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Energy Systems Integration: an analysis of European energy regulatory framework

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Abstract

Greenhouse emissions are a significant factor in the well-known problem of global warming. Thus, the European Union has developed a strategy to fight the phenomenon: the plan aims to create an economy with net-zero greenhouse gas emissions by 2050. Energy Systems Integration (ESI) is considered key to reducing greenhouse emissions in the energy industry. ESI technology has been developed to connect different Power Industries, such as gas, electricity and heating, to exploit all the synergies and efficiencies of the networks. Providing a holistic view of the energy industry, ESI integrates the use of innovative Distributed Renewable Energy Systems (DRESs) with storage and conversion systems for a clean and affordable energy supply. Specifically, the approach allows ESI to be flexible, leading to an increase in the reliability of DRESs. As any type of innovation, ESI needs a proper regulatory framework to overcome the economic and social barriers of a market adaptation-phase. This work analyses the policies issued by European Countries, highlighting their effectiveness in the adoption of ESI. Moreover, supported by the IREN experimental program data, it identifies the incentives required to implement a Power to Heat system in 5 different European Countries. Finally, the analysis concludes that the current European regulatory framework does not sufficiently incentivise the adoption of ESI.

Summary

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Introduction

Global warming, i.e., the global average temperature rise, is one of the most debated issues in the last decade. The consequences of this event can be found in extreme weather phenomena such as floods, droughts, desertification, ice melting, rising ocean levels that even contributed to animal extinction, reducing biodiversity. According to most affirmed scientific periodicals, such as National Geographic and Our World in Data[1,2], the causes of these phenomena can be found in higher and higher emission levels of greenhouse gases (GHG), which can retain a considerable number of infrared radiations that hit the Earth, contributing to global temperature rise. The Most harmful gases are CO2, N2O, CH4, sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs), and perfluorocarbons. Suffice it to say that in 2016, 35,753,305,000 ton of CO2[3] were emitted anthropologically[4], and only 39%[5] of that amount is absorbable from the environment. In addition, is simply notable that even if there were actions such as Kyoto Protocol[6] that lead to change these bad and harmful human attitudes, in period from 1996 to 2016 global mean temperature has increased by 0.7 °C[7] and greenhouse gases raised by 48.5%[1]. A more in-depth analysis of industries emitting harmful gases showed that 38.5% of CO2 comes from the Power Industry, 20.9% belongs to Transports and 9.4% is due to Commercial and Residential Building emissions. As a result, these stats suggest that 68.8% of CO2

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[1] https://www.nationalgeographic.com/environment/global-warming/global-warming-overview/

[2] https://ourworldindata.org/greenhouse-gas-emissions

[3] https://www.worldometers.info/co2-emissions/

[4] CO2 is not only emitted anthropologically; every kind of species has its carbon-impact to nature: plants, animals, etc.

[5] Google Public Data

[6] An international agreement favouring the reduction of greenhouse gases came into force in 2005 and was extended in 2012 in Doha, with validity until 2020

[7] Istituto Superiore per la Protezione e la Ricerca Ambientale 2019. https://annuario.isprambiente.it/sys_ind/report/html/122

emissions are produced by burning fossil fuels for energy and heat. In addition, besides environmental pollution, there's also an economical reason that explains why replacing fossil fuels has been put as a focal point of the EU and UN's[8] agenda: as a consequence of the envisaged scarcity of fossil fuels[9], its price has greatly raised during last years[10], becoming economically unsustainable.

For these reasons, there was the need to find a solution that could low GHG emissions and that could be economically sustainable. Researchers believe that renewable energies are the answer either to preventing the environment from pollution or to low companies' costs by exploiting the growing availability of reliable renewable energy systems that can reduce the use of fossil fuels.

As part of the European Green Deal[11], to encourage the adoption of green energy solutions and make them economic sustainable, the Commission presented the EU strategy for energy system integration on 8 July 2020. This strategy was designed to try to overcome technical inefficiencies and high costs of the traditional energy systems. Energy System Integration (ESI) joins together different sectors, such as industrial, personal dwellings, and transports, to create energy flows between producers and users, reducing wasted resources and money, but it also joins different sources of energy such as electricity, gas, and heating to try to make sustainable energies affordable and safe.

In light of these premises, this study has the purpose to understand what are the economic, technical and social characteristics that allow ESI to be effectively implementable and if there are some local regulations that could be extended in bigger areas to support the energetical innovation.

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[8]https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

[9] Barnett D. J., Parker C.L., Caine V.A., Mckee M., Shirley L. M., Links J.M. 2011. Petroleum Scarcity and Public Health: Considerations for Local Health Departments. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3154218/

[10] https://www.macrotrends.net/1369/crude-oil-price-history-chart

[11] The European Green Deal is a plan to make the EU's economy sustainable in next 30 years.

The study is divided in 4 chapters; the first one explains what is ESI, what are the technologies that make ESI implementable and what are pros and cons of using this holistic view of an energy system. The second chapter focuses on the existing energy regulation and displays the differences between 5 different countries: Italy, France, Sweden, Germany and UK. The third one underlines how European regulatory proposals are trying to overcome the barriers to ESI deployment and how TSOs[12] and DSOs[13] should be regulated. The last chapter draws the conclusion and suggestions derived from the study.

1.1 ESI

As specified before, the EU Commission, with the support of the Council of European Energy Regulators (CEER), is giving a lot of importance to fight GHG emission, and as a result, they have jointly developed a long-term strategy to reach an economy with net-zero greenhouse gas emissions by 2050[14]. Since 2018, CEER is drafting and developing guidelines[15] of good practice for incentive schemes that can be used to regulate DSOs[16]. This idea is based on Energy System Integration, that is, the creation of the connection between different sources of energy in order to provide a portfolio of options for clean energy. As commonly known, energy can be provided for several uses and in different forms such as electricity, gas, heating and transport. Regulators understood that the only way to stimulate decarbonization and, at the same time, keeping total systems costs affordable for the state coffers, was a system integration between different energy sectors. First of all, this is a result of the cost reducing

[12] Distribution System Operators

[13] Transmission System Operators

[14] https://ec.europa.eu/clima/policies/strategies/2050_en

[15] Short Paper on Whole System Approach (CEER) - July 2020

[16] Distribution System Operators

avoiding investment duplication: every sector has different segments (i.e., generation, transmission, distribution, retail), with the creation of a total system there will be the possibility to build a cross-sector infrastructure that could join where it is possible, every source of energy. Also, there are other positive aspects of developing system integration; the first one is the existence of synergies within and between energy sectors that can provide efficiency gains that are ascribable to vertical and horizontal economies of scope[17]. Furthermore, by using an all-around network, there are lower transaction costs for grid users, and this leads to other efficiency gains. Other positive aspects are in avoiding energy waste, which is possible only with the support of the technological development that stimulates energy flows, linking heat, gas and electricity by using ICT and digitalisation, smart grids, smart meters and flexibility markets.

While some of these synergies have always characterised the structure of the energy system, others are now emerging due to technological progress. Although in last studies it emerged that there are significant advantages in bundling services for domestic and commercial utilities, since 1990 for 30 years, EU reforms tried to unbundle utilities by splitting them in competitive and regulated segments[18]. The reason why regulators have been doing this separation between transmission and distribution segments is firstly related to the maximization of social welfare and, secondly, to a different demand flows of energy, the old one-directional one, and to a primordial technological stage of decentralised generation that didn't show enough potential in the first years of developing. Moreover, these choices were heavily encouraged by the fossil fuel lobby that had economically ruled the world in the last

[17] Jamasb, T., Llorca, M., 2019. Energy systems integration: economics of a new paradigm. Econ. Energy Environ. Pol. 8, 7–28. http://refhub.elsevier.com/S0301-4215(20)30346-3/sref55

[18] Cambini C., Congiu R., Iamash T., Llorca T., Sorousch G. 2020. Energy Systems Integration: Implications for public policy https://www.sciencedirect.com/science/article/pii/S0301421520303463

100 years[19]. The studies of Gugler et al. (2017)[20] estimated that using an integrated system, even only in the electric industry, would let cut about 13% of the total expenses, thanks to vertical integration of transmission and generation in medium-sized utilities. The analysis also revealed that the larger the firm was, the higher were the amount of cost savings that it would get; this was attributable to economies of scale. In addition, Badami and Fambri (2019)[21] and Brown et al. (2018)[22] find that the use of flexibility-enhancing technologies allows a 28% reduction of total system costs, while a cross-border transmission system shows a 25% cost savings.

The reforms[23,24,25], that started in the 1990s, led to the unbundling of vertically integrated utilities and to split them into competitive and regulated segments. This strategy was made to avoid market failures that could affect the electric industry. Many utility industries, such as water and electricity, are natural monopolies for many reasons: the high costs of infrastructure, high fixed cost and the low marginal cost of transmission, presence of economies of scale and the need to provide the

[19] https://yaleclimateconnections.org/2020/01/fossil-fuel-political-giving-outdistances-renewables-13-to-one/

[20] Gugler, K., Liebensteiner, M., Schmitt, S., 2017. Vertical disintegration in the European electricity sector: empirical evidence on lost synergies. Int. J. Ind. Organ. 52, 450–478. https://doi.org/10.1016/j.ijindorg.2017.04.002

[21] Badami, M., Fambri, G., 2019. Optimising energy flows and synergies between energy networks. Energy 173, 400–412. https://doi.org/10.1016/j.energy.2019.02.007.

[22] Brown, T., Schlachtberger, D., Kies, A., Schramm, S., Greiner, M. 2018. Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system. Energy 160, 720–739. https://doi.org/10.1016/ j.energy.2018.06.222.

[23] Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity. (OJ L 27, 30.1.1997, p. 20–29).

[24]Directive 98/30/EC of the European Parliament and of the Council of 22 June 1998 concerning common rules for the internal market in natural gas. (OJ L 204, 21.7.1998, p. 1–12).

[25] Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC (OJ L 176/37, 15.7.2003, p 1-19)

service to the entire population even if it wouldn't economically worth[26]. As a result, transmission and distribution became subject to different economic regulations that make it heavily difficult the cooperation within these two segments. Although, as said before, there are nowadays several studies that show that utilities unbundling might be inefficient, regulators haven't found a permanent solution to enhance market competition within this sector.

1.2 What really is ESI

As anticipated before ESI is an integration between different energy sectors: electricity, gas and heat. There are three principal elements of the system that are required: network, link different energy sector, storage and conversion systems, renewable energy resources; all supported by a proper Information and Communication Technology System (ICT). In this initial phase of the innovation of ESI systems, it hasn't been developed yet a dominant design of the configuration of an ESI system. It's important to understand that ESI setup might be different from place to place, due to various weather conditions, pre-existing infrastructures and energy required and morphology of the territory.

However, in the last five years, ESI setups for pilot projects are quite similar to each other. An interesting proposal is the one made by Badami and Fambri (2019), in table 1 is presented their principal idea that consists in linking three different main networks: Electric Grid, Gas Network and District Heating Network (DH Network).

[26] Mosca M. 2008. On the origins of the concept of natural monopoly: Economies of scale and competition https://www.researchgate.net/publication/24079931_On_the_origins_of_the_concept_of_natural_monopoly_Economies_of_scale_and_competition

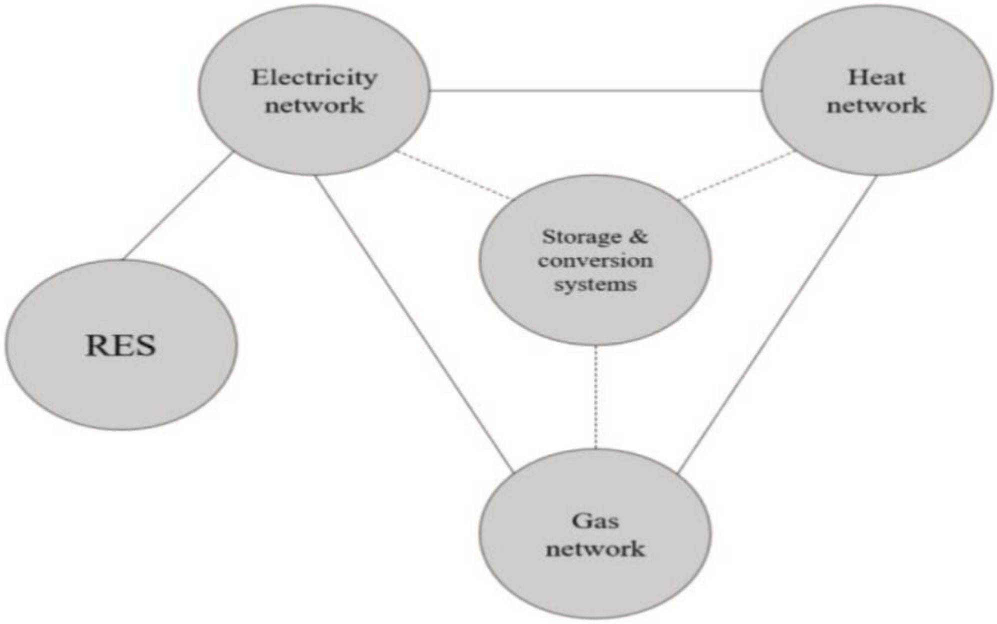

Table 1 ESI's framework

Their idea was to build a system in which Electric energy is provided by wind turbines (WT) and photovoltaic plants (PV), while heat is supplied by Combined Heat Power plants (CHP) by using Power to Heat technologies (P2H), Heat pumps, Electric Heaters, and Gas To Heat (G2H) boilers. Really important for this energy system, are electric batteries (EB), wich are useful as electric storage in order to manage demand flexibility and, as we can see in next pages, for the supply of Ancillary Services. In P2G, there's additional heat belonging from the heat recovery during the methanation process. In this model, NG is designed as an open system and it allows that Natural Gas (NG) can be purchased or sold without any restrictions. As is shown in the picture there's the need to complete the scheme by adding centralized Gas Boilers (CP2H), Centralized Power to Heat (CP2H) for providing District Heating, and Local Gas Boilers (LG2H) and Local Power to Heat (LP2H) for the supply of Local Heating. A possible support to Electric batteries, as a storage device, is a Thermal flywheel[27]. This one is a rotor that works with the power of electricity as a consequence of the principle of

[27] European Commission. Planning and operational tools for optimising energy flows e synergies between networks. 2020. https://cordis.europa.eu/project/id/773839/it

conservation of energy. This system allows storing energy as rotational energy, which can be instantly extracted to help the system when the pick of demand occurs. Furthermore, there are several other studies that presents Energy System Integration schemes. For example, the one designed for the Brandenburg region in Germany by Moeller et al. (2014)[28], adds the possibility to receive dispatchable electricity generation from biogas and solid biomass through a biomass power plant and, differently to Badami and Fambri scheme, Natural gas grid is "closed",

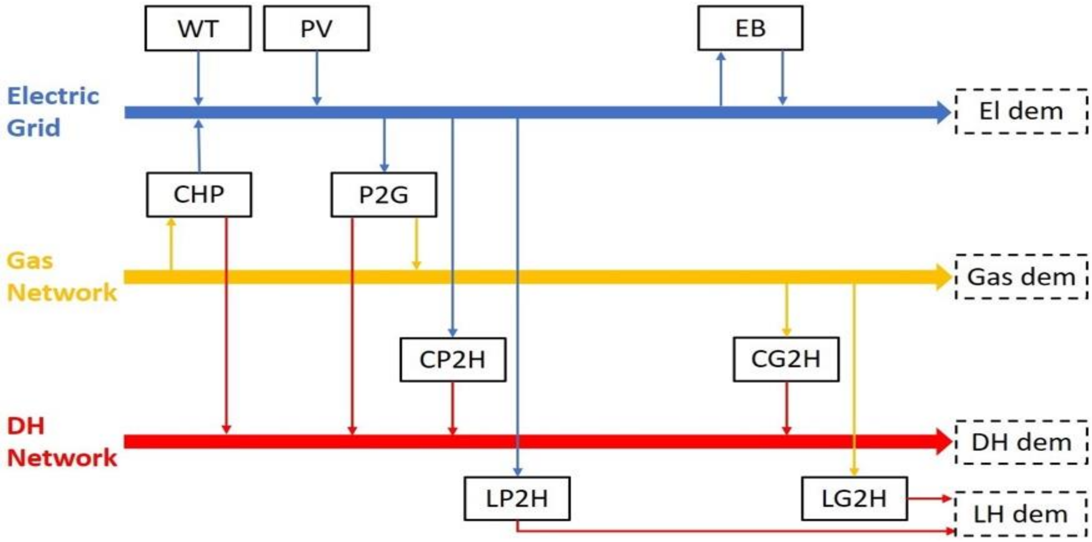

Table 2 ESI's framework #2

in fact in German ESI view, NG can't be purchased or sold. This was probably made because in 2014 the costs and the technological development couldn't allow having satisfying cost/benefit results with open NG grid configuration; the NG market was immature and not ready yet to greet this change. Another way of integration is the one present by Hanggi et al. (2019)[29] that suggests that energy that exceeds when there's a lack of demand, can be used to make synthetic-electric fuel. As displayed,

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[28] Moeller C., Meiss J., Muller B., Hlusiak M., Breyer C, Kastner M., Jochen T. 2014.Transforming the electricity generation of the Berlin–Brandenburg region, Germany https://www.sciencedirect.com/science/article/pii/S0960148114003826?casa_token=KN27-gOQI5wAAAAA:b-p5VKZiTYdOjj3OENk7w_lVdtU82CCc3bZXvGoVpYr_owotOZmQ1akZfpEPyh0ySVhXCKaUhw#fig4

[29] Hanggi S., Elbert P., Bütler T., Cabalzar U., Teske S., Bach C., Onder C. 2019. A review of synthetic fuels for passenger vehicles. https://www.sciencedirect.com/science/article/pii/S235248471830266X

the current ESI scheme is quite similar all over the world and it differs for few characteristics linked to local needs. An example of different requirements is highlightable in District Heating, in fact in "cold" countries the demand for district heating is very high, and it's often supplied by integration of heat and power, while in "warm" countries the energy in excess can be sold to a neighbour trough a smart grid. Another example of possible changes in ESI schemes is the storage method: although in many pilot projects electric batteries are used, in places that have lakes and dams it's possible to store energy with Pumped Hydro Storage (PHS). The size of energy integrated systems it's commonly projected for regional scale, because as pointed out by Lyden et al. (2019)[30], this is the dimension[31] that is currently more suitable for technological complexity and economic and social reasons.

1.3 Technologies that make ESI possible

Technologies that make ESI possible are dividable into three different categories: generation phase, conversion phase, storage phase and information and communication technologies. Every category of technologies represents a necessary phase to a clean and economic supply of energy of an ESI system to its final customer.

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[30] Lyden A., Pepper R., Touhy P.G. 2019. A modelling tool selection process for planning of community scale energy systems including storage and demand side management https://www.sciencedirect.com/science/article/pii/S221067071730982

[31] 3 TWh per year of electric demand and 4TWh per for heating demand. The heating demand is very variable because it really depends on the city that is analysed.

1.3.1 Generation phase

The Energy Industry has the purpose to produce, store and distribute energy in all its sources.

The generation is the most changed phase in last 20 years; this happened because generation gives the higher contribution of Energy Industry in GHG pollution. In fact, the governments are progressively trying to replace fossil fuels and nuclear generation with renewable energies. Wind Turbines and Photovoltaic Panels are currently the most used devices to produce eco-energy.

Wind Turbines (WT)

Wind Turbines are mechanical devices that use wind power to make electricity. The Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, which creates electricity. The amount of energy produced is variable, according to EWEA[32] a wind turbine can generate from 250W to 7MW, with an average for onshore turbines of 2-3 MW, that annually supplies about 6 million kWh, and for residential ones of 10KW. Calculating the real power output of a wind turbine in Watts includes the consideration of some very important benchmarks: the mechanical efficiency by the wind speed, air density, and rotor blade length.

Photovoltaic Panels (PV)

A Photovoltaic Panel is a collection of photovoltaic modules, that is, an assembly of photo-voltaic cells mounted in a framework for installation. Photovoltaic cells use sunlight, that is, a portion of the electromagnetic radiation given off by the Sun, to

[32] European Wind Energy Association
http://www.ewea.org/blog/2011/01/wind-power-capacity-watts-and-kilowatt-hours-–-how-is-it-all-connected/

generate direct current electricity. A photovoltaic module produces on average 3,000 KWh[33] per year, but, as for Wind Turbines, this value is variable, and it mainly depends on weather conditions.

1.3.2 Energy Conversion phase

Energy conversion activities are the most important technological development for Energy Integrated Systems. These activities allow having different forms of energy to supply and to exploit in order to give flexibility and to guarantee efficiency gains to the system. Without the technological development of conversion activities, it couldn't be developed any feasible ESI pilot project.

Combined Heat and Power Plants (CHP)

CHP is a technology for the conversion of energy from gas that generates electricity and captures the heat that otherwise would have been wasted. The heat recovered is useful to provide thermal energy that can be used for heating domestic hot water and industrial processes. Combined Heat and Power Plants can be located at individual dwelling (residential estates), in an energy district or utility resource. CHP is a capital-intensive technology and for this reason, it is usually located at facilities where there's more need for electricity and thermal energy. When CHP is close to final users, it can be used in District Heating (DH) to reduce inefficiencies by producing power and heat on-site. CHP can achieve efficiencies of over 80 percent, compared to 50 percent for typical technologies (i.e., conventional electricity generation and an on-site boiler)[34]. A study conducted by the Environmental

[33] Centre for Alternative Technology Canolfan y Dechnoleg Amgen https://www.cat.org.uk/info-resources/free-information-service/energy/solar-photovoltaic/

[34] EPA, United States Environmental Protection Agency. https://www.epa.gov/chp/what-chp

Protection Agency (EPA) revealed that the average efficiency of fossil-fueled power plants in the United States is 33%, while with Combined Heat and Power Plants, by recovering that wasted energy, the efficiency results assert that these systems could reach 60-90% of efficiency. This range is caused by the differences in technology used and system design, as displayed in Table 3. Colmenar-Santos et al. (2016)[35] study shows that using CHP in District heating to replace boilers can heavily lower the annual cost of the system. For example, the study considers a 100,000 inhabitants city with an urban centre of 75 km and fuel consumption for boilers of 1.1 £/kWh$_e$ while for CHP of 0.125 £/kWh$_e$[36]. They found out that with a one-time investment of 315 billion euros, there would be a yearly cost savings of 93.6 billion euros and a 15% reduction of the final energy consumption. This reduction was possible because about 6400 PJ[37] of heat per year could be recovered and used. This is a reason why CHP is considered a capital-intensive technology; in fact, it has an enormous initial investment that has a relatively short payback time. Another reason why CHP is really useful to ESI is its mechanical design. While traditional systems aren't integrated, CHP can exploit the connections of the District heating to manage and coordinate the loads and use them as a form of virtual energy storage, raising systems' flexibility and providing ancillary services that are necessary to guarantee electrical system security and a balance between supply and demand.

CHP type	% of efficiency[38]
Steam turbine	80-90%
Reciprocating engine	75-80%

[35] Colmenar-Santos, A., Rosales-Asensio, E., Borge-Diez, D., Blanes-Peiro J. 2016. District heating and cogeneration in the EU-28: current situation, potential and proposed energy strategy for its generalisation. https://doi.org/10.1016/j.rser.2016.05.004

[36] These values are taken from A. Riddle, 2013. District energy & smart energy grids experience from Denmark

[37] Petajoule (PJ)= 10^{15}J

[38] EPA, Catalog of CHP Technologies https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf

Combustion turbine	65-70%
Microturbine	60-70%
Fuel cell	55-80%

Table 3 CHP efficiency

Power to gas (P2G)

Power to Gas (P2G) plants pilot projects proved that Integrated systems are possible and are the future of the Energy sector. They allow an efficient connection between power systems and Natural Gas (NG) networks. P2G represents a process that converts water and carbon dioxide into methane while consuming energy provided by the electricity. This process generally consists of two steps, electrolysis and methanation; this latter one could be optional for electrolyser-only P2G plants.
An electrolyser is a proton exchange membrane, and it replaces the electrolysis in several P2G plants.
According to Liu W., Wen F. and Xue Y. (2017)[39], who analysed existing P2G facilities of Germany, Power to gas plants aren't currently economical efficient. On the other hand, Capex and Opex of P2G show that there are tangible possibilities that this system will be more affordable and interesting from the economic point of view in next year. This would be really important for the developing of Energy System Integration because, not only P2G helps the supply of ancillary services in electricity markets, but they also enable integrated systems to have better performances providing efficiency gains and cost reduction to gas and electricity network, simultaneously guarantying flexibility and safety to the system.

[39] Liu W., Wen F. and Xue Y. 2017. Power-to-gas technology in energy systems: current status and prospects of potential operation strategies.
https://www.researchgate.net/publication/316439688_Power-to-gas_technology_in_energy_systems_current_status_and_prospects_of_potential_operation_strategies

Power To Heat (P2H)

Power to Heat (P2H) is a process that has the purpose to convert electrical energy into heat. This technology is used for giving flexibility to energy sources, especially renewable ones, that may have excess electricity. In Europe, around 75%[40] of annual heating and cooling requirements are met by fossil fuels, while only 19% is generated from renewable energy[41]. In addition, IEA data[42] revealed that 40% of CO2 emissions come from energy production, as a result when P2H is linked to a renewable source of energy, it is identified as a solution that helps the environment supporting the transition to renewable sources and contributing to decarbonisation avoiding as much is possible fossil fuels. Power to Heat can be realized in different ways: by using heating resistors, electrode boilers and heat pumps. According to Bloess et al. (2018)[43] and IRENA[44], P2H technological design can have different shapes. As is shown in Table 4, Power To Heat can be integrated either into personal dwellings (Decentralised Heating System) either to the District Heating network (Centralised Heating System); in particular Decentralised Heating System is more and more adopted by industries that use the heat coming from P2H to dry their own production processes. An analysis from IRENA[32] revealed that even in 2018 the heating cost of a KWh of heat, produced by heat pumps air to air (P2H), is lower than any further method of heat supply, such as natural gas (NG), oil, Electricity for heating using

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[40] IEA - Energy Information Administration, 2018

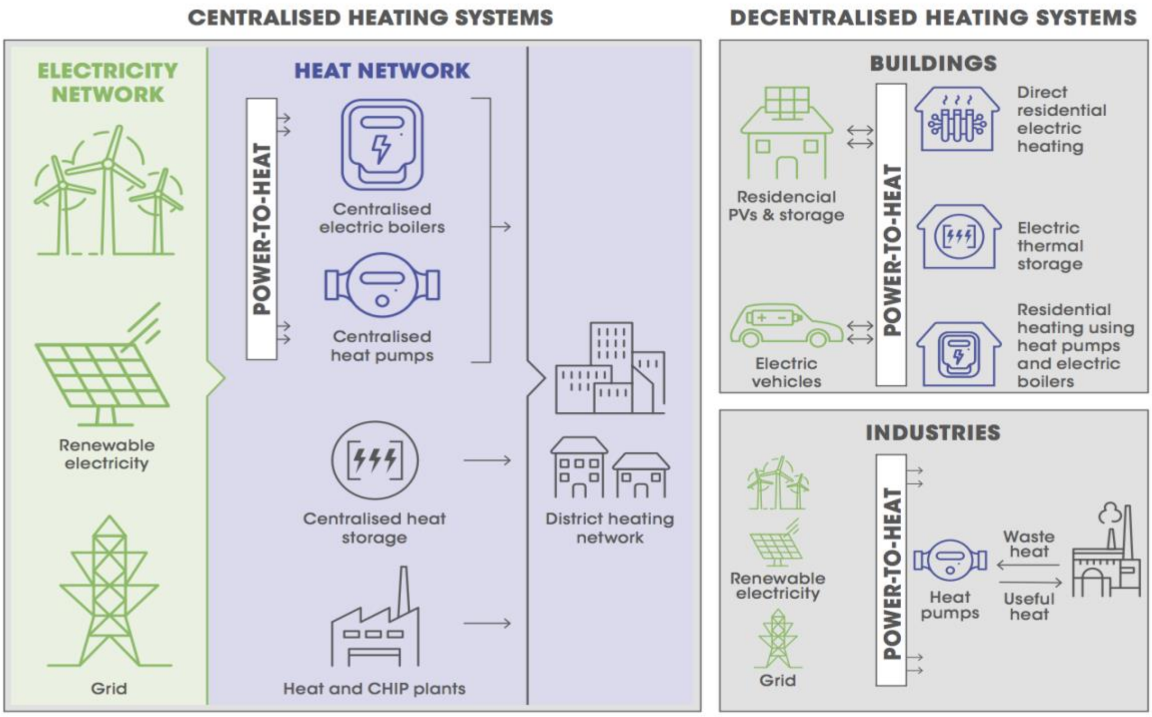
[41] European Commission, 2019a

[42] https://www.iea.org/reports/co2-emissions-from-fuel-combustion-overview

[43] Bloess A., Schill W.P., Zerrahn A. 2018. Power-to-heat for renewable energy integration: A review of technologies, modeling approaches, and flexibility potentials. https://www.sciencedirect.com/science/article/pii/S0306261917317889

[44] IRENA - International Renewable Energy Agency. Renewable Power-to-heat - Innovation Landscape Brief 2019. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Power-to-heat_2019.pdf?la=en&hash=524C1BFD59EC03FD44508F8D7CFB84CEC317A299

boilers or resistance heaters, District Heating (That are the most used sources of heating supply).



CHP = combined heat and power; PV = photovoltaic.
Based on: Bloess et al. (2018).

Table 4 Comparison between decentralised and centralised systems

1.3.3 Storage Phase

Energy storage is the key of ESI projects. This is because there had always been a lack of technological development that can allow to store energy in an affordable way. As a result, in 2017 EU European Commission, EU countries, industries, and the scientific community launched the European Battery Alliance (EBA), an alliance with the aim of implementing a strategic action plan for batteries.

Electric Batteries (EB)

Electric Batteries are devices device consisting of one or more electrochemical cells with external connections essential to help the systems to collect energy and to use it when it's necessary. With the project BRIDGE[45] funded by Horizon 2020, the EU is trying to develop a stronger link between electric batteries and smart grids. The idea is to exploit the synergies that this integration creates, first of all, ensure the security and quality of electricity supply and support the system balancing while keeping operating costs under control. Besides, EB allows renewable power systems to be more flexible and this helps the reduction of the intermittency of renewable power generation. It's really interesting that with the spreading of Electric Vehicles, second-life batteries can be reused for stationary storage to serve buildings, districts or grid needs; this means that there will be a reduction in terms of costs (production and disposal) and pollution by reducing CO2. There are three different types of EB: high voltage (higher than 110 kV), medium voltage (between 1 kV and 50 kV) and low voltage (lower than 400 V). Most of the batteries in the H2020 projects are connected to the low voltage level as displayed in Table 5.

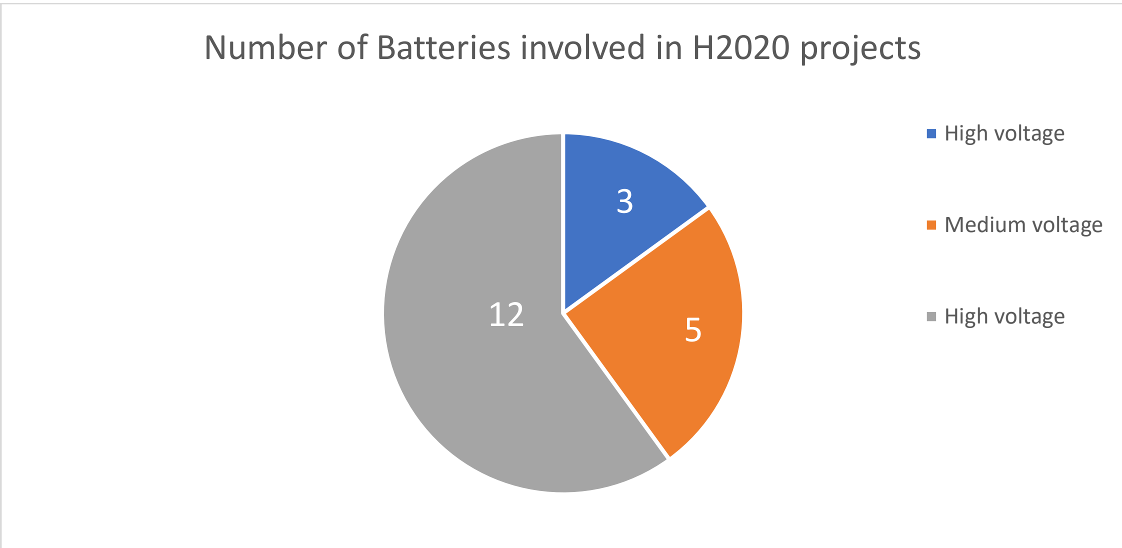


Table 5 Numbers of batteries involved in H2020 projects

[45] https://www.h2020-bridge.eu/wp-content/uploads/2018/09/BRIDGE_Battery_report_Aug18.pdf

European regulators are studying in terms of ownership, who should operate batteries, because at this time there isn't any rule that clarifies the storage ownership. The most credited hypothesis is that DSO, that provides energy services, should either supply batteries because it has more opportunities to fit the services provided and energy storage and this is completely in line with European Commission that tries to promote the aggregation and the technological development of batteries.

Pumped hydroelectric energy storage (PHES)

PHES is a hydroelectric energy storage device used by electric power systems for load balancing. It helps renewable systems when an energy demand pick occurs, as it stores in the form of gravitational potential energy of water. This type of energy storage works in two times, one when the electrical demand is low, because by the exploitation of low-cost surplus off-peak electric power, the water is pumped from a lower elevation to a higher elevation. The other time is when there's high electrical demand, in this case, the stored water is released through turbines to produce electric power. This storage device guarantees a safer and more reliable energy system, when picks occur, and it avoids the waste of excess energy. This technology seems to be one of the most interesting in the field of storage devices, because according to Rehman et al. (2015)[46], the energy efficiency of PHES varies in practice between 70% and 80%, with some studies that claim up that PHES efficiency is up to 87%.

[46] Rehman S., Luai M. Al-Hadhrami L. M., Alam M.M. 2015. Pumped hydro energy storage system: A technological review https://www.sciencedirect.com/science/article/pii/S1364032115000106?via%3Dihub

1.3.4 Information and communication technologies (ICTs - Smart Energy)

It was already clear in 2010[47] that information and communication technologies were the centres of renewables source projects. As the efficiency of the integrated systems raises with the connection of different energy sectors, renewable energy needs ICTs to allow consumer and data analyst to monitor consumption, energy suppliers available and forecast energy and heat demand in order to manage a flexible and safe system. An analysis of the European Commission[48] showed that smart meters using, or any other device that can allow households to track the consumption of different utilities, helps the reduction of energy demand up to 10%. This is firstly attributable to information asymmetry, that as for the cost of capital analysis[49], cause higher consumptions and prices. This is why without any kind of transparency for quantity supplied or for the price that is spending "real time", the consumer can't really understand the value of what he is buying; secondly, this reduction of energy demand is related to the possibility to manage the whole system even in remote; for example, when none is at home, remote controls allow to turn off lights or the heating avoiding any kind of waste. In addition, by the metering of the energy consumed, "Smart energy" can develop a forecast of when the energy excess will occur, based on personal energy system historical data. This could be very valuable for two reasons; the first and most obvious one, is the possibility to sell excess energy produced to the network, the second one is to transform it for example in heat. As well as cutting consumer costs, this attitude can also reduce CO2 emissions in the EU by between 9

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[47] A strategy for competitive, sustainable and secure energy. European Commission (2010) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum:en0024

[48] Commissione Europea - Smart ICT for energy efficiency https://ec.europa.eu/digital-single-market/en/news/smart-ict-energy-efficiency

[49] Kazemi H., Rramhani F. 2012. Relationship between information asymmetry and cost of capital https://www.researchgate.net/publication/271068597_Relationship_between_information_asymmetry_and_cost_of_capital

and 15% and reduce primary consumption by the EU energy sector by almost 9% in couple of years.

1.4 Barriers

These technical stats seem to be very reassuring, but the are several constraints that limit the feasibility of ESI projects. There are some economic, social, technical and institutional barriers that ESI has to climb over during its affirmation process. The economic ones are linked to the investments that this technology needs. This is caused by the costs of an immature technology that has no certainty to become the dominant design of the industry. From the social point of view, there is the risk of adverse nature of the firms against the adoption of these technologies causes waste of time, duplication of investments and without a wide approval of the firms, there won’t be any stimulus for customers to change their energy habits. Moreover, this point is very important, because it’s related to total integrated systems costs, as this paradigm needs to “cross the chasm” in order to reach the suitable quantities that guaranty economies of scale and consequently cost reductions. In addition, Energy Systems need coordination between grid users that can low the investments in RES. This leads to another problem: how to regulate the flow between the grid users, the energy provider and the solar panel owner (in case of RE provided with solar energy). From the technical side Distributed Renewable Energy Sources’ principal weakness is the low amount of storable energy that is another reason why this technology hasn’t spread out yet. These problems are very important, and they limit the diffusion of this technology, but there is another bigger barrier: the regulative one. As for all the innovations, there are several problems linked to the regulation and the implementation of new systems in real life.

1.4.1 Economic Barriers

The first and clearer barrier that hinders the statement Energy System Integration systems is the economic barrier. The reasons are attributable to the high costs of technologies that make ESI possible. For example, CHP and Power to heat are at the beginning of their lifecycle, it implies that researchers haven't found yet a dominant design of the technology and as a consequence, there isn't the possibility to low the costs of these technologies. As pointed out in the study of Lacko and van Sark et al. (2008)[50] , "Technological learning in the energy sector", the costs of ESI systems' technology will reduce when the number of sales starts to increase (Table 6). This

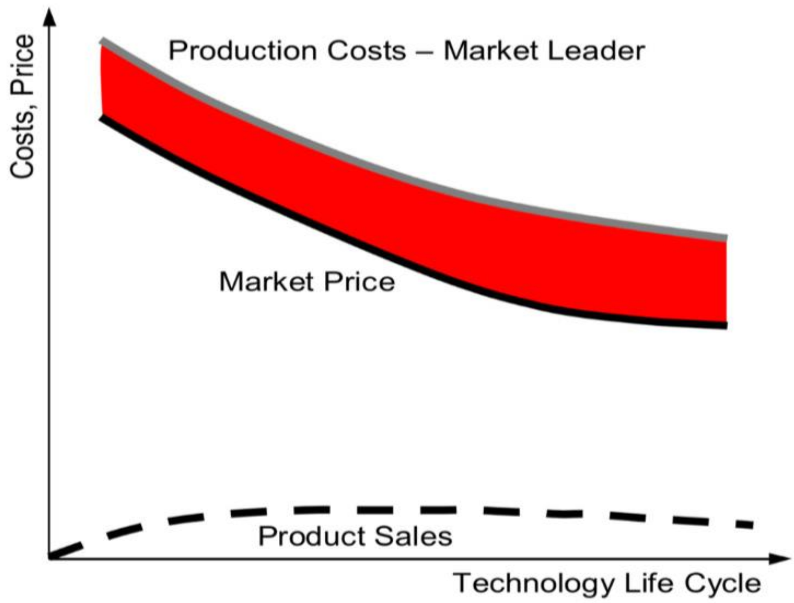

Table 6 Technological learning in energy sector

is related to two principal economic phenomena: economies of scale and learning economies. These events could be quite similar to the rapid costs falling of electric batteries for electric vehicles. As shown by Nykvist and Nilsson (2015)[51], the

[50] Lacko P., van Sark W., Weiss M., Lensink S., Junginger W. H. 2008. Technological learning in the energy sector. https://www.researchgate.net/publication/27715090_Technological_learning_in_the_energy_sector

[51] Nykvist B., Nilsson M. (2015). Rapidly falling costs of battery packs for electric vehicles.

production costs of EB have been cut by 8% per year, and these reductions are forecasted for next years too. This is very important for ESI systems implementation because it helps to reduce the initial investment needed to begin integrated systems projects.

1.4.2 Social Barriers

When a new technology is trying to emerge in the market, it has to overcome some psychological "walls" caused by the fear of discovering something different and they are called in economy switching costs. These costs are not necessarily monetary, they could affect customers for different reasons: time waste, psychological, effort based. This attitude is observable in terms of customer acceptance of the transition from traditional energy systems to distributed resources. An example of this, it is a lack of economic interest in investing in innovation: many customers would change the used technology only if there were economic gains in investing in innovation, this is caused by an absence of care about environmental pollution, as people are not considering the enormous ecological gain. In addition, customers are worried by energy regulation in further years; it's clear that the EU Commission is currently investing[52] in the implementation of DR systems giving incentives and eco-bonus for the reduction of customer expenses. Unfortunately, this regulatory behaviour is not sustainable for too much time and further diffusion of DR and storage systems can lead to a scenario in which the increasing independence of prosumers from the grid would cause higher energy costs for grid users in next years; these forecasts are worrying potential customer to adopt ESI systems. Moreover, the metering and data sharing is another problem that slows down the adoption of ESI; customers are against the collection of their data and the diffusion of technologies deemed

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https://www.researchgate.net/publication/274407248_Rapidly_falling_costs_of_battery_packs_for_electric_vehicles

[52] https://ec.europa.eu/energy/sites/ener/files/energy_system_integration_strategy_.pdf

intrusive; a clear example of that is Covid-tracing apps[53] that have been adopted with many difficulties. This is why, as explained in the IEEE Security & Privacy by Acquisti and Grossklags[54], "Traditional theory suggests consumers should be able to manage their privacy. Yet, empirical and theoretical research suggests that consumers often lack enough information to make privacy-sensitive decisions and, even with sufficient information, are likely to trade off long-term privacy for short-term benefits". Instead, from the firms' point of view, investing in technologies that could not be the dominant design of the energy market strongly reduces investments and the adoption of these solutions, contributing to slow down ESI's "crossing the chasm"[55]. Another social barrier is the creation of coordination between grid stakeholders (i.e., generators, TSOs, DSOs, retailers, consumers). Energy integrated systems can be efficient only if there will be cooperation, between these different interesting subjects, in terms of data sharing and in terms of managing the complexity of an ESI system. In addition, as ESI requires grid users to provide a service that minimises the overall system cost, there would be necessary a better understanding of what are customers' needs and in which way they can help TSOs and DSOs to provide energy, assuming some behaviours that may help to create a sustainable network.

[53] https://www.ilsole24ore.com/art/covid-immuni-e-app-altri-contro-virus-ma-passi-troppo-lenti-AD15HVj?refresh_ce=1

[54] Acquisti A., Grossklags J. 2005. Privacy and rationality in individual decision making. https://ieeexplore.ieee.org/document/1392696

[55] The chasm refers to the technology adoption lifecycle or the transition from the early market into the mainstream eye.

1.4.3 Institutional Barriers

Any innovation process needs ideas, producers, complementors and complementary systems, suppliers, but first of all, there's the need of being in a suitable and favourable context. It may seem superfluous, but innovations without regulation or customers' acceptance, e.g., autopilot for cars[56], won't penetrate the market, even if their technological progress would be exponentially valuable. In the ESI case, its diffusion is heavily hampered by the adoption of effective policies and regulations for managing the mainstream adoption of integrated energy systems. These measures are also required because, as said before, ESI components aren't currently economically sustainable for DSOs and TSOs, that have to be incentivised in investing a big amount of money in projects that have a long payback-time and a high level of risk. Moreover, even consumers have to be incentivised in order to buy personal or local energy generation devices such as photovoltaic panels. In addition, it would be necessary to regulate and incentivise the grid networks and the peer-to-peer energy sharing in order to reduce the inefficiencies and to make economic affordable the cost of energy.

Another big challenge that regulators have to climb over is to define the boundaries between regulated activities and the market, and which measures and with which depth they can intervene on the whole energy system cohesively. Another question that regulators should solve is the involvement of DSOs because Distribution System Operators are crucial to the diffusion of the ESI paradigm. European regulators doubt about regarding whether to involve DSOs also in the roll-out of PEVs[57], after having involved them in EV's operations[58]. Another doubt regards the attribution of the own

[56] https://www.forbes.com/sites/danielaraya/2019/01/29/the-challenges-with-regulating-self-driving-cars/?sh=4285848eb260

[57] Plug-in electric vehicles batteries

[58] Wargers, A., Kula, J., Ortiz de Obregòn, F., Rubio, D., 2018. Smart Charging: Integrating a Large Widespread of Electric Cars in Electricity Distribution Grids. European Distribution System Operators for Smart Grids, Brussels, Belgium.
https://scholar.google.com/scholar_lookup?title=Smart%20Charging%3A%20Integrating%20a%20La

and the operation of storage systems. EU Commission has come to a crossroads, allowing or not DSOs to act as neutral market facilitators by providing storage services for the final customer. The risk in the attribution of these energy services is observable in these two different scenarios: if the attribution to DSOs occurs, there could be the risks that the market leads to be a monopoly, in which DSOs act like a monopolist that operates in potentially competitive market. While if the attribution doesn't occur, there could be the possibility of lack of interests for DSOs in investing for Distributed Generation (DG) connection. The second scenario may lead to an increase of the difficulties of the cooperation between DSOs and TSOs and final customers that would really complicate the implementation of Energy Systems Integration.

2.1 Energy regulation frameworks

In order to overcome the barriers that hinder the affirmation of ESI technologies it is vital to design a proper energy regulation framework that incentives the stakeholders of the whole Energy supply chain. Energy regulation frameworks could be divided in two different sections: electrical and gas supply. This division represents the ancient idea of Energy industry, that used to be organized with a divisional by product structure. Following the wake of the innovation, regulation has the purpose to allow the transition from a divisional energy industry to a holistic view of the systems.

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rge%20Widespread%20of%20Electric%20Cars%20in%20Electricity%20Distribution%20Grids&author=A.%20Wargers&publication_year=2018

As part of the European Green Deal[59], the EU commission has given guidelines and key targets that each country has to reach till 2030 in its "2030 climate and energy targets". The main goals for 2030 are three[60]:

- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 32% share for renewable energy
- At least 32.5% improvement in energy efficiency

To help the UE to reach its 2030 climate and energy targets, the Commission has created the Governance of the Energy Union and Climate Action that sets common rules for planning, reporting and monitoring. This regulatory tool also ensures that EU planning and reporting are synchronised with the ambition cycles under the Paris Agreement, and its purpose to be carbon neutral till 2050[61]. In any case, each EU country has to follow these guidelines, but they can choose different regulatory schemes, this is because European countries are very heterogenous in terms of number of inhabitants, culture, average salary, environmental awareness and available public funds. In the following section, it is reported the current adopted regulation by several European countries and are pointed out the differences between their local policies.

[59] EU Commission plan to make the EU's economy sustainable. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

[60] https://ec.europa.eu/clima/policies/strategies/2030_en

[61] https://ec.europa.eu/clima/policies/strategies/progress/governance_en#tab-0-0

2.2 Italian Energy regulation

Starting from the domestic energy market, Italian regulators have developed a hybrid mechanism of regulation. The tool that has been created to foster innovations in the energy industry is a revenue cap with cost-of-service elements. Efficiency incentives are added to this mechanism of regulation to strengthen the attention to the efficiency of the systems and to induce firms to develop technological innovations. Tobiasson et al. (2015)[62] study confirms that using an input-based approach, where firms are rewarded for cost-minimisation isn't a forward-looking view. This analysis reveals that without an output-based approach, the cost-minimisation would lead to avoiding the investment in the quality of the service that it's crucial to progressively cut the average cost-of-service. As a result, the length of the regulatory period is very important, because adopting a wide regulatory period can allow firms in investing in the efficiency of the systems without causing a negative profit. Especially for Energy System Integration that requires capital intensive investments, the regulatory period must be proper. Thus, Italian regulators have set a different regulatory period length for electricity 4 years and for Gas (from 4-6 years), a 4-year period for gas transmission and a 6-year period for gas distribution, that requires a higher amount of time in order to implement new innovations in the pre-existing system and to let firms reach, at least, the break-even point for long payback time projects.

[62] Tobiasson W., Poudineh R., Jamasb T. 2015. Output-based incentive regulation and benchmarking of network utilities. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjLg8nPx6DvAhUG8BQKHQH_DSAQFjABegQIARAD&url=https%3A%2F%2Fwww.iaee.org%2Fen%2Fpublications%2Fproceedingsabstractpdf.aspx%3Fid%3D12810&usg=AOvVaw0RW4LmHdGkV1ByTVljoOSn

2.2.1 Italian output-based Approach

As pointed out in Cambini et al. (2014)[63] and Lo Schiavo et al. (2013)[64], AEEG[65], the Italian Regulatory Authority for Energy, Networks and the Environment and currently known as ARERA[66], designed an incentive-based mechanism as a hybrid revenue cap with cost-of-service elements. The revenue cap is a regulatory method in which regulators determine a “revenue cap index” that represents the maximum amount that a firm is allowed to earn during its regulatory period. Thus, in these conditions, the firm is allowed to raise or low the price as long as the cap is respected. As said before, the Italian framework is a hybrid one because it is thought to consider the flexibility of the external environment and it’s resumable in this formula:

$$P_t = (1 + RPI_t - X) * P_{t-1}$$

Where:

- P_t= Service/Product price at time period “t”
- RPI_t= Retail Price Index at time period “t”, it expresses the changing percentage of the inflation that affects the purchasing power of the firm and it reflects the average trend costs of firms
- X= X-factor, it reflects the impact of the innovation
- P_{t-1}= Service/Product price at time period “t-1”

[63] Cambini C., Croce A., Fumagalli E. 2014. Output-based incentive regulation in electricity distribution: Evidence from Italy. https://www.sciencedirect.com/science/article/pii/S0140988314001595?via%3Dihub

[64] Lo Schiavo L., Delfanti M., Fumagalli E., Olivieri E. 2013 Changing the regulation for regulating the change: Innovation-driven regulatory developments for smart grids, smart metering and e-mobility in Italy
https://www.sciencedirect.com/science/article/pii/S0301421513001079

[65]AEEG: Autorità per l'Energia Elettrica e il Gas

[66] ARERA: Autorità di Regolazione per Energia Reti e Ambiente

The most innovative aspect introduced by ARERA is the term X in the formula, it is a negative factor that reduces the firm revenue during the regulatory period, and it reflects the efficiency gains that the firm has to achieve with investments in productive efficiency and service quality for its system during the regulatory period. Supporting the regulatory mechanism, ARERA introduced a reward and penalty scheme that linked the distribution tariff to an output measure of continuity of supply. The continuity of supply is evaluated considering the average number of minutes lost per customer for long (longer than 3 min), unplanned interruptions. In addition, the continuity of supply, that is an expression of the quality of the service, is measured with 3 different indexes:

- SAIDI (System Average Interruption Duration Index):

Average duration of long interruptions per consumer (or customer minutes lost)

- SAIFI (System Average Interruption Frequency Index):

Average number of long interruptions per customer.

- MAIFI (Momentary Average Interruption Frequency Index):

Average number of long interruptions per customer by and the average number of short (shorter than 3 min and longer than 1 s) interruptions per customer.

Rewards and penalties are calculated per district on an annual basis, as a function of the difference between a target-SAIDI and the actual-SAIDI. Two different valuations of quality are considered to point out the different willingness to pay (WTP) for quality of residential and non-residential customers. Targets are defined separately in 3 different levels for each territorial district and year based on population density, where a better continuity is expected in the most populated areas. This type of regulation with a divisional structure by different geographic district is very important because it allows regulators to choose, for every single area, the efficiency target that firms have to achieve. If the calculated SAIDI exceeds the target SAIDI, the firm increases its revenue. In addition, AEEG has introduced customer surveys that, as pointed in Sappington (2005)[67], are another form of quality monitoring that is very important to let regulators understand which is the satisfaction level of all the stakeholders. From the data collected since 2004, it's observable that quality has improved more than what was required by target-SAIDI, and it means that rewards earned by the firms are greater than total penalties paid.

2.2.2 Italian specific investments in innovative projects

Another interesting tool of regulation was introduced in 2008 for specific investments in innovative projects in smart grids and in storage devices. Italian regulators understood that to incentivise investment with high level of risk (operational and economic) they had to assume a part of firms' risks. Thus, they decided that every firm that presents a valuable innovative project receives additional increase in tariffs of +2% WACC (Weight Average Capital Cost) for 12 years as a source of funding, namely: +2% WACC for DSOs in network tariffs for smart grids projects and +2% WACC for TSOs in metering tariffs for projects relating storage devices. For other specific projects Italian Autorità Energia[68,63] has set a WACC methodology to remunerate with a fixed rate of return the cost of capital as Table 7 shows. With the introduction of the Law n. 290/2003, capital expenses have passed through to consumers.

[67] Sappington D. 2005. Regulating Service Quality: A Survey https://link.springer.com/article/10.1007%2Fs11149-004-5341-9

[68] Autorita Energia, 2012. Received from: http://www.autorita.energia.it/allegati/docs/11/199-11TITnew.pdf.

TSO regulation (according to Lo Schiavo 2013)

Type of projects	Remuneration
Security of Supply and reduction of congestion	Input-based incentives (+1.5–2% WACC for 12 years on specific investments)
Integration of RES	Input-based incentives (+2% WACC for 12 years on selected projects)
Secondary grid capacity increase	Input-based incentives (+1% WACC for 7 years on selected project)

Table 7 TSO regulation Italy (Lo Schiavo)

DSO Regulation

Type of projects	Remuneration
Service quality	Input-based incentives (+1.5% WACC for 8–12 years on specific investments)[69]
Output-based incentives (SAIDI, SAIFI, MAIFI)	Input-based incentives (+1.5% WACC for 8 years on specific investments)

Table 8 DSO regulation Italy (Lo Schiavo)

For projects regarding the integration of DG, while in 2008-2011 the remuneration was input-based (+2% WACC for 12 years on selected projects), since 2012 the remuneration is output-based with an open consultation.

Besides, costs added to RAB (Regulatory Asset Base) are valued as capital expenditures, which means that firm is refunded only for Capex, avoiding the possibility of a refund for unexpected operative extra costs.
In 2010, Italian regulators set an additional ancillary mechanism that allows the Italian TSO, Terna S.p.a., to receive an additional remuneration in on-going projects

[69] In addition to Output-based incentives (SAIDI, SAIFI, MAIFI)

with specific requirements. The TSO can achieve this additional amount of money if it respects at least 70% of planned project milestones proposed ex-ante by itself and previously approved by Italian regulator[70,71].

2.3 United Kingdom Energy regulation

Although in 2021 UK is definitely out of the European Union[72], it is impossible not to mention the pioneer country of the regulatory discipline in Energy industry. Ofgem[73], the equivalent of Italian ARERA, published in 2010 RIIO regulatory framework[74], a revenue cap with output, efficiency and innovation incentives. As the name RIIO suggests, the expected revenue comes from the sum of three main factors: incentives, innovation and outputs. Ofgem was the first regulatory body that understood the necessity to set a wider regulatory period for firms' remuneration in order to incentivise long-time projects and investment. This is very important, because Ofgem proved that setting a shorter time of price controls only led to reduce current costs, while setting wider regulatory period helps firms to undertake long-time investments that guarantee dynamic and operative efficiencies.

RIIO (Revenue = Incentives + Innovation + Outputs)

[70]AEEG decision 40/2013/R/eel

[71] European Commission, 2014, Study on regulatory incentives for investments in electricity and gas infrastructure projects-Final report.

[72] https://en.wikipedia.org/wiki/Brexit

[73] Ofgem: Office of Gas and Electricity Markets

[74] https://www.ofgem.gov.uk/ofgem-publications/51871/riiohandbookpdf

In July 2018, OFGEM published new RIIO-2[75], that will be applied in 2021 for a second round of price controls. The differences between the first version are mainly two: while in the original RIIO prices were calculated with the formula Revenue= Incentives + Innovation + Outputs, RIIO-2 adds to these three parameters the mitigation of the impact of networks on the environment and a parameter that is the expression of customer satisfaction. This new regulation proposal is similar to Hawaii Public Utilities Commission's one that was published under the name of Investigation of Performance-Based Regulation's in RRFE[76] in 2010, revised in 2017. Hawaiian proposal[77] is a scorecard that reports on cost, earnings, customer service quality, reliability, Demand-side Management, and safety performance.

RIIO 2 (Revenue = Incentives + Innovation + Outputs + Customer Satisfaction + Mitigation of the impact on the environment)

RIIO 2 has other two big differences from RIIO (2010) that is necessary to point out. The first one is related to the regulatory period of the price controls. Considering the flexibility of the markets and the technology revolution Ofgem reduced the regulatory period time from 8 to 5 years. The second one regards the equity cap, the baseline firms' returns, are set to 4%. The effects on customers of Ofgem action is an average saving of £45 per consumer on yearly expenses.

[75] https://www.ofgem.gov.uk/system/files/docs/2018/07/riio2_july_decision_document_final_300718.pdf

[76] RRFE: Renewed Regulatory Framework for Electricity

[77] Innovative Regulatory Approaches with Focus on Experimental Sandboxes. 2019 https://www.iea-isgan.org/wp-content/uploads/2019/05/ISGAN_Casebook-on-Regulatory-Sandbox-A2-1.pdf

2.3.1 UK investment funding

In order to support RIIO (2010) and the innovations for each network, UK created in 2010 three different funds: Network Innovation Allowance (NIA), Network Innovation Competition (NIC), and Innovation Roll-out Mechanism (IRM).

2.3.1.1 Network Innovation Allowance

NIA is a fund that fosters network licensees, small R&D and demonstration projects. This allowance is added to the base revenue when determining the annual amount that the licensee can recover from its customers. More specifically, NIA funds are intended for smaller technical, commercial, or operational projects directly related to the licensees' network that have the potential to deliver financial benefits to the licensee and its customers and it also useful for raising money to submit a request of funding to the Network Innovation Competition (NIC)[78]. The project approval is automatically notified trough NIA official website, only in special circumstances the Authority decides to assign or not the allowance. Up to 2017, NIA funded about 70 mln€ for network licensees.

2.3.1.2 Network Innovation Competition

NIC, as NIA, is an annual funding opportunity for energy and gas stakeholders. In particular, NIC selects an amount of large development and demonstration projects for transmission and distribution operators. The early amount of money funded for gas networks and electricity networks is respectively, £20 mln and £70 mln[79]. Usually,

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[78] https://www.ofgem.gov.uk/network-regulation-riio-model/network-innovation/electricity-network-innovation-allowance

[79] https://www.ofgem.gov.uk/system/files/docs/2020/05/stage20gate20approval20letter_fusion_002.pdf

the size of a NIC approved funding is between £3 mln and £15 mln. When a project is selected for NIC annual funding, it can be funded up for 90% of total costs, while the other costs must be covered by the operator.

2.3.1.3 Innovation Roll-out Mechanism

The purpose of the IRM is to provide additional funding to licensees to facilitate the roll-out of innovation that meets certain requirements into business-as-usual[80]. In 2019, IRM is supporting Smart Street Programme to install novel optimisation software using real-time measurement data to manage voltage on the low voltage (LV) network, linking new substation assets to create an integrated system that allows real-time network reconfiguration.

2.3.2 UK investment funding after RIIO2

With the advent of RIIO, Ofgem is thinking to eliminate IRM and NIA. During the past 8-year price controls, there weren't enough evidence that these two funds could help the network innovation. Moreover, regulators think that IRM and NIA could have been funded through companies' totex allowance, instead of creating other regulatory bodies, as they have the potential to deliver savings for other network companies. These projects would be included in RIIO-2 remuneration as business as usual (BAU) project as they have low level of investment and risks.
In addition, Ofgem is thinking that even NIC should be replaced with a new innovation funding pot dedicated to larger and more strategic projects. UK regulators' scope is to re-organize the innovation funding for the creation of an only one big fund. This is also because the revenues coming from RIIO, added up to NIC, NIA and IRM funding,

[80] https://www.ofgem.gov.uk/system/files/docs/2019/10/decision_document_-_enwl_irm.pdf

allow firms to have higher profit and these leads to have high utility bills for customer, consequently to the regulatory framework used.

While ARERA chooses to considerate only the capital expenditures that the firms sustain during its regulatory period, Ofgem takes in consideration also the operating expenditures (Capex+Opex=Totex). Capex and Opex are two of the most utilized method for value the amount money that has to be refunded. The main difference that is notable between the two methods is that the Capex method is an ex-ante regulation, because it forecasts the costs the firm will sustain during the whole regulatory period; while the Opex method is designed as an ex-post regulation, regulators, at the end of the regulatory period, check the expenses and the investments to make economic adjustments to be in line with the contract. Both methods have pro and cons; the Capex one incentivises long-time period investments, the one that generally have many risks in the completion of the projects and a long payback period. For these reasons, firms may decide not to invest in this kind of projects if there isn't a Capex method. On the other hand, in this way firms could be incentivised in inflating their initial costs. While the Opex method, incentivises short term investments, and it favouris having current efficiencies instead of expenses in R&D investments and future efficiencies.
With Totex-costs system, regulator can reduce the differences that can be evidenced considering only one type of expenditures method: capex or opex. Even ARERA, in 683/2017 /R/EEL (*)[81], shows in its initial guidelines for the new regulatory period, the introduction of incentivising regulation schemes based on the overall control of expenditure. The main pros of this method, according to Arera, are the focus on total expenditure, forward-looking orientation, application of regulatory menus. In addition, with the IQI matrix, which combines efficiency incentives with incentives, regulators can formulate truthful forecasts and they can also benchmark and verify actual expenditure of the firms.

[81] https://www.arera.it/allegati/schede/683-17st_eng.pdf

2.4 French regulation

French regulatory framework is quite similar to the Italian one, as they both are hybrid systems of regulation with cost-of-service elements and efficiency incentives. The regulatory period set by CRE[82], the independent administrative body in charge of regulating the French energy markets, is the same for gas and for electricity and it lasts 4 years; the regulatory period is the same for distribution and transmission too.

$$R_t = OPEX_{F,t} + D_{F,t} + \mathrm{WACC} * RAB_{F,t} + CRCP_{t-1} + I_{t-1}$$

Where:

- $OPEX_{F,t}$ = forecast OPEX for year t.
- $D_{F,t}$ = forecast assets depreciation for year t.
- $RAB_{F,t}$ = forecast regulatory asset base for year t.
- $CRCP$ = regulatory account balance at the end of the previous year. t–1
- I_{t-1} = financial incentives from the previous year. t = 1, ...,4

CRE dispenses innovation incentives, considering the 50% cost recovery for innovative projects that fall under ministerial funding programmes. The cost recovery

[82] CRE: Commission de Régulation de l'Énergie

is evaluated on capex and opex, but it's a different method from Totex-costs based. In fact, French regulators use an approach called "building blocks". As it is possible to see in equation above, opex are directly added to revenue allowance, they are estimated by consulting the projected business plan of the year and benchmarked with the costs proposed by the firm with the existing market. On the other hand, capex are not directly added to revenue allowance, but their evaluation goes through the regulatory asset base (RAB). To sum up, this regulatory discipline has the purpose to reward the firms that look forward to long-term payback investments, but by directly considering opex, it also pushes the efficiency and the quality in the current operative projects. The name "building blocks" is related to the four categories that this regulatory framework considers:

- return on capital, which represents the opportunity cost of the investment and it equals the cost of capital or WACC,
- tax, if not added in the process of computing the WACC
- depreciation, which allow to spread CAPEX over the assets' useful life
- OPEX, which include the expenditures that the regulated firm incurs in running its business.

This constitutes a hybrid system, in which Opex are subject to incentive regulation while Capex are subject to rate of return regulation, and can thus create incentive bias. This has been recognized by the regulator, which introduced a differentiation in the way grid and off-grid expenditures are treated, which however does not entirely resolve the problem.[83,84]

The catherization of French regulatory framework as a hybrid one, is also related to its scheme of reward and penalties designed for monitoring TSO and DSOs. The scheme contains efficiency indicators that are useful to understand which is the quality of the service that firms are providing.

2.4.1 French innovation funding

Full cost recovery is the method that CRE, the French Energy network regulation Authority, has set to evaluate the approval of network innovative projects. At the beginning of the regulatory period, each firm, that prompts the funding, has to hand in a report containing an annual R&D budget that will be approved or rejected by the regulator. In addition, every year, each firm has to submit an updated report in order to communicate if there are some discrepancies with reference to the planned budget and eventually which are the causes. Every deviation from the planned R&D report will be entirely recovered during the regulatory period with an adjustment to the revenue allowance.

[83] Cambini C., Congiu R., Soroush G. 2020. Regulation, Innovation, and Systems Integration: Evidence from the EU
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwi6zPPS97LvAhWOqaQKHcbUAFIQFjABegQIARAD&url=https%3A%2F%2Fwww.mdpi.com%2F1996-1073%2F13%2F7%2F1670%2Fpdf&usg=AOvVaw1iCd2YysMWACZptvgxZqdQ

[84] CRE. Délibération de la Commission de Régulation de L'énergie du 17 Novembre 2016 Portant décision sur les Tarifs D'utilisation des Réseaux Publics D'électricité dans le Domaine de Tension HTB; Délibération; Commission de
Régulation de l'Energie: Paris, France, 2016.

2.5 German regulation

The German regulator Authority, BNetzA[85], set as regulatory framework a revenue cap with expansion incentives, it replaced the cost-plus incentive one in 2009. The regulatory period lasts 5 years and the remuneration for the firms is heavily related to the historical costs, as every previous year is set as base year in order to let regulators benchmark the new costs to the previous year. German regulation divides firms' costs in two macro areas: non-controllable costs and controllable costs. The first ones, are costs that firms can't manage or change in any case; this category of costs is showed in the regulation ordinance ARegV[86] and it considers costs of the overlying grid levels, EEG[87] remuneration for owners of distributed renewable energy systems, concession fees, expansion projects for TSOs, transmission charges for DSOs, mandatory smart meter installation[88]. On the other hand, controllable costs are the costs that can be really influenced by the firm, these costs can be once again divided in two different voices: efficient costs and inefficient costs. The main difference can be found in the duty that firms have in reaching a zero-level of the inefficient costs before the end of the second regulatory period. Instead, efficient costs are related to the competence and the strategic decisions that each firm pursues. More specifically, the equation below explains in a better way the system of remuneration designed by the German energy Authority:

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[85] BNetzA: Bundesnetzagentur, the German regulatory office for electricity, gas, telecommunications, post and railway markets

[86] Anreizregulierungsverordnung, German Incentive Regulation Ordinance)

[87] EEG: Erneuerbare-Energien-Gesetz, stands for The Renewable Energy Sources Act is a series of German laws that originally provided a feed-in tariff (FIT) scheme to encourage the generation of renewable electricity.

[88] Matschoss P., Bayer B., Thomas H., Marian A. 2019. The German incentive regulation and its practical impact on the grid integration of renewable energy systems https://www.sciencedirect.com/science/article/pii/S0960148118313090

$$R_t = NC_t + \left[C_{E,0} + (1 - V_t) * C_{I,0}\right] * \left(\frac{CPI_t}{CPI_0} - XF_t\right) * EF_t + Qt$$

Where (considering the current third regulatory period 2019-2023):

Rt = allowed revenues for year t

NC_t = non-controllable costs in the year t

$C_{E,0}$ = controllable efficient costs in the base year

V_t = percentage of inefficiency that has to be reduced by the end of year t

$C_{I,0}$ = controllable inefficient costs in the base year

V= (5 + t)/10

CPI_t = consumer price index in the year t

XF_t = The general sectoral productivity factor that represents the efficiency target specific to this sector that benchmarks the firm in the year t

XF = (1 + XF)^t − 1 with XF_1 = 1.50%

EF = expansion factor in the year t. This factor applies only for distribution, and it depends

on the number of connections to the grid (50%) and on the size of the service area (50%).

Qt = reward or penalty for quality targets in the year t.

Regulatory period t = 1, ...,5

2.4.1 German innovation funding

The innovation funding for fostering network innovation is government-based. Grants are given by the federal Government under ministerial funding programmes, relieving BNetzA from other regulatory duties. R&D projects are funded by considering a full recovery cost on 50% of the Totex. In the third regulatory period, the German Energy Authority decided that capital cost had to be integrated to the calculation of the revenue cap without any delay, in order to consider the impact on

revenues in the year of their competence. Moreover, in the third period German regulators decided to eliminate some mandatory parameters that were used for the measuring of DSOs quality output. The parameters were previously used for benchmarking the quality of distribution but as displayed in ARegV amendment, not all mandatory parameters helped to explain the cost differences between DSOs. In addition, with the introduction on the new model, in the third regulatory period DSOs with a 100% efficiency rating are allowed to receive a mark-up of 5% (maximum) on the revenue cap.
Besides, the Government took also the decision to incentivise R&D investments by lowering by 40% the rate of interest on equity capital (before taxes), from 9,05% of the second regulatory period to 6,91% of the third one.

2.5 Swedish regulation

The national regulatory authority (NRA) for energy, the Swedish Energy Markets Inspectorate (EI), determines a revenue cap for each distribution system operator (DSO) and the transmission system operator (TSO) for a regulatory period of four year[89]. The regulatory framework adopted is a revenue cap with an incentive scheme for reliability of supply and for an efficient utilization. This is an implementation of the first ex-ante Swedish regulation that took place in 2012-2015. EI understood that in the first regulatory period there weren't enough efficiency incentives that could lead to innovate the energy sector. Before 2014, the regulatory framework was different for gas or electricity but, with the Swedish Natural Gas Act[90], the revenues

[89] Wallnerström C.J., Grahn E., Wigenborg G., Werther Öhling L., Bobadilla Robles H., Alvehag K., Tommy Johansson.2016. The Regulation of Electricity Network Tariffs in Sweden https://www.researchgate.net/publication/308116249_The_Regulation_of_Electricity_Network_Tariffs_in_Sweden_from_2016

[90] The Swedish electricity and natural gas market 2016, Ei R2017:06 https://www.ei.se/pagefiles/310277/ei_r2017_06.pdf

of gas network companies are now regulated just as they are in the electricity market. More specifically, the regulatory scheme is showed in table 9. As German regulatory framework, EI splits operational costs in controllable and non-controllable costs. Last ones are related to costs that are difficult to influence, such as the cost of the feeding grid, the cost of purchasing energy losses and agency fees. In order to incentivise the efficiency of the network, EI introduced a factor that oblige firms to reduce the controllable costs each year. The regulatory asset base is refunded evaluating the capital expenditures, that include the cost of depreciation that can be split year by year. The average share between different cost categories is controllable costs (about 23 %), non-controllable costs (about 33 %) and capital costs (about 44 %)[91].

As specified before with the start of the second regulatory period, 2016-2019, the adjustments on firms' revenues changed a bit, for example the amount of the adjustment passed from ± 3% to ± 5%. The adjustments increase the effect of the output-based regulation, in fact, they are the expression of 3 parameters: quality of supply, efficiency grid utilisation, cost of feeding grid and average load factor. The adjustments are estimated as it follows:

$$Total\ adjustment = \begin{cases} -0.05*[revenue\ cap] & if\ \ (QT+Kn+Kb) \leq -0.05*[revenue\ cap] \\ +0.05*[revenue\ cap] & if\ \ (QT+Kn+Kb) \geq 0.05*[revenue\ cap] \end{cases}$$

Where:

- Qt is an efficiency parameter that reveals the quality of the supply (interruption etc, considering $CEMI_n$, that is an evolution of the indicators

[91] Stenberg S., Wallnerström C.J., Hilber P., Hansson O. 2012.The new Swedish Regulation of Power Distribution System Tariffs: A Description and an Initial Evaluation on its Risk and Asset Management Incentives https://www.researchgate.net/publication/233918416_The_new_Swedish_Regulation_of_Power_Distribution_System_Tariffs_A_Description_and_an_Initial_Evaluation_on_its_Risk_and_Asset_Management_Incentives

SAIDI and SAIFI, it gives more importance to the quality of supply in urban areas

- Kn is the value of the incentive for network loss and it's the expression of the efficiency grid utilisation
- Kb is the value of the incentive for cost of feeding grid and average load factor.

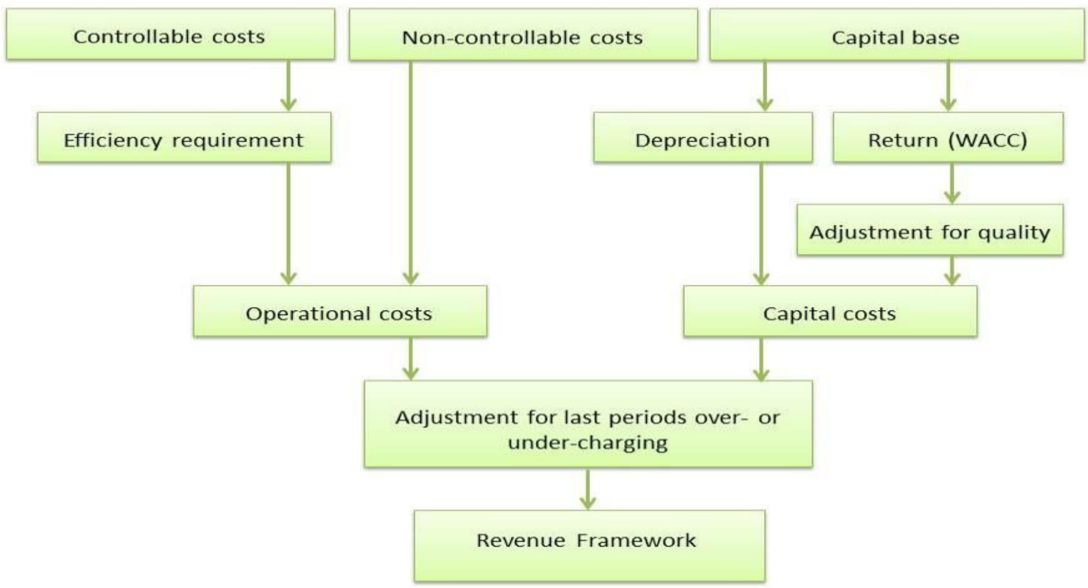

Table 9 Cost evaluation for Swedish regulation

2.6 District heating

The regulation of the district heating has been slightly put away of the European Commission core strategies in the last 15 years. This is due to a higher attention for gas and electricity considering that CHP technologies, or more in common district heating, are averagely used for less than 5% of the total final energy consumption (as it shows table[92] 10). It is clear that, the share of DH depends on the climate and on the buildings of the analysed country.

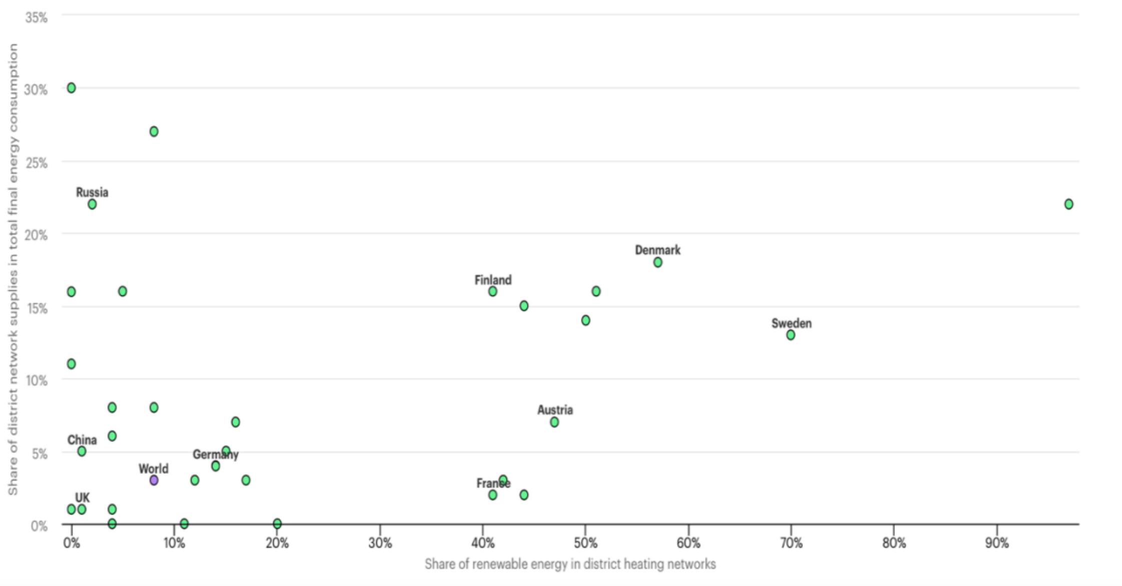

Table 10 District heating average supply for each country

[92] https://www.iea.org/data-and-statistics/charts/share-of-renewable-energy-in-district-heating-networks-2018

2.6.1 UK, Italy and Germany

While Italy and UK were the first mover in the gas and electricity regulation, they haven't drafted yet a DH regulation. UK guaranteed only the possibility to receive grants for district heating networks that supply renewable heat.

Even in Germany, district heating networks are not regulated, Wissner M. (2014)[93] shows why is difficult for German Authority to create a proper regulatory framework that incentivises innovation projects of DH and at the same time maximise the welfare of the consumers. Wissner says that there are three main problems that affect the creation of DH regulation: district-heating systems are mostly closed systems of production and distribution, they compete with other heat sources and it's really difficult to clearly delineate and quantify the exact cost of DH operators. For these reasons it results impossible to treat DH as Gas and electricity networks, mainly because, treating these systems as natural monopoly can cause a discrimination against alternative heating sources and potential abuse of monopoly power for the compulsory connection to and usage of the network.

2.6.2 France

From the previous regulatory framework country analysis, only France and Sweden are moving forward to the creation of a regulation and a proper scheme of incentives.

Even if the share of DH is about 3% of the total energy consumption, France designed a dual fixed and variable fees structure[94], more specifically:

Fixed fees ("R1" fees) are yearly fixed, and they depend on housing heat exchanger capacity expressed in €/kW (that has to be split between for several users in

[93] Wissner M. 2014. Regulation of district-heating systems https://www.sciencedirect.com/science/article/pii/S0957178714000629
[94] D3.1 – Benchmark of markets and regulations for electricity, gas and heat and overview of flexibility services to the electricity grid.

apartment buildings). They cover capacity investment and maintenance costs, network refurbishment costs, power purchase for operating heat production facilities.

There are two kinds of variable fees ("R2" fees):

- For each DH, there is a fee component which depends on consumed heat and is calculated with an annual or seasonal variable price (expressed in €/MWh). It covers fuel purchase for heat production.
- When the DH also provides domestic hot water (which is not always the case), a second fee component depends on consumed hot water (expressed in €/m^3). It covers fuel purchase for domestic hot water production (but not the consumed water).

In addition, French regulators published some policy support for arising the share of RES (including waste recovery) in heat production of DH:

- Reduced VAT for consumers of a DH with RES/Waste recovery share >50%.
- Heat fund for project with a RES Share >50%.
- Mandatory cost-benefit analysis of the use of industrial waste heat in DH for any new large DH project.
- Energy Transition law: target of a 5- fold increase in RES/Waste heat share in DH towards 2030.

2.6.3 Sweden

On the contrary, Sweden has about 15% of the share of the district network supplies in total final energy consumption and about 70% of share of renewable energy in district heating networks. It is, without any doubt, linked to the climate of the country but, even to the policy applied in promoting DH. The Sweden uses a retribution scheme that is composed of 2 fixed fees and 2 variable fees.

The fixed ones can be distinguished in fixed constant costs and capacity costs; fixed constant costs, that are applied by 65% of 179 Swedish[95] DH operators, are useful to cover housing network connection costs (the network maintenance costs). Indeed, capacity costs are applied by 67% of DH operators. They depend on customer's capacity need, which is estimated from previous consumption data (14%) or is based on a general category figure method (user's classification). They cover capacity investment and maintenance costs.

The variable fees can be distinguished in energy costs and flow costs; energy costs are based on metered heat consumption. Prices might be constant (59% DH companies) or seasonal (37% DH companies) with higher winter prices. They cover fuel purchase for heat production and are applied by 100% of DH operators. Flow costs depend on the volume of consumed hot water. They cover fuel purchase for heat production for domestic hot water production and supply. Only 42% of DH operators apply this kind of fees.

[95] Magnusson D. 2016. Who brings the heat? – From municipal to diversified ownership in the Swedish district heating market post-liberalization. https://www.sciencedirect.com/science/article/pii/S2214629616302390?via%3Dihub

2.6.4 Denmark

Even if it wasn't analysed in the previous regulatory analysis, it seems impossible not to mention one of the most forward-looking DH regulatory framework and the largest source of domestic heating, the Danish one. The Danish regulatory scheme for DH is composed of two part: a fixed contribution and a variable contribution.

The fixed one depends on the occupant's residential area, the property, to some extent the volume of heat consumption (stepwise decreasing fixed fee with increasing volume of consumed heat), the maximal flow capacity (which could be based on the last 3 years of heat demand). It partially covers fuels costs, costs for installations, grids and pipelines, buildings connection to the network and inventory, installation and grid maintenance, network operation/administration, insurance, CO2 taxes, energy taxes and Sulphur taxes on fuels.

While the variable contribution depends on the actual consumption and it might be seasonally adjusted. It covers fuel costs and operating & maintenance costs too.

In recent years, the Danish government has taken action to incentivise the diffusion of heat pumps. For instance, DKK[96] 26.7 million was allocated to investments in 10 heat pump projects in 2015[97] and another DKK 53 million was awarded in 2017–2018[98].

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[96] Danish Krone

[97] Patronen, J.; Kaura, E.; Torvestad, C. 2017. Nordic Heating and Cooling: Nordic Approach to EU's Heating and Cooling Strategy; Nordic Council of Ministers: Copenhagen, Denmark,2017.

[98] IEA. Energy Policies of IEA Countries—Denmark 2017 Review; International Energy Agency: Paris, France, 2017. p. 213.

3.1 ESI regulation and stakeholders

The social barrier that has been presented in the first chapter of the thesis was referred to the difficulty of integrating different stakeholders such as generators, network operators, retailer and consumers in a big circle of production. Moreover, there's the additional difficulty in involving ESI project from different background and sector, i.e., gas and electricity. The tables[99] 11 and 12 show the amount of the investment made from each stakeholder. It is clear from the charts that DSOs are the most investors in smart grids.

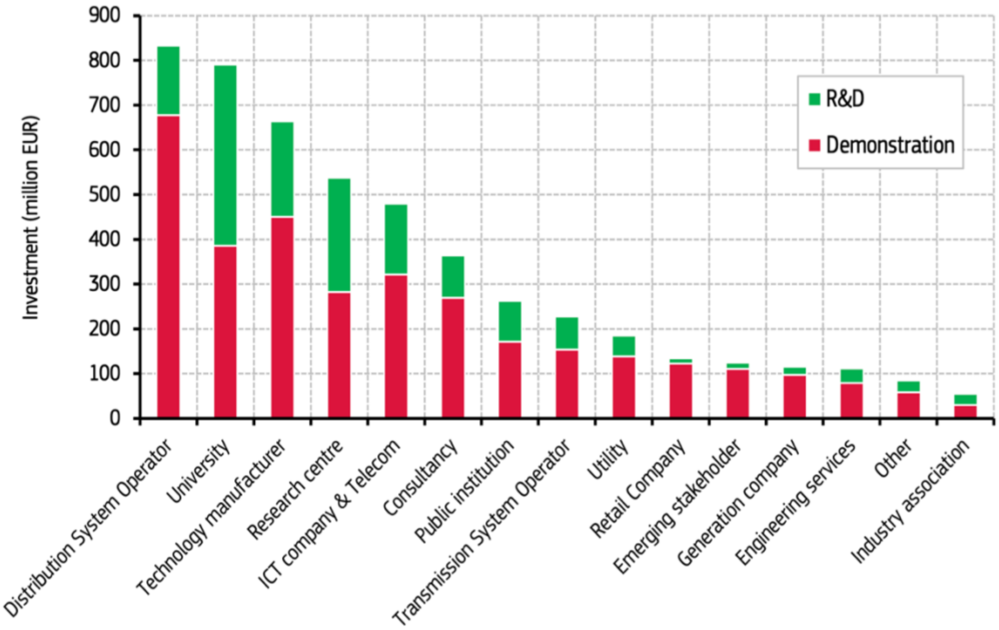

Table 11 R&D demonstration investment per stakeholder category

[99] https://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/u24/2017/sgp_outlook_2017-online.pdf

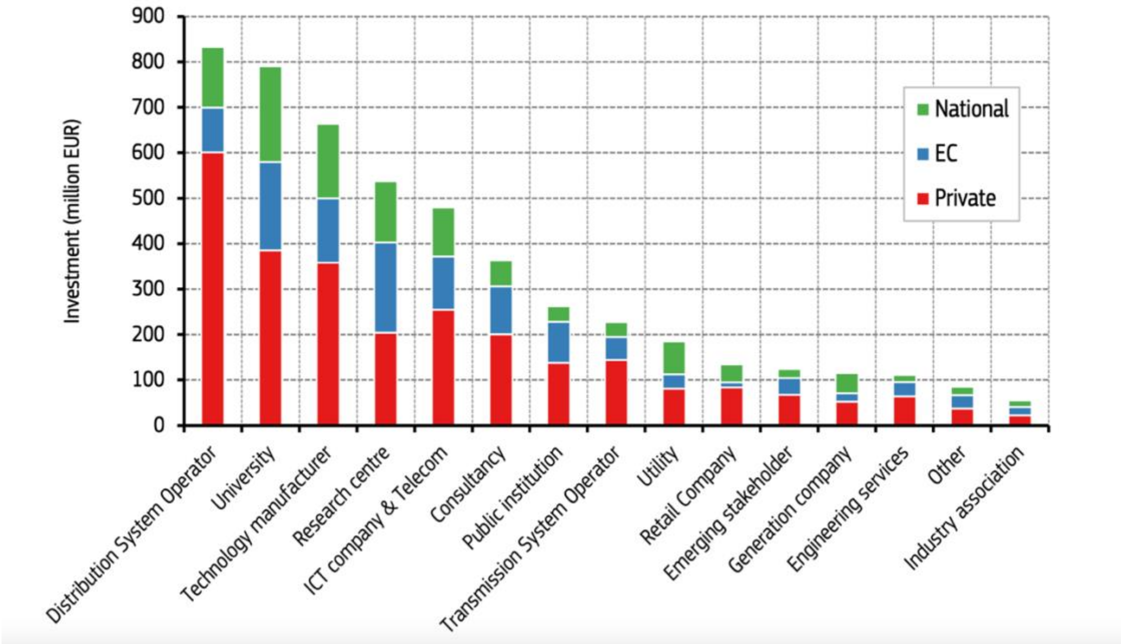

Table 12 Investment by stakeholder category and source of financing

The investments made by DSOs are in line with CEER[100] Short paper on whole system approaches[101] that suggests continuing improving the distribution network in order to facilitate the cooperation with TSOs and the coordination of a Whole System Approach (WSA). A WSA is an integration across different energy areas and across a sectoral chain (e.g., in electricity or in gas). It would be an integrated view of the regulation of the distribution and the transmission networks with a main focus on network operation and planning. CEER identifies this approach as one of the best answers to exploit the technical efficiencies of ESI systems.

[100] CEER: Council of European Energy Regulators

[101] Short paper on whole system approaches [Public], [Whole System Approach WS of DS WG], Ref: C20-DS/WSA-60-07. Draft Version 4, for GA approval June 2020

3.2 WSA - Whole System Approach and Policy recommendations

For fostering the creation of a holistic view of the sector, the cooperation between DSOs and TSOs is the main key that could let be possible a Whole System Approach. Currently, in any regulatory framework DSOs and TSOs are treated separately; it causes a lack of interests in the cooperation between these two system operators. It is clear that, regulating each firm separately would only incentivise a focus on minimising DSO's and TSO's costs separately from each other. With a WSA, DSOs and TSOs would be stimulated not to follow personal interests but to optimise the network as a whole. A better coordination of incentive would lead to a more efficient and reliable supply and, by exploiting the network synergies there could be reduction of network tariffs, to a better scenario even for consumers. It also important to highlight the importance of cross sector working, for example the development of bundled products between DSOs of different sectors. In particular, as a WSA includes many energy technologies, the integration between gas, heat and electricity, it would require a reliable and a fast ICT technology system. The sharing of data between DSOs and TSOs or DSOs and DSOs would be very useful for managing and preventing the local congestions. The challenge for regulators is to create a scheme of incentives that creates a holistic view of energy industry but, at the same time, that prevents the consumers from abuse of power. The main difficulties are for the creation of a mechanism of funding for supporting new technologies e.g., Power to Gas, that could foreclose competition. In addition, NRAs should avoid the risk of cross-subsidies between sectors of different services provided.

The transmission and the distribution, that have been widely analysed, are only two activities of the Electricity and Gas system chain. The whole chain is completed, as it shows figure table 13, by some other activities and surrounded by other stakeholders. The main activities could be resumed in generation, system operation, transmission, distribution, metering and supply, and third parties' activities. The third

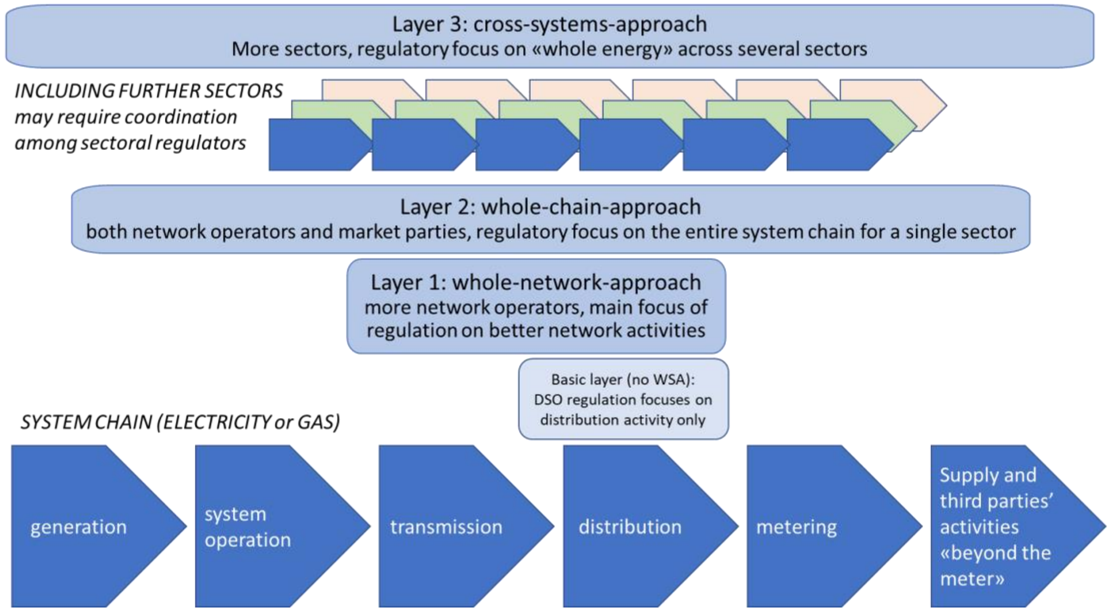

Table 13 Whole System Approach

parties' activities are for example the electric transports[102], that are constantly growing even in the year of COVID-19. As battery electric cars (comprising battery electric cars and plug-in hybrid electric cars) made up a larger portion of electric car sales (almost three-quarters) in 2019[103], investing in the R&D electric cars enables studies on storage technologies, that, as previously said, are the main technical lack of the renewable energies. Even the possibility to exploit technologies like Vehicle to Grid (V2G)[104] could create interests from DSOs in investing in the creation of network infrastructures that could be multi-purpose: residentials and for electric transports. For these reasons, NRA should create a regulatory framework that would incentivise the collaboration between the whole chain of the energy system. As pointed out in

[102] Electric transports: it is related to all the electric vehicle industry and its complementaries.

[103] https://www.iea.org/reports/tracking-transport-2020/electric-vehicles

[104] Vehicle-to-grid is the charging infrastructure that allows electric car owners to charge their car in different places of the city with a network of fast-charge stations

the Article 18 of Regulation (EU) 2019/943: "Tariff methodologies shall reflect the fixed costs of transmission system operators and distribution system operators and shall provide appropriate incentives to transmission system operators and distribution system operators over both the short and long run, in order to increase efficiencies, including energy efficiency, to foster market integration and security of supply, to support efficient investments, to support related research activities, and to facilitate innovation in interest of consumers in areas such as digitalisation, flexibility services and interconnection."

Moreover, "Distribution tariff methodologies shall provide incentives to distribution system operators for the most cost-efficient operation and development of their networks including through the procurement of services. For that purpose, regulatory authorities shall recognise relevant costs as eligible, shall include those costs in distribution tariffs, and may introduce performance targets in order to provide incentives to distribution system operators to increase efficiencies in their networks, including through energy efficiency, flexibility and the development of smart grids and intelligent metering systems".

Another important point analysed by the European Commission is the possibility to introduce a reward/penalty scheme that reveals if the firms are using a WSA or/and allow the access to innovation funding only to firms that meet the WSA requirements. Even the creation of a data hub that enables the access to data and information would give benefits to system operators and even to consumers that could monitor all their consumptions. As is possible to see in Hvaler case study in next chapters, the use of a data platform for energy monitoring changed some energy bad habits of Hvaler community. In this specific case it led to a reduction of energy demand picks, that are very harmful for the renewable sources energy systems.

WSA - 3 layers

The Council of European Energy Regulators clarifies with the introduction of three different layers which is its energy holistic view and how it should be reformed to achieve cost optimum results from a societal perspective. As changing an entire sector is an enormous challenge, CEER sets different expected outcomes for each layer:

- Layer 1: Whole-network-approach
- Layer 2: Whole-chain-approach
- Layer 3: Cross-systems-approach

The first layer, Whole-network-approach, aims a better coordination between the main actors of Energy System Integration “revolution” in order to exploit the synergies of the network. As specified before, in the current regulations TSO and DSOs and DSOs with other DSOs, have no interests in cooperating each other. If the cooperation between different network operators occurs, it’s possible to build a more reliable network that can reduce or even avoid congestions or system disturbances. The data sharing and the incentive in reaching common targets will lead to lower tariffs and a better electricity supply for customers.

The second layer, Whole-chain-approach, opens the possibility to change the way network operators procure and use the flexibility to ensure a reliable supply of energy. The idea of CEER is to widen the current chain of stakeholders, permitting the entrance of new actors that allow DSOs and TSOs to optimise the way ancillary services are provided. An entry of new market players could lead to provide or develop efficient new solution that might reduce the overall cost of the system, creating more viable business cases and a more competitive market.

The third layer, Cross-systems-approach, has as a goal the integration of different technologies that may give additional flexibility in the electricity sector. Exploiting the excess capacity of different sources of energy like gas or heat, or even of different sectors (e.g., transport), could reduce overall costs for consumers and the CO2 emissions, by reducing the need of energy.

CEER together with ACER[105] in its European Energy Regulators' White Paper[106] give some regulatory guidelines for the integration of Power to Gas technology in the pre-existing regulatory schemes designed for gas and electricity. The guidelines are very useful to regulate every kind of conversion technology (e.g., Power to Heat or Power to Hydrogen, that is not analysed in this thesis). The main focus of this paper is the network tariffs management and the levies. The first suggestion is that network tariffs should not be used to subsidize technologies, as they are meant to recover the cost of the networks. Subsidising technologies should be done with ad-hoc instruments because, if network tariffs are used for these grants, there could be the risk of allocating the cost of the subsidization to final consumers in an un-transparent and less equitable way. The second suggestion is for the costs that are not directly related to the energy generation and transport, for example taxes and levies, should be carefully applied in order to minimise distortive effects. This is because, as it happens for power plants, these costs are unjustly passed to customers through the electricity bids, creating an unfair rent for all market operators.

In the implementation of a WSA CEER identifies 4 enablers that should considered:

- setting proper direct or indirect regulatory incentives to encourage the network operators to use WSA
- defining specific regulatory requirements for network operators or removing unwanted regulatory barriers that may exist
- evolving EU and national laws and regulations in order to create appropriate pathways to work across sectors, whilst keeping to a minimum any potential negative impacts
- improving data transparency and interoperability to facilitate cooperation and coordination and to boost the opportunities to use the WSA.

[105] ACER: Agency for the Cooperation of energy regulator

[106] European Energy Regulators' White Paper. 2020. Regulatory Treatment of Power-to-Gas. Relevant to European Commission's Clean Energy Proposals

3.3 Regulatory Sandboxes

After having analysed which are the guidelines that should be followed for fostering a WSA, it's very important to introduce the Regulatory Sandboxes. Regulatory Sandboxes (RS) are used to test in pilot new configurations and demonstration projects, as they help the understanding in how innovations can affect the social ed economic environment. RS is a practical feasibility analysis that reveals if the regulatory solution proposed is potential scalable in other sites. By reducing the field of analysis, negative effects, that may come from wrong regulatory decisions, can be contained. Many countries like United Kingdom, Italy, Sweden, Denmark and Netherlands, as first, are using this approach in the energy sector. The pioneer in this sector is UK, that from 1998, is simulating the integration of different ways, from the traditional ones, to provide energy. In order to understand in a better way how innovations can affect "the real life", regulatory sandboxes are not applied once but, there's the need of several applications of them in order to create a regulatory framework that is increasingly similar to the final one. In the following sub-chapters are analysed some examples of Regulatory Sandboxes from different countries.

3.3.1 UK

As said above, UK was the first European country to begin the innovation and the implementation of regulatory sandboxes in distributed renewable energies. This explains why there is a stronger structure that supports innovations in this field. In 2017, OFGEM, Office of Gas and Electricity Markets, opened "Innovation Link"[107] that is a 'one stop shop' that offers support on energy regulation to businesses looking to

[107] https://www.ofgem.gov.uk/about-us/how-we-engage/innovation-link

launch new products, services or business models. It gives a feedback on regulatory issues and grants regulatory sandbox support on a case-by-case basis, in instances where current regulation prevents the launch of a product or service that could benefit consumers. Since 2006 OFGEM is developing a multi-party contract between licensed electricity distributors, suppliers and generators in Great Britain called The Distribution Connection and Use of System Agreement (DCUSA)[108], that regulates the use of the electricity distribution system.

The most important active regulatory sandbox regards the second layer of WSA. It is related to the diffusion of Local Energy Markets: Verv 2.0 and Centrica LEM[109]. The last one is a cloud-based trading platform that enables participants to sell flexibility from their energy generation or consumption to the local network and get paid for that flexibility. The participants of this market are Cornwall inhabitants. In this initial trial phase, Western Power Distribution (WPD)[110], the local distribution network operator, will place bids for flexible capacity onto the platform for participants to make offers against. Participants will then receive a payment for their response if their offer is accepted. Verv 2.0 is a peer-to-peer energy trading platform. It was created after the closing of the feed-in-tariff Scheme by the UK Government, 2019, in which households with renewables were remunerated for generating green energy. So, from that time people were not allowed buying or selling energy to one from another. Sustained by OFGEM, Verv 2.0 has become a regulatory sandbox with the goal of unlocking the solar energy, helping power residents' homes to develop a peer-to-peer market that is very useful for turning down their energy bills, and at the

[108] https://www.dcusa.co.uk

[109] Innovative Regulatory Approaches with Focus on Experimental Sandboxes. 2019 https://www.iea-isgan.org/wp-content/uploads/2019/05/ISGAN_Casebook-on-Regulatory-Sandbox-A2-1.pdf

[110] West and East Midlands, South Wales, South West England Distribution Network Operator (DNO)

same for reducing carbon emissions. In the past, peer-to-peer trade was often regulated with two different prices for selling and for buying[111]:

$$C_{spot} = P_{spot} + C_1$$
$$I_{spot} = P_{spot} - C_2$$

Where:

P_{spot}: is the external price signal and it specifies what other markets will pay or charge for energy

$C_{spot}\left[\frac{€}{\mathrm{kWh}}\right]$: is the unit cost and it defines the references for sellers if they wish to deal in the external market

$I_{spot}\left[\frac{€}{\mathrm{kWh}}\right]$: is the unit reward and it defines the references for buyers if they are interested in dealing with the external market

C_1: it defines the regular cost for import and includes tariffs, taxes and commissions per kWh

C_2: it defines similar types of cost for exports.

The idea of Verv is that the market efficiency is reachable only if consumer takes the control; Verve creators think that it really happens only when the consumer is price taker. So, in Verv trading platform there won't be any tariff, as it's the only way that would let become energy peer-to-peer market flexible and fast.

[111] Bremdal B.A., Olivella-Rosell P., Rajasekharan J., Ilieva I. 2017 Creating a local market energy https://www.researchgate.net/publication/321205609_Creating_a_local_energy_market

3.3.2 Denmark

During last years, regulatory sandboxes of Scandinavian countries are taking place in islands because of their social and physical characteristics. In these places, traditional centralized ways of providing energy are progressively been replaced by distributed, heterogeneous, multidirectional and smart energy systems. According to Skjølsvold et al. (2020)[112] there are 5 European projects that have been developed in islands that are really important to be considered. These ones are, for the majority, funded by EMPOWER, that is a Horizon 2020 (H2020) project, that has the purpose to empower local public authorities to build integrated sustainable energy strategies; instead, H2020 is a European program drafted in 2014 that supports, by funding money and by creating networks between different actors of the scientifical research: innovation, digital society, education, environment (fighting climate changing), energy and mobility, competition regulation. One of the most important projects is Smart Energy Hvaler (SEH), born in 2013 with the partnership between Hvaler municipality, Fredrikstad Energi (FEN)[113], the Sweden NRA and Smart Innovation Norway[114]. It is a distributed energy case study in Hvaler island. This site was perfect for put into practice the RS: it is a little 5000 inhabitants island in the south-east of Norway which has a weak connection with an old cable to the mainland energy. This type of connection doesn't ensure the access to energy for all Hvaler population for the whole time; this is caused by the excess of demand of energy, the malfunctions

[112] Skjølsvold T.M., Ryghaug M., Throndsen W. 2020. European island imaginaries: Examining the actors, innovations, and T renewable energy transitions of 8 islands https://www.sciencedirect.com/science/article/pii/S2214629620300682

[113] Norwegian Centre of Excellence for Smart Energy Markets

[114] Local energy utility

of the cable and its breaks. For this reasons Hvaler inhabitants were really interested and proud to begin the Smart Energy Hvaler project; in addition, Norwegians, and all the Scandinavians, have the most awareness tax for environment and its respect[115]. Other positive characteristics of the island were that the Summer demand of energy was approximal to a 30.000 inhabitants city, because of the high number of electric car and due to the festivals and fairs that took place in Hvaler. These means that this site could be very interesting for understanding the feasibility of implementing this regulation in a small city.

After having analyzed the site, the project started in 2014 and it has been operationally applied by Fredrikstad Energin (FEN), that is a Norwegian DSO. The project area covered 86 km2 and 6.800 houses. Hvaler average consumption was about 80 GWh per year[116]. Every house had smart meters (AMI) that allowed the metering data analysis for EMPOWER services. It consists in collecting data in order to have a daily report of active and reactive energy consumption. FEN linked the grid to the traditional energy "provider", the old cable mainland connection, too; this was made to be ready in case energy demand picks occurred. The data collected suggested that with self-produced electricity and a battery bank, the microgrid can operate without external power only from spring to fall. The project required the installation of PV panels setup for the production of energy for each house. Every setup needed[117]: Smart meter (a device that helps the data collection), eWave monitor (where households could see their energy consumption), web Portal (created to join all the data collected for the EMPOWER analysts), PHEV / EV (energy storage devices), Smart plugs, heat pumps, inverter and PV Panels. These setups had different sizes and different costs: the cheapest was 2000€, while the most expensive was 12.000€. The average size setup was 5.000€, including the cost of installation,

115 Devon Hanie 2017. Countries That Care the Most About the Environment. https://www.usnews.com/news/best-countries/articles/2017-04-21/countries-that-care-the-most-about-the-environment

116 http://empowerh2020.eu/partners/

117 Throndsen W., Skjølsvold T.M., Koksvik G, Ryghaug M. 2017 https://www.match-project.eu/digitalAssets/344/344919_d2.3_norway-case-study-report_match.pdf

and comprehended 12 PV panels over 18 square meter area that can produce at the pick 3.2 KW output. With the economic support of Enova (company of the Norwegian Ministry of Petroleum and Energy that contributes to the reduction of greenhouse effect gas emissions) every household could have a discount of 1500€ on the price of the setup; this let average setup price to be around 3500€. This setup produced about 3600 KWh/year of which 1000 KWh were sold. This energy was bought by people who wasn't interested in investing money in PV panels setup or by someone who couldn't afford the price of the setup.
The price of one kWh of electricity delivered to a Norwegian household averages at around 0.10€, or 1 Norwegian krone. This price is a total purchase price because it is an aggregate of grid tariff, electricity price, and taxes. The pure market price for electricity in this cost and tax bundle is only around 0.02€, or 20 Norwegian øre. For this reason, the earnings for a 1 kWh of energy would be only 0.02€ and this amount of money doesn't incentive household investments for PV panels. However, in this case government funded money in order to create a feed in tariff that sets 0.10€/kWh sold or bought. As said before, if we consider that a household sells about 1000 KWh per year, the payback period for an average PV setup is about 10 years.
Considering:

- 3600 (kWh/year) * 0.10 (€/kWh) =360 €/year
- 3500 (€) / 360 (€/year) = 9,72 years

The fact that a PV setup has an average service life of 25 years[118] reveals that households could an average profit of 1750€, considering an average maintenance cost of 150€ per year[119].

[118] Jordan D.C., Kurtz R.S. 2012. Photovoltaic Degradation Rates — An Analytical Review 2012 https://www.nrel.gov/docs/fy12osti/51664.pdf

[119] https://www.homeadvisor.com/cost/cleaning-services/solar-panel-maintenance/

Considering:

- 360 (€/year) * 25 (years) - 3500 (€) - 150 * 25 years = 1750(€)

On the other hand, regulators thought that this tariff couldn't be sustained forever, so they created other ones that tried to stimulate the load shifting in order to reduce energy picks. The second tariff tested was called Smart Neighborhood; this tool allowed neighbors to purchase electricity at a 30% discount if there was a surplus of locally produced solar power anywhere in the neighborhood. This tariff caused many problems with the billing systems that was not able to manage with the amount of flexibility that this kind of account settling would require. These problems reveal and underline the complexity to build a system of regulation that is concretely applicable. Another tariff proposal was made for the electricity bill. Since the smart meter were installed, the electricity bill could consider different prices for each household. This way of tariff incentives the reduction of the local picks energy because it was built on the analysis of the of the three largest consumption peaks (peak is per day) within each month.

The tariff calculation considered:

$$Montly\ cost = [(p_1 + p_2 + p_3)/3] * 7\ (€)]$$

Where:

- p_1, p_2, p_3 are the largest consumption peaks

Additional flat charge = 65€

The monthly cost was about 35€, considering energy picks in range 4-7 kWh. The EMPOWER analysis revealed that only one household could low energy pick to less than 2kWh. This could be done avoiding the simultaneous use of PHEV charging, dishwasher, tumbler and using alternative way of heating such as wood burners and solar thermal for water heating. The statistics confirmed that only the people that could be at home all day, such as home-workers or seniors, could reduce their energy demand picks. This tariff produces a similar annual cost for the households to the feed in tariff and it apparently incentives households to reduce their picks. In fact, interviews to real users displays that if there were picks in early days of the month there won't be any incentive to reduce picks in the rest of the days of the month. The survey revealed that the majority of the customers was often using the web portal where they could monitor the picks and the monthly bill. This personal web area was really appreciated from households, even who didn't own PV panels, that affirmed that they were happy for bill transparency and energy management. On the other hand, the web portal caused big amount of energy consumption for the data sharing. The only part of the Smart Energi Hvaler (SEH) that was a failure, was the neighbor pooling because regulators couldn't find a way to create a tariff that could be sustained by the billing system. This project is already set to be followed by the new H2020 project INVADE (Smart system of renewable energy storage based on Integrated EVs and batteries to empower mobile, Distributed and centralized Energy storage in the distribution grid), which is the largest smart energy project in Norway to date and which SEH is also a part.

3.3.3 Netherlands

Another remarkable project is the one promoted by EDSEP, Experiments Decentralized Sustainable Electricity Production, a Dutch organization that invites homeowners' associations and energy cooperatives to propose projects that are prohibited by extant regulation. According to Esther C. van der Waal et al. (2020)[120]

[120] Van der Waal E.C., Das A.M., van der Schoor T. 2020. Participatory Experimentation with Energy Law: Digging in a 'Regulatory Sandbox' for Local Energy Initiatives in the Netherlands https://www.mdpi.com/1996-1073/13/2/458/htm

EDSEP stimulates local experimenters that can organize peer-to-peer supply and determine their own tariffs for energy transport in order to localize, democratize, and decentralize energy provision. From the 2015 17 projects have been approved, but only four have been actually implemented. The projects are divided into two categories: Large Experiment, with a maximum of 10.000 grid users, and the Project Network, with a maximum of 500 grid users. Another difference between these two different types of project, is the ownership of the grid: in Large Experiment the grid is owned by the project while in Project Network the grid is property of the grid operator. EDSEP's projects last 10 years, this duration is completely different from all the other European regulatory sandboxes, that last in average about 3 years. That is a very important innovation, because Dutch think that regulatory sandbox has to develop as similar as the real world, and this is possible only with wider time horizon. The four projects have been implemented in 2019, they are all Project Networks, but none of these is currently delivering energy. The goal for EDSEP is to implement the remaining 13 in next 5 years. The projects are very young and three of them are for future inhabitants, this is why there isn't so much data available. In addition, 3 of them are managed by HOA (Home Owner Association) and it means that, future inhabitants are really important in process of taking decisions; this is a remarkable innovation in term of customer attention. The most developed and big Project Network in Netherland is Collegepark Zwijsen, it consists in the transformation of a former school building in 115 apartments with PV panels and solar collectors jointly owned by the condominium. All households are connected to one shared large-scale use connection to the national grid. Every house has got an EMS that is a system of computer-aided tools used by to monitor, control, and optimize the performance of the energy system. This tool, in combination with dynamic tariffs, is expected to incentivize the apartment owners to better align demand to supply. The initial tariff structure is in place and approved by regulator ACM, Ministry of Economic Affairs. The occupants are guaranteed to a 3-year zero energy charge, provided if their consumption remains within a certain bandwidth. Later on, grid balancing is seen as a way to negotiate better tariffs, and then the HOA will be involved in deciding upon tariffs and new investments. Local experimenters can organize peer-to-peer supply and determine their own tariffs for energy transport in order to localise, democratise, and decentralise energy provision, but all the tariffs have to be approved by ACM. Experimenters says that a grid can save costs, because one high-volume connection to the regional grid is cheaper than the total sum of connections for individual dwellings to the regional grid. This is an important financial incentive for project grids, because the fewer (in terms of number) connections with the regional grid are required, the cheaper the connection costs. By considering the Dutch actual tariffs[121,122,123] the creation of one high volume connection produces savings on operative costs sustained for DSOs, this can result a significant saving as the DSO costs are about 1/3 of the total electricity bill. By considering the Collegepark Zwijsen as individual connections to regional grid the electricity bill would amount 230.36€/dwelling per year, while considering only one high-volume connection the amount for the electricity bill 17.457,50€ per year, namely 151,80€/dwelling per year. As for the Hvaler project, there isn't an innovative regulation for selling the energy peer to peer, and it causes a delay in the regulation of stored energy too. In fact, unfortunately, if a household decides to sell energy stored, he has to pay taxes two times: one for the energy stored, and the other one for the energy sold. For these reasons the HOA according to the project manager decided to store the excess energy as heat and not as energy.

[121] Stedin Tarieven. https://www.stedin.net/tarieven#3x25

[122] Belastingdienst Tabellen Tarieven Milieubelastingen. https://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/zakelijk/overige_belastingen/belastingen_op_milieugrondslag/tarieven_milieubelastingen/tabellen_tarieven_milieubelastingen?projectid=6750bae7-383b-4c97-bc7a-802790bd1110

[123] CBS StatLine - Aardgas en Elektriciteit, Gemiddelde Prijzen van Eindverbruikers. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/81309NED/table?fromstatweb

3.3.4 Austria

Although Austria has no regulatory sandboxes in action, it is very interesting the analysis of the strategy introduced by Energie.Frei.Raum, an Austrian Energy Research Initiative funding project. As Austria has no active projects for creating integration between different energy generation technologies, with Energie.Frei.Raum they have the purpose to prepare the strategy and give the guidelines for subsequent regulatory sandboxes. This project started in 2019 and it was supported by the Federal Ministry for Sustainability and Tourism[124]. The main goal of Austrian Energy regulator is to identify the best practices for a smart, secure and affordable energy integrated system. It could be done by evaluating the necessities in order to establish temporary regulatory innovation zones to allow operators to test new technologies. After having evaluated the social, economic and regulatory barriers, it has been drafted an overview of the needs that regulatory sandboxes have to satisfy. It has been organized in 15 main topics. Every topic is ranked for giving a guideline of how to approve regulatory sandboxes and with which criteria. If a topic is ranked 1st, a regulatory sandbox, that has it as main goal, has the priority to be approved confronted to the other RSs. To give this prioritisation, the ranking is based on 4 parameters:

- Overall effectiveness for CO2-neutrality
- Complexity of implementation
- Potential for social transformation
- Defining legal parameters

On the basis of these parameters, it is possible to show the table below with all the 15 regulatory sandboxes topics.

[124] Veseli A., Moser S., Kubeczko K., Madner V, Wang A., Wolfsgruber K. 2021. Practical necessity and energy law options for introducing regulatory sandboxes in Austria.

Topics	Rank	Cluster
1. Proximity criteria for energy communities: what shall be the parameters proximity is legally defined with?	1	energy communities
2. Gas network limits: what adaption of standards can be made order to increase the allowed share of hydrogen or biogas while network safety and energy quality are maintained?	1	gas regulation
3. Dynamic electricity network tariffs: Which design of dynamic tariffs (instead of static kWh- or kW-dependent ones) may enable supportive customer behaviour in smart grids?	3	network charges and new services
4. Gas network feed-in: To what extent can the standards be adapted to allow for the direct feed-in of hydrogen or biogas into the gas grid?	3	gas regulation
5. Compliance with the status of being a supplier: how can standards be adapted to ease the market entry of new-type energy market players (e.g., aggregators, energy communities)?	3	energy communities
6. Non-profit orientation of energy communities: should profit-oriented service providers be eligible to operate and manage (not: to legally control) energy communities?	3	energy communities
7. ICT for distribution network control: should there be a harmonisation/ standardisation among distribution system operators as different technologies may hamper the introduction of smart services?	7	network charges and new services
8. Central platforms for power grid data: how can the provision of actual and near-time data (smart meter, transformers, power flows) be organised to enable smart services?	7	network charges and new services
9. Exemptions from electricity network tariffs: should distribution system operators be able, based on a sound methodology, to decrease a customer's charges in case of network- supporting behaviour?	7	network charges and new services
10. Network tariff exemptions for system-relevant technologies: which technologies' (future) system relevance justifies exemption? (E.g., batteries, power-to-gas/heat, pumped storage.)	7	preference for system-friendly technologies
11. Accreditability of smart technologies as network costs: how can the regulatory acceptance of using smart technologies instead of common network extension be mainstreamed?	11	optimised network cost recovery
12. External relations of energy communities: how should energy communities interact with the rest of the electricity system (control power, balancing, market participation)?	11	energy communities
13. Network operator benchmarking: what should be the parameters to assess the efficiency and innovation of network operators?	13	optimised network cost recovery

14. Real-time electricity network status ('traffic light system'): what are the parameters that define the status of the grid and what restriction of market actions should be associated?	14	network charges and new services
15. Control energy market participation: should there be more specific requirements to enable smart technologies and renewables to participate?	15	preference for system-friendly technologies

Table 14 Austrian regulatory sandboxes ranked topic (Veseli A.)

To sum up in a more concise way which are the objective that Austrian energy regulator requires, the 15 topics are clustered in 6 categories of subareas: gas regulation (light blue), network charges and new services (yellow), optimised network cost recovery (green), preference for system-friendly technologies (red), energy communities (orange). For a better identification, in table 14, the topics of the same cluster are underlined with the same colour.

It is important to underline that, 13 of 15 topics refers to the electricity market, and it confirms that the majority of the changings are expected to come from the electricity sector. As it is possible to understand, some topic needs are out of the national competence, it once again confirms that for developing a proper regulation for integrated energy systems and for regulatory sandboxes, there should be an experimentation not only in the national regulation, but also, at the level of European legislation.

3.3.5 Slovenia

Energy Agency, the Slovene energy regulator has incentivised the investments in smart grids for several years. Since 2013 Slovene NRA designed a scheme of incentives that were focused on the developing of a WSA. Even if these are not regulatory sandboxes, it seems to be very important to underline one of the first proposal of regulatory framework for layer 1 and layer 2 of the CEER's WSA. With the third regulatory period, that occurs from 2019 to 2021, Energy Agency of Slovenia

added some other economic features to the previous Whole System Approach regulatory scheme.
The incentive scheme based on WSA approach is intended for categories of project of DSOs and TSOs that have the following characteristics:

- investment costs exceeding 100.000€
- consistency with standardised definitions of smart-grids and smart grid infrastructure
- directed to solving the problem in at least one of the defined 10 target application domains

If the projects meet the requirements indicated above, DSOs and TSO will receive:

- basic incentive: 2% of the current value of the asset, that were put into service in the regulatory period
- WSA based incentive: additional 3% of the current value of the asset, that were put into service in the regulatory period if there is an evidence of the use of a WSA approach in the design and implementation of the project. The evidence must be presented with one or more KPIs which include also the effective real-time data interchange on the important state of the distribution system (less than 30 seconds, e.g., observability of distributed energy resources)
- Output based incentive: a one-time financial incentive (reward) in the amount of 5% of the costs of acquiring the assets for improving performance. The incentive will be given only if the initial KPIs calculated are improved at the end of the regulatory period
- Opex: an additional incentive which relates to the assets of qualified smart grid projects as pass through costs in the regulatory procedure for granting the deviations from planned costs

The sum of all incentives granted is capped by a maximum of 10% of project net benefits (output-based incentive cap), excluding Opex.

3.3.6 Italy

ARERA, in the wake of the other European countries, published in 2017 National Energy Strategy (NES) that joined with Integrated National Energy and Climate Plan for 2021–2030 (NECP), represents a comprehensive environmental action plan focused on renewable energy. From 2010 Italy has been one the most active country in developing projects and regulatory sandboxes relating renewable energies. In the period from 2010-2019, ARERA with ISGAN[125] support, started 8 projects in different fields of innovation: Smart Grid functionalities, Energy Storage Systems at utility scale, Dynamic Thermal Rating for transmission lines, Electric mobility, smart metering, Ancillary Services Market. From the first pilot project resulted very important to give an economic incentive to DSOs because, according to Delfanti M. et al. (2016)[126], these ones could have no interest in developing such solutions or in cooperating with Italian TSO, Terna. In the first project seemed that DSOs were trying to find solutions that were more convenient and capital-intensive only for them, not pursuing the social welfare. On the basis of these considerations, the Italian Energy Regulator understood that in order to avoid this barrier, it would be appropriate to assess the development of an incentive mechanism that "internalised" part of the benefit in favour of the DSO, avoiding DSOs' free riding in fostering the sector innovation. This incentive was output-based and "selective in nature", in other terms it should have been oriented itself primarily toward those areas in which the intervention yielded the greatest net benefits. The incentive was calculated in two differ steps: incentive for power flows and incentive for voltage regulation.

The first one, incentive for power flows was:

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[125] International Smart Grids Action Network

[126] Delfanti M., Olivieri V., Larzeni S., Lo Schiavo L. (2016) Regulatory incentive mechanisms for promoting investments in smart distribution system https://ieeexplore.ieee.org/document/7861208

$$I_{OSS1} * P_{RES} * Months/12$$

where:

- I_{OSS1} is equal to 20 €/MW, (it represents the real time information from DSO to TSO about busbar voltage and line current of at least one MV feeder in Primary Substation that connects a pure photovoltaic generator only)
- P_{RES} is the sum of the rated power of DG from RES in the area [MW]
- Months are the number of months in a year with a satisfying real time estimate.

The second one was:

$$I_{REGV-1} * S_{PS}$$

where: -

- I_{REGV-1} is equal to 250 €/MVA (REGV-1: utilization of the tap-changer of the HV/MV transformers in PS on the basis of load flow calculations on the network suitably modelled (loads, generators, line, etc.)
- S_{PS} is the rated power of HV/MV trafos in the area [MVA].

In the next sub-chapter, it is analysed a practical example of the implementation of a P2H technology foreseeing an inclusion of the grid users in the market chain.

3.4 The Iren Experimental Program - The installation of a P2H technology

Iren is one of the largest and most dynamic multiutility companies on the Italian scene and operates in the sectors of electricity, thermal energy for district heating and gas, and in the management of integrated water services, environmental services and technological services.[127]

IREN s.p.a. conducted "The Iren Experimental Program". This pilot project is supported by Italian NRA, ARERA, that has the scope to identify the requirements of the energy market through a series of pilot projects run by the Italian TSO Terna with the cooperation of DSOs and other stakeholders. In this pilot project, Iren runs the installation of a reversible Heat Pump (HP) in a building to test the HP's response to the different thermal loads throughout the year. It was done to understand the amount of flexible capacity that HP can provide under diverse conditions and to analyses which would be the economic implication for the customers. In addition, Iren and the regulators test the efficiency and the economic advantages that could bring the selling of excess capacity to a Balancing Service Provider (BSP).

A BSP is an aggregator of consumption and production units, UVAM (Virtually Aggregated Mixed Units), and provides ancillary services to the grid by balancing their load or production. Thus, BSP is the liaison between the prosumer's distributed generation resource or the consumer's load.

In 2017, through the Deliberation 300/2017/R/EEL of the Italian NRA, opened the Italian ancillary services market (MSD) to new flexible and distributed resources. This strategy was made for the development of distributed resources that, with diversification of provided ancillary services (AS), can guarantee an electrical system's security. These services are not only technical tools, that can only give strength to electrical system, but they also unload and help TSO to manage energy demand and low total systems costs. In fact, in centralized energy systems, ancillary services are fundamental to balance supply and demand. AS are provided from external suppliers, so ARERA, in order to start a new pilot project on these services, decided to review

[127] https://www.devex.com/organizations/iren-s-p-a-132031

their schemes of remuneration. The barrier of this project pilot is that UVAMs[128] for being accepted, need to provide at least 1 MW. "The remuneration for the BSP[129] can follow two schemes: it can either follow the ordinary remuneration of the MSD, thus being granted according to the actual usage of the UVAM, or it can have a two-component structure. This second remuneration scheme comprises a fixed component, which remunerates the resource availability, and a variable component, linked to actual energy provided. To choose the second scheme, the UVAM needs to offer ancillary services for at least 2 consecutive hours between 14:00 and 20:00 Monday to Friday. The fixed remuneration is defined through a lowest unique bid auction starting from either 15,000 € per MW per year – if 2 hours of daily availability are granted – or 30,000 €/MW/year for 4 hours of daily availability. The variable remuneration depends on the price offered by the BSP, with a strike price of 400 €/MWh. This remuneration option is limited for the duration of the pilot projects"[130].

After having analysed the regulatory framework of the RS, it is provided a brief description of the site of the project.

The building is located in Turin and it's composed of 9 apartments. Before the pilot project, the total thermal energy demand of the building was satisfied by a classical energy system based on chiller and gas condensing boiler units that covered the cooling and heating energy demand, respectively. The Iren project (system ex-post) sees the installation of a reversible Heat Pump to cover the total cooling energy demand (with a chiller used as a backup unit to guarantee that the comfort of the building ex-ante would be almost unchanged), and also a part of the heating energy

[128] Virtually Aggregated Mixed Units: which are consumption and production units

[129] Balancing Service Provider that provides ancillary services to the grid by either reducing or increasing their load or production, it aggregates UVAMs services.

[130] ARERA. Deliberazione 5 Maggio 2020—153/2020/R/eel—Approvazione delle modifiche, predisposte da Terna S.P.A., al regolamento relativo al progetto pilota per la partecipazione di unità virtuali miste al Mercato per il Servizio di Dispacciamento (MSD), ai sensi della Deliberazione dell'Autorità 300/2017/R/eel; Autorità di regolazione per energia reti e ambiente: Milan, Italy, 2020.

demand in combination with the gas condensing boiler[131]. As a support, the system was equipped with a fly-thermal wheel that has the function of collecting the excess capacity

The pilot project takes place in 2020-2021 and due to the pandemic, it has been possible only to develop a forecasted simulation that lasts 10 years for 3 different scenarios:

- Scenario A or Baseline Scenario: the inhabitants of the building continue using the classical energy system by buying a new chiller and gas condensing boiler
- Scenario B or HP Scenario: the inhabitants of the building buy the reversible Heat-Pump
- Scenario C or UVAM Scenario: the inhabitants of the building buy the reversible Heat-Pump with the possibility to participate in a BSP pilot project to sell at least 1 MW of excess energy.

3.4.1 Technical Data

The following tables describes the energy needs of the building and all the 3 Scenarios are presented.

Baseline - Ex ante system

[131] Planning and operational tools for optimising energy flows e synergies between networks.

Boilers' technical data

Effective Power	Supply/Return flow temperature 50/30 °C	64 – 318 kW
	Supply/Return flow temperature 80/60 °C	58 – 291 kW
Firebox power	300 kW	
Operating pressure max/min	6/1 bar	
Water content	180 l	
Flue mass flow	Useful potential	477 kg/h
	Reduced load (30% of useful potential)	143 kg/h
Seasonal efficiency	Supply/Return flow temperature 40/30 °C	Until the 98 (LHV) Until the 109 (HHV)
	Supply/Return flow temperature 75/60 °C	Until the 96 (LHV) Until the 106 (HHV)
Gas consumption (ex-ante) [MWh/y]	466.3	

Table 15 Boiler's technical data

Chiller units' technical data

Fluid coolant	R407c
Temperature max/min	100/35 °C
Operating pressure max	30 bar
Useful cooling power	211 kW
Absorbed electrical power	67,4 kW
EER (Energy Efficiency Ratio)	3,13
Electricity consumption (ex-ante) [MWh/y]	31.6

Table 16 Chiller units' technical data

Baseline simulation data

BASELINE	Without HP real data	Without HP data from model
Building Heat requirement in terms of energy [MWh/a]	493,5	434,6
Building Heat requirement with losses in terms of energy [MWh/a]	551,3	473,3
Building cool requirement in terms of energy [MWh/a]	54,7	93,0
Building cool requirement in terms of energy with losses [MWh/a]	58,2	98,8
Thermic energy produced by RF [MWh/a]	58	99,0
Thermic energy of the boiler [MWh]	551,3	473,3
Natural gas heat consumption [MWh/a]	543,2	466,3
Electricity for cool consumption [MWh/a]	18,6	31,6

Table 17 Baseline simulation technical data

HP technical data

Heating	
Nominal power	189,4 kW (Air temperature 7°C Supply/return water flow temperature 50/45 °C)
Absorbed electrical power	75,3 kW
COP (Coefficient of Performance)	2,52
Water pressure drop	36 kPa (31,9 m^3/h)
Cooling	
Nominal power	186,1 kW (Air temperature 35°C Supply/return water flow temperature 7/12 °C)
Absorbed electrical power	75,3 kW
EER (Energy Efficiency Ratio)	2,83
SEER (European Seasonal Energy Efficiency Ratio)	4,57

Table 18 HP technical data

The simulation differentiates in two season the analysis: a heating season, that runs from the 15th of October to the 30th of April, and a cooling season, that runs from the 1st of May to the 14th of October.

Intending for:

- low regime: HP works at 0-40%
- medium regime: HP works at 40-80%
- high regime: HP works at 80-100%

	Cooling season			
WITH HP	**HP low regime**	**HP medium regime**	**HP high regime**	**Cooling Season total**
Building Heat requirement in terms of energy [MWh/a]	75,2	17,8	0	93
Building Heat requirement with losses in terms of energy [MWh/a]	79,9	18,9	0	98,8
Scenario Frequency occurency [%]	94,60%	5,40%	0%	100%
Percentage of demand covered by HP [%]	100,00%	100,00%	0%	100%
Thermal energy produced by HP [MWh] [MWh]	79,9	18,9	0	98,8
Thermic energy produced by RF [MWh/a]	0	0	0	0
Thermic energy of the boiler [MWh]	-	-	-	-
Natural gas boiler consumption [MWh/a]	-	-	-	-
Electricity consumption heat/cool HP [MWh/a]	28,3	6,7	0	34,92
Electricity consumption of RF [MWh/a]	0	0	0	0,0
Average HP power [kWt]	20,9	86,8	-	24,5

Table 19 HP scenario cooling season

	Heating Season			
CON HP	**HP low regime**	**HP medium regime**	**HP high regime**	**Cooling Season total**
Building Heat requirement in terms of energy [MWh/a]	69,8	227,8	126,1	423,7
Building Heat requirement with losses in terms of energy [MWh/a]	78	254,4	140,9	473,3
Scenario Frequency occurency [%]	47,23%	39,40%	13,16%	100,00%
Percentage of demand covered by HP [%]	85,20%	82,70%	77,10%	81,67%
Thermal energy produced by HP [MWh]	66,4	210,3	109,0	385,7
Thermic energy produced by RF [MWh/a]	-	-	-	-
Thermic energy of the boiler [MWh]	11,6	44,1	31,9	87,6
Natural gas boiler consumption [MWh/a]	11,4	43,5	31,4	86,3
Electricity consumption heat/cool HP [MWh/a]	26,4	83,5	43,2	153,1
Electricity consumption of RF [MWh/a]	-	-	-	-
Average HP power [kWt]	29,7	112,9	172,5	81,2

Table 20 HP scenario heating season

	Total per year
WITH HP	
Building Heat requirement in terms of energy [MWh/a]	516,7
Building Heat requirement with losses in terms of energy [MWh/a]	572,1
Thermal energy produced by HP [MWh]	484,5

Table 21 HP scenario consumptions

UVAM Scenario

Intending for:

- low regime: HP works at 0-40%
- medium regime: HP works at 40-80%
- high regime: HP works at 80-100%
- complete regime: HP works at 100%

	Cooling season			
UVAM	**HP low regime**	**HP medium regime**	**HP high regime**	**HP complete regime**
Building Heat requirement in terms of energy [MWh/a]	25,4	19,9	65,7	111,0
Building Heat requirement with losses in terms of energy [MWh/a]	27,0	21,2	69,8	118,0
Scenario Frequency occurency [%]	86,04%	4,83%	9,13%	100%
Percentage of demand covered by HP [%]	100,00%	100,00%	94%	96%
Thermal energy produced by HP [MWh]	27,0	21,2	65,7	113,9
Thermic energy produced by RF [MWh/a]	0,0	0	4,1	4,1
Thermic energy of the boiler [MWh]	-	-	-	-
Natural gas boiler consumption [MWh/a]	-	-	-	-
Electricity consumption heat/cool HP [MWh/a]	9,5	7,5	23,2	40,2
Electricity consumption of RF [MWh/a]	0	0	1,3	1,3
Average HP power [kWt]	7,8	108,8	178,4	28,2

Table 22 UVAM scenario cooling season

	Heating season			
UVAM	**HP low regime**	**HP medium regime**	**HP high regime**	**HP complete regime**
Building Heat requirement in terms of energy [MWh/a]	162,5	157,8	103,4	423,7
Building Heat requirement with losses in terms of energy [MWh/a]	181,5	176,3	115,5	473,3
Scenario Frequency occurency [%]	60%	29%	11%	100%
Percentage of demand covered by HP [%]	54%	86%	78%	71%
Thermal energy produced by HP [MWh]	97,9	150,8	89,7	338,4
Thermic energy produced by RF [MWh/a]	-	-	-	-
Thermic energy of the boiler [MWh]	83,6	25,5	25,8	134,9
Natural gas boiler consumption [MWh/a]	82,4	25,1	25,4	128,7
Electricity consumption heat/cool HP [MWh/a]	38,9	59,8	35,6	135,8
Electricity consumption of RF [MWh/a]	-	-	-	-
Average HP power [kWt]	34,3	110,9	174,3	71,6

Table 23 UVAM scenario heating season

3.4.2 Cost/Benefit analysis

In order to compare the results coming from this pilot project, it has been decided to simulate the Iren experimental program in other countries: France, Germany, Sweden, UK. The main difference, between these countries, is findable in the price of electricity and gas that will lead to results that are completely different for each country. The cost benefit analysis for each country is compared with the use of the Net Present Value (NPV) evaluation. This analysis is based on previously introduced hypothesis that are explained below.

Hypothesis:

- The lifetime of the heat pump is expected to be 10 years, so the time window of the analysis lasts 10 years
- The cost of the heat pump is 35,5 k€ and it is assumed to be the same for all countries
- The cost of the installation of the heat pump is 38,787 k€ and it is assumed to be the same for all countries
- The cost of the gas boiler and chiller is 47k€ and it is assumed to be the same for all countries
- The cost of the installation of gas boiler and chiller is 50,5k€ and it is assumed to be the same for all countries
- The cost of maintenance of the system is 13,5 k€ per year and it's the same for every configuration and country
- The price of electricity and gas is the same for the 10 years of the project simulation.
- The prices of the electricity and gas are taken from EU commission report[132,133]. Reported in Table 24
- The CBA adopts a financial discount rate (FDR) of 4%.

[132] https://ec.europa.eu/eurostat/statistics-explained/pdfscache/64915.pdf

[133] https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

- The energy consumption is assumed to by the same for all country. This simulation takes the technical data coming from Iren simulation as the simulation technical data

	Electricity prices [€/kWh]	Gas prices [€/kWh]
Italy	0,223	0,093
France	0,190	0,081
Sweden	0,220	0,1167
UK	0,183	0,055
Germany	0,304	0,059

Table 24 Electricity and gas prices

Since the ancillary services market for flexibility and distributed technologies are only at a trial phase, some additional assumptions are required regarding its functioning. These assumptions regard only the UVAM scenario:

- The aggregator (BSP) takes the fixed part of the UVAM remuneration and shares evenly with the Consumption Unite[134] the profit on the variable part (i.e., the difference between the variable payment and the cost of energy)
- The UVAM provides 4 hours of ancillary services per day, and these services are all requested by the TSO; thus, it is assumed that UVAM requests all the capacity made available by the Consumption Unites
- The variable remuneration of the UVAM equals the strike price set on 400€/MWh
- UVAM regulation is assumed to be the same for all the countries in order to understand in which country UVAM could more efficient

In addition, for considering a more optimistic case, in the Italian simulation has been added a scenario, called High DG penetration, in which the cost of electricity every year is reduced of 3%.

[134] Consumption Unites assumable as building inhabitants

3.4.3 Results

The tables 25,26,27 below shows the NPV investment evaluation method of the simulation of the experiment in the Italian country. As is it possible to see there are 3 different scenarios:

The first one is the scenario that simulates the adoption of the same ex-ante setup for the supply of energy and gas. In the model are added capital costs that are used for the purchase of the gas boiler and chiller and for their installation, and operational costs, for the cost of maintenance and the cost of gas and of electricity. In order to discount the investments, it has been introduced the financial discount rate of 4%.

BASELINE										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (gas and chiller purchase)										
€47.000	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Capital costs (installation and equipment)										
€50.500	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€37.770	€37.770	€37.770	€37.770	€37.770	€37.770	€37.770	€37.770	€37.770	€37.770
Cost of electricity										
	€7.034	€7.034	€7.034	€7.034	€7.034	€7.034	€7.034	€7.034	€7.034	€7.034
Total Undiscounted Costs										
€97.500	€58.304	€58.304	€58.304	€58.304	€58.304	€58.304	€58.304	€58.304	€58.304	€58.304
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€97.500	€56.062	€53.906	€51.832	€49.839	€47.922	€46.079	€44.307	€42.602	€40.964	€39.388
Total Discounted Cumulated Cost										
€97.500	€153.562	€207.468	€259.300	€309.139	€357.061	€403.140	€447.447	€490.049	€531.013	€570.401
Net Present Value										
-€570.401										

Table 25 Italian Baseline scenario NPV

For the second scenario, the HP one, it has been introduced the purchase of an HP that replaces the old energy system. The cost of maintenance is assumed to be the same to the previous scenario.

WITH HP										
YEAR										
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Capital costs (HP installation and equipment)										
€38.787	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€6.990	€6.990	€6.990	€6.990	€6.990	€6.990	€6.990	€6.990	€6.990	€6.990
Cost of electricity										
	€41.853	€41.853	€41.853	€41.853	€41.853	€41.853	€41.853	€41.853	€41.853	€41.853
Total Undiscounted Costs										
€74.287	**€62.344**	**€62.344**	**€62.344**	**€62.344**	**€62.344**	**€62.344**	**€62.344**	**€62.344**	**€62.344**	**€62.344**
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	**0,962**	**0,925**	**0,889**	**0,855**	**0,822**	**0,790**	**0,760**	**0,731**	**0,703**	**0,676**
Total Discounted Costs										
€74.287	**€59.946**	**€57.640**	**€55.423**	**€53.292**	**€51.242**	**€49.271**	**€47.376**	**€45.554**	**€43.802**	**€42.117**
Total Discounted Cumulated Cost										
€74.287	**€134.232**	**€191.873**	**€247.296**	**€300.587**	**€351.829**	**€401.100**	**€448.476**	**€494.030**	**€537.832**	**€579.949**
Net Present Value										
-€579.949										

Table 26 Italian HP Scenario NPV

In the third scenario, and most innovative one, there's the purchase of an HP, as for HP scenario, but, in this scenario, there is the possibility for households to earn some money from the sale of excess capacity, with reference to the hypothesis done above for the regulation applied.

UVAM										
YEAR										
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Capital costs (HP installation and equipment)										
€38.787	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€10.422	€10.422	€10.422	€10.422	€10.422	€10.422	€10.422	€10.422	€10.422	€10.422
Cost of electricity										
	€37.996	€37.996	€37.996	€37.996	€37.996	€37.996	€37.996	€37.996	€37.996	€37.996
Revenues from UVAM participation - Fixed component										
	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Revenues from UVAM participation - Variable component										
	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753
Total Undiscounted Costs										
€74.287	**€60.165**	**€60.165**	**€60.165**	**€60.165**	**€60.165**	**€60.165**	**€60.165**	**€60.165**	**€60.165**	**€60.165**
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	**0,962**	**0,925**	**0,889**	**0,855**	**0,822**	**0,790**	**0,760**	**0,731**	**0,703**	**0,676**
Total Discounted Costs										
€74.287	**€57.851**	**€55.626**	**€53.486**	**€51.429**	**€49.451**	**€47.549**	**€45.720**	**€43.962**	**€42.271**	**€40.645**
Total Discounted Cumulated Cost										
€74.287	**€132.138**	**€187.763**	**€241.250**	**€292.679**	**€342.130**	**€389.679**	**€435.400**	**€479.361**	**€521.632**	**€562.278**
Net Present Value										
-€562.278										

Table 27 Italian UVAM scenario NPV

Besides, it has been added an Italian more optimistic case, “High DG penetration”. It is a more optimist case in which the cost of electricity is reduced by 3% per year for the increase of distributed generators in the market. This scenario has been added for a better analysis of the results.

For simplicity the results of each country are been resumed in table 28.

For France, Germany, Sweden and UK is assumed that the energy consumption is the same of the Italian simulation. Each foreign country scenario considers the prices of gas and energy provided by UE commission. The results below are explained in a more exhaustive way in the appendix.

Scenario	Baseline	HP	UVAM
Italy	-€570.401	-€579.949	-€562.278
Italy with High DG	-€605.372	-€526.380	-€518.545
France	-€534.604	-€525.007	-€509.441
Germany	-€526.612	-€799.080	-€752.231
Sweden	-€706.315	-€610.247	-€604.355
UK	-€484.827	-€637.675	-€604.071

Table 28 NPV results for each country

In table 29, 30 it is made a comparison between the adoption of a new system (HP) and the adoption of the elder system (gas and chiller). HP-baseline and UVAM-baseline it refers to the economic difference between NPV of the two different scenarios.

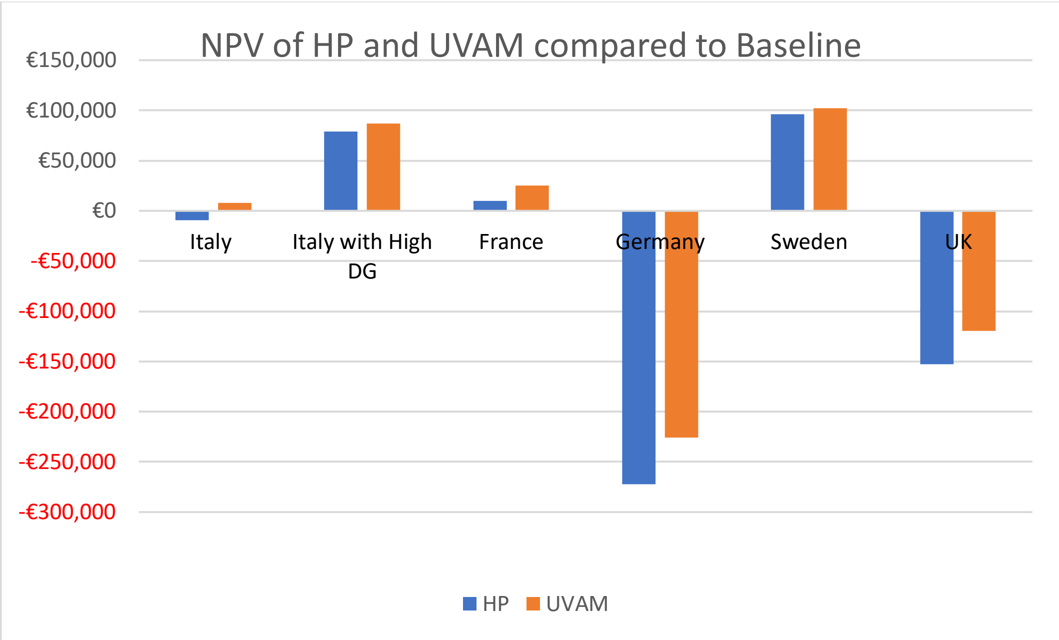

Table 29 NPV comparison for each country

Scenario	HP-BASELINE	UVAM-BASELINE
Italy	-€9.547	€8.124
Italy with High DG	€78.991	€86.827
France	€9.597	€25.163
Germany	-€272.468	-€225.619
Sweden	€96.068	€101.960
UK	-€152.848	-€119.244

Table 30 NPV comparison for each country #2

The analysis reveals that adopting a new system for meeting the energy demand is not economically efficient for almost all countries. Sweden is the only country in which the adoption of the Heat Pump seems to be worth, as the economic difference between the ex-ante scenario and ex-post one is 96k€. For the other cases, the difference between ex-ante and ex-post configuration doesn't justify the adoption of the Heat pump. Especially for UK and Germany, the difference with the ex-ante configuration suggests avoiding adopting the new configuration. As it is possible to see in table 30, Germany and UK's HP scenarios exceed 100k€ of potential loss. This is because the cost of electricity in these countries is very high and, replacing a technology that is gas based with a technology that is electricity based, explains the inconvenience of the investment. Analysing the UVAM case, it shows that this regulation doesn't sufficiently incentive the adoption of a Heat-pump. Only in the Italian standard case, UVAM is useful to make positive the NPV results. This is because, as showed in tables, the UVAM per year remuneration is about 1,7K€, that is very low if it is confronted with the price of the HP. In addition, the current difference between gas and electricity prices is very high and the adoption of a HP would cause a higher use of electricity, that would lead to higher costs. It's really interesting to understand that, if the evaluation period would be extended to 15 years, the comparison with the ex-post and the ex-ante scenario would lead to have worse results in scenarios in which the households adopted the HP. Once again, this is because the initial price for the purchase of the HP is not so far from the one paid for the old technology but the higher use of electricity for the HP, at expense of the cheaper gas, causes higher total costs for HP scenario.

In addition, considering the best-case scenario, the High DG one, in which the cost of the electricity is reduced of 3% year by year, it reveals that this reduction could be very positive for the results of the NPV. This is because, as previously specified, the cost of electricity is strongly affecting the final results and the evaluation on the adoption, more than the possibility of selling excess capacity with UVAM.

3.5 Ancillary Services

As the Iren experiment program was about the selling of excess capacity to a Balancing Service Provider (BSP), it is important to give a brief description of what are ancillary services and what are the implication for its market with the advent of decentralised generation.

Ancillary services (AS) are necessary to guarantee an electrical system security and a balance between supply and demand. ASs are crucial for giving support to synchronous generators, giving them flexibility, when picks occur, or for avoiding sudden shutdown or power surges that could be really dangerous for the network preservation.

Unfortunately, replicate the Ancillary Service Market for SGs for DRESs it's very difficult and currently very unremunerative for BSP. This is caused by several reasons, the first is a technical one: the physical differences between the traditional energy system and distributed energy system are many. Current Ancillary services are designed and created to work with synchronous generators (SGs) and as they are currently provided only for TSOs, there aren't any economic incentives to change it[135]. Some of the most important ancillary services created for traditional market are frequency control, voltage control and reactive power, black-start capability/grid restoration. These ones are very important for lowering the total costs of the system, guarantying the continuous grid run in different situation and keeping it in safe from sudden swings. In addition, there is the problem that in some cases, AS for DRESs are functions that are already carried by SGs, so there's the need to create a tool or a device that makes possible the availability of these functions even for DRESs. One clear example is the Inertial Response, it prevents fast frequency variations in the first few cycles after a power imbalance. Due to the lack of rotating mass in DRES, there's a physical impossibility of creating inertia, so there's the need of the creation of an

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[135] Oureilidis, K. Malamaki, K. Gallos, A. Tsitsimelis 2020.Ancillary Services Market Design in Distribution Networks: Review and Identification of Barriers https://www.mdpi.com/1996-1073/13/4/917

ancillary service that recreates this inertial response. The more suitable answer to this problem has been found in the virtual inertia. There are several companies that produce wind turbines to recreate the rotating mass effect. Unfortunately, up to now, doesn't exist a market for trading virtual inertia from converter interfaced DRES nor inertia from conventional SGs. There are several ASs, beyond inertial response, that aren't already provided or are in testing phases, or are too expensive to penetrate the market, such as: Active power ramp, Frequency Response, Voltage Control, Fault Contribution and Harmonic mitigation.

Another reason that this market is currently unremunerative, and more predictable one, is that companies providing ASs have no economic interests to explore this new market, due to high R&D cost, lack of regulated markets and lack of demand, that causes no economies of scale.
As it emerges, NRA should incentivise the supply of these Ancillary Services and stimulate the creation of Ancillary Service Market for DRESs. It isn't really clear how it should be done, but a walkable road could be to oblige BSPs, that already operate in SGs market, to provide a bundle of services that could be purchased. The world bundle is not random for Ancillary Services, as it would be currently economically unsustainable to supply a single AS, due to the high fixed costs of BSPs.

Conclusions

The scope of the thesis was to understand if the technical innovations brought by Energy System Integration were moving in the same direction and at the same pace of the regulatory framework. Unfortunately, regulation in this field is very complicated to implement, because of the difficulties of managing cross-sectors tariffs and of the enormous number of changing from the pre-existing regulation that were and currently are to do, the European energy regulatory bodies haven't succeeded yet in creating a proper regulatory scheme that incentives a holistic view of the energy sector.

On the other hand, it's important to say that European guidelines for next years are very promising. The introduction of a Whole System Approach clarifies in which economic area each European NRA should incentive the stakeholders in order to achieve the hoped results. In addition, even if there isn't a certain evidence of a regulatory framework published from the European countries, regulatory sandboxes are bringing some important suggestions that are useful to design a proper regulation.

The analysis of the Italian business case, Iren experimental program, underlines some lacks in the regulation especially in the customers' energy sale. The CBA shows that isn't currently convenient to buy heat pumps, that are at the basis of ESI principles as they allow to conversion of energy from Power to Heat. Even ancillary service market for DRESs seems that hasn't kept up the yet the transition from centralised technology to the decentralised one. In fact, there aren't any solutions available for guarantying ancillary services for decentralised renewable energy sources.

Appendix

Italian Scenario with high distributed generation penetration

Confronting three cases in which the electricity and gas prices are reduced by 3% every year, for the cost reduction due to the high DG penetration.

Baseline scenario: considering the technical characteristics of the previous setup of gas boiler and chiller designed for the building located in Turin.

ITALY HIGH DG PENETRATION										
BASELINE										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (gas and chiller purchase)										
€47.000	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Capital costs (installation and equipment)										
€50.500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€43.366	€43.366	€43.366	€43.366	€43.366	€43.366	€43.366	€43.366	€43.366	€43.366
Cost of electricity										
	€6.506	€6.311	€6.121	€5.938	€5.759	€5.587	€5.419	€5.256	€5.099	€4.946
Total Undiscounted Costs										
€97.500	**€63.372**	**€63.176**	**€62.987**	**€62.803**	**€62.625**	**€62.453**	**€62.285**	**€62.122**	**€61.965**	**€61.812**
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	**0,962**	**0,925**	**0,889**	**0,855**	**0,822**	**0,790**	**0,760**	**0,731**	**0,703**	**0,676**
Total Discounted Costs										
€97.500	**€60.934**	**€58.410**	**€55.995**	**€53.685**	**€51.473**	**€49.357**	**€47.331**	**€45.392**	**€43.536**	**€41.758**
Total Discounted Cumulated Cost										
€97.500	**€158.434**	**€216.844**	**€272.840**	**€326.524**	**€377.998**	**€427.355**	**€474.686**	**€520.079**	**€563.614**	**€605.372**
Net Present Value										
-€605.372										

Table 31 Italy high DG penetration baseline scenario

HP scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation.

WITH HP										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Capital costs (HP installation and equipment)										
€38.787	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€8.026	€8.026	€8.026	€8.026	€8.026	€8.026	€8.026	€8.026	€8.026	€8.026
Cost of electricity										
	€38.709	€37.548	€36.421	€35.328	€34.269	€33.241	€32.243	€31.276	€30.338	€29.428
Total Undiscounted Costs										
€74.287	€60.235	€59.073	€57.947	€56.854	€55.795	€54.766	€53.769	€52.802	€51.864	€50.954
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€57.918	€54.617	€51.515	€48.599	€45.859	€43.283	€40.860	€38.582	€36.439	€34.422
Total Discounted Cumulated Cost										
€74.287	€132.205	€186.821	€238.336	€286.936	€332.795	€376.077	€416.938	€455.519	€491.958	€526.380
Net Present Value										
-€526.380										

Table 32 Italy high DG penetration HP scenario

UVAM scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation, adding the possibility to sell energy to BSPs according to the Italian current regulation for UVAM.

UVAM										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Capital costs (HP installation and equipment)										
€38.787	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€11.966	€11.966	€11.966	€11.966	€11.966	€11.966	€11.966	€11.966	€11.966	€11.966
Cost of electricity										
	€35.141	€34.087	€33.064	€32.072	€31.110	€30.177	€29.271	€28.393	€27.542	€26.715
Revenues from UVAM participation - Fixed component										
	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Revenues from UVAM participation - Variable component										
	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753
Total Undiscounted Costs										
€74.287	€58.854	€57.800	€56.777	€55.786	€54.823	€53.890	€52.985	€52.107	€51.255	€50.429
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€56.591	€53.439	€50.475	€47.686	€45.061	€42.590	€40.264	€38.074	€36.011	€34.068
Total Discounted Cumulated Cost										
€74.287	€130.877	€184.317	€234.792	€282.477	€327.538	€370.128	€410.392	€448.466	€484.477	€518.545
Net Present Value										
-€518.545										

Table 33 Italy high DG penetration UVAM scenario

French prices Scenario

French prices Scenario: for each sub-scenario the energy consumption is assumed to be the same of the Italian simulation. It applies to any sub-scenario: baseline, HP and UVAM. The price of electricity and gas are taken from the data provided by EU commission and they are fixed for the entire duration of the NPV evaluation.

Baseline scenario: considering the technical characteristics of the previous setup of gas boiler and chiller designed for the building located in Turin.

FRENCH PRICES										
BASELINE										
YEAR										
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
EXPENSE DESCRIPTION										
Capital costs (gas and chiller purchase)										
€47.000	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Capital costs (installation and equipment)										
€50.500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€34.390	€34.390	€34.390	€34.390	€34.390	€34.390	€34.390	€34.390	€34.390	€34.390
Cost of electricity										
	€6.001	€6.001	€6.001	€6.001	€6.001	€6.001	€6.001	€6.001	€6.001	€6.001
Total Undiscounted Costs										
€97.500	**€53.891**	**€53.891**	**€53.891**	**€53.891**	**€53.891**	**€53.891**	**€53.891**	**€53.891**	**€53.891**	**€53.891**
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	**0,962**	**0,925**	**0,889**	**0,855**	**0,822**	**0,790**	**0,760**	**0,731**	**0,703**	**0,676**
Total Discounted Costs										
€97.500	**€51.818**	**€49.825**	**€47.909**	**€46.066**	**€44.294**	**€42.591**	**€40.953**	**€39.378**	**€37.863**	**€36.407**
Total Discounted Cumulated Cost										
€97.500	**€149.318**	**€199.143**	**€247.052**	**€293.118**	**€337.413**	**€380.004**	**€420.956**	**€460.334**	**€498.197**	**€534.604**
Net Present Value										
-€534.604										

Table 34 French prices baseline scenario

HP scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation.

WITH HP										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Capital costs (HP installation and equipment)										
€38.787	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€6.365	€6.365	€6.365	€6.365	€6.365	€6.365	€6.365	€6.365	€6.365	€6.365
Cost of electricity										
	€35.705	€35.705	€35.705	€35.705	€35.705	€35.705	€35.705	€35.705	€35.705	€35.705
Total Undiscounted Costs										
€74.287	€55.570	€55.570	€55.570	€55.570	€55.570	€55.570	€55.570	€55.570	€55.570	€55.570
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€53.432	€51.377	€49.401	€47.501	€45.674	€43.918	€42.228	€40.604	€39.043	€37.541
Total Discounted Cumulated Cost										
€74.287	€127.719	€179.097	€228.498	€275.999	€321.673	€365.591	€407.819	€448.423	€487.466	€525.007
Net Present Value										
-€525.007										

Table 35 French prices HP scenario

UVAM scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation, adding the possibility to sell energy to BSPs according to the Italian current regulation for UVAM.

UVAM										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Capital costs (HP installation and equipment)										
€38.787	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€9.490	€9.490	€9.490	€9.490	€9.490	€9.490	€9.490	€9.490	€9.490	€9.490
Cost of electricity										
	€32.414	€32.414	€32.414	€32.414	€32.414	€32.414	€32.414	€32.414	€32.414	€32.414
Revenues from UVAM participation - Fixed component										
	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Revenues from UVAM participation - Variable component										
	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753
Total Undiscounted Costs										
€74.287	€53.651	€53.651	€53.651	€53.651	€53.651	€53.651	€53.651	€53.651	€53.651	€53.651
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€51.587	€49.603	€47.695	€45.861	€44.097	€42.401	€40.770	€39.202	€37.694	€36.244
Total Discounted Cumulated Cost										
€74.287	€125.874	€175.477	€223.172	€269.033	€313.130	€355.530	€396.300	€435.502	€473.197	€509.441
Net Present Value										
-€509.441										

Table 36 French prices UVAM scenario

German prices Scenario

German prices Scenario: for each sub-scenario the energy consumption is assumed to be the same of the Italian simulation. It applies to any sub-scenario: baseline, HP and UVAM. The price of electricity and gas are taken from the data provided by EU commission and they are fixed for the entire duration of the NPV evaluation.

Baseline scenario: considering the technical characteristics of the previous setup of gas boiler and chiller designed for the building located in Turin.

Germany PRICES										
BASELINE										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (gas and chiller purchase)										
€47.000	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Capital costs (installation and equipment)										
€50.500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€27.512	€27.512	€27.512	€27.512	€27.512	€27.512	€27.512	€27.512	€27.512	€27.512
Cost of electricity										
	€9.606	€10.087	€10.591	€11.121	€11.677	€12.260	€12.873	€13.517	€14.193	€14.903
Total Undiscounted Costs										
€97.500	€50.618	€51.098	€51.603	€52.132	€52.688	€53.272	€53.885	€54.529	€55.205	€55.914
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€97.500	€48.671	€47.243	€45.875	€44.563	€43.306	€42.102	€40.948	€39.844	€38.786	€37.774
Total Discounted Cumulated Cost										
€97.500	€146.171	€193.415	€239.289	€283.852	€327.158	€369.260	€410.208	€450.052	€488.838	€526.612
Net Present Value										
-€526.612										

Table 37 German prices baseline scenario

HP scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation.

WITH HP										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Capital costs (HP installation and equipment)										
€38.787	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€5.092	€5.092	€5.092	€5.092	€5.092	€5.092	€5.092	€5.092	€5.092	€5.092
Cost of electricity										
	€57.158	€60.016	€63.017	€66.168	€69.476	€72.950	€76.597	€80.427	€84.449	€88.671
Total Undiscounted Costs										
€74.287	€75.750	€78.608	€81.608	€84.759	€88.068	€91.542	€95.189	€99.019	€103.040	€107.263
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€72.836	€72.677	€72.550	€72.453	€72.385	€72.347	€72.336	€72.352	€72.395	€72.463
Total Discounted Cumulated Cost										
€74.287	€147.123	€219.800	€292.350	€364.803	€437.188	€509.534	€581.870	€654.222	€726.617	€799.080
Net Present Value										
-€799.080										

Table 38 German prices HP scenario

UVAM scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation, adding the possibility to sell energy to BSPs according to the Italian current regulation for UVAM.

UVAM										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Capital costs (HP installation and equipment)										
€38.787	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€7.592	€7.592	€7.592	€7.592	€7.592	€7.592	€7.592	€7.592	€7.592	€7.592
Cost of electricity										
	€51.890	€54.484	€57.208	€60.069	€63.072	€66.226	€69.537	€73.014	€76.665	€80.498
Revenues from UVAM participation - Fixed component										
	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Revenues from UVAM participation - Variable component										
	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753
Total Undiscounted Costs										
€74.287	€71.228	€73.823	€76.547	€79.407	€82.411	€85.564	€88.876	€92.353	€96.003	€99.837
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€68.489	€68.253	€68.050	€67.878	€67.736	€67.623	€67.538	€67.481	€67.451	€67.446
Total Discounted Cumulated Cost										
€74.287	€142.776	€211.029	€279.079	€346.957	€414.692	€482.315	€549.853	€617.335	€684.785	€752.231
Net Present Value										
-€752.231										

Table 39 German prices UVAM scenario

Swedish prices Scenario

Swedish prices Scenario: for each sub-scenario the energy consumption is assumed to be the same of the Italian simulation. It applies to any sub-scenario: baseline, HP and UVAM. The price of electricity and gas are taken from the data provided by EU commission and they are fixed for the entire duration of the NPV evaluation.

Baseline scenario: considering the technical characteristics of the previous setup of gas boiler and chiller designed for the building located in Turin.

Sweden PRICES										
BASELINE										
YEAR										
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
EXPENSE DESCRIPTION										
Capital costs (gas and chiller purchase)										
€47.000	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Capital costs (installation and equipment)										
€50.500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€54.417	€54.417	€54.417	€54.417	€54.417	€54.417	€54.417	€54.417	€54.417	€54.417
Cost of electricity										
	€5.770	€6.059	€6.362	€6.680	€7.014	€7.364	€7.733	€8.119	€8.525	€8.951
Total Undiscounted Costs										
€97.500	**€73.687**	**€73.976**	**€74.279**	**€74.597**	**€74.931**	**€75.282**	**€75.650**	**€76.036**	**€76.442**	**€76.869**
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	**0,962**	**0,925**	**0,889**	**0,855**	**0,822**	**0,790**	**0,760**	**0,731**	**0,703**	**0,676**
Total Discounted Costs										
€97.500	**€70.853**	**€68.395**	**€66.034**	**€63.766**	**€61.588**	**€59.496**	**€57.488**	**€55.559**	**€53.707**	**€51.930**
Total Discounted Cumulated Cost										
€97.500	**€168.353**	**€236.748**	**€302.782**	**€366.547**	**€428.135**	**€487.631**	**€545.119**	**€600.678**	**€654.385**	**€706.315**
Net Present Value										
-€706.315										

Table 40 Swedish prices baseline scenario

HP scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation.

WITH HP										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Capital costs (HP installation and equipment)										
€38.787	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€10.071	€10.071	€10.071	€10.071	€10.071	€10.071	€10.071	€10.071	€10.071	€10.071
Cost of electricity										
	€34.332	€36.049	€37.852	€39.744	€41.731	€43.818	€46.009	€48.309	€50.725	€53.261
Total Undiscounted Costs										
€74.287	€57.904	€59.620	€61.423	€63.315	€65.303	€67.389	€69.580	€71.880	€74.296	€76.832
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€55.677	€55.122	€54.605	€54.122	€53.674	€53.259	€52.875	€52.522	€52.199	€51.905
Total Discounted Cumulated Cost										
€74.287	€129.963	€185.086	€239.690	€293.812	€347.486	€400.745	€453.620	€506.142	€558.342	€610.247
Net Present Value										
-€610.247										

Table 41 Swedish prices HP scenario

UVAM scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation, adding the possibility to sell energy to BSPs according to the Italian current regulation for UVAM.

UVAM										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Capital costs (HP installation and equipment)										
€38.787	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€15.016	€15.016	€15.016	€15.016	€15.016	€15.016	€15.016	€15.016	€15.016	€15.016
Cost of electricity										
	€31.168	€32.726	€34.363	€36.081	€37.885	€39.779	€41.768	€43.856	€46.049	€48.352
Revenues from UVAM participation - Fixed component										
	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Revenues from UVAM participation - Variable component										
	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753
Total Undiscounted Costs										
€74.287	€57.931	€59.489	€61.126	€62.844	€64.648	€66.542	€68.531	€70.619	€72.812	€75.115
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€55.703	€55.001	€54.340	€53.719	€53.136	€52.589	€52.078	€51.601	€51.157	€50.745
Total Discounted Cumulated Cost										
€74.287	€129.989	€184.991	€239.331	€293.050	€346.186	€398.775	€450.852	€502.453	€553.610	€604.355
Net Present Value										
-€604.355										

Table 42 Swedish prices UVAM scenario

UK prices Scenario

UK prices Scenario: for each sub-scenario the energy consumption is assumed to be the same of the Italian simulation. It applies to any sub-scenario: baseline, HP and UVAM. The price of electricity and gas are taken from the data provided by EU commission and they are fixed for the entire duration of the NPV evaluation.

Baseline scenario: considering the technical characteristics of the previous setup of gas boiler and chiller designed for the building located in Turin.

UK PRICES										
BASELINE										
YEAR										
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
EXPENSE DESCRIPTION										
Capital costs (gas and chiller purchase)										
€47.000	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Capital costs (installation and equipment)										
€50.500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€25.647	€25.647	€25.647	€25.647	€25.647	€25.647	€25.647	€25.647	€25.647	€25.647
Cost of electricity										
	€6.952	€7.300	€7.665	€8.048	€8.450	€8.873	€9.316	€9.782	€10.271	€10.785
Total Undiscounted Costs										
€97.500	**€46.099**	**€46.446**	**€46.811**	**€47.194**	**€47.597**	**€48.019**	**€48.463**	**€48.929**	**€49.418**	**€49.931**
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	**0,962**	**0,925**	**0,889**	**0,855**	**0,822**	**0,790**	**0,760**	**0,731**	**0,703**	**0,676**
Total Discounted Costs										
€97.500	**€44.325**	**€42.942**	**€41.615**	**€40.342**	**€39.121**	**€37.950**	**€36.828**	**€35.752**	**€34.720**	**€33.732**
Total Discounted Cumulated Cost										
€97.500	**€141.825**	**€184.768**	**€226.382**	**€266.724**	**€305.845**	**€343.796**	**€380.623**	**€416.375**	**€451.095**	**€484.827**
Net Present Value										
-€484.827										

Table 43 UK prices baseline scenario

HP scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation.

WITH HP										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Capital costs (HP installation and equipment)										
€38.787	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€4.747	€4.747	€4.747	€4.747	€4.747	€4.747	€4.747	€4.747	€4.747	€4.747
Cost of electricity										
	€41.364	€43.433	€45.604	€47.884	€50.279	€52.793	€55.432	€58.204	€61.114	€64.170
Total Undiscounted Costs										
€74.287	€59.611	€61.679	€63.851	€66.131	€68.525	€71.039	€73.679	€76.450	€79.361	€82.416
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€57.318	€57.026	€56.763	€56.529	€56.323	€56.143	€55.990	€55.862	€55.758	€55.677
Total Discounted Cumulated Cost										
€74.287	€131.605	€188.631	€245.394	€301.923	€358.246	€414.389	€470.379	€526.240	€581.998	€637.675
Net Present Value										
-€637.675										

Table 44 UK prices HP scenario

UVAM scenario: considering the purchase of the HP and the energy consumption of the building of the Iren simulation, adding the possibility to sell energy to BSPs according to the Italian current regulation for UVAM.

UVAM										
YEAR										
0	1	2	3	4	5	6	7	8	9	10
2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
EXPENSE DESCRIPTION										
Capital costs (HP purchase)										
€35.500	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Capital costs (HP installation and equipment)										
€38.787	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]	€[illegible]
Operational costs for maintenance										
	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500	€13.500
Cost of gas										
	€7.077	€7.077	€7.077	€7.077	€7.077	€7.077	€7.077	€7.077	€7.077	€7.077
Cost of electricity										
	€37.552	€39.429	€41.401	€43.471	€45.644	€47.927	€50.323	€52.839	€55.481	€58.255
Revenues from UVAM participation - Fixed component										
	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Revenues from UVAM participation - Variable component										
	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753	€1.753
Total Undiscounted Costs										
€74.287	€56.376	€58.253	€60.225	€62.295	€64.468	€66.751	€69.147	€71.663	€74.305	€77.079
Discount Factor: [(1/((1+FDR)^Y)]										
1,000	0,962	0,925	0,889	0,855	0,822	0,790	0,760	0,731	0,703	0,676
Total Discounted Costs										
€74.287	€54.207	€53.858	€53.540	€53.250	€52.988	€52.754	€52.546	€52.363	€52.206	€52.072
Total Discounted Cumulated Cost										
€74.287	€128.494	€182.353	€235.892	€289.142	€342.130	€394.884	€447.430	€499.793	€551.999	€604.071
Net Present Value										
-€604.071										

Table 45 UK prices UVAM scenario

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