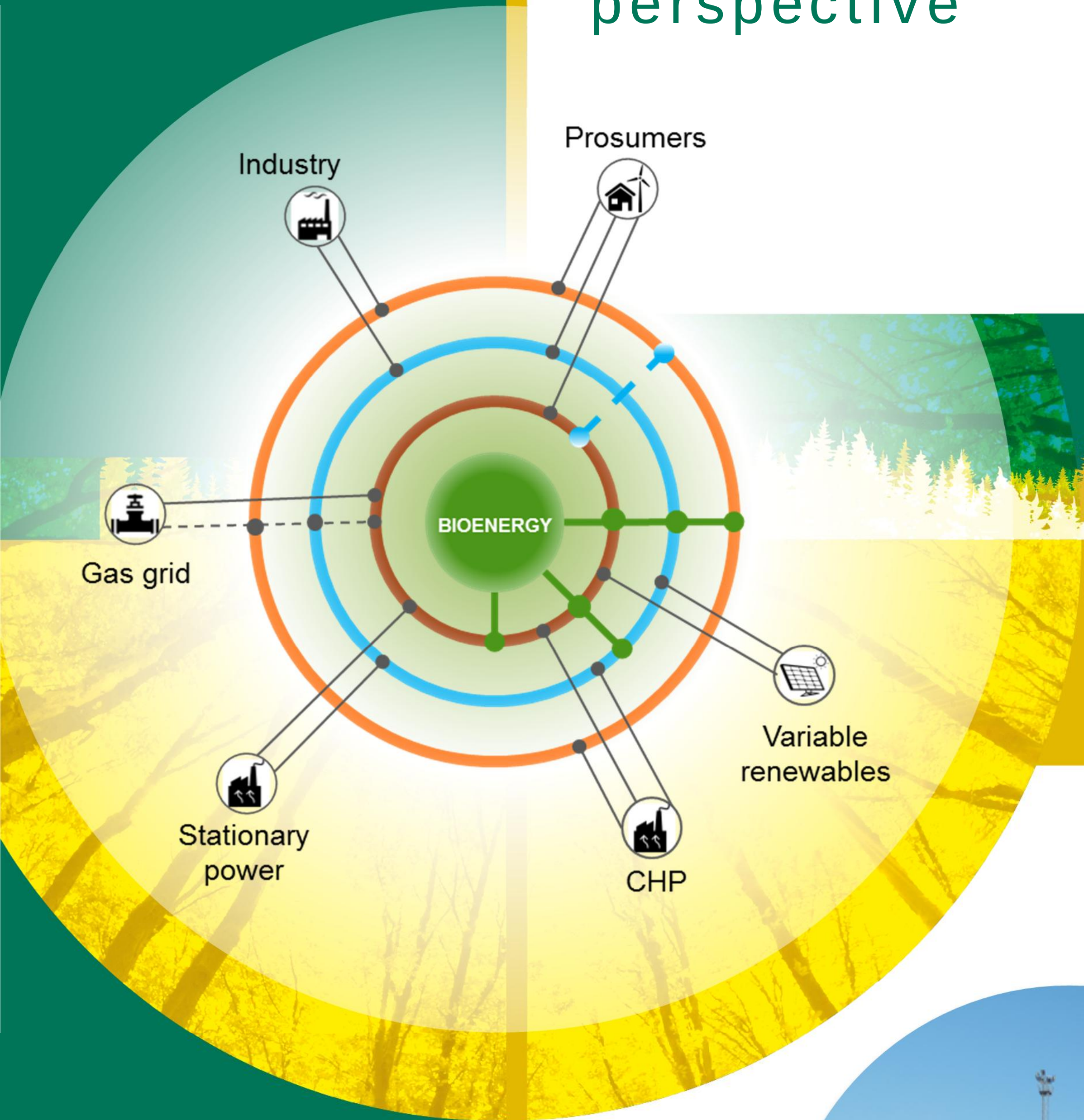
Bioenergy's role in balancing the electricity grid and providing storage options – an EU perspective



Front cover information panel

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Bioenergy's role in balancing the electricity grid and providing storage options – an EU perspective

Antti Arasto, David Chiaramonti, Juha Kiviluoma, Eric van den Heuvel, Lars Waldheim, Kyriakos Maniatis, Kai Sipilä

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Foreword

The global energy supply system is currently in transition from one that relies on polluting and depleting inputs to a system that relies on non-polluting and non-depleting inputs that are dominantly abundant and intermittent. Optimising the stability and cost-effectiveness of such a future system requires seamless integration and control of various energy inputs. The role of energy supply management is therefore expected to increase in the future to ensure that customers will continue to receive the desired quality of energy at the required time. The COP21 Paris Agreement gives momentum to renewables. The IPCC has reported that with current GHG emissions it will take 5 years before the carbon budget is used for +1,5C and 20 years for +2C. The IEA has recently published the Medium- Term Renewable Energy Market Report 2016, launched on 25.10.2016 in Singapore. According to the report; "The increase in generation from renewables in 2015-2021 represents 60% of the global increase in electricity output, although prospects vary regionally; Solar PV & wind account for almost 2/3 of the rise in renewable generation; total renewable electricity surpasses 7600 TWh by 2021, equivalent to the EU+US today; the share of renewables rises in all sectors, despite persistent challenges in heat & transport; interactions between energy efficiency & renewables become critical".

In countries where wind and solar are expected to play a dominant role in the energy transition, integration of these intermittent energy sources with the power grid places significant pressure on the grid operation as the supply of the power especially from wind cannot be controlled or rapidly predicted. This has led to extensive discussions with the grid operators concerning how to balance the grid. Furthermore the renewable electricity from wind or solar is often provided in times when demand is low and the electricity has to be stored or wasted. There is a huge market need to create solutions for industrial scale, cost effective electricity storage capacity.

Bioenergy can be used to relieve the pressure on system level management of the grid by making the grid more stable. In this respect, bioenergy has the potential to play a focal role as a stabilising element in the renewable power supply system.

Bioenergy technologies are already commercially available and widely applied at various size ranges and locations. Integration of bioenergy with the grid for balancing or storage options will open completely new application areas for bioenergy ranging from operation during peak demand to other services needed to maintain a reliable and secure renewable power supply with low environmental impact. Fundamental technical barriers are not expected to arise as a result of such new applications. Rather, problems are expected to emerge in optimisation, proper sizing, control and management, and a successful resolution of such issues is therefore needed to support and accelerate the widespread implementation of these new applications.

Following the conclusions of a workshop organised at the Directorate General of Energy on 09/11/2015, the European Commission and Finland, represented respectively by the undersigned Executive Committee Members Kyriakos Maniatis and Kai Sipilä, decided to coordinate and fund a study on the Topic "Bioenergy in balancing the grid & providing storage options" as a Special Project of the IEA Bioenergy Technology Collaboration Programme. A team of experts was nominated, including Antti Arasto, David Chiaramonti, Juha Kiviluoma, Eric van den Heuvel and Lars Waldheim. The work was coordinated by Antti Arasto while the two ExCo Members supervised the team's work.

Kyriakos Maniatis
EC ExCo Member (1998-present)
European Commission
Directorate General for Energy

Kai Sipila
Finland ExCo Member (1991 – 2015)
VTT Technical Research Centre of Finland Ltd.

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Executive summary

Low carbon energy targets and policy are driving renewable energy to markets. Widespread solar and wind electricity penetration of the energy system drives market change. Electrification and price formation change the role of energy consumables and distribution grids, further driving the change in earning logic that will eventually create new business models and radically modify old ones. The energy market transformation from an energy optimized to capacity optimized system is expected when the share of intermittent or uncontrollable electricity becomes large enough. Despite the significant regional differences in solar and wind resources, the unexpectedly fast declining production costs of solar and wind power will further drive and accelerate the transformation. In this kind of future energy system, energy will not be the limiting factor, but rather security of supply will instead. Conventional dispatchable energy production will be pushed out of the market due to higher operational costs, thus being dispatched less frequently; thus becoming even more unprofitable due to low operational hours. Price fluctuation will increase, and capacity based market instruments will most probably be introduced to address security of supply.

Bioenergy is currently the major source of renewable energy in the world, while wind, solar and geothermal are the fast growing alternatives. The role of wind and solar in electricity production will increase more rapidly compared to other renewable sources. However bioenergy will continue to provide the bulk of heating and transport fuels for decades to come. Bioenergy, in its various forms, can eventually contribute to balancing the electricity grid, including as one form of solar energy storage. So far little attention has been paid to the possible role of bioenergy as an effective, low carbon and low cost grid management and energy storage option.

Balancing can be roughly divided into two time periods. Most of the variability in load and variable generation is balanced by committing generation units to dispatch. This is mid-term balancing. Short-term balancing is mainly about correcting forecast errors in the original dispatch. This is achieved with intra-day and balancing markets and finally, in real time by activating frequency reserves either automatically or manually. Both mid-term and short-term balancing are affected by long-term decisions on investments and retirements of generation and consumption units. Seasonality, i.e. energy demand fluctuations in the winter and summer seasons, is one of the key challenges for future smart energy system management, which will have various consequences for optimization in various parts of Europe and globally. Photovoltaic power production goes down dramatically in winter time, especially in northern countries, while electricity consumption grows (e.g. for heat pumps). The backup need in winter time also coincides with increased heat demand, which is a perfect fit with combined heat and power. This shows a clear synergy in seasonal balancing between photovoltaics and biomass. In addition, solid biomass co-firing, power and combined heat power and cooling (CHP-C) systems add synchronous generators to the transmission grid which in itself is a stabilizing factor. These can also contribute to primary frequency control.

Regional differences in challenges for future grid balancing are mainly due to availability of hydro power and integrated markets (strong electricity grid). Regarding bioenergy, using the heat and gas networks for flexibility will be another important flexibility factor that will be enabled by existing and planned heat and gas network infrastructure. From this perspective, European regions can roughly be divided in three categories:

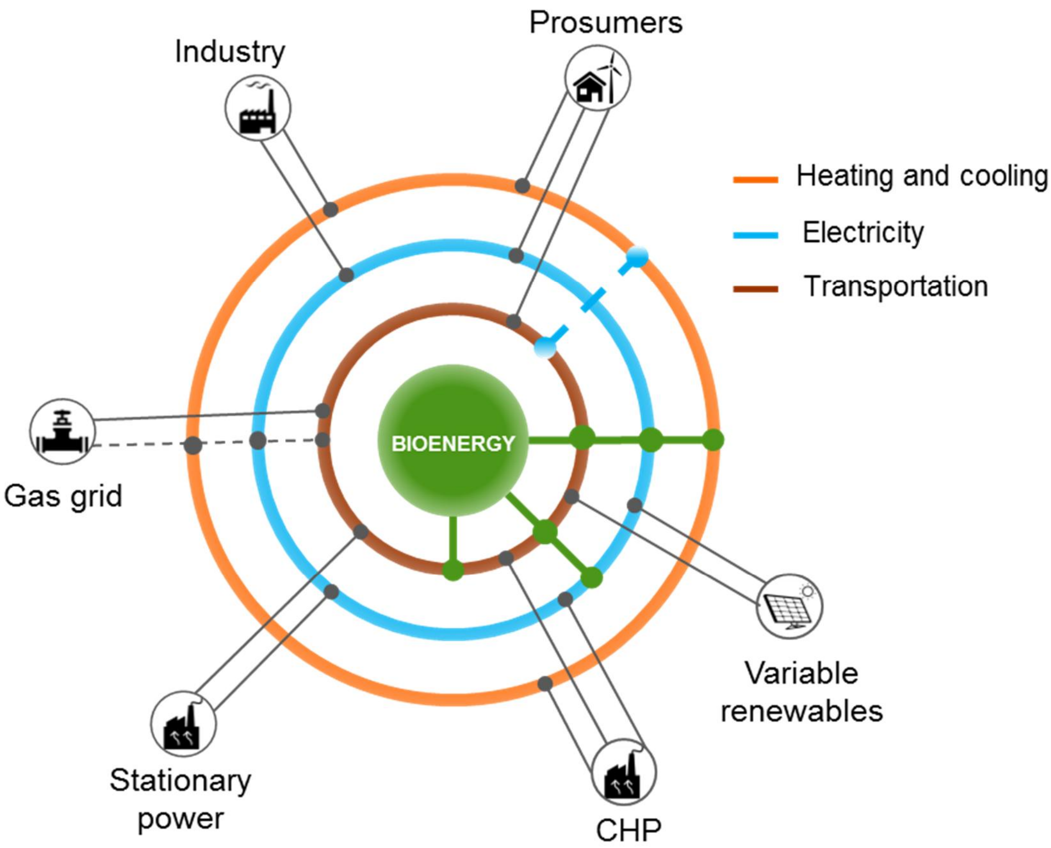
- Areas with high interconnectivity, high use of biomass, a lot of hydro and existing CHP infrastructure, no gas grid
- Areas with medium power interconnectivity, existing gas grid, moderate biomass resources

- Areas with low interconnectivity, medium biomass resources and no gas grid

Bioenergy power plants can contribute to balancing by participating in day-ahead, intra-day and balancing markets as well as by offering frequency control reserves in addition to seasonal balancing. The use of bioenergy for balancing and frequency control is currently limited, since many bioenergy plants often do not have the required control capability. However, something needs to replace the controllability offered by fossil fuel power plants when they are pushed out of the European power systems. There bioenergy could have an important role. Existing technologies and value chains for liquid and gaseous intermediates are currently in the market (e.g. biomethane, ethanol, pyrolysis oil). These stored bio intermediates have properties: high usability (accessible when you need it, no preparation needed) and high energy density and can provide embedded generation. Some of these existing intermediate energy carriers could also be used in existing engine power plants and gas turbines. Excess electricity from solar and wind power generation can be converted to H2 and/or transformed into a variety of renewable fuels or used in manufacturing renewable chemicals. Biomass could play a role in these schemes in various ways: for instance, renewable CO_2 derived from the separation of biomethane in anaerobic digestion systems or other processes could be converted to additional biomethane through thermochemical methanation. Gas and heat networks can and should also play a bigger role in balancing the electrical grid. In addition to liquid biofuels, with the advent of electric vehicles, the transport sector is also poised to become more integrated with the power system and, if implemented with price sensitivity, could bring considerable flexibility to balancing the power grid.

Three potential development paths can be identified in order to strengthen the role that biomass can have in the future low carbon energy system in addition to identifying the optimal cost solutions by developing systemic knowledge on the impact of bioenergy on the future energy system. Firstly, increasing the flexibility of existing assets by increasing the flexibility of individual biomass installations and promoting smart integration of energy carrier distribution grids. Secondly, developing more advanced biomass based energy carriers more suitable to the electricity generation portfolio and capable of balancing operation. Thirdly, developing next generation concepts including appropriate biogenic CO_2 utilization and smart integration of renewable hydrogen. Quantifying the value of balancing and determining the cost competitiveness of different competing balancing options and thus the long term viability of these balancing investments would be needed. The value of balancing should be evaluated in the current system, and this has been done in other projects. However, the value in current systems is really low, and the need is still moderate, and can be handeled by current option sin the system. The essential question is the value in the future system (that will be different than the existing one). How much more flexibility can be achieved from improving current processes and systems, how much additional balancing capacity is needed and what is the competition?

Energy system that is significantly more distributed, interconnected and flexible than today’s!



Bioenergy is already used for balancing and it could be used more extensively in the future as fossil generation is phased out. In this respect, bioenergy has potential to play a focal role as a flexible resource in the renewable power supply system. Finally, while bioenergy could certainly contribute in a significant way to balancing future grids, it can also be expected that competition between different forms of flexibility will occur. Hydropower, batteries, demand side management, power to heat, etc. will be alternatives to bioenergy for balancing. It is not likely that there will be “one-solution”, but rather different options will be used to different combination degrees depending on different flexibility needs and local characteristics. Balancing represents a challenge of a different magnitude in different parts of Europe depending on the characteristics of the generation portfolio, availability of demand response and interconnections to neighbors. Moreover, gas and heat networks can and should also play a bigger role in balancing the electrical grid. With the advent of electric vehicles the transport sector is also poised to become more integrated with the power system and, if implemented with price sensitivity, could bring considerable flexibility to balancing the power grid. In all these, bioenergy can play a central role.

1 Introduction

The significant advances of wind and solar energy in the EU have created concerns about how to manage the power system that is facing increasing variability and uncertainty. Consequently, European transmission system operators, research organizations and other stakeholders are devoting a lot of resources to understand the problem and to develop solutions and strategies to balance the grid of the future.

1.1 OBJECTIVE

This document has been produced by the IEA Bioenergy Task 41 Special Project: "*Bioenergy in balancing grid and providing storage options*". The overall approach of the document will be more electricity system and market driven than technical in nature.

The objective of this document is to identify those areas in the grid system where bioenergy in balancing the grid & providing storage options can play a strategic role, and to promote the commercialization of a diverse set of such bioenergy applications and processes. In addition, this document seeks to identify and disseminate sound business models for practical, cost-effective and environmentally friendly ways to facilitate the transformation of the electricity grid based to a great extent on bioenergy technologies. Finally, in addition to market prospects, the document will put forward suggestions for policy and RTDD options.

1.2 BACKGROUND

The global energy supply system is currently in transition from one that relies on polluting and resource limited fuels to a system that relies on non-polluting and non-depleting inputs that are predominantly abundant, variable, but uncertain. Optimizing the stability and cost-effectiveness of such future systems requires coordinated integration and control of various energy inputs. The role of energy supply management is therefore expected to increase in the future to ensure that customers will continue to receive the required amount of energy at the required time with high reliability.

In countries where wind and solar are expected to play a dominant role in the energy transition, integration of these variable energy sources with the power grid places significant pressure on power system operation due to increasing variability and uncertainty. Consequently, there is a lot of research and discussions on how to balance the future grid. Furthermore, at higher penetration of variable generation, situations will start to emerge where there is surplus power generation available that needs to be either curtailed, used or stored.

The majority of existing electricity grid infrastructure and wholesale markets were designed to accommodate centralized and dispatchable national power output from conventional thermal and hydro-electric plants. Most of the new capacity that currently comes online within the EU is variable renewable energy i.e. wind and solar.

As the share of wind and solar power grows and as system technology and markets evolve, the system architecture is becoming flexible in a variety of ways. The functioning of the electricity system and its ability to absorb wind and solar power is improved by a reinforced, interconnected European power grid and coupled markets with clear price signals and price responsiveness to resources. A strong grid gives access to a wider variety of flexible resources, increased backup and storage capacity and, demand response measures. A more dispersed deployment of renewables will smooth out fluctuations in RES generation across Europe. As a consequence, a broader allocation of balancing responsibilities becomes feasible[1].

Thermal power plants can be dispatched to meet demand patterns on any time scale, subject to technical ramping restrictions. Significant quantities of renewables are also easily "dispatchable" (biomass, geothermal and hydro power with reservoirs). Initially, when wind and solar power generation started, there was no practical need to curtail electricity without fuel costs. Even balancing costs due to forecast errors were waived in most countries to provide a small additional support to the fledgling renewables. However, controllability of wind and solar power generation cannot be ignored any longer. In fact, most wind power plants and many, especially larger, solar power plants can already be dispatched within their predicted output as long as their uncertainty is considered. The uncertainty decreases considerably as the time of operation gets closer. For instance, standard deviation of wind power production forecasts is close to 2 % for two hours ahead, but beyond the first few hours it is considerably larger. This potential flexibility from wind and solar power is still at demonstration phase and for the most part not currently used. However, it works and can be used in future situations where there will be surplus generation or an urgent need for controllable output from wind or solar power generation.

Bioenergy is already used for balancing and it could be used more extensively in the future as fossil generation is phased out. In this respect, bioenergy has the potential to play a focal role as a flexible resource in the renewable power (RE) supply system. Finally, while bioenergy could certainly contribute in a significant way to balancing future grids, it can also be expected that competition between different forms of flexibility will occur. Hydropower, batteries, demand side management, power to heat, etc. will be alternatives to bioenergy for balancing. It is not likely that there will be “one-solution”, but rather different options will be used to different degrees depending on different flexibility needs and local characteristics.

1.3 DEFINITION AS USED IN THIS ASSESSMENT:

<u>Storage:</u>

Storable and dispatchable intermediate energy. Examples: biomethane, bioliquids

> Wood pellets, wood chips, thermally treated wood e.g. torrefied or steam exploded and pellets are also energy stored in chemical bonds.

<u>Balancing:</u>

matching of demand and supply in grids (electricity, gas and local heat grids)

- active balancing in electricity grid
- from frequency control to balancing inter-annual variations in electric grids

[1] European Commission, European Commission guidance for the design of renewables support schemes - Accompanying the document: Communication from the Commission Delivering the internal market in electricity and making the most of public intervention, Commission Staff Working Document, November 2013, SWD(2013) 439 final.

- Balancing excess production
- Balancing deficit production

> The demand and supply will also need to be in balance in gas grids as well as in heating and cooling networks.

Biomass:

Biomass is material of biological origin excluding material embedded in geological formations and/or transformed to fossil. Biomass includes woody biomass, herbaceous biomass, fruit biomass, and aquatic biomass (ISO 16599:2014). In this report biomass is considered to be of sustainable origin and the amounts used within sustainable availability.

2 Role of renewables, bioenergy and bioelectricity today

From 2004 to 2014 the share of renewable energy in the gross final energy consumption nearly doubled, from 8.5% to 16.0% (see Figure 1). Half of the primary energy in Europe is used for heating and cooling, while the rest of the energy consumption is equally split between electricity and transport (Figure 2). The share of renewable energy for electricity heating/cooling and for transport differs, as can be seen in Figure 3. In 2013 the share of renewable energy in the electricity sector was 25.4%, of which less than one fifth was provided by bioenergy. In the heating and cooling sector the share of renewable energy in 2013 was 16.6%, of which bioenergy provided nearly 90%. In the transport sector, the renewables share was only 5.4% - bioenergy contributed about 80% of this share[2].

Focusing on bioenergy, most biomass is consumed in the heating and cooling sector, at roughly 75% of the final bioenergy consumption. The remaining biomass is equally used for electricity generation and for transport fuels.

[2] Eurostat, 2014

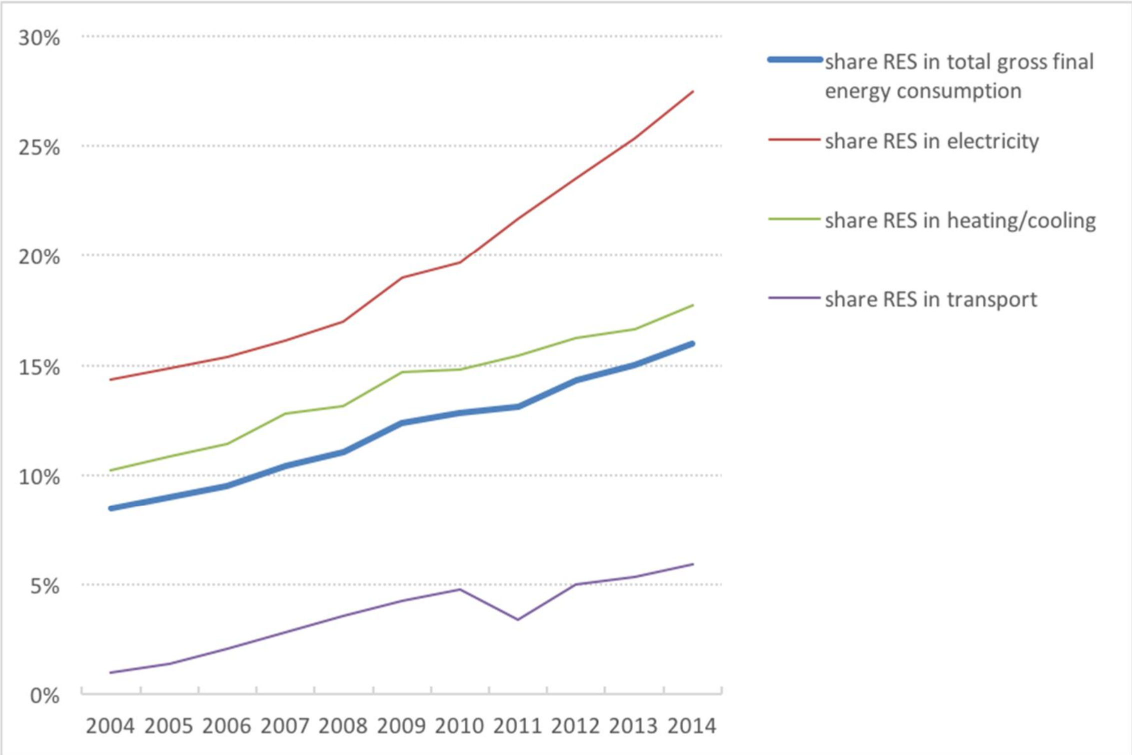


Figure 1 Development of the share of renewable energy in gross final energy consumption and in the three energy sectors: electricity, heating and transport EU 28 (Eurostat 2016)

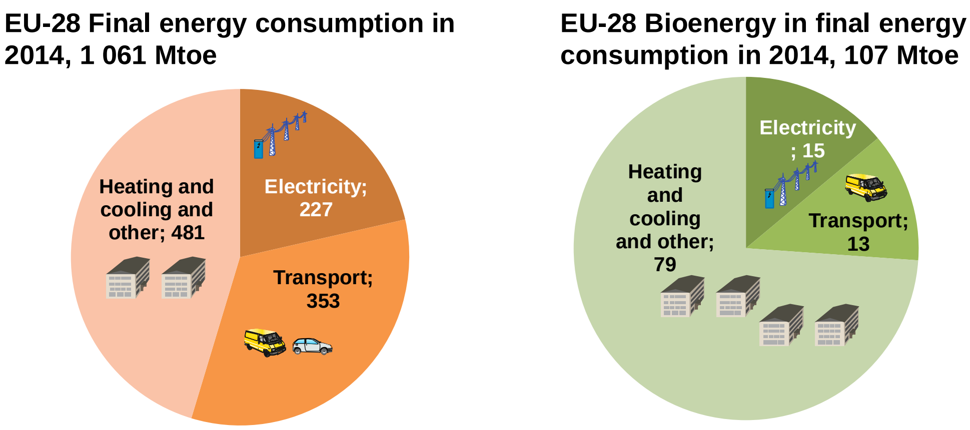


Figure 2. Proportion of heating and cooling in total final energy consumption and final energy consumption of bioenergy in EU 28 (2014, Mtoe)[3]

[3] EUROSTAT 2016

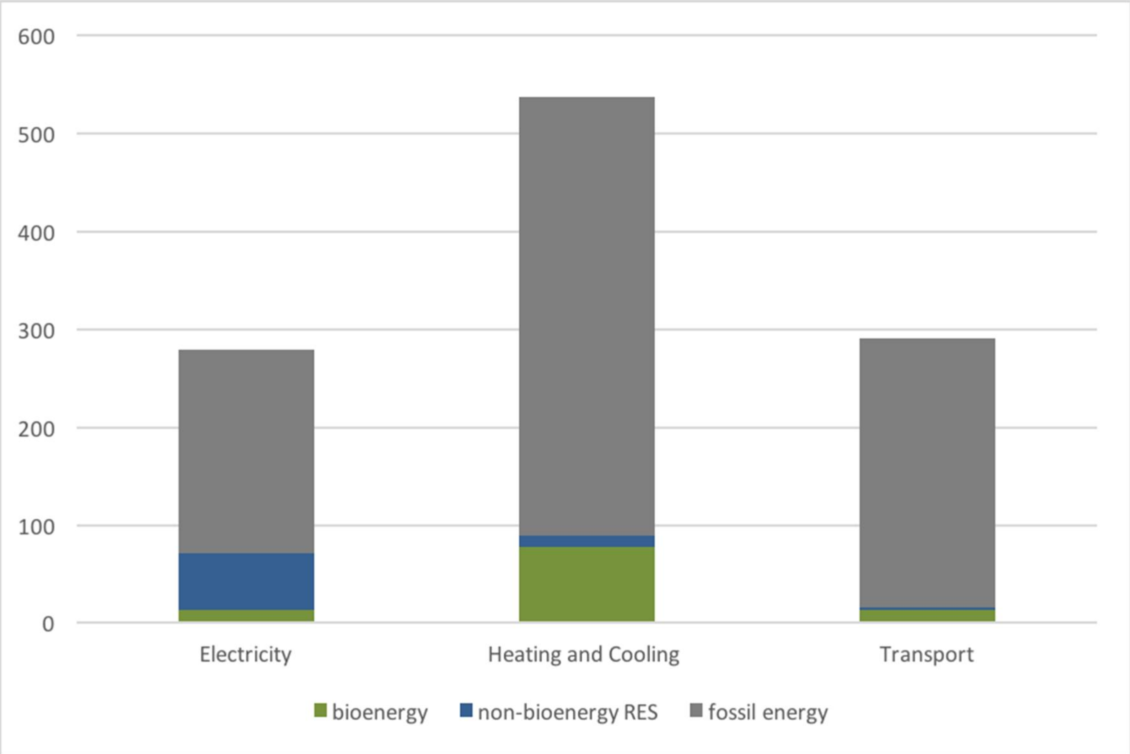


Figure 3. Share of bioenergy and other renewable sources in final energy consumption in EU 28 (2013, Mtoe)[3]

The information presented above provides a good overview of the situation at EU-level. Among the member states, however the share of renewables in final electricity generation and the contribution of bioenergy in this renewables share varies a lot. Figure 4 provides an overview of the share of renewables in gross electricity generation in EU Member States (in 2014). Austria has the highest share (81%), followed by Croatia (74%). Then a group of four MSs achieved between 55-65% share: Portugal, Sweden, Denmark and Latvia. Then another group of 6 countries have a renewables share of more or less 40%: Italy, Romania, Lithuania, Spain Finland and Slovenia.

In many of these countries the majority of the renewable energy is provided by hydropower. Bioenergy and variable renewable sources (i.e. wind and solar power) are less dominant (except for Denmark, Spain and Italy) as can be seen from Figure 5 and Figure 6. In Figure 6 the size of the pie diagram presents the total amount of renewable electricity generated. This allows a proper comparison among the member states. For example, Croatia has a high share of renewable energy in its electricity portfolio, but is small in terms of total amount of renewable electricity generated. Another example is Denmark, where the share of variable renewable electricity is the largest of all Member States (see Figure 8) but in the absolute amount of generated variable electricity it's variable electricity generation capacity is only 15% of that of Germany (see Figure 9). Germany has both the highest amount of bioenergy based electricity generated as well as the highest amount of variable renewable energy.

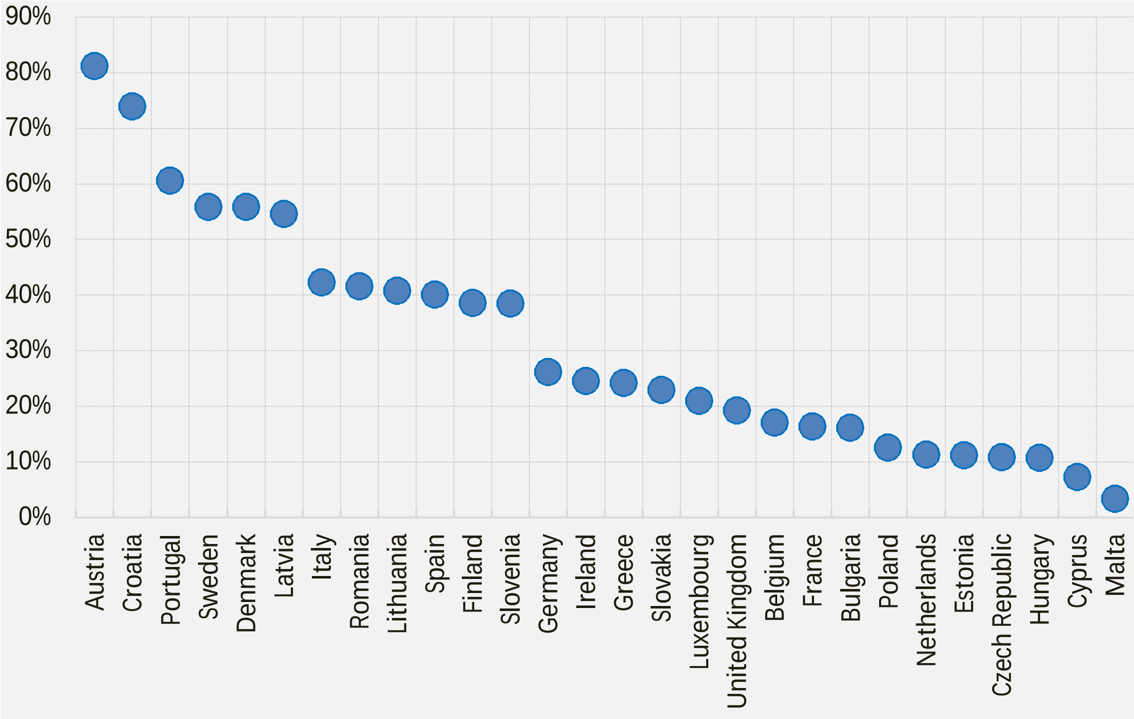


Figure 4. Share of renewable electricity in total gross electricity generation (2014) for the various EU Member States (Eurostat, 2016)

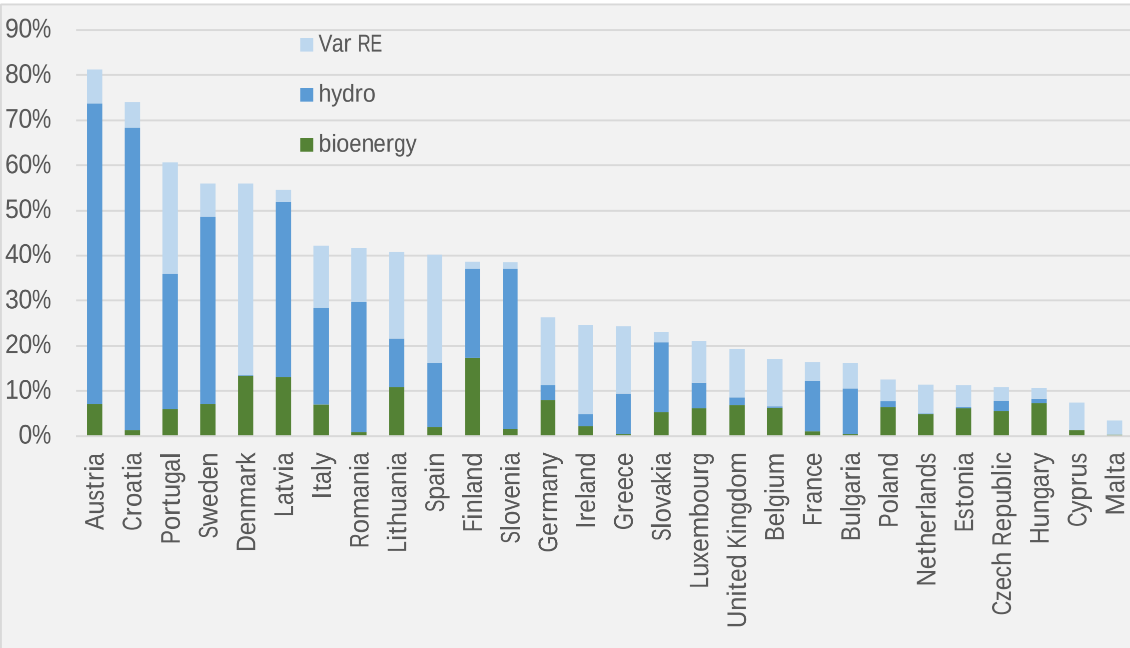


Figure 5. Overview of the energy sources that provide renewable electricity in total electricity generation in 2014[3]

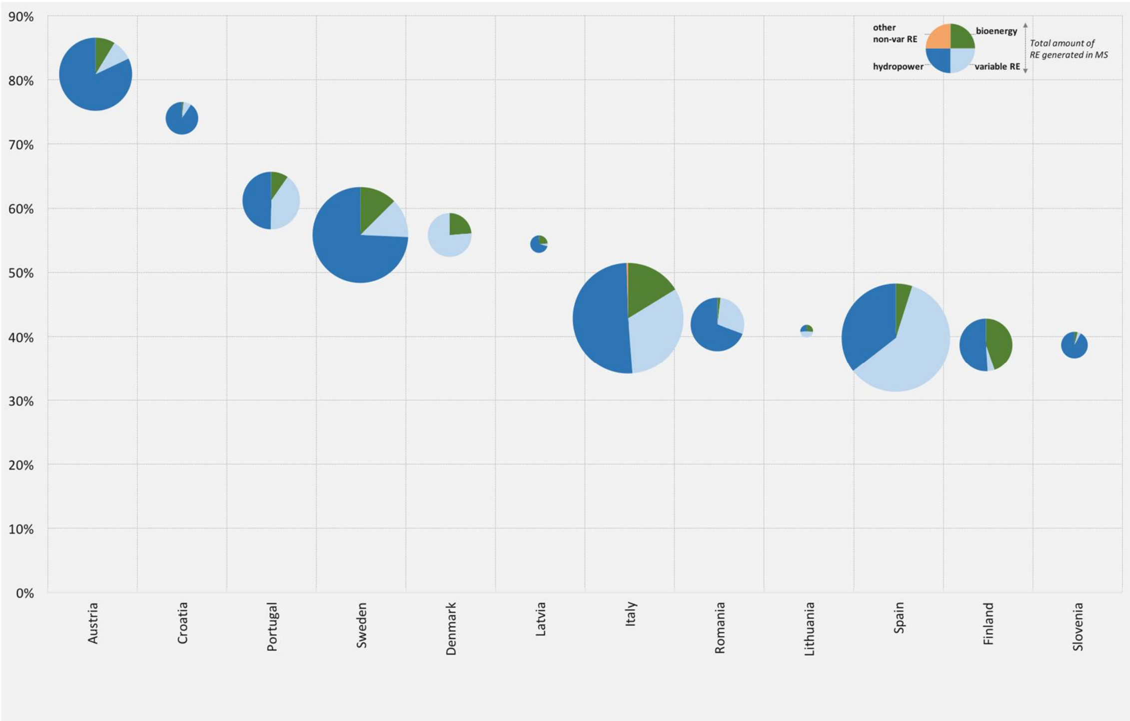


Figure 6. Share of renewable electricity (and contribution of the renewables sources) in total electricity generation (Member States with >30% RE share in electricity)

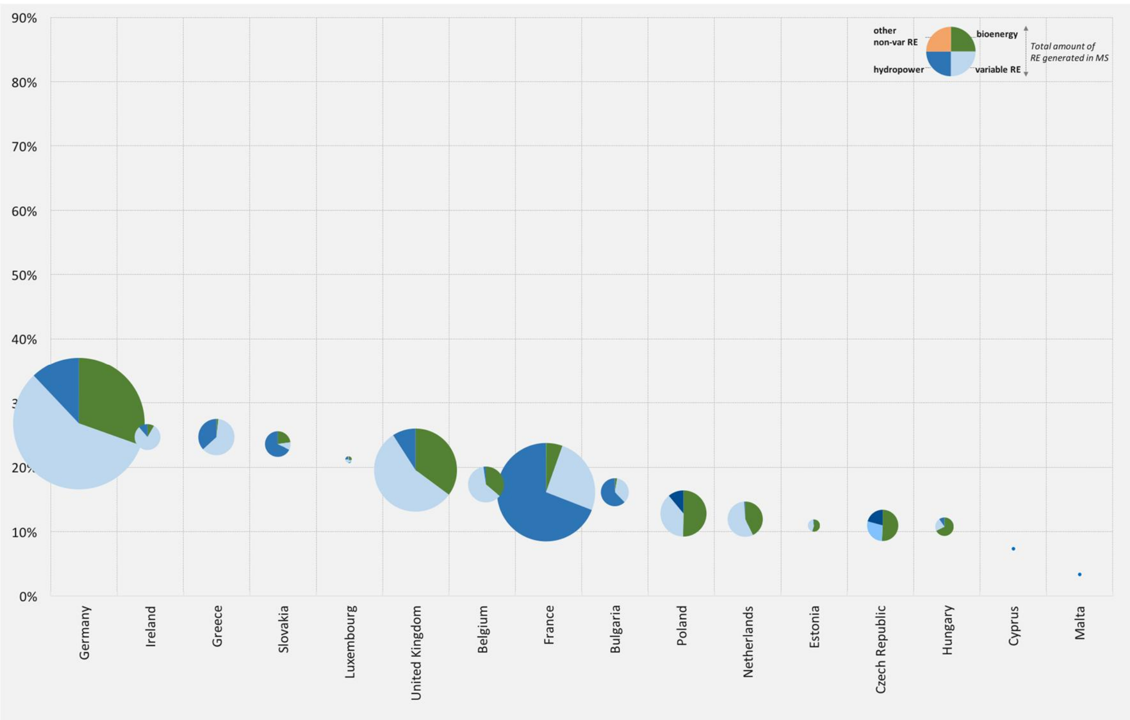


Figure 7. Share of renewable electricity (and contribution of the renewables sources) in total electricity generation (Member States with less 30% RE share in electricity)

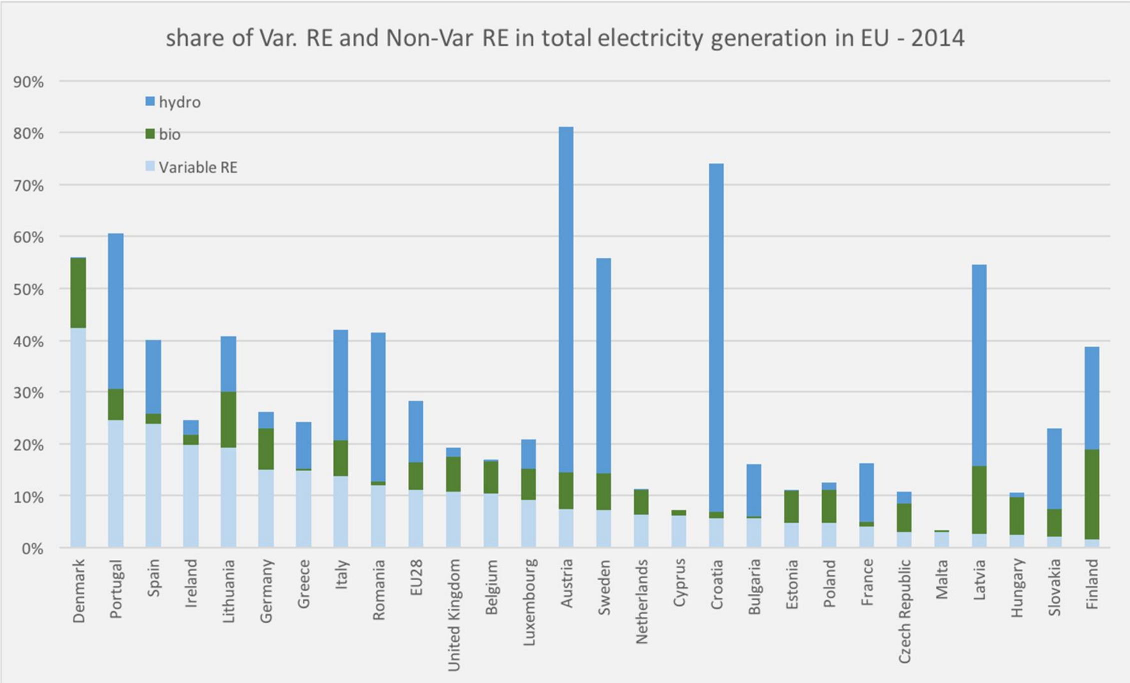


Figure 8. Member States ranked on the share of Variable renewable energy (VarRE in total electricity generation (in 2014)[3]

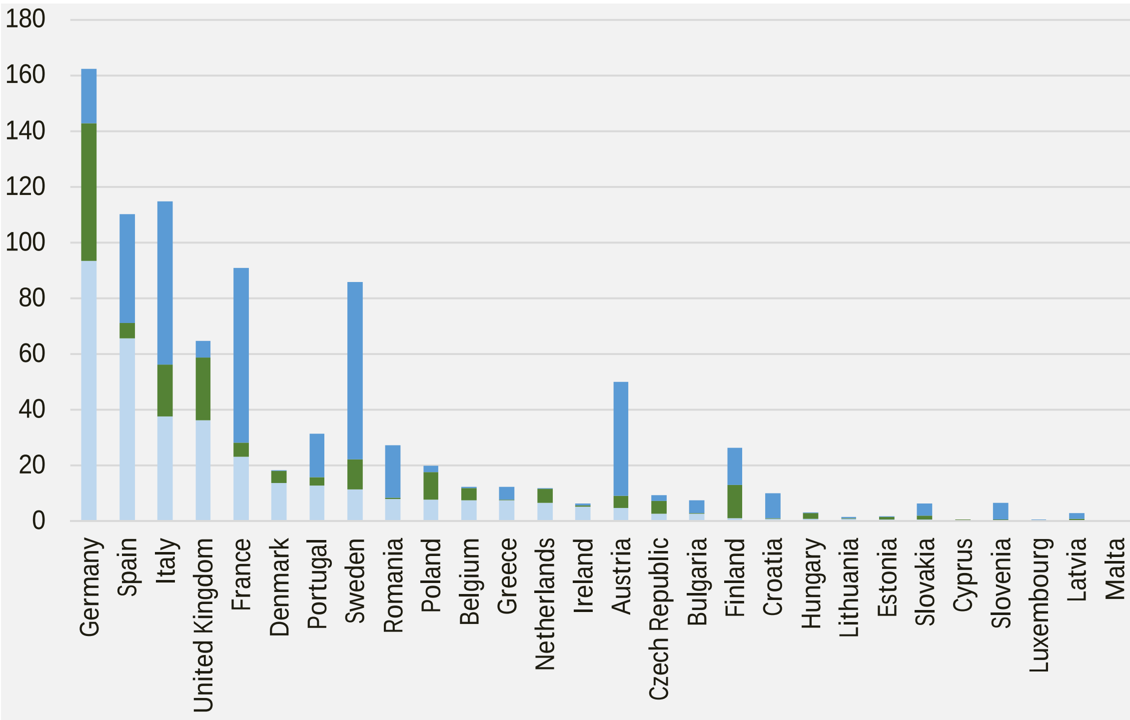


Figure 9. Amount of renewable electricity generated in 2014 (in 1,000 GWh) in various Member States, ranked on the share of variable renewable energy.

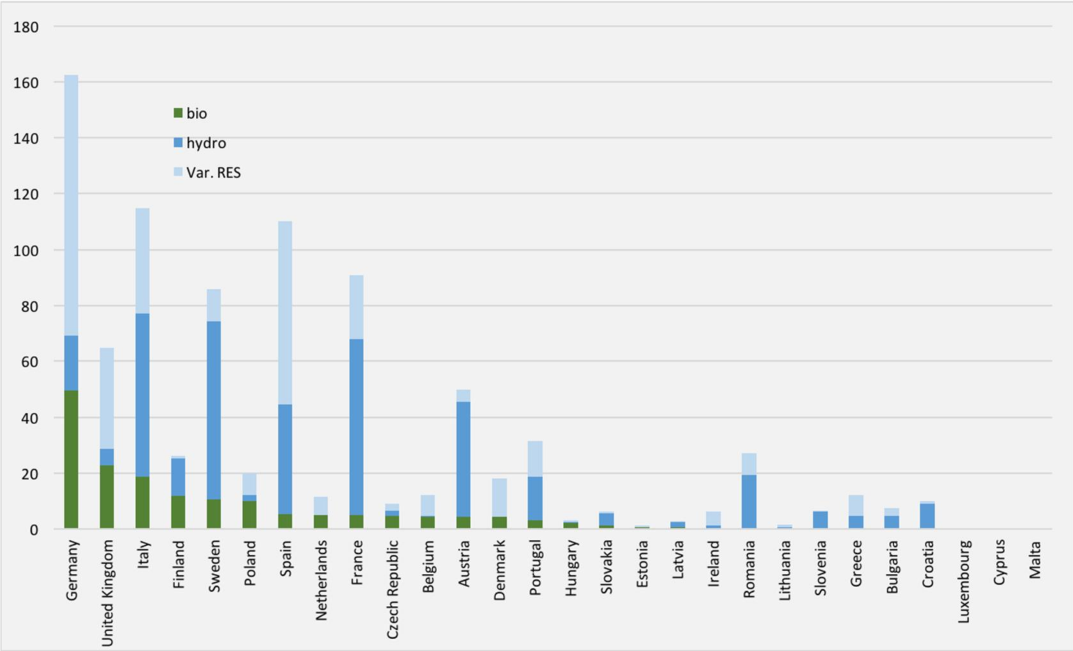


Figure 10 Amount of renewable electricity generated in 2014 (in 1,000 GWh) in various Member States, ranked on the amount of bioenergy.

The figures above show the shares and quantities of variable generation for hydro power and bioenergy with waste energy. It shows that some countries are in a better position to utilize local renewable generation resources to balance fluctuations in variable generation. However, most European countries are well interconnected with neighbors and the resources can consequently be shared. Many countries already produce much more electricity with variable generation than with more controllable renewables.

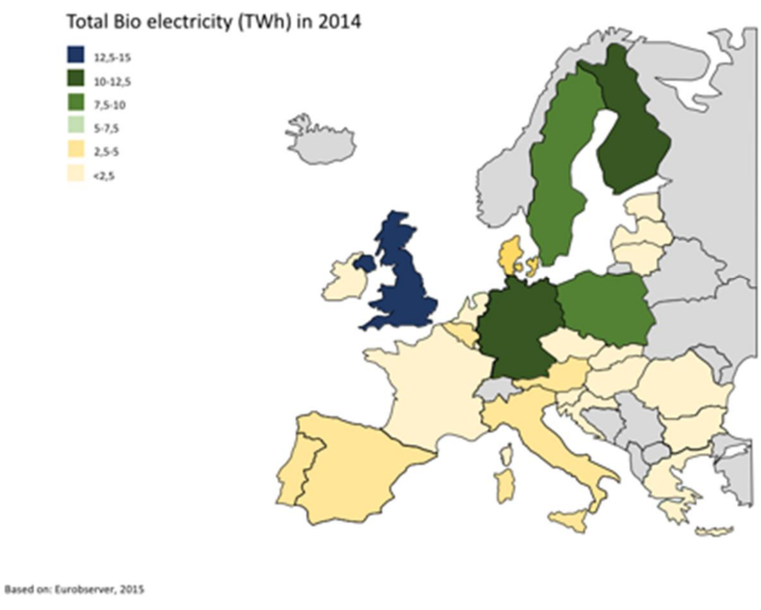


Figure 11. Regions with high absolute share of electricity generated from solid biomass in 2014 (in 1,000 GWh) in various Member States. When biogas is also included bioelectricity is Germany is more than 40 TWh, UK more than 20 TWh and in Italy about 19 TWh.

In the regions where in absolute terms high volumes of biomass are used, on average much of the electricity is also produced in Combined Heat and Power facilities. The next map (Figure 12) indicates the countries in which bio-based electricity is mainly produced in such facilities and the share of bioelectricity and variable renewable electricity in electricity generation (Figure 13).

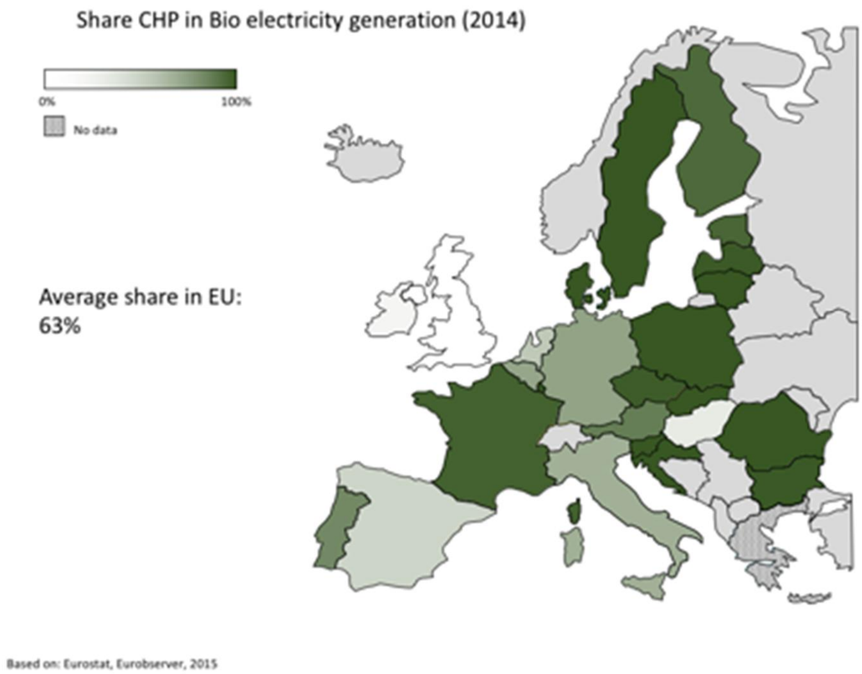


Figure 12 Share of CHP in bioelectricity production in various Member States.

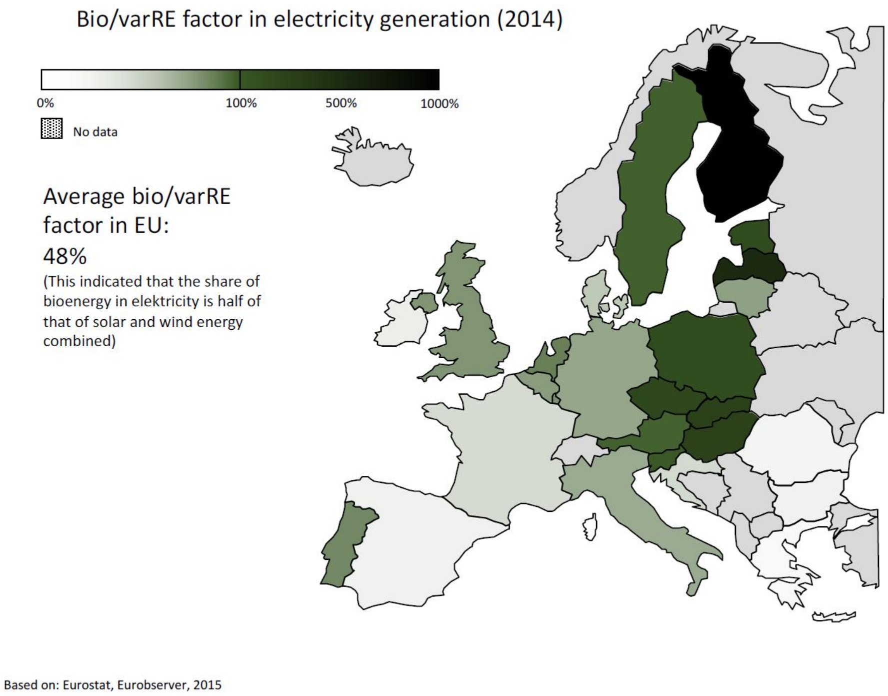


Figure 13 Share of bioelectricity and variable renewable electricity in electricity generation.

In Figure 14, the bio/varRE-factor is coupled to the overall share of RES in total electricity generation. The group of countries that have a more than 25 or 30% share of RE in electricity generation and that have a low bio/varRE-factor (e.g. less than 50-60% meaning a high contribution of variable RE and low contribution of bio in electricity generation) might be more vulnerable to grid balancing problems (the countries in the lower right section of this graph).

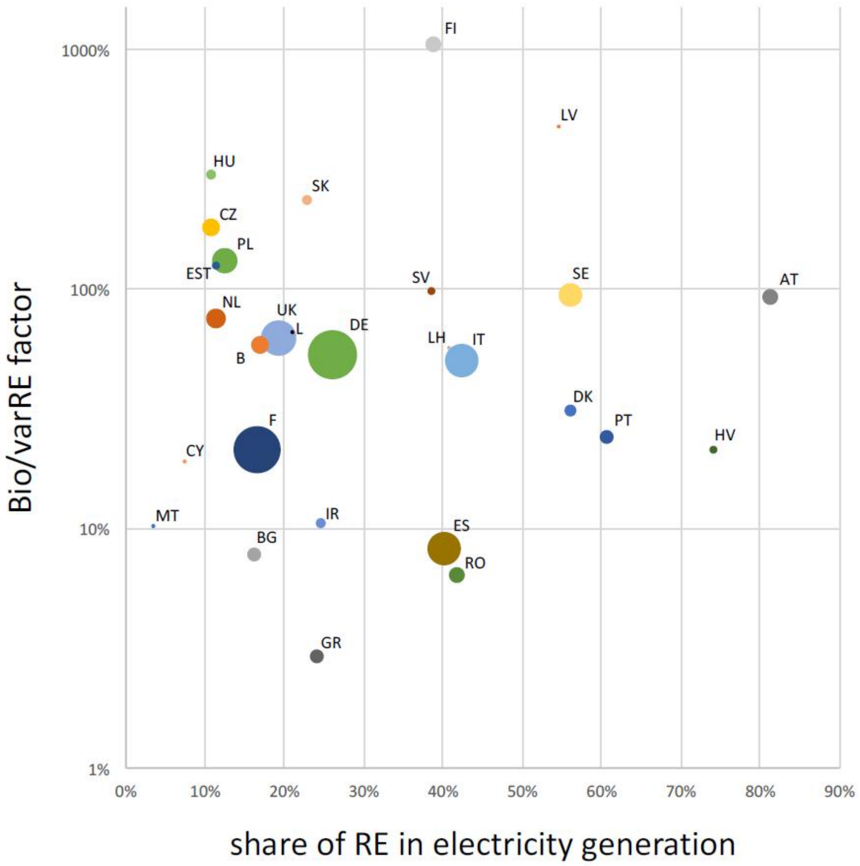


Figure 14 The bio/varRE-factor coupled to the overall share of RE in total electricity generation in 2014 (the size of the dots reflects the total TWh generated electricity).

With respect to Figure 14 including bioenergy and hydro versus variable RE, we see that a limited number of countries are in the lower-right, vulnerable section of the graph. This reflects the situation in 2014. With the upcoming 2030 package it is expected that the share of wind and solar technology will increase. This may result in more countries moving towards the lower-right section of this graph: the share of RE in electricity generation will increase with solar and wind expanding faster than bioenergy, and assuming that hydro does not expand anymore.

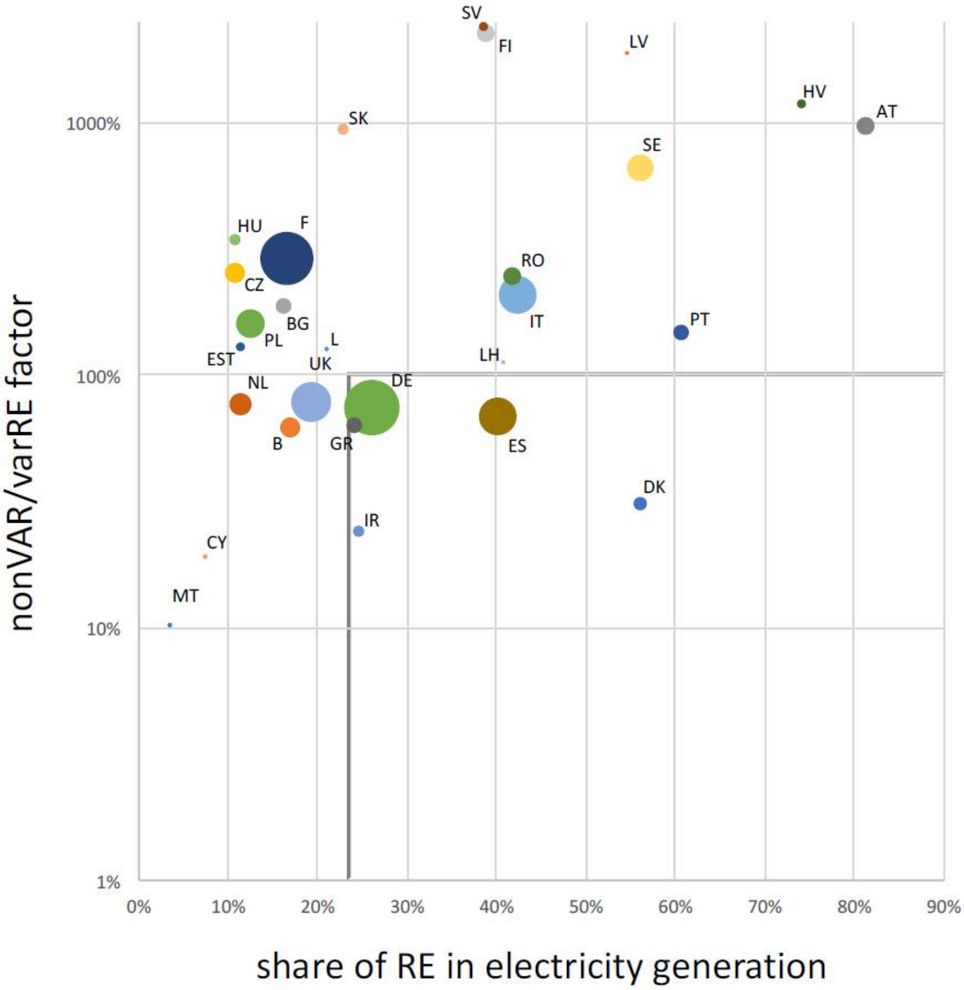


Figure 15 The nonVAR/varRE-factor coupled to the overall share of RE in total electricity generation in 2014 (the size of the dots reflects the total TWh generated electricity).

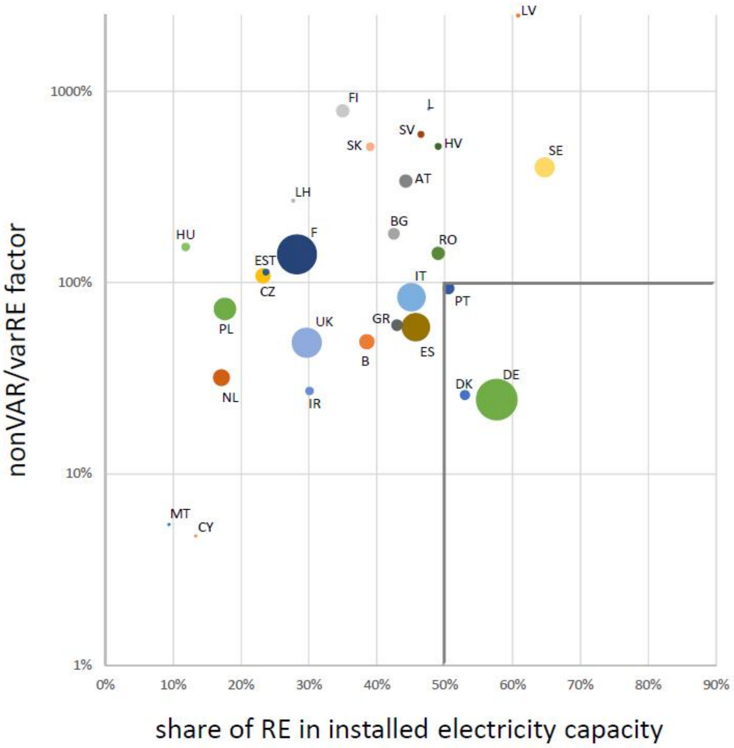


Figure 16 Ratio between bio and variable RE in installed electricity capacity in 2014 (the size of the dots reflects the total TWh generated electricity).

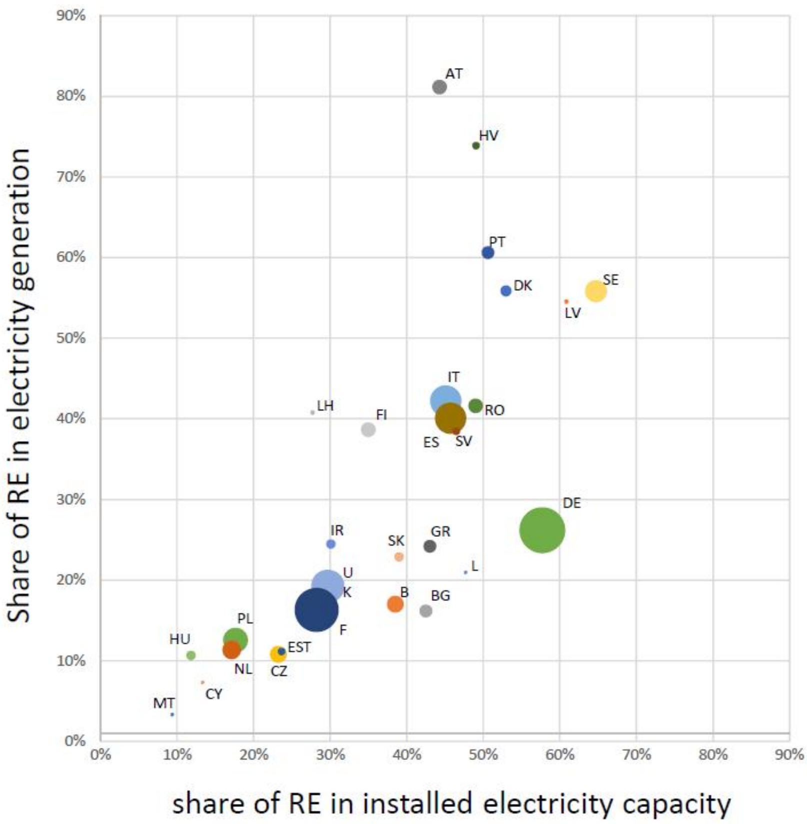


Figure 17 Share of RE in installed capacity and generated electricity in 2014

3 Increasing market demand for renewables in 2030 meeting the climate targets

Low carbon energy targets and policy are driving renewable energy to markets. Solar and wind electricity penetration of the energy system, in particular, drives the market change. Electrification and price formation change the role of energy consumables and distribution grids, further driving the change in earning logic that will eventually create new business models. The energy market transformation from an energy optimized to capacity optimized system is expected when the share of intermittent or uncontrollable electricity becomes large enough. Despite significant regional differences in solar and wind resources, the unexpectedly fast declining production costs of solar and wind power will drive the transformation further (Figure 18). This is the objective of fiscal policy support in developing production technologies to become more and more feasible. In this kind of future energy system, energy will not be the limiting factor, but rather security of supply will be instead. Conventional dispatchable energy production will be pushed out of the market due to higher operational costs and its place in the dispatch merit order, so becoming unprofitable due to low operational hours. Price fluctuation will increase, and capacity based market instruments will most probably be introduced to address the security of supply.

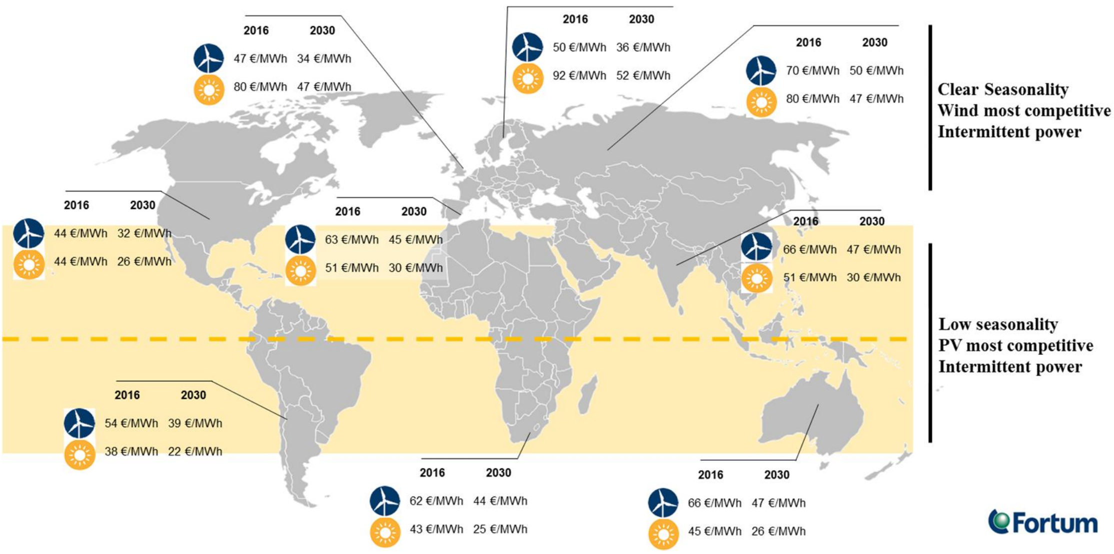


Figure 18 Solar and wind energy resources and associated levelised cost of electricity[4]

3.1 CURRENT POLICY INSTRUMENTS AND PROJECTIONS TO 2030

This chapter summarizes the key points of the main European Directives regarding both access to and dispatching of electricity produced from renewable sources and the production of sustainable biofuels/bio liquids. It reports on the main existing regulations and possible future developments beyond 2020. A new RED II package is expected by the 30 November 2016 which may address

[4] Langer, Energy market transformation from energy optimized to capacity optimized system, 16.8.2016, Helsinki

several of the issues raised in this study.

Support schemes for electricity generated from renewable energy sources (RES) have formed the backbone of the success of RES electricity penetration in the European Union (EU) electricity market. Amongst these, seemingly the most successful mechanism is the feed-in tariff (FiT), a policy mechanism aimed at accelerating investment in RES technologies. National laws or regulations regarding FiTs require utilities to purchase electricity generated from RES suppliers at a percentage above the prevailing retail price of electricity. An EU-wide bioenergy policy database has been published in the S2Biom – project (http://S2Biom.vito.be).

Furthermore, since most RES at the moment are in some way or other still dependent on financial support from different support schemes[5], this section focuses on the various RES support schemes that are implemented by the various EU member states.

In this regard, the EU adopted guidance for the design of RES support schemes for Member States in 2013[6], to ensure that these support schemes did not distort the functioning of the energy market and thereby lead to higher costs for European households and businesses. Pertinent to this study, the Commission guidance suggests that FiTs should be phased out and replaced by support instruments that expose renewable energy producers to market price signals such as feed in premiums. In addition, the Commission considers that schemes should include automatic degressive elements and be complemented by a built-in revision mechanism. Finally, the guidance suggests limiting support to comparable periods (10/15 years) or to a pre-set number of full-load hours calculated based on reasonable expectations for capacity utilization over a defined period.

3.1.1 Outlook for EU

Energy Roadmap 2050 - COM(2011) 112

The Energy Roadmap 2050 COM(2011) 112 of the European Commission aims at cost-efficient ways to make the European economy more climate friendly and less energy consuming. However, while switching to an economy based on low-carbon technologies is technically and economically feasible, it requires that a very large decarbonisation of the electricity generation sector is put in place in the EU.

In addition, the main European goal of decarbonizing its energy system by 2050 will also increase competitiveness and security of supply in Europe: this is another major strategic reason supporting the EU long-term goal of achieving an 80% greenhouse gas emissions reduction compared to 1990 levels. In order to do that, private and public investments are needed in new low-carbon technologies, energy efficiency and in the replacement of grid infrastructures.

The first measures towards reaching the ambitious 2050 goals were contained in the 2030 climate energy Framework.

2030 Climate and Energy Policy Framework

By adopting the 2020 Climate and energy package, the EU set three major targets to meet its energy policy objective of a sustainable, secure and competitive energy system. These targets were then translated into nationally binding legislation in 2009 (Renewable Energy Directive) and

[5] Held H et al, Design features of support schemes for renewable electricity, Task 2 report, January 2014

[6] European Commission, European Commission guidance for the design of renewables support schemes - Accompanying the document: Communication from the Commission Delivering the internal market in electricity and making the most of public intervention, Commission Staff Working Document, November 2013, SWD(2013) 439 final.

in 2012 (Energy Efficiency Directive).

In order to achieve a more competitive, secure and sustainable energy system and to reach the goal of the 2050 greenhouse gas reduction target defined in the Energy Roadmap 2050, the European Commission, in 2014, proposed a new Energy and Climate Strategy, with new targets set up to 2030.

This strategy aims at encouraging private investment in new pipelines, electricity networks, and low-carbon technologies in an effort to cost-effectively address decarbonisation by 2050, by shifting the spending and investments away from conventional fuel sources and towards low-carbon technologies.

Targets for 2030

The targets set by the EC for 2030 were the following:

- 40% reduction of greenhouse gas emissions compared to 1990 levels;
- at least a 27% share of renewables in energy consumption;
- at least 27% energy savings compared with the business as usual scenario.

A comparative chart of the different targets of the 2020 and 2030 Climate and Energy Strategy is shown in the Figure 19.

It is worth underlining that these measures are expected to have a significant impact on the whole EU energy system, as the share of renewable energy sources in gross inland energy consumption already increased in the EU-28 from 4.3% in 1990 to 11.0 % in 2012, with an average annual rate of 4.4%, and reached 15.0% in 2013[7].

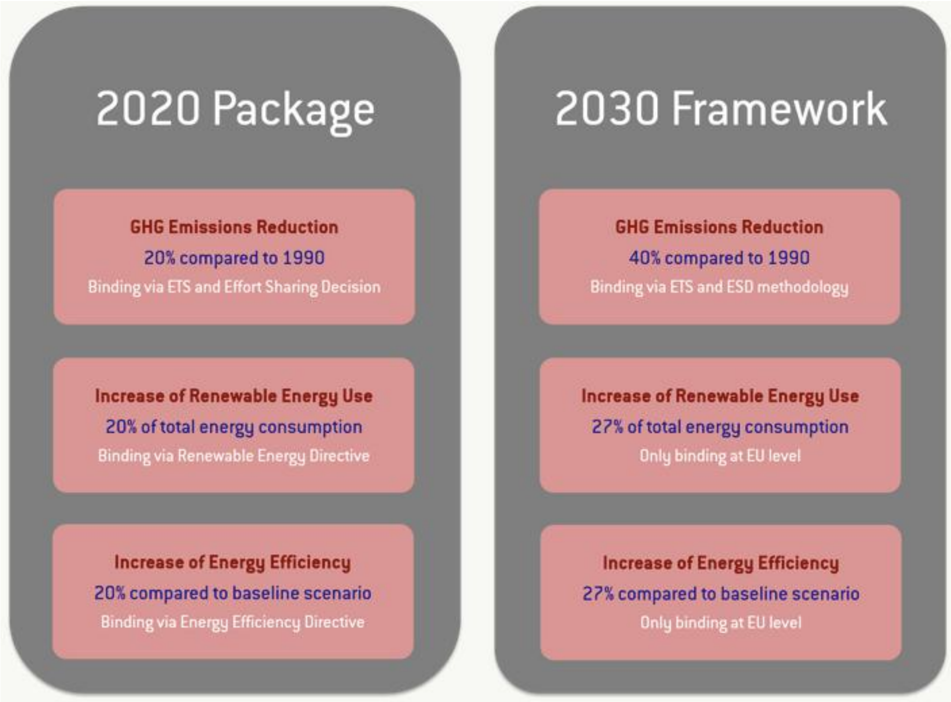


Figure 19 Comparative chart of the targets to be reached in 2020 and 2030[8]

To meet the targets, the European Commission proposed the following legislative elements:

- A revised EU emissions trading scheme (ETS) with an effort sharing decision for sectors not covered by the EU emissions trading system, and also on land use, land use change and forestry;

[7] Eurostat. http://ec.europa.eu/eurostat/web

[8] Tagliapietra, S. Zachmann, G. (2015). The EU 2030 Climate and Energy Framework: Keeping up the pressure on governance structures, Sept 2015. Available at: http://bruegel.org/2015/09/the-eu-2030-climate-and-energy-framework-keeping-up-pressure-on-governance-structures/

- New indicators for the competitiveness and security of the energy system, such as price differences with major trading partners, diversification of supply, and interconnection capacity between EU countries.

As opposed to the previous 2020 package, the new EU targets will not be translated into binding national targets under the EU legislation. Although this is in accordance with Article 194 (2) of the Treaty on the Functioning of the European Union (TFEU), which leaves the decision with Member States on national control of the energy mix, this decision seems to reflect a still absent EU common vision on how to organize the future European energy market. In order to guarantee that the 2030 targets will be achieved, and to provide a stable economic environment for investors, the EC proposed the following potential governance scheme based on national plans for competitive, secure and sustainable energy in the 2030 framework communication:

- Detailed guidelines, to be prepared by the EC on the content of national plans;

- Preparation of Member State plans through an iterative process;

- Assessment of the Member States' plans and commitments (if insufficient, "a deeper iterative process would take place between the EC and the Member State to reinforce the plan's content").

3.1.2 European targets and needs for balancing the grid

From the point of view of the electricity grid, these EC targets aimed at achieving higher volumes of variable renewable energy (VRE), will inevitably require a dedicated effort in balancing the electrical systems: even more importantly, this will have to happen within the time frame already determined by the EC regulatory actions, e.g. the EC Directives.

The Energy Union policies on energy (and specifically power generation) point towards decarbonisation, and therefore favour possibilities that maximize the absorption of renewable power, which is typically accepted in the grid with priority over conventional fossil-based dispatchable power. Priority access would occur in the electricity market context anyway as low marginal cost power is dispatched first, although, during times of excess energy, priority dispatch becomes problematic and new rules abandoning priority access are being prepared at EU level. It will also clearly be necessary to develop dedicated policies in the EU that take into account the energy system needs, and therefore market designs that promote flexibility in quantities that are needed in future.

3.2 OVERVIEW OF RES ELECTRICITY SUPPORT MECHANISMS IN THE EU

A major part of the EU energy policy is the promotion of energy produced from renewable energy sources (RES). RES are naturally renewing energy sources, including bioenergy, solar energy, wind energy, hydropower, and geothermal energy.

In the absence of public intervention, it would have been impossible for the EU to achieve its goals related to the promotion of electricity generated from RES. Consequently, support schemes for electricity generated from RES have formed the backbone of the success of RES electricity penetration in the EU electricity market.

Amongst these, seemingly the most successful support scheme is the feed-in tariff (FiT), a policy mechanism aimed at accelerating investment in RES technologies. FiTs require utilities to purchase electricity generated from RES suppliers at a percentage above the prevailing retail price of electricity.

Feed-in tariffs (FiTs) are an energy supply policy focused on supporting the development of renewable energy projects by offering long-term purchase agreements for the sale of electricity generated from RES. This scheme works on the premise that any person generating electricity from RES can sell what they produce at a fixed tariff for a specific time period under specific conditions depending upon, *inter alia*, the location and the technology deployed.

Feed-in premiums (FiPs) work in a similar way to the FiT scheme, with one fundamental difference whereby the plant operators sell the electricity generated directly on the electricity spot market and in return receive a premium in addition to the market price.

Auction Schemes for RES generally work well when combined with any aforementioned form of support scheme. Tenders and auctions are used as a competitive allocation mechanism for cost effectively allocating financial support to RES electricity generation projects.

Tradable Green Certificates (TGCs) are certificates that can be sold on a certificate market. This allows RES electricity producers to obtain revenue in addition to the revenue from the sale of the electricity they produce and feed into the grid.

Quota Obligations are obligations that require energy suppliers to purchase a quota of RES energy (or green certificates representing the production of such energy). TGCs are usually combined with quota obligations, but TGCs can in principle have a wider use.

Investment Support is provided by member states at a national level for RES electricity and is often given to power plant generators using less mature technologies such as solar PV. It is coupled with other support measures such as FiTs and FiPs, and is often not the only support mechanism for RES electricity generation.

Tax Exemptions or Incentives are often used in addition to the other kinds of RES electricity support schemes and are targeted at specific kinds of technologies used to generate RES electricity.

Low Interest Loans are provided to power plant generators producing RES electricity at interest rates lower than those available in the market or by way of providing other concessions such as longer repayment periods or interest holidays, etc.

The support schemes have been successful in increasing the uptake of energy produced from RES. As a result, today it is mostly variable RES energy such as wind and solar that constitutes the new capacity coming online in the EU. It is difficult for RES such as wind and solar to be easily "dispatchable", as they have very short high probability time frames during which their power output can be predicted. In order to avoid turning to conventional power plants while meeting demand patterns in any time period, bioenergy, one of the most efficient options, can be easily dispatched.

4 Challenges of balancing the grid with large shares of variable generation

The balance between electricity demand and generation (power balance) is closely maintained at all times as otherwise the power system would be de-stabilized and a black out would follow. Here a qualitative description of different time periods involved and how things might evolve with increasing shares of wind power and PV is given. Finally, the impact of the power grid and transmission bottlenecks are briefly explained.

Balancing can roughly be divided into two time periods (Figure 20). Most of the variability in load and variable generation is balanced by committing generation units to dispatch. In the figure, this is mid-term balancing. Short-term balancing is mainly concerned with correcting forecast errors in the original dispatch. This is achieved with intra-day and balancing markets and ultimately, in real time by activating frequency reserves either automatically or manually. Both mid-term and short-term balancing are affected by the long-term decisions on investments and retirements of generation and consumption units. Investment decisions are driven by policy measures and by expected market revenue.

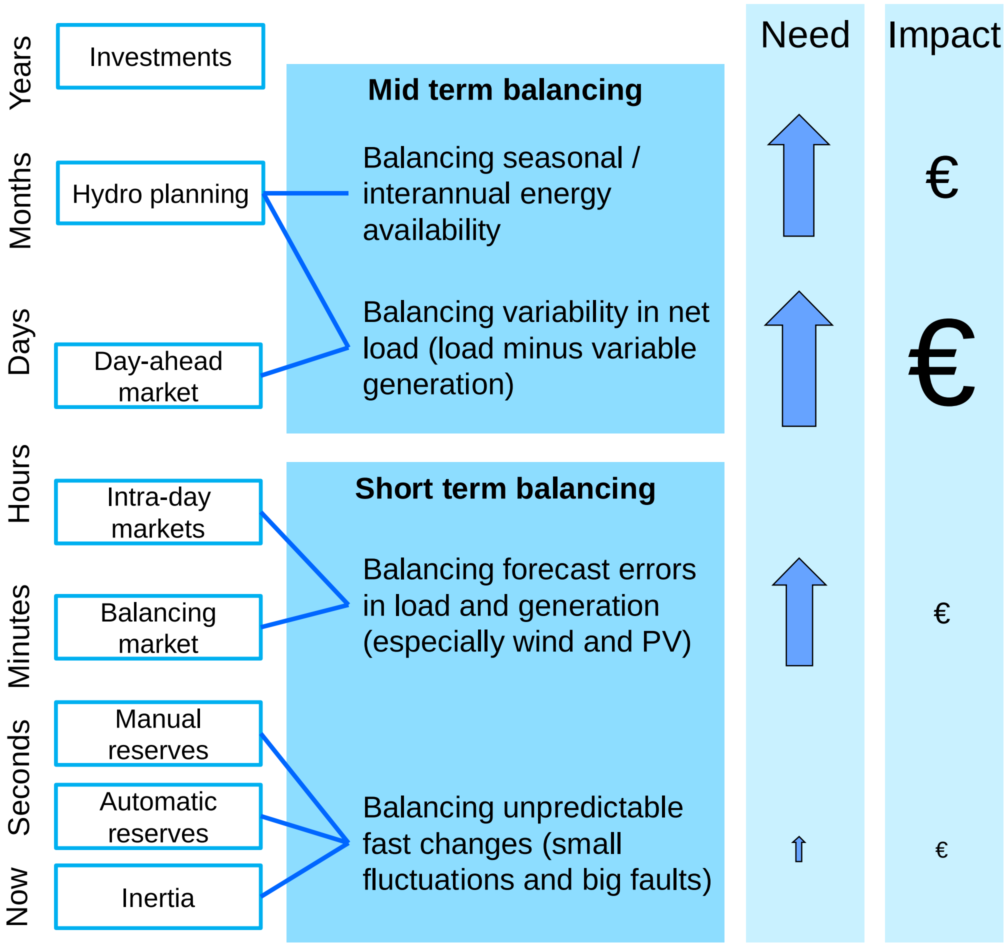


Figure 20 Balancing in different time scales and approximate influence of increasing variable generation on the need and economic impact of balancing.

Variable generation has potentially a large impact on investment decisions by changing the markets. The largest economic impact is in mid-term balancing through the day-ahead market. Forecast errors also considerably increase the need for short term balancing, but the volume of those markets is much smaller than the volume of day-ahead markets.

4.1 MID-TERM ENERGY BALANCE

The power balance is maintained with the least cost supply of power generation available. The power plants with the lowest marginal costs are dispatched first in the day-ahead and real time markets. Day-ahead and intra-day markets are responsible for the bulk of the energy balancing resulting from variations in load and generation. Where in use, real time markets encapsulate the balancing reserves/markets that correct forecast errors.

The power markets are supplemented by future energy markets where fiscal agreements on future generation and consumption can be made. These are typically used to mitigate financial risks related to seasonal/inter-annual variation in electricity price, but they could also help to support new investments. Currently their temporal resolution is not high enough for initial balancing of the following few days.

As wind power and PV have negligible operational costs, and possibly have subsidies based on generated electricity, they are typically first to be dispatched. In some jurisdictions they may even have priority in dispatch along with some other forms of generation (e.g. run-of-river hydro power and small scale CHP units). The next power plants to be dispatched are so-called baseload power plants, which have low marginal prices (e.g. nuclear power, coal, and many CHP power plants including some biomass power plants). For higher levels of electricity demand there are power plants that do not typically run all the time. These include natural gas combined cycle power plants, many biomass based power plants, gas turbines and gas engine power plants. Reservoir hydro power plants have a limited energy resource and are typically used when the power prices are around average or higher. Their usage depends on the reservoir levels, expected reservoir inflow and expected power prices.

As the share of wind power and PV increases, there will be less need for baseload power plants and more need for intermediate/peak power plants. Many biomass based power plants have high fixed costs and would benefit from a baseload type of operation, which is a long term challenge to biomass use in balancing the power system. The question is which pathways from biomass to power can be cost-effective in intermittent power generation.

4.2 SHORT-TERM ENERGY BALANCE / FREQUENCY CONTROL RESERVES

There is more to power system balancing than simply matching generation with demand. The balance needs to be maintained with very high precision and this forces the power system operators to continuously pre-plan the operations. There needs to be enough power generation reserves to mitigate imbalances that arise or threaten to arise during the operation. These reserves are called frequency reserves, since the frequency of the alternative current starts to change when there is an imbalance between generation and demand. There are many ways to divide the frequency reserve time periods and what is presented here reflects the needs of the report, and the division is not based on the practices of any particular power system.

4.2.1 Frequency containment reserves

The very short time periods are the realm of inertia and automatic frequency containment reserves. Frequency containment reserves are used when there is a large and very fast change in the power balance. Typically, this is due to a large power plant tripping out or a fault in a loaded high voltage transmission line. Once used, these frequency containment reserves need to be supplanted as fast as possible in order that they be ready for the next event, to prevent a potential system wide power black-out.

Wind power and PV are connected as relatively small power plants and do not effect the largest possible fault that could happen (dimensioning fault). However, they are non-synchronous forms of power generation and replace inertia providing synchronous generators in the power system. This makes the power system more susceptible to disturbances in the power balance. Ongoing research is trying to find the best ways to mitigate this, but in general faster and more accurate frequency response would be helpful. Frequency containment reserves are typically acquired from large power plants that operate slightly below their maximum output or from frequency controlled demand response. In thermal power plants, fast response is possible by using the existing steam in the boiler to increase power generation and consequently it is of limited size. Biomass based power plants typically have different boilers compared to other thermal plants due to fuel quality, but they still have similar levels of steam available for fast response.

Frequency containment reserves are utilized relatively rarely and consequently the main cost component is the readiness cost (e.g. not running at full power and losing money on the energy market). They are often procured with long term contracts, but with the increasing share of wind power and PV it is becoming more important to procure the reserve for shorter time periods.

4.2.2 Regulation

The next level is the regulation where changes in demand and generation over seconds to minutes are balanced with automatically activated reserves (secondary reserves, frequency restoration reserves). These have been procured beforehand by the system operator so that they can be called into service relatively rapidly. What is corrected is the sum of the changes in the electricity demand and generation that cannot be predicted beforehand. However, their possible size can be estimated statistically in advance.

Wind power and PV will increase the need for regulating reserves but usually to a very small degree as the second to minute fluctuations from thousands of individual wind turbines and PV panels are smoothed out, and not correlated with fluctuations in demand. The nominal size of the regulation reserves is also quite small and even if it is doubled in size, it will still be small.

These reserves are typically procured from power plants with a marginal price close to the current market price. If the price difference would be high, it would be costly to utilize them. Biomass based power plants can gain additional revenue by participating in providing these reserves, but that requires flexibility in their operation and relatively rapid response times (seconds to minutes).

4.2.3 Balancing reserves/ markets

The next time period concerns forecast errors that become apparent when forecasts become more accurate as the moment of operation approaches. The errors considered in this category can be balanced by activating balancing market bids (or by real time markets where in use) or with dedicated tertiary reserves.

Wind power and PV can increase the aggregate forecast error in power systems considerably, even if the forecast errors and variability are smoothed out and not correlated with errors in demand. Again, the need for balancing is only 1-5% of total generation, so even if the need for balancing increases substantially, the market for this service will be relatively small.

As an example, short-term balancing costs (mainly for correcting forecast errors) of wind power increase as the share of wind power rises in the system. Figure 21 shows this from several different studies where the balancing cost is calculated per MWh of wind electricity. The results vary depending on the power system characteristics but also due to methodological differences.

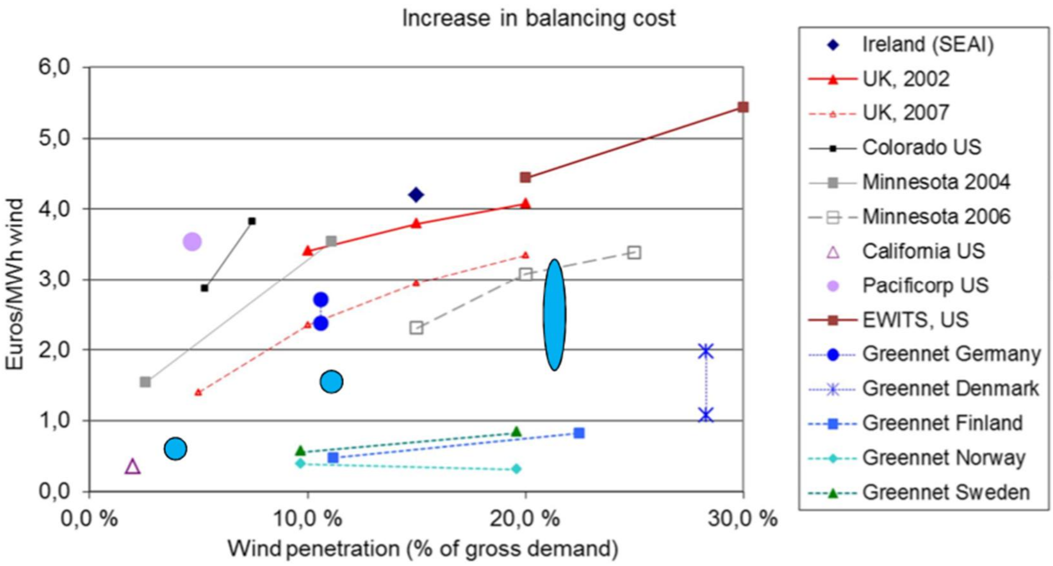


Figure 21 Increase in balancing costs vs wind penetration. Also the range of imbalance costs paid by wind power in the markets are shown for Denmark, Spain and the Netherlands. [9]

The forecast errors are corrected by power plants with marginal costs close to the power market price as these are the most economically available resources. The activation time is typically around 15 minutes in balancing power markets. This means that biomass power plants will need to be running and have headroom to ramp up or down. Many plants can only partially ramp in 15 minutes and cannot offer their full operational range.

4.3 GRID CONSTRAINTS

4.3.1 Transmission grids

The electric grid system in Europe is composed of various synchronous areas[10], e.g. Continental Europe, Nordic, British, Irish etc., in Figure 22. Each area can be composed of several national states with a regulator, and one or more transmission system operators (TSOs) (Figure 23), with the monopoly and responsibility for transferring electricity in the area through the HV system (100-400 kV) and also for offering the interconnections to other areas. The transmission grids are high voltage grids, 50-400 kV in Europe and transmission links are either AC (inside synchronous areas) or DC (between synchronous areas, or sometimes used also in synchronous areas if the transmission distance is long).

[9] Holttinen et al. Design and operation of power systems with large amounts of wind power, Final summary report, IEA WIND Task 25, Phase two 2009–2011. VTT Technology 75, Espoo 2013.

[10] ENTSO-e at a glance 2015

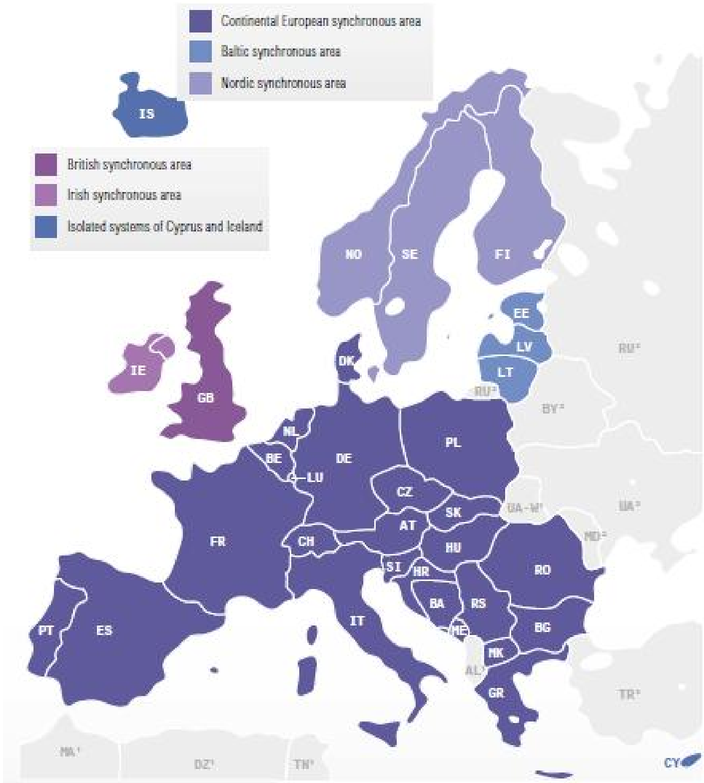


Figure 22 The syncronous grid system areas in Europe.

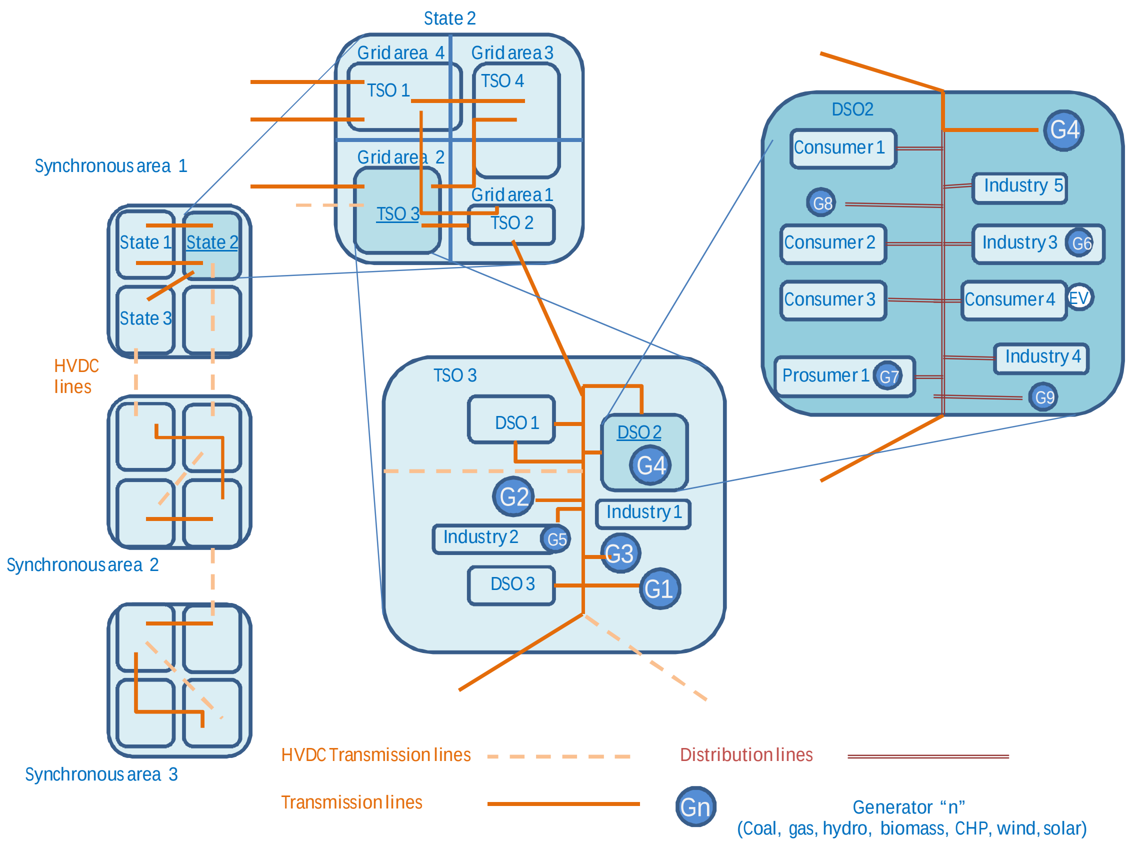


Figure 23 The Electrical grid system

Within each grid area there are distribution system operators (DSOs), generators providing energy to the grid and larger industrial consumers connected to the transmission grid. Each DSO supplies electricity between electricity suppliers and consumers ranging from households to industries. There may also be other smaller generators connected to the DSO grid; these are typically individual wind turbines and solar PV plants. This also involves a new group called “prosumers[11]”, i.e. over time being both producers and consumers.

Balancing can be provided from one region to another only if there are no binding restrictions in transmitting the power between the regions. As transmission lines cost money and are often difficult to permit, there are limited quantities of available transmission capacity. As part of the EU Energy Union a target of a minimum of 10% interconnection capacity between the Member States has been set[12], and European wide transmission planning by ENTSO-E[13] defines Projects of Common Interest (PCI) for implementation by 2020, Figure 24.

Increasing the share of wind power and PV will increase power transfer in Europe. Windy periods in one part of Europe will result in power flows from that region to another, and if the transmission network reinforcements do not keep up with the need caused by wind power, the transmission lines will be congested and less available for other balancing. This will increase the use of local balancing resources, which is a system sub-optimization. While there are plans to build more transmission lines[14], the current pace of wind power and PV deployment will result in more congestion.

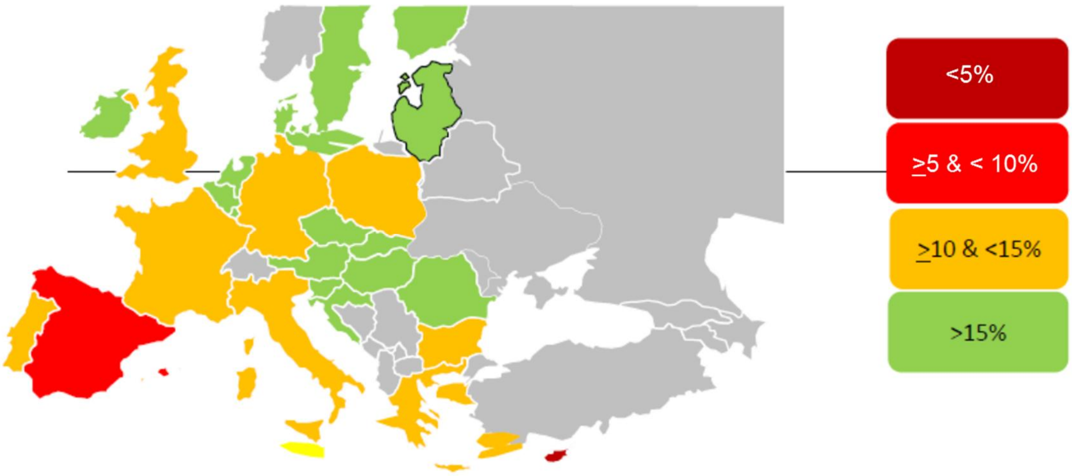


Figure 24. Expected status of grid interconnection capacity level 2020 after implementation of PCI

In the ENTSO-E 10-year plans, about 100 spots on the European grid have been identified where bottlenecks exist or may develop in the future if reinforcement solutions are not implemented. The most critical area of concern is the stronger market integration to mainland Europe of the four

[11] Prosumer:”a consumer of electricity who also produces it and can sell it back to the grid”.

[12] ENERGY UNION PACKAGE Achieving the 10% electricity interconnection target Making Europe's electricity grid fit for 2020. Brussels, 5.2.2015 COM(2015) 82 final

[13] https://www.entsoe.eu/Pages/default.aspx

[14] Ten-Year Network Development Plan (TYNDP). ENTSO-E 2014. https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/141031%20TYNDP%202014%20Report_.pdf

main “electric peninsulas” in Europe. The Baltic States have a specific security of supply issue, requiring stronger interconnection with other EU countries. Spain with Portugal, Ireland with Great Britain, and Italy show a similar pattern. These are all large systems (50-70 GW peak load) supplying densely populated areas with high RES development prospects, and as such, they require increasing interconnection capacity to enable the development of wind and solar generation. Storage technologies for individual prosumers and small scale electricity storage, such as Tesla Powerwall are currently introduced to markets. This type of solution lowers the need for strengthening grids and enables more isolated operation of microgrid types of arrangement.

Transporting the power generated along the shores of the North Sea to major load centers in the adjacent coastal states also triggers a significant investment need for the portfolio of projects of pan-European significance by 2030; €150 billion, of which €50 billion relates to subsea cables. These projects of pan-European significance must be complemented at regional or national level to achieve consistent overall development of the entire energy system. However, the investments are estimated to represent only about 1.5-2 €/MWh of power consumption in Europe, and this is off-set by an overall levelling of electricity prices in Europe, mitigating electricity prices on average by 2 to 5 €/MWh. It is also associated with a higher penetration of RES, and thereby reducing GHG emissions, while also having a positive effect on European social economic welfare.

4.3.2 Distribution grids

The DSO system, where voltages are typically from 50 kV down to 1 kV in the regional or city grids, down to household voltages of 400 or 230 V, is quite fragmented as in most member states there are hundreds of DSOs while there are typically only a handful of DSOs with a customer stock of 100,000, Figure 25.

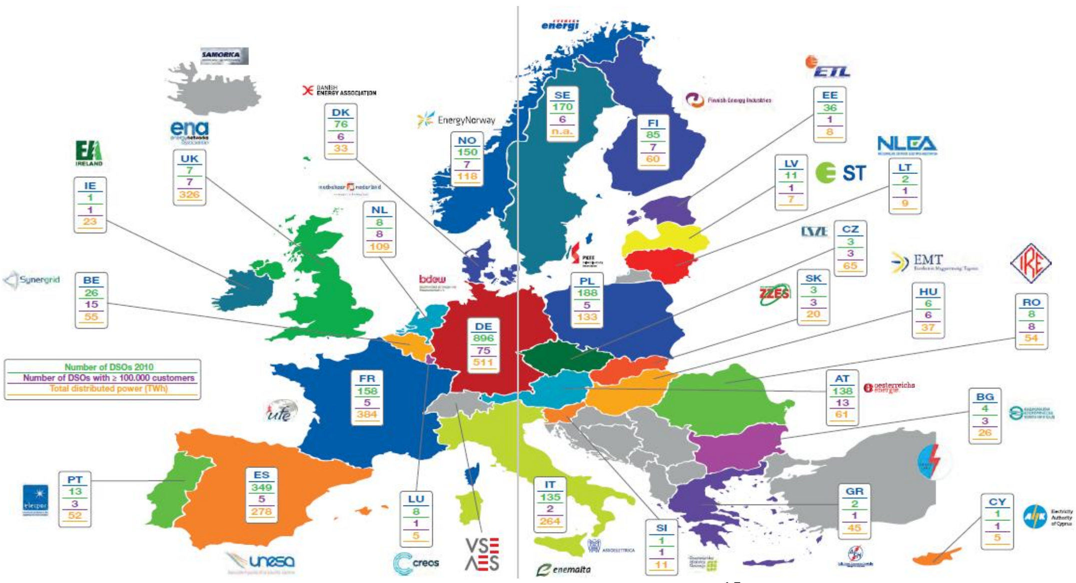


Figure 25. Distribution system operator´ situation in the EU[15].

The outermost distribution grids are typically operated as feeder lines, where a single line provides the electricity to a branching set of connected customers. The electricity consumption minus any

[15] Power Distribution in Europe Facts & Figures Eurelectric

power generation in the distribution feeder needs to closely match the power exchange with the higher voltage distribution/transmission grid. If this is not so, then the voltage in the feeder will start to deviate from accepted limits, which can cause equipment trip-offs and/or failures.

In the past, almost all power generation was connected to higher voltage levels, whereas today large numbers of wind power plants are connected to distribution feeders at 20 kV or less, and rooftop PV panels to low voltage grid at the consumers. Their generation changes the typical operation range of distribution lines and there is a need to adjust operations more than previously. This also involves a new group called "prosumers", i.e. over time being both producers and consumers. Consumers may also in the future increase the use of electrical energy for transport purposes via hybrid and electric vehicles.

Distribution connected small-scale biomass plants, if they can be controlled, could also play a role in the voltage management of distribution grids, but only if they can do this more economically than grid devices, grid upgrades or wind power and PV plants. A lot of generation in a distribution feeder can also cause congestion that will limit the amount of power that can be safely generated in the feeder.

4.4 EXAMPLES OF GRID BALANCING

Balancing represents a challenge of a different order in different parts of Europe depending on the characteristics of the generation portfolio, the availability of demand response and interconnections to neighbors. Moreover, gas and heat networks could also play a role in balancing the electrical grid. With the advent of electric vehicles the transport sector is also poised to become more integrated with the power system and, if implemented with price sensitivity, could bring considerable flexibility to balancing the power grid.

4.4.1 Nordic countries

The Nordic power system is characterized by a very high level of integration between the different countries through interconnections and a common wholesale market, and a high share of reservoir hydro power, mainly in Norway and Sweden. For the most part Nordic hydro power is highly controllable although there are some limitations due to minimum and maximum river flows and reservoir levels. Reservoirs are often large, which also gives flexibility in the seasonal time period and rivers have a series of reservoirs and power stations so that water released upstream can be stored in the next unit downstream, although this is limited by river flow constraints and variations in the inflow. There is potential to further increase flexibility by building pumped hydro plants in Norway at sites where upper and lower reservoirs already exist. The feasibility studies have been made but the financial decisions to build still await higher volatility in market prices.

Nuclear is the second largest form of electricity generation. Energy intensive industries are prevalent and consequently there is more room for baseload generation than in most other power systems. The share of wind power was 7 % in 2014 and it is increasing. Fossil generation was 12 %, but this changes from year to year depending mainly on the inflows to the hydro reservoirs. Biomass together with waste is a relatively large contributor at 8 % of electricity. A large portion of this comes from CHP plants as part of district heating plants and in the paper and pulp industry where by-products are used for heat and power generation. The individual countries have very marked differences in the share by energy source, with Denmark having predominantly wind and fossil power and Norway predominantly hydropower, for example (Figure 26 in comparison to Figure 27).

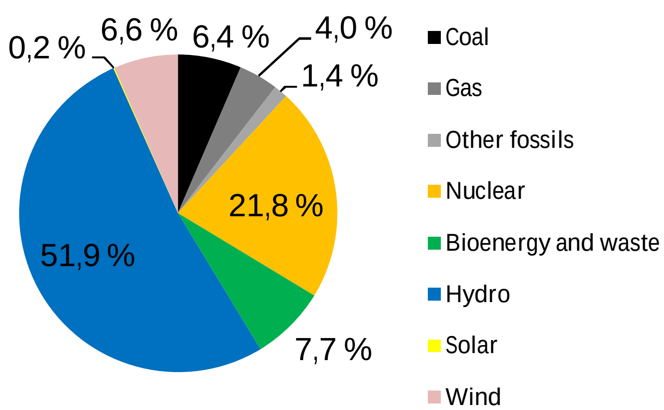


Figure 26. Share of energy sources from Nordic electricity generation in 2014. The total electricity is 400 TWh.

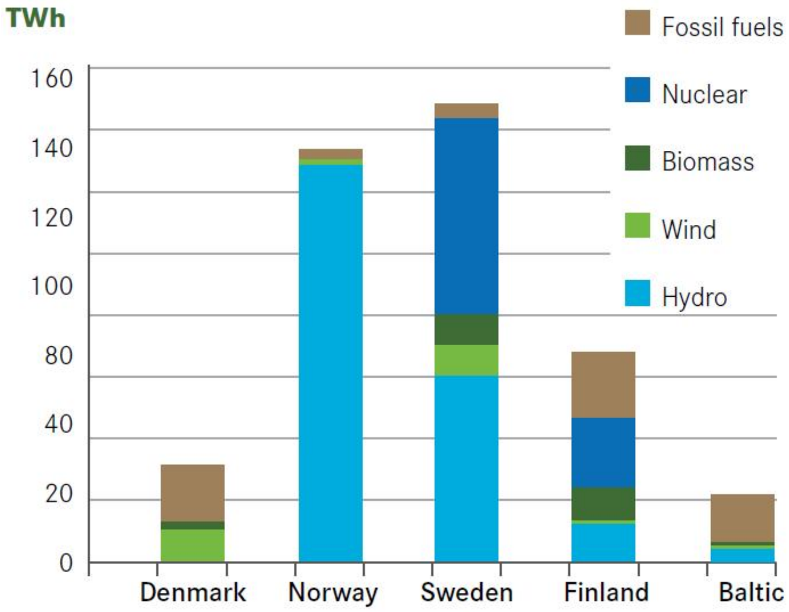


Figure 27. The electrical mix in the individual Nordic countries and the Baltics[16].

Over the coming decades the share of nuclear is likely to decrease, as nuclear phase out is planned in Sweden. In Finland new nuclear is planned, but it will not be enough to compensate for the reductions in Sweden. At the same time, the share of wind power and possibly solar power is likely to increase due to support mechanisms. Power prices are currently too low to support new, unsubsidized generation investments. Decreasing electricity consumption, low fuel and CO_2 prices, climate change related high water inflows and the increasing share of wind power have all contributed to the power price collapse, and this price situation will remain so unless the oversupply situation changes.

The Nordic region has around 11 GW of interconnections to neighboring countries (Germany, Netherlands, Russia, Poland, Estonia, and Lithuania). The high and increasing amounts of variable generation, especially in Germany, also means that the interconnections are likely to increase, rather than decrease, price fluctuations in the Nordic countries.

Electricity from bioenergy in the Nordic countries has mainly been generated in industrial or district heating CHP plants, driven by the generation of process steam and district heat when needed, while electricity has been a by-product. Currently bioenergy together with waste has a power generation capacity of around 7 GW in relation to the 65 GW peak load in the Nordic system.

Balancing in the Nordic electricity markets has mainly been provided by reservoir hydro power (from Norway and Sweden), to a lesser extent by fossil fuel power plants (mainly in Denmark) and by electricity import/exports between the countries and from the outside. In this hydro dominated system, the main task of condensing fossil generation has been to balance seasonal/inter-annual and short-term variations in electricity demand. It is conceivable that fossil generation will be phased out almost completely: the contribution is not significant in Sweden and Norway, and in Denmark a decision to phase out coal by 2020 has already been taken. Hydropower is therefore

[16] Adapted from Fortum Energy Review March 2015

expected to have an even more important role in the future.

Almost all heat networks have sufficient heat boiler capacity to allow shut-down of CHP plants (or to by-pass the turbines) when it is more cost-effective to use the heat boilers. Consequently, bioenergy is already an important source of flexibility and can also participate in short-term balancing when the market price is close to its operating cost. However, it is an open question as to how much CHP capacity future prices can support. On the other hand, heat networks can increase flexible capacity at a relatively low cost by installing electric boilers.

To a large extent fossil generation has been used to balance seasonal/inter-annual variations in rainfall and consequent hydro power generation, as well as changes in electricity demand. Wind power is also starting to contribute to the longer term fluctuations in available energy. When fossil generation is phased out, bioenergy could take a larger role in this seasonal/inter-annual balancing. While biomass can be stored, it loses energy over longer durations and requires considerable (dry) space. Consequently, if biomass is to be used for seasonal balancing, it probably needs to be converted to a more storable fuel. These fuels would be partially used in peak load power plants (turbines or engines) and consequently some of them should be gaseous[17] or liquids. If this happens, biomass will also have a larger role in providing enough generation capacity to meet future peak loads. Currently bioenergy together with waste has a power generation capacity of around 7 GW in relation to the 65 GW peak load in the Nordic system. Liquid fuels could also be easily transported to buildings without district heating and, if the boilers also include electric coils, they could contribute to power system flexibility.

4.4.2 Italy

Italy achieved an overall contribution of renewable energy to its gross energy consumption of 17% during 2014[18]: this includes heating and cooling (19%), electricity (33%) and transports (4%), and corresponds to 20,245 ktoe. Focusing on power generation, the contribution of renewable energy reached 121 TWh in 2014, which equates to 43% of total electricity generation.

[17] in practice, large qunatities of gasous energy carriers can currently only be stored in the gas grid

[18] GSE. Rapporto Statistico: Energia da Fonti Rinnovabili. Anno 2014. Gestore Sistema Energetico, December 2015. Available at www.gse.it

RES COAL NAT.GAS. OIL PRODUCTS OTHER

Figure 28. Renewable Power Generation in Italy[18]

The introduction of further variable renewable energy, and the need for actions aimed at balancing the grid, could in particular benefit from foreseen developments in smart grid and gas network infrastructural elements of Italian current and future scenario.

Simultaneously, with the diffusion of the smart meters, the Italian government has strongly encouraged the production of energy from renewable sources: this has led to large private investments, especially in the south of the country, in photovoltaic and wind plants. This has resulted in surplus energy being transported to the north of the country, where there is a greater concentration of industries and thus a greater demand for energy.

Smart metering and smart grids enable power companies to take control of the low voltage network and the new flow of information becomes a commodity as never before. It will not only transform the way to balance demand / response, but also lead to more active and collaborative relationships - especially with customers who are able to supply the network through local renewable sources or by using electric vehicles.

The natural gas grid (Figure 29) is another important action that will be carried out in Italy by the Snam Group through its 2016-2020 Strategic Plan. Snam will invest €4.3 billion in natural gas transportation and storage in Italy: the investment plan will focus on the development of an Italian infrastructure and its interconnection with the European infrastructure, thus enhancing the security, flexibility and liquidity of the overall gas system. The impact of this on balancing the energy system will be significant, and bioenergy will greatly benefit from this. In fact, the more that local, regional and National/EU infrastructure becomes available, the more biomethane installations will become technically and economically feasible. A share of biomethane will thus become available for renewable power generation aimed at balancing the grid in existing plants. In its 2016-2020 investment plan, Snam explicitly stated that "In a medium-to-long term perspective, the company closely follows emerging uses for natural gas, such as the transformation of biogas into bio-methane, power-to-gas facilities [...]".

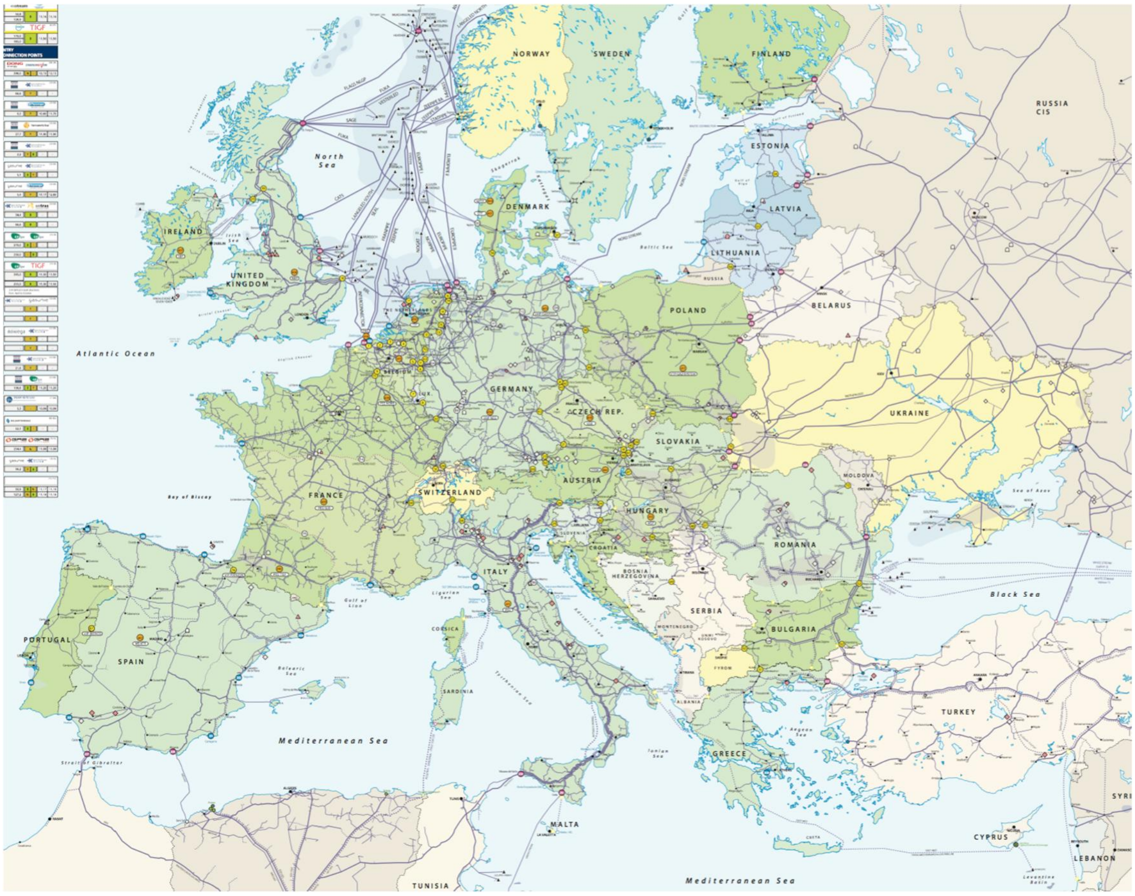


Figure 29. European Natural Gas Grid. Extract from the 2015 European Natural Gas Grid[19].

4.4.3 Conclusions on regional differences in balancing

Differences in challenges for future grid balancing are mainly due to availability of hydro power and integrated markets (strong electricity grid). Regarding bioenergy, using the heat and gas networks for flexibility will be another important flexibility that will be enabled by existing and planned heat and gas network infrastructure. The regions can roughly be divided into three categories:

- Areas with high interconnectivity, high use of biomass, a lot of hydro and CHP infrastructure, no gas grid
- Areas with medium power interconnectivity, existing gas grid, moderate biomass resources
- Areas with low interconnectivity, medium biomass resources and no gas grid

[19] European Network of Transmission Systems Operators for Gas (entsog). The 2015 European Natural Gas Grid – Capacities at Cross-Border Points on the Primary Market. Available at www.entsog.com

5 Opportunities for bioenergy in balancing the grid

5.1 EXISTING BIOENERGY ASSETS FOR GRID BALANCING

5.1.1 Biogas

Biogas is of interest for grid balancing as it is used in gas engines and gas turbines which have a quick response time, even from a cold start, as well as high ramping capabilities.

The global substrate potential for biogas production has been estimated at 10 000 TWh annually; in China alone it is estimated to be 3 500 TWh. The figures for the actual total biogas extraction is not known but considered to be 300–400 TWh[20]. In the EU 28[21], 57 TWh of electricity was produced in 17,240 biogas plants in 2014, with a total installed electrical capacity of 8.3 GW, i.e. an average capacity of approximately 0.5 MW per plant. The total biogas production in the EU 28 amounted to some 14 Mtoe in 2013. National Renewable Energy Action plans (NREAPs) indicate a production of 22 Mtoe in 2020, and the projection of industry is 50 Mtoe in 2030. However some 30-40% of this is expected to be used as bio-methane in the transportation sector[22].

The predominant prime mover technology is gas engines. In terms of response time gas engines are quick acting, being able to be cold-started and come to load within 10 minutes and endure ramp rates of up to 40%. Biogas contributes to embedded generation of power in the distribution grid.

Biogas is produced in a relatively slow process and consumed as it is produced, with a minimum of storage in low pressure gas holders. This limits the opportunities for balancing services. However, the expansion of upgrading facilities, where impurities and inerts such as CO_2 are removed from the products of anaerobic digestion, means that bio-methane can equally well be distributed by, and also be virtually “stored” in, the gas grid and retrieved for short-term use in larger gas turbines for balancing. With biogas, upgrading of the gas with surplus hydrogen when electricity demand is low is also a technical option for balancing the system.

5.1.2 Bioliquids

Liquid biofuels, such as biodiesel (FAME), vegetable oil (VO) and pyrolysis oil (PO), ethanol, methanol and FT diesel, etc. are of interest for grid balancing as they are storable and can be used as required, decoupled from their manufacture. Such fuels can in principle be used in both engines and gas turbines as well as in boilers for heating applications. However, such use is limited to FAME and VO in engines at present. Other options require additional development work to be deployed in prime movers.

The current situation is that the installed capacity for liquid biofuels is 1.9 GW_e yielding an annual production of 4.8 TWh power[3]. Of this capacity, 0.9 GW is in VO installations in Italy.

The technical opportunity for balancing is in this case higher than for biogas, as dedicated quantities can be stored. However, the economics of such low capacity factor installations using biofuels is not very favorable compared to using conventional fossil fuels. The application where

[20] IGU - BIOGAS-report 2015

[21] Eurostat

[22] The present status and future prospects of the European biogas/biomethane industry. Dr. Attila Kovacs, European Biogas Association. Madrid, 14th April, 2015

bioliquids could be feasible, and also make the overall power system more flexible is where they substitute the fuel oil that is used for firing up and down coal boilers or other existing assets. A typical power plant boiler could use between 1,000 and 20,000 m^3 of auxiliary fuel oil per year, depending on the operating conditions. Even if no power is delivered to the grid, green power is still generated and it also results in overall lower GHG emissions. Fuels that have been used for this purpose include tall oil pitch. Pyrolysis oil could also be considered for this application.

5.1.3 Solid biomass

Solid biomass is mostly used in stationary heat and power generation and especially in relation to combined heat and power generation in Scandinavia, but also for condensing power production. Solid biomass can be used as co-feed along with other fuels or also in boilers capable of firing up to 100% biomass.

Biomass use in dedicated biomass boilers

Solid biomass for power generation can be used in dedicated power plants, as a co-firing fuel in fossil (coal) plants or in CHP plants for production of district heating or industrial steam and heat. Generally, these plants are based on grate firing technology or fluidized bed technology. As a rule, fluidized bed boilers offer the best fuel flexibility. If properly designed, biomass fuels can be used with coal in any percentage from 0–100% in circulating fluidized bed (CFB) boilers. The variety of biomass fuel options is increasingly diverse, although the availability of some biomass fuels can be limited. Power plants with high fuel flexibility can adapt to the prevailing fuel market by optimizing the fuel mix accordingly. Overall, the installed electric capacity for solid biofuels in the EU in 2014 was 16.5 GWe, and the total production of electrical energy was 86 TWh[3]. The dominant technology by far is a combustion boiler plant generating steam for a steam turbine prime mover.

Solid biomass power plants and non-industrial CHP installations in the EU were mapped by the project Basisbioenergy[23]. Although this mapping seems to be far from complete, about 100 dedicated biomass power plants[24] have been identified, mainly located in continental Europe, the UK , Italy and Spain, and representing 5 GW thermal capacity (corresponding to about 1 GW electric capacity). More than two thirds are above 20 MW thermal (corresponding to some 4 MWe and upwards), and in this group the average capacity is 70 MW thermal (corresponding to 18-20 MWe). The list also contains 750 CHP plants, of which half are 1-20 MW thermal (corresponding to 0.1-1.5 MW_e) with an installed capacity of 3 GW thermal (corresponding to some 0.7 GW_e). The other half are above 20 MW thermal with an installed capacity of 35 GW thermal (corresponding to some 8-10 GW_e). The smaller units are found predominatly in continental Europe whereas for the larger capacity range, continental Europe and the Nordic and Baltic countries have a signficant numer of installations. The overall average capacity for CHP plants above 20 MW thermal is 97 MW thermal (corresponding to some 25-30 MW_e).

There are both dedicted biomass power plants and CHP plants with installed capacity of 300-800 MW thermal, and above 100 MW electrical. Examples include the 130 MW_e CHP boiler recently commissioned by Fortum in Stockholm, Sweden, the 265 MW_e industrial co-generation plant at Alholmen, Finland, operating since 2005, the 200 MWe Polaniec plant of Engie in Poland that was installed in 2013 and several plants in the range of 100-300 MW_e in planning in the UK. A large number of smaller biomass power plants, 10-100 MW_e are also built in the EU, USA[25] and

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[23] www.basisbioenergy.eu

[24] No WSW incineration included

[25] http://biomassmagazine.com/plants/listplants/biomass/US/

elsewhere.

In addition to the plants mentioned above, there are industrial CHP plants using biomass fuels, predominatly in the paper and pulp industries. In Sweden alone there are some 50 such plants and Finland has 23[26] CHP units in the forest industry. The main fuel in these plants is the internally generated black liquor used in recovery boilers. Out of more than 40 industrial CHP plants in Sweden, 11 were greater than 50 MW_e installed capacity while 8 were in the range of 25-50 MW_e with the rest being smaller ones. The combined installed power in Swedish industrial biomass-based CHP was 1.2 GW_e in 2015. While most of these industries consume more power than the internal CHP power generated, balancing opportunities still exist if the plant can substitute the CHP heat generated with other heat boilers depending on power prices.

Use of biomass in pulverized coal-fired boilers

Coal produced over 41% of the world's electricity[27] in 2014. There are over 1,400 coal-fired steam boiler and turbine power plants[28, 29] with a total capacity of 1 900 GW in 2016. Although coal power is static or decreasing in many parts of the world, in the Asia-Pacific region 275 GW of new capacity is foreseen within the next few years[33].

In Europe there are over 250 coal-fired power plant sites, ranging from small single-unit plants of <100 MW_e to sites with 2-6 or more units, with a combined capacity of 1,000–4,000 MW_e. The total installed capacity in the EU is of the order of 150-180 GW[30] producing[3] 870 TWh in 2013. Most of these plants have already a service life of 30 years or more. There are still new plants coming on-stream in certain parts of Europe while plants are decommissioned or converted elsewhere[31].

Coal fired plants have typically been operated in base load or upper mid-load regimes, i.e. with capacity factors above 60%. In Europe, the competition from renewable sources is strongly affecting the outlook for coal-fired power plants. Even if some plants can still operate in base-load, e.g. lignite plants and those in the Netherlands[32], typical capacity factors[33,34,35] for hard coal plants are only in the range of 30-60%, based on week-day operation and closing over the week end or two-shift operation and being shut down overnight. Furthermore, in practical terms this means that the number of start-ups is increased relative to base load operation, resulting in higher maintenance costs. It also means the use of an auxiliary fuel, which could be replaced by a liquid biofuel as discussed in the section on bioliquids above.

Co-firing[36, 37, 38]

[26] Metsäteollisuus ry.

[27] Emissions Reduction through Upgrade of Coal-Fired Power Plants. IEA 2014.

[28] http://globalenergyobservatory.org/

[29] Boom and Bust 2016. TRACKING THE GLOBAL COAL PLANT PIPELINE. COALSWARM / SIERRA CLUB / GREENPEACE REPORT | MARCH 2016

[30] Estimate based on ENTSO-E and some statistics and data from EU member states. Uncertainty is caused due to that listed installations may be operative, temporarily or long-term non-operative.

[31] Outlook for new coal-fired power stations in Germany, the Netherlands and Spain. Pöyry for UK DECC, 2013

[32] Renewable Energy in The Netherlands December 2015. M Visser. Hanze University of Applied Sciences Groningen

[33] Stromerzeugung aus Solar- und Windenergie im Jahr 2014. Bruno Burger Fraunhofer-Institut für Solare Energiesysteme ISE Freiburg, den 07.01.2015

[34] Digest of United Kingdom Energy Statistics (DUKES). Electricity: Chapter 5, 2015

[35] Energinet.dk

[36] The status of large scale biomass firing. IEA Bioenergy Task 42, 2016

[37] http://www.eubia.org/index.php/about-biomass/co-combustion-with-biomass/european-experiences-in-co-combustion

Various technologies have been developed to enable co-firing biomass with coal in pulverized coal (PC) boilers. The large capacity of existing PC boilers offers great potential for increasing biomass utilization as well as economic benefits compared to new stand-alone biomass power plants, which are also usually significantly smaller than PC plants. Utilizing biomass in an existing thermal power plant can be accomplished through direct or indirect co-firing.

Direct co-firing is the most straightforward, most commonly applied, and lowest-cost concept for partially replacing coal or other solid fossil fuels with biomass. The use of biomass in PF boilers designed for coal ranges from a few percent through an increasing share of the biomass by co-combustion (*aka* co-firing), to complete conversion of the boiler to 100% biomass firing. The burner system and the boiler's ability to cope with increased fouling and corrosion from biomass ash components typically limits the co-firing rate to below 10%. For thermally treated densified biomass fuels such as torrefied or steam exploded pellets, co-firing rates can reach 30% of fuel energy input (www.sector-project.eu). For very high co-firing rates, and also for complete conversion, operational and logistical factors favour the use of wood pellets as these are relatively clean, available in consistent quantities and in the quantities, i.e. millions of tons per year, required. The current pellet demand is 14 million tonnes worldwide[39], but both capacity and demand is growing. Indirect co-firing consists of converting the solid biomass to a gas or liquid prior to combustion in the same furnace with the other fuel. This allows for greater amounts of biomass to be used, up to 50%. However, this approach requires greater investment and a larger footprint at the plant site.

In terms of potential, a 10% co-firing rate would be equivalent to around 15 GW capacity and some 90 TWh of power produced.

Biomass retrofiting

In addition to these co-firing options, there is also the option of full conversion which is rapidly gaining ground. This is the case for two out of six units at Drax in the UK, each having a capacity of 660 MW_e, and with a third one in planning. The fuel used is pellets from the USA, where Drax has invested in an integrated supply chain. In Lynmouth in the UK, 3*140 MW are also being converted. Similar developments are in progress in Denmark, where coal is to be phased out by 2020 and both Avedöre 1 and 2 at 200 and 500 MW_e have already been converted. In Gardanne France, EON is revamping what was once the largest coal-fired CFB power plant, at 250 MW_e, to operate on wood chips at 170 MW_e[40]. Additionally, since 2008 at least eight PC boilers have been converted into bubbling fluidized bed (BFB) boilers in Poland to enable pure biomass combustion, , with capacities in the 100–200-MW_{th} range. In Canada, the 200 MW_e Atikokan Generation Station has also been converted[41]. Conversion projects have far lower investment costs compared to new, dedicated biomass power plants and can also achieve the higher efficiency associated with the large scale of the original coal plant. Nevertheless, a higher fuel cost means that in terms of operational economics a high capacity factor is important, i.e. participation in grid balancing services rather than energy sales may not be so attractive.

The impact of further conversion of PF plants is difficult to judge at the moment as it depends on

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[38] Cofiring of biomass in coal-fired power plants – European experience. C Henderson, IEA Clean Coal Centre FCO/IEA CCC workshops on policy and investment frameworks to introduce CCT in Hebei and Shandong Provinces, China, 8-9 and 13-14 January 2015

[39] PÖYRY'S GLOBAL PELLET MARKET REPORT 2015

[40] PROJECT PROFILE: CFB, France Gardanne Coal to biomass conversion. Doosan Lentjes GmbH

[41] http://www.opg.com/generating-power/thermal/stations/atikokan-station/Pages/atikokan-station-biomass-conversion-project.aspx

the power pool prices, pellets and biomass price, sustainability considerations and on the support system and public acceptance.

Operational characteristics of steam boilers operating on coal and biomass[42, 43, 44, 45, 46, 47]

It takes many hours to start a coal-fired or biomass-fired power or CHP plant from cold, mainly due to the firing system and furnace heat-up. However, if heat is retained in the system after a shut-down, e.g. overnight, a hot start takes 2-3 hours. In this case, the heating of the high pressure parts of the boiler and the steam turbine is limiting. During this phase, the boiler is consuming auxiliary and main fuels without generation, while the heat-up and cool-down are associated with cost for increased maintenance and loss of service life. Based on data[48] originally derived from US conditions or large coal-fired boilers, each cold start is associated with an approximate cost of 70 €/MW_e and each hot start with an approximate cost of 30-40 €/MW_e, i.e. a hot start-up in a 500 MW_e plant could cost of the order of €15,000-20,000 .

The net electrical efficiency at full load of such units, operating on hard coal, ranges from just over 30% to 40% for small and old units with sub-critical steam conditions. Super-critical and ultra-supercritical steam cycles can reach 44% and 48% respectively[49], and are used exclusively in the most modern larger scale plants. If lignite is used, the efficiency is a 3-4 % lower than for hard coal at comparable conditions.

For biomass plants, the efficiency to power can be below 20% for industrial CHP with steam extraction, but in most cases falls between 20 and 40% or higher. The lower number reflects smaller scale plants and CHP, but even for large biomass plants the efficiency to power rarely exceeds 35 % as heat extraction and less complex steam cycles are used. The highest efficiency numbers represent co-firing and conversions, due to the high efficiency of the large steam cycle in such plants. However, CHP plants can have total efficiencies, including the heat produced, of close to 90%, or when using flue gas condensation reaching even above 100% in fuel LHV terms. This translates to a power/heat ratio of 0.3 to 0.6, i.e. a heat load of 1 MW can be used as a basis for generating 0.3 to 0.6 MW electrical in a CHP system.

In the past, a low minimum load was not a design requirement, and it is in practice limited to 30-40%. New plants allow minimum loads of 20-25%, and with special measure 10 % can be achieved. However, at such low loads the efficiency drops quite considerably, some 10-20% relative to the nominal efficiency. For the smaller biomass plants this drop is even more pronounced, as is the effect on the power/heat ratio of CHP plants. This translates to an increased cost of generation and for e.g. district heating CHP plants, it becomes more economic to supply heat by other means.

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[42] Thermal Power Generation in 2030: Added Value for EU Energy Policy. M. Farley EPPSA. All Energy 2015, Glasgow UK.

[43] Baseline Efficiency Analysis of Fossil Fuel Power Plants. Economic Commission for Europe. Committee on Sustainable Energy. CEP-11/2015/INF.4 Version 1, 9 October 2015

[44] Erneuerbare Energie braucht flexible Kraftwerke – Szenarien bis 2020. VDE

[45] Technical Assessment of the Operation of Coal & Gas Fired Plants. Parsons Brinckerhoff
DECC. 286861A. Dec. 2014

[46] Fossil befeuerte Großkraftwerke in Deutschland, Stand, Tendenzen, Schlussfolgerungen. VDI Dezember 2013

[47] Increasing the flexibility of coal-fired power plants. Colin Henderson. IEA Clean Coal Centre September 2014

[48] INTERMITTENT RENEWABLES, THERMAL POWER AND HYDROPOWER - COMPLEMENTS OR COMPETITORS? Lisa Göransson Liv Lundberg. In SYSTEMSPERSPECTIVES ONRENEWABLE POWER2014. Ed. Björn Sandén. Chalmers University of Technology, 2014

[49] Baseline Efficiency Analysis of Fossil Fuel Power Plants. Economic Commission for Europe. Committee on Sustainable Energy. CEP-11/2015/INF.4 Version 1, 9 October 2015

The rate of load output change is of the order of 2-4% per minute in older plants and as high as 6% per minute in new boilers designed for variable operation. So, to come from 40% load to 90% load (or vice-versa) would take 8-25 minutes. In addition to this, short term fluctuations of 2-5% or even 10%, within 10-30 sec can typically be accommodated using accumulation effects in the steam system.

5.1.4 The potential of biomass in district heating and industrial CHP systems

In the EU, the use of district heating is widespread with over 6,000 district heating systems[50], both small and large, in operation. There is a concentration in the Nordic EU members, the Baltics and East Europe, with some in the UK and few in the Mediterranean countries. The Nordic countries, the Baltic states and some of the Eastern European countries have in the range of almost 40% to over 60% of their populations served by district heating[51], compared to an average of only 5-20% for the rest of the EU. Among the EU countries, both Germany and Poland have consumption of around 70 TWh, while for Sweden and a group of other EU countries it is between 20 and 50 TWh. For the EU28 the total figure for district heating sold is 400-450 TWh[51, 52], of which 100 TWh was from coal[52] with natural gas also being used. The amount of renewable district heating in 2012 was estimated at 113 TWh, this predominantly involving bioenergy, with a contribution of 76 TWh[53] in 2012, particularly in Sweden, Finland, Denmark and Austria. The NREAPs (National Renewable Energy Action Plan) of the EU member states indicate a growth in the use of renewable district heating[52] from 113 TWh in 2012 to 206 TWh in 2020. Heat pumps, solar and geothermal heating are expected to make large inroads in the future and reduce the basis for CHP generation. However, the numbers shown above still indicate a considerable potential for increasing renewable power from district heating system by 10-20 TWh_e or more, and for substituting fossil fuels in existing units, or replacing them with new units, thereby potentially generating 20-30 additional TWh_e. This could correspond to 2-5 GW and 5-7 GW installed capacity, respectively, in the future.

In relation to the electricity grid, a district heating system typically is not served by a CHP plant alone. Generally, it also contains other production units that are used for base-load, peaking or redundancy purposes, to take advantages of available waste heat or opportunities where power prices are low. Therefore, the overall operation is controlled by an optimization model to ensure that the heat demand is met by the lowest cost production units in terms of marginal pricing, as exemplified by Figure 30. Waste incineration and industrial waste heat (if either is available) are typically used as base load. Therefore, the operational room for CHP plants is typically reduced to mid-merit, i.e. they do not operate outside of the firing season from September-October to April-May. To complement such units, there are in addition heat-only boilers fired with fuels such as forest residues, wood pellets, bio-liquids and fossil oil, as well as heat pumps. These are used for peaking in the winter period and for balancing the demand during the summer periods when CHP plants are not operating.

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50 HEAT ROADMAP EUROPE 2050. Euroheat & Power 2012 and 2013.

51 Statistics overview 2013. Euroheat Power

52 Renewable Based District Heating in Europe - Policy Assessment of Selected Member States. IEE project towards 2030-dialogue. August 2015.

53 Europe: the contribution of bioenergy. Heinz Kopetz, World Bioenergy Association,Vienna, 2 March 2016

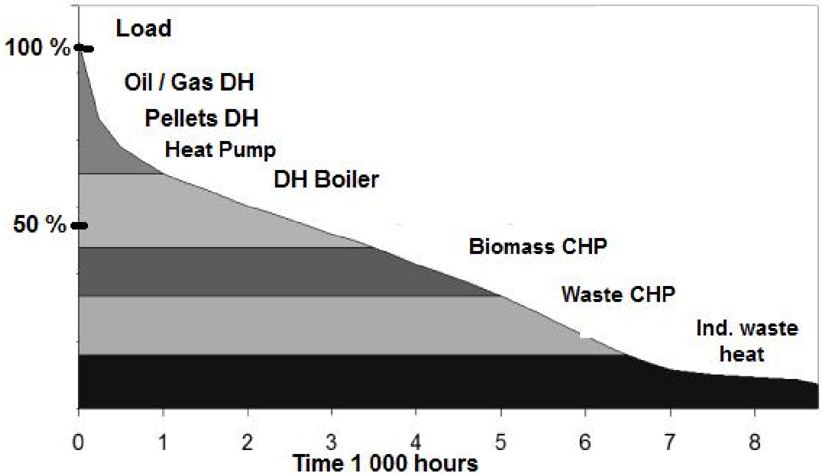

Figure 30. Example of district heating system load curve

This becomes a flexible system that can be used to decouple the CHP boiler from the heat load demand and allow the production of more or less power than that dictated by the heat load alone. To increase the power output above what is dictated by the heat load, cooling the return water by sea, lake or river water is used, whereby the operation partially approaches condensing operation and economics. Another way of temporarily increasing the heat load is to use an accumulator[54, 55], steel tanks up to 50,000 m^3 (30-35 m diameter, 60-70 m high and with a heat storage capacity of up to 2,000 MWh), allowing the CHP plant to operate above the minimum load at night, thereby avoiding shut-downs. This also avoids use of heat-only boilers, which often use more expensive fuels, at night and at the peak day periods. The rate of filling or discharge is between 4 and 24 hours. The Avedoere plant in Copenhagen can charge or discharge 330 MW from its 44,000 m^3 storage, i.e. for this large plant the impact on power generation would be of the order of +/-200 MW.

In many district heating systems there are also electrical boilers and large heat pumps. Electrical boilers can be of a significant size, several tens of MWs, and heat pumps can also be of an electrical capacity of up to 10 MW, with several heat pumps being operated in parallel. The largest heat pump installation in terms of gross heat produced is in Helsinki, five 6.5 MW heat pumps, and Stockholm also has several heat pumps. These add significant flexibility when used to reduce the output of a CHP plant. In a power surge situation, this impact can be significant as there is a leverage effect with a factor of 1.3 to 1.8, whereas most other demand side measures typically only give a 1:1 response when switching from thermal generation to electrical supply. For example, a 10 MW electric boiler will take this same amount from the grid, while a CHP plant can have a reduction in the heat load by a corresponding amount with the avoidance of an additional 3-6 MW electricity. For a heat pump which typically has a COP of 3, 10 MW power consumed results in 30 MW heat, while a CHP system can go down in load by 30 MW heat to reduce the power output by 9-18 MW.

5.1.5 Stockholm CHP system as an example

The Stockholm CHP system is a good example of a highly flexible CHP system showing what smart

54 Säsongvärmelager i kraftvärmesystem. Rapport I 2008:1. H Zink et al. Svensk Fjärrvärme

55 Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion. D Andrews et al. JRC Report EUR 25289 EN, 2012.

integration of different technologies in a low carbon energy system can achieve. There are two aspects to the system characteristics: first is the role of the system in a larger energy system (Figure 31) and secondly how the consumer experiences it (Figure 32). Whereas the consumer enjoys a stable electricity and heat/cooling supply to satisfy their quality of living, the system operator still has a handful of different technologies to balance these demands, even outside a larger system and market, in the most optimum way without the customer being disturbed by the fluctuations. The key is the smart use of different technologies added to the buffer capacity of the district heating network. This results in +700MW to 400MW balancing capacity on an hourly basis that can be utilized. The technologies are optimized to cover different time intervals for feeding the system thermal buffer, the system itself being topped up with additional thermal storage. The buffering capacity of the system determines the selection of conversion technologies for hour-by-hour optimization based on, for example, heat pumps to heat only boilers and CHP plants based on low carbon fuels, such as waste and biomass.

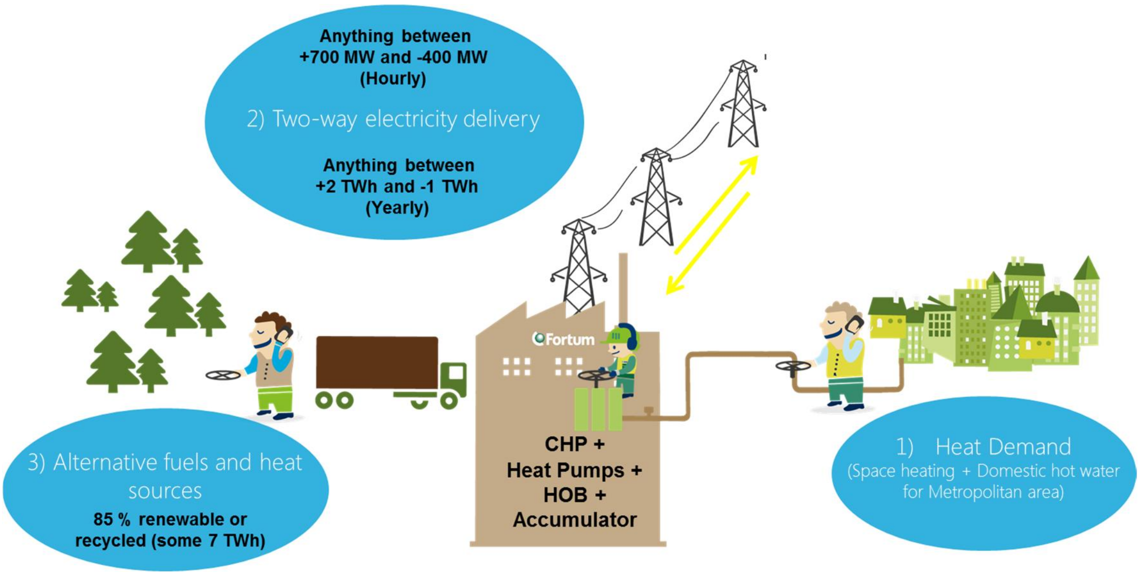

Figure 31. Characteristics and technologies utilized in Stockholm CHP system

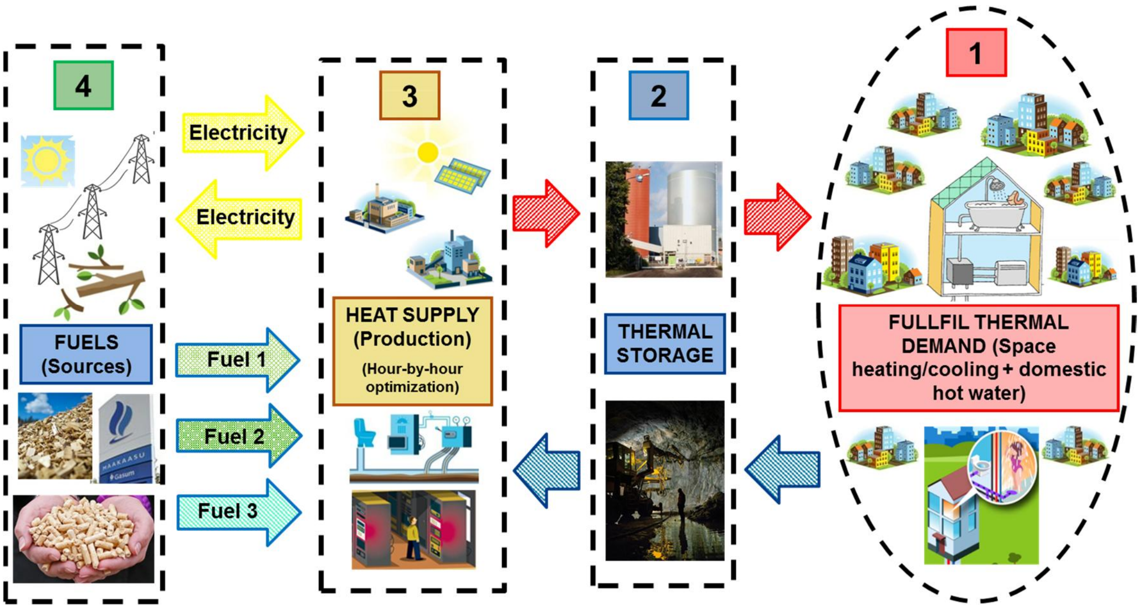

Figure 32. Customer need being satisfied by the smart energy system operator

5.2 FUTURE ASSETS FOR GRID BALANCING

5.2.1 Biofuels and electricity

There is a potential synergistic relationship between many biofuels and the occurrence of low cost electricity. The electricity can be converted into hydrogen which is an immensely important chemical in both fossil refining, chemical production and also for biofuels. If there is an availability of cheap electricity, this can be used for electrolysis of water to generate hydrogen and oxygen by splitting water.

The cost of the hydrogen produced is strongly influenced by the cost of electricity, but in comparison with most common hydrogen routes, such as steam reforming of natural gas (SMR - steam methane reforming), it can already today achieve lower hydrogen cost at smaller capacities. If electricity prices go down while the current low natural gas price goes up, the capacity boundary will shift towards higher capacities. In the future, the expectations are that for more and more of the year, the cost of electricity will go down as a result of the addition of more wind and solar power production.

Electrolysis has an efficiency of 60-74% for state of the art (alkaline, PEM) technologies and the efficiency is higher for technologies in development (e.g. SOEC); a cost of 0.6-2.6 M€/MW electric input[56, 57], i.e. 0.8-3.9 M€/MW product output. A report[58] reviewing the subject gives the current range as 1-1.2 M€/MW electric input and 50-77% efficiency. Since the electrolyzers have limited capacity per unit, a larger plant has more and more parallel cell stacks and the economy of scale is therefore not so pronounced. In this report other O&M costs were given as 1.5 to 4%, depending on the capacity. In addition, the cell stacks, representing 25-35% of the original investment typically have a lifetime of 5-10 years, i.e. they are replaced 2-4 times over a 20-year plant lifetime.

The hydrogen can be used to replace fossil hydrogen in, or add hydrogen to a variety of biofuel processes. One use is for hydrogenation processes, such as HVO and processes in development for upgrading pyrolysis oil, HTL oil and lignin depolymerizates. Hydrogen can also be used to enhance biogas processes by conversion of the CO_2 contained in the biogas to additional methane. In biomass gasification processes, added hydrogen means that the yield can be increased as hydrogen can, firstly, give the right stochoimetric ratio and avoid loss of CO for water gas shift, and secondly reduce CO_2 to CO that can then be converted to additional products.

5.2.2 Hydrogenation of HVO, PO and HTL liquids

To upgrade the triglyceride fed to HVO in plants of 100,000–1,000,000 tonnes per year capacity, the hydrogen consumption is in the range of 3-4% by weight of the feed depending on the process and feedstock[59, 60, 61], and approximately 80-85% of the feed comes out as liquid fuels. For a

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[56] POWER: THE CASE OF ELECTROFUELS FOR TRANSPORT Maria Grahn Maria Taljegård Jimmy Ehnberg Sten Karlsson. In SYSTEMSPERSPECTIVES ONRENEWABLE POWER 2014. Ed. Björn Sandén. Chalmers University of Technology, 2014.

[57] Technology Roadmap Hydrogen and Fuel Cells. IEA 2015

[58] Development of Water Electrolysis in the European Union. Final Report. Fuel cells and hydrogen Joint undertaking. E4tech, Sàrl with Element Energy Ltd, February 2014

[59] LIFE CYCLE ASSESSMENT OF BTL AS COMPARED TO HVO PATHS IN ALTERNATIVE AVIATION FUEL PRODUCTION M. Gehrer, H. Seyfried, S. Staudacher. Institute of Aircraft Propulsion Systems. Deutscher Luft- und Raumfahrtkongress 2014 DocumentID: 340090

100 000 tonne/year plant like the UPM plant in Lappeenranta, Finland, and assuming a yield of 80% and a hydrogen consumption of 3.5% by feed weight, the hydrogen requirement is then of the order of 0.55 tonne/hr, i.e. assuming a 50 MWh/tonne electrical usage, the electrical consumption could be 27 MW to supply all the hydrogen.

Fast pyrolysis is a way of converting solid biomass to a liquid fuel, or "bio-oil", that can substitute for other fuels in combustion applications. However, if a more valuable product is desired, the bio-oil requires upgrading to allow its use as a drop-in hydrocarbon fuel. One way of upgrading pyrolysis oil is by hydrogenation of the oxygen to steam, whereby the carbon yield is higher compared to the alternative FCC (Fluidized Catalytic Cracker) route where oxygen and excess carbon are rejected as CO_2 and soot, respectively. Pyrolysis oil[62] typically contains 5-30% water, while the dry oil can, depending on the process and oil recovery, hold 28-40% oxygen. Methods such as catalytic pyrolysis and staged condensation recovery can reduce both the water content and the oxygen content. For example, in the case of the Fortum plant in Joensuu, that is producing 50 000 tonnes of bio-oil per year, approximately 0.2 tonne/hr hydrogen or some 3 % by weight would be required to hydrogenate this bio-oil, i.e. a 10 MW electrolysers.

For other forms of thermal treatment of biomass such as HTL and of biomass by-products such as lignin, a considerable amount of hydrogen is also required. HTL crude bio-oils typically contain 5-12% oxygen that would require 0.5-1.5% hydrogen per kg of feed. Raw lignin contains approximately 30% oxygen and unless treated by some intermediate de-polymerization/deoxygenation process, would require up to 4% hydrogen.

5.2.3 Upgrading of biogas

External hydrogen could be used to hydrogenate the CO_2 fraction in biogas, with a typical input of 40 %, producing additional methane and saving on the upgrading cost. This is being studied by the CO_2 Electrofuels project funded by Nordic Energy Research[63], which claims that the methane output can be increased by 65 %, using SOE technology. In 2013 the average biogas plant in Europe produced 11 GWh and from the associated CO_2 an additional 7 GWh of methane could be recovered, which would require 20GWh electricity, i.e. a 2-2.5 MW electrolyser for such an average biogas installation.

5.2.4 Gasification-based biofuels

Gasification-based biofuels such as methanol/DME, bio-methane and FT diesel are all produced by conversion of the biomass to a synthesis gas, i.e. a mixture of CO and H_2. In the raw syngas, there are also considerable amounts of CO_2 formed in the gasification process that is later removed in the syngas upgrading process, resulting in CO_2 levels of a few % by volume in the final gas.

Depending on the fuel produced, the stoichiometric ratio of H_2/CO should be 2, with the exception of methane where it should be 3. However, typical biomass gasifiers produce a gas that has a ratio of 1:1 to 1.5:1, such that the water gas shift reaction $CO+H_2O \rightarrow CO_2+H_2$ is required to convert some CO to hydrogen. This adds to the CO_2 already present in the gas, and typically the

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[60] GREENHOUSE GAS AND ENERGY INTENSITY OF PRODUCT CHAIN: CASE TRANSPORT BIOFUEL. Sami Nikander. Matser Thesis. Helsinki University of Technology. May 9,2008

[61] An Assessment of Energy and Greenhouse Gases of NExBTL. IFEU, Heidelberg, Germany for Neste Oil, June 2006

[62] Catalytic Fast Pyrolysis: A Review. Theodore Dickerson and Juan Soria. Energies 2013, 6, 514-538

[63] http://www.nordicenergy.org/project/synthetic-fuels-for-heavy-transportation/

CO_2 is removed. The combined loss of CO_2 from the gasification and the shift processes means that around half of the biogenic carbon is lost as CO_2, i.e. the carbon yield to biofuel is decreased.

If there is hydrogen available, this could have a considerable impact on the biofuel output. As an initial step, the hydrogen could be used to partially or fully avoid the use of water gas shift whereby some 30-50 % more CO could be converted to biofuels. For an indirect system this could mean 2-3 kg hydrogen/MW biomass feed, e.g. for the GoBiGas[64] plant of 30 MW making bio-methane, up to 60 kg/hr of hydrogen or an electrolyser of 3 MW. For an oxygen blown gasifier the hydrogen potentially used is doubled, i.e. a 200 MW unit could consume 1 tonne/hr of hydrogen or 50 MW input to the electrolyzer.

As a second step, the CO_2 in the gas can also be partially or fully hydrogenated to CO such that all biogenic carbon ends up in the product. For example, for an oxygen-blown gasifier of 100 MW, an electrolyser of 170 MW could be used, and for an indirect gasifier of 100 MW biomass feed, a 95 MW electrolyser could be used[65]. As a side effect the oxygen produced in the electrolyser could be routed to the gasifier and substitute for oxygen from an air separation unit.

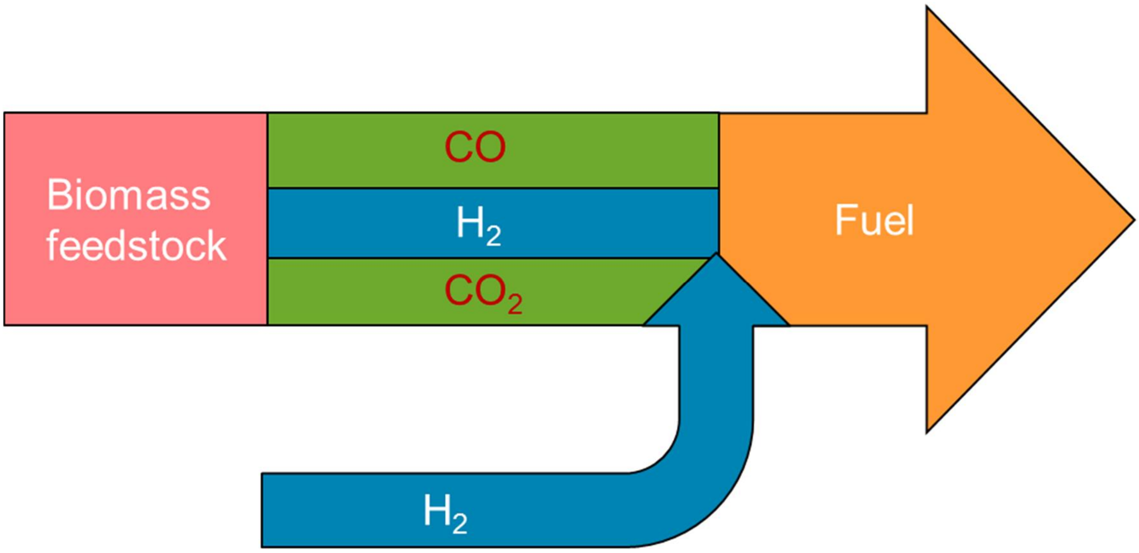

Figure 33. The principle of external hydrogen enhancement[65]

The overall gain of such systems is that more biogenic carbon is retained in the fuel product, with more substitution of a fossil fuel equivalent. The marginal efficiency from electricity to biofuels for the complete conversion was found to be around 50%, while for shift conversion only it is higher, at around 65%, as less hydrogen is consumed per carbon atom in CO compared to CO_2. In this concept, the economic impact of the average electricity break-even price was as low as 27-35 €/MWh for different configurations. The impact of the potential for generation of low-carbon fuels is also very high, as the biomass and waste resources in the EU could theoretically be used as a basis for production of half the transport fuels in the EU, compared to a less significant 10-20% without this exploitation of synergies.

[64] https://www.goteborgenergi.se/English/Projects/GoBiGas__Gothenburg_Biomass_Gasification_Project

[65] Hydrogen enhancement potential of synthetic biofuels manufacture in the European context: A techno-economic assessment Ilkka Hannula, Energy 104 (2016) 199e212

5.2.5 BIO-CCS and BIO-CCU enabling negative GHG emissions

Biomass based carbon capture, storage and re-use (Bio-CCUS) enables negative emissions. Bioenergy RES-hybrids provides a pathway to negative CO2 emissions and to integrating larger shares of variable and intermittent renewable energy at all scales of applications, from residential scale to large systems. CCU (Carbon capture and utilization) is referred to as a family of technology concepts utilizing captured CO2 as a feedstock for other processes, to produce materials, transportation fuels or to be utilized as a process medium e.g. carbon chemistry products, liquid biofuels, other products or enhanced oil or gas recovery. These technologies can potentially provide a cost effective pathway for deployment of CCS technologies, and contribute to climate mitigation, resource efficiency and cascading use of raw material provided that additional renewable electricity is available. Bio-CCUS and energy systems based on different renewable energy sources alsoknown as "RES-hybrids" are an essential part of the large scale deployment of both the bioeconomy and circular economy with a special contribution to cascading use of woody biomass especially in the chemical industry.

5.3 COSTS OF DIFFERENT TECHNOLOGIES

Levelised costs (LCOE, levelised cost of electricity) for different renewable and fossil energy generation technologies are shown in Figure 34. A decreasing cost trend has been strongest with solar PV, and the trend has further continued after 2013. As it can be seen, renewable energy technologies are becoming cost competitive in comparison to conventional fossil technologies.

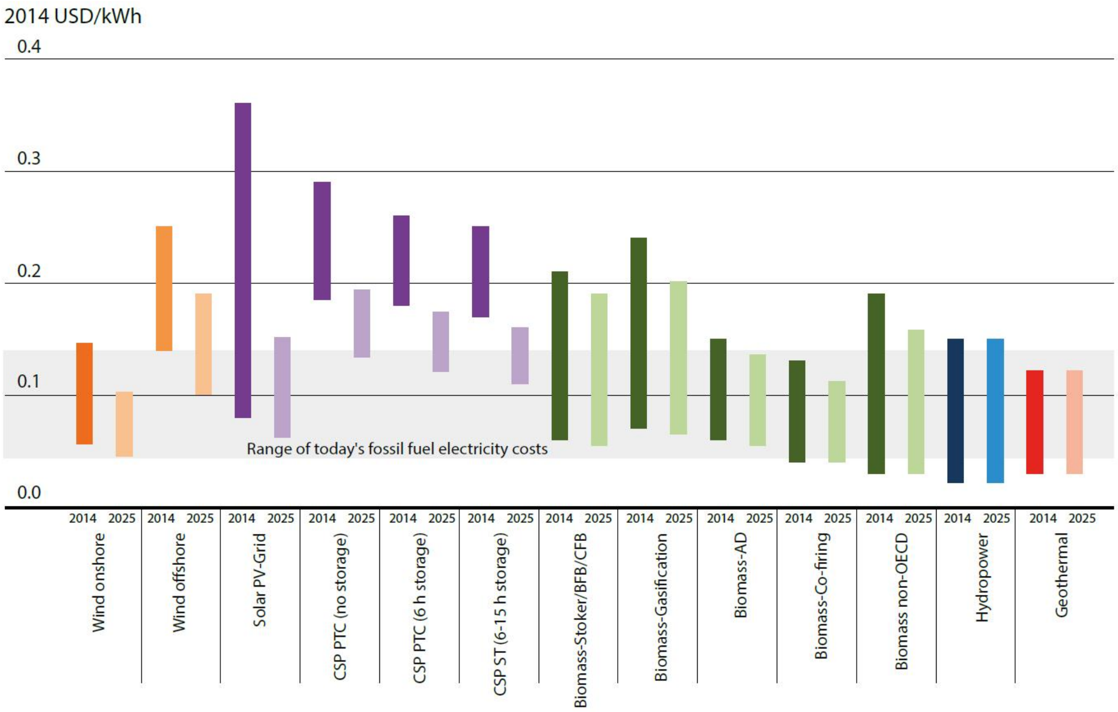

Figure 34. Levelised cost of electricity (LCOE, US$/kWh) ranges by renewable power generation technology, 2014 and 2025[66]

[66] IRENA, 2015, Renewable Power Generation Costs in 2014, http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

In addition to becoming comparable in terms of LCOE, the most significant difference is the different balance between CAPEX (capital expenditure) and OPEX (operating expenses) in the production cost structure. Even with the same LCOE, solar and wind are higher in merit order, as the operational expenses are significantly lower compared to thermal power generation, so that they are dispatched first. Power plants with higher marginal costs will be dispatched less often. This saves the operational costs of those power plants, but does not reduce their fixed costs. Consequently, there will be less need for power plants with a combination of low operational costs and high fixed costs. The power system will see the need to cover their fixed costs with less operating hours. However, there are significant differences in costs between regions due to different wind conditions and solar irradiation levels. The electricity demand can also be satisfied with electricity from various energy and electricity storage installations that have stored energy during low demand periods. The balancing capacity in electricity generation is competing with the cost levels of these energy storage technologies. Costs of energy storage technologies are presented in Figure 35 and Figure 36.

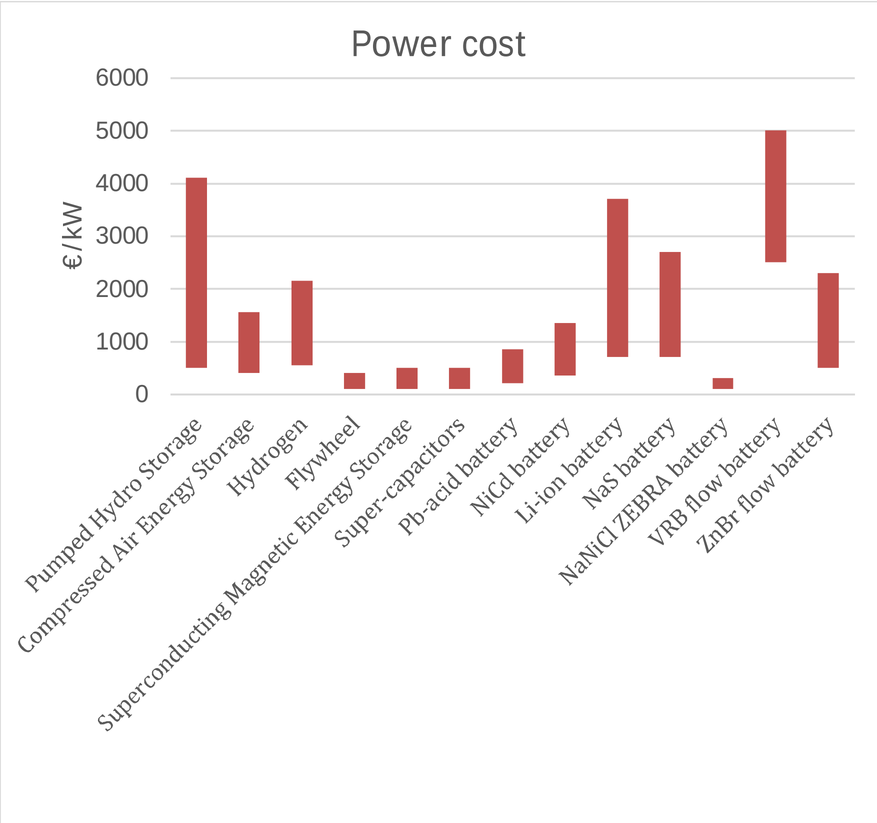

Figure 35. Power cost of power storage technologies[67]

[67] DG ENER Working Paper The future role and challenges of Energy Storage

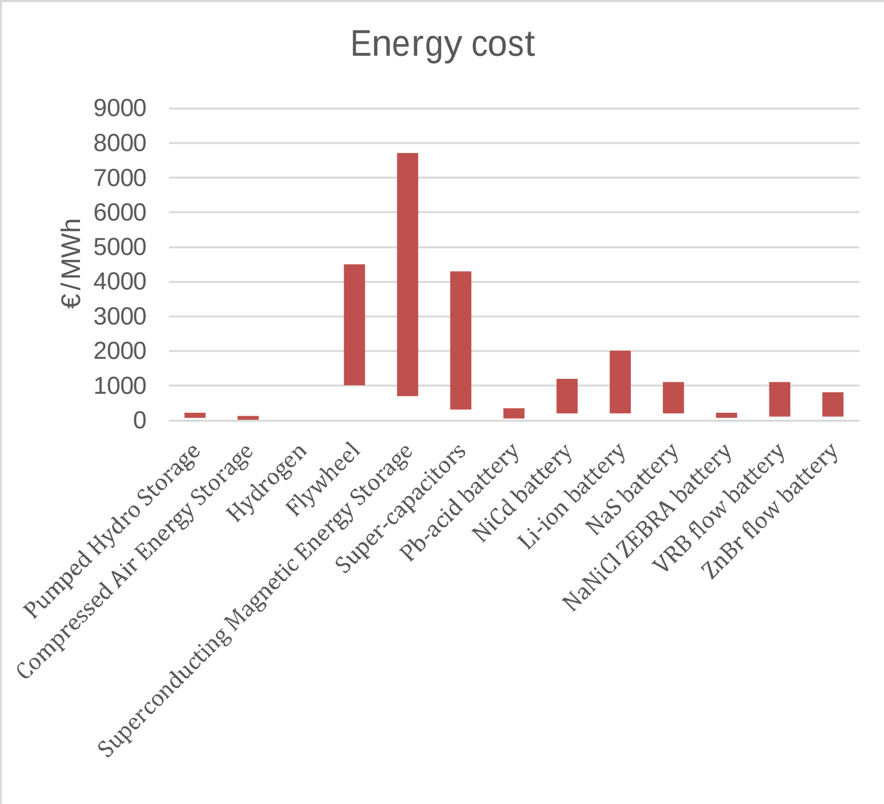

Figure 36. Energy cost of power storage technologies[67]

5.4 TECHNICAL CONCLUSIONS

5.5 THE POTENTIAL ROLE OF BIOENERGY POWER PLANTS IN BALANCING

Bioenergy power plants can contribute to balancing by participating in day-ahead, intra-day and balancing markets as well as by offering frequency control reserves. The use of bioenergy for balancing and frequency control is currently limited, since many bioenergy plants often do not have the required control capability. However, something needs to replace the controllability offered by fossil fuel power plants when they are pushed out of the European power systems. Here bioenergy could have an important role. Modern ICT offers controllability at reasonable cost for smaller plants also, as long as fuel processing and feed at the plant can operate as flexibly as needed. In any case, synchronously connected bioenergy plants add to the power system inertia, which is an important contribution in the future generation mix, presumably dominated by non-synchronous inverter-based generators.

In addition to short- to mid-term grid balancing, the role of seasonality is also important. Photovoltaics power production goes down dramatically in winter time, especially in northern countries, while electricity consumption grows (e.g. for heat pumps). The backup needed in winter time also coincides with increased heat demand, which is a perfect fit with CHP. This shows a clear synergy in seasonal balancing between PV and biomass.

The total installed capacity of biomass power generation plants in the EU is about 25 GW. If co-firing is assumed to be utilized to its full potential of 15 GW, the total biomass based capacity could be around 40 GW. The fossil generation mix to be retired is much larger than this figure and it would look like biomass based power generation will have a limited role with the balancing capabilities of the existing portfolio. However, if bioenergy resources can be converted to be competitive in peak load type power plants (that use gaseous or liquid fuels), the contribution of bioenergy could become considerably larger. After all, if the future energy system is dominated by variable generation, there is not much room for the base load type of operation of thermal power plants.

All power plants fired with biomass add to the synchronous generators connected to the transmission grid which in itself is a stabilizing factor. The power plants can also contribute to balancing through electricity markets and balancing markets and offer frequency control. Balancing and frequency control is used today in limited amounts and will require changes in operation for smaller, embedded generation in distribution grids to be able to contribute.

5.5.1 Balancing with solid biomass power plants

Dedicated biomass power plants and CHP plants have a capacity of 16 GW in the EU today. Although the power output from a CHP system is controllable to the same extent as other boiler-steam systems, CHP plants are primarily operated to follow a local heat load. However, district heating systems typically contain other components such as heat pumps and accumulators, besides CHP and heat only boilers. This gives the system more flexibility to change operation based on the price signals. Such combinations have a potential for both generation and demand side interaction to control the energy balancing, if the entire combination were available for balancing purposes. In the summertime, however, most CHP plants are not in operation while at the wintertime peak, they are typically operating at full heat load and therefore have no margin to increase the output, should variable power decrease.

The constraints in the flexibility of operation of large biomass (co-fired or dedicated) power plants or CHP plants are on the firing side with regard to the minimum stable load, and on the steam system and turbine side for the dynamic rates of load change and start-up times, i.e. these constraints are not fuel related such that a change of fuel from coal to bioenergy does not really affect the flexibility of operation in relation to grid balancing. The steam system allows load rate changes of the order of a few percent per minute and secondary and tertiary control can therefore be limited. A complete conversion of a power plant needs to recover the cost of the investment and the higher cost of the fuel, i.e. drive towards a high capacity factor or capture higher market prices.

5.5.2 Balancing with biogas biomethane and bioliquids

Biogas and biofuels could be used to generate power through flexible gas engines and gas turbines. While the existing pathways to biogas and biofuels are expensive in comparison to natural gas prices, other options to replace fossil fuels in peak load power plants may be even more expensive. Consequently, there is a plausible case for using bioenergy for balancing the net load also near the peaks.

- Existing technologies and value chains for liquid and gaseous intermediates are currently in the market (e.g. biomethane, ethanol, pyrolysis oil, HVO). These stored bio intermediates have properties: high usability (accessible when you need it, no preparation needed) and high energy density and provide embedded generation. Some of these existing intermediate energy carriers could also be used in existing engine power plants and gas turbines.
    - Biomethane could be produced, stored and injected into the natural gas grid to supply (in a mass balance mode) energy to conventional natural gas plants operated to balance the grid in an active mode. This would allow running biomethane plants at a high load factor, while using the product in large scale

natural gas conventional plants operated in balancing mode (thus at low load factor), without additional investment in building new plants.

  - Bioliquids could be another pathway to actively balance the grid using engine power plants and gas turbines. Some bioliquids require extensive and costly refining before they can be used as vehicle fuel. They might find better use in power plants that can burn less clean fuels.

  - Bioliquids could also have a small role by replacing the (fossil) auxiliary fuel, which is used for starting up and heating steam power plants. Start-ups are expected to increase as the share of variable generation increases.

- Excess electricity from solar and wind power generation can be converted to H2 and/or transformed into a variety of fuels or used in manufacturing chemicals. Biomass could play a role in these schemes in various ways: for instance, renewable CO2 derived from the separation of biomethane in anaerobic digestion systems or other processes could be converted to additional biomethane through thermochemical methanation.

5.5.3 The impact of the electrical market structure on bioenergy grid balancing

Whilst most thermal biomass power producers of some scale are already selling their production on the OTC (over the counter) or the spot market, their participation in the balancing markets is low. One reason is technical limitations in the load ramping of the steam cycle itself, meaning that bioenergy power can only compete with other thermal power plants and not against hydro in faster ramping and higher paying markets. This results in the situation that the marginal cost is the fuel price where biomass is disadvantaged compared to e.g. coal and oil. Secondly, since the bid size is in the range of ±1-10 MW in the balancing markets and most biomass CHP installation are small, say 5 MW-100 MW, setting such a big fraction of the generation capacity aside for use in balancing for extended periods means that a significant part of the capacity factor is lost, and it may be more lucrative to sell power instead on the spot market.

Another complication for both industrial and district heating CHP is that the main purpose and product is heat, that the change in power output cannot be matched by heat demand and that the efficiency in the generation is reduced. In district heating the peak heat demand also coincides with the peak electricity demand such that when balancing power is more valuable, the plants are being used at full capacity. On the other hand, smart integration of electricity production and heat grids can offer significant balancing possibilities, as described in the Stockholm example.

As the heat demand is expected to go down in most district heating systems, the number of full-load equivalent hours will be reduced, and hence there are more operating hours at part load and where there could be spare capacity. There are also pulp and paper industries with condensing steam turbines that could, in high price periods, produce more steam than required for the process to run the condensing stage. Using the heat flexibility more would actually be a significant advantage in a system. Heat storage and electric boilers is another development that will allow more flexibility to be offered for the electricity sector.

Changes in market design that are required to incentivize bioenergy to have a larger role in balancing are related to allowing smaller size power plants to contribute to frequency control and balancing markets. These are to a large extent the same as outlined for wind and solar energy (reference for example EU projects Reservices[68] and Market4RES[69]).

Biomass power plants are typically smaller than 50-100 MW while some reserve market products can have a minimum bid-size of 10 MW. The size of the bid, i.e. the capacity reserved, in combination with the time of reservation becomes a non-technical barrier for participating in the balancing market. Additionally, the following issues are of importance:

- feed-in tariffs or green certificates of high value (now or in the future) provide lower incentives to reduce output at low pool prices
- taxation of electricity use, grid fees and other surcharges mean that electric boilers and heat pumps cannot compete with other forms of heat, even if the pool electrical price is low.
- on the other hand, the cost of fossil fuel can be so high that for heat provision, the use of electricity in heat pumps becomes more favorable than fossil heat only plant, even at peak power demand.

Fossil fuel prices will remain low as long as they are abundantly available. The current drive to decrease the use of fossil fuels suppresses fossil fuel prices as there is more supply than demand. Consequently, renewable energy, including biomass, will either require support to compete with fossil fuels, or carbon costs need to be fully factored into the price of fossil fuels. At the end of their public support period biomass plants have challenges in operating on a purely commercial basis, given the high feedstock and OPEX costs. There is a danger that the growth in wind and solar power production will push out bioenergy generation capacity rather than coal, unless decarbonisation policies prevent this.

The policies for supporting more renewable deployment may develop towards grid friendly renewables – incentivizing deployment towards locations and technologies that support the grid and cause less challenges. The IEA has identified major improvements to facilitate the integration of higher quantities of VREs (Variable Renewable Energy)[70]:

- At a strategic level, a dedicated effort in better planning the introduction of new VRE plants through a systematic approach that coordinates the whole energy system at various levels (national/regional/local) and integrates all components into a fully coherent system. Similarly, planning of infrastructure should be carried out in parallel with the development of new installations.
- From a purely technological point of view, modern VRE systems can contribute to their own system integration, and a more effective site-dependent VRE mix can significantly support grid balancing. Storage and interconnection will also have to play a major role in achieving this goal, including CHP with district heating with improved flexibility (heat storage).
- These actions will then generate positive impacts on costs of more flexible renewable plants. In

[68] http://www.reservices-project.eu/

[69] http://market4res.eu/

[70] International Energy Agency. The Power of Transformation. Wind, Sun and the Economics of Flexible Power Systems. Paris, 2014. ISBN: 978 92 64 20803 2

the long term, high shares of VRE may come at zero additional costs.

In parallel, improved grid management (for instance, optimizing forecasts) will enable a higher penetration of VREs reducing the need for technical interventions

5.6 REGIONAL DIFFERENCES IN OPPORTUNITIES FOR BIOENERGY

Different regional characteristics provide room for different types of opportunities and needs for market driven biomass and bioenergy balancing applications. The need for balancing differs significantly, especially due to the share of solar and wind in an area and the quality and strength of grid interconnections. Secondly, the role that biomass installations can and will provide is closely related to the existing biomass use in the area, local resources and types of uses and their operational capabilities. Thirdly, other balancing capacity in power generation and other balancing characteristics of energy use, such as heat grids set the competitive environment for biomass to provide these services. Different opportunities in different types of areas are presented in Figure 37.

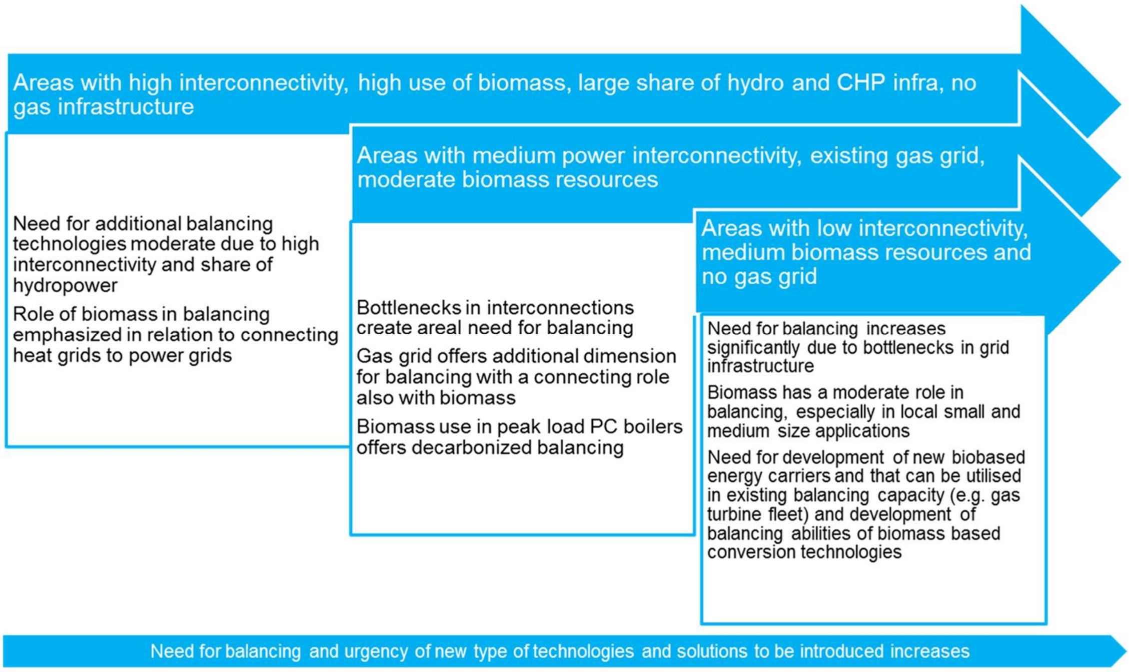

Figure 37 Regional differences in need for balancing and solutions enabled by the infrastructure by 2030.

6 Summary and recommendations

6.1 SUMMARY

Bioenergy is currently the major renewable energy source in the world. However wind, solar and geothermal are fast growing alternatives. The role of wind and solar will increase rapidly relative to other renewable sources. The seasonality, or energy demand fluctuations in the winter and summer season, is one of the key challenges for future smart energy system management, and will have various optimization outcomes in various parts of Europe and globally. Bioenergy, in its various forms, can eventually contribute to balancing the electricity grid. It is one form of solar energy storage. Thus far, little attention has been paid to the possible role of bioenergy as an effective, low carbon and low cost grid management and energy storage option. Solid biomass co-firing, power and combined heat power and cooling (CHP-C) systems add synchronous generation to the transmission grid which in itself is a stabilizing factor. These can also contribute to primary frequency control.

Biomass can play a role in balancing the grid, as bioenergy plants are dispatchable and can be operated in a similar way to conventional (fossil fuel) installations. This can happen through the thermo- and bio-chemical conversion of the renewable feedstock into storable energy products, either gaseous, liquid or solid, adding flexibility to its use. A wide range of possible technical options exist to implement balancing actions with biomass, supporting the electrical grid and allowing more solar and wind power generation on the grid. The use of sustainable biomass to replace fossil fuel based power generation in balancing can create economic, environmental and security of supply related benefits. The potential, role and technologies for balancing the power grid vary significantly between regions, mainly due to differences in the current use and availability of biomass, to existing infrastructure (such as the gas grid) and to the degree of grid interconnectivity and thus the need for balancing capacity.

Most current biomass power and CHP plants have not been designed with grid balancing in mind, yet they can be optimized to incorporate more balancing aspects. However, there are constraints (technical and economic) that limit the possible flexibility of the current portfolio. Biomass is largely used for residential and industrial heat production and for CHP (combined heat and power). While the conversion itself is not very flexible, connecting it to a heat system brings significant additional flexibility opportunities. There are state of the art biomass conversion technologies now entering the market that can provide storable fuels which could also be used for balancing (i.e. cellulosic ethanol and diesel-replacement type fuels such as hydrotreated vegetable oils and biomethane). In the future, new technologies and/or value chains are expected to come to the market, some with a more dedicated approach to balancing. For example, periods where electricity prices are low could be used to transform electricity to hydrogen which could be used in biofuel production.

Currently, the role of bioenergy in balancing is increasing as the time interval of balancing increases, and is most significant in seasonal balancing especially when associated with heat grids. The role of bioenergy in the future is seen as developing more towards short term balancing as balancing needs also increase due to the increasing share of variable power generation. Biomass balancing is already seen in the day-ahead time period, when power prices are sufficiently low and power generation with biomass is not profitable (balancing excess generation). In future, the role of biomass in balancing could increase as wind and solar power generation push fossil generation out and the full load hours of thermal generation are reduced. In this case, the same amount of biomass energy can serve a larger portion of the needed balancing capacity.

In terms of balancing deficit generation, the installed capacity for biomass today is smaller than the variable power installed capacity in almost all regions and it therefore cannot be expected to take more than a share of the balancing required. Even if biomass power increases, the growth of variable power is expected to be more rapid. At very high levels of wind and solar power generation, biomass together with hydro power could potentially cover a large portion of the balancing need. However, current levels of biomass-based generation capacity are not sufficient. Capacity could be increased either by building capacity capable of burning biomass directly, or converting biomass to more suitable gaseous and liquid fuels. However, both routes are likely to remain more expensive compared to fossil fuels, unless the carbon penalty of fossil fuels is high enough.

The impact of bioenergy in reducing residual power (i.e. the temporal difference between actual demand and variable power) can be significant. Biomass plants, in the same way as wind, PV, ocean and geothermal, need support under existing policies to compete with fossil fuels. At the end of their public support period biomass plants will have difficulty in operating on a purely commercial basis, given the high feedstock and OPEX costs. The growth in wind and solar power production will push out bioenergy generation capacity rather than coal, unless decarbonisation policy would prevent this from happening. In a future with higher shares of wind and solar energy, existing power plants may need to run at lower load factors and also be used actively in short-term balancing and frequency reserves.

6.2 RECOMMENDATIONS

Balancing represents a challenge of varying magnitude in different parts of Europe depending on the characteristics of the generation portfolio, the availability of demand response and interconnections to neighbors. Moreover, gas and heat networks can and should also play a bigger role in balancing the electrical grid. With the advent of electric vehicles the transport sector is also poised to become more integrated with the power system and, if implemented with price sensitivity, could bring considerable flexibility to balancing the power grid. In all these cases bioenergy can play a central role (Figure 38).

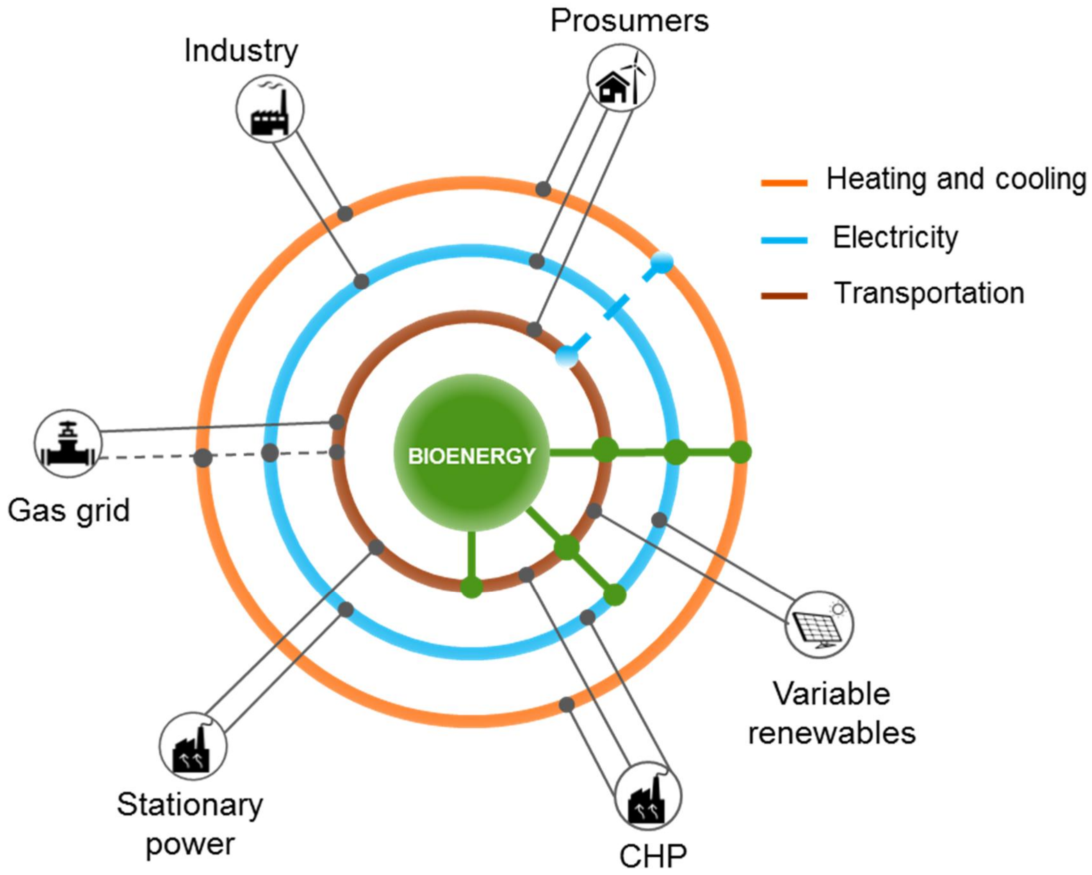

Figure 38. Energy system that is significantly more distributed, interconnected and flexible than today's!

In view of the large potential of bioenergy in grid balancing, the authors propose a set of activities and studies to be undertaken related to the following topics:

- The value of balancing the electricity grid is essential for the economic viability of concepts and determines whether a higher payment for production in peak periods compensates for the lower operating hours. Quantifying the value of balancing and determining the cost competitiveness of different competing balancing options is needed.
- Develop solutions to combine renewable energy resources and different energy sectors in a cost- and resource-effective way to find the best overall solutions for a low carbon energy future in Europe.

- Encourage conversion of existing high efficiency fossil power and CHP plants to use more biomass; also in peaking operation– match plant technologies and biomass feedstock.
- Development of smart concepts for RES-hybrid integration with biomass power, combined heat power and cooling plants, and their system level integration.
- Detailed research, development and demonstration efforts for bio-CCUS to develop cost-effective technologies and practices for flexible RES integration.
- Develop different routes to utilize biomass in a more flexible manner (how to cost-effectively use biomass in power generation with less full load hours).
- Technology and service development to enable using recurring periods of low-cost electricity as an energy storage mechanism in the conversion of biomass into more storable and easy-to-use bio-energy carriers. Such technologies could range from e.g drying to improve biomass energy content and storage properties compared to direct heating of processes to save on bioenergy used for internal energy generation to producing hydrogen that can be efficiently used directly as a co-feed in biofuel plants.
- Deployment efforts for fleets of bio-fueled hybrid-vehicles to be operated for balancing small grids (smart grid), with very short intervention times from batteries, that could be charged by the biofuel-fed car, increasing the hours of operation of the system and thus reducing amortization costs.
- Energy and power system modelling: improving the data to see what is the share of bioelectricity that is easily used for balancing; to what extent small installations are able to participate in reserve and how much this will change in the future; what would be the additional cost for the small players due to increased balancing.
- Review decarbonisation policies to ensure that they do not discourage dispatchable renewable production in comparison to fossils.

Further Information

IEA Bioenergy Website
www.ieabioenergy.com

Contact us:
www.ieabioenergy.com/contact-us/