Implementation of flexible bioenergy in different countries

Status quo of implementation, barriers and policy framework

IEA Bioenergy: Task 44 Flexibility and System Integration

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Status quo of implementation, barriers and policy framework

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Executive summary

In energy systems with dramatically increasing share of variable energy sources (VRE) like solar and wind, bioenergy has an increasingly important role to play, particularly in fields where alternative renewable energy sources are difficult or costly to provide. Climate-efficient and cost-effective flexibility of bioenergy is key, for example when providing flexible electricity, and also in different energy system services such as biofuels provision, renewable heat implementation as well as carbon capture and utilization options and the reduction of grid operation costs.

However, to unlock the enormous potential of flexible bioenergy's contribution to the transformation of the energy system, favorable policy conditions are necessary (as they are for the whole energy system transformation). With this report on the implementation of flexible bioenergy in different countries we analyse the developments in flexible bioenergy implementation in 14 countries (counting the European Union as a country) over the last three years.

The report is mainly based on questionnaires answered 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 assign different priorities to short-term flexible bioenergy and multiproduct systems and longer-term flexibility services as well.

Flexible bioenergy is considered in many different fields of application and differently prioritised between countries. The highest importance is seen in using flexible feedstocks and providing flexible power: Day-to-day and seasonal flexibility are stated as the most important for system integration. Also, flexibility in resource supply is well established: Storage and international trade of bioenergy carriers contribute predominantly to longer periods to meet winter demand. When it comes to flexible production of hydrogen or CO_2, as well as poly-generation of energy and non-energy products, more countries see the need to better consider these topics in the debate and in parallel state them as topics for research and demonstration. Between those early stage concepts, flexible bioenergy and BECCS can be seen as an emerging topic, as it is considered in many energy strategies.

Due to rising share of variable renewable energy (VRES), flexibility in the power sector is of increasing relevance. Flexibility issues in the power provision field have entered the agenda during the last three years. Almost all of the investigated countries are expecting to invest or are already investing in flexibility. Statistics on and monitoring of flexible bioenergy are also of increasing interest. However, there are still very different approaches in describing flexible capacities between the countries, so that a clear definition and procedure could improve the comparability of the numbers. Advanced technologies to ensure reliability are expected in more than half of the investigated countries until 2030. In many countries different flexibility options are currently in implementation, mainly driven by research and development and pilot and demonstration plants, but also already in the market in some cases. The comparison of the different renewable flexibility options shows that, across the countries, an innovation and implementation pipeline for flexible power generation is visible. However, this is more prominent for hydrogen and hydropower than for biogas and solid biofuels.

Increasing efforts for flexible bioenergy production and/or the simultaneous production of electricity, heat, and fuels in the past three years are stated with adoption of strategies, investment support and also adjustment of energy legislation. Many of these efforts are linked to BECCU and BECCS, which have entered the policy field in almost all of the investigated countries. Concerning flexible power provision, countries largely differ in their focus and approach, e.g. emphasizing day-to-day flexibility or seasonal flexibility, poly-generation, combination with excess energy, hydrogen and/or power-to-X. Moreover, efforts mainly are in a research, development and pilot stage; implementation support for those flexibility options is rare.

Increasing interest is also stated for feedstock flexibility, including varying biomass sources (and more

residues and waste), as well as storage and trade options. These options have gained larger attention during the last three years in most of the countries, and implementation is ongoing.

Many support mechanisms for the implementation of renewable energy production are stated, where most of them only support flexible bioenergy and system integration indirectly. Direct policy support is stated from Austria, Denmark, Germany, Italy, Netherlands, Sweden, Switzerland, Turkey. Those mechanisms support the creation of flexible bioenergy capacities on biogas plants (in Germany), feed in tariffs and premiums for flexible bioenergy (Austria and Denmark) or focus Capex and Opex contribution to biobased CHPs (Switzerland). However, the effect of those mechanisms also depends on the level of support. This is why indirect mechanisms, i.e. carbon pricing or emission trading, are not necessarily second-best options.

To accelerate flexible bioenergy, insufficient policy instruments and market mechanisms are seen as main barriers in almost all investigated countries. Only in the United States of America, technical barriers are seen as a bigger issue and in the Netherlands, acceptance issues are dominant. Competition with other flexibility options is of increasing importance. However infrastructural aspects are not stated as a barrier, which might distinguish flexible bioenergy from other options of system integration and can be clearly concluded as an advantage in short-term implementation.

This report is part one of our analysis. The report on expectations of flexible bioenergy in different countries will follow, as well as a summarizing synthesis report as part 3.

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 all 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 changes 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. 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 (Schildhauer et al. 2021). To fulfil those demands, climate-efficient and cost-effective flexibility of bioenergy is key.

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 to meet energy demand during winter months;
- 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 (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 from flexible biogenic feedstocks, and/or in integrated biorefineries or Power-to-X-systems, 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 the implementation of flexible bioenergy in different countries 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 in our study design, so that questions were asked more specifically and the experts were better

aware of the different dimensions of flexibility. To handle the manifold information, this report is part one of our analysis, which will be followed by a report on expectations of flexible bioenergy in different countries, as well as a summarizing synthesis report as part 3.

1. Method

This report is based on a questionnaire with 44 different topics on flexible bioenergy and on a statistical analysis on the role of bioenergy, which is based on IEA World Energy Balances and elaborated at DBFZ. The questionnaire was answered in written form by bioenergy experts from 14 countries (Austria, Australia, Brazil, Canada, Denmark, Finland, Germany, Italy, Netherlands, Sweden, Switzerland, Turkey, United Kingdom and United States of America) and the European Commission/EU (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. Unfortunately, we could not engage more countries from the Far East or the Global South to participate.

The questionnaire is included in Appendix II. It consists of open and closed questions and is based on our first round of analysis, published in report "Expectation and implementation of flexible bioenergy in different countries" (Thrän et al. 2021). We improved questions where necessary and also added questions in fields that were mentioned but not fully covered last time. Most of the countries from the first round contributed again, so in some cases we repeated questions from our former analysis.

The assessment and answering of the questionnaires was not conducted following a uniform procedure. The experts from different countries had different backgrounds – including i.e. technology experts, energy market experts, and energy system analysts. In some countries, several experts answered the questionnaires, in other countries only one person gave his or her expertise. This of course influences the depth and quality of the assessments. Not every person may have the same amount of knowledge in all the areas surveyed. As a consequence, we had also to deal with some data gaps and incomplete answers (Brazil, for example, only answered four questions altogether, and Denmark provided no information on the obstacles and bottlenecks to the introduction of flexible bioenergy). This should always be taken into account when reading the report.

The report is structured as follows:

- The starting point: Bioenergy in national energy supply
- Flexibility in the power sector
- Flexible bioenergy in other energy sectors
- Flexible feedstock provision, bioenergy carrier storage and BECCS
- Support mechanisms for flexible bioenergy
- Influencing factors for the implementation of flexibility

2. The starting point: Bioenergy in national energy supply

Bioenergy serves as a fundamental pillar within the energy frameworks of various nations, playing a key role in advancing renewable energy goals and supporting sustainability efforts. This introductory section aims to provide a comprehensive overview of the bioenergy landscape in 14 countries (which responded to the survey), using data from the IEA World Energy Balances. By analysing key metrics such as total renewable energy supply, renewable power generation and renewable energy use in the transport sector, this chapter attempts to shed light on the complex nature of bioenergy use in these countries and define the space for potential flexible bioenergy options.

The data shows considerable differences between the countries in terms of the use of renewable energies (Figure 1). Sweden stands out with a share of 50% of the total energy supply from renewable energies (see black dots in Figure 1), which is largely above the average share of renewable energy supply in the EU with 21,8% in 2021 (European Commission, EU energy in figures — Statistical pocketbook 2021). Brazil, Denmark, Finland and Austria also have very high levels, each above 30%. Almost all of these countries (except Denmark) and Switzerland rely on hydropower and all use primary solid biofuels on a large scale. Despite Canada's enormous forest and water resources, the share of renewable energies in this country is only just below 20%. Countries such as Australia, Turkey and the US have the lowest shares of renewable energies. The Netherlands bring up the rear among European countries responding to the questionnaire with a share of just 13%. Countries with a high share of wind energy include the United Kingdom, the US and Germany. Countries with favourable geographical conditions for solar radiation are ahead in the expansion of solar energy. These are Turkey, Australia and the US. In Europe, Italy and Germany are making great strides in the utilisation of solar energy.

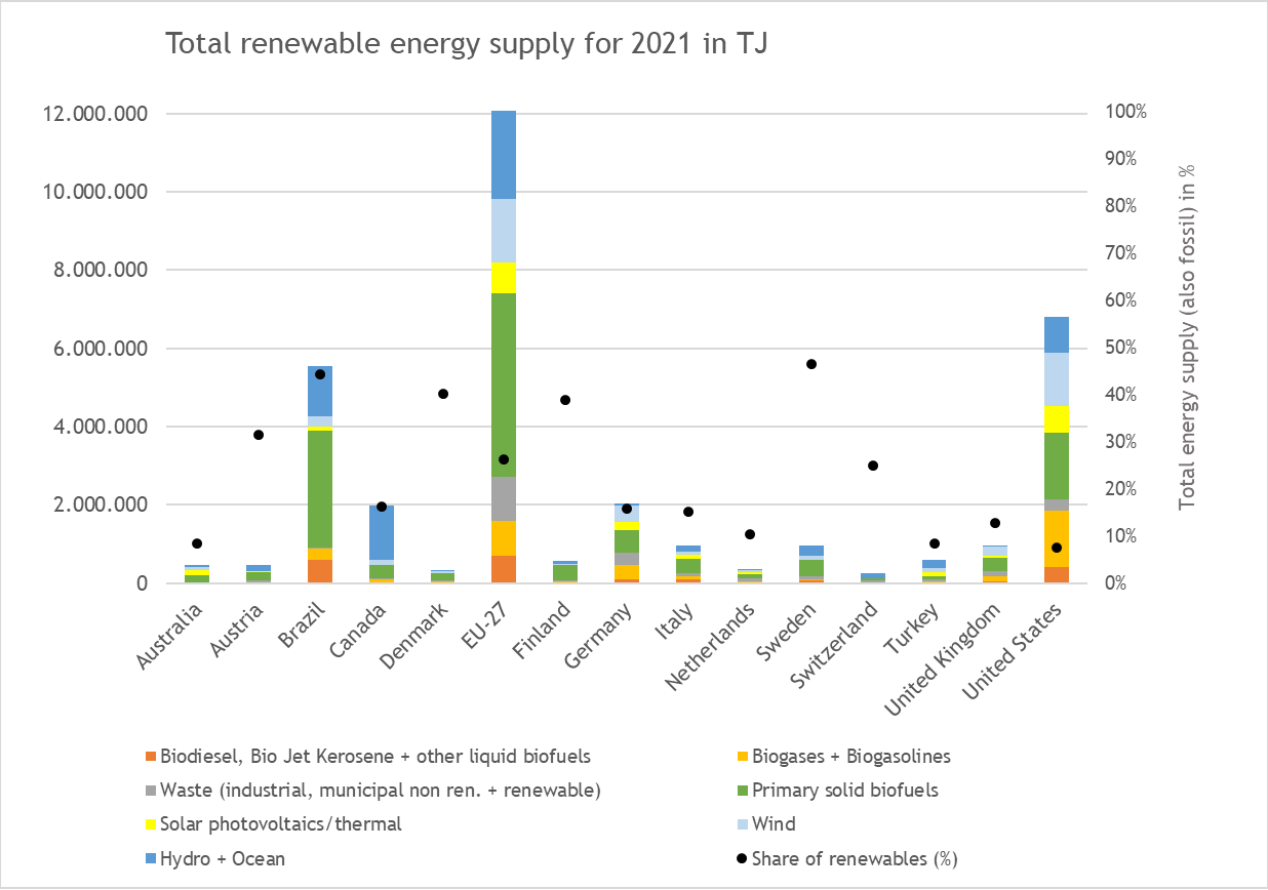


Figure 1: Total energy supply from renewables and biomass in 14 countries and the EU for year 2021. Data from IEA Key World Statistics.

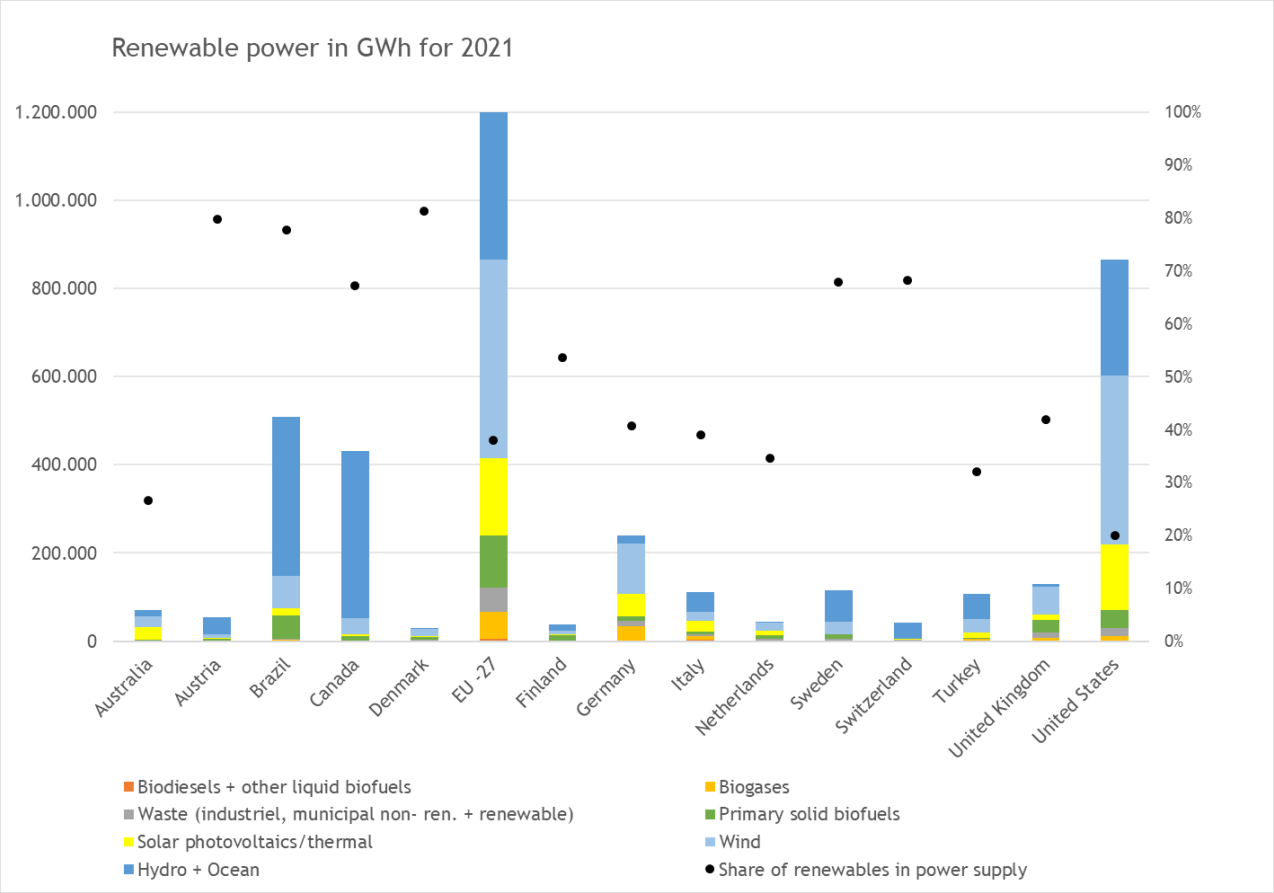


Figure 2: Renewable power for year 2021 in 14 countries and the EU.
Data from IEA Key World Statistics.

The role of biomass for power provision is also very diverse (Figure 2). In several nations, renewable energies account for a substantial portion of the power sector, as evidenced by the high percentages in Denmark (80%), followed by Austria and Brazil. In contrast, Australia and the US have the lowest shares of renewables in their power supply among the 14 countries, with 25% and 20%, respectively.

Hydropower emerges as a significant and flexible renewable energy source across almost all countries, particularly notable in Austria, Brazil, Canada, Sweden, Switzerland and the US. Wind energy plays a crucial role in Denmark, Germany, the United Kingdom and the US. Photovoltaics and solar energy are prominent contributors to power provision in Australia, Germany, Italy, and the United States. Primary solid biofuels are extensively used in Brazil, Denmark, Finland, the Netherlands and the UK.

In the EU, wind and hydro are the two main renewable power contributors as well, followed by solar and bioenergy.

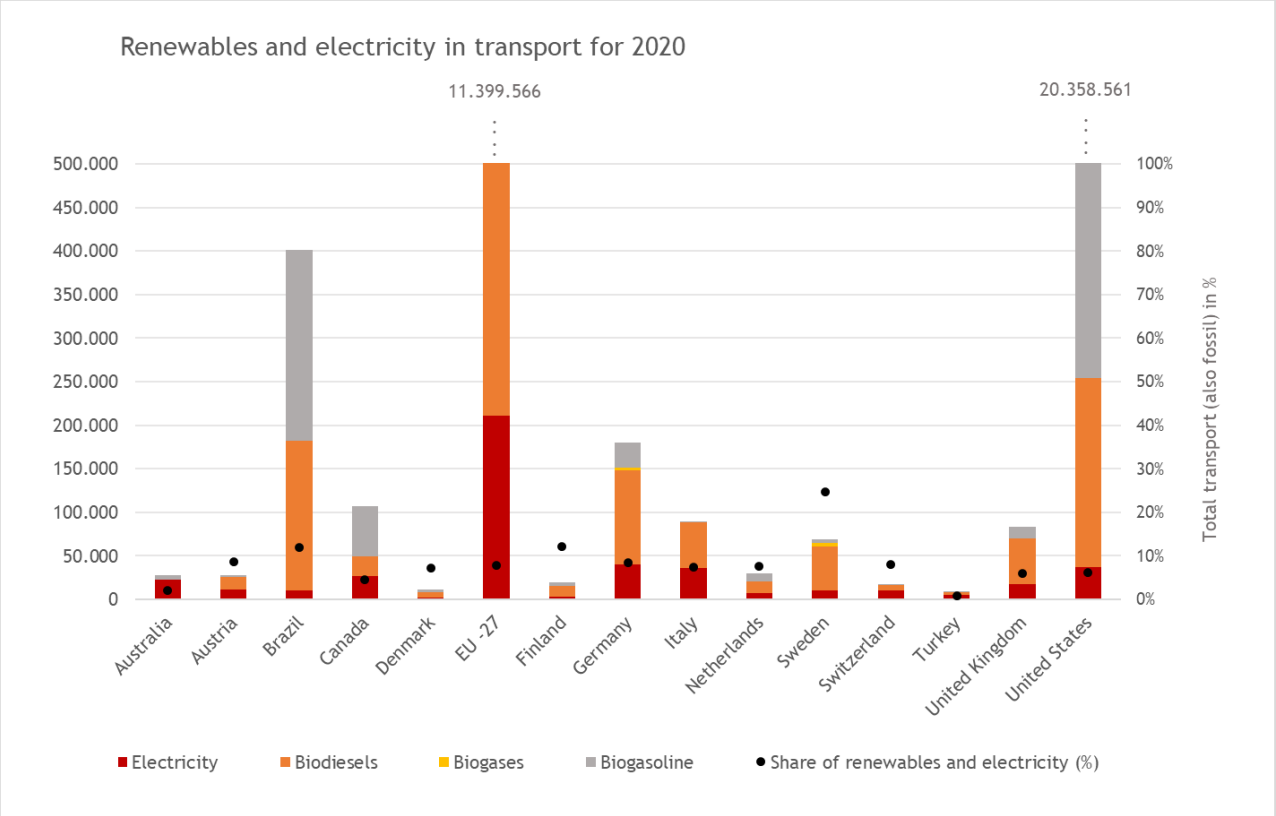


Figure 3: Renewables and electricity in transport sector in 2020 for 14 countries and the EU. Data from IEA Key World Statistics.

The situation in the transport sector is very different (Figure 3). Despite significant advances in the use of renewable energy, fossil fuels continue to dominate. This can be seen, for example, in the United States, where the total volume of transport is shown in Figure 3 only as a numerical value, as the inclusion of the total volume would distort the visualisation due to its overwhelming proportion. For comparison, the graphic also includes the share of electricity as a transport fuel, which has grown significantly in recent years. Sweden stands out with 25% of its transport sector powered by renewable energy. Finland and Brazil also have significant shares of more than 10%. Biodiesel is emerging as a significant player among the biomass sources used, particularly in countries such as Brazil, Germany, Sweden, the UK and the US. However, despite these progresses, renewables still have a small share in transport in most countries. For example, in the EU, the share of RES in transport was 7,92% in 2020 (IEA Key World Statistics) and 9.1% in 2021 (European Commission, EU energy in figures 2023).

The figures (Figure 1, Figure 2, Figure 3) presented clearly show the diverse role of biomass in the energy systems of the countries analysed. Biomass contributes to varying degrees in all sectors and countries, reflecting the different approaches to its utilisation. However, it is crucial to recognise that the supply of bioenergy is not dictated by energy demand alone, but is rather influenced by a variety of factors. One of these factors is the domestic resource base, which depends on the size of the available agricultural and forest land. In addition, economic and technical barriers as well as political incentives play a decisive role in shaping the bioenergy landscape of each country.

With these considerations in mind, our analysis examines whether flexible bioenergy initiatives are strategically initiated or supported within the energy transition strategies of different countries. By examining the policy frameworks, technological advancements and socio-economic dynamics at play, we aim to identify patterns and trends that indicate proactive efforts to harness the potential of bioenergy to promote a sustainable energy transition. Further analysis of the longer-term expectations on flexible bioenergy (i.e. targets for 2030) is provided in a second report (forthcoming in autumn 2024).

3. Relevant topics for flexible bioenergy in different countries

Flexible bioenergy is discussed in many aspects, including feedstock, conversion, products and services. In our first question, we therefore asked about the relevant dimensions of flexible bioenergy in the dedicated country. The results are shown in Figure 4. They show that the majority of the 13 countries (and EU) surveyed state that flexible bioenergy is considered in many different fields of application. The highest relevance is seen in using flexible feedstocks and providing flexible power. When it comes to trade and storage of bioenergy carriers as well as poly-generation of energy and non-energy products, more countries see the need to better consider them in the debate. The answers "not relevant for the debate" and/or "considered but overcomplex" are rare in each of the possible application fields. Examples are:

- Austria states that flexible and/or poly-generation of electricity, heat, fuels and non-energy products according to market demand and trends are considered in the debate. However, this leads to excessive complexity.
- Similarly, Turkey questions the flexible provision and processing of biogenic CO_2 converted into synthetic fuels (e.g. with hydrogen from PV or wind surpluses) or captured and stored (Bioenergy Carbon Capture and Storage (BECCS)). Also, the storage of renewable hydrogen in intermediate bioenergy carriers in synergy with the variable generation of electricity from renewable energy sources is not part of the debate in Turkey.
- Trade and storage of bioenergy carriers is not relevant in the current flexible bioenergy debate in Germany and Italy.
- Utilising 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 is not considered relevant in Switzerland, nor are flexible generation of power for grid stability and ancillary services for power systems.

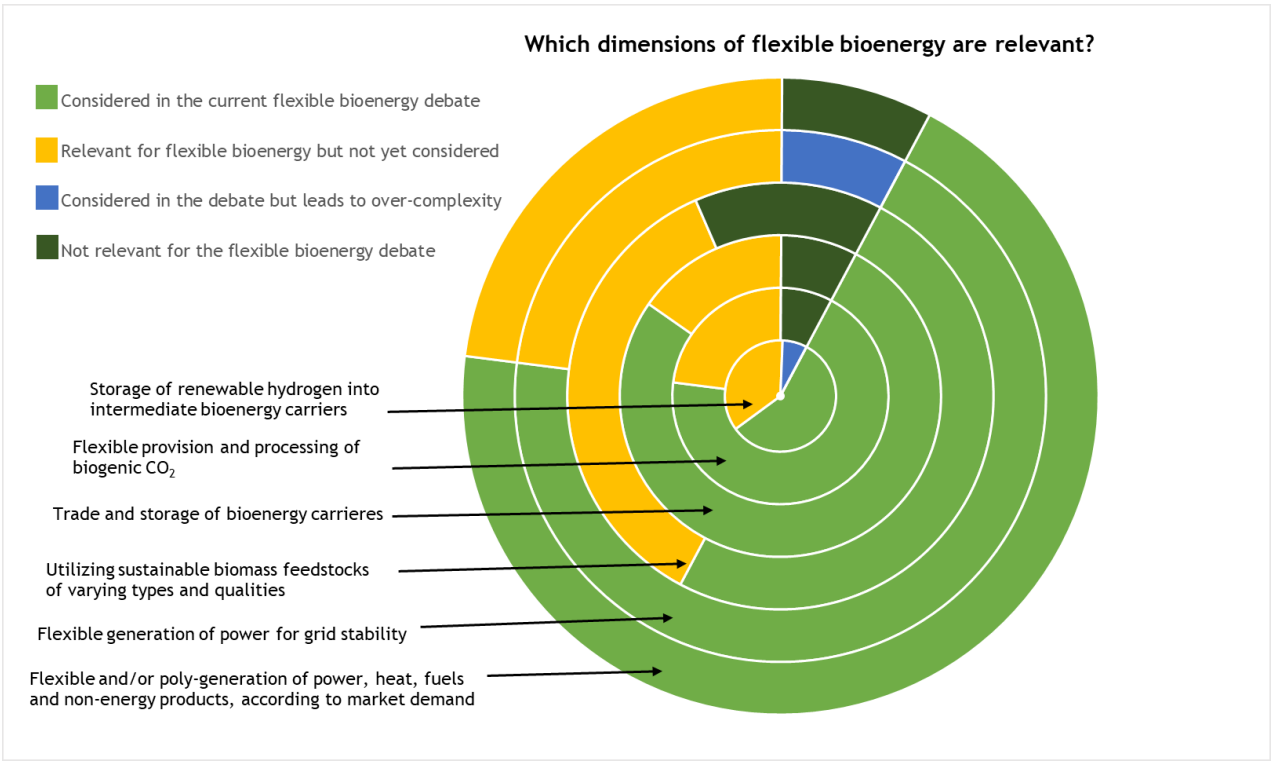


Figure 4: Overview of relevant dimensions of flexible bioenergy in 13 countries and EU.
Austria, Australia, Canada, Denmark, EU, Finland, Germany, Italy, Netherlands, Sweden, Switzerland, Turkey, UK, US.
Brazil did not answer.

In Figure 5, we show an overview of results from several questions addressing the status of flexible bioenergy considering its broad definition:

- Which flexible power supply technologies have been established to contribute to integration in the energy system?
- Which option best describes the current status of bio-based flexibility options with respect to sector coupling and system integration?
- How has the storage and trade of bioenergy carriers developed over the last 3 years?

In summary, we see that several options to increase flexibility in the power market have been implemented, viz. flexible combined heat and power plants (CHPs) and virtual power plants but also non-biobased solutions like hydropower or battery storage.

With regard to provided flexibility options from biomass, day-to-day and seasonal flexibility are currently considered the best options for serving system integration. Combinations of bioenergy with hydrogen as power-to-X are implemented in a few countries, but are mainly seen as a topic for research and demonstration. Other options such as flexible bioenergy and hydrogen or flexible fuel production or flexible bioenergy and BECCS are in an early stage: most of the countries state research and demonstration, with only some countries providing financial support for implementation. Between those early stage concepts, flexible bioenergy and BECCS can be seen as emerging topics, because they are considered in many energy strategies.

Flexibility in resource supply is already implemented in several countries, but also seen as a topic for research and development: Storage and international trade of bioenergy carriers contribute predominantly to overcoming seasonal fluctuations and contribute to match supply and demand. Considering a broader range of feedstocks provides many advantages, such as increasing security of supply, reducing costs and meeting overall sustainability requirements.

More detailed information will be provided and illustrated in the next chapters.

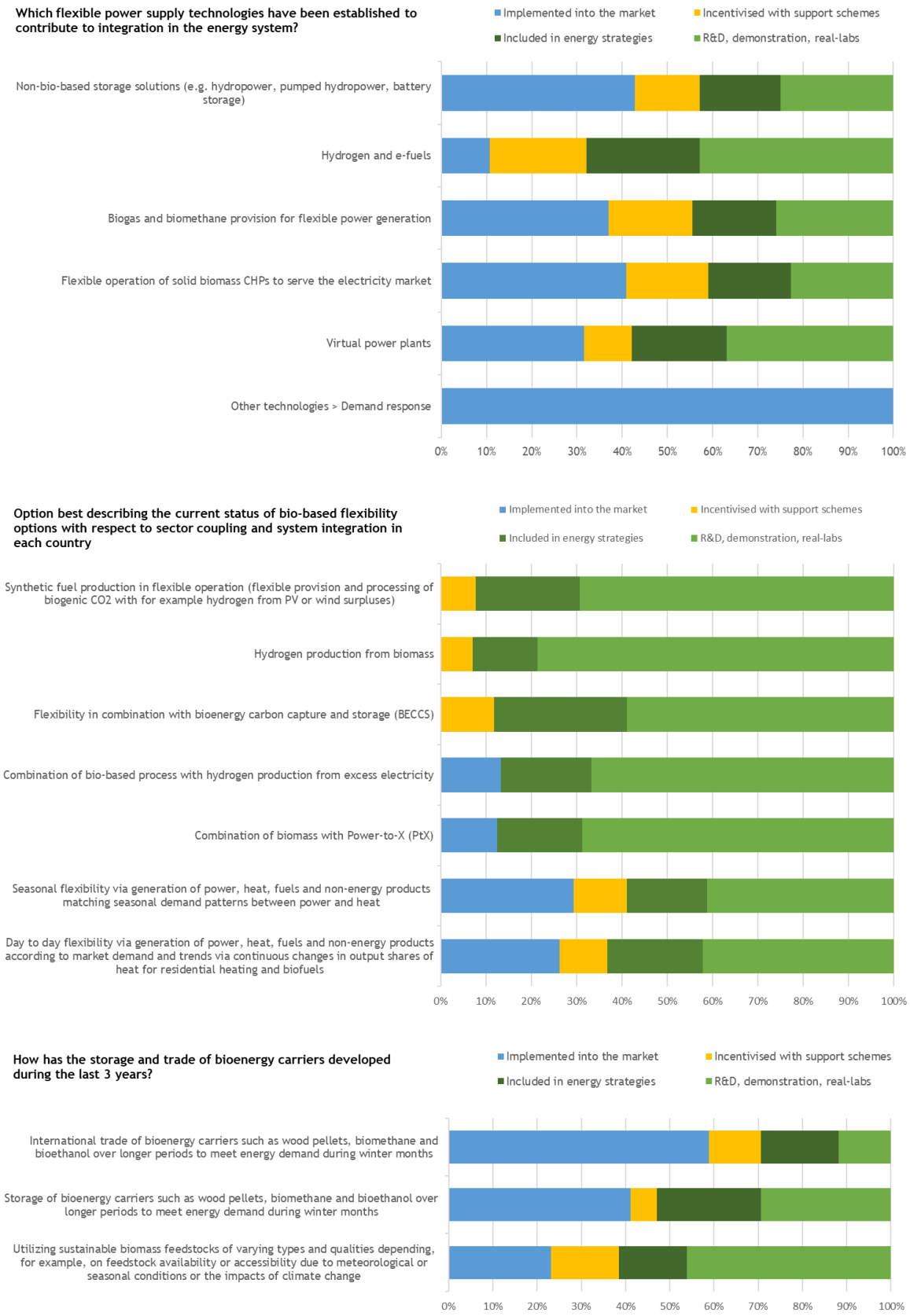


Figure 5: Information in a nutshell comparing some results.
This overview graphic shows some information in a nutshell comparing some questions and providing a first idea of results. All questions will be described in more detail in the following chapters. The figures are expressed in percentages, so one can observe the distribution for the categories rather than the total sums or number of responses. Brazil did not answer these questions.

4. Flexibility in the power sector

PHASES OF INTEGRATION OF RENEWABLE ENERGIES

The introduction of flexible bioenergy provision in the power sector is often driven by increasing shares of variable wind and solar capacity in the power sector. When those variable renewable energy sources (VRES) substitute fossil resource to a larger extend, additional measures to integrate them in the energy system are necessary. Besides this, land and resource availability for renewable energy installations set the directions and mechanisms for the energy transition These different transformation efforts can be seen in the national phase-out strategies for fossil fuel power, which differ between countries. To better understand the expectations of energy system transformation, the surveyed countries gave their estimation on the integration of VRES into the power sector in 2030, based on the IEA's "Six phases of integration", explained in Table 1.

The self-assessment of the surveyed countries reveals a wide range of system integration phases, reaching from a moderate influence of variable renewable energy sources to almost complete coverage of electricity generation during some favourable periods for wind and PV power generation. We asked for the phase of integration of VRES into the power sector in 2020/2021 and 2030, based on their current national strategies. The results are given in Figure 6.

IEA's "Six phases of system integration"

- Phase 1: No relevant impact on system integration
- Phase 2: Drawing on existing system flexibility
- Phase 3: Investing in flexibility
- Phase 4: Requiring adv. technologies to ensure reliability
- Phase 5: VRE surplus from days to weeks
- Phase 6: Seasonal or inter-annual surpluses of VRE
  -> Seasonal storage and use of synfuels/hydrogen

Table 1: IEA´s phases of integration of renewable energies in the energy system; following the classification from (https://www.iea.org/topics/system-integration-of-renewables)

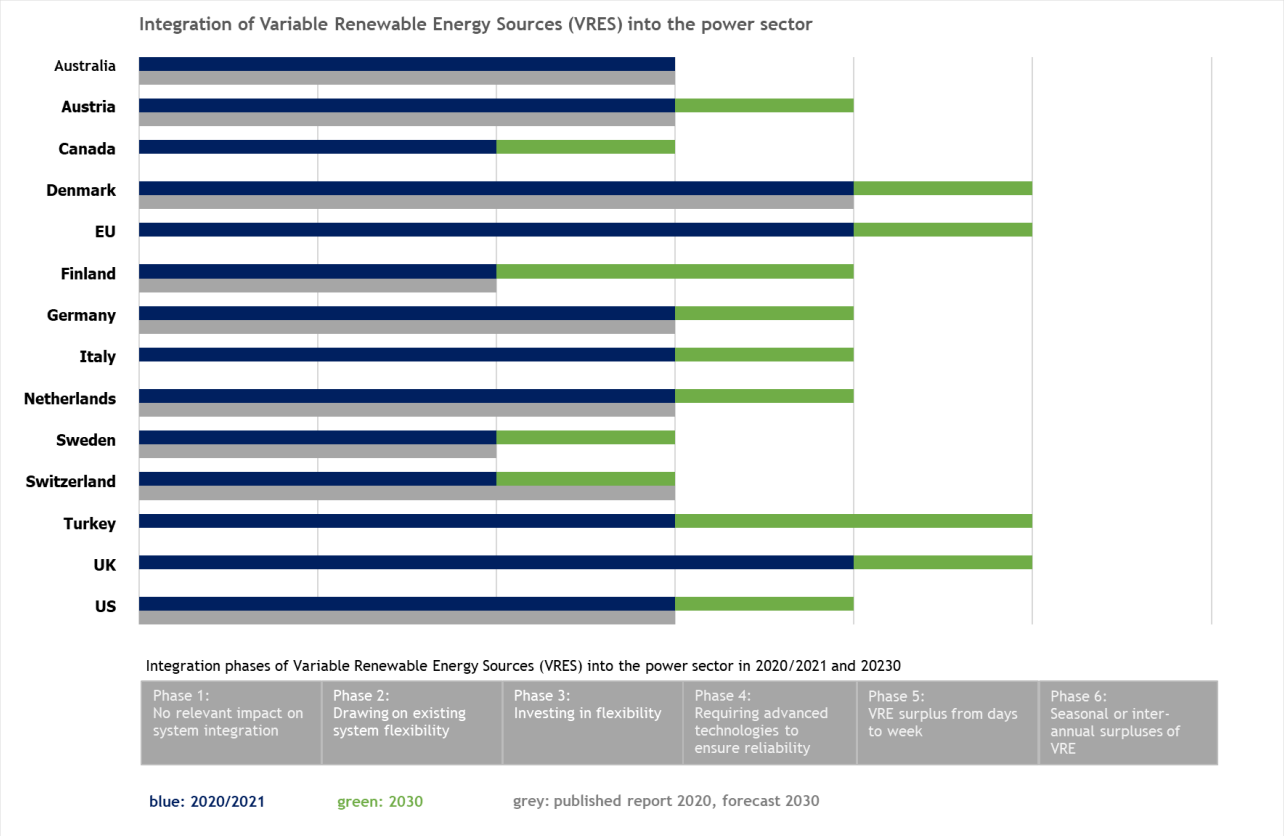


Figure 6: Estimation of the integration of Variable Renewable Energy Sources (VRES) into the power sector for 13 countries and EU.
Brazil did not answer. Please note for Australia: investing in battery storage – not bioenergy. Almost all countries surveyed in 2020 had already achieved their 2030 targets earlier than expected (grey line).

Three general results can be stated:

(1) All countries are at least in or facing Phase 3 “investments in flexibility”. Seven out of 13 countries expect to require advanced technologies to ensure reliability. This includes European countries but also Turkey and the US.
(2) 13 out of 14 countries state to reach at least one further phase till 2030. Some countries indicate that they will even reach Phase 5 (VRE surplus from days to weeks). Denmark, the EU, Turkey, and the UK are leading the transition, with Turkey and Finland projected to progress two phases within a decade. However, the majority of countries are forecasting only one advancement by 2030. Australia envisions maintaining its current status without progression. Notably, no country anticipates reaching Phase 6 (seasonal or inter-annual surpluses of VRES).
(3) Many of the countries have achieved the 2030 expectation from the last survey (Thrän et al 2021) already (grey line in Figure 6). Two possible reasons are seen for this effect: rising awareness or rising ambition concerning the necessary transition and the integration of VRES.

STATISTICS AND MONITORING OF FLEXIBLE RENEWABLE ENERGIES

The majority of countries actively monitors or chooses specific statistics (e.g. from pilot programmes, statistics of reserve markets) for their assessments. But it seems rather hard to figure out flexibility in detail. Italy states: Statistics and monitoring reports related to flexibility services are slightly “scattered” across different authorities’ databases; some of the services are compulsory, while others are traded on the Dispatching Services Market, the Balancing Market and the newest Capacity Market.

Interestingly, Sweden and the US are exceptions, having stated that they do not conduct monitoring.

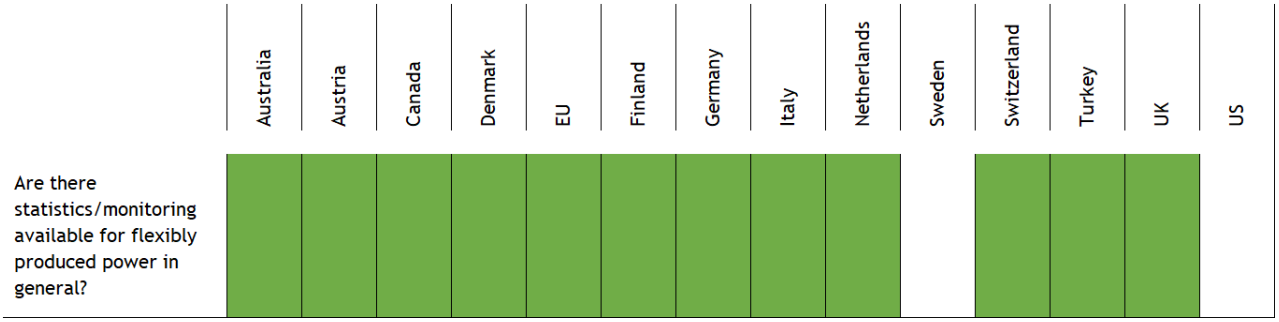


Figure 7: Overview of countries which monitor flexible renewable energies.
Brazil did not answer. White boxes mean no to the question.

Nine countries specified their flexibility information. The answers are considering different power provision systems and are difficult to assess. The given information can lead to the conclusion that capacities for flexibility are understood in different ways. A clear definition on how to calculate the flexibility of bioenergy production could improve the situation.

FLEXIBLE POWER SUPPLY TECHNOLOGIES ESTABLISHED TO CONTRIBUTE TO INTEGRATION IN THE ENERGY SYSTEM

The relevance of flexible bioenergy options between other flexible power supply options was another topic addressed in the questionnaire. Countries were supposed to weigh the relevance of various flexible power supply technologies, viz.:

- Virtual power plants
- Biogas and biomethane provision for flexible power generation

- Flexible operation of solid biomass CHPs for serving the electricity market
- Hydrogen and e-fuels
- Non-bio-based storage solutions (e.g. hydropower, pumped hydropower, battery storage)
- Other options

Respondents provided the status quo for these categories, ranging from implementation into the market, incentivisation through support schemes, inclusion in energy strategies to R&D, demonstration, real labs.

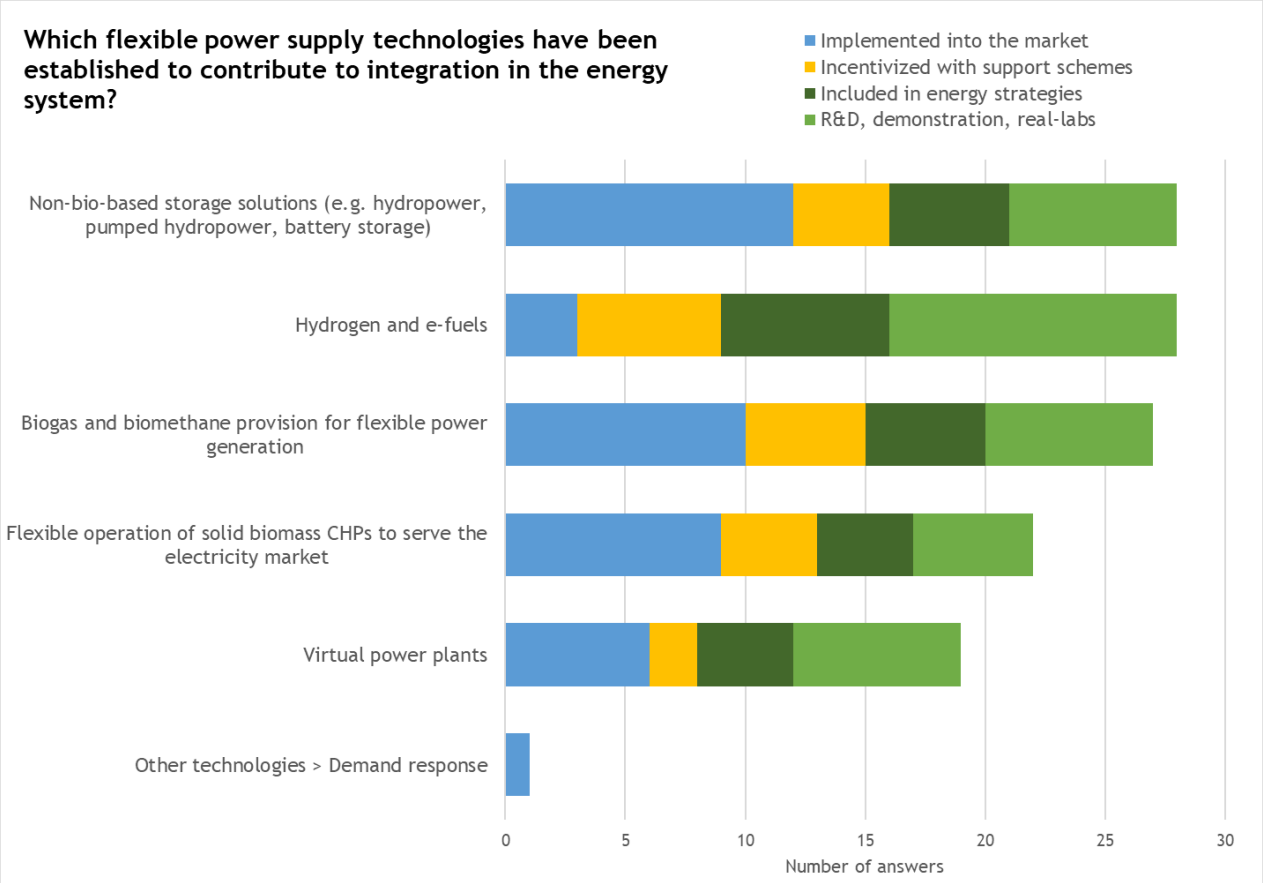


Figure 8: Flexible power supply technologies contributing to integration into the energy system

As highlighted in Figure 8, hydrogen/e-fuels technologies and non-bio-based storage solutions (such as hydropower, pumped hydropower, and battery storage) garnered significant attention across all countries. The latter, particularly, is notably common as a power supply technology and has been implemented in most countries' markets. Several countries also mention extra- large scale batteries deployed with grant support (as in Australia – both state and federal support incentivised with support schemes). Also, South Australia and Victoria and New South Wales and Queensland (Australia) are on the same strained electricity grid and are investing in pumped hydro and battery storage to compensate for the closure of coal-fired generators.

Additionally, biogas and biomethane plants as well as CHP plants with solid biomass are recognised as established flexibility solutions serving the electricity market in several countries.

Countries are notably incentivising hydrogen/e-fuels technologies, often including them in their energy strategies. However, these technologies remain predominantly in the demonstration and R&D phase. Similarly, virtual power plants and biogas/biomethane provision exhibit a comparable status across countries. They are either implemented or still in demonstration phase, with some countries not mentioning them at all.

In some countries, such as Australia, Denmark, Finland and Turkey, three or more of the suggested flexible power supply technologies are implemented in energy strategies. In Australia, Denmark and Turkey three or more of the technologies are incentivised.

An interesting case is Finland, which highlights demand response as a flexible technology contributing to energy system integration.

Summing up, the picture shows (see Figure 8 and Figure 9 and Figure 5) that across the countries an innovation and implementation pipeline for flexible power generation is visible. However, this is more prominent for hydrogen and hydropower than for biogas and solid biofuels.

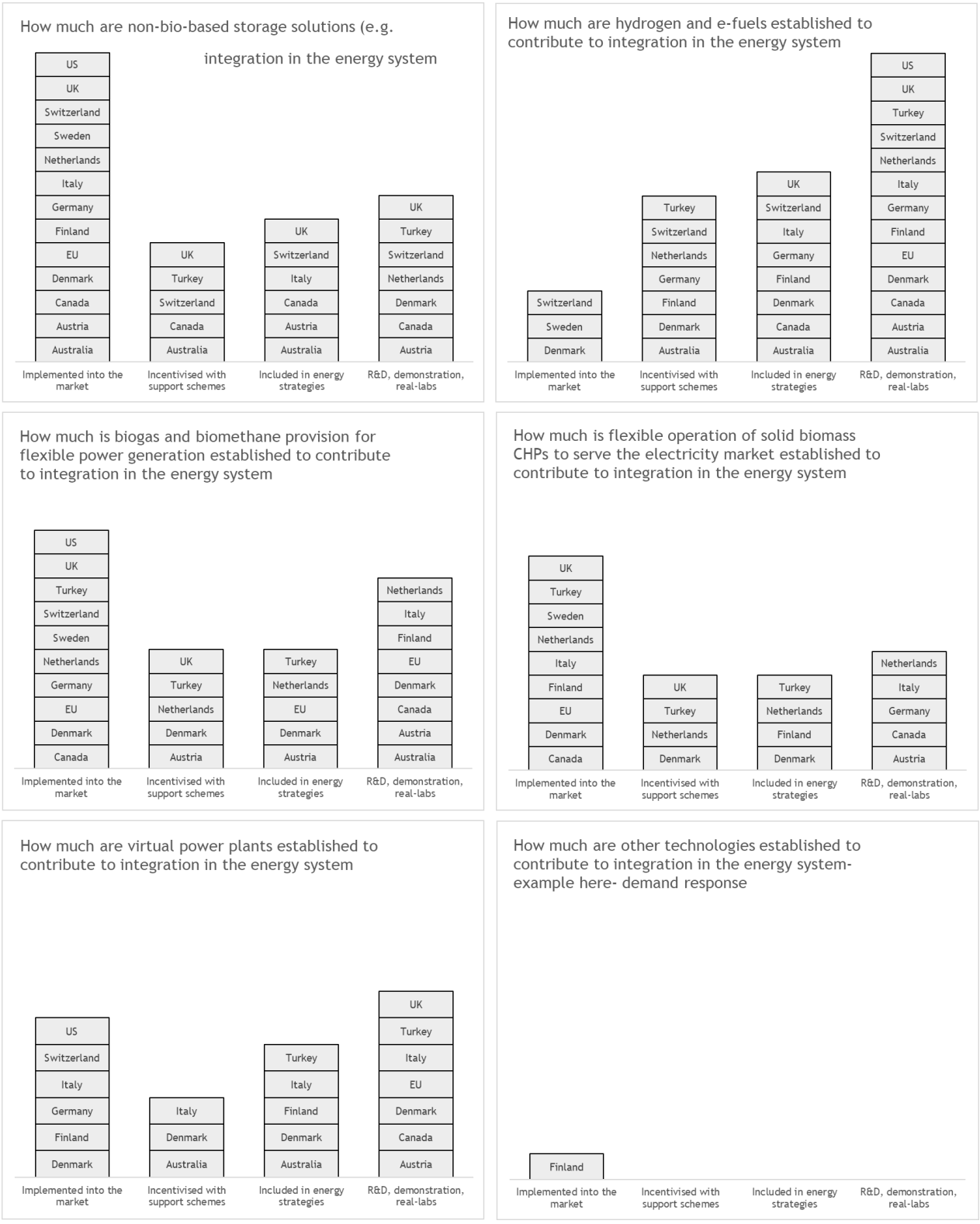


Figure 9: Current state of flexible power supply technologies integration in the energy system in 13 countries and EU. Brazil did not answer. More than one answer was possible.

5. Flexible bioenergy in other energy sectors

FLEXIBLE AND/OR POLY-GENERATION OF POWER, HEAT, FUELS AND CO_2 CAPTURE

Beyond flexible power also poly-generation and CO_2 removal (CDR) are options to provide flexible bioenergy for better system integration. We therefore asked for increasing activities in those fields over the last three years (Figure 10). Many of the countries state that poly-generation has evolved, and even more countries state dynamics in BECCS.

The following increasing efforts in flexible bioenergy production and/or the simultaneous production of electricity, heat, and fuels over the past three years are stated:

- Flexible bioenergy generation and poly-generation of power, heat, and fuels from bioenergy are important components of Canada's renewable energy sector and have grown from 2260 MW of installed capacity in 2019 to 2298 MW of installed capacity in 2021.

- Denmark has a strategy for Power-to-X (PtX) and utilisation of carbonaceous products (Carbon Capture and Utilisation – CCU). In 2022, the Danish Energy Agency granted DKK 194 million, financed by the NextGenerationEU initiative, for 3 projects which will promote pyrolysis technology for reducing greenhouse gas emissions within the agricultural sector.

- The capacity and wind power production in Finland has increased significantly during the last three years, and the growth is foreseen to continue. In 2022, the capacity grew by 2430 MW (75% increase), and the production volume grew by 41%. In total, 16.7% of domestic power generation in Finland were generated by wind power. The development implicates an increased need for flexibility with increased relevance for flexible bioenergy as potential means to provide it.

- In Sweden CHP has already been implemented for a long time and several companies are now working on broadening the use of CHP to produce fuels, both for external use and for own consumption, e.g. for peak load.

- Several laws are now in the parliament procedures in Switzerland which could strongly improve the situation of PtX and thus also PtMethane with biogas.

- In Turkey, the capacity of (licensed) bioenergy has increased from 1163 MW in 2019 to 2219 MW by October 2022.

- Since 2019 the installed CHP capacity in the UK has increased year after year. Greater emphasis is being placed on system efficiency to maximise output.

- The main interest in the US related to flexible bioenergy is arguably the increased exploration of power-to-liquids to provide energy storage and/or fuels and products options. While there is little to no commercial relevance yet, the prominence of the subject in private and government strategic visions is growing.

Only in Italy, Germany, Australia and Austria, there have been no significant developments (Figure 10). In Australia, there are no policy incentives to support the deployment of bioenergy. However, there are two incinerators being built in Western Australia. Italy states that, in the last years, subsidy schemes for the use of biomass for power generation in new plants were stopped, and the installed capacity is stagnating. Biomethane production is being fostered, with subsidies for the use in the transport sector. No specific incentive scheme for flexible bioenergy use is in place. Under this framework, flexible bioenergy generation is not growing and only few small examples are operating: i.e. the two biomass-powered ORC turbines for power and heat generation that power district heating systems in the north of Italy and participate in the demand-side management (DSM), one of them within a Virtually Aggregated Mixed Unit (UVAM) (EGO, 2019 and FIPER, 2020).

Increasing relevance of **bioenergy carbon capture and storage (BECCS)** over the past three years is indicated by 11 out of 14 countries (Figure 10). Three countries responded negatively: (1) The Australian author has answered the question vaguely: I would describe it as an increased interest - but again, there are not enough facilities to make BECCS a real solution.

(2) Turkey states no relevance.

(3) In Finland, the relevance of carbon capture has significantly increased and CCS is mentioned together with CCU in national climate and energy strategies, but its potential is seen from 2040 onwards. For this reason, Finland also answered the question with "No". Currently, there are no CCS demos/R&D programmes, but CCU is an interesting option for Finland, and several research projects and demos take place. The national climate and energy strategy highlights the development and use of CCS/CCU technologies and solutions, and funding is allocated for them, e.g. the Sustainable Growth Programme for Finland foresees EUR 156 million for hydrogen and CCS/CCU in industry.

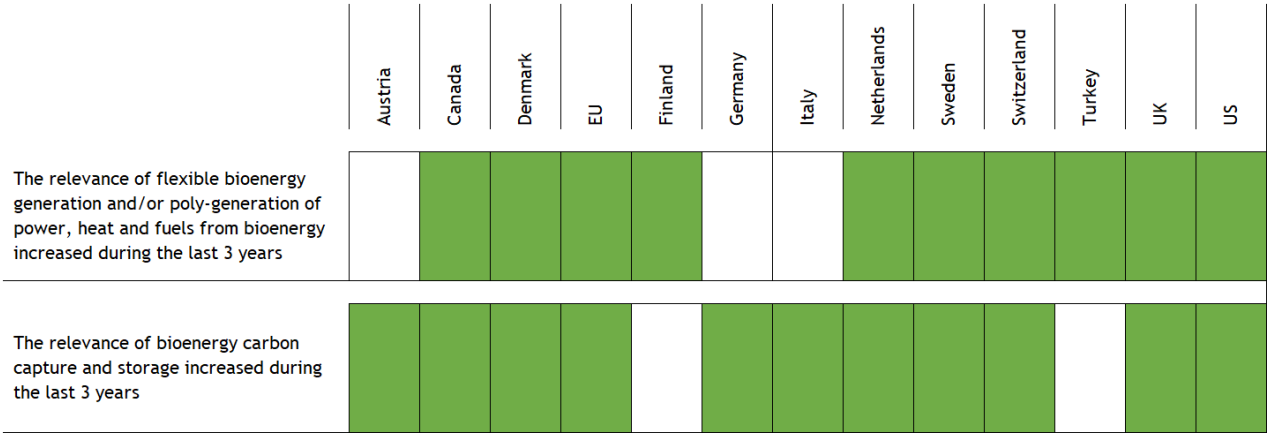


Figure 10: Increase of relevance of flexible bioenergy generation and/or poly-generation of power, heat and fuels from bioenergy or bioenergy carbon capture and storage.
Out of 15 countries, 13 gave feedback (Australia, Brazil missing). White boxes indicate a negative answer.

For the following countries, an increased significance of BECCS is reported:

- In Austria, for CCS, the permanent storage of CO_2 in geological structures is specifically forbidden by law since 2011, what affects BECCS options substantially. But currently, a discussion on policy level is ongoing whether to end this ban.

- BECCS is an important component of Canada's energy transition, and the utilization of BECCS is considered an important component of Canada's net-zero targets. Based on existing facilities, the theoretical emissions abatement potential of BECCS across economic sectors is enormous. Emission-intensive industries combusting fossil fuels include coal-fired power plants in Alberta, Saskatchewan and Atlantic Canada, iron and steel mills, primarily located in Southern Ontario along with cement and lime kilns. If these industries were to switch fuel to biomass with CCS, the emissions abatement potential approximates 20% of current national emissions and would consist of 70Mt/year of CO_2 in avoided emissions from fossil fuel combustion plus an equivalent quantity of negative emissions of biogenic CO_2 that would be captured and stored from biomass use. Capture and storage of biogenic carbon from existing facilities that currently process biomass extends the abatement potential by another 35Mt/year. Net-zero modelling scenarios in Canada assume biomass-CCS to be a considered net-negative technology that would receive credits for carbon removal. As the carbon price increases, biomass CCS units become a negative cost generation option, where its average cost of electricity in 2050 is -$85/MWh. The potential

cumulative biomass CCS capacity addition by 2050 is 6 GW. Due to the limitations in available biomass resources, modelling assumes that this would be the maximum possible biomass CCS capacity.

- In 2022, Denmark settled for an agreement on "A roadmap for capture, transport and storage of CO_2", including 13 initiatives of which one is specifically targeted to waste incineration and biomass-based production facilities. Other initiatives include negative emissions and BECCS. With the agreement comes a financial support pool of DKK 16 billion, which is divided into two phases. The first phase of the implementation aims to realize CO_2 reductions of 0.4 million tonnes annually from 2025.

- The total potential for bio-CCS in Sweden is around 30 Mt/y, both from CHP:s in district heating, from pulp mills and from fermentation processes (bioethanol and biogas). Many companies are analysing this and some have committed to investing in BECCS or BECCU. The government has introduced a support programme with reverse auctions for 2-3 Mt over the next few years. For district heating based on bioenergy, BECCS offers the opportunity to sell "heat with negative emissions".

- In Switzerland, the association of waste incineration plants signed a contract to capture 100 kt of CO_2 per year from 2030. Of this, 50% is biogenic, both CCU and transport to Norway (BECCS) are discussed. In addition, the first of its kind production of heat, electricity and biochar can be found at a plant in Frauenfeld (link to the best practice example).

- The UK Government has funded several R&D and demonstration initiatives to support the development and deployment of BECCS. Besides that, the Hydrogen BECCS Innovation Programme supports innovation in hydrogen BECCS technologies (bioenergy with carbon capture and storage) with £31 million. The projects can be accessed via the following link: https://www.gov.uk/government/publications/hydrogen-beccs-innovation-programme-successful-projects.

- In the US, there has been an increase in support of and incentives for activities that capture and store waste carbon dioxide underground at Federal and State level. This includes existing biomass conversion or combustion facilities (such as CHP and/or ethanol plants) as well as new dedicated BECCS facilities, though the process has thus far been slow and actual deployment has been minimal.

CURRENT STATUS OF BIO-BASED FLEXIBILITY OPTIONS WITH RESPECT TO SECTOR COUPLING AND SYSTEM INTEGRATION

To describe the status of the different flexibility options beyond the power sector, we asked to give indications for the following categories:

- Seasonal flexibility via generation of power, heat, fuels and non-energy products according to market demand and trends matching seasonal demand patterns
- Day-to-day flexibility via generation of power, heat, fuels and non-energy products according to market demand and trends matching seasonal demand patterns
- The potential of bioenergy combined with carbon capture and storage (BECCS) to enhance flexibility
- The combination of bio-based processes with hydrogen production from excess electricity, hydrogen production from biomass
- Combination of biomass with Power-to-X (PtX)
- Synthetic fuel production in flexible operation (flexible provision and processing of biogenic CO_2 with, for example, hydrogen from PV or wind surpluses)

The results (Figure 11) show that market introduction is stated for seasonal flexibility and day-to-day flexibility (Denmark, Finland, Germany, Italy, Netherlands and Sweden), combination of bio-based processes with hydrogen production from excess electricity in Denmark and Sweden and with Power-to-X in Denmark and Switzerland. All the other options, such as BECCS, hydrogen from biomass and synthetic fuel production are still in research, development and piloting. Compared to flexible bioenergy in the power sector, those fields are in an earlier stage of implementation. Also, implementation schemes are rare: only four countries have support programmes (Denmark, the Netherlands, Sweden and the USA). Denmark and the Netherlands support seasonal/daily flexibility through the generation of electricity, heat, fuels and non-energy products. Sweden and the US support BECCS. The US also promotes hydrogen production from biomass and synthetic fuel production in flexible operation.

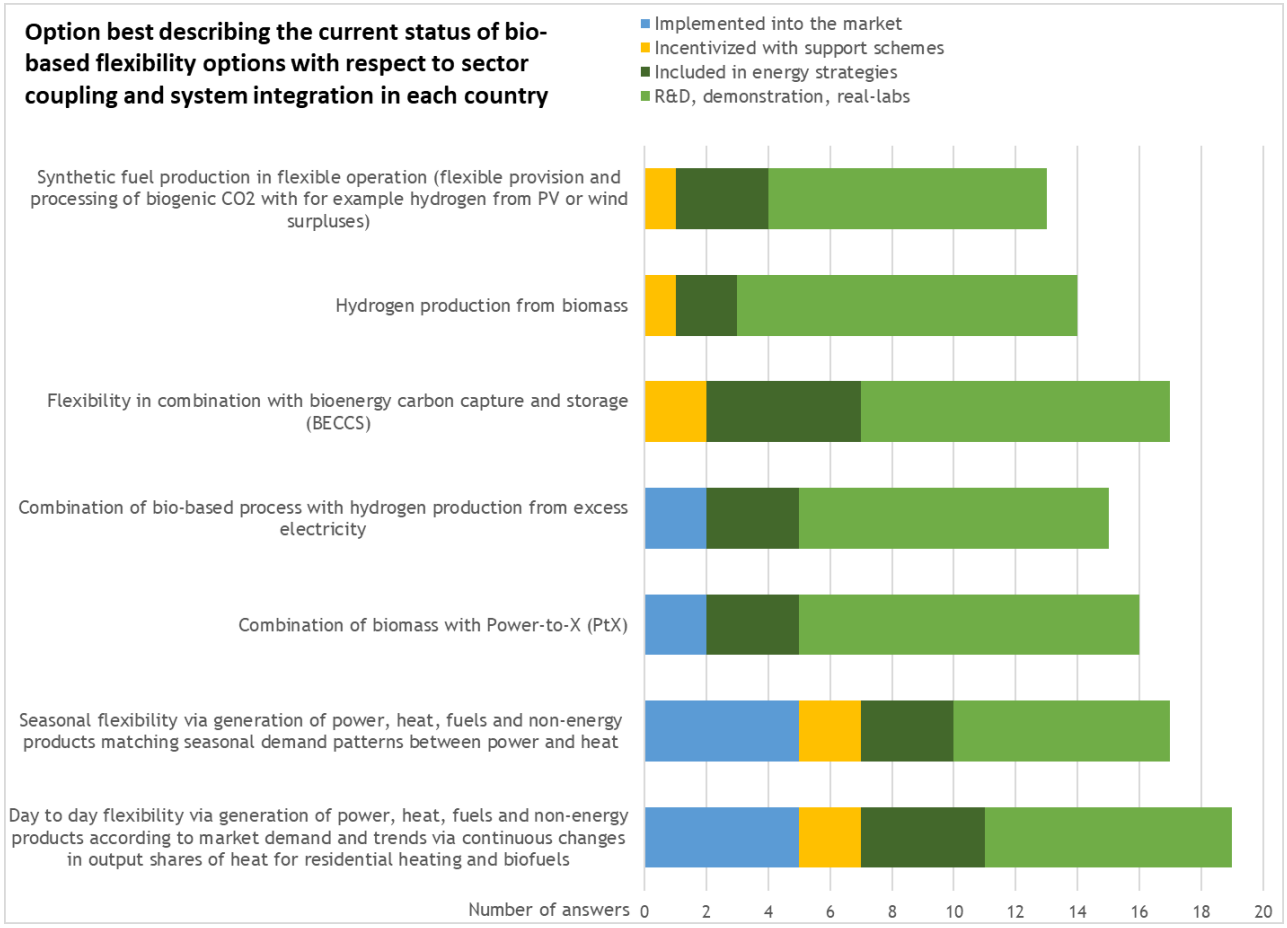


Figure 11: Current status of bio-based flexibility options with respect to sector coupling and system integration in 13 countries and EU; Brazil did not answer.

Consideration of flexible bioenergy in energy strategies is another indicator for the future relevance of the different options. It differs widely between the countries (see Figure *12*). Flexibility in combination with bioenergy carbon capture and storage (BECCS) is covered in energy strategies in five countries. In six countries, there are no categories implemented at all. The Netherland, Switzerland and Finland have the most elaborated energy strategies for flexible bioenergy with respect to sector coupling, system integration, covering also seasonal and day-to-day flexibility, combination with excess energy, hydrogen and Power-to-X. Germany and Sweden only cover BECCS. Canada and Italy name hydrogen production from biomass.

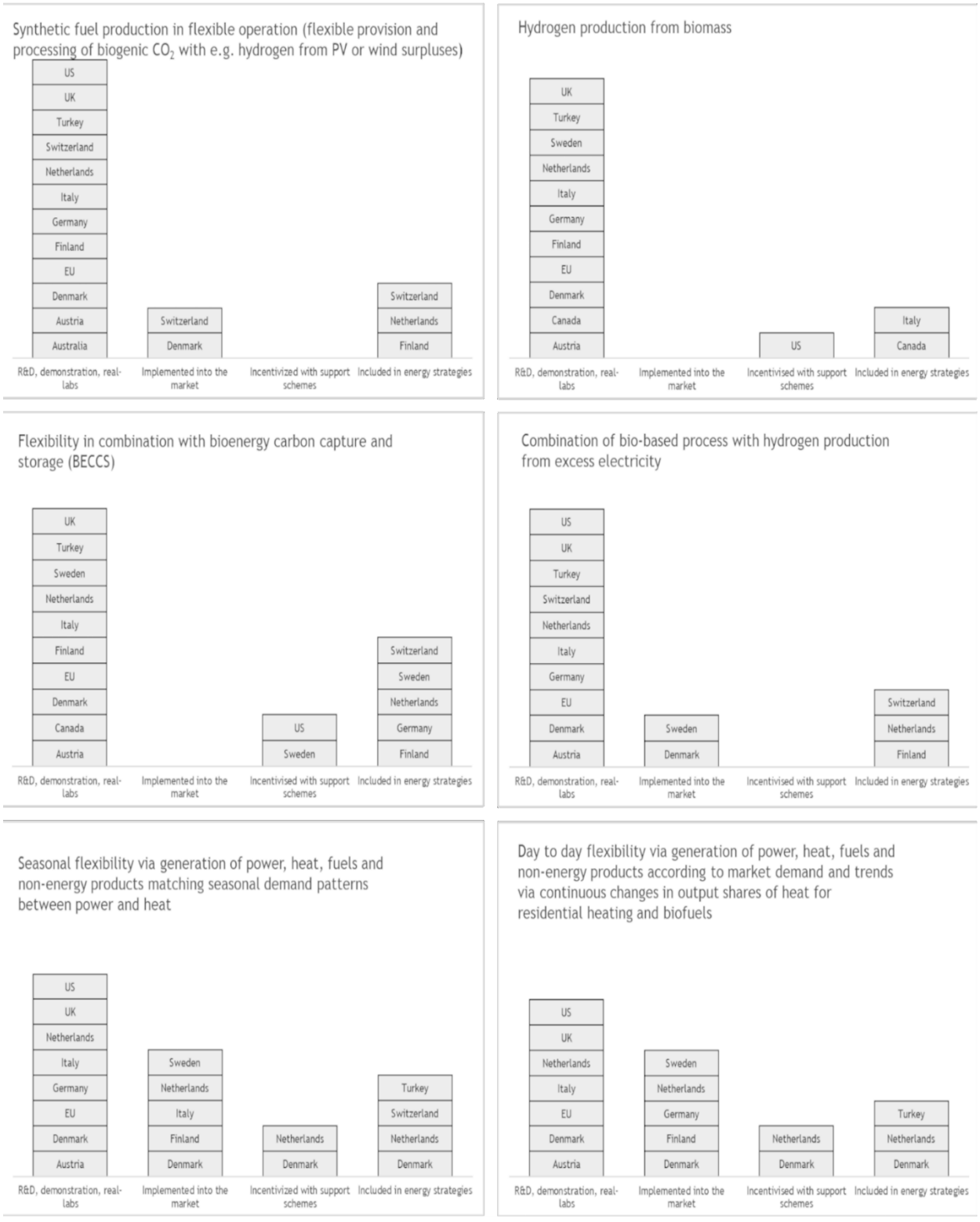


Figure 12: Detailed information on current status of bio-based flexibility options with respect to sector coupling and system integration
in 13 countries and EU. Brazil did not answer.

The Netherlands have cited concerns regarding market implementation, particularly focusing on biomass co-firing in coal-fired power plants. Currently, there are four plants in operation, two of which are dedicated to power generation only, while the other two are combined heat and power (CHP) plants connected to heating grids. Additionally, the country boasts several industrial CHP plants and heating networks equipped with biomass boilers.

6. Flexible feedstock provision, bioenergy carrier storage and BECCS

Flexibility in feedstocks covers the diversity of feedstocks (variation in type and/or quality), the use of residues as well as the storage of bioenergy carriers and BECCS. Here, we consider bioenergy sources for short-term use and bioenergy with carbon capture and storage (BECCS) as a long-term storage option. In at least 60% of the investigated countries, the relevance of these different dimensions of flexible feedstock has increased over the last three years (see Figure 13). The relevance of the three topics is diverse:

- In Australia, Denmark, Finland, Sweden and Switzerland, there was no increase in the diversity of the raw materials used in the last three years.
- The importance of residues as feedstocks did not increase in Canada, Denmark, Finland, UK and US, but in all other countries (see Figure 13).
- The relevance of storage of bioenergy sources and BECCS has increased in most countries, except for Australia, Germany, Italy and Turkey.

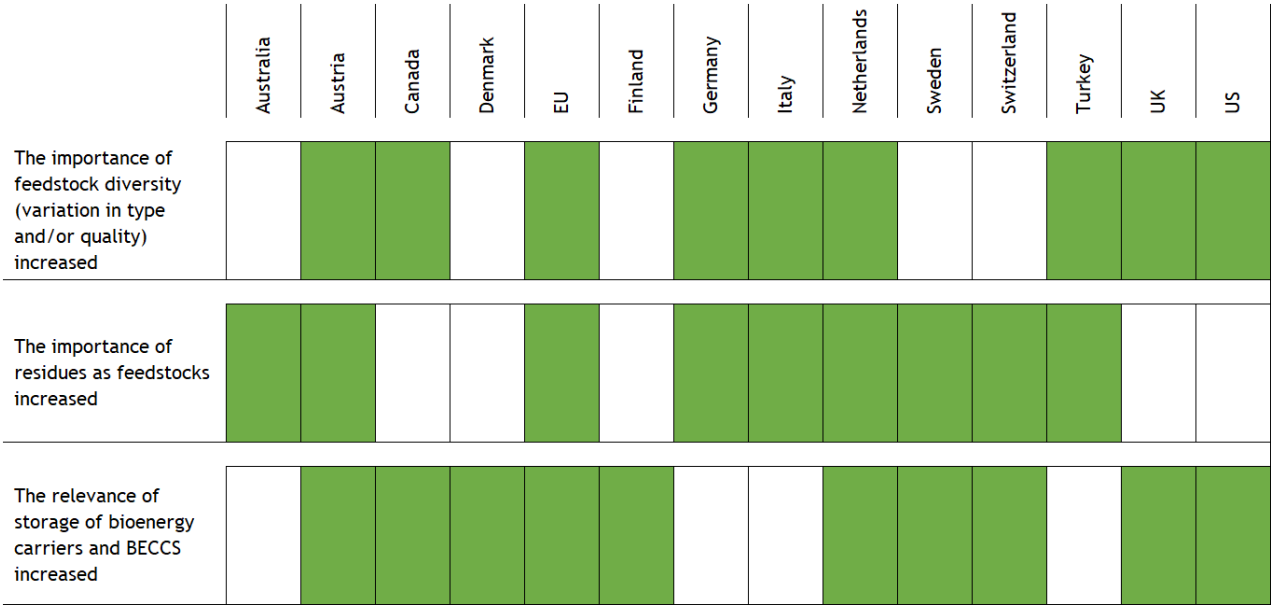


Figure 13: Flexible feedstock, residues use, storage of bioenergy carriers and BECCS.
13 countries and EU answered, Brazil did not. White boxes are countries without answer/information.

Additionally, we asked what kind of measures were taken in this field (Figure 14 and Figure *15*). Countries were asked to indicate whether there was support for these categories, if policies had been implemented in national energy strategies, whether they were already integrated into the market or currently in demonstration mode. Market implementation was reached in all three fields, but mainly in storage and trade, while the use of varying materials is still also under research, development and demonstration.

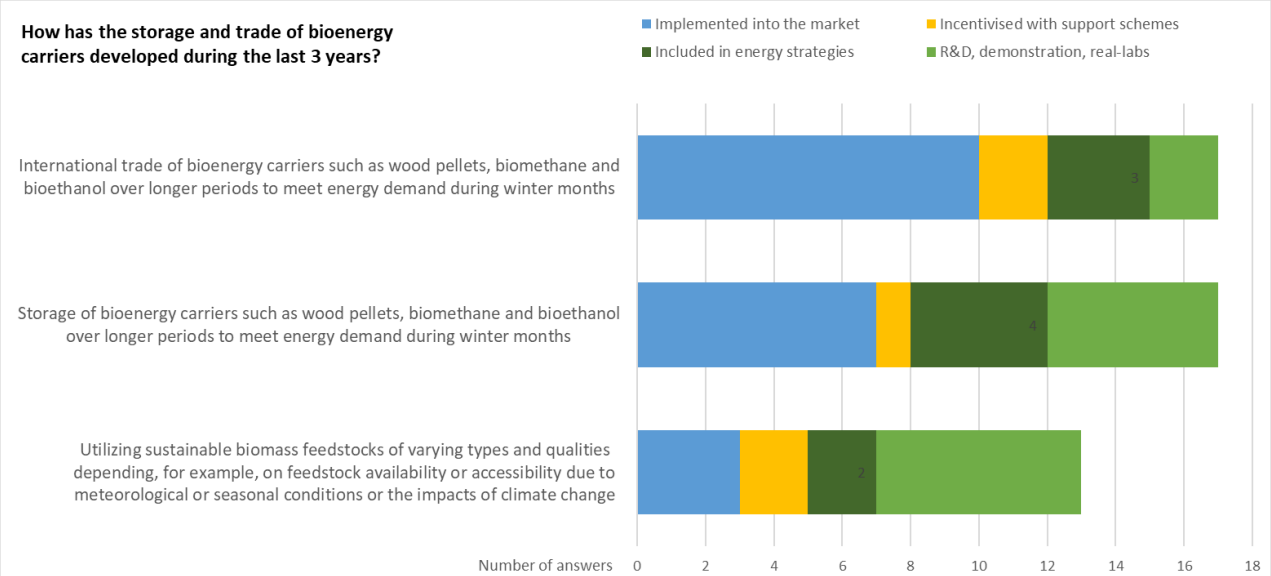
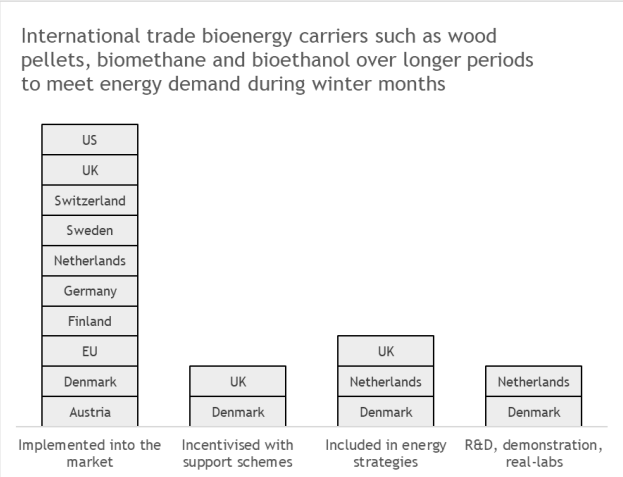
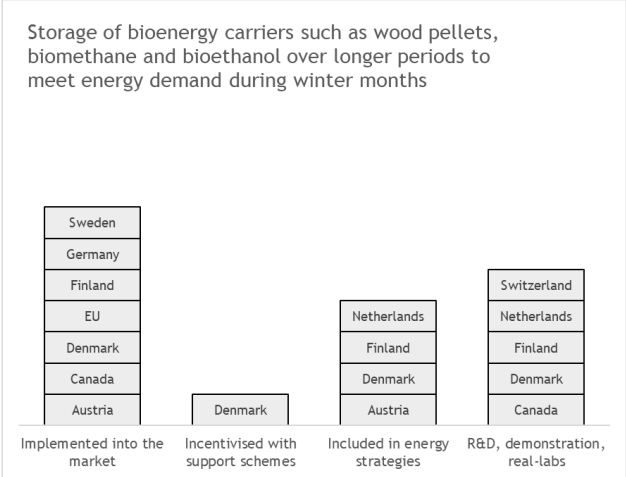


Figure 14: Overview of the development of storage and trade of bioenergy carriers during the last three years in 13 countries and EU, Brazil did not answer.

As highlighted results, international trade is implemented into the market in most countries, but only included in three national strategies (see Figure 14) in Denmark, Netherlands and UK. The storage of bioenergy carriers such as wood pellets, biomethane and bioethanol over longer periods to meet energy demand during winter months is in R&D state in Canada, Denmark, Finland, Netherlands and Switzerland, but mostly implemented into the market in all other countries and included in four national energy strategies (Austria, Denmark, Finland and Netherlands). Utilizing sustainable feedstock 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 appears to be the most ambitious project for all countries involved. Here, most countries indicate that they are still in the R&D phase. However, Denmark, Netherlands and Sweden have already implemented some solutions into the market. Additionally, Denmark and Netherlands have incorporated this issue into their energy strategies.

In all the categories, there are almost no incentives provided by support schemes(Figure 14 and Figure *15*). Denmark and Germany support the utilisation of sustainable biomass feedstocks. Additionally, Denmark also provides support for storage and international trade of bioenergy carriers. The latter is also supported by the UK.





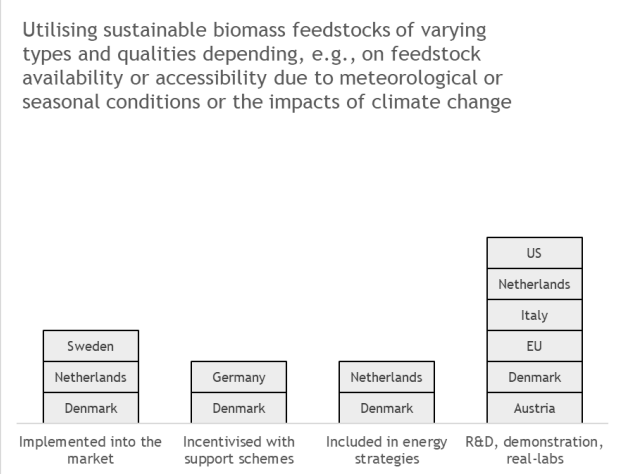


Figure 15: Detailed information of storage and trade of feedstocks in 13 countries and EU. Brazil did not answer.

7. Support mechanisms for flexible bioenergy

ELECTRICAL POWER SYSTEM

National support mechanisms for bioenergy used in the electrical power system are listed in Table 2. Most of the listed mechanisms do not specifically support flexible bioenergy. Many countries support renewable energy production overall, and thus indirectly also bioenergy and flexible bioenergy production, e.g. the Australian Renewable Energy Agency grants non-commercial renewable energy deployments, four Canadian provinces require electricity suppliers to obtain a minimum percentage of their power from renewable energy sources, Finland supports investments replacing coal in energy production and Turkey supports renewable energy resources.

For all EU member states, the emission trading system EU-ETS is a strong incentive for replacing fossil fuels in large installations – heavy industries and energy plants (power plants and CHPs). With the introduction of ETS2, also smaller heat plants and residential heating will also have a strong inventive for renewable solutions such as bioenergy. In some countries, CO_2 taxes already have a similar effect.

In Germany, the EEG (Erneuerbare-Energien-Gesetz) uses a mixture of obligations and incentives to support flexible power generation, e.g. by exploiting biogas and biomethane cogeneration plants. The Netherlands have a subsidy scheme for reducing the cost of renewable electricity production only, including bioelectricity, but it has been announced that after 2025 no new subsidies will be granted for renewable

electricity production. US reports on some regional grid systems in which biomass-based production is counted as renewable and, thus, not included in total emissions. Switzerland has Capex and Opex contribution to biobased CHPs.

Austria and Denmark report on feed-in tariffs and premiums for flexible bioenergy. In Canada, the provinces of Ontario and Nova Scotia have feed-in tariff programs for renewable energy including bioenergy. In Finland, feed-in premiums for electricity provision technologies from wind, biogas, forest chips and wood-based fuels were established in 2011, but they ended in 2017 for wind, 2019 for biogas and wood-based fuels, and 2021 for forest chips.

Table 2: Feedback from countries for support mechanisms for bioenergy used in the electrical power system.

Country	General	Investment grants	Feed in tariffs/premiums
Australia	There are grants available for non-commercial renewable energy deployments primarily though ARENA — The Australian Renewable Energy Agency. They are not bioenergy-specific.		
Austria		Investment grants	Feed-in tariffs and premiums
Canada	Four Canadian provinces have a Renewable Portfolio Standard, which requires electricity suppliers to obtain a minimum percentage of their power from renewable energy sources.	Support for clean energy projects in indigenous, rural and remote communities including biobased CHP.	The Provinces of Ontario and Nova Scotia have feed-in tariff programs for renewable energy.
Denmark			There is a feed-in tariff system, which guarantees a fixed price for electricity generated from bioenergy sources. Premium tariffs are available to bioenergy projects that demonstrate flexibility in their operations.
Finland		The ministry of Economic Affairs and Employment can grant aid for innovative energy investment projects and for energy audits. Special aid for new energy technology and large-scale demonstration projects is granted for investments worth over EUR 5 million that take forward future energy technologies. Aid for investments replacing coal in the energy production can be granted to projects that enable the substitution of coal with	Feed-in premiums for electricity from wind, biogas, forest chips and wood-based fuels were established in 2011 and ended in 2017 for wind, 2019 for biogas and wood-based fuels, and 2021 for forest chips.

		renewables in the energy production before the end of 2025.	
Germany	The EEG (Erneuerbare-Energien-Gesetz) uses a mixture of obligations and incentives to support flexible power generation.	Additionally, the EEG contains the funding mechanism of the flexible surcharge which is set to 65,-€ per kW of installed capacity for biogas and biomethane plants to economically balance the lower turnover by the limited utilisation of such plants.	In the EEG, for the binding tendering mechanism, which is relevant for most of the plant concepts with more than 150 kW of installed capacity, the legislator limits the annual utilisation of power plants to force a flexible operation. For example, biogas plants with on-site cogenerations are only allowed to produce for 45% of /the annual hours and biomethane CHPU are allowed to run for 10% of the annual hours.
Italy	A support scheme is in place for the virtual exchange of renewable energy within Renewable Energy Communities.		
Netherlands	The SDE+ and SDE++ scheme are used to reduce the cost of renewable electricity production only (e.g., solar, wind, bioelectricity). It has been announced that after 2025 no new subsidies will be granted for renewable electricity production.	A scheme for investment support, the Energie Investerings Aftrek (EIA), is in place.	A feed-in premium subsidy to cover the difference between the wholesale market price and the production cost of energy products from renewable sources (SDE+) or GHG emission reduction measures (SDE++). The subsidy for biomass co-firing in coal-fired power plants is capped to 25 PJ/year.
Sweden	Exceptional support peak-load to power units using biooil (Stockholm) and biogas (Malmö).		
Switzerland	Grid operators have to accept/inject renewable electricity and bio-methane.	Capex and Opex contribution to biobased CHPs, ancillary service as additional revenue.	
Turkey	The Renewable Energy Resources Support Mechanism (YEKDEM) is established.		
UK	Renewable Obligation Order, Contract for Difference		
US	Some regional grid systems in the US allow for biomass to count as renewable electricity generation and therefore do not include it in the emissions total for their cap-and-trade programs (Ex. RGGI in the Northeastern US).		

THERMAL ENERGY PRODUCTION

The countries do not report on specific support mechanisms for flexible bioenergy in thermal energy production, although support mechanisms for CHP production may be seen as such. Mentioned support mechanisms for bioenergy in thermal energy production are listed in Table 3. Tax reductions for solid biofuels are in place in Austria and a CO_2 tax for fossil fuels in heating exists in Finland and in Sweden. Finland targets to phasing out of fossil fuel oil in heating by the beginning of the 2030s and applies quota obligations for bioliquids. Sweden has an incentive for renewable heat and a support scheme for green gas. Canada has support for clean energy projects overall, including biomass heating (district, CHP, power) and supply chains. In Denmark, companies are obligated to source a portion of their heat supply from renewable sources and biomass-based CHP plants are supported by several mechanisms.

Table 3: Feedback from countries for support mechanisms for bioenergy in thermal energy production.

Country	Quota obligations	Tax exemptions	Investment grants	Incentives/support schemes
Austria		Tax reductions on solid biofuels, 13% instead of 20%		
Canada			Support for clean energy projects in indigenous, rural and remote communities. This funding can go towards many renewable energy and energy storage projects including biomass heating, district heating, combined heat and power systems and biomass supply chains.	
Denmark	A heat supply obligation requires companies to source a portion of their heat supply from renewable sources, including bioenergy.		Biomass-based CHP plants receive support through various mechanisms such as premium tariffs, feed-in tariffs or investment grants.	
Finland	For biofuels in heating to apply to light fuel oil used in heating and machinery so that the share of bioliquids must be at least 10% by 2028.	A CO_2 tax for fossil fuels in heating has been a long-term incentive to promote RES-heating.		
Netherlands				Since 2012, renewable heat projects have been supported. Subsidy for biomass co-firing in coal-fired power plants

				was capped to 25 PJ/year.
Sweden		High carbon tax	Certain investment grants are given to small and medium-size enterprises to complement the carbon pricing mechanism.	Renewable heat incentive Green gas support scheme

TRANSPORT

In the EU, the revision of the RED establishes transport sub-targets for advanced biofuels and RFNBOs (5.5%). It is noted by the respondent from the Netherlands that, for transport, the Netherlands basically follow European policy measures, e.g. as described in the RED, REDII and REDIII. This includes diesel and gasoline blending obligations. In this respect, also the new SAF blending targets (from 2% in 2025 via 6% in 2030 to 70% in 2050) are agreed on European level.. Several other respondents make note on quota obligations for biofuels blending for fossil transport fuels in their country (Austria, Denmark, Finland, Germany, Sweden, UK). In Finland, the blending target is relatively high; 30% by 2030. They also report on distribution obligation for biofuel and biogas for transport. In Canada, the minimum required blending requirement for low CI fuels in gasoline (5%) and diesel (2%) is given as CI-based standard in Clean Fuel Regulations.

Sweden has tax exemptions for high blends of pure biofuels, Switzerland for biofuels from wastes, and the US have a federal tax credit for SAF. In the Netherlands, large scale production of renewable transport fuels (bioethanol, biomethanol and diesel and gasoline substitutes from solid lignocellulosic biomass and bio-LNG based on digestion) is supported by the SDE++ scheme. National support mechanisms for bioenergy in transport are listed in Table 4.

Table 4: Feedback from countries for support mechanisms for bioenergy in transport.

Country	General	Quota obligations	Tax exemptions
Austria		For biofuels for diesel and gasoline	
Canada	Clean Fuel Regulations (CFR) increase incentives for the development and adoption of clean fuels, technologies, and processes with the goal of significantly reducing pollution caused by common fuels.	CFR adopt a volumetric requirement for low CI fuels (5% for gasoline, 2% for diesel), and expand the types of eligible alternative fuels to be any 'low carbon intensity fuel' recognised under the regulation. The British Columbia Renewable and Low-Carbon Fuel Requirements Regulation targets a 20% reduction of average fuel CI by 2030.	
EU	Notably strengthened measures to support renewables uptake in transport. Measures to promote the use of renewable fuels, including hydrogen, in sectors where electrification is not yet a feasible option.	Revision of RED foresees transport sub-targets for advanced biofuels and RFNBOs (5.5%).	

Finland		For biofuel use (target 30% by 2030) Distribution obligation for biogas, electrofuels and biofuels	
Denmark		Blending mandates	Tax reductions on biofuels used in transportation
Germany		GHG quota in transport sector	
Netherlands	In 2022, a new category for the large-scale production of renewable transport fuels (both biofuels and synthetic fuels) was opened in the follow-up SDE++ support scheme to promote cost reduction and industrialisation. Categories included are: bioethanol, biomethanol, diesel and gasoline substitutes from solid lignocellulosic biomass and bio-LNG based on digestion.	For transport, the Netherlands basically follows European policy measures, e.g. as described in RED, REDII and REDIII. This includes diesel and gasoline blending obligations. In this respect, also the new SAF blending targets (from 2% in 2025 via 6% in 2030 to 70% in 2050) are agreed on European level.	
Sweden		For blending of biofuels in fossil transport fuels, both for transport and for aviation.	For high blend of pure biofuels (e.g. for biogas used in transport, for E85 ethanol)
Switzerland			On biofuels from wastes
UK		Renewable transport fuel obligation	
US	Renewable Fuel Standard (Federal) Low Carbon Fuel Standard (California)		SAF Tax Credit (Federal)

INDIRECT AND DIREKT SUPPORT MECHANISM

In conclusion, the experts from the different countries mentioned a lot of support mechanism, to support flexible bioenergy in the different energy markets. Some of the support mechanism are directly addressing flexibility, i.e. the flexibility investment support but most of them are indirect mechanism. Direct policy support is stated from Austria, Denmark, Germany, Italy, Netherlands, Sweden, Switzerland, Turkey. Those mechanisms support the creation of flexible bioenergy capacities on biogas plants (in Germany), feed in tariffs and premiums for flexible bioenergy (Austria and Denmark) or focus Capex and Opex contribution to biobased CHPs (Switzerland)With regard to the effect, both indirect and direct support can have a significant effect: For all frameworks it is also important that the support mechanism are high enough, i.e. the German EEG did not initiate many flexible plants in the last years, because there is a cap in the premium.

RELEVANCE OF EU STRATEGIES FOR EU COUNTRIES

In the questionnaire, we posed additional questions specifically for EU countries, with responses received from seven countries and the EU itself. We sought to gauge the extent to which EU policies and strategies are perceived to support national activities concerning flexibility actions. According to the findings illustrated in Figure 16, the European Green Deal and the "Fit for 55 Package" are widely regarded as offering strong support. However, opinions vary regarding the REPowerEU initiative. Most countries reported either slight support or no support for the EU Energy System Strategy, EU Methane Strategy, and EU Hydrogen Strategy.

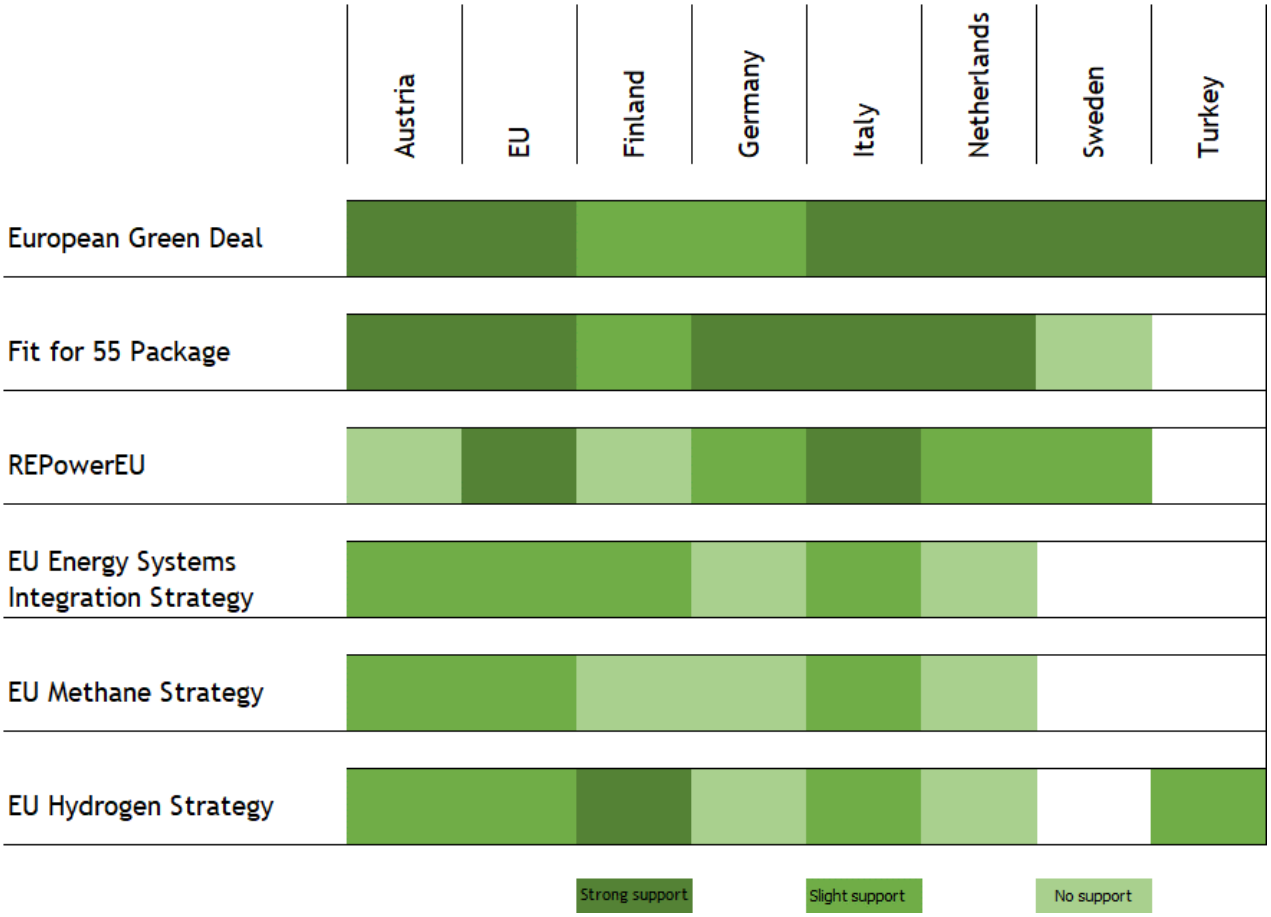


Figure 16: Activities related to flexible bioenergy supported by EU policies and strategies.
Answers from six EU countries, the EU and Turkey; Denmark did not answer. White boxes indicate no information provided.

Table 5: Additional information about country activities related to flexible bioenergy supported by EU policies and strategies.

Country	Support schemes	More details
Austria	**European Green Deal**	Builds the frame for transition, hydrogen is mentioned, bioenergy is not explicitly mentioned. In the Green Deal Industrial Plan, advanced biofuels are considered, bioenergy or flexible bioenergy is not mentioned.
	Fit for 55 Package	E.g. the higher target for renewable energy. ReFuelEU Aviation with the focus on Sustainable Aviation Fuels (SAF) which includes biofuels. A more ambitious EU emission trading system ETS will support the implementation of flexible bioenergy.
	REPowerEU	The short-term measures are rather hindering as they aim to replace fossil gas from Russia with fossil gas from other countries. The medium-term measures are supportive as for instance the European renewables target for 2030 is now increased from 40% to 45% and funds for investments will be provided.
EC	**European Green Deal**	Climate-neutrality by 2050 and ambitious RES and hydrogen plans. Energy system integration strategy acknowledges the importance of biomethane.
	Fit for 55 Package	Ambitious targets with room for RES to contribute to RES share, including bioenergy
	REPowerEU	Specific momentum for biomethane uptake and possible synergies with acceleration of hydrogen uptake
	EU Energy Systems Integration Strategy	Support specifically for biomethane
	EU Hydrogen Strategy	Possible synergies for bioenergy
Finland	**European Green Deal**	As part of the European Green Deal, a revision of the REDII (Renewable Energy Directive) has raised some concerns within the bioenergy industry in Finland. At least the suggested classification of primary wood fuels and lowering the threshold of applicability criteria to 10 MW are seen to have a potentially negative influence on bioenergy production in general (https://www.bioenergia.fi/2022/09/19/puusta-on-pitkalle-edelleen-myos-energiaksi/). The national climate and energy strategy (2022) anticipated additional potential in forest wood chip utilisation. As bioenergy producers are foreseen to have a central role in the implementation of flexible bioenergy in Finland, these concerns can also be seen to have impacts on flexible applications and can be seen as justified to be considered in the answer. However, we emphasize that, as the legislative package of the European Green Deal is extremely large and most probably also includes positive elements for certain applications/stakeholders, e.g. considering hydrogen, the possibilities to give unambiguous and overarching answers for the wide concept of flexible bioenergy are very limited. Hence, the answer must be reviewed very carefully and one could have justified other opinions.

	Fit for 55 Package	Here, only indicative thoughts can be given based on the position of the bioenergy industry of Finland. The Bioenergy Association of Finland sees the initiatives belonging to Fit for 55, at worst, diminishing the utilisation potential of forest-based bioenergy (key source in Finland). The revision of RED II, posing new requirements for sustainable bioenergy, is being seen as the most direct and significant legislation of Fit for 55 having impact. See further information at https://www.bioenergia.fi/2021/07/14/uusiutuvan-energian-direktiivin-paivitys-bioenergia-alan-kiikarissa/.
	REPowerEU	Only biomethane mentioned, not very relevant for Finland. However, from the point of view of hydrogen, REPowerEU is relevant and supportive with respect to Finland's hydrogen targets, also in connection to bioenergy as a significant amount of hydrogen is consumed for biofuel upgrading in Finland.
	EU Energy Systems Integration Strategy	Based on description of the strategy, where e.g. flexibility markets are mentioned, the impact for flexible bioenergy can generally be seen as promising. However, real impact, if any, remains to be seen in the implementation of the strategy.
	EU Methane Strategy	The significance of natural gas in Finland is lower than, for example, in central Europe and diminished rapidly during 2022 after abandoning the imports from Russia. Thus, this strategy is not seen as very relevant for the implementation of flexible bioenergy in Finland.
	EU Hydrogen Strategy	The European Commission has proposed to produce 10 million tonnes of renewable hydrogen by 2030 and to import 10 million tonnes by 2030. The Finnish government adopted a resolution on hydrogen in February 2023 stating that Finland has the capacity to produce at least 10% of the EU's emission-free hydrogen in 2030. Finland is part of hydrogen IPCEIs Hy2Tech and H2Use.
Italy	**EU Hydrogen Strategy**	All policy frameworks that open up to higher uses of bioenergy are at least indirectly fostering the uptake of flexibility actions. Anyway, if not explicitly supported by schemes or market advantages, maybe most of the processes involving bioenergy use could just focus on their main business case (i.e. energy, intermediate, final product(s)).

DEDICATED SUPPORT SCHEMES IN DIFFERENT COUNTRIES

In discussing strategies, we were also keen on understanding the presence of policies in various countries that support flexible bioenergy, as well as gauging the importance of these actions. In detail, we asked for actions in the different categories: governmental support, financial incentives, legal guidelines, market support (e.g. infrastructure, standards) and research and economically driven projects.

The policy is perceived to be very strong for research and commercially oriented projects (see Figure 17). Government support and financial incentives are also seen as important instruments. However, market support through standardisation or other guidelines is unclear for most countries. In summary, the majority of countries are actively implementing policies to support flexible bioenergy initiatives.

Figure 17: Overview of current state of policies in 14 countries.
Brazil did not answer.

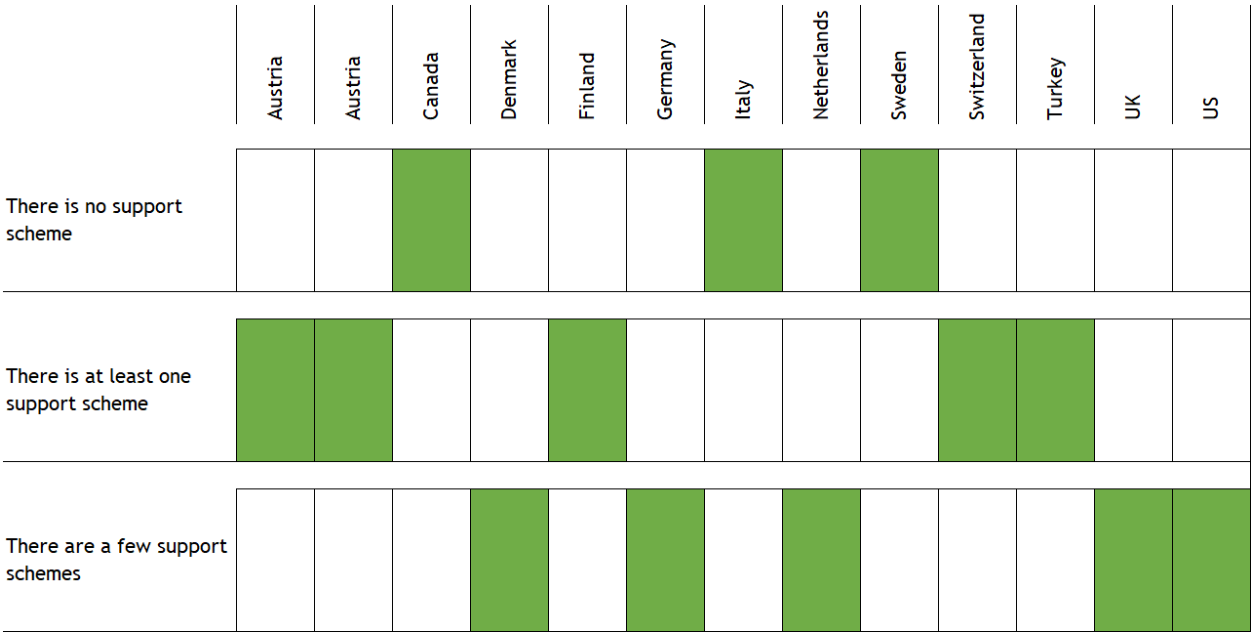


Figure 18: Overview of support schemes for flexible bioenergy in 13 countries.
Brazil and EU did not answer.

Figure 18 provides details about the existence of support schemes for flexible bioenergy in various countries. Among the 11 countries and the EU, a few (5) have multiple support schemes, while others (5) have at least one support scheme. Notably, only three countries — Canada, Italy, and Sweden — have no support schemes for flexible bioenergy.

Below in Table 6, you will find a compilation of examples highlighting the most relevant support schemes for flexible bioenergy across several countries and the EU.

Table 6: Information provided from ten countries and the EU for the most relevant support schemes for flexible bioenergy.

Country	Most relevant support schemes for flexible bioenergy
Australia	- ARENA - Emission Reduction Fund - Clean Energy Finance Corporation
Austria	- Investment support: Raus aus Öl und Gas (Out of oil and gas) - Erneuerbaren-Ausbaugesetz —EAG — Investitionszuschüsse (Renewable Expansion Act — investment grants regulation 2022) - Umweltförderung Inland — UFI (Domestic environmental grant) - Feed-in tariffs, premiums: EAG-Marktprämienverordnung 2022 (Renewable Expansion Act — premium regulation 2022) - Quota obligations: Kraftstoffverordnung (Fuel regulation) - Erneuerbares-Gas-Gesetz (Renewable Gas Act)
Denmark	- Promotion of Renewable Energy Act - Energy Agreement - Green Investment fund
EU	- General targets for Renewable energy targets and sub-targets for transport and industry
Finland	- Quota obligation for biofuel use in transport sector - Investment aid for renewable energy and energy efficiency - Taxation, e.g. for fossil fuels in heating - Quota obligation for heating and machinery
Germany	- EEG 2023
Netherlands	- (SDE+ and SDE++) schemes
Switzerland	- Specific P+D and research programmes
Turkey	- TR: Yenilenebilir Enerji Kaynaklarını Destekleme Mekanizması (YEKDEM) - ENG: Renewable Energy Resources Support Mechanism
UK	- Renewables Obligation (RO), a main support mechanism for large-scale renewable electricity projects in UK - RFTO - Renewable Heat Incentive (RHI) - Green Gas Support Scheme (GGSS), Green Gas Levy (GGL)
US	- Renewable Fuel Standard - Low Carbon Fuel Standard - Sustainable Aviation Fuel Tax Credit

In our discussion about support schemes, we also inquired about investments in power grid stabilisation within the countries. We categorised these investments into three groups: dispatchable capacity, grid stabilisation and local capacity in cities. The results are displayed in Figure 19. It appears that most countries have implemented dispatchable capacity and grid stabilisation measures. However, Sweden appears to lack action in this regard. Investments in local capacity in cities are less common, with only six out of the 12 reporting countries having implemented such measures.

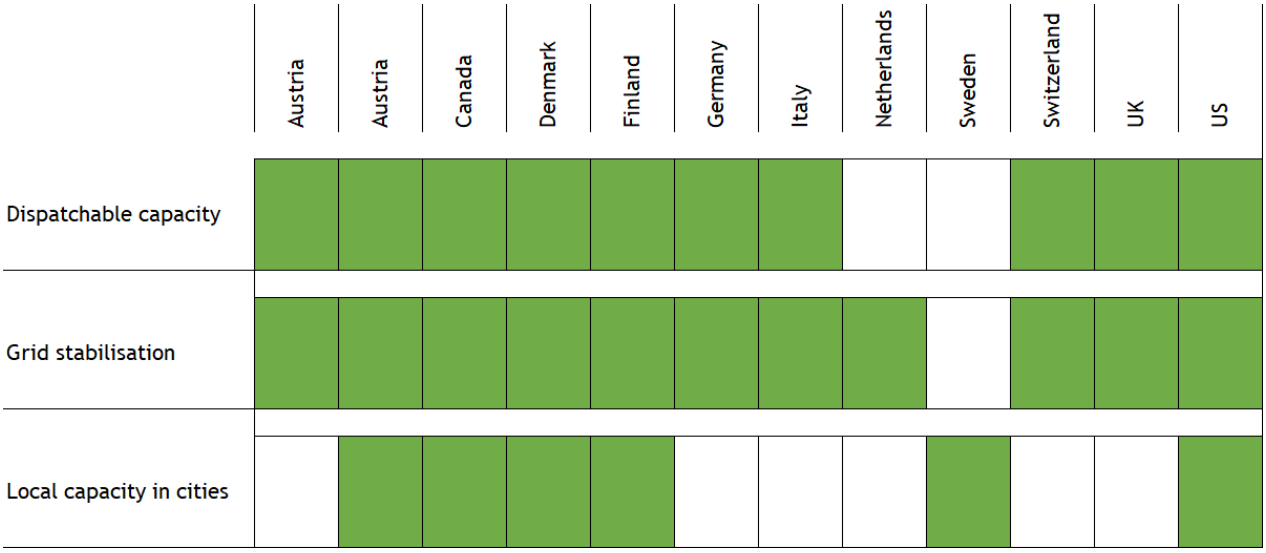


Figure 19: Investments in power grid stabilisation in 12 countries. Brazil, EU and Turkey did not answer.

8. Influencing factors for implementation of flexibility

TECHNICAL AND NON-TECHNICAL BARRIERS AND BOTTLENECKS

There are a number of obstacles or bottlenecks that hinder the implementation of flexible bioenergy. Several were mentioned in the assessment, such as regulations and political framework, economic reasons and market mechanisms or technical barriers. Also, competing flexibility options may be a barrier for development. Most of the obstacles were mentioned from most countries (see Figure 20). Several countries view infrastructure as a barrier, although its impact is not considered significant. The lack of acceptance is an important factor in Canada, EU and Netherlands.

Countries were asked to indicate whether these categories were important at all, and how much of an impact they had. Figure 20 shows the results, the size of the bubbles indicating the importance of the issue. The question was asked in regard to three time periods. Countries were therefore asked to assess (future) developments in the time series from 2018 to 2020, 2021 to 2030 and 2031 to 2050. In Figure 20, all time periods and the perceived barriers are presented for comparison.

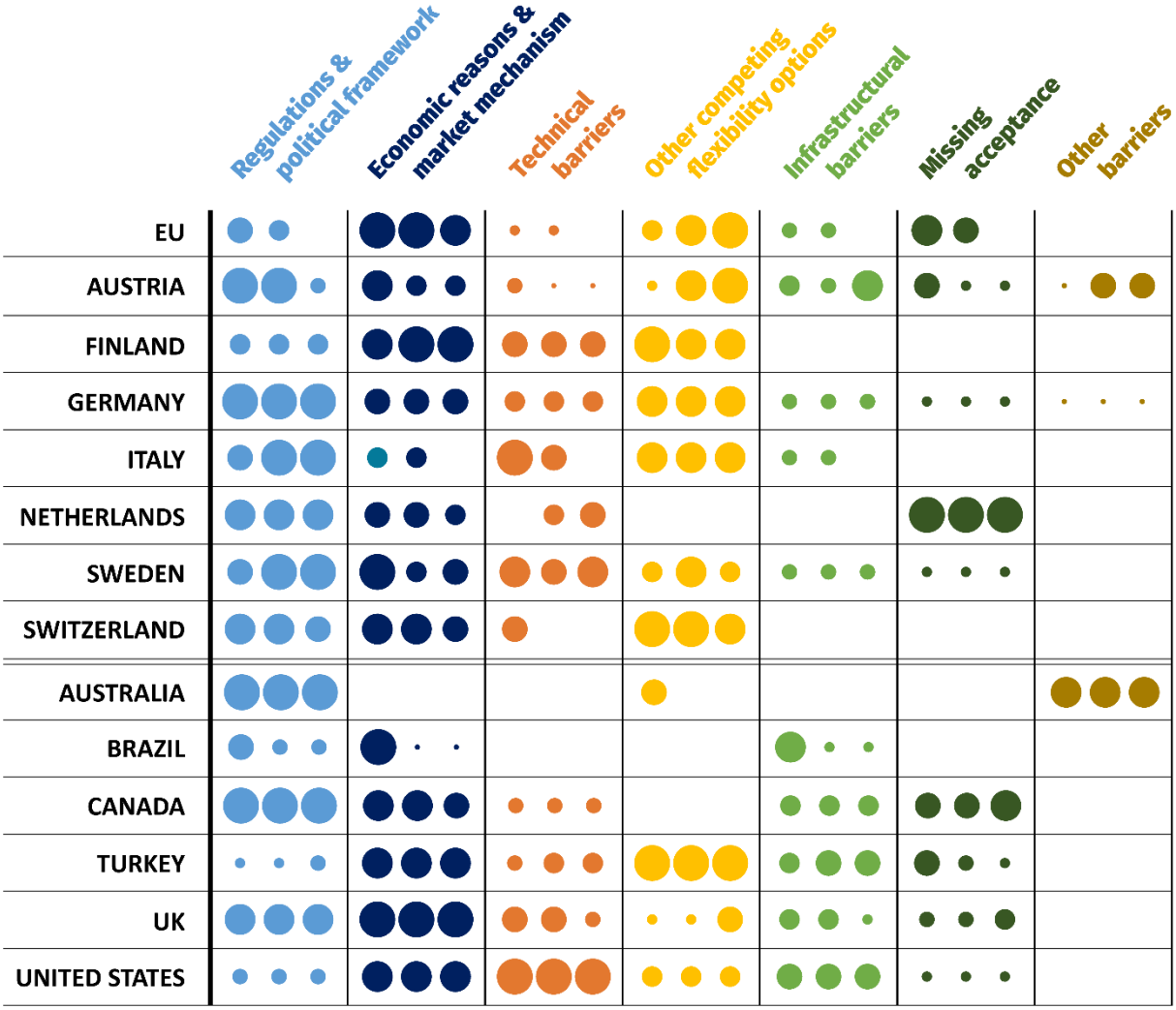


Figure 20: Perceived barriers to flexible bioenergy implementation.
In all columns and rows, the first bubble on the left represents a country's prediction for the period 2018-2020, the middle bubble represents 2021-2030 and the right bubble represents 2031-2050. The size of the bubble indicates the impact of the barrier (large bubble - high impact, small bubble - low impact, no bubble - no information/impact). Answers from 13 countries and the EU. Denmark did not provide data.

EFFECT OF THE COVID-19 PANDEMIC, RECENT GEOPOLITICAL DEVELOPMENTS, THE CLIMATE CHANGE DEBATE AND NATURAL DISASTERS ON THE PERCEPTION OF FLEXIBLE BIOENERGY

Most of the respondents estimated that the COVID-19 pandemic did not change the perception of bioenergy relevance. In four countries (Australia, Austria, Italy and Turkey), the perception was considered to be slightly increased. It was described that the COVID-19 pandemic affected energy security, put focus on regional supply and resilience, caused large variations in energy consumption and increased communities' awareness related to the amount of waste that is produced and its retention. In Finland, the COVID-19 pandemic decreased the energy demand in 2020 and public discussion focused on the pandemic, thus it is estimated that the attention to new solutions such as flexible bioenergy was decreased there.

Recent geopolitical developments have affected energy security and supply and increased the energy prices in Europe. They have affected the perception of flexible bioenergy in all the European respondent countries, whereas no change is reported in Canada and the US. Flexible bioenergy (to be precise biogas/biomethane here) has been seen as an alternative to natural gas and as a way to reduce dependency on natural gas. In

Finland, additional attention was paid to domestic energy supply due to the sudden stop of energy and wood imports from Russia. In the UK, the discussion around “food vs. fuel” increased due to loss of crops grown and imported from Ukraine.

In some of the respondent countries, the recent climate change debate has increased perception of flexible bioenergy relevance due to the need to transform fossil-based industries (e.g., refinery/chemical sector, shutdown of coal power plants). On the other hand, in Finland and the UK, the perception has decreased due to increased discussion on forest sinks, sustainable level of cuttings, forest management and biodiversity.

Recent natural disasters have not changed the perception of flexible bioenergy relevance in most of the countries. Relevant to bioenergy, forest fire risk and forest losses due to pests have been debated globally. Finland and Austria report that they have avoided large undesired impacts at least so far in these respects. In Finland, the benefits of current active forest management practices have been recognized for their contribution to the development of the discussion in Finland. Hence, the arguments for maintaining current forest management practices can be seen slightly increased, justifying the viability of traditionally significant use of forests in general, including bioenergy as an option.

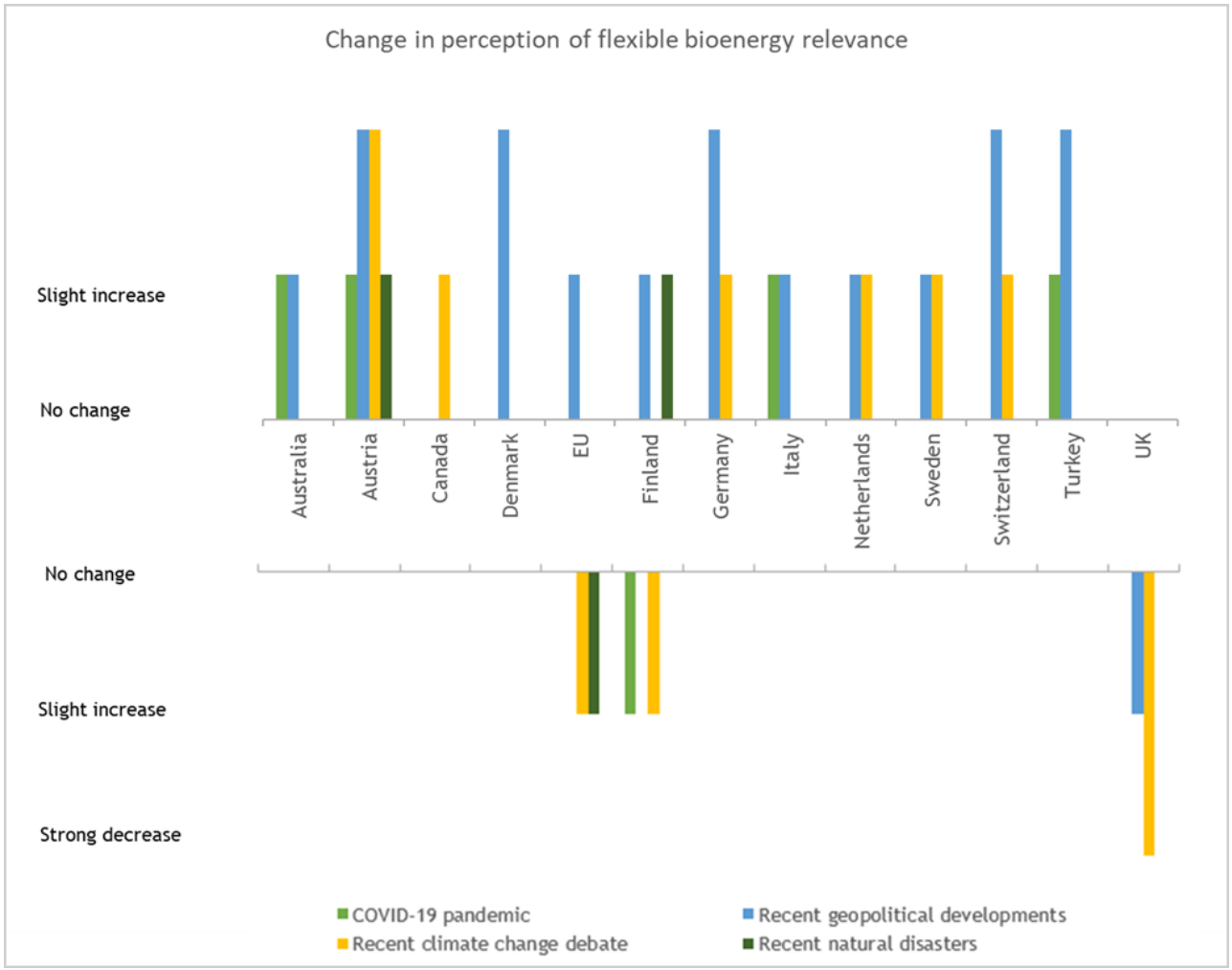


Figure 21: Change in perception of flexible bioenergy relevance due to COVID-19 pandemic, recent geopolitical developments, recent climate change debate, and recent natural disasters. Brazil did not answer this question.

SHORT TERM MARKET BARRIERS AND/OR OPPORTUNITIES

Concerning market barriers and opportunities for the introduction of flexible bioenergy, countries were asked to rank four categories from strong positive influence, no influence to strong negative influence. They were asked to assume that high energy prices, high raw material prices, sustainability requirements and energy security requirements influence the introduction of flexible bioenergy. The results in Figure 22 show that feedstock prices have the strongest negative influence. Energy requirements have a more positive influence on the introduction of flexible bioenergy.

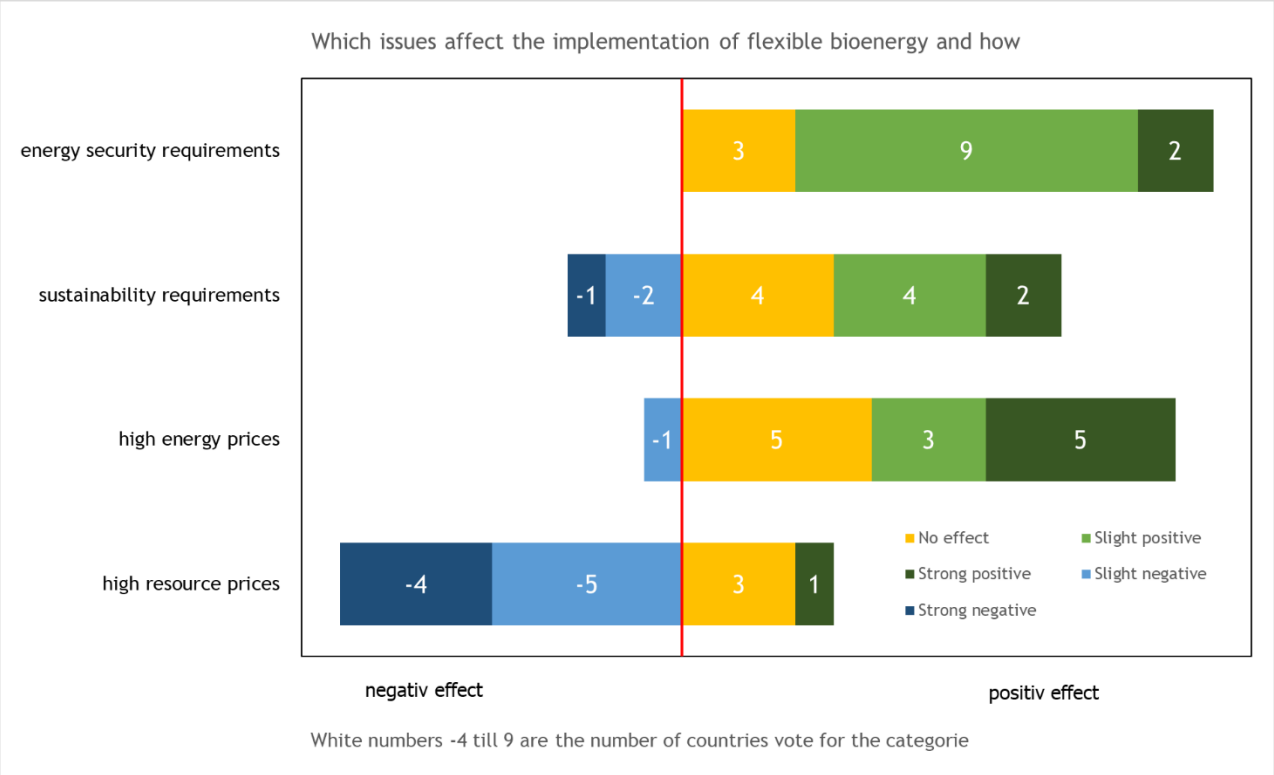


Figure 22: Information on which short-term market obstacles and/or opportunities influence the introduction of flexible bioenergy.
Answers provided from 13 countries and EU. Some questions are without information. Brazil did not answer.

ADDITIONAL BARRIERS AND/OR OPPORTUNITIES

The following table summarises the information provided by some countries on additional barriers/opportunities for the short-term introduction of flexible bioenergy.

Table 7: Information on additional barriers/opportunities for the short-term introduction of flexible bioenergy from nine countries.

Country	Additional barriers/opportunities for flexible bioenergy implementation in the short term
Austria	Main possible barriers are, as already mentioned, nonserious sustainability discussions and excessive resource/feedstock prices.
Canada	Public misconceptions about the forest sector, sustainability and supply chains; debate on biogenic emissions; policy inconsistencies that do not support country-wide implementation of flexible bioenergy.
Denmark	It is a hot topic in DK to what extent flexible bioenergy can help offsetting emissions from the agricultural sector. Significant funds are directly to biochar production via pyrolysis.
Finland	There are more than 600 000 private forest owners in Finland. Fragmented ownership of forests in Finland may result in non-optimal forest management to contribute to availability of resources for flexible bioenergy. There is much discussion on forest cuttings taking place in Finland after the LULUCF sector turned from carbon sink to carbon source in 2021. This may place negative perceptions also on bioenergy use for energy, though it is a side-product from forest industry.
Germany	Questions 36-40 are not easy to answer. How do you define positive and negative impacts? Is it positive if more wood is replaced by residual and waste materials in energy use? Yes, but at higher costs, which in turn could have a negative impact on use. Aspects such as higher production costs for biofuels from residual and waste materials, for example, cannot be answered simply. The question here would be whether it should be answered from an energy, environmental, economic or social perspective.
Italy	Questions 36-40 are not easy to answer. How do you define positive and negative impacts? Is it positive if more wood is replaced by residual and waste materials in energy use? Yes, but at higher costs, which in turn could have a negative impact on use. Aspects such as higher production costs for biofuels from residual and waste materials, for example, cannot be answered simply. The question here would be whether it should be answered from an energy, environmental, economic or social perspective.
Netherlands	Nb1. Economic barriers / market mechanisms: many biobased options still require subsidies. Absence of these subsidies form a barrier (which is politically influenced of course). Frequent changes in subsidy schemes have a negative impact on investments. Nb2. Technical barriers are not the main barriers. However, there is a need to build up more operating experience with various technologies at scale to improve their reliability/availability and reduce cost. In this respect, there is a need for technical demos and first-of-a-kind commercial plants. Nb3. Infrastructural barriers do not seem to be eminent. Use can be made of, e.g., the dense methane/natural gas grid, the port facilities in Rotterdam and other harbours, the extensive transport fuels storage and trade infra and the large refinery and chemicals infrastructure.
Sweden	The major barrier is that the flexibility is not priced in an adequate way. Pricing mechanisms need to be developed.
US	Not that are noteworthy. The main hurdles are the low cost of incumbent energy options, a lack of incentives to support flexible bioenergy, and the low technology readiness/high cost of flexible bioenergy options.

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Appendix - Questionnaire on Flexible Bioenergy Policies 2023

Contact (name and email address) Please insert your information here.

Date of entry Please insert your information here.

Country Please insert your information here.

Background information for the questionnaire

The purpose of this questionnaire is to assess the status and recent developments in the field of flexible bioenergy in different countries. The questionnaire covers the status of and plans for flexible bioenergy implementation, national goals, opportunities in different applications and sectors, barriers and support schemes. As implementation of renewable hydrogen and bioenergy are expected to have multiple synergies, also renewable hydrogen is covered in the questionnaire. The answers will be used in *'Flexible Bioenergy Policies'* report that will be produced by IEA Bioenergy Task 44 *Flexible Bioenergy and System Integration*[1].

The questionnaire is an expert assessment, and requires a certain level of expertise in the field of bioenergy, energy systems and energy and climate policies. We acknowledge that the questionnaire is answered from a specific perspective, depending on the expert's background and expertise.

The report resulting from this questionnaire is continuation for the report[2] published in 2021, which covered data until 2018. Therefore, some questions ask to record the development over the last 3 years.

We suggest to take a look at the paper *'Five cornerstones to unlock the potential of flexible bioenergy'*[3] before filling in the questionnaire. The paper presents the definition of flexible bioenergy and summarizes the key findings during 2019-2021 by IEA Bioenergy Task 44.

Introduction

Dimensions of flexibility

On the aggregate level, energy system flexibility is defined as the ability to effectively cope with variations in the supply or demand of energy. In this questionnaire, the definition of flexible bioenergy extends beyond the power sector. 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. 2021). This broad definition includes feedstock flexibility, flexibility through bioenergy carriers, operational flexibility and product flexibility. This questionnaire focuses on the energy sector, but it is recognized that the use of bio-based feedstocks may also interact with the materials sector (e.g. chemicals, fibres). Examples of flexible bioenergy fulfilling the definition are given in the paper 'Five cornerstones to unlock the potential of flexible bioenergy'.[3]

[1] https://task44.ieabioenergy.com/
[2] 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
[3] https://task44.ieabioenergy.com/wp-content/uploads/sites/12/2021/11/Five-cornerstones-to-unlock-the-potential-of-flexible-bioenergy.pdf

1. *Which dimensions of flexible bioenergy are relevant in your country? Please mark the relevant option/options with 'X' for each dimension of flexible bioenergy.*

	Considered in the current flexible bioenergy debate	Not relevant for the flexible bioenergy debate	Relevant for flexible bioenergy but not yet considered	Considered in the debate but leads to over-complexity	Considered in the following answers of the question-naire
Flexible generation of power for grid stability and ancillary services for power systems					
Flexible and/or poly-generation of power, heat, fuels and non-energy products, 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					
Utilizing 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 to meet energy demand during winter months					
Flexible provision and processing of biogenic CO_2 converted to synthetic fuels (with for example hydrogen from PV or wind surpluses) or captured and stored (bioenergy carbon capture and storage (BECCS))					
Storage of renewable hydrogen into intermediate bioenergy carriers in synergy with variable renewable power generation					

1. Overview on status quo / frame condition for bioenergy integration

This chapter will be produced with existing data from IEA and IEA Bioenergy.

2. Status of Flexible Bioenergy

2.1. Flexibility in power sector

IEA has defined a framework made of six different phases of variable renewable energy (VRE) integration in the energy system (Table).[4,5] To better understand the expectation on energy system transformation, please give your estimate on the phase in your country in 2020/2021 and in 2030.

Table 1: IEA´s six phases of integration of variable renewable energy (VRE) in the energy system [4,5]

IEA's "Six phases of system integration"
▪ Phase 1: No relevant impact on system integration
▪ Phase 2: Drawing on existing system flexibility
▪ Phase 3: Investing in flexibility
▪ Phase 4: Requiring adv. technologies to ensure reliability
▪ Phase 5: VRE surplus from days to weeks
▪ Phase 6: Seasonal or inter-annual surpluses of VRE -> Seasonal storage and use of synfuels/hydrogen

2. *How would you categorize your country with regard to the integration of Variable Renewable Energy (VRE) sources into the power sector in **2020/2021**? Please mark the relevant option with 'X'.*

	Phase 1 - No relevant impact on system integration
	Phase 2 - Drawing on existing system flexibility
	Phase 3 - Investing in flexibility
	Phase 4 - Requiring advanced technologies to ensure reliability
	Phase 5- VRE surplus from days to week
	Phase 6- Seasonal or inter-annual surpluses of VRE

3. *How would you categorize your country with regard to the integration of Variable Renewable Energy (VRE) sources into the power sector in **2030** based on the current national strategies?*

	Phase 1 - No relevant impact on system integration
	Phase 2 - Drawing on existing system flexibility
	Phase 3 - Investing in flexibility
	Phase 4 - Requiring advanced technologies to ensure reliability
	Phase 5- VRE surplus from days to week
	Phase 6- Seasonal or inter-annual surpluses of VRE

[4] https://iea.blob.core.windows.net/assets/ede9f1f7-282e-4a9b-bc97-a8f07948b63c/Status_of_Power_System_Transformation_2018.pdf
[5] https://www.iea.org/reports/introduction-to-system-integration-of-renewables?mode=overview

4. *Are there statistics/monitoring available for flexibly produced power in general?*

	Yes
	No

5. *If yes, please quantify the bioenergy contribution in the following table:*

Year	Type of flexible bioenergy (biogas, biomethane, biomass power etc.)	Capacity in MW	Energy provision in MWh
2019			
2020			
2021			

Flexibility is not only promoted through bioenergy. The following table is intended to collect information on the dynamics of flexible energy supply **with multiple technologies**, and how they are promoted and implemented (e.g. through R&D, market mechanisms, support schemes).

6. *Which flexible power supply technologies have been established to contribute to integration in the energy system? Please mark relevant options with 'X'.*

	R&D, demonstration, real-labs	Implemented into the market*	Incentivized with support schemes**	Included in energy strategies**	No information
Virtual power plants					
Biogas and biomethane provision for flexible power generation					
Flexible operation of solid biomass CHPs to serve the electricity market					
Hydrogen and e-fuels					
Non-bio-based storage solutions (e.g. hydropower, pumped hydropower, battery storage)					
Other (please name it)					

**Will be described more in detail in the next chapters

7. **If implemented into the market, please give capacities installed in*
   2019 Please insert your information here.
   2020 Please insert your information here.
   2021 Please insert your information here.

2.2. State of transition towards renewables

Flexible and/or poly-generation of power, heat, fuels and CO_2 capture

8. Has the relevance of flexible bioenergy generation and/or poly-generation of power, heat and fuels from bioenergy increased during the last 3 years?

	Yes
	No

If yes, please insert more information here.

9. Has the relevance of bioenergy carbon capture and storage increased during the last 3 years?

	Yes
	No

If yes, please insert more information here.

10. *Please mark with 'X' the option best describing the current status of bio-based flexibility options with respect to sector coupling and system integration in your country.*

	R&D demonstration, real-labs	Implemented into the market*	Incentivized with support schemes **	Included in energy strategies**	No information
Seasonal flexibility via generation of power, heat, fuels and non-energy products matching seasonal demand patterns between power and heat					
Day to day flexibility via generation of power, heat, fuels and non-energy products according to market demand and trends via continuous changes in output shares of heat for residential heating and biofuels					
Flexibility in combination with bioenergy carbon capture and storage (BECCS)					
Combination of bio-based process with hydrogen production from excess electricity					
Hydrogen production from biomass					
Synthetic fuel production in flexible operation (flexible provision and processing of biogenic CO_2 with for example hydrogen from PV or wind surpluses)					
Combination of biomass with Power-to-X (PtX)					

**Will be described more in detail in the next chapters

*11. *If implemented into the market, please give capacities installed in*

2019 Please insert your information here.
2020 Please insert your information here.
2021 Please insert your information here.

2.3. Flexible feedstock provision, storage and BECCS

12. Has the importance of feedstock diversity (variation in type and/or quality) increased during the last 3 years?

	Yes
	No

If yes, please insert more information here.

13. Has the importance of residues as feedstocks increased during the last 3 years?

	Yes
	No

If yes, please insert more information here.

14. Has the relevance of storage of bioenergy carriers and BECCS increased during the last 3 years?

	Yes
	No

If yes, please insert more information here.

15. How has the storage and trade of bioenergy carriers developed during the last 3 years?

	R&D, demonstration, real-labs	Implemented into the market*	Incentivized with support schemes**	Included in energy strategies**	No information
Utilizing 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					
Storage of bioenergy carriers such as wood pellets, biomethane and bioethanol, over longer periods to meet energy demand during winter months					
International trade bioenergy carriers such as wood pellets, biomethane and bioethanol, over longer periods to meet energy demand during winter months					

**Will be described more in detail in the next chapters

16. **If implemented into the market, please give capacities installed in*
    2019
    2020
    2021

3. Expectation on flexible bioenergy

3.1. Frame conditions for flexibility

17. *What kind of net zero targets does your country have (including time frame)?*

Please insert your information here.

18. *Where do you see the strongest needs for flexible bioenergy? Where does this need come from (e.g. need to substitute fossil fuels, proportional increase of variable renewables, increase security of supply)?*

Please insert your information here.

3.2. National goals to implement flexible bioenergy

19. *Please describe the recent development of flexible bioenergy use in your country? (Were there any goals set, were these goals achieved, which mechanisms were crucial in achieving these goals?) How has the development been influenced by phase-out strategies for certain fossil energy carriers?*

Please insert your information here.

20. *Evaluate the strength of the different drivers for flexible bioenergy implementation in your country during the last 3 years? Please mark the relevant option with 'X'.*

	Not a driver	Weak driver	Strong driver
Renewable energy targets			
Climate neutrality targets			
Specific targets for flexible bioenergy			
Energy policies			
Phase-out strategies			
Energy security			
Shortage of fossil energy carriers			
Energy prices			
Energy market design			
Incentives for renewable energy or flexible bioenergy			
Other (please name it)			

21. *Which support mechanisms for flexible bioenergy are in place in different sectors in your country? (e.g. feed in premiums, tenders, quota obligations, investment support, tax exemptions, feed in tariffs)*

Overarching measures

Please insert your information here.

Electrical power system

Please insert your information here.

Thermal energy production

Please insert your information here.

Transport

Please insert your information here.

22. *Has the perception of flexible bioenergy relevance changed in response to the COVID-19 pandemic, recent geopolitical developments, the climate change debate or natural disasters? Please mark with 'X' the most relevant option and describe the changes.*

	Strong decrease	Slight decrease	No change	Slight increase	Strong increase	Please describe
COVID-19 pandemic						
Recent geopolitical developments						
Recent climate change debate						
Recent natural disasters						

23. *Is flexible bioenergy integrated into national energy scenarios? If yes, please provide further information on how (including time horizon, specific technologies) and to which extend it is integrated? What is lacking in the scenarios? How should the scenarios be improved regarding flexible bioenergy? (please cite source)*

	Yes
	No

Please insert your information here.

3.3. Opportunities for flexible bioenergy

24. *Please rank from your expertise the three most important opportunities for flexible bioenergy systems for your country for the time horizons 2020-2030 and 2030-2050, using numbers from 1 to 3.*

	2020-2030	2031-2050
Operate as a key element in the coupling of different energy sectors		
Provide low-carbon energy to complement wind and solar (residual load and grid stabilization)		
Provide synergies with e-fuels to store electricity chemically into fuels to enable more efficient use of wind and solar		
Provide sustainable fuels for sectors where other decarbonization options are not available or exceedingly expensive		
Provide high temperature heat to industry		
Provide low temperature heat for buildings (and sanitary water) during dark and cold seasons		
Coproduce heat, electricity, fuels and other products in a single high-efficiency processing plant		
Provide synergies with hydrogen value chains		
Provide synergies with CCUS (Carbon Capture and Utilization/Storage)		
Provide additional flexibility to the methane grid		
Valorizing biogenic residues and waste		
Other opportunity for flexible bioenergy systems		
Please describe the other opportunity		

3.4. Sectors that can benefit from flexible bioenergy implementation

25. *Please rank from your expertise the three sectors which can benefit most from integration of flexible bioenergy systems in the future. Please do the ranking separately for category a) and b), using numbers from 1 to 3.*

a) Energy sector	*Ranking from 1 to 3*	*b) Other economic sectors*	*Ranking from 1 to 3*
Power		Agriculture	
Heating and cooling		Consumer industry	
Transport		Heavy and chemical industry	
Methane networks		Other industries	
Hydrogen networks		Public	
		Other (please specify)	
		Households	

3.5. Flexibility from synergies of renewable hydrogen and bioenergy

Hydrogen and bioenergy have links and synergies in terms of producing hydrogen from biomass and using hydrogen in bio-based processes. In addition, they can both enhance sector coupling and provide flexibility in the energy system.

26. Is hydrogen integrated into national energy scenarios? If yes, please provide further information on how (including time horizon, specific technologies) and to which extend (including specific targets) it is integrated? What is lacking in the scenarios? How should the scenarios be improved regarding hydrogen? (cite source)

	Yes
	No

Please insert your information here.

27. In which areas do you see possible synergies (i.e. win-win possibilities) between hydrogen and bioenergy? Please mark with 'X' relevant option(s) and describe the synergy/synergies more in detail.

		Please describe the synergy
	Technical performance	
	Infrastructure	
	GHG balance	
	Sustainability	
	Value chain	
	Business model	
	Other synergy (please name it)	

28. Are the possible synergies between hydrogen and bioenergy already exploited in the following areas? Please mark with 'X' relevant option(s) and describe how the synergies are exploited.

		Please describe the synergy
	Research	
	Business models	
	Adaption of national strategies	
	Infrastructure	
	E-fuels	
	Other area (please name it)	

29. Is implementation of hydrogen linked to biomass or bioenergy? If yes, please describe the link(s).

	Yes
	No

Please insert your information here.

4. Steps forward

4.1. Technical and non-technical barriers and bottlenecks for implementing flexible bioenergy

30. Please rank from your expertise the following barriers for the implementation of flexible bioenergy in your country for the time horizons 2018-2020, 2021-2030 and 2031-2050, the most important with number 1, the least important with number 7.

Do not rank at all if the option is not relevant for your country.

Please explain the two most important barriers (rank 1 and 2) in detail for each time horizon.

	2018-2020	2021-2030	2031-2050
Regulations & political framework			
Economic barriers & market mechanisms			
Technical barriers			
Other competing flexibility options			
Infrastructural barriers			
Missing acceptance			
Other barrier / future barrier (please name)			
Explanation for rank 1:			
Explanation for rank 2:			

4.2. Policy instruments driving flexibility

Influence of national and supra-national policies (e.g. EU level policies)

31. *Please evaluate the influencing strength of policy instruments (e.g. energy and climate policies, biomass strategy) for flexible bioenergy in your country. Please mark with 'X' the most relevant option and describe the policies.*

National policy level

	Strong influence
	Slight influence
	No influence
Please describe:	

Supranational/international policy level

	Strong influence
	Slight influence
	No influence
Please describe:	

32. *Are there contradictions between different policy instruments which hinder the implementation of flexible bioenergy?*

Please insert your information here.

33. *Are there synergies between different policy instruments which help the implementation of flexible bioenergy?*

Please insert your information here.

34. *Is the value of flexible bioenergy mentioned in policy documents? If yes, please give the name of the documents.*

	Yes
	No

Please insert your information here.

Additional question for EU countries

35. How far are your activities related to flexible bioenergy influenced by EU policies and strategies?
Please mark with 'X' the most relevant option for each concept.
Please describe the influence more in detail if you choose 'Strong support' or 'No support/hindering'.
Please name and describe any other EU policies or strategies influencing flexible bioenergy.

	European Green Deal[6]	Describe details for 'Strong' or 'No support/ hindering'
	Strong support	
	Slight support	
	No support/hindering	

	Fit for 55 package	Describe details for 'Strong' or 'No support/ hindering'
	Strong support	
	Slight support	
	No support/hindering	

	REPowerEU[7]	Describe details for 'Strong' or 'No support/ hindering'
	Strong support	
	Slight support	
	No support/hindering	

	EU energy systems integration strategy[8]	Describe details for 'Strong' or 'No support/ hindering'
	Strong support	
	Slight support	
	No support/hindering	

	EU methane strategy[9]	Describe details for 'Strong' or 'No support/ hindering'
	Strong support	
	Slight support	
	No support/hindering	

	EU hydrogen strategy[10]	Describe details for 'Strong' or 'No support/ hindering'
	Strong support	
	Slight support	
	No support/hindering	

Please insert your information here.

[6] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[7] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en
[8] https://energy.ec.europa.eu/topics/energy-systems-integration/eu-strategy-energy-system-integration_en
[9] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1833
[10] https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en#eu-hydrogen-strategy

Short term market barriers and/or opportunities

36. How do high energy prices affect the implementation? Mark with 'X' the most relevant option. Please describe the effect.

		Please explain further:
	Strong positive effect	
	Slight positive effect	
	No effect	
	Slight negative effect	
	Strong negative effect	

37. How do high resource prices affect the implementation? Mark with 'X' the most relevant option. Please describe the effect.

		Please explain further:
	Strong positive effect	
	Slight positive effect	
	No effect	
	Slight negative effect	
	Strong negative effect	

38. How do sustainability requirements affect the implementation? Mark with 'X' the most relevant option. Please describe the effect.

		Please explain further:
	Strong positive effect	
	Slight positive effect	
	No effect	
	Slight negative effect	
	Strong negative effect	

39. How do energy security requirements affect the implementation? Mark with 'X' the most relevant option. Please describe the effect.

		Please explain further:
	Strong positive effect	
	Slight positive effect	
	No effect	
	Slight negative effect	
	Strong negative effect	

40. Are there additional barriers/opportunities for flexible bioenergy implementation in the short term?
Please insert your information here.

Support schemes

41. Are there support schemes (e.g. feed in premiums, tenders, quota obligations, investment support, tax exemptions, feed in tariffs) for flexible bioenergy in your country? Please mark with 'X' the most relevant option.

	No
	There is at least one
	There are a few
	Flexible bioenergy is considered in many support schemes

42. Please describe the most relevant support schemes for flexible bioenergy in your country.

Name of the support scheme	Description (since when, theme, quantity)	Did it change during the last 3 years?

43. Are there any investments in power grid stabilization in your country? Please mark with 'X' all relevant option.

	Dispatchable capacity	Grid stabilization	Local capacity in cities
Yes			
No			

Please insert more information here.

Policy instruments for implementation of flexible bioenergy – concrete action

According to expert evaluation in the past report from 2021[11], regulatory framework was seen as the most important barrier for flexible bioenergy. Different categories of measures, such as governmental support and legal guidelines, can be derived from the existing and expected measures, which promote the implementation of flexible bioenergy systems within and between different energy sectors.

44. Please show how your country is settled with policies at the moment.
How important are the actions?

Governmental support		If you have a concrete action, please describe:
	Not important	
	Very important	
	Unclear	

Financial incentives		If you have a concrete action, please describe:

[11] Result from Task 44 report Expectation and implementation of flexible bioenergy in different countries (2021), (Section 5.1).

	Not important	
	Very important	
	Unclear	

Legal guidelines		If you have a concrete action, please describe:
	Not important	
	Very important	
	Unclear	

Market support (e.g. infrastructure, standards)		If you have a concrete action, please describe:
	Not important	
	Very important	
	Unclear	

Research and economically driven projects		If you have a concrete action, please describe:
	Not important	
	Very important	
	Unclear	

5. Best Practice examples

IEA Bioenergy Task 44 collects Best Practice examples of flexible bioenergy to increase knowledge of potential solutions for different end uses. Best Practices are collected along the entire value chain: from feedstock flexibility through energy carriers and operational flexibility to product flexibility. They present both planned and existing solutions. Best Practice examples can be found here: https://task44.ieabioenergy.com/best-practices/ and in Appendix A of publication https://www.sciencedirect.com/science/article/pii/S1364032122000247#appsec1.

Please provide ideas for potential Best Practices in your country, including a reference.

Please insert your information here.