MARKET ENABLING INTERFACE TO UNLOCK FLEXIBILITY SOLUTIONS FOR COST-EFFECTIVE MANAGEMENT OF SMARTER DISTRIBUTION GRIDS

Deliverable: D1.1

Characterisation of current network regulation and market rules that will shape future markets

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Abbreviations

BEV	Battery Electric Vehicle
CEC	Citizen Energy Communities
CHP	Combined Heat & Power
DG	Distributed Generation
DSO	Distribution System Operator
ETS	Emission Trading System
EV	Electric Vehicle
GHG	Greenhouse Gas
HHP	Hybrid Heat Pump
HP	Heat Pump
HV	High Voltage
LIFO	Last In, First Out
LULUCF	Land Use, Land Use Change and Forestry
LV	Low Voltage
MV	Medium Voltage
NECP	National Energy and Climate Plan
PHEV	Plug-in Hybrid Electric Vehicle
PV	Photovoltaic
REC	Renewable Energy Communities
RES	Renewable Energy Sources
RES-C&H	Renewable Energy Sources in the Cooling & Heating sector
RES-E	Renewable Energy Sources in the Electricity sector
RES-T	Renewable Energy Sources in the Transport sector
ToU	Time-of-Use
TSO	Transmission System Operator
V2G	Vehicle-to-Grid

Executive summary

The aim of this deliverable is to examine how current regulation and market rules will shape the future electricity grid and markets. This will be performed by analysing the following four questions:

- Which new types of network users are coming by 2030?
- How big is the challenge to integrate these new users into the distribution network and can the impact be reduced by flexibility mechanisms?
- Which regulatory flexibility mechanisms are currently in place and how do they look like?
- Which other intermediaries can play a role in valorising flexibility?

Ten countries are examined in this deliverable: Belgium, Germany, Norway, Poland, Portugal, Spain and the UK are included because of their involvement in the EUniversal project. France, Italy and the Netherlands are covered as important developments on new network users, impact studies and regulations are ongoing in these countries.

Which new types of network users are coming by 2030?

An analysis of the National Energy and Climate Plans shows the ambition of each target country to reduce greenhouse gas emissions, increase energy efficiency and extend the share of renewables in their final energy consumption, the electricity sector, the transport sector and the heating sector. From this analysis, we suggest that, besides other technologies, the following three network users will be present in the future electricity network:

- Renewable energy sources, as Germany, Italy, the Netherlands, Portugal and Spain expect that more than 50% of electricity will come from renewables by 2030.
- Electric vehicles, as Italy, Spain, Portugal, Poland, the Netherlands and Norway expect to have millions of electric vehicles present on the roads by 2030.
- Heat pumps, as they will be part of the solution to integrate large shares of renewables in the cooling and heating sector, with this share being between 25% to 40% for most target countries.

How big is the challenge to integrate these new users into the distribution network and can the impact be reduced by flexibility mechanisms?

Impact studies from different stakeholders are examined based on the following five questions: What types of studies are performed? Which technologies are included? What network challenges are arising? How are these challenges analysed? And finally, what are the proposed solutions to reduce this challenge? Although the details differ by country, the following overall conclusions can be made for the integration of distributed generation, electric vehicles and heat pumps in the distribution network:

- <u>Distributed generation.</u> To integrate large shares of distributed generation, substantial network reinforcements will be required. According to most studies, savings in additional network investments can be achieved by implementing explicit flexibility mechanisms such as connection agreements and flexibility markets.
- <u>Electric vehicles.</u> Implicit flexibility mechanisms such as dynamic distribution tariffs and dynamic energy prices have the potential to change the charging behaviour of electric vehicles users and limit the amount of network reinforcements required to integrate large shares of electric vehicles into the network.
- <u>Heat pumps.</u> In scenarios where heat pumps are the only technology used to decarbonize the cooling and heating sector, large network investments will be required. The assumed insulation level of buildings will highly affect the required network reinforcements. Besides integrating heat pumps flexibly, a mix with other technologies such as hybrid heat pumps, district heating and hydrogen boilers is seen as a possible pathway to reduce additional

network investments. However, it must be noted that national impact studies on the challenge of heat pumps integration are still limited available.

Which regulatory flexibility mechanisms are currently in place and how do they look like?

From the impact studies, we understand that the following regulatory flexibility tools can be used to integrate high shares of new grid users in a cost-efficient way: distribution network tariffs, connection agreements and flexibility markets. An analysis of the three regulatory tools in the different target countries gives us an idea of how these regulatory instruments can be designed and how complex they might become in the future.

- Distribution network tariffs. The use-of-system charges of distribution network tariffs are analysed by the following five questions: Is the analysed distribution network tariff currently in place or a planned reform? Which network costs are addressed? What tariff components are part of the tariff? Do the components have temporal and/or locational granularity? And finally, to which customer class(es) do these tariffs apply? We noticed that most target countries are working on implementing more dynamic distribution tariffs to not only recuperate costs in a cost-reflective way, but also give signals for smart network usage.
- Connection agreements. National regulation on connection agreements is examined based on the following questions: Is the analysed connection agreement currently in place or a planned reform? Which network challenge does the connection agreement address? Which technologies are targeted? How is the amount of curtailment determined? Is the agreement entered by default or by consent? And finally, is there a compensation when being curtailed? In most cases, connection agreements are currently used to solve critical network situations. However, four out of ten target countries see the financial benefits of integrating connection agreements in active system management of distribution system operators.
- Flexibility markets. Based on the research questions of Schittekatte & Meeus (2020), flexibility markets will be analysed in detail in deliverable D1.2 of the EUniversal project.

Which intermediaries can play a role in valorising flexibility?

Besides regulatory measures, there will also be third parties that valorise flexibility of network users. On the one hand, (independent) aggregators are unlocking demand-side flexibility in the network. On the other hand, customers can participate in self-consumption or come together in energy communities to optimise their behaviour and valorise their flexibility e.g. for grid purposes.

1. Introduction

The primary goal of the EUniversal project is to overcome existing limitations in the use of flexibility by Distribution System Operators (DSOs). A Universal Market Enabling Interface will be implemented to foster the provision of flexibility services and interlink active system management of distribution system operators with electricity markets. In this context, the aim of this deliverable is to analyse recent and on-going policy and regulation initiatives that will shape the future electricity grid and markets.

The scope of this deliverable is limited to ten target countries. Belgium, Germany, Norway, Poland, Portugal, Spain and the UK are included due to their involvement in the EUniversal project. France, Italy and the Netherlands are covered as important developments on new network users, impact studies and regulations are ongoing in these countries.

The analysis is performed in four stages that are each described by a chapter of the deliverable. First, National Energy and Climate Plans (NECPs) are examined to see which network users will be present in the future electricity network. Second, the challenge of integrating these new network users in the distribution network and the opportunity of flexibility mechanisms to reduce this challenge for DSOs are examined. This will be achieved by looking at impact studies of different energy stakeholders such as system operators, research institutions, regulators and governments. As the flexible integration of new users in the distribution network requires a supportive regulatory framework, the following three flexibility mechanisms are analysed in the third stage: distribution network tariffs, connection agreements and flexibility markets. Since these regulatory tools will not be the only way for network users to valorise their flexibility, the analysis is extended by a last stage that describes three intermediaries between electricity markets and flexibility sources: (independent) aggregators, energy communities and self-consumption.

The results of this deliverable will serve as an input to the following tasks of the EUniversal project:

- From the analysis of the NECPs of the target countries, scenarios towards 2030 are deduced that will be used in Task 1.3, which defines challenges and opportunities for grids and markets towards 2050.
- The regulatory review of distribution tariffs, connection agreements and flexibility markets will serve as input for Task 5.1, which identifies relevant market mechanisms for the procurement of flexibility needs and services, and Task 5.2, which identifies a methodology for dynamic distribution network tariffs.

2. National Energy and Climate Plans: new types of network users are coming

In order to meet the European energy and climate targets for 2030, each EU Member State had to submit a final National Energy and Climate Plan (NECP) by the end of 2019. The plan contains a 10-year national strategy on the following five dimensions: decarbonisation (emission reductions and renewables), energy efficiency, energy security, internal energy market and innovation & competitiveness (European Commission, 2020).

In this section, the NECPs of the target countries are analysed to gain insight on their national commitment to the energy and climate targets, and the growth of new types of network users in the future. The final versions of the NECPs for the period from 2021 to 2030 of Belgium (ENOVER & Nationale Klimaatcommissie, 2019), France (Ministère de la Transition écologique et solidaire, 2020), Germany (BMWi, 2020), Italy (MISE, 2019), the Netherlands (Ministerie van Economische Zaken en Klimaat, 2019), Poland (Ministerstwo Aktywów Państwowych, 2019), Portugal (DGEG, 2019) and Spain (MITECO, 2020) are studied. For the UK, the draft of the NECP (UK Government, 2019) and the assessment of the draft by the European Commission (European Commission, 2019a) are analysed, as the final NECP is not submitted to the European Commission (2020) to date. The National Plan on Climate of Norway (Norwegian Ministry of Climate and Environment, 2019), which is part of its cooperation with the EU to reduce greenhouse gas emissions, is also analysed.

From the NECPs, we developed eight research questions to evaluate which types of network users will be present in the future electricity grid and markets. An overview of the answers for each target country can be found in Table 1. In the table, a distinction has been made between targets, which Member States are obliged to reach by national or European regulation, and expected amounts, which indicate national ambitions or forecasts.

Q1 - What will be the reduction of greenhouse gas (GHG) emissions in the non-EU Emission Trading System (ETS) sector by 2030 compared to 2005 while excluding Land Use, Land Use Change and Forestry (LULUCF)?

Each NECP describes the Member States' contribution to the EU Effort Sharing Regulation which "*mandates Union-wide reduction in sectors not covered by the Emission Trading System of 30% compared to 2005"* (European Commission, 2019b). The most ambitious national emission reductions can be found in the plans of Portugal, Norway and Germany with percentages of 45% to 55%, 40% and 38% respectively. While the target in France is a slightly lower with 37%, its NECP forecasts that the achieved emission reductions will be up to 42% by 2030, matching the ambition of Portugal. Also, in Belgium, the Netherlands and Italy, the contributions to the Effort Sharing Regulation stay well above 30%. While emissions will be 30% lower in Poland compared to 1990, the expected reduction of GHG emissions in non-ETS sectors compared to 2005 will be 7% by 2030. Spain has a target to reduce national emissions in all sectors with 23% compared to 1990. The UK sets caps on its total emissions for 4-year periods rather than having a target by 2030. Between 2028 and 2032, the average required GHG emissions reductions are 57% compared to 1990. Under this regulation, a contribution of 37% emission reductions to the EU Effort Sharing Regulation is likely to be achieved.

Q2 - What will be the increase of energy efficiency in primary or final energy consumption[1] by 2030 compared to the Primes reference scenario in 2007?

[1] Eurostat defines primary energy consumption as *"the total energy demand of a country. It covers consumption of the energy sector itself, losses during transformation and distribution of energy, and the final consumption be end users."* (Eurostat, 2018a) and final energy consumption as *"the total energy consumed by end users, such as households, industry and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself.*" (Eurostat, 2018b)

Targets or ambitions on energy efficiency must be included in the NECPs to support the Union's objective to reduce primary and final energy consumption by 32.5% in 2030 compared to the Primes reference scenario of 2007 (European Commission, 2019b). From the NECPs it can be observed that most countries express their efforts by reductions in primary energy consumption. Italy has the highest ambition of the studied target countries with an expected increase in energy efficiency of 43%. Other significant reductions in primary energy consumption are expected in Spain and Portugal, where the projected percentages are 39.5% and 35% respectively. The German government implemented a national target of 30% energy efficiency in its primary energy consumption by 2030 compared to 2008 as part of its Energy Efficiency Strategy towards 2050. The forecasted increase in energy efficiency of primary energy consumption in France, Poland and Belgium is 24.5%, 23% and 15% respectively. The energy efficiency target of the Netherlands is expressed as a maximum primary energy consumption of 1950 PJ by 2030 and no contributions are stated in the National Plan on Climate of Norway and the draft NECP of the UK.

Q3 - What will be the share of Renewable Energy Sources (RES) in the gross final energy consumption by 2030?

Each NECP describes the country's effort to the Union's binding target of integrating at least 32% of renewable energy in the gross final energy consumption by 2030 (European Commission, n.d.). The expected share of renewables in Portugal's and Spain's final energy consumption is 47% and 42% respectively. In France, a national objective of 33% is in place, which is in line with their forecasted renewable energy share in gross final energy consumption by 2030. The German Energy Concept, which was approved in 2010, states a national objective of 30% renewable energy sources in Germany's final energy consumption by 2030. In Italy, the proportion of renewables in the gross final energy consumption is also 30% and the Netherlands aims to achieve at least a share of 27% renewable energy in its gross final energy consumption by 2030. Depending on funds granted by the EU, Poland has the ambition to integrate 21% up to 23% of renewables in their gross final energy consumption. The planned policy measures in Belgium will result in a share of renewables of 17.5% in proportion to the gross final national energy consumption in 2030. This gives the following allocation between the different regions: Brussels 0.3%, Wallonia 6.7%, Flanders 6.9% and Federal 3.6%. No national contribution to the EU 2030 target is expressed in the National Plan on Climate of Norway and the draft NECP of the UK. Scotland however, sets a target of integrating 50% of renewables in its final heat, transport and electricity consumption.

Q4 - What will be the share of RES in the final consumption of the electricity sector (RES-E) by 2030?

A first sector where renewable energy resources can be integrated is the electricity sector. As this can be achieved by technologies such as Photovoltaic (PV) installations and wind turbines that are already well mature and low-cost, high shares of renewables are expected to be integrated in the final consumption of the electricity sector in the different member states. In the Netherlands, Spain and Portugal, the integration of renewables in the electricity sector goes up to 70%, 74% and 80% respectively by 2030. More than half of the electricity consumption is expected to come from RES following the NECP of Italy and the Renewable Energy Sources Act in Germany. Furthermore, the German government set a target to increase the share of renewable energy in the electricity sector to 65%. The expected share of renewables in the final consumption of the electricity sector for France, Belgium and Poland is 40%, 37.4% and 32% respectively. No trajectory of the national growth of renewables in the electricity sector is determined in the National Plan on Climate of Norway and the draft NECP of the UK. However, the Welsh government has set targets to integrate 70% of renewables into its final electricity consumption.

Q5 - What will be the share of RES in the final consumption of the transport sector (RES-T) by 2030?

Overall, the expected share of renewables in the final consumption of the transport sector is between 15% and 25%. This is significantly lower than the integration of renewables in the electricity sector and can be explained by the fact that cars on renewable technologies such as green or blue hydrogen, biofuels, biomethane and renewable electricity still require more technological development and cost reductions to gain larger market shares.

Q6 - What is the expected growth of Electric Vehicles (EVs)?

As electric vehicles will mostly be connected to the distribution network and might create network peaks and adequacy challenges, their growth in the different target countries is studied in more detail. Specific ambitions and expectations on the future number of electric vehicles are not yet developed for every country. For example, actual numbers are missing in the final NECP of Flanders (Belgium) and France, and the draft NECP of the UK.

Other countries do have planned trajectories or even objectives for electric vehicles. In Germany, 7 to 10 million electric vehicles are expected to be registered by 2030. In Italy, the investments in EVs are expected to be particularly effective in 5-7 years which is expected to result in almost 6 million electrically powered vehicles in overall circulation by 2030. Approximately 4 million of these cars are likely to be all-electric vehicles. Under the ambition of having 17.5% of renewables in the transport sector of Spain, it is forecasted that there will be around 3 million electric cars and more than 2 million electric motorcycles driving around by 2030. In Portugal it is suggested that by 2030, 36% of passenger cars mobility demand will be served by electricity and Poland targets 1 million electric vehicles by 2025. In the region of Wallonia in Belgium, it is expected that 15% of total person cars will be all-electric by 2030, and 5% will be Plug-in Hybrid Electric Vehicles (PHEVs). Norway and the Netherlands have forecasts on the sale of zero emission cars, which includes the uptake of EVs. In Norway, all new passenger cars and light vans should be zero emission by 2025. In the Netherlands, there is the ambition for all new cars to be emission-free by 2030 at the latest, using both hydrogen and electric cars.

Q7 - What will be the share of RES in the final consumption of the cooling and heating sector (RES-C&H) by 2030?

Shares of RES in the cooling and heating sector of the target countries are expected to be between 25% and 40% for most target countries. Belgium is an exception with a lower forecast of 11.3% and no forecasts are given in the final NECP of the Netherlands, the National Plan on Climate of Norway and the draft NECP of the UK. The growth of renewables in the cooling and heating sector could be explained by the new version of the Renewable Energy Directive (European Council, 2018), in which Member States must strive to achieve an annual average increase of 1.3% renewable energies' share in the cooling and heating sector compared to 2020 (D2018/2001 Art.23). The highest shares of renewables in the cooling and heating sector are expected in France and Portugal, with both 38%. Again, this is achieved by the integration of different technologies such as (hybrid) heat pumps, district heating, electric heating, hydrogen heating and biofuels.

Q8 - What is the expected growth of Heat Pumps (HPs)?

To focus on the impact of the cooling and heating sector on the distribution network, heat pumps are examined in more detail. No details on the expected growth of HPs were found in the final NECP of Germany and the National Plan on Climate of Norway. In Belgium, the demand of heat pumps is expected to grow up to 3.36TWh by 2030. In France already 27.6TWh of (air-to-air and air-to-water) heat pumps were installed in 2017, but this is expected to increase up to 39TWh or even 45TWh by 2028 depending on the considered scenario. The final energy consumption of heat pumps in Italy is currently 30.82TWh. In order to meet the ambitious target of 33.9% renewables in the heating sector, 66.29TWh of heat pumps must be installed by 2030. However, with current regulation, it is expected that the amount of heat pumps in the heating sector in Italy will grow up to 40.71TWh. In Spain, the energy consumption of heat pumps is expected to rise up to a minimum of 5.78TWh (Comisión de Expertos de Transición Energética, 2018) and a maximum of 8.82TWh by 2030 (Monitor Deloitte, 2018). The gross final energy consumption of heat pumps in Poland will be approximately 8.5TWh by 2030 and in Portugal, heat pumps are predicted to satisfy 15% of cooling and heating energy demand in buildings by 2030. The Netherlands and the UK do not forecast the demand growth of heat pumps but describe their ambition as follows. The NECP of the Netherlands describes the national ambition to make 1.5 million existing dwellings and buildings natural gas-free with alternatives such as heat pumps, waste heat or geothermal energy by 2030. In the UK, a target of integrating 1 million heat pumps a year by 2035 is being supported, but no official objective is yet in place (Blackman, 2020).

	GHG emissions by 2030 compared to 2005 excluding LULUCF and EU ETS sectors?		Energy efficiency in primary or final energy consumption by 2030 compared to Primes scenario 2007?		Share RES in gross final consumption by 2030?		Share RES in final consumption of the electricity sector by 2030?		Share RES in final consumption of transport sector by 2030?		Share RES in final consumption of the cooling and heating sector by 2030?	
NECP	Target	Expected	Target	Expected	Target	Expected	Target	Expected	Target	Expected	Target	Expected
Belgium (ENOVER & Nationale Klimaatcommissie, 2019)	-35%			15% prim 12% final		17.5%		37.4%		23.7%		11.3%
France (Ministère de la Transition écologique et solidaire, 2020)	-37%	-42%		32.5% final 24.6% prim	33%			40%		15%		38%
Germany (BMWi, 2020)	-38%		30% prim vs 2008			30%	65%			27%		27%
Italy (MISE, 2019)	-33%			43% prim	30%			55%	22%		33.9% RES-H	
The Netherlands (Ministerie van Economische Zaken en Klimaat, 2019)	-36%		Max 1950 PJ prim			27%		70%				
Norway (Norwegian Ministry of Climate and Environment, 2019)	-40%											
Poland (Ministerstwo Aktywów Państwowych, 2019)	-7%		23% primary		21% to 23%			32%		14%		28.4%
Portugal (DGEG, 2019)	-45% to -55%			35% prim		47%	80%		20%		38%	
Spain (MITECO, 2020) *(European Commission, 2019c)	-23% total emissions vs 1990			39.5% prim	42%		74%			17.5%*		30.8%*
The UK (draft) (European Commission, 2019a; UK Government, 2019)	-57% total emissions vs 1990 between 2028-2032	-37%										

Table 1: Overview of the National Energy and Climate Plans

3. Integrating new network users into the distribution grid: how big is the challenge?

3.1. Distributed generation

The analysis of the NECPs in the previous section shows that high shares of renewable energy sources will be installed in Europe by 2030. Some renewables, like offshore wind turbines or large onshore wind farms, will be connected to the high or extra-high voltage network. Other renewables, such as smaller onshore wind farms and PV, will mostly be integrated at medium and low voltage level. In this section, we examine studies from different institutes, such as system operators, research institutions, regulators and governments that estimate the impact of integrating distributed generation (DG) in the distribution network. The following sample of studies, covering seven out of ten target countries, is taken for analysis:

- Modern distribution networks in Germany, performed by E-Bridge Consulting GmbH on behalf of the Federal Ministry for Economics and Technology (BMWi, 2014).
- The value of smart grids, performed by the French DSO Enedis and the Association of the Distributors of Electricity in France (Enedis & ADEeF, 2017).
- Mid-term availability study of Spain by Greenpeace (Greenpeace, 2018).
- Intelligent electric networks with plug-in electric vehicles by the Portuguese R&D institute Inesc Tec (Inesc Tec, 2012).
- The value of congestion management by Ecofys on behalf of Netbeheer Nederland, which is an organisation of all electricity and gas network operators in the Netherlands (Netbeheer Nederland, 2016).
- Flexible connection agreements in Flanders, performed by 3E for the Flemish regulator VREG (VREG, 2017).
- Flexibility roadmap of the future smart project by UK Power Networks, one of the distribution network operators in the UK (UKPN, 2018).

The following five questions were developed to summarize the impact studies and show some main trends and differences among them. Table 2 gives an overview of the answers.

Q1 - Which technologies are included?

Most impact studies include wind and solar, but also other DG technologies can be added. Combined Heat and Power (CHP), for example, is considered in the study of VREG (2017) and Inesc Tec (2012), and biomass is included in Greenpeace (2018). Besides that, Greenpeace (2018), Inesc Tec (2012), Netbeheer Nederland (2016) and UKPN (2018) already take into account other new electricity users such as EVs and HPs.

Q2 - Which network challenges are modelled?

All studies indicate that grid investments at low voltage (LV) and medium voltage (MV) will be required to integrate large shares of renewables in the distribution network. Reinforcements can be performed to deal with bidirectional energy flows, congested lines and transformers, and to handle voltage problems (Inesc Tec, 2012).

The impact studies of BMWi (2014), Enedis & ADEeF (2017), Netbeheer Nederland (2016), VREG (2017) and UKPN (2018) also consider network challenges and investments at high voltage (HV) levels and/or connection points between the transmission and the distribution grid.

Q3 - Are the required grid reinforcements without remedial action quantified in the study and how are they measured?

There are two ways to quantify the required reinforcements without remedial actions: financial and technical. Most impact studies include one of the methodologies, apart from Inesc Tec (2012) and Greenpeace (2018) that do not quantify any required grid reinforcements.

- Financial. BMWi (2014) expects additional grid investments up to €23 billion to €49 billion in Germany, of which the MV and HV networks make up 80% of the costs. The study of Netbeheer Nederland (2016) distributes the expected network and generation costs of over all households. Without remedial action, the yearly additional cost per household is expected to be between €139 and €224. In VREG (2017), the total cost of integrating different shares of renewables for different regulatory frameworks is analysed. The impact studies of Enedis & ADEeF (2017) and UKPN (2018) focus more on quantifying the expected network savings when implementing solutions, than the expected investments without any solutions. This will be discussed in more detail in the last question (Q5) of this section.
- Technical. In the study BMWi (2014), the length of additional cables is analysed. Without any measures, between 130,000km and 280,000km of new lines must be constructed by 2032. Besides that, Enedis & ADEeF (2017) performs a detailed technical analysis for each of the occurring challenges and proposed solution.

Q4 - What are the alternative solutions or remedial actions that can reduce the need for grid reinforcement and which incentives are used to encourage these solutions?

A first alternative solution to network reinforcement is the curtailment of active power of distributed generation during critical network periods, which is considered in BMWi (2014), Enedis & ADEeF (2017), Netbeheer Nederland (2016) and VREG (2017). The amount of curtailment can be agreed on between the DG owner and DSO in a connection agreement, which is a regulatory measure that will be discussed in detail in the next chapter.

A second alternative solution to network reinforcement is to procure flexible resources in order to resolve local congestion problems (Enedis & ADEeF, 2017; Inesc Tec 2012; UKPN 2018). This flexibility can be contracted via longer-term connection agreements or short-term flexibility markets.

The studies of BMWi (2014) and Enedis & ADEeF (2017) also consider advanced network planning and strengthening the network with intelligent technologies as alternative solutions to network investments. In Greenpeace (2018), no alternative solution to grid reinforcements is mentioned.

Q5 - How effective are the proposed solutions?

The advantages of the alternative solutions discussed in the previous paragraph, are given in all impact studies except of Inesc Tec (2012) and Greenpeace (2018):

- DG curtailment. The benefits of DG curtailment are highly positive in BMWi (2014), Enedis & ADEeF (2017) and VREG (2017). BMWi (2014) shows that curtailment of the annual feed-in from DG by 3% would be enough to save 40% of additional network costs. In Enedis & ADEeF (2017) it is estimated that an investment in active power curtailment of €150,000 can create a benefit of €770,000 in the form of reduction of losses in the network and postponed or avoided investments. VREG (2017) indicates that using smart connection agreements with curtailment in distribution network planning will always result in the lowest social cost if appropriate regulatory choices are made. The effect of PV curtailment on the additional costs to customers in Netbeheer Netherland (2016) are limited, with a reduction of only 3%.
- Flexibility. The market based or contractual procurement of flexible sources currently results in mixed benefits. The impact study of UKPN (2018) indicates that flexibility auctions with an approximate cost of £30,000 a year can help to defer a reinforcement cost of £2 million for 4 years. On the contrary, the cost-benefit analysis of flexibility services in Enedis & ADEeF

(2017) shows more precautionary results as the implementation cost can be highly variable. Estimated benefits in investment postponement might go up to €24,000 per MW per year and the network operation gain might rise up to €20,000 per MWh. However, the actual savings will be highly dependent of the local situation.

	Included technologies?			Network challenge?		Challenge quantified?			Proposed solutions?			Solution effective?	
Impact study	Wind	Solar	Other	LV/MV	HV	Financial	Technical	No	Curtailment	Flexibility	Other	Yes	Other
BMWi, 2014 (Germany)	X	X		X	X	X	X		X		Advanced planning, intelligent network technologies	X	
Enedis & ADEeF, 2017 (France)	X	X		X	X	X	X		X	X	Advanced planning, intelligent network technologies	X for curtailment	Uncertain for flexibility
Greenpeace, 2018 (Spain)	X	X	Biomass, EV	X				X			Network reinforcements		
Inesc Tec, 2012 (Portugal)	X	X	CHP, EV	X				X		X			
Netbeheer Nederland, 2016 (The Netherlands)		X	EV, HP	X	X	X			X				Limited
VREG, 2017 (Flanders, Belgium)	X	X	CHP	X	X	X			X			X	
UKPN, 2018 (The UK)	X	X	EV, HP	X	X	X				X		X	

Table 2: Overview of impact studies on distributed generation

3.2. Electric vehicles

According to the NECPs, millions of electric vehicles are expected to drive on the roads of Europe by 2030. As these vehicles will be mostly charged through a connection with the distribution network, a significant impact of electric vehicles on the LV and MV grid is expected. Different studies are being conducted by system operators, research institutions, regulators and governments to estimate the ability of the national network to integrate these vehicles. The following studies from nine target countries are taken for analysis:

- The impact of electromobility on distribution network expansion during the energy transition in Germany performed by Navigant and commissioned by Agora Verkehrswende, Agora Energiewende and the Regulatory Assistance Project (Agora, 2019).
- Analysis of the developments in the area of electromobility by the Polish Government (Atmoterm, 2019).
- Challenges and needs for efficient deployment of EVs charging infrastructure in Spain (Deloitte, 2018).
- The integration of electric mobility in the French distribution network by the DSO Enedis (Enedis, 2019a).
- The impact of EV and PV on the Flemish LV Grid by the DSO Fluvius and Deloitte (Fluvius, 2019).
- The impact of the integration of electric vehicles in the distribution network in Spain, performed by the Spanish University Comillas (Frías, 2011).
- Intelligent electric networks with plug-in electric vehicles by the Portuguese R&D institute Inesc Tec (Inesc Tec, 2012).
- Future energy scenarios in the UK by the electricity system operator NationalGridESO (NationalGridESO, 2019).

- The value of congestion management by Ecofys on behalf of Netbeheer Nederland, which is an organisation of all electricity and gas network operators in the Netherlands (Netbeheer Nederland, 2016).
- The gains of coordinated charging by DNV GL and Pöyry Management Consulting for the Norwegian Water Resources and Energy Directorate (NVE, 2019a).
- The challenges of electromobility for the French electricity system by the Transmission System Operator (TSO) RTE (RTE, 2019).
- Pilot on smart charging of electric vehicles in the UK by the distribution network operator Western Power Distribution and the Network Innovation Allowance (WPD, 2019).

In this section, the impact studies on electric vehicles are compared and concluded by means of the following seven questions that were created for this deliverable based on the content covered in the studies. Table 3 gives an overview of the answers.

Q1 - What type of study is performed?

The impact on the distribution network can be studied by modelling the integration of EVs in (part of) the national grid (Agora, 2019; Atmoterm, 2019; Enedis, 2019a; Fluvius, 2019; Frías, 2011; Inesc Tec, 2012; NationalGridESO, 2019; Netbeheer Nederland 2016; NVE, 2019a; RTE, 2019) or by examining the network effects of EVs in a real-life pilot (WPD, 2019). The modelling approach can be useful to give more information on the arising grid challenges and the overall network impact on national scale, while pilots can gain more insight on feasibility of the proposed solutions.

The models used in the impact studies are typically based on real information of DSOs in common network areas and are scaled-up to simulate a larger part of the country (Agora, 2019; Fluvius, 2019; Frías, 2011; Inesc Tec, 2012; NVE, 2019a). The characteristics of these areas differ from country to country based on geography and population, but some main categories that can be distinguished are urban city, suburban municipality and rural municipality.

Q2 - What type of electric vehicles and other technologies are analysed?

Different vehicles types can be used to decarbonise the transport sector. The examined impact studies mainly focus on two types of electric vehicles: Battery Electric Vehicles (BEVs) and Plug in Hybrid Electric Vehicles (PHEVs). Other car types that can be included are hydrogen cars (NationalGridESO, 2019) and range extenders (WPD, 2019). While BEVs are included in all impact studies, PHEVs are often seen as transitional cars. Therefore, their market share reduces in the long term (Deloitte, 2018; Inesc Tec, 2012; NationalGridESO, 2019) or they are not included at all (Agora, 2019; Enedis, 2019a; Frías, 2011; Netbeheer Nederland, 2016; NVE, 2019a). However, several studies contain a steady mix of BEVs and PHEVs (Atmoterm, 2019; Fluvius, 2019; RTE, 2019; WPD, 2019).

The amount of EVs included in the analysed impact studies is often modelled in different scenarios. Impressive numbers of BEVs are taken into account in the most ambitious EV scenarios. For example, 15 million BEVs by 2030 and 45 million BEVs by 2050 in Agora (2019), 15.5M EVs by 2035 in RTE (2019), all passenger cars fully electric by 2040 in NVE (2019a) and 94% of electric cars in Netbeheer Nederland (2016) by 2050.

As electric vehicles will not be the only technology to have impact on the network, some impact studies also include the growth of other technologies that are discussed in this chapter. The growth of PV (Fluvius, 2019; Netbeheer Nederland, 2016) or DG (Agora, 2019; Enedis, 2019a; Inesc Tec, 2012; RTE, 2019) is included in most cases. Some studies go even further by also including the growth of HPs (Agora, 2019; Netbeheer Nederland, 2016).

Q3 - Which charging profiles are analysed?

While the number of future EVs is an important parameter that influences the outcome of the different impact studies, the way these cars will be charged also affects the results. It must be noted that there is a lack of consistency in terms and definitions that are used to describe the different charging technologies. Overall, four categories can be distinguished:

- Uncontrolled or dumb charging, in which the car starts charging when it is plugged in and stops charging when it is plugged out or the battery is full. (Agora, 2019; Atmoterm, 2019; Fluvius, 2019; Frías, 2011; Inesc Tec, 2012; NationalGridESO, 2019; Netbeheer Nederland, 2016; NVE, 2019a; RTE, 2019; WPD, 2019;)
- Load shifting, in which the charging is shifted to off-peak periods to relief the network. Often this is incentivized by a price signal such as Time-of-Use (ToU) rates in the retail and/or network component of the electricity tariff. (Agora, 2019; Atmoterm, 2019; Deloitte, 2018; Frías, 2011; Inesc Tec, 2012; NationalGridESO, 2019; Netbeheer Nederland, 2016; NVE, 2019a; RTE, 2019; WPD, 2019)
- Smart charging, which goes further than load shifting by optimizing and evenly distributing the charging over multiple parking periods. This charging technique is more advanced than load shifting and often performed by a third party. (Agora, 2019; Atmoterm, 2019; Deloitte, 2018; Frías, 2011; Inesc Tec, 2012)
- Vehicle-to-Grid (V2G), in which smart charging takes place and the car participates to ancillary services of the TSO. It is mostly a third party that offers V2G to EVs owners, which are financially compensated for their flexibility. (Inesc Tec, 2012; NationalGridESO, 2019; RTE, 2019)

Q4 - Which network challenges are examined?

While the main goal of the analysed studies is to address the impact of EVs on the distribution network, the way these challenges are examined is not always the same.

- Some studies focus on describing the network challenge as congestion or over loading of power lines and substations. (Agora, 2019; Deloitte, 2018; Enedis, 2019a; NationalGridESO, 2019; Netbeheer Nederland, 2016; NVE, 2019a; RTE, 2019; WPD, 2019)
- Other studies go more into technical detail by including network challenges such as voltage limit violations, violations of current limits, power loss increases (Atmoterm, 2019; Fluvius, 2019; Inesc Tec, 2012; Frías, 2011)

Besides that, challenges can arise at different voltage levels. While the scope is in general the distribution grid (Agora, 2019; Atmoterm, 2019; Deloitte, 2019; Enedis, 2019a; Fluvius, 2019; Frías, 2011; Inesc Tec, 2012; Netbeheer Nederland, 2016; NVE, 2019a; RTE, 2019; WPD, 2019), several studies also include the impact on the HV network (Agora, 2019; NationalGridESO, 2019; Netbeheer Nederland, 2016; RTE, 2019).

Q5 - Are these challenges quantified in the study and how are they measured?

Most studies quantify the estimated network challenge by technical and/or financial parameters, with the exception of Atmoterm (2019) and WPD (2019).

- Technical. The load profile of a network user that owns an electric vehicle is a technical parameter that is often analysed in impact studies. By aggregating these load profiles, it can be examined if the network lines and transformers will be able to take the local peak load or not (Fluvius, 2019; Frías, 2011; Inesc Tec, 2012; NationalGridESO, 2019; Netbeheer Nederland, 2016; NVE, 2019a; RTE, 2019). In some cases, this peak load is taken as input for further calculations such as the total length of network lines that need reinforcements (Fluvius, 2019). Another technical parameter that can be analysed is the amount of voltage and current harmonic distortions (Inesc Tec, 2012).
- Financial. Required network reinforcement or avoided investments by implementing flexible solutions are financial parameters that are used to quantify the arising network challenge (Agora, 2019; Deloitte, 2018; Enedis, 2019a; Frías, 2011; Inesc Tec, 2012; Netbeheer Nederland, 2016; NVE, 2019a; RTE, 2019). This paragraph focusses on required investments

without the implementation of flexible solutions. The expected network savings when implementing solutions are discussed in Question 6. Agora (2019) estimates that with dumb charging, investments of €35 billion or €72 billion will be required to integrate respectively 6 million or 15 million BEVs into the German distribution network. The study of Netbeheer Nederland (2016) estimates that without load shifting of EVs, Dutch households will pay an additional yearly cost of €277 to €407 for network reinforcements and energy production. The study of Enedis (2019) is an exception in estimating that the initial impact of EVs on the distribution network will be low. This is due to the robust and intelligent network that Enedis has been creating since the first adoptions of DG. It must be noted that it is rather unclear which charging profiles are assumed in these calculations.

Q6 - What are the proposed solutions and which incentives are used to encourage these solutions?

There are two types charging profiles that are proposed as major solutions to reduce or delay network investments. Both solutions are incentivised in different ways.

- Load shifting. A first solution, that is included in all impact studies, is load shifting. The pilot of WPD (2019) shows that this solution is effective and easy to implement. The advantages of loads shifting are also illustrated in other impact studies. Agora (2019) estimates that load shifting can reduce distribution network investments up to 50% by 2030. In Netbeheer Nederland (2016) the additional cost per household when applying load shifting (taking into account network investments, flexibility and production cost) is 47% lower compared to the additional cost per household with dumb charging. The study of NVE (2019a) indicates that 11 billion Norwegian krone can be saved by shifting EV charging away from the afternoon peak. There are different ways to incentivise load shifting. Customer can react to dynamic retail prices (Deloitte, 2018; Fluvius, 2019; Frías, 2011; Inesc Tec, 2012; NationalGridESO, 2019; NVE, 2019a; RTE, 2019; WPD, 2019) or to dynamic distribution tariffs (Agora, 2019; Atmoterm, 2019; NVE, 2019a).
- Vehicle-to-Grid. A second solution is V2G, which is included in half of the impact studies (Atmoterm, 2019; Frías, 2011; Inesc Tec, 2012; NationalGridESO, 2019; NVE, 2019a; RTE, 2019). None of the impact studies quantifies the financial benefits of V2G. The compensation received in the balancing market serves as a financial incentive to enter a V2G contract with a third party.

Also, explicit control by third parties that offer compensations or by DSOs that charge reduced tariffs can be a solution to reduce network reinforcements (Agora, 2019; Fluvius, 2019; NVE, 2019a; RTE, 2019). Other ways to reduce network challenges are limiting charging connections (Fluvius, 2019), increasing renewable self-consumption (Enedis, 2019a; RTE, 2019) and vehicle to home optimisation (NVE, 2019a; RTE, 2019).

Q7 - Conclusion of the study?

Half of the analysed studies expect the impact of electric vehicles on the network to be large, but with a solution as load shifting by ToU pricing, the required network investments can be limited (Agora, 2019; Atmoterm, 2019; Netbeheer Nederland, 2016; NationalGridESO, 2019; NVE 2019a; WPD, 2019). V2G can create extra benefits (NationalGridESO, 2019), however it is possible that this remains a niche market according to RTE (2019) and NationalGridESO (2019). Besides that, Atmoterm (2019) and Fluvius (2019) suggest that, initially, the existing network can address the impact of EVs, but in the long-term network reinforcements will be needed. The studies of Enedis (2019a) and RTE (2019) in France indicate that for the integration of EVs, no more investment than in the past will be required.

It can be interesting to compare the challenge of integrating DG and EVs in the distribution network. Fluvius (2019) estimates the impact on the Flemish distribution network to be higher for EVs than for DG. On the contrary, the French DSO Enedis (2019) expects the network investments due to growth of EVs to be less than the amount linked to the growth of DG.

	Type of study?		Included technologies?			Studied charging profiles?				Network challenge?		Challenge quantified?			Proposed solutions?			Proposed incentives load shifting?	
Impact study	Model	Pilot	BEV	PHEV	Other	Dumb	Load shifting	Smart	V2G	LV/MV	HV	Technical	Financial	No	Load shifting	V2G	other	Dynamic retail	Dynamic distribution
Agora, 2019 (Germany)	X		X		DG, HP	X	X	X		X	X		X		X		X		X
Atmoterm, 2019 (Poland)	X		X	X		X	X	X		X				X	X	X			X
Deloitte, 2018 (Spain)			X	X			X	X		X			X		X			X	
Enedis, 2019a (France)	X		X		DG					X			X		X		X		
Fluvius, 2019 (Flanders, Belgium)	X		X	X	PV	X				X		X			X		X	X	
Frías, 2011 (Spain)	X		X			X	X	X		X		X	X		X	X		X	
Inesc Tec, 2012 (Portugal)	X		X	X	DG	X	X	X	X	X		X	X		X	X		X	
NationalGridESO, 2019 (The UK)	X		X	X	Hydrogen	X	X		X		X	X			X	X		X	
Netbeheer Nederland, 2016 (The Netherlands)	X		X		PV, HP	X	X			X	X	X	X		X				
NVE, 2019a (Norway)	X		X			X	X			X		X	X		X	X	X	X	X
RTE, 2019 (France)	X		X	X	DG	X	X		X	X	X	X	X		X	X	X	X	
WPD, 2019 (The UK)		X	X	X	Range extenders	X	X			X				X	X			X	

Table 3: Overview of impact studies on electric vehicles

3.3. Heat pumps

While the amount of heat pumps is expected to grow in the future according to the NECPs of the examined target countries, particular national ambitions and impact studies of this technology are still limited. In this section, the following four studies from the Netherlands and the UK are compared:

- System costs of heating for households in the Netherlands performed by Ecofys and ECN on behalf of Alliander, Gasunie and TenneT (Ecofys, 2015).
- Heat pump trail in the UK called the Freedom Project by Western Power Distribution and Wales & West Utilities, performed by PassivSystems in cooperation with Imperial College, Delta-ee and City University (Freedom, 2018).
- The value of congestion management by Ecofys on behalf of Netbeheer Nederland, which is an organisation of all electricity and gas network operators in the Netherlands (Netbeheer Nederland, 2016).
- Cost analysis of future heat infrastructure options in the UK by Element Energy and E4tech for the National Infrastructure Commission (NIC, 2018).

The following five research questions were developed to examine if the future electricity demand of HPs could create congestion problems to the distribution network and how this challenge could be reduced. Table 4 gives an overview of the findings of each impact study.

Q1 - What type of study is performed?

Similar to electric vehicles, the impact of the upcoming technology can be analysed by modelling the network on national level or by conducting a pilot at a more local area. Three models (Ecofys, 2015; Netbeheer Nederland, 2016; NIC, 2018) and one pilot (Freedom, 2018) are included in this section. National wide models are an extrapolation of several living environments such as city centres, small villages or rustic houses. Assumptions on the number of houses, heat demand per household and deployment of the distribution network in these living environments differ from country to country.

Q2 - What heating technologies are considered?

Although Netbeheer Nederland (2016) fully focuses on heat pumps, other heating technologies such as hybrid heat pumps (HHPs), district heating, gas boilers, electric resistive heaters, biofuels and micro CHP are included in Ecofys (2015), NIC (2018) and Freedom (2018). While Ecofys (2015) and NIC (2018) try to examine possible pathways of these different technologies, the pilot Freedom (2018) makes a clear comparison between heat pumps and hybrid heat pumps.

Q3 - What type of buildings are included in the study?

There are studies that focus on one building type, and studies that consider a mix of different types of buildings. The total heat demand and thus network challenge of integrating heat pumps is highly dependent on the assumed building types and insulation levels. If the study fails to include the appropriate mix of buildings, the estimated impact on the network can be much higher or much lower.

- One building type. In Netbeheer Nederland (2016), the heat pump scenario is only a small part of the study that also looks at the impact of PV and EVs. Therefore, the analysed building mix and demand profiles are limited to terraced houses.
- Mix of buildings types. In a more detailed study of Ecofys (2015) on the future of heating, different households' types such as terraced houses, corner houses, apartments and sole buildings with different insulation rates are analysed. Also, the modelling study of NIC (2018) and the pilot Freedom (2018) include a mix of different building types. It is important to note that in NIC (2018), all houses are renovated until high thermal efficiency before a heat pump is installed. This assumption moves part of the network costs to building renovation costs. It is therefore always important to look both at the required investments of network as of buildings to analyse the full impact of the integration of heat pumps.

Q4 - What network challenges are arising and how are they quantified?

In the four studies, congestion problems at all voltage levels are examined. The challenges are quantified by the expected required network reinforcement costs without implementation of solutions at each voltage level.

The study of Netbeheer Nederland (2016) estimates that without management of HPs, Dutch households will pay an additional yearly cost of €221 to €332 for network investment and energy production in a dominant heat pump scenario. Of all heating technologies analysed in Ecofys (2015), the highest network reinforcement costs are required in the scenario with high shares of heat pumps and medium insulation rates in buildings. Yearly additional costs are estimated to be €10 billion at distribution and €2 billion at transmission level. Renovating buildings up to high thermal efficiency can decrease the network investments by 75%. However, this implies that yearly costs of buildings increase from €8.6 billion to €15.4 billion. In the study of NIC (2018), any deep electrification option will lead to an additional peak electricity demand of at least 45 GW. The capability to generate and distribute this additional electricity demand would represent a major infrastructure investment over the next 30 years, including around £20 billion associated with the distribution network. Similar, in

Freedom (2018), up to about £1.7 billion should be invested into the South Wales electricity distribution network by 2050 to accommodate the baseline load growth and the growth of HPs.

Q5 - Which solution are being proposed and what can be concluded?

There are four ways to reduce the network challenge of integrating heat pumps into the distribution network:

- Buildings. Overall, insulation and renovation works in buildings are a solution to move to a fully decarbonated cooling and heating sector. As this lowers the heat demand and creates opportunities for load shifting, the impact of building on the required network investments will be important (Ecofys, 2015; NIC, 2018).
- Load shifting. While load shifting is the recognised solution to integrate EVs into the network, it is not yet being considered as much for heat pumps. This can be because storing heat in a room is more complex and dependent on external parameters than storing energy in a battery. The study of Netbeheer Nederland (2016) shows that possible saving on yearly additional cost for households can be around 31% when performing load shifting. Also, in the Freedom project (2018), preheating of rooms to avoid network peaks was successfully implemented.
- Flexibility. Also heat pumps could participate in flexibility services such as ancillary services of the TSO. The Freedom project (2018) analyses the potential of (hybrid) heat pumps as a flexibility provider.
- Alternative heating technologies. A first alternative technology that can be used to reduce heat demand during peak moments are hybrid heat pumps. Here, a smaller gas boiler is still installed next to the heat pumps and is activated during network peaks. The Freedom Project (2018) estimates that by moving from a full HP to a complete HHP scenario, accumulated network savings by 2050 at all network levels of South Wales's network can be around £1.4 billion. Ecofys (2015) and NIC (2018) are rather designed for explorational purposes of the heating sector than for picking one future heating solution. The main focus is to see how much emissions savings are possible at which system cost for each technology. As results are very differentiated, the studies like to use this diversity as a solution, by moving to a mixture of different technologies in the future.

	Type of study?		Included heating technologies?			Type of building?	Network challenge?		Proposed solutions?			
Impact study	Model	Pilot	HP	HHP	Other		LV/MV	HV	Buildings	Load shifting	Flexibility	Alternative technologies
Ecofys, 2015 (The Netherlands)	X		X	X	X	Mixed	X	X	X			X
Freedom, 2018 (The UK)		X	X	X		Mixed	X	X		X	X	
Netbeheer Nederland, 2016 (The Netherlands)	X		X			Terraced house	X	X		X		
NIC, 2018 (The UK)	X		X	X	X	Mixed	X	X	X			X

Table 4: Overview of impact studies on heat pumps

3.4. Stakeholder perspective on the regulatory toolbox

It is interesting to see which flexibility tools the different impact studies propose to address the upcoming network challenges of integrating new network users. In Figure 1, all impact studies on DG and EVs are mapped to their proposed regulatory solutions. The studies of Greenpeace (2018) on DG is not included as only network reinforcements are proposed as solution. On the regulatory toolbox of EVs, Enedis (2019a) and Netbeheer Nederland (2016) are excluded from the figure as it is unclear which flexibility mechanisms were suggested as a solution. No mapping is performed for impact studies on HPs as only a limited number of studies were analysed in this deliverable.

There are two major types of regulatory mechanisms to which the impact studies are categorized:

- Implicit flexibility mechanisms, in which network users react to variable price signals. Both dynamic distribution tariffs and dynamic retail prices are seen as implicit flexibility mechanisms. Dynamic distribution tariffs refer to the regulated price component of retail tariffs that DSOs use to recover network usage and investment costs. Dynamic retail prices cover the energy part of the total retail tariffs, which is set by the market or retailer and represent the purchase cost of electricity (CEER, 2020).
- Explicit flexibility mechanisms, where flexibility of network customer is explicitly activated due to a contractual of market incentive. Both smart connection agreements and flexibility markets can be seen as explicit flexibility mechanisms.

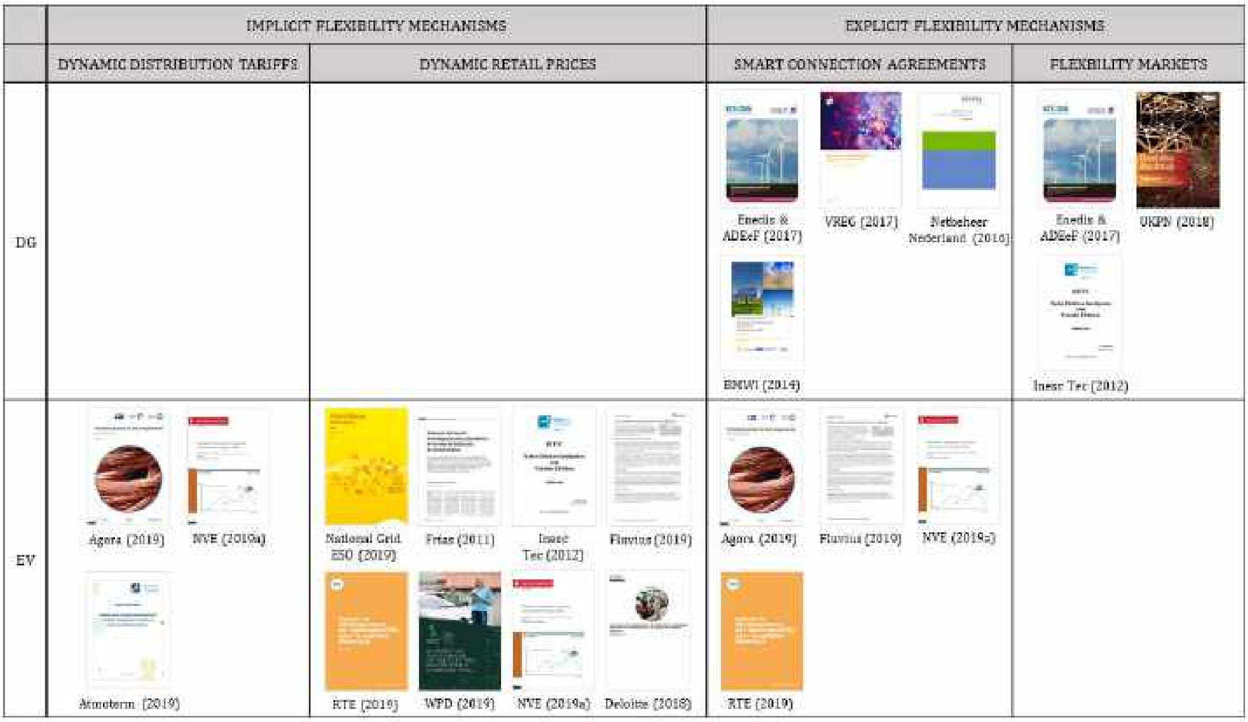

Figure 1: Stakeholder perspective on regulatory toolbox

From Figure 1 can be derived that the flexibility of distributed generation is most likely to be activated by explicit flexibility mechanisms. Hereby, the curtailment of DG by a smart connection agreement is the most popular solution in the impact studies to reduce the challenge of integrating renewables in the network.

In contrast, most impact studies on EVs suggest implicit flexibility mechanisms to integrate large shares of electric vehicles in the distribution network in a cost-efficient way. Reflecting dynamic retail prices and network tariffs to EV owners can incentivise charging behaviour outside peak hours of the network such that peak consumption can be reduced and network benefits can be created. However, some studies also suggest explicit flexibility mechanisms such as active control and limitations to the charging connection of electric vehicles as a solution to reduce network reinforcements.

4. Regulatory tools to source flexibility

The previous chapter indicates that a cost-efficient integration of new network users, such as DG, EVs and HPs, will require are regulatory framework of implicit and explicit flexibility mechanisms. This chapter discusses the current implementations and developments of three of these regulatory tools to source flexibility: distribution network tariffs, connection agreements and flexibility markets. In this way, an idea of how these regulatory instruments can be designed and how complex they might become in the future is given.

4.1. Distribution network tariffs

In this section, we will discuss the regulatory framework of distribution network tariffs that should not be confused with retail energy prices. Typically, DSOs charge use-of-system distribution network tariffs to recuperate network usage costs from grid users in a regulated way. Therefore, the main objective of these use-of-system charges has been to reflect network operation costs and investments e.g. for network maintenance, replacements, extensions and reinforcements. Recently, a second purpose is added to distribution network tariffs: sending price signals for efficient network usage. By reacting to granular tariff signals, network users can valorise their flexibility and their impact on the network.

The aim of this section is to analyse to which extent current and future distribution network tariffs of the target countries meet these two tariff purposes by showing the possible complexity and design choices of distribution network tariffs, rather than giving a complete representation of all regulatory measures. The following five research questions were developed to meet this purpose. Table 5 gives an overview of the findings of distribution network tariffs in eight target countries.

Q1 - Is the analysed distribution network tariff currently in place or a planned reform?

In recent years, the cost reflectiveness of volumetric distribution network tariffs has been questioned. As a result, network tariffs are/were being reformed in several European countries. In this section, network tariffs that are currently in place (Belgium, France, Germany, Norway, Poland, Portugal, the UK) and planned tariff reforms (Flanders, Norway, Spain, the UK) or pilot projects (Portugal) of the ten target countries are analysed.

Q2 - Which network costs are addressed? Are sunk and forward-looking costs treated separately or not?

To create a cost-reflective and flexible distribution network tariff, system charges can best consist of two elements: residual charges and forward-looking charges. Ofgem (2017) differentiates the cost components as follow:

- Residual charges can be used to reflect sunk or fixed network costs and are preferably recovered by a fixed tariff component.
- Forward-looking charges reflect running costs and give signals to customers for efficient network usage. This can be achieved by a combination of volumetric and (peak) capacity tariff components.

While this approach on use-of-system cost is extensively covered in literature, its application in practice is still limited (e.g. only the distribution tariff in Germany and planned tariff reforms in Norway and the UK clearly make this distinction).

Q3 - Of which components does the tariff exist?

Typically, three different tariffs components can be distinguished: a fixed charge (€/connection), a volumetric element (€/kWh) and a capacity component (€/kVA). In the following paragraphs, we discuss the details of the distribution network tariffs of eight target countries.

Belgium. Three different tariffs structures are present in Brussels, Flanders and Wallonia as distribution network tariffs are a regional regulatory responsibility in Belgium. Since the last regulatory period (2020-2024), the distribution network tariff of all grid users in Brussels contains a volumetric and capacity-based component. For all small consumers (<56 kVA) and big consumers (>56 kVA) without metering point that are connected to the low voltage level, the capacity charge is based on contracted capacity. For big consumers with metering point or users connected to higher voltage levels, the capacity component reflects the peak consumption (Sibelga, 2020). Besides that, customers and small companies in Flanders currently pay use-of-system charges based on a complete volumetric component (VREG, 2020a). A correction is implemented for prosumers to increase the cost-reflectiveness of the tariff. PV owners without smart meter pay an extra fixed component based on connection size of the solar installation (VREG, 2020b). Big companies in Flanders currently pay both a volumetric and a peak consumption capacity-based charge (VREG, 2020c). In 2022, the Flemish regulator VREG aims to reform the tariffs structure for customers and small companies to a volumetric and capacity component, which will be based on the peak consumption over the last 12 months (VREG, 2020d). The tariff for big companies in Flanders will become fully capacity-based, depending both on the connection size and 15 min peak consumption over the past month. (VREG, 2020c). In Wallonia, small consumers (<56 kVA) and big consumers (>56 kVA) without metering point that are connected to the low voltage level have a purely volumetric based tariff. Other network users are subjected to a tariff with both a volumetric and a peak capacity consumption component (CWaPE, 2019; CWaPE, 2020).

France. Small consumers connected to the low voltage network in France are charged by a volumetric and contracted power component that both have different pricing rates dependent on the duration of connection and type of user (e.g. self-consumption). The tariff of customers connected to the low voltage network with a connection size of >36kVA or to higher voltage levels consists of a volumetric and peak consumption capacity-based component (Enedis, 2019b).

Germany. The distribution network tariff in Germany consists of a fixed and volumetric component for consumers without metering point at all voltage levels and a volumetric and yearly peak capacity peak for metered customers at all voltage levels. According to the § 19 StromNEV regulation (BMWi, n.d. c), an extra monthly capacity component is charged to metered consumers with a temporarily high voltage consumption. Besides that, interruptible consumer installations such as heat pumps, electric heating and others defined in the § 14a EnWG regulation (BMWi, n.d. a) are charged a sole volumetric-based tariff and can receive a discounted price. Other discounts to distribution tariffs can be provided under the § 18 Abs. 2 StromNEV regulation (BMWi, n.d. b), which possibly limits the effectiveness of dynamic prices (Bonn-Netz, 2020; MINTNETZ STROM, n.d.; N-ERGIE Netz, 2020).

Norway. The current distribution tariff of small Norwegian consumers (<100kW) that are connected to low voltage network consists for 1/3 of fixed and 2/3 of volumetric charges. A few DSOs decided to add a capacity-based component to this tariff. For big consumers (>100kW) at low voltage level and customers at higher voltage levels, a capacity-based component has been introduced beside a fixed and volumetric component for years. In order to make distribution network tariffs more reflective for small low network users, the Norwegian Energy Regulatory Authority proposed a planned reform for 2022. The tariff should consist of an energy component and a fixed charge, but a capacity-based component stays a voluntary choice of each DSO. While the energy components will reflect the short-term marginal cost of the network, residual costs will be recovered by a fixed or capacity-based charge that will be differentiated to customers based on their power demand (CEER, 2020; Eriksen & Mook, 2020).

Poland. The distribution network tariff of households and small consumers at LV level in Poland consists of a fixed and volumetric component. Besides that, large consumers at low voltage level and all customers at medium and high voltage levels are charged a volumetric and monthly capacity-based tariff. A reform to more dynamic tariffs is expected as part of Poland's Electromobility Development Plan (Ministerstwo Energii, 2019; PGE Dystrybucja, 2020).

Portugal. Low voltage network users in Portugal are charged a tariff with a volumetric and contracted power component to recuperate use-of-system network charges. For higher voltage levels, the power term is based on both contracted capacity and peak capacity consumption (ERSE, 2019).

Spain. Low, medium and high voltage network customers in Spain will be subjected to tariffs with a volumetric and contracted capacity component as of April 2021. The capacity component is significant, consisting of 88% of the charge for low voltage users and 70% for medium and high voltage users (CNMC, 2019/2020).

The UK. Customers at extra-high voltage levels in the UK are subjected to nodal distribution network prices under the EHV Distribution Charging Methodology. Network users at lower voltage levels are charged following the Common Distribution Charging Methodology (CEER, 2020). The tariff of domestic users and small business currently consists of a fixed and volumetric component. For big companies at all voltage levels, a capacity term is added. This capacity component exists of a charge for contracted capacity and an extra cost when this amount of power withdrawal is exceeded (WPD, 2018). From 2022 onwards, DSOs in the UK will address sunk costs by a fixed tariff component. In a later tariff reform, also forward-looking charges will be addressed separately by a price-reflective volumetric and capacity-based component (Ofgem, 2019).

Q4 - How granular is the tariff?

A first category to make distribution tariffs more dynamic is temporal granularity, in which charges differentiate over the time of the day, or even the time of the year. In this way, peak periods of the network may be charged higher prices, incentivising customer to consume less during these periods and relieving network constraints. There is no temporal granularity in current distribution network tariffs of Germany and Norway, and the future distribution tariff of Flanders. Temporal granularity can occur in the volumetric- and/or capacity-based component of the tariff.

- Volumetric component. A basic form of temporal granularity is to distinguish energy consumption during peak and off-peak or day and night by charging different prices. This tariff can be chosen by all network users in Brussels, Flanders, France and Poland, by medium voltage users in Wallonia and by low voltage customers in Portugal and the UK. The amount of stages can be extended to 3 periods (large LV consumers and all MV and HV customers in Poland; LV users in Portugal; future LV, MV and HV users in Spain; all customers in the UK) or even 4 periods (LV users in Wallonia; MV and HV customers in Portugal; Pilot 1 of EDP Distribuição). Temporal granularity can be improved by adding seasonality to the tariff components. In this way, tariff prices and periods change depending on the network stress during the season. Two seasons are present in the energy tariff component of MV and HV customers in Portugal and all network users in France. Also in Spain, the 3 periods in the future tariff structure of MV and HV consumers will change along 4 defined seasons. Temporal granularity is also provisioned in the volumetric component of the future tariffs of Norway, where the volumetric component will represent the marginal cost of the network at all times.
- Capacity component. Adding temporal granularity to the capacity component of tariffs can also improve the signal for efficient network usage. Optimally, the capacity component reflects the cost of peak power consumption during critical network moments. For big consumers at low voltage and network users at medium and high voltage levels in France, the capacity component of the tariff changes along 2 or 3 daily periods and 2 seasons. In Spain, low voltage users will react to 2 periods in the capacity component of the tariff and Spanish MV and HV customers will be subjected to a 3 period capacity component that changes among 4 seasons. Pilot 1 of EDP Distribuição in Portugal experimented with a tariff that has a capacity-based component of two periods and three seasons. Also, Norway and the UK plan to have temporally granularity in the capacity component of future tariffs.

A second category is location granularity. By having varying tariffs in each region, local network characteristics such as congestion can be reflected in the charges and divided among the contributing network customers. This type of locational granularity is not yet implemented everywhere as for example France and Portugal have the same distribution prices charged over the whole country. There is limited locational granularity in the tariff structures of Belgium, Germany, Poland and the UK as different prices are charged among DSOs or in separate regions of the country. This is also the case in Norway, but more granularity is reached by some regions there are DSOs that charge a capacity component, while others do not. Besides that, there is limited locational granularity in Spain, as the seasons on which the temporal granularity is based differ on the Spanish islands compared to the main land. Similar, in the Portuguese pilot of EDP Distribuição, local network characteristics are taken into account by varying the temporal granularity in different regions.

Q5 - To which customer class(es) do these tariffs apply?

In the studied countries, tariffs are always default to all customers. However, the design of the tariff such as granularity and components can be differentiated among customer categories and/or voltage levels.

	Practice?		Addressed network costs?			Tariff components?			Granularity?			Customer class?
Country	Currently in place	Planned reform	Sunk	Forward looking	No distinction	Fixed	Volume	Capacity	Locational	Temporal energy	Temporal capacity	
Belgium, Brussels (Sibelga, 2020)	X				X		X	X		2 periods		LV<56 kVA or LV>56kVA w/o metering point
	X				X		X	X		2 periods		Trans MV, MV, Trans LV, LV>56kVA
Belgium, Flanders (VREG, 2020a; VREG, 2020b; VREG, 2020c; VREG, 2020d)	X				X		X		X	2 periods		Household and small companies
	X				X	X	X		X	2 periods		Prosumers without smart metering
	X				X		X	X	X	2 periods		Big companies
		X			X		X	X	X			Households and small companies
		X			X			X	X			Big companies
Belgium, Wallonia (CWaPE, 2019; CWaPE, 2020)	X				X		X		X	4 periods		LV<56 kVA or LV>56kVA w/o metering point
	X				X		X	X	X	2 periods		Trans MV, MV, Trans LV, LV>56kVA
France (Enedis, 2019b)	X				X		X	X		2 periods 2 seasons		LV <36kVA
	X				X		X	X		2 periods 2 seasons	2 periods 2 seasons	LV >36kVA
	X				X		X	X		2 periods 2 seasons + 1period	2 periods 2 seasons + 1period	MV, HV
Germany (Bonn-Netz, 2020; MINTNETZ STROM, n.d.; N-ERGIE Netz, 2020)	X		X	X		X	X		X			All voltage levels without metering of load profiles
	X		X	X			X	X	X			All voltage levels with metering of load profiles
	X		X	X			X		X			Interruptible consumer installations[2]

[2] Interruptible consumer installations such as electric heating, heat pumps, others defined in the §14a EnWG regulation (BMWi, n.d. a).

Norway (CEER, 2020; Eriksen & Mook, 2020)	X				X	X	X	(X)	X			LV<100kW
	X				X	X	X	X	X			LV>100kW, MV, HV
		X	X	X		X	X	(X)	X	X	(X)	LV<100kW
Poland (Ministerstwo Energii, 2019; PGE Dystrybucja, 2020)	X				X	X	X		X	1 or 2 periods		Households and small LV customers
	X				X		X	X	X	1, 2 or 3 periods		Large consumers at LV, all MV, all HV
Portugal (EDP distribuição, 2018; ERSE, 2019)	X				X		X	X		1, 2 or 3 periods		LV
	X						X	X		4 periods 2 seasons		MV, HV
		Pilot			X		X	X	X	4 periods	2 periods 3 seasons	MV, HV, EHV
Spain (CNMC, 2019/2020)		X			X		X	X		3 periods	2 periods	LV
		X			X		X	X		3 periods 4 seasons	3 periods 4 seasons	MV, HV
The UK (Ofgem, 2019; WPD, 2018)	X				X	X	X		X	1, 2 or 3 periods		Domestic and small business
	X				X	X	X	X	X	3 periods		Large business
		X	X	X		X	X	X	X	X	X	LV, MV, HV

Table 5: Overview of national regulation on distribution network tariffs

4.2. Connection agreements

Typically, network users could enter a simple connection agreement where they pay a connection cost in exchange for assured grid access. However, with increased probability of congestion at distribution level, a firm connection might not always be guaranteed anymore or might simply become too expensive to guarantee. As a result, more smart types of connection agreements are being introduced to relieve the network at critical moments.

The design of these non-firm agreements can take various forms. In this section, we want to give an idea of the diversified regulatory implementations that currently exist of this flexibility tool by answering the following research questions. Table 6 gives an overview of the answers of six target countries.

Q1 - Is the analysed connection agreement currently in place or a planned reform?

Some countries have plans to implement flexible connection agreements, others already implemented them. No information on connection agreements was found for Italy, Portugal and the Netherlands.

- Currently in place. Wallonia (CWaPE, 2017), Germany (BMWi, 2014; Bundesnetzagentur, 2018), Norway (NVE, 2019b) and the UK (ENA, n.d.) already have connection agreements with varying amount of flexibility in place. For the UK, flexible connections of UK Power Networks (UKPN, n.d.) are analysed in this section. Other DSOs such as Electricity North West (Electricity North West, 2020), Northern Powergrid (Northern Powergrid, 2020) and Scottish & Southern Electricity Networks (SSEN, n.d.) also offer connection agreements to customers. While the overall designs of connection agreements in the UK are comparable, some details that are discussed here for UKPN may not be the same for other DSOs.
- Planned reform. Flanders (VREG, 2017), France (Enedis, 2018) and Spain (CNMC, 2019) are planning to have some type of smart connection agreement implemented in the future. In Germany, a reform of feed-in management is planned. From October 2021, feed-in

management will be integrated into the redispatch scheme of the operational planning phase. In this way, emergency-based feed-in management is replaced by a planned process such that less system imbalance will be caused by curtailment.

Q2 - Which network challenge does the connection agreement address?

Two network challenges can be distinguished:

- Critical network cases. A first goal of smart connection agreements is to react to critical network situations in order to maintain security of supply. This is the purpose of the connection agreements in Wallonia, Norway, Spain and the UK, and the feed-in management regulation in Germany. In Norway, such type of connection agreements is provisional and can only be entered when the required network investments for a full connection will be undertaken by the DSO.
- Active system management. A second application is using smart connection agreements in active system management and network planning. In this way, DSOs are allowed to use curtailment as an alternative to network reinforcement and use it as a tool to manage their network in a more economical and flexible way. The Flemish regulator VREG and the French DSO Enedis want to offer such connection agreements to renewable energy sources in the future. In Germany, DSOs already have the right to include curtailment of solar and wind in network planning to save network investments and also several DSOs in the UK (Electricity North West, 2020; Northern Powergrid, 2020; SSEN, n.d.; UKPN, n.d.) already use flexible connections in active system management.

Q3 - Which technologies are targeted?

In different impact studies on distributed generation, smart connection agreements are suggested as a solution to reduce grid congestion and save network investments. As a result, the 3% curtailment rule in Germany and the connection agreements in Flanders, France and Spain, are designed specifically for renewables. The regulation in Wallonia and Norway, the feed-in management regulation in Germany and the flexible connections of UKPN do not discriminate between technologies and offer smart connection agreements to all types of generation sources. UKPN is planning to extend its scope even more, by contracting flexible connections to storages and loads in the near future. Besides that, it must be noted that in this deliverable, the described design of the German feed-in management regulation focuses on its application to renewable energy sources instead of all generation sources.

Q4 - How is the amount of curtailment determined?

A first approach to determine the allowed curtailment of the connection agreement is capacity-based. In this way, the connection capacity is divided into a firm and a flexible part that may be curtailed by the DSO. This is the case in the connection agreements of Wallonia, France, Norway, Spain and UKPN. For UKPN, the firm capacity is determined by the LIFO principle, in which new customers are first curtailed, before curtailing generation that already have been connected for a longer time. The feed-in management regulation and 3% curtailment rule in Germany do not divide the connection capacity into a firm and non-firm part, rather curtailment is activated in steps of 30%, 60% and 100% of the connection capacity. From the German reform in October 2021 onwards, curtailment may also be activated at different capacity rates.

A second type of connection agreement is based on a maximum amount of yearly curtailed energy. This energy component can be based on the amount of injected (France; 3% curtailment rule Germany) or produced (Flanders) energy. It must be noted that the French DSO Enedis first wants to introduce a capacity-based connection agreement and later an injected energy-based connection offer.

Q5 - Is the agreement entered by default or by consent?

On the one hand, generation sources will enter a connection agreement by default. For example, in Wallonia, all new electricity production facilities with a capacity of more than 250 kVA will be connected flexibly. In Germany, feed-in management applies to all generation sources and DSOs have the power to imply the 3% curtailment rule on all renewable energy sources connected to their network.

On the other hand, DSOs offer smart connection agreements to new generators that can choose to agree on this proposal or not. Hereby, the customer makes a trade-off between the value of a firm connection, the cost of each type of connection, and the potential compensation received in the smart connection agreement. This is the case for the flexible connection proposal in Flanders, the future access agreements in Spain, the smart connection offers in France and UKPN, and the provisional connection agreements in Norway.

Q6 - Is there a compensation in case of curtailment?

Most connection agreements compensate the cost of lost production to curtailed generation sources. However, some exemptions where no compensation is given can exist. In Flanders and Wallonia, non-produced energy due to curtailment of firm capacity is always compensated, while no compensation is given for reasons of emergency or to non-firm parts of the connection. Renewables under the German feed-in management regulation and 3% curtailment rule are currently always compensated for curtailed energy. However, from October 2021, the compensation will be taken care of in the redispatch scheme of the operational planning phase

While we see that a lot of countries compensate by repaying lost production, other compensation mechanisms can also be in place. For example, Enedis and UKPN incentivise customers to enter flexible connection agreement by offering reduced connection cost and a shorter connection delay. In Spain and Norway, no compensation is given to curtailed customers in critical network situations.

	Practice?		Addressed network challenge?		Targeted technology?		Curtailment?		Agreement?		Compensation?		
Country	Currently in place	Planned reform	ASM and planning	Critical cases	RES	All generation	Capacity based	Energy based	By default	By consent	Curtailed energy	Other	No
Belgium, Flanders (VREG, 2017)		X	X		X			X		X	X		X
Belgium, Wallonia (CWaPE, 2017)	X			X		X	X		X		X		X
France (Enedis, 2018)		X	X		X		X	X		X		X	
Germany feed-in management (Bundesnetzagentur, 2018)	X	X		X		X	X		X		X		X
Germany 3% curtailment rule (BMWi, 2014)	X		X		X		X	X	X		X		
Norway (NVE, 2019b)	X			X		X	X			X			X
Spain (CNMC, 2019)		X		X	X		X			X			X
The UK (ENA, n.d.; UKPN, n.d.)	X		X			X	X			X		X	

Table 6: Overview of national regulation on connection agreements

4.3. Flexibility markets

Flexibility markets are a third regulatory tool that is developed to procure flexibility for DSOs' congestion management in a market-based setting. While flexibility markets are not yet defined in most national regulation, various pilots and research projects already exist, e.g. Piclo Flex, Enera, GOPACS and NODES. In Schittekatte & Meeus (2020), the following five questions were determined to summarize the design possibilities of flexibility markets:

- Is the flexibility market integrated in other existing energy markets? Flexibility markets can be separate or integrated in the zonal intraday market, the TSO redispatching market and/or the TSO balancing market.
- Who operates the flexibility market? The market operator can be a third party, a single DSO or TSO, or a combination of DSOs and TSOs.
- Is there a reservation payment?
- Are there standardized products or can the products change, based on the needs of the market organizer?
- Is there cooperation for market organization? Typically, there is coordination between DSOs and/or between TSOs and DSOs.

A detailed analysis of the design of flexibility markets with additional research questions will be performed on an extensive list of pilots and research projects in deliverable D1.2 of the EUniversal project.

5. Intermediaries to valorise flexibility

5.1. (Independent) Aggregators

A first actor that can help to unlock flexibility of grid users is the aggregator. Definitions, characteristics and functionalities of aggregators are described in the Electricity Directive of the Clean Energy Package (European Council, 2019). An aggregator combines multiple loads, storages or generated electricity of customers for its sale, purchase or auction in any electricity market (D2019/944 Art.2(18)). As aggregators are allowed to participate in any electricity market, also transmission system operators and distribution system operators must allow them to their markets in a non-discriminatory way (D2019/944 Art.17(2)). As a results, aggregators can provide a large range of flexibility services and can be seen as an intermediary between electricity markets and flexible sources located at distribution level. Suppliers can take up the role of aggregation, but due to slow developments, also independent aggregators, which are not affiliated to the customer's supplier, started to arise (D2019/944 Art.2(19)). All customers' rights and rules for aggregators' market participation can be found in Art.12, Art.13 and Art.17 of Directive 2019/944.

From the following figure (Figure 2) of the SmartEn market monitor in 2019 can be deduced that a significant number of actors are currently active across Europe to develop demand-side flexibility. With around 45 players, the market in Great Britain is currently the most competitive one (SmartEn, 2019). The actors are mainly independent aggregators and electricity suppliers. This shows that, in the future, (independent) aggregators will play an important role in valorising demand-side management and flexibility in generation and/or energy storage assets of customers.

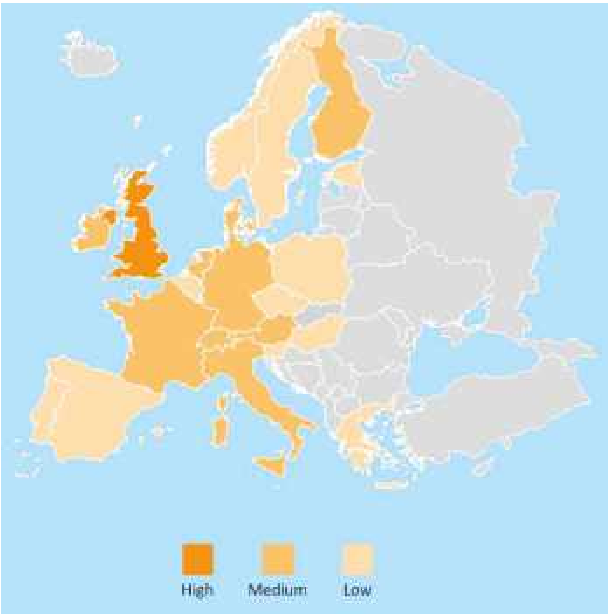

Figure 2: Development of demand-side flexibility actors across Europe (SmartEn, 2019)

5.2. Energy communities

A second actor to which customers can participate in order to monetize their flexibility are energy communities. In the Clean Energy Package, there are two types of energy communities defined that can be distinguished based on membership, shareholders, activities, technology and geographical scope. Renewable Energy Communities (REC) are covered in the Renewable Energy Directive (European Council, 2018) and Citizen Energy Communities (CEC) are described in the Electricity Directive (European Council, 2018) of the Clean Energy Package.

- Renewable Energy Communities are legal entities of which shareholders or members consist of natural persons, small-medium enterprises or local authorities that enter the community voluntary and have the primary purpose to provide environmental, economic or social community benefits (D2018/2001 Art.2(16)). An important condition to this is that members and shareholders must be located in proximity of each other. The definition of this proximity will be defined by national legislation. REC are entitled to participate in following activities: producing, consuming, sharing, storing and selling of renewable energy (D2018/2001 Art.22(2)).
- Citizen Energy Communities are less limited in membership, technology and geographic scope compared to renewable energy communities. Membership of CEC is open to all categories of entities. However, the decision-making powers should be limited to those members or shareholders that are not engaged in large-scale commercial activity and for which the energy sector does not constitute a primary area of economic activity (D2019/944 (44)). Besides that, CEC may engage in generation, distribution, supply, consumption, aggregation, energy storage, energy efficiency charging services or services for electric vehicles, or provide other energy services to its members or shareholders (D2019/944 Art.2(11c)). Compared to REC, the scope is not limited to renewable energy sources. Also, there is no proximity limitation to the community and CEC are allowed to manage distribution networks (D2019/944 Art.16(4)).

The federation of energy communities estimated that there are about 3400 communities active in the European Union (REScoop, 2019). The Joint Research Centre report (Caramizaru & Uihlein, 2020) forecasts that by 2050, 45% of renewable energy production could be from citizens and 37% of that production could come through from collective projects, such as energy communities. This indicates that energy communities could take on similar roles as aggregators and will become an important intermediary to valorise flexibility of customers in energy markets.

5.3. Self-consumption

A final manner to valorise demand side flexibility is individual and collective self-consumption. In the Electricity Directive (European Council, 2019), individual and collective self-consumption are described under (jointly acting) active customers (D2019/944 Art.15). The Renewable Energy Directive (European Council, 2018) describes renewable self-consumers as end consumers that produce renewable energy for their own consumption and are allowed to store and sell their excess of renewable electricity through power purchase agreements, electricity suppliers and peer-to-peer trading arrangements (D2018/2001 Art.21(2)). This is under the condition that the self-consumption activities do not constitute the main commercial or professional activity of the end-consumer (D2018/2001 Art.2(14)). Self-consumers can engage in joint agreements if they are in proximity of the same building or multi-apartment block, here referred to as collective self-consumption. In a collective self-consumption agreement, it is also possible to share renewable energy that is produced on their site between their members, without prejudice to network or other relevant charges (D2018/2001 Art 21(4)).

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