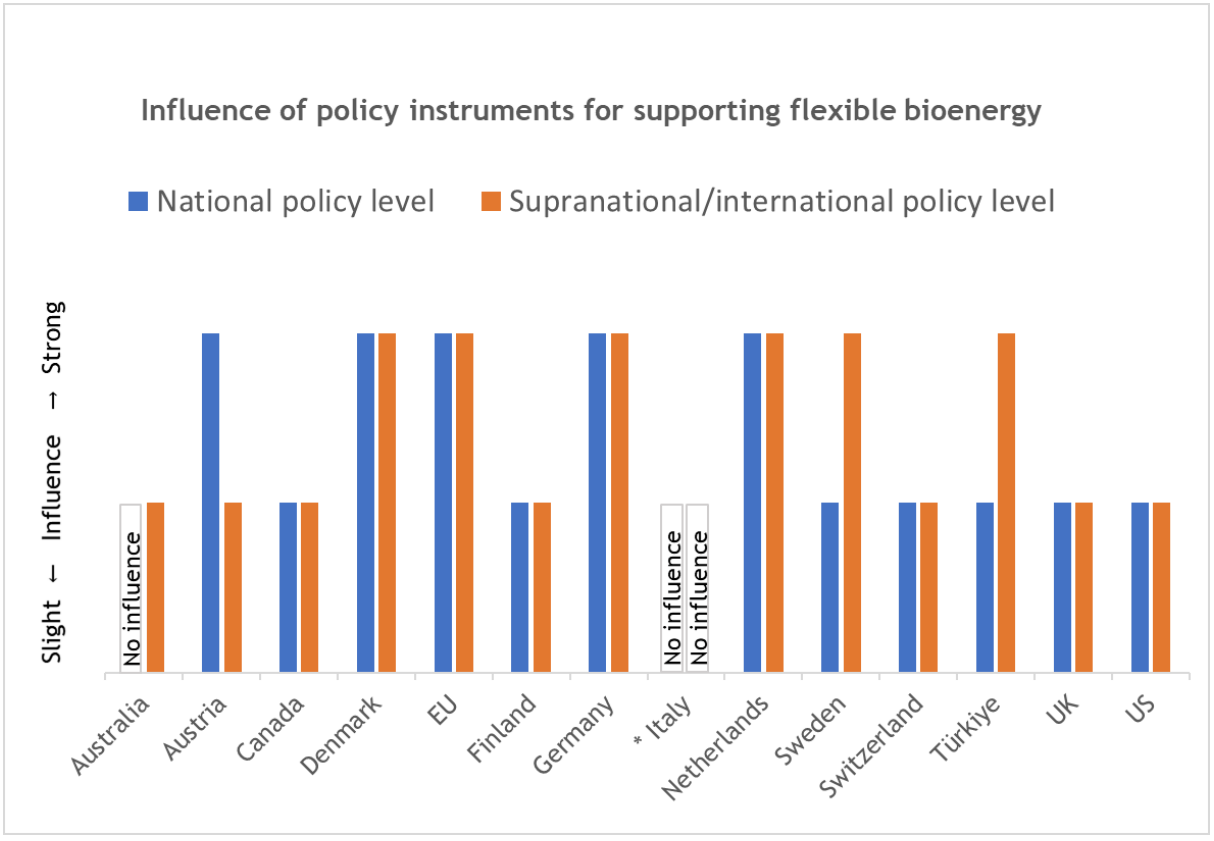

Figure 4: Influence of policy instruments (e.g., energy and climate policies, biomass strategy) for supporting flexible bioenergy in countries at the national and supranational/international level. Brazil not included.
* Italy updated its National Energy and Climate Plan (NECP) in 2024, introducing significant changes, particularly in recognizing hydrogen of biological origin for use in the transport sector, either directly or for biofuel production. As a result, a current update would see Italy with slight influence both for national and supranational levels.

[6] https://julkaisut.valtioneuvosto.fi/handle/10024/164323
[7] https://energy.ec.europa.eu/topics/energy-systems-integration/eu-strategy-energy-system-integration_en

Austria, however, asserts that 'Only intelligent national regulations can drive implementation.' Meanwhile, two countries, Sweden and Türkiye, regard supranational and international influences as particularly strong drivers. Sweden, for example, will likely focus on the EU's RED regulations, which currently have a substantial impact on Swedish forestry and bioeconomic activities. Türkiye responds to the question about national instruments as follows: Although certain incentives supporting renewable energy production encourage investors, market dynamics and economic barriers are the main drivers. As international incentives, it mentions the Paris Agreement, which Türkiye ratified in 2021, and the Green Deal.

The table in Appendix 2 - *Impact of policy instruments at national level and supra/international level* contains further information on the statements made by countries regarding the impact of political instruments and their role in shaping energy policies.

SYNERGIES BETWEEN POLICY INSTRUMENTS

We asked the countries: **Are there synergies between different policy instruments that support the implementation of flexible bioenergy**? Four countries and the European Commission responded to this question and identified various approaches and synergies.

- Austria notes that national regulations are strengthened by alignment with European regulations.
- Canada highlights numerous synergies among its policy tools — such as the Clean Fuels Fund, renewable portfolio standards, and Clean Fuel Regulations — that together drive technological innovation and R&D in bioenergy. Canada also emphasizes financial synergies, as funding initiatives, including those for Indigenous and remote communities, help reduce investment risks and promote bioenergy projects, particularly in areas facing energy reliability challenges.
- The European Commission sees synergies in increasing the share of renewable energy sources in line with EU targets, as well as in energy system integration and security strategies (e.g., REPowerEU).
- Sweden also acknowledges potential synergies but points out that policy efforts so far have largely focused on renewable energy production volumes rather than on system issues such as flexibility and capacity.
- The United Kingdom considers a revised Biomass Strategy as an opportunity to better align various sectoral strategies for biomass and bioenergy, fostering cross-sector synergies.

These responses reflect the different national and international approaches for creating synergies through policy instruments to strengthen the role of flexible bioenergy.

CONTRADICTIONS BETWEEN DIFFERENT POLICY INSTRUMENTS WHICH HINDER THE IMPLEMENTATION OF FLEXIBLE BIOENERGY

We investigated **whether contradictions between different policy instruments hinder the implementation of flexible bioenergy**. Responses were received from 10 out of 14 countries, including the European Commission, highlighting varying challenges across nations. The feedback mainly focused on practical issues, particularly regarding feedstock availability. As shown in detail in Annex 3, the primary concerns included uncertainties about resource availability and the division of responsibilities between ministries, especially in relation to EU-level directives. Common themes included contradicting objectives in policy frameworks, conflicting sustainability criteria, regulatory obstacles, and political resistance, e.g. to implement EU related actions.

- Austria: Strong NGO (non-governmental organization) push against bioenergy, limiting available biomass due to Natura 2000 expansion.
- Canada: Lack of clear bioenergy policy creating investment uncertainty.
- Denmark: Exporting bioethanol contradicts domestic biofuel targets.
- EC: Linear business models restrict bioenergy's climate benefits.
- Finland: Quotas and tariffs hinder flexibility.
- Germany: Regulatory complexity limits plant expansion.
- Netherlands: Public resistance limits bioenergy potential.
- Sweden: RED III restrictions and production-only rules hinder investments.
- Switzerland: Lack of PtX plant exemptions.
- UK: Fragmented policies lead to market distortions.

The responses from these countries reveal significant contradictions between different policy instruments, ranging from inconsistent sustainability criteria to regulatory hurdles and political resistance. These discrepancies pose challenges to the effective integration of flexible bioenergy systems. To enable the successful implementation of flexible bioenergy, more coherent, harmonized policies and frameworks are needed to overcome these barriers and maximize the potential of bioenergy across different sectors.

VALUE OF FLEXIBLE BIOENERGY IN POLICY DOCUMENTS

In the survey, countries were also asked **whether the value of flexible bioenergy is referenced in their policy documents.** As shown in *Figure 5*, the importance of flexibility is already documented in the policy frameworks of four parties: Canada, Denmark, the European Commission, and the Netherlands. These parties have acknowledged the role of flexible bioenergy within their energy strategies, highlighting a growing recognition of energy flexibility as essential to their approach to energy security and sustainability.

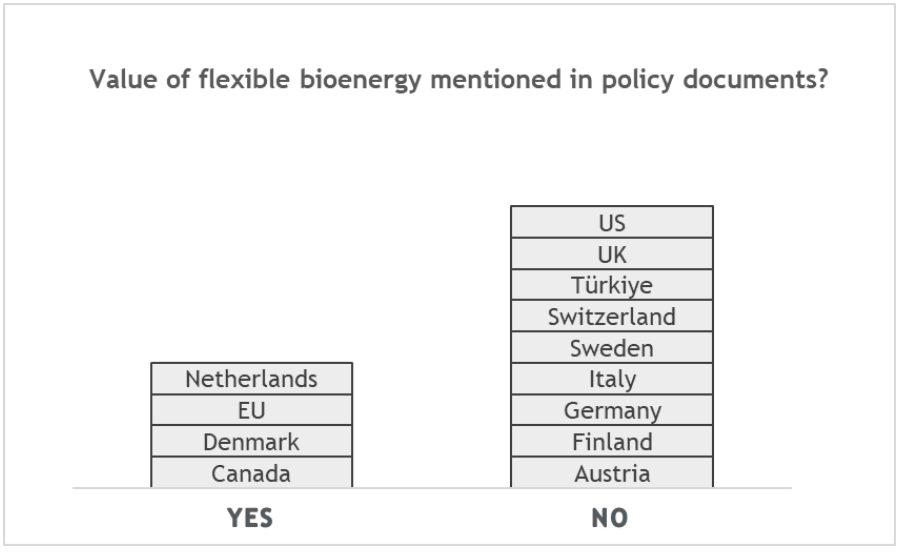

Figure 5: Answers of countries if the value of flexible bioenergy is mentioned in national policy documents. Australia and Brazil not included.

Some countries, such as the United States, explicitly responded with a 'No' when asked whether the value of flexible bioenergy is a notable point of discussion in their policy documents. Others, like Austria, Germany, and Switzerland, did not provide further comments on this issue. Several countries acknowledge the value of flexibility in general across various national documents, though they do not specifically address bioenergy flexibility in detail. For instance:

- Finland recognizes the need for flexibility overall.
- Italy is taking steps to support flexibility through NRA Act No. 352/2021/R/EEL, which introduces pilot projects for ancillary services at the DSO level, potentially enabling more biomass-powered plants to participate in flexibility markets.
- The Netherlands often acknowledges the value of flexible bioenergy in policy documents, though the flexibility aspect is rarely addressed explicitly.
- Sweden includes flexibility considerations in recent energy scenarios by the Swedish Energy Agency (ER 2023:07) for 2023–2050, though the focus is limited to end-user flexibility.
- Türkiye provides a "partially Yes" response. While flexible bioenergy is not explicitly mentioned in its main energy policy document, the Türkiye National Energy Plan, bioenergy considerations are evident in the Turkish Energy Model. This model, developed with EU funding under the Long-Term Energy Scenarios and Capacity Building Project, is designed to create long-term energy forecasts and includes a sectoral analysis framework that considers various energy sources, including bioenergy.
- The United Kingdom acknowledges bioenergy's potential flexibility in general terms but does not align with the report's definition of flexible bioenergy. The Climate Change Committee (CCC) emphasizes BECCS (Bioenergy with Carbon Capture and Storage) as a key but relatively inflexible solution due to biomass feedstock availability and the UK's current subsidy regime, which incentivizes continuous operation. However, in their 2021 Independent Assessment of the UK's Net Zero Strategy, they refer to the opportunities that biomass can provide to areas such as agriculture and land use, calling on the UK's revised Biomass Strategy (which was due in 2022) to clarify the variety of options for biomass in the UK. In two reports, the CCC outlines the importance of flexibility in the energy system and bioenergy, but not together. The National Grid's Future Energy Scenarios also acknowledge the flexibility of bioenergy to contribute to decarbonisation in transport and heating, but focus on negative emission potential of BECCS, supplied primarily by domestic biomass feedstock. In their 'Leading the way' scenario, which outlines the fastest pathway for decarbonising the UK energy system, the role of flexible bioenergy is limited as the focus is on BECCS.

These responses suggest that while there is a broad awareness of the need for flexibility in energy systems, few countries provide explicit descriptions of the diverse applications of flexible bioenergy. Australia and Brazil did not respond to this question.

6. Drivers for flexible bioenergy implementation

When asked about **the strongest drivers for flexible bioenergy**, most countries identified climate neutrality targets as the primary driver (Figure 6), followed by energy prices and energy security. In contrast, dedicated flexible energy targets, specific market designs, and fossil fuel phase-out strategies or shortages are seen as having relatively minor influence.

Austria, Brazil, Germany, Türkiye, and the United Kingdom identified the strongest drivers for flexible bioenergy among the options presented (Figure 6), while Australia, Italy, and the United States did not consider any of the given drivers as particularly strong. Canada, Denmark, the European Commission, Finland, the Netherlands, Sweden, and Switzerland see some drivers as strong and others as less influential.

It's important to note that this survey reflects expert assessments, with variations in evaluation criteria among experts.

In general, climate neutrality targets, energy prices, and energy security were considered as the most important strong drivers for flexible bioenergy implementation, while renewable energy targets, energy policies, and energy market design were evaluated as weak drivers. E.g., Sweden and the UK state that more bioelectricity is planned, and in Sweden this is particularly to complement increasing amount electricity generated from of wind power.

In Denmark, the Russian Invasion of Ukraine has been a strong driver to further increase the deployment of biogas, increasing its share of the total gas consumption from 20% in 2021 to 70% in 2030. This will also support technology development, such as PtX solutions, to upgrade biogas and boost the methane yield. This connects to energy security. In Sweden, base load power capacity is needed locally in cities and certain regions to support energy security. Türkiye mentions energy dependency, and thus the necessity to produce substitutes for fossil fuels, as the strongest driver for flexible bioenergy.

Energy prices also divide the respondents significantly. While many view them as strong drivers, the European Commission and the Netherlands consider them weak drivers, and some countries— Australia, Canada, Italy, Switzerland, and the United States—do not see them as drivers at all.

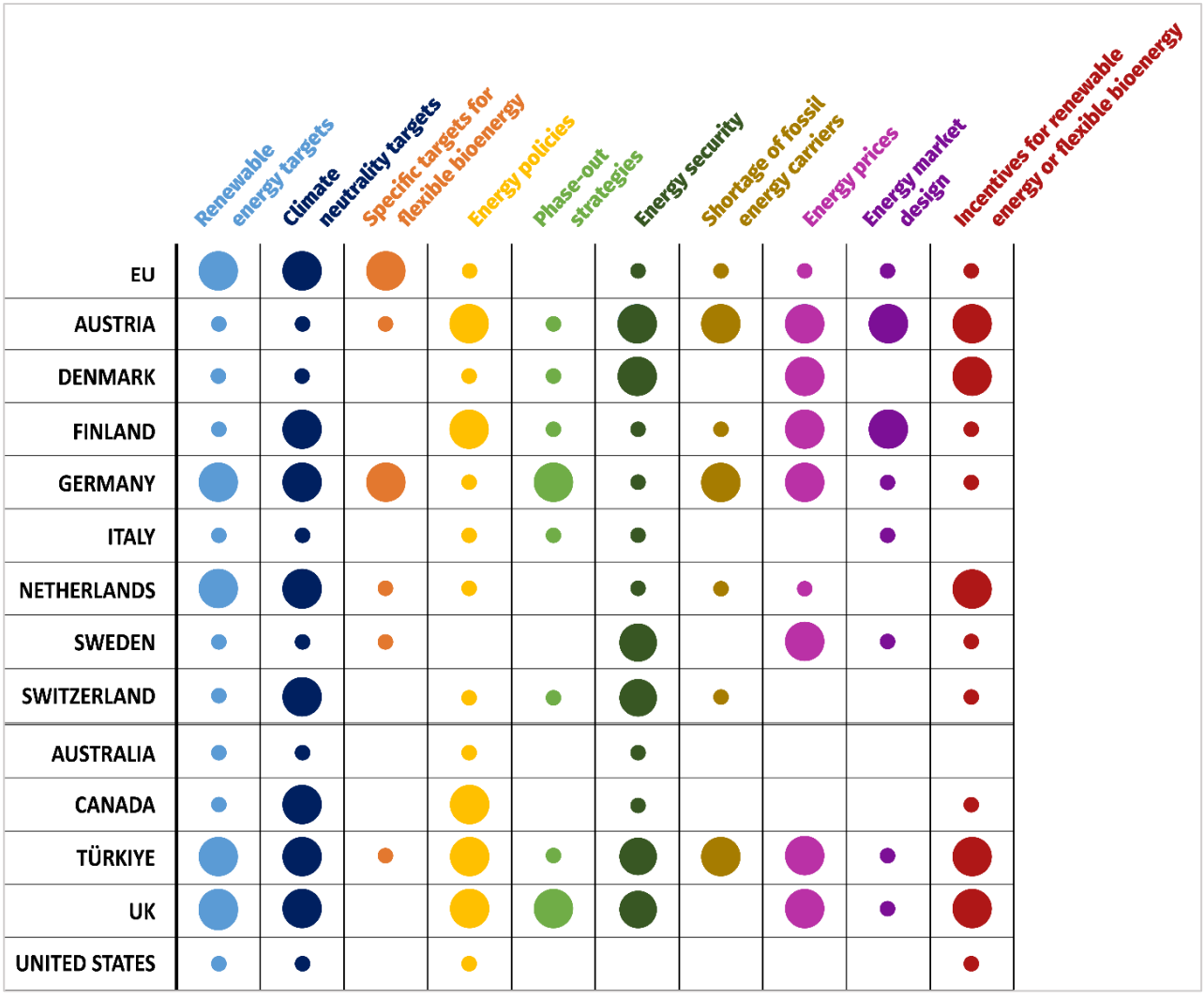

Figure 6: Strength of different drivers for flexible bioenergy implementation during 2020-2022 in different countries. Large bubbles represent strong drivers, small bubbles are weak drivers. Brazil not included.

From the assessed countries, only Germany and EC on the overall European Union's level considered specific targets for flexible bioenergy as a strong driver. In Germany, the Renewable Energies Act (REA)[8] requires bioenergy plants to become more flexible and it is planned to ensure 8.4 GW of flexible installed capacity in 2030. However, many countries have policies that can potentially support deployment of flexible bioenergy.
Phase-out strategies for fossil fuel use do not seem to be a strong driver for flexible bioenergy. Instead, in the Netherlands, they are considered as a limiting factor. In Sweden, phase-out strategies are not a driver as fossil fuels have already been substituted in heat and power production. However, for example Finland, that will phase out coal for power generation by 2029, mentions bioenergy as one of the possible substitutes for coal, but considers this only as a weak driver for flexible bioenergy.

7. Opportunities for flexible bioenergy systems

Flexible bioenergy systems present numerous opportunities to advance energy integration and sustainability:

1. Sector Coupling: They act as a bridge between energy sectors, enabling chemical storage of electricity through synergies with e-fuels and hydrogen, thus optimizing the use of intermittent renewables like wind and solar.
2. Grid Stabilization: Bioenergy complements wind and solar by providing low-carbon, dispatchable energy for residual load balancing, enhancing grid reliability during peak demand or low renewable output.
3. Sustainable Fuels: They offer decarbonization options for challenging sectors, such as aviation and heavy industry, where alternatives like electrification are not feasible or costly.
4. Industrial Heat: Bioenergy provides high-temperature heat for industrial processes and low-temperature heat for buildings during colder months, addressing seasonal energy demands.
5. Integrated Production: High-efficiency plants can coproduce electricity, heat, and biofuels, maximizing resource use and efficiency while supporting circular economies by valorising biogenic residues and waste.
6. Carbon and Hydrogen Synergies: Bioenergy systems integrate well with CCUS technologies and hydrogen value chains, enhancing carbon utilization and storage while expanding renewable energy solutions.

These capabilities position bioenergy as a cornerstone for a low-carbon, resilient energy future.

Respondents were asked to identify the three most important opportunities for flexible bioenergy systems in their country for the time horizons 2020–2030 and 2030–2050, choosing from 12 predefined topics. The descriptions of these options are provided in Figure 7, and the ranking results are presented in Figure 8.

[8] https://www.gesetze-im-internet.de/eeg_2014/EEG_2023.pdf

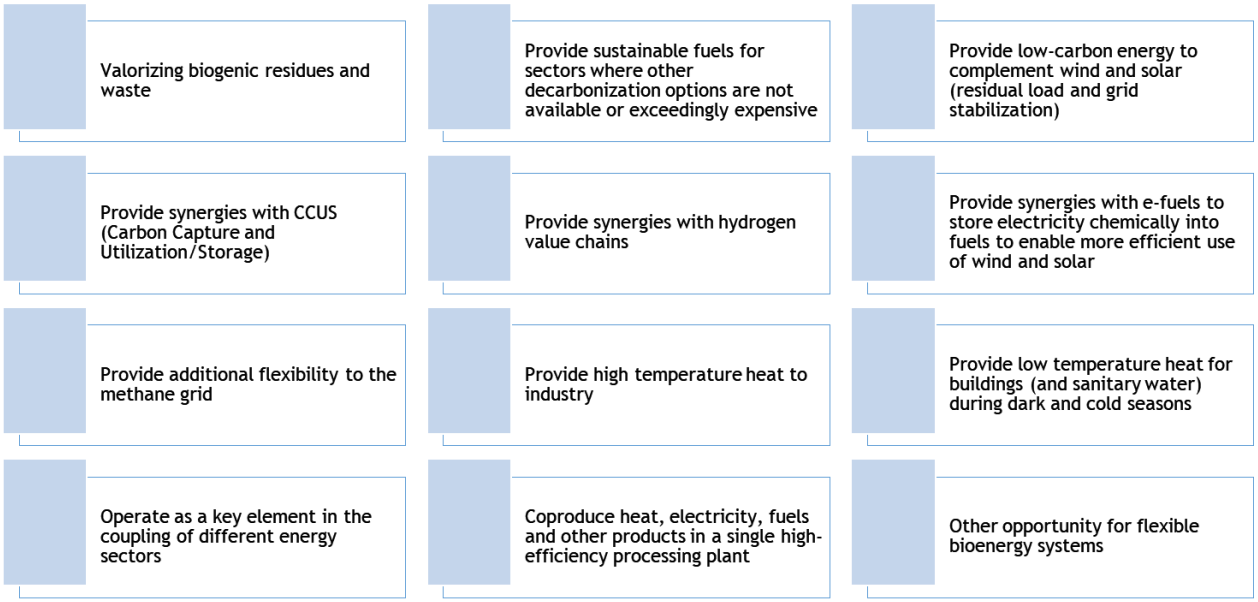

Figure 7: Overview of the selection of predefined options for flexible bioenergy systems that could be chosen by the countries for the 2020-2030 and 2030-2050 time horizons.

By the **end of this decade**, three key focus areas stand out: valorising biogenic residues and waste, providing sustainable fuels for sectors with limited or costly decarbonization options, and delivering low-carbon energy to complement wind and solar through residual load and grid stabilization. Other opportunities, such as adding flexibility to the methane grid, supplying low-temperature heat for buildings during dark and cold seasons, and providing high-temperature heat to industry, are also highlighted. Coproducing heat, electricity, fuels, and other products in high-efficiency plants begins to emerge as an important opportunity but is less emphasized in the longer term.

For the **period 2030-2050**, providing sustainable fuels for sectors with limited or expensive decarbonization options remains the top priority. Additionally, increased focus is placed on creating synergies with hydrogen value chains, CCUS (Carbon Capture and Utilization/Storage), and e-fuels to enable the efficient storage of wind and solar energy as chemical fuels. While providing low-carbon energy to complement wind and solar continues to be important, long-term opportunities like acting as a key element in sector coupling gain prominence. Providing additional flexibility to the methane grid and high-temperature heat for industry also retain significance. On the other hand, opportunities like coproducing heat, electricity, fuels, and other products in high-efficiency plants, as well as valorising biogenic residues and waste, become less relevant.

Notably, the experts did not prioritize providing low-temperature heat for buildings and sanitary water during dark and cold seasons for 2030–2050. However, this outcome may be influenced by the design of the questionnaire, making it difficult to interpret. The Netherlands, for example, highlighted the challenge of limiting their selection to only three opportunities. They emphasized that some options excluded from their top priorities remain highly relevant for the 2030–2050 timeframe. Specifically, they noted that providing low-carbon energy to complement wind and solar, particularly for residual load coverage and grid stabilization, might still play a significant role in their energy strategy. Additionally, synergies with hydrogen value chains may gain importance as the hydrogen economy develops. Valorising biogenic residues and waste, in their view, will always remain relevant due to its potential for resource efficiency and circular economy benefits. These considerations underscore the need to interpret the results cautiously, as the questionnaire design may not fully capture the complexities and nuances of long-term planning in all countries.

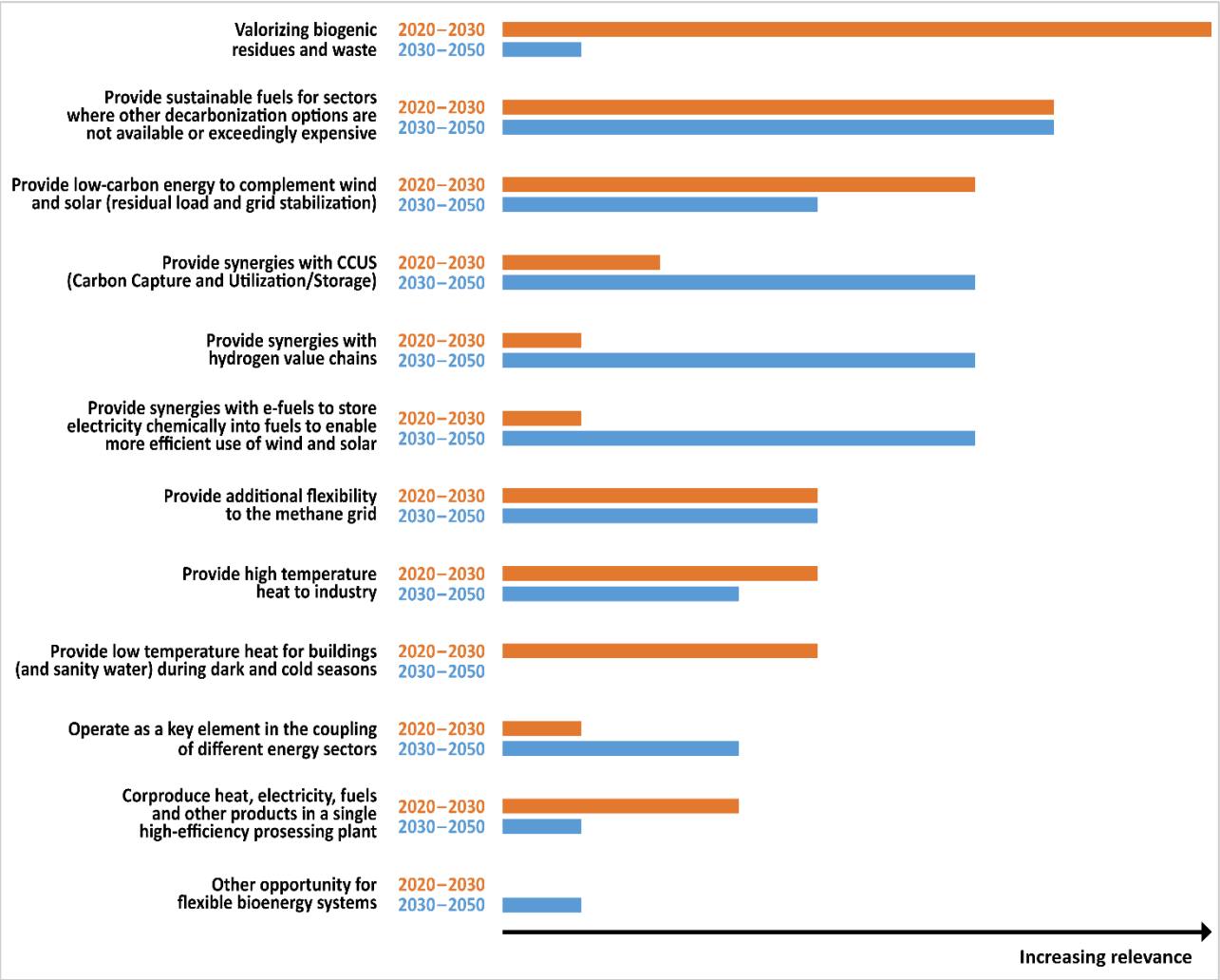

Figure 8: The most important opportunities for flexible bioenergy systems selected by 14 parties for the time horizons 2020-2030 and 2030-2050. Analysis considers answers from following countries: Austria, Australia, Brazil, Canada, Denmark, Finland, Germany, Italy, Sweden, Switzerland, The Netherlands, Türkiye, United Kingdom, and the European Commission.

One notable observation is that while providing sustainable fuels for sectors with limited or expensive decarbonization options remains crucial across **both periods,** biogenic residue valorisation diminishes in relevance by 2050. Nevertheless, these findings should be approached with caution, considering the limitations inherent in the questionnaire design.

In summary, the context highlights a shift from the short-term adoption of flexible bioenergy systems to their long-term integration into broader energy and decarbonization frameworks, focusing on strategic goals like sector coupling, hydrogen synergies, and e-fuels.

Furthermore, the respondents were asked **to rank three energy and three other economic sectors that can benefit the most of flexible bioenergy in the future**. Results can be seen in Figure 9.

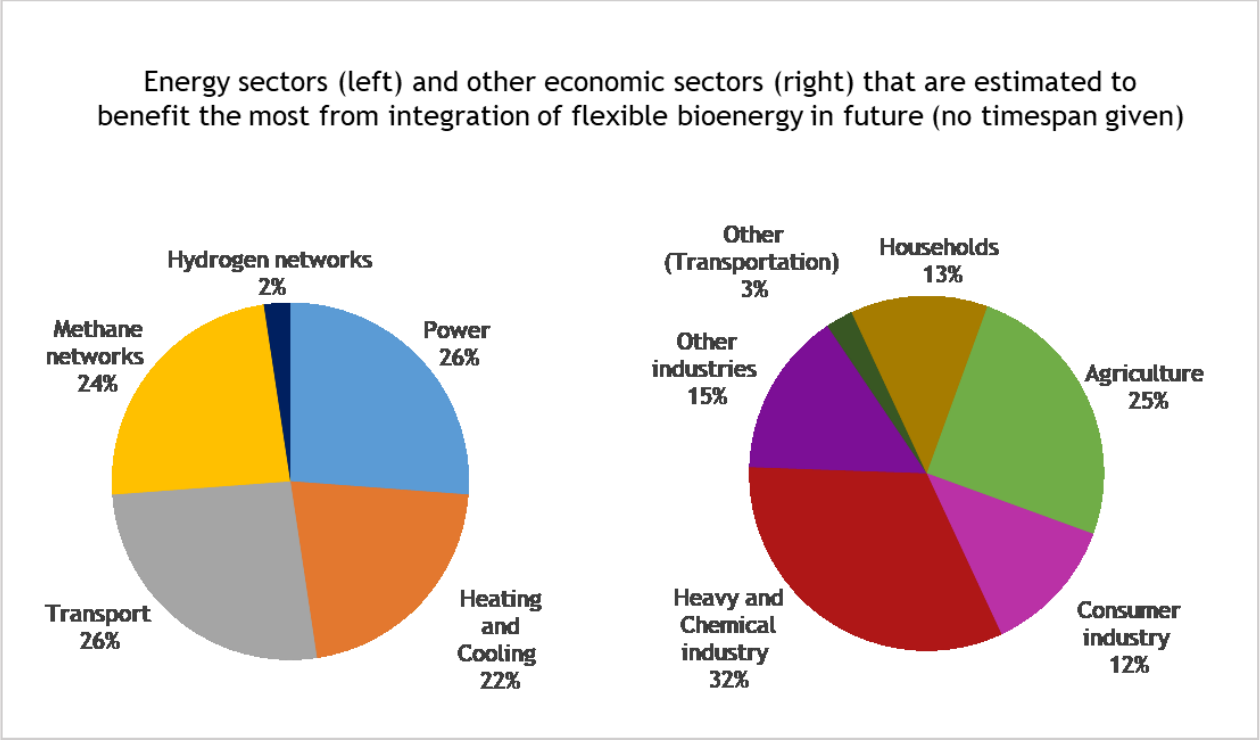

Figure 9: Energy sectors (left side) and other economic sectors (right side) that are estimated to benefit from integration of flexible bioenergy in future, shown in % for 14 parties. The United States are not included.

All energy sectors, except hydrogen networks, were ranked fairly evenly in terms of benefiting from flexible bioenergy in the future. Notably, the growing and expected dominant role of synergies between flexible bioenergy, hydrogen, and CCS is significant. This combination is seen as a strong contributor to decarbonizing "hard-to-defossilize" energy sectors[9].

Of the six economic sectors considered, heavy and chemical industries were ranked as the most likely to benefit from the integration of flexible bioenergy, followed closely by agriculture and other industries. Notably, the public sector was not seen as a key beneficiary at all. Türkiye identified transportation as another potential sector that could benefit from flexible bioenergy, though without providing further details. When looking at the future benefits, the picture is diverse, reflecting the varied expectations across countries. In comparison to the current situation, the responses suggest a clear and strong expectation that many sectors will undergo significant transitions in the coming years to meet net-zero goals. This indicates that flexible bioenergy is seen as a crucial element in these transitions.

[9] For further reading about new challenges when combining these three system services and utilise their potential also see: Hennig, Christiane; Olsson, Olle; Thrän, Daniela; Mäki, Elina (2023): BECCUS and flexible bioenergy – finding the balance. Contribution of IEA Bioenergy Task 44 & Task 40 to the Inter-task project Deployment of BECCUS value chains. IEA Bioenergy. [s.l.] (IEA Bioenergy Task 40). Online available https://www.ieabioenergy.com/wp-content/uploads/2021/05/Hennig-Olsson-2023-Bio-CCUS-and-flexibility_final_for-upload.pdf.

8. Synergies between hydrogen and bioenergy

HYDROGEN IN THE NATIONAL ENERGY SCENARIOS

In the majority of the surveyed countries[10], renewable hydrogen is integrated into national energy scenarios. Many have adopted comprehensive clean hydrogen strategies, including Austria, Canada, Germany, Italy (preliminary), Sweden, Türkiye, and the UK.

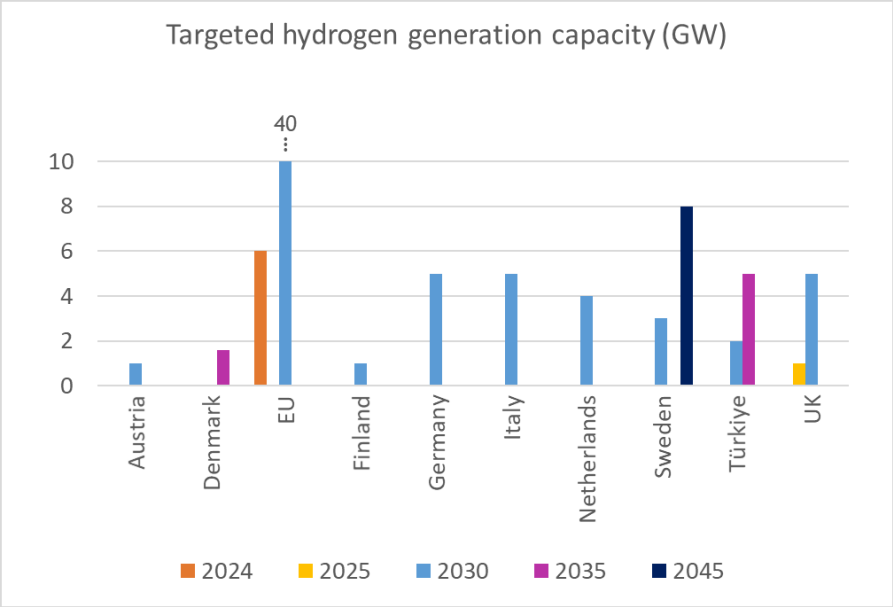

Figure 10: Targeted hydrogen generation capacity in GW in responded countries (10 out of 15 parties).

At the EU level, the REPowerEU plan (Publications Office of the European Union 2022) outlines specific actions to accelerate clean hydrogen adoption, building on the Green Deal (European Commission: Directorate-General for Communication 2021) and its Hydrogen Strategy (Opinion of the European Economic and Social Committee 2021). These strategies set ambitious targets for hydrogen production (Figure 10). For instance, Canada (Hydrogen Strategy for Canada 2020) aims to deliver up to 30% of its end-use energy through hydrogen, potentially cutting GHG emissions by 190 Mt-CO_2 annually by 2050, while Austria envisions hydrogen as a core element of its energy system.

The preceding section highlights hydrogen strategies and presents a figure summarizing the targeted hydrogen generation capacity in gigawatts across several countries. Building on this, the following section transitions to focus specifically on green hydrogen. It examines its envisioned role in national energy scenarios and outlines the varied approaches countries plan to implement for its utilization.

Green hydrogen is foreseen to be exploited with diverse manners in the national energy scenarios:

- In research and development, piloting activities and demonstrations of emerging applications,
- In energy supply among other renewable gases and instead of natural gas,
- As grid power storage and in peak-load balancing,
- In increasing energy system flexibility,

[10] Brazil N/A

- In industrial uses as such and blended with natural gas,
- In decarbonisation of energy-intensive industry,
- Replacing fossil-based hydrogen in energy-intensive industry,
- And in decarbonization of transport/mobility sector (aviation, shipping, medium and heavy duty on-road transport, public and private transport).

FORESEEN CHALLENGES IN THE HYDROGEN INTEGRATION

Respondents observe multiple challenges in reaching the green hydrogen production targets and exploiting the produced hydrogen. Firstly, it is not clear if enough renewable electricity will be available for the planned electrolyser capacity/hydrogen production. To reach the political ambitions it is pointed out that improved framework conditions (e.g., tariffs) and a political decision on framework conditions for a hydrogen infrastructure are essential. Regarding the hydrogen supply chain, it is indicated that investment in research and development is needed first. Coordinating the timing of supply and distribution infrastructure development with growth in demand is considered as a complex task that requires a regionally focused approach.

Developments to convert potential uses of green hydrogen into concrete projects are still in an early stage. Supply of low carbon intensity hydrogen is currently limited, hindering the rollout of commercial and pilot end-use applications. Achieving scale in production and application is crucial for economic viability. Hydrogen is not yet cost-competitive with conventional fuels and the cost of green hydrogen production must be reduced. Furthermore, some hydrogen and fuel cell technologies are commercially ready, but sustained R&D support is needed to reduce costs and develop solutions for less mature applications.

LINKAGES OF HYDROGEN IMPLEMENTATION TO BIOMASS OR BIOENERGY

Approximately one-third of the surveyed countries report a linkage between the implementation of hydrogen and biomass or bioenergy (Figure 11). Austria's Hydrogen Strategy[11] explicitly mentions biogenic hydrogen. In Finland, hydrogen from electrolysers is linked to biofuels production, using biogenic CO_2 from bio-CHP plants. Sweden provides industrial examples, such as Cortus at Höganäs, showcasing biobased hydrogen production. Türkiye's roadmap sketches biomass gasification, biogas pyrolysis, and reforming systems for green hydrogen production (technologies roadmap[12]) but focuses more on organic waste inventories and pilot plants. The UK Hydrogen Strategy[13] refers to the upcoming UK Biomass Strategy, also the H_2 and BECCS capacity is expected to contribute a combined 473 MW by 2030[13]. Although Italy answered "no" to the specific question, its Preliminary Hydrogen Research Strategy[14] still notes synergies between hydrogen and bioenergy. Similarly, in the Netherlands, industrial players like Tata Steel are exploring biobased hydrogen options.

[11] Federal Ministry Republic of Austria. 2022. Hydrogen Strategy for Austria. Vienna, Austria.
[12] Republic of Türkiye ministry of energy and natural resources. Türkiye Hydrogen production technologies strategy and roadmap. Available at: https://enerji.gov.tr/Media/Dizin/SGB/en/HSP_en/ETKB_Hydrogen_T_Strategies.pdf
[13] HM Govenment. 2021. UK Hydrogen strategy. CP 475. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1175494/UK-Hydrogen-Strategy_web.pdf
[14] Ministero dello sviluppo economico. 2020. Strategia Nazionale Idrogeno Linee Guida Preliminari. Available at: https://www.mimit.gov.it/images/stories/documenti/Strategia_Nazionale_Idrogeno_Linee_guida_preliminari_nov20.pdf

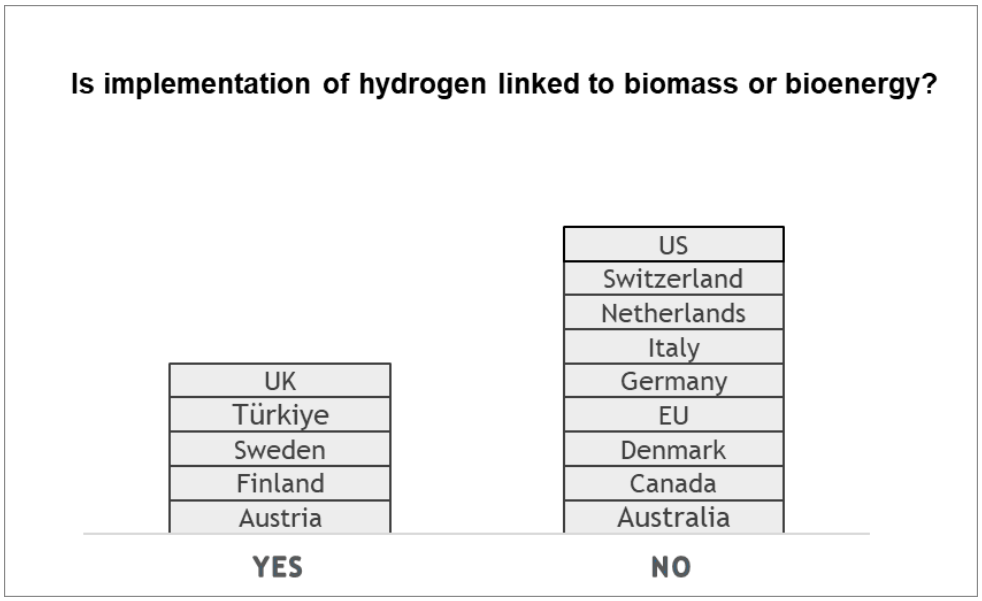

Figure 11: Hydrogen implementation linked to biomass or bioenergy in the respondent countries. Brazil not included.

POSSIBLE AND ALREADY ESTABLISHED SYNERGIES BETWEEN HYDROGEN AND BIOENERGY

Countries identified where they see possible synergies between hydrogen and bioenergy across multiple dimensions: technical performance, infrastructure, GHG balance, sustainability, value chain, and business models. The strongest synergies were observed in technical performance, value chain, and business models, while fewer were noted in GHG balance, infrastructure, and sustainability. Detailed insights are provided in Figure 12.

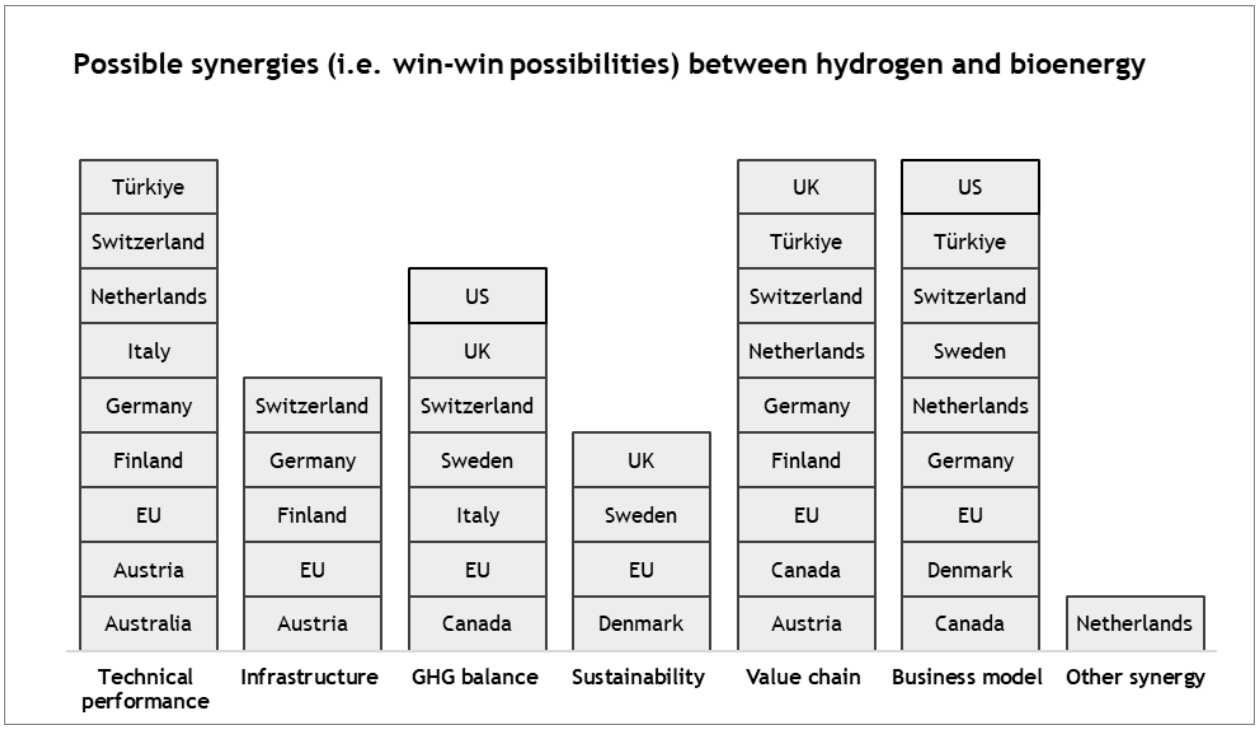

Figure 12: Areas of possible synergies between hydrogen and bioenergy. Brazil not included.

Green hydrogen can serve as either a product of biomass processing or a feedstock for biomass conversion processes, enabling the development of diverse business models. Business opportunities include storing hydrogen in carbon-based chemical commodities, maximizing biomass carbon utilization, and integrating power-to-gas or power-to-methanol technologies.

Existing examples of business models exploiting these synergies include Sweden, where projects focus on producing synthetic fuels using renewable hydrogen and biogenic CO_2 from bio-CHP, or Fischer-Tropsch processes. In Denmark, hydrogen-related synergies are found in biogas (in-situ and ex-situ) upgrading, converting biogenic CO_2 into methanol, and producing sustainable aviation fuels (SAF).

From a technical perspective, synergies are mainly associated with biofuel production, such as:

- Biogas upgrading or enhancing biomethane production with hydrogen,
- Hydrogen integration into advanced biofuel processes, such as hydrodeoxygenation of pyrolysis bio-oil and catalytic hydropyrolysis,
- Biomethane pyrolysis to extract hydrogen while capturing CO_2 as biochar.

The Netherlands highlights how hydrogen integration into biofuel production could ensure stable demand for renewable hydrogen, supporting large electrolysers to operate at constant loads. These synergies demonstrate significant potential for combining hydrogen and bioenergy to enhance both technical performance and economic viability.

Respondents highlighted value chain synergies primarily within the conversion stage, particularly in advanced biofuel production, and in chemicals and steel manufacturing. Four countries (Austria, Finland, Germany and Switzerland), and the European Commission identified common and existing gas infrastructure for hydrogen, biomethane, and natural gas as a key infrastructure synergy. Some respondents noted that this synergy is already partially exploited and speculated that large-scale hydrogen production from biomass could accelerate the development of hydrogen markets and applications.

In terms of GHG balance, synergies are seen in producing fuels with very low or negative emissions through technologies such as bioenergy carbon capture and utilization (BECCU) and power-to-gas systems in biogas upgrading. Regarding sustainability, synergies include improving feedstock sustainability, increasing synthetic fuel conversion efficiency, and utilizing bioenergy to provide fossil-free carbon for sustainable aviation fuels (SAFs) and green marine fuels. The later are specifically mentioned. Residual feedstocks and waste reduction are also cited as pathways to enhancing sustainability.

These synergies demonstrate the potential for integrated hydrogen and bioenergy systems to advance decarbonization while leveraging existing infrastructure and improving resource efficiency.

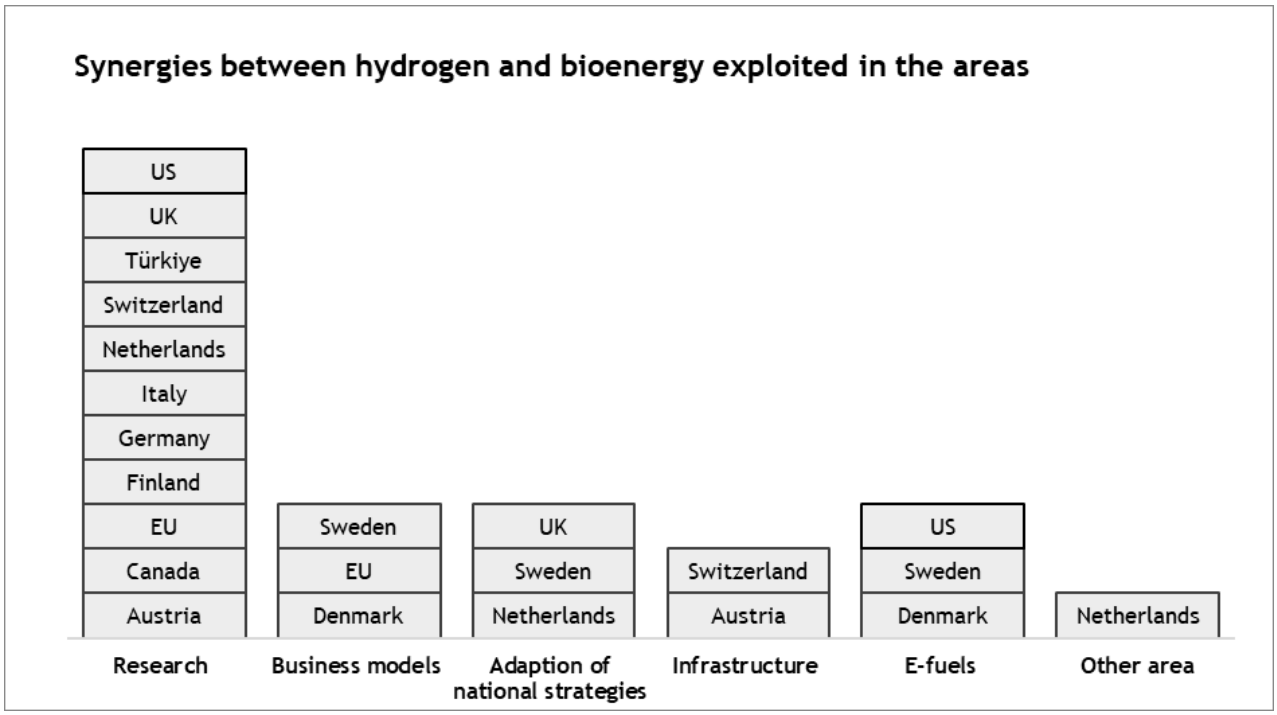

Figure 13: Areas, in which possible synergies between hydrogen and bioenergy are already exploited. Australia and Brazil not included.

In most participating countries, research on synergies between hydrogen and bioenergy is actively pursued, as shown in Figure 13. Research organizations and ongoing R&D projects are prominent in this area. At the EU level, synergies are being explored in the development of renewable synthetic fuels. In the US, extensive research and development is underway in the area of bioenergy using H_2 as part of the pathway, either through a conventional route such as hydrotreating or through a novel mechanism such as e-fuel production from CO_2. Several countries highlight specific research activities: Finland and Austria report ongoing studies, while the UK focuses on a strong theoretical understanding at lower technology readiness levels (TRL). Notable examples include Switzerland's work on power-to-methane and methanol from biogenic CO_2, considerable research efforts are taking place concerning the production of hydrogen from biomass in Türkiye.

9. Conclusion

Flexible bioenergy is seen as a necessary element and an important enabler of the transition of energy systems towards net zero among the surveyed stakeholders. Figure 14 summarizes the key findings by combining the most relevant results. It highlights the integration of hydrogen (see also on page 24) and flexible bioenergy (see also in Figure 3) into national energy scenarios across different countries, and illustrates the reported linkages between the implementation of hydrogen and biomass or bioenergy (see also in Figure 11). 8 of the 14 countries have considered not only flexible bioenergy, but also hydrogen in the longer-term scenarios and expect future benefits. This comparison underscores the interconnected role of hydrogen and bioenergy in shaping future energy strategies. While green hydrogen strategies go for high capacities, flexible bioenergy is a smaller, but also in many cases cheaper option (Millinger et al. 2023; Esmaeili Aliabadi et al. 2024; Meisel et al. 2024).

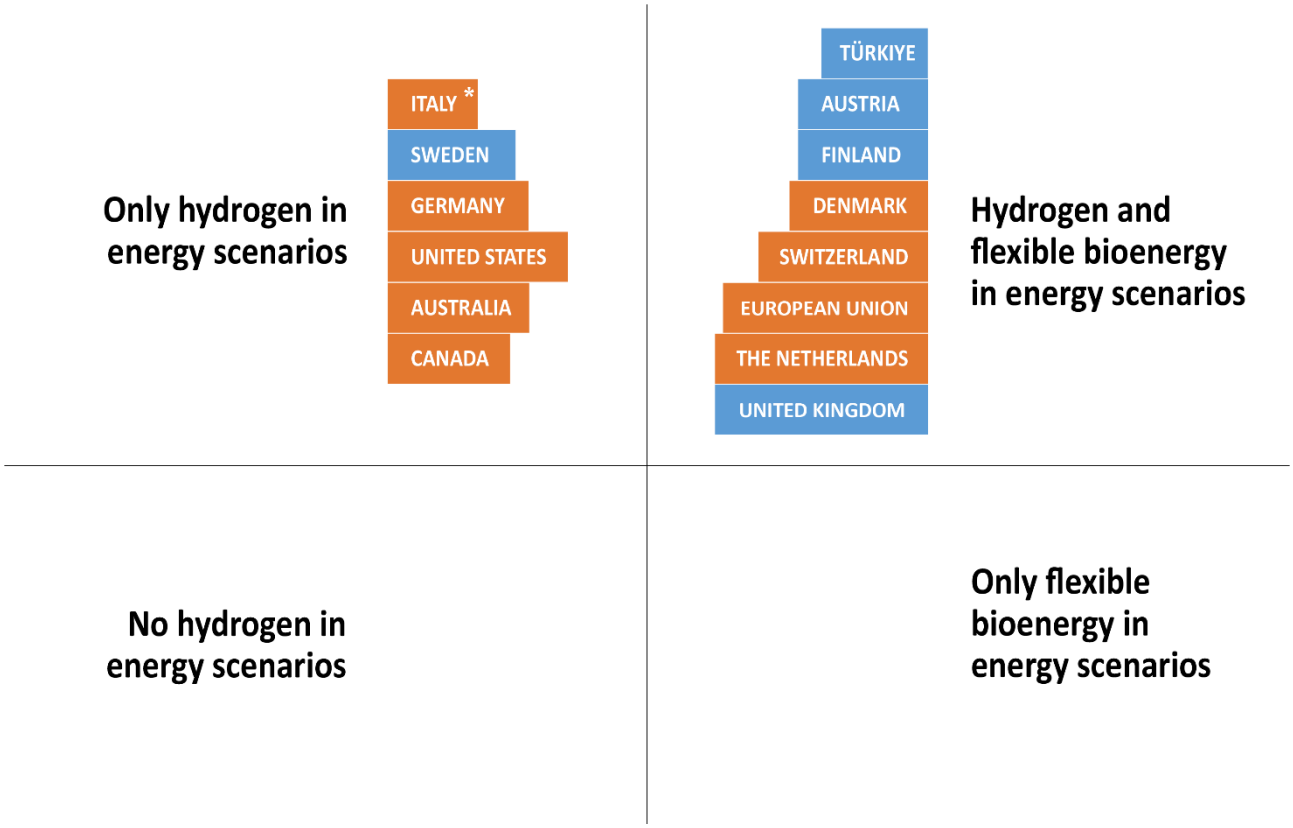

Figure 14: Overview of hydrogen and/or flexible bioenergy integrated in energy scenarios in different countries (see also Figure 3). Brazil not included.
Colours distinguish between countries, which see a link between flexible bioenergy and hydrogen (in blue) and countries which do not see this link (in orange) (see also Figure 11). * Italy updated its National Energy and Climate Plan (NECP) in 2024, introducing significant changes, particularly in recognizing hydrogen of biological origin for use in the transport sector, either directly or for biofuel production. As a result, a current update would see Italy change position in the graphic to “Hydrogen and flex. bioenergy in energy scenarios” box.

However, due to the uncertainties in biomass availability the leverage of this option is not very clear in many countries. Here possible synergies between flexible energy provision and the biomass use are not very well considered yet: If bioenergy is much more focused on times with low availability of VREs and high energy prices, bioenergy plant operation can be successful also with a lower number of full load hours, and a better contribution of the limited biomass. Beyond just compensating wind and solar in the power sector, interesting examples for the heat sector are two-phase digestors with biochar instead of

single phase digestors, heat pumps with bioenergy for industrial high temperature heat, harvesting waste heat from flue gases. More elaboration is needed regarding if and how we can describe the added value of flexible bioenergy for the overall energy system. First analyses of this added value for certain countries is published under the Task 44 upcoming report "*The value of flexible bioenergy",* soon available at Task 44 homepage (https://task44.ieabioenergy.com/iea-publications/).

But there are also still uncertainties about sectors with the highest benefit from flexible bioenergy related to the role of it in the longer term. The different expectations between the countries can be explained by (1) different stage of energy transition from fossil to renewables, or (2) different renewable energy potentials (i.e. hydropower, biomass) and energy infrastructures (i.e. district heating systems). In addition, there are uncertainties in the development of competing flexibilization solutions such as demand side management, bi-directional loading of electricity vehicles and transregional balancing of electricity.

Under those uncertainties it is not surprising that strategic energy policy makers do not have strong expectation in steering flexible bioenergy alone and tend to implement wider instruments for general flexibility support. To appropriately consider the possible valorisation of flexible bioenergy as one element of flexible energy provision, we propose:

- Clarification of biomass availability, quality, and quantity, as well as supply chains and losses as a starting point for any flexible bioenergy implementation strategy.

- Ensure common definition of flexibility in the different energy sectors and agree on common metrics on an international level.

- Enable small to medium scale bioenergy provision units to run flexibly.

- Demonstrate flexible bioenergy options, with variable renewable energies like wind and solar, but also with hydrogen and BECCUS and evaluate the effects on net zero energy targets, value chains and business opportunities.

- Evaluate existing price and energy market design on their effect on flexible bioenergy in different energy sectors.

The survey results from 14 countries and the European Commission presented in this report and the previously published study (Thrän et al. 2024) reveal important interconnections and findings. These insights will be compiled into a standalone summary document, offering a comprehensive overview of key outcomes, trends, and strategic linkages identified throughout the analysis. This summary will serve as a consolidated reference, highlighting policy implications, technological synergies, and future directions in the integration of hydrogen and bioenergy.

Appendices

Appendix 1 – Goals and mechanisms for the implementation of flexible bioenergy by the respondent countries

Table A 1: Goals and mechanisms of the flexible bioenergy implementation.

Country	Goals	Mechanisms
Austria	Renewable Energy Expansion Act (EAG - Erneuerbaren-Ausbau-Gesetz), entered into force on 27.07.2021 to phase out fossil energy carriers. Goals until 2030: - Additional 1 TWh electricity from solid biomass, - Minimum 5 TWh renewable gases The EAG goals are currently not achieved. On the contrary, because the EAG was delayed, biomass CHP plants had to be shut down in the meantime because the feed-in tariff had expired. Important additional regulations like the Renewable Heat Act (EWG – Erneuerbare-Wärme-Gesetz) and the Renewable Gas Act (EGG - Erneuerbares-Gas-Gesetz) are still under negotiation. These acts are already in delay. There are doubts as to whether these two laws will come into force in this legislative period which lasts until 2024.	The EAG includes Investment grants, feed-in tariffs and for larger plants market (feed in) premiums as important mechanisms.
Canada	Canada has committed to supporting the development of biofuels through several policy, regulatory and funding programs. Canada's Pan Canadian Framework on Climate Change recognizes bioenergy as a key component in the energy transition and reaffirming its interest in supporting bioenergy under the recently released 2030 Emissions Reduction Plan to explore the potential for a national bioenergy strategy.	Canada has implemented several regulatory and program measures to support these ambitions. - In December 2024, the Clean Electricity Regulations were adopted, under which biomass is recognized as a compliance pathway for power plants to meet annual emissions limits. - Canada's Clean Fuel Regulations require liquid fossil fuel (gasoline and diesel) suppliers to gradually reduce the carbon intensity – or the amount of pollution – from the fuels they produce and sell for use in Canada over time, leading to a decrease of approximately 15% (below 2016 levels) in the carbon intensity of gasoline and diesel used in Canada by 2030. These regulations are anticipated to reduce Canada's emissions by up to 26 million tonnes by 2030 while simultaneously supporting demand for biofuels.

		- Canada's $1.5B Clean Fuels Fund will support regulatory requirements under the Clean Fuels Regulations by providing support for domestic production of liquid biofuels, biomass supply chains and standards development. - Canada's $2.2B Low Carbon Economy Fund supports the uptake and deployment of bioenergy technology such as biomass-fired district heat networks and single building biomass heating systems in institutional and community buildings. - Canada's $300 M Clean Energy for Rural and Remote Communities support the adoption and deployment of renewable energy technologies in rural and remote communities in Canada of which includes biomass heating systems, district heating, and biomass fired combined heat and power systems. - Canada's Emissions Reduction Plan under the Canadian Net-Zero Emissions Accountability Act supports the development of a bioenergy strategy that optimizes Canada's agricultural, forestry and municipal waste resources to support a transition to net-zero energy. - The Federal Budget 2023 also committed to promoting the growth of Canada's biofuels sector through engagement with the biofuels industry and an examination of different support mechanisms to promote the sector's capacity in meeting the growing demand for low-emissions fuels. Canada also recently committed to developing measures to support the biofuels industry in its 2023 federal budget. - The Investments in Forest Industry Transformation (IFIT) program supports innovative projects and technologies in the Canadian forest sector. Since it's inception in 2010, the program has successfully funded 43 capital investment projects that help diversify the forest product market through high-value bioproducts such as bioenergy, biomaterials, biochemicals and next generation building products. - The Forest Innovation Program (FIP) supports research, development and technology transfer initiatives that foster innovation and create new market opportunities for Canada's forest sector. Under the FIP, FPInnovations is Canada's not-for-profit forest research institute and directly supports the Canadian Wood Fibre Centre (CWFC) in ongoing technology transformation activities and the adoption of emerging technologies ready for commercialization. - As part of the 2030 Emissions Reduction Plan, the Agricultural Clean Technology Program (ACT) supports the development and adoption of clean technology to drive the transition to a low-carbon economy and promote sustainable growth in Canada's agriculture and agro-foods sector. The program has two streams – the Adoption Stream and the Research and Innovation Stream. - The Low Carbon Economy Fund (LCEF) provides funding to

		support communities in their transition to clean energy. In Budget 2022, the Government of Canada committed to expanding the Low Carbon Economy Fund by investing an additional $2.2 billion over seven years, starting in 2022-23.
Denmark	Denmark has a high consumption of biomass, a large part of which is imported, and higher than what is regarded as long-term sustainable. The Danish Council on Climate Change propose a long-term strategy for phasing out and prioritize Denmark's consumption of biomass. At the same time, more should be secured. There are currently no specific/official goals for flexible bioenergy. However, flexible bioenergy will be needed to reach the following goals: - No use of coal in the electricity production by 2030. The Danish climate council in November 2019 stated that this goal is achievable but will require further actions to be realized. - A share of renewable energy of 7 %, 1.25 % advanced biofuels. It is expected that DK will fulfil the overall requirement of 7 %, however, The Danish Council on Climate Change doubts if Dk can meet the specific target for electro fuels and advanced biofuels. - It has been decided to phase out gas for heating. However, this should not lead to higher biomass consumption.	
EU		MS are encouraged to present their targets, action plans and attached resources in the National Energy and Climate Plans, where they should, among others, propose measures to implement flexible bioenergy and the effect on the national targets. The national energy and climate plans (NECPs) were introduced by the Regulation on the governance of the energy union and climate action (EU)2018/1999, agreed as part of

		the the https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_enU countries intend to address the 5 dimensions of the energy union: • decarbonisation • energy efficiency • energy security • internal energy market • research, innovation and competitiveness By 30 June 2023, Member States were due to submit their draft updated NECPs in line with article 14 of the Governance Regulation. On 18 December 2023, the Commission published its EU-wide assessment of the draft updated NECPs, together with individual assessments and country-specific recommendations for the 21 Member States that submitted their draft plans in time. Member States were due to submit their final updated NECPs, taking account of the Commission's assessment and recommendations, by 30 June 2024. **Further info on: National energy and climate plans (europa.eu)** Increased biomethane targets in REPowerEU (35 bcm by 2030)
Finland		The need for flexibility and its implementation through steering mechanisms have been recognized in national energy and climate strategy launched in autumn 2022 (Carbon neutral Finland 2035 – national climate and energy strategy (valtioneuvosto.fi)). The act banning the use of coal for energy generation in 2029 may lead to substitution of coal by bioenergy.
Germany		Within the REA (Renewable Energies Act, EEG, Erneuerbares Energien Gesetz) bioenergy plants are forced to become more and more flexible and it is planned to ensure / 8.4 GW installed capacity in 2030.
The Netherlands	There were no specific goals set for flexible bioenergy as such; it was just seen as one of the options to meet the overall goals for GHG emission reduction and renewable energy (see Questions 17 and 18 as well). However, there were policy instruments in place to steer the development of various technology options, of which the main instruments were the so-called 'Stimulering Duurzame Energieproductie' (SDE+ and SDE++) schemes. These are subsidy schemes to cover the 'unprofitable top', i.e. the difference between the wholesale market price and the production cost of energy	Biomass co-firing, having been during the last decade and still being a/the major flexible bioenergy option for the power sector, has clearly been influenced by the planned phase-out of coal-firing. Of the currently four coal-fired power plants in the Netherlands, the RWE-Amer 9 is scheduled to stop coal-firing by 2025, while the other three (RWE-Eemshaven, Onyx-Rotterdam and Uniper-Rotterdam) are scheduled to stop coal-firing by 2030. Prior to this full stop, a 35% load cap (on annual basis) was already imposed. However, this cap was lifted in January 2022 following Russia's invasion in Ukraine. Possibly one or more of these plants will continue to operate as 100% biomass plants. In this respect also important to notice that 2 of the 4 serve as CHP plants. However, given the current biomass policy views, it is not likely that this will be actively supported/subsidized by the Dutch government.

	products/GHG emission reduction measures from renewable sources.	
Sweden		The government initiated an electrification strategy, where they identified the need to increase production of power from biobased combined heat and power. The potential is not utilized to its full extent. Fossil fuels in CHP have already been phased out, but there is a need for more local power capacity in many cities and regions, and a need to produce more renewable electricity in winter months in periods with little wind (typically high pressure periods with cold-spells and little wind).
Switzerland	Three different scenarios in discussion of which one sees a stronger role of renewable gases incl. biomethane. Gas industry promised to cover 30% of domestic heating with renewable methane by 2030, e.g. by import of biomethane and some support for PtMethane. Generally PV and hydropower way more dominant in discussions.	
Türkiye		The main driver for the development of bioenergy in Türkiye has been the Renewable Energy Resources Support Mechanism (YEKDEM) (please also see the answer for "Question 42"). This mechanism provides a foreign currency (USD) (since 07/2022 the local currency Turkish Lira is used) based purchase guarantee, and has been implemented in the last twelve years (since 2011). After the commissioning of YEKDEM, there has been a significant increase in the installed power of renewable energy power plants including bioenergy-based ones.
UK	Flexibility of UK bioenergy focuses on the import of biomass vs. domestic production debate. However, no official targets have been set to influence this situation. The recent 'Independent Review of Net Zero' concluded that as the UK's use of bioenergy is outpacing its domestic supply, this might lead to greater dependence on imported biomass and other countries, suggesting diversifying supply from domestic sources will need to be increased.	Biomass/energy is part of the energy system basket and while there are sustainability standards within the renewable energy policies, there is no dedicated policy on flexible bioenergy as such. The upcoming new UK Biomass Strategy, currently under development, could potentially change this. The phase out from coal has clearly been a vehicle for the increased capacity of bioelectricity from solid biomass (conversion and new establishment of biomass power plants). Latest Government strategies (e.g. Net Zero Strategy) will require an increase of bioenergy, but these have not been clearly described or quantified. A large role is seen for bioenergy, but it is not clear how that can be put into practice; cross-sectoral and cross-departmental efforts will be required (which can also lead to potential sectoral competition).

US	There are no “flexible bioenergy” specific goals nationally in the United States. The major bioenergy goal in the US is the Sustainable Aviation Fuel Grand Challenge, which targets 3B gallons of SAF by 2030 and 35B gallons by 2050.	

Appendix 2 - Impact of policy instruments at national level and supra/international level

Table A 2: Additional information on the impact of policy instruments at national level and supra/international level

Country	National policy level	Supranational/international policy level
Australia		Slight impact – for SAF
Austria	Only intelligent national regulations can drive the implementation.	International policy is an important basis but sometimes not in favour of several nations. E.g. under the revision process of RED (Renewable Energy Directive) it was discussed to ban or reduce the utilisation of wood for energy production. Such discussions are dominated by nations with minor forest-based industry. But for countries like Sweden, Finland and Austria the forest-based industry is essential inclusive the energetic utilisation of wood residues. Finally, such bans could be prevented (see https://ec.europa.eu/commission/presscorner/detail/en/IP_23_2061).
EU	National policies influence to a big extend the relative share of different RES, including bioenergy.	Although the legal framework (RED I-III) switches the focus from how much bioenergy can be produced to how much climate benefits bioenergy could provide, the existing business models as well as national support schemes for bioenergy production are still very much linear. This approach is very limiting for bioenergy that is ready or need small adjustments to provide additional benefits to the climate and energy independency with defossilisation, either directly through the energy system integration (e.g. auxiliary services of balancing, storage, coupling with intermitted renewables, following demand and not the production capacity, local and storable renewable energy carrier...) and indirectly (e.g. combining with phytomining to

		get the critical raw materials, ecosystem services to prevent eolean erosion and nitrate leakage to the water bodies, utilisation of biogenic CO_2 in food and beverage industry, digestate as a local source of nutrients, pairing biomass use for energy with biochemical extraction of bioactive compounds (e.g. vanillin, beta glucan, resveratrol...) and pelletising the exhausted biomass or using the pellet dust to innovative bioeconomy value chains that need fine dust for biotechnological conversions...). In short, much more could be done from the existing biomass going to the energy system, including more bioenergy and more bio-based products, all to the benefit of the climate.
Finland	In general, increased need for flexibility is recognized in National Climate and Energy strategy published in 2022 (Carbon neutral Finland 2035 – national climate and energy strategy (valtioneuvosto.fi). However, in most cases, there are no specific flexible bioenergy connections, but the discussion is on more general/technology-neutral level, e.g., ICT/smart consumer solutions, smart grids, demand response, electricity markets, are highlighted. There are a couple of references with more relevant connections, e.g., ”As district heating systems in Finland are closed and use fixed prices, the utilisation of the flexibility potential of district heating systems or the integration of energy systems may not be optimal at present" ... “The district heating network offers more flexibility in the energy system and an opportunity to partly store energy”, … “ In industry, the identified impacts [of policy measures] concern the electrification of processes, which increases demand and employment in electricity-based industrial energy production solutions. Industry is increasingly integrated into the energy market, both as an energy producer and through flexibility in consumption”. General measures such as R&D supports mentioned in many connections have an impact. Specifically, under policy guidelines describing “renewable energy” and “hydrogen and electro fuels”, there are policies potentially promoting flexible bioenergy. Noteworthy, but not limited to: - “Biogas and electro fuels have been included in the transport distribution obligation as of	The influence assumedly comes through many different general policy mechanisms such as emissions reduction targets, renewable energy targets, EU ETS, energy market regulations, different investment supports, R&D funding, …

	the beginning of 2022. The obligation to distribute biofuels will be increased to 34 per cent by 2030." - "A target set for the electrolysis equipment used in hydrogen production will be at least 200 MW in 2025 (9 MW in 2021) and at least 1,000 MW in 2030, taking into account the commercialisation of hydrogen technology." In the new edition of Finnish Bioeconomy strategy (30 March 2022), there are no direct references to terms "flexible" or "flexibility" The Finnish Bioeconomy Strategy. Sustainably towards higher value added (valtioneuvosto.fi). However, there are elements of flexible bioenergy that can be seen acknowledged by quotes in the strategy e.g., about, value-added products, multi-product biorefineries, development of technology, research, and related measures e.g., in funding and other support measures, "One of the bioeconomy's key strengths is the ability to make sustainable and efficient use of raw materials, including side streams, in the production of high value added products and chemicals", … "The potential of many new products and processes is high due to the efficient use of raw materials and compliance with the principles of the circular economy. The development of the bioeconomy's industrial applications and technologies will be of wide-ranging benefit if the new solutions are affordable, sustainable and easy to adopt in practice, and where possible supported by digitalisation."	
Germany	REA (EEG, e.g. structures feed in tariffs and sets limits for new plants) GHG-quota in transport.	European legislation set often the framework for national regulation.
Italy		Unfortunately the policy framework is coherent in not mentioning explicitly flexible bioenergy; indeed this is a major hindrance for its development and implementation.
The Netherlands	Integrated National Energy and Climate Plan, 2021 – 2030 - Policies concerning specific energy sectors/technology options, like biomass co-firing, biomass for low-temperature heat - Policy concerning cascading use of bioresources - Policy concerning "greening" of industry	Relevant policies mainly concern EU policies including policies like RED, REDII, REDIII, Green Deal, Fit for 55, etc. This in addition to or as a concrete translation of global policies, like the ones on GHG emissions reduction.

	sector, including refineries and chemical industry - Policies concerning subsidizing various technology options (e.g., SDE+, SDE++, EIA) - Green gas blending obligation	
Sweden	Still low awareness of the potential to use bioenergy for flexibility in the electricity market. Higher awareness in the heat market and for industry.	We are afraid that negative signals from "Brussels" will hamper flexible bioenergy, e.g. provisions in the Renewable energy directive, and in the taxonomy.
Switzerland	Discussion on Net zero etc. has a strong drive, but most strategies and laws are still in negotiations.	Indirectly: Becoming independently from Russian gas and need for import/export to cover seasonal imbalance and special needs (e.g. renewable jet fuels) automatically creates international influence, especially considering t electricity contract with EU.
Türkiye	Although certain incentives supporting renewable energy production encourage investors, market dynamics and economic barriers are the main drivers.	Türkiye signed the Paris Climate Agreement in 2016. The agreement was approved by the Turkish Grand National Assembly (TBMM) in 2021. Following the signing of the Paris Climate Agreement, an Intended Nationally Determined Contribution (INDC) was prepared. According to the declaration (INDC), Türkiye made a commitment of reducing emissions by 21% in 2030 compared to the current situation scenario. The European Green Deal, the details of which became clear in 2021, is another foreign policy that will encourage Türkiye to present more concrete steps in tackling climate change. Türkiye's goal of achieving net zero emissions, which was declared by the President of the Republic of Türkiye at the 76th General Assembly of the United Nations, is set as the year 2053.
UK	We are still awaiting the publication of the revised UK Biomass Strategy which many energy strategies and scenarios refer to, and will determine which biomass feedstocks are prioritised, and which sectors/end users the biomass will be prioritised for. However, there is a need for more joined up policy on biomass which would positively influence options for the flexibility of feedstocks and the ability of bioenergy to contribute more to the UK's energy mix. Strategies and policies don't mention bioenergy at all which could lead to a missed opportunity. Despite this, the UK Government is putting funds towards biomass, such as the Biomass Feedstocks Innovation Programme in 2021 to	UK bioenergy production heavily reliant on biomass imports from the US and Canada, which are impacted by international polices. Many of the UK's net zero pathways suggested by the CCC outline the need for upscaling BECCS to produce negative emissions. However, the UK does not currently have the capacity to produce enough biomass domestically for this, unless major policy decisions are made. If competition for biomass increases globally (which it is expected to by the IPCC and IEA), this will put bioenergy in the UK at risk.

	put £26m into the development of domestic biomass feedstock options.	
US	There is some incentive to deploy bioenergy in the US, mainly in the transportation sector. However, those policies and incentives do not target flexible bioenergy specifically.	Energy policies outside of the US do incentivize the export of some bioenergy outside of the United States (example: wood pellet export to Europe).

Appendix 3 - Contradictions between different policy instruments which hinder the implementation of flexible bioenergy

Table A 3: Additional information of contradictions between different policy instruments which hinder the implementation of flexible bioenergy in the responded countries.

Austria:	On international and on European level especially NGOs are pushing strongly towards a ban or significant reduction of bioenergy by claiming that bioenergy is in general not sustainable. So far, these wrong accusations resulted in stronger sustainability criteria (e.g. within RED III) but not in a ban or reduction. But this is an ongoing process and especially IEA Bioenergy is aware of that (especially Task 45). Under the Biodiversity Strategy for 2030 the EU plans to enlarge existing Natura 2000 areas. This could result in a reduced amount of available biomass residues for energetic utilization.
Canada	The lack of a clear national policy for biofuel development contributes to creating uncertainty for firms and could have a negative impact on industry investment, with industry holding off on large-scale flexible bioenergy infrastructure investments. In addition, differences in blending mandates between federal and provincial jurisdictions may also prove to be a challenge for cross-sectoral industry adoption of biofuels.
Denmark	Nearly all 2nd generation bioethanol is exported due to unfavourable market conditions. This is in contradiction to the mandate of the advanced biofuel target, which currently will be hard to meet.
European Union	Although the legal framework (RED I-III) switches the focus from how much bioenergy can be produced to how much climate benefits bioenergy could provide, the existing business models as well as national support schemes for bioenergy production are still very much linear. This approach is very limiting for bioenergy that is ready or need small adjustments to provide additional benefits to the climate and energy independency with defossilisation, either directly through the energy system integration (e.g. auxiliary services of balancing, storage, coupling with intermitted renewables, following demand and not the production capacity, local and storable renewable energy carrier...) and indirectly (e.g. combining with phytomining to get the critical raw materials, ecosystem services to prevent eolean erosion and nitrate leakage to the water bodies, utilisation of biogenic CO_2 in food and beverage industry, digestate as a local source of nutrients, pairing biomass use for energy with biochemical extraction of bioactive compounds (e.g. vanillin, beta glucan, resveratrol...) and pelletising the exhausted biomass or using the pellet dust to innovative bioeconomy value chains that need fine dust for biotechnological conversions...). In short, much more could be done from the existing biomass going to the energy system, including more bioenergy and more bio-based products, all to the benefit of the climate.
Finland	In case of stiff quotas (e.g., biofuel obligations) or support mechanisms (e.g., feed-in tariffs) and/or limited biomass resources, it is possible that flexible applications are hindered. This can be the case if an instrument gives the producer an incentive to, e.g., to meet annual quota independently of operational needs for flexibility by the power system. However, in this questionnaire, we cannot give a specific example/quantitative estimation of the significance of the

	impact, if any.
Germany	Things like BImSchV'en (emission by-laws) or Düngemittelverordnung (fertilizer by-law) etc. complicate the construction and renovation of plants. In some cases the overarching policy framework is too complicated to extend energy production time scale of existing plants
The Netherlands	On the one hand high ambitions concerning GHG emission reductions and the energy and materials transition, but on the other hand a large hesitance to exploit biobased options due to strong public/political opposition. As a consequence, flexible bioenergy options are not used to their full potential.
Sweden	Yes. One example is the proposed restrictions against electricity only installations in RED III. This regulation may stop investments in peak-load units. Another is the production-only rule in the EU power market designs, which makes it difficult to reward capacity installations and reward planned effect.
Switzerland	Exemption from grid use fee for PtX plants that help grid stability is needed but not granted. Big discussion as proposals are under discussion in parliament.
United Kingdom	Bioenergy policy from an energy perspective sits within the remit of the Department for Energy Security and Net Zero (DESNZ), bioenergy policy from a biomass and feedstock perspective sits within the Department for Environment, Food, and Rural Affairs (DEFRA) remit, and bioenergy policy from a renewable fuels perspective sits within the Department for Transport (DfT). Whilst there are obvious points of synergy between these departments, a lack of a revised UK Biomass Strategy can contribute to a dissonance in policies which impact a single bioenergy system or supply-chain. A key challenge is that the RFTO (transport) has adopted EU RED standards and has therefore much more stringent sustainability measures than, for example, the Renewable heat Incentive and the Renewable Obligation Order or Contracts for Difference. This leads to a distortion for biomass use and energy markets limiting the flexibility of biomass.

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Further Information

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