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GRASSHOPPER

Grid Assisting Modular Hydrogen PEM Power Plant

D8.13: FCH technologies evaluation for DSO/TSO operation

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Executive Summary

This deliverable D8.13 FCH technologies evaluation for DSO/TSO operation, presents a report on evaluation of potential of FCH technologies to become an integral part of emerging new energy market concept for DSO/TSO operation, including the feedback to European policy maker. Furthermore, it describes the potential DSO/TSO services that could be possibly provided by the FCPP, as well as the FCH relevant market opportunities.

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List of Acronyms and Abbreviations

Abbreviation	Definition
FCPP	Fuel Cell Power Plant
FRR	Frequency Restoration Reserve
VPP	Virtual Power Plant
BRP	Balance Responsible Party, i.e. market participant connecting to TSOs and financially responsible to keep balance between supply and demand, usually electricity producers and suppliers.
BSP	Balancing Service Provider
CHP	Cogeneration of Heat and Power
DR	Demand Response
DSO	Distribution System Operator
TSO	Transmission System Operator of power grid
FCR	Frequency Containment Reserve
a/mFRR	automatic / manual Frequency Restoration Reserve
PEMFC	Proton Exchange Membrane Fuel Cells
prosumer	Party connecting to the grid with roles of electricity producer and consumer.
PV	Photovoltaics to convert sunlight into electricity
(v)RES	(variable) Renewable Energy Sources
RR	Replacement Reserves
UPS	Uninterruptible Power Supply for providing emergency power

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Ancillary services	The specialty services and functions provided by the electric grid that facilitate and support the continuous flow of electricity so that supply will continually meet demand (Wikipedia).
Micro grids	A localized group of electricity sources and loads that normally operates connected to and synchronous with the traditional wide area synchronous grid (macro grid) but can also disconnect to "island mode" — and function autonomously as physical or economic conditions dictate (Wikipedia).
ETPA	Energy Trade Platform Amsterdam
MARI	Manually Activated Reserves Initiative
PICASSO	Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation
SMR	Steam Methane Reforming
GOPACS	The grid operator's platform that helps solve congestion in the electricity grid
PHES	Pumped hydro storage
FEC	Front End Controller

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1 Introduction

1.1 Purpose

The document describes the Main Advisory Board activities that took place to evaluate the potential of FCH technologies to become an integral part of emerging new energy market concept for DSO/TSO operation. Based on the input provided, the potential DSO/TSO system services are discussed and detailly described. FCH relevant market opportunities considered for the FCPP are analysed, resulting with short feedback to European policy makers provided at the end of this document.

1.2 Related Documents

The D8.13 is closely related to the D8.11 "Draft Business Plan", D8.12 "Final Business Plan", D8.15 "First Advisory Board minutes meeting", "Grant Agreement No.779430 GRASSHOPPER" as well as GRASSHOPPER MOMs from teleconferences held and e-mails exchanged within the advisory board members and consortium members.

1.3 Document Structure

The deliverable structure is consisted of few chapters' discussion about:

- The first chapter represents an introduction of this deliverable.
- In the second chapter the advisory board input is being presents, provided through different meetings/activities within the project.
- In the third chapter DSO/TSO services are being described, considering the information provided in chapter 1.
- In the fourth chapter evaluation of FCH technologies through description of FCH relevant market opportunities.
- The last content chapter refers to the feedback to the EU policy makers.

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2 Advisory board inputs

This consortium unites component suppliers (JMFC, NFCT), research institutions (ZBT, Polimi) and integrators (AI, INEA) who will partner with existing energy market stakeholders (DSO, TSO) and EU smart grid projects committed to participate as advisory board members. This collaboration maximises the business case value proposition, by ensuring the delivered technology will respond to grid services' requirements for flexible dynamic power operation. Innovative DSM programmes will be completed to establish the best path forward for commercialization of the technology for a fast response FCPP.

Advisory board members will present the important link to on-going EU smart grid projects and will contribute to exchange of good practices while implementing new technologies for grid support challenges. One of the main Advisory Board activities is to evaluate the potential of FCH technologies to become an integral part of emerging new energy market concept for DSO/TSO operation, including with the feedback to European policy makers. For that reason, few meetings were held and questionaries were shared with the advisory board members: Henrie Mathijssen and Jeroen Drewes (TenneT), Roland Berlet (BAUM), Gerhard Meindl and Markus Hausmann (SWW), Joost Sandberg (Nouryon).
Few teleconferences were held on this topic, as well as few e-mails were exchanged with questions and answers. Additionally, Advisory Board meeting took place.
An overview from the information received is provided bellow:

- Opportunities for hydrogen technologies lie in the regions with abundant RES integrated, resulting in numerous grid congestions and in increased need of grid balancing.
- Challenges are seen in the big scale deployment, efficiency of the technology, its flexibility and costs.
- Clarifications on ancillary services and congestion management mechanisms have been received.
- Currently many new players are entering the reserve markets, therefore the prices of providing reserves are decreasing year by year.
- Fast response times of the FCPP will make its use in balancing the microgrids possible.
- For the utilities in Germany, sector coupling is important: hydrogen as an energy source for electricity, heat, transport. Batteries and electrolysers are being installed by different utilities in Germany.
- Vent H2 in Europe is practically unavailable. Other regions should be investigated, possibly Asia. Hydrogen prices are currently in range 2 to 9 Eur/kg depending on quantities.

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- Advantages of FCPP over burning the hydrogen in the revamped gas turbines should be investigated.

2.1 Questions and answers

Within the cooperation with Advisory Bard Members, some questions were provided, aiming to evaluate the potential use of the FCPP. The topic for the discussion was in a direction if the technology seems promising, how would you use it if you receive the FCPP for free? The questions, as well as the answers provided by some of the advisory board members, are given in the following Table 1.

Table 1: Questions and answers

Questions	Answers provided by Gerhard Meindl, SWW	Answers provided by Joost Sandberg, Nouryon.
Where do you see the potential use of FCPP (within your sector / range of expertise)?	In DSOs with sectorcoupling, with or without surplus of H2.	Power & heat production for built environment (offices / houses / apartment blocks etc.). Able to deliver zero emission decentral power & heat from H2.
Market size? Trends, recommendations? Any information on markets overseas?	Germany: about 400 DSOs; Industrial compounds with H2 supply.	Trends: large increase in renewable power generation: decreasing costs of power in "baseload", but high volatility (with peaks when no renewables are producing) Trend: zero emission in 2050. How to produce power & heat without CO2 emissions? Trend: customer autonomy. Recommendation: decentral power & heat production.

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What needs/expectations should the FCPP fulfil for you as a potential end user? • FCPP Must haves • FCPP Should haves • FCPP Could haves	• FCPP Must haves Easy going, plug and play, systemic fit in existing surrounding. • FCPP Should haves High efficiency level, lowest level maintenance. • FCPP Could haves	• FCPP Must haves: Independent, remote operated units. Fast ramp rates for auxiliary power. • FCPP Should haves: Very limited operator handling. Heat as output. • FCPP Could haves
Requirements: technical specifications – anything to be improved according to your needs?	Black start and islanding mode.	Heat delivery.
What would represent the value of the product to you (please rate from 1 to 10)?	• Financial viability at early stage • Costs • Fast ramp rate • Quick start • H2 as single energy carrier (electricity, heat, transport) • Modularity: broad range of power output with high part-load efficiency • Size • Dependability • Zero emissions	• Financial viability at early stage: 3. Outlook on financial viability, but not required now. • Costs: 5. Total cost of ownership most important, not so much cost of the unit. Also: important to compare with alternatives (zero emission power & heating sources) • Fast ramp rate: 8. For back-up & auxiliary services. • Quick start: 8. For back-up & auxiliary services. • H2 as single energy carrier (electricity, heat, transport): 9. Very important to combine uses of H2 in one device / CHP operation.

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	• New technologies, environmental awareness • Noiseless operation • Other suggestions?	• Modularity: broad range of power output with high part-load efficiency: 8. Important for standardization & economies of numbers. • Size: 5. CHP use expected in larger buildings / neighbourhood. Space not big concern. • Dependability: Undependability. 10. Should be able to operate on stand alone basis. • Zero emissions: 10. That is key element of the value proposition. • New technologies, environmental awareness: This is driver for this development. Not product requirement. • Noiseless operation: 8. Important requirement for operation in build environment. • Other suggestions?
How would you use the FCPP?	In sector coupling like CHP	Decentral power & heat use.
Pain points you have with existing technologies?	Necessary invest *(Return on Investment)*	Not zero emission. Makes noise (current CHP units)
Key stakeholders in your sector?	Bayernwerk (the next level DSO for SWW), Baywa RE (investor in some activities	Regional government of Groningen & Drenthe.

	of SWW, also a BRP for small DSOs and a technology provider for any customer interested)	
Risks and key barriers for the implementation of the FCPPs including regulatory or legal aspects?	Permanent availability of H2 as surplus	Safety?

2.2 Teleconferences

Two teleconferences were held with the advisory board members and consortium members: one on 4th March 2019 and another one on 13th March 2019, covering the topics provided bellow, as part of this chapter.

2.2.1 General overview of the energy market transition and trends.

What should be the focus of the products for the future?

Roland Berlet (BAUM) pointed out the new EU Directive on Clean energy package. Ownership of the flexibilities, i.e. storage capacities is now specified. DSOs and TSOs are not allowed to own storage capacities. They can purchase these services via aggregators.

He considers flexibility as a nice USP (Unique Selling Proposition), but the FCPP needs a basic business case, which allows the FCPP to run many hours at a certain level. The use of its flexibility should come additional on the top. There will probably be different applications and business cases for selling its flexibility.

As an alternative to ancillary grid services, he sees a big potential in **microgrid management** – selling flexibility to interested parties such as microgrids, BRPs etc.

2.2.2 Applicability of the FCPP for Utilities.

Gerhard Meindl (SWW) presented the situation within utilities. Apart from FCPP, flexibility can be provided by MW-sized batteries or Virtual Power Plants for managing and offering different energy sources. Two examples of German utilities were presented:

- Hassfurt utility: many windmills are installed in the area and energy storage can be provided by the 8 MWh battery and the 1,25 MW electrolyser. Hydrogen is injected into the natural gas grid, the process is managed by Greenpeace energy. The battery is not operating due to administrative

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barriers – fire safety measures. Hydrogen is used for power production only on a small scale: FC within one single private house.

- Wunsiedel utility (SWW): Same battery type is being installed. A new electrolyser is planned to be installed this year.

Utilities do not directly deal with ancillary grid services, they use brokers for that if needed.

Roland Berlet commented that the market of the ancillary services is getting crowded. FCPP should take the advantage of its quick response time, e.g. for **microgrids.** It could also be used for the **DSO/TSO congestion management**, e.g. in the meantime before grid reinforcements are built.

2.2.3 Ancillary grid services

Henrie Mathijssen (TenneT) presented the TSO's point of view. In the Netherlands, the grid congestions occur between areas with wind infeed farms in North and consumption sites in South. To manage congestion a new process is used called GOPACS. The mechanism is based on buying the electricity in the congested area and selling it in the non-congested area. Negative impact of the intervention to the rest of the grid is prevented by thorough checks. The DSOs and the TSO will reimburse the difference between the buying and the selling price. GOPACS is implemented through ETPA - Energy Trade Platform Amsterdam.

FCR: Prices are dropping year-by-year, it is not known how phasing out of the coal PP will impact the prices in future. Changes are coming by the harmonisation of the FCR product. By July 2019, pay-as-bid principle will be replaced with marginal pricing and the auctions will be changed from weekly to daily. 30% of the Netherland's FCR will be provided by local providers, all FCR auctions will be made at the regelleistung.net platform. Transfer of obligations (contracts with other parties for the case of PP outage) will be made possible instead of current system of penalising.

aFRR: The product is currently harmonised only within single zones. The ENTSO-E PICASSO (Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation) is the European implementation project for the creation of the European aFRR platform.

mFRR: Manually Activated Reserves Initiative (MARI) is the European implementation project for the creation of the European mFRR platform.

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a/mFRR: The contracted and the non-contracted participants can participate in bidding. Contracted ones (such as big power plants) are obliged to provide bids within a pre-defined price range.

Passive balancing in NL: is based on public information. Activated power and prices are published. Participants can jump-in when they consider it profitable. Risks are related to that as the prices change every minute.

2.2.4 Market potential in the chemical sector:

General comments, trends, recommendations.

Within the chemical sector, there is a potential of increased use of the **blue and the green H2** as an alternative (decarbonised) feedstock to the conventional Steam Methane Reforming (SMR) process. With increasing CO2 prices, the H2 prices are going to rise in future.

Data available to Nouryon on vented quantities of H2 in the chemical sector?

Capturing the vent H2 is connected to minor costs, mostly related to the installations. However, the vented H2 is presented in a baseload profile. This baseload H2 is typically used for high value (chemical feedstock) production. Profile of H2 that can be used for power generation is peaks during unexpected events, when spikes in H2 quantities take place and the compressor capacity is exceeded; also there is a fluctuating production (driven by demand for chlorine) that is “on top of” the baseload. Such events can occur both as unexpected peaks and as certain periods within a day/week/month.

Jorg (NFCT) asked about the structure of H2 production in Nouryon. Generally, 2/3 of max. H2 capacity is a baseload, 25-30% is over the compressor capacity and is going to the vent. This is raw H2 from chlor-alkali production containing some oxygen and nitrogen. Joost was unable to provide any specific data on timing of the vents. Joost recommends to get an overview of the H2 vent sites at Eurochlor.

2.2.5 Estimation of the sales price /kg H2 if supplied to external user:

Currently, the H2 prices from the SMR production are in the following range:

- 2 – 2.5 eur/kg for quantities comparable to Chlor-Alkali by-product production (at very large scale 1.5 – 2).
- 9 eur/kg for small quantities such as mobility (HRS).

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2.2.6 Chlorate industry: any data on H2 (im)purity in this sector? What are the pollutants? Other sources of vent H2 and their purity?

Jorg commented that additional investments into the cleaning equipment are needed within the chlorate industry sector.

2.2.7 Electrolysers being built in northeast NL. Interest to combine them with FCPP?

Electrolysers of 100 MW capacity are planned within the region and the green H2 is going to be produced at 3-4 eur/kg H2 dropping down to 2 eur/kg H2 by 2030. Current business models are focusing at using H2 as a feedstock for chemical industry. Some pilots on the use of (green) hydrogen in fuel cells for cogeneration of heat and power (CHP) at residential areas and for transport applications. Grid services may be interesting past 2030.

Joost suggests comparing the PEM FC with burning of the H2 in a revamped gas turbine. He sees this as a main competitor.

Jure: In fact, the FCH analysis showed that the most cost-effective technology for long-term energy storage in 2030 will be creating hydrogen through water electrolysis, storing it in a salt cavern and re-electrifying by burning it in a turbine. Pumped hydro storage (PHES) is most competitive today and will remain competitive in 2030. It should be investigated if FCPP brings technical advantages compared to the H2 gas turbines and PHES in terms of short response times.

2.2.8 Grid support potential: decentralized supply, quick response.

Microgrids within the sector?

Chlorine production factories are generally located close to sources of cheap electricity. Therefore, the business cases for FC power generation within the sector will generally not be positive. Joost sees the value of the FCPPs as **small decentralised applications**. Nouryon doesn't need the microgrid applications for its use.

2.2.9 Concluding remarks

Both Roland and Henrie agree that markets of providing the reserves are opening; more participants result in stiffer competition. It is however not sure how the prices of providing the reserves will develop in future.

Roland sees the potential of the FC in the **emergency electricity supplies** (such as UPS in hospitals or data centres) or FCPPs as the flexibility suppliers within **microgrids**. UPS's operation

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must be periodically tested, and this can be done in the periods of power shortages within the (micro)grid.

Rashi commented that solid oxide fuel cell technology is popular in datacentres rather than PEM technology.

2.3 Advisory Board meeting

The first Advisory Board Meeting took place on 21st May 2019 in Duisburg, Germany. The topic of the discussion was about the markets in different sectors, evaluate the market potential, to learn about different sectors' requirements and to map customer needs.

As a conclusion of the inputs provided TenneT advisory members, it will be interesting to mention few points:

- Due to integration of RES, grids are in transition from the centralized to the decentralized production. Frequency deviations (spikes) outside the 50 ± 0,1 Hz are now more common which never occurred in the past. System services to provide balance between production and demand are done by FCR, aFRR, mFRR and RR reserves. The ENTSO-e PICASSO project is establishing the aFRR exchange in Europe while MARI project deals with mFRR exchange.
- There is a trend of growing need of aFRR and mFRR caused by the growing size of the biggest plants being installed, such as 1 GW combined cycle power plant in south Netherlands.
- Observe the competitors. At FCR the competitors are batteries which are cheaper but can deliver energy only for a limited time – insufficient for aFRR. It would be better to focus on aFRR and compete with gas and coal PP. These will gradually phase out, it will be easier to face them and there are higher bid price variations. Different products should be targeted as well.
- In general, there is a lack of load in the North Netherlands i.e. overproduction. There still is a lack of transmission capacities there.
- Some concepts to satisfy the potential needs of new products, i.e. reserve types, that are emerging in the TenneT's grid:

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    - Fast responding inertia: Due to lack of spinning reserves in RES dominant power systems, a quick responding technology is needed for a quick response to frequency deviations (perhaps this could be provided by RES with power electronics).
    - Shaving the frequency deviations at ±5 min from full hour due to trading schedules. These are caused by the difference between energy trading markets and the system response. Each time change between CET and CEST represents a particular risk.
    - Electrolysers controlled by the Front End Controller (FEC) can limit grid frequency excursions during the electrolyser startup.
    - The coordination between loads and generators is needed during the black start. The infeed of intermittent RES such as wind and solar during the black start will create a new blackout. The electrolyser can represent a perfect load and can be the solution for this.
- Black start is a part of system services and should be considered as a possible service to be provided by FCPP, in particular in microgrids. In his response to the discussion guidelines, Gerhard Meindl (SWW) pointed out the importance of the FCPP black start capability for utilities. Stefano (POLIMI) commented that pumped hydraulic PP are used for black starts in Italy. Juan (AI): Black start and island operation mode is a matter of power electronics, data collection and coordination with the grid, so it is worth investigating the costs of its implementation in the FCPP.
- Ronald Berlet (BAUM) provided a few points:
    - Advantages of the FCPP to batteries in heat production (side product of FCPP).
    - FCPP fits perfectly into energy transition as defined in the EU Directive on Clean energy package. Main FCPP advantage is zero emission and market for this technology is getting bigger.
    - Focus is needed on flexibility of power plant as a service, it is recommended to get in contact with aggregators, as the FCPP's flexibility is useful.
    - The idea of mobile container unit with standardized connections, which could be moved occasionally between different locations.
    - Even though 1500 Eur/kWe being a nice target, trends are going in direction of providing energy as a service. Customers avoid risks related to the technology.

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- High reliability of electric supply is needed in some applications. Diesel generators are often still used. With 1500 Eur / kWe target achieved, the FCPP would absolutely be competitive. Possible applications include UPS systems, data centers and servers. There are some potential opportunities at providing services for large companies where the energy price is not the main criterion. They require fast response and potential fast black start. Reliability is the key, rather than availability.
- There is a trend of emerging energy communities getting off the grid. This is an opportunity for FCPP as a secure power supply and a grid service provider with automatic response, in particular in regions with high shares of RES. Coupling with electrolysers is essential and the producers of electrolysers should be contacted.
- Joost (Nouryon): FCPP could be used in built environments (houses, apartments, offices) where its advantages towards gas turbines would be pronounced (zero emissions, noiseless, decentralized, fast response when needed). No one wants to have a gas turbine next to his house (noise). Vicinity of the FCPP to living environment can represent value as placing behind the meter is possible and no network fees incur. To be considered: supplying the hydrogen.
- Joost (Nouryon): the challenge of coupling FCPP with the electrolysers in industrial areas lie in fact that these are often located in the areas of cheap electricity. A big market potential in the built areas where cogeneration of heat and power combined with zero emissions would be valued.
- Juan (AI): Transition of gas infrastructure from natural gas to hydrogen will take time as it is technically difficult.

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3 DSO/TSO system services

3.1 European Balancing Market

The fundamental constraint of electrical grids is that supply must always balance demand. System reliability is paramount as outages cause severe economic and social damage. A so-called balancing power is injected if any difference between the two should arise. The goals of balancing power are to ensure that the frequency stays, within a defined tolerance, at 50 Hz and to compensate for regional differences in power generation and power consumption, appearing as frequency drops or spikes in the grid.

Traditionally the system operation ancillary services were provided by thermal units. But since they are being replaced by RES, which do not provide ancillary services, it creates new challenges. Between 2025, 2030 and 2040, all scenarios presented in (ENTSO-E, 2018) show a steady reduction in fossil fuel and a significant increase of renewables. The intermittent nature of RES will produce a big burden on grid balancing capacities. If RES shares and new electricity usage keep growing as foreseen, new levels of business unoperability or even blackouts will take place. Significant amounts of renewable energy may go to waste if no reinforcements of transmission grids are done and if no innovative methods of grid balancing are introduced.

Three types of balancing power interact dynamically in the today's power grids: the Frequency Containment Reserve (FCR), the automatic Frequency Restoration Reserve (aFRR) and the manual Frequency Restoration Reserve (mFRR), Figure 1. The Replacement Reserve (RR) is the slowest type of reserves can be activated to support or replace FRR but is not implemented in all systems.

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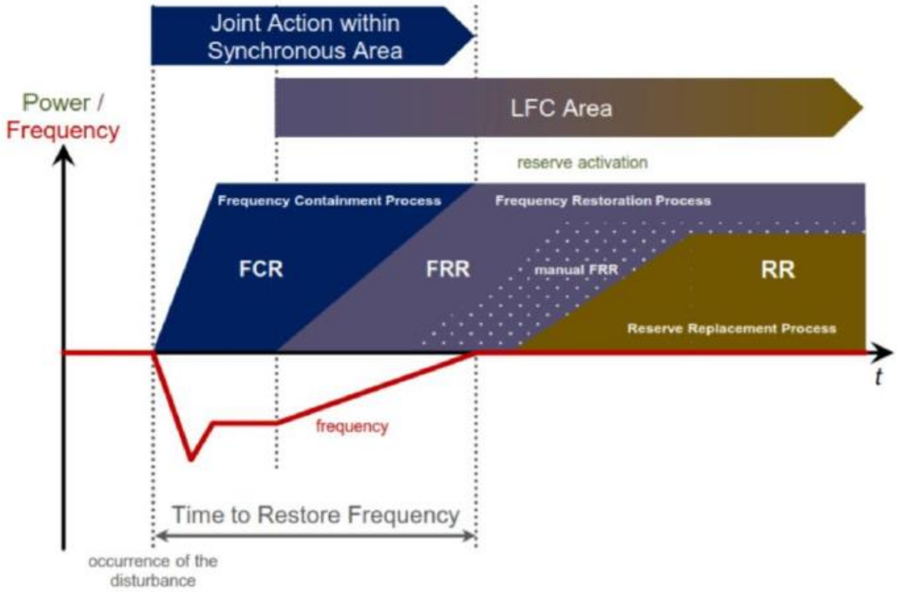

Figure 1: A frequency drop and the reserve activation structure (ENTSO-E, 2018).

Balancing power is obtained from ancillary grid service providers. The services can be provided through organised market where the providers are responding to offers to tender issued by the transmission system operators (TSOs). Before the operator can bid on this balancing power market, each of his power generation units has to undergo TSO prequalification. For details on the reserve types and the European balancing market, the reader is referred to the EU Electricity network codes report (Schittekatte, et al., 2019). In some countries, services are arranged through national regulation, i.e. there is no market.

3.1.1 Frequency Containment Reserve (FCR)

Previously known as the Primary reserve, this is the "first defence line" for the electrical grid stability. From the moment of frequency deviation, FCR is almost instantaneously activated to stabilise the drop/spike. FCR is the fastest type of reserves and is operated using a joint process involving all TSOs of the synchronous area. FCR must be fully activated within 30 s after request and the period per activation to be covered is up to 15 minutes.

Efforts to make the FCR market more efficient have resulted in establishment of http://www.regelleistung.net platform, where TSO's joint calls for tenders are implemented. Tenders are published, bids are processed, and bidders are informed whether their bids have been accepted or rejected. German, Belgian, Dutch, French, Swiss and Austrian reserve

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markets have been coupled so far with Denmark to join in the near future. The platform unites 1470 MW of FCR (January 2019), which is nearly a half of European capacity 3000 MW.

Harmonisation and implementation of new FCR market design is in process within the countries taking part on the regelleistung.net platform (regelleistung.net, 2019). FCR will remain symmetric product, meaning there is no separate call for tenders for positive and for negative FCR. Minimum bid size has been decreased to the current 1 MW in order to give small players the access to the market. Auction frequency was changed from weekly to daily auctions in July 2019. Marginal pricing was introduced meaning that all successful bids get paid the amount of the most expensive successful bid. By July 2020, products will be shortened from daily to 4h products.

As evident from shortening the forward period and the commitment period, reserve market trends develop towards real-time markets of balancing capacities.

FCR delivery should be 100% sure and outages should only exceptionally occur. The Balancing Service Provider may find a backup provider for the case of outage, which allows for establishment of secondary markets within the control area.

3.1.2 Automatic Frequency Restoration Reserve (aFRR)

The aFRR was previously known as secondary reserve and the mFRR as the minute reserve. The auto/manual FRR are the products which are still not harmonized within Europe as they are typically operated within the load frequency control (LFC) area covered by a single TSO. Generally, full activation of a/m FRR must occur within 5/15 minutes after the receiving request and the capacity must be delivered in duration of 10-15 minutes. The exact product definition can still differ substantially from one control area to another. Also, the way balancing resources are procured in balancing markets and the exact working of imbalance settlement mechanism varies. The ENTSO-e project PICASSO (Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation) was initiated by eight TSOs from five countries: the Austrian TSO APG, the Belgian TSO Elia, the Dutch TSO TenneT, the French TSO RTE and the German TSOs – 50Hertz, Amprion, TenneT and TransnetBW. The project aims at integrating the European aFRR markets by designing, implementing and operating a common aFRR Platform while respecting the TSO-TSO model.

aFRR in Germany and in the Netherlands is an asymmetrical product although in some markets it can be symmetrical (e.g. France). Minimal bid size amounts 1 MW. In German market, bids

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are placed 1 week ahead with 4 hr blocks of commitment. This is slightly different in the Netherlands where bids are placed for 15 minute intervals (the so-called Programme Time Units, PTUs) and can be changed until 3 PTUs before delivering the reserve. In contrast to this, aFRR in France is a symmetrical product and is in principle open to providers of any size provided that they can comply with technical requirements (FCH-JU, 2017). Services are not procured through a market, there is a pre-defined remuneration (regulated price), both for holding ready the capacity and for activating it.

Upward aFRR reserve capacity in continental Europe amounted 7500-8100 MW in 2015. The amount of downward aFRR capacity was 6700-7300 MW (E-Bridge, IAEW, 2015). According to (Srnovšnik, 2019), the European market potential of the aFRR in 2019 is 9133 MW which makes room for 3-5 platforms for aggregation and for regional exchange of energy flexibilities in the European market.

3.1.3 Manual Frequecy Restoration Reserve (mFRR)

After 15 minutes, the aFRR is replaced by the third balancing level, the mFRR (also referred to as tertiary balancing energy or a minute reserve). It is switched on manually following a request by the transmission system operator.

There is a difference between the positive and the negative balancing energy. If power consumption increases suddenly, this is balanced by the positive minute reserve. Highly responsive power plants as well as selected electricity loads under control are able to provide /decrease power extremely rapidly in the short term.

If more power is fed into the grid than is used, the negative minute reserve is used. This term is used to refer to the capacity of plants to withhold or store power. For loads (industry/household processes) their response would be to increase their consumption.

The minute reserve market is interesting for flexibility trading since the users can reduce or increase their energy production and consumption in line with demand within a time-frame of 15 minutes. However, individual plants or consumers (industrial, commercial or households) are usually too small to act optimally at the balancing energy markets. Therefore a Virtual Power Plant (VPP) takes the role of aggregator and thus becomes competitive to traditional services.

Efforts towards a common European mFRR platform are taking place in frame of a Manually Activated Reserves Initiative (MARI) project in collaboration of 19 TSOs.

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3.1.4 Other mechanisms

Passive balancing: It is a unique feature of the Dutch balancing system. The Dutch TSO TenneT provides market participants with live updates on reserve activation volumes and prices. This is how TenneT financially stimulates market participants to deviate from their portfolio if this reduces the overall system imbalance (TenneT TSO , 2018). Due to the nature of passive balancing, TenneT has no overview of the availability of the reserves in these mechanisms. Participants in passive balancing are exposed to some risks as the remuneration of providing the reserves is changing in 4s intervals but the published prices are averaged over 1-minute intervals and published with a 3 minute delay.

Congestion management: Balancing services are also often referred to as ancillary services for frequency control. Examples of ancillary services for non-frequency control (grid services) are voltage support and congestion management. The latter refers to the situation where the transmission (or distribution) line capacities are exceeded. This was traditionally solved by line reinforcements, i.e. building additional capacities.

As an alternative to traditional solving of congestions, the GOPACS mechanisms is being tested in the Netherlands. Grid congestions typically occur between infeed areas with wind farms in north and consumption sites in south. To solve such congestion, the grid operators incentivize reduction in electricity production or an increase in consumption in the north part. A request for bids is sent to market parties through GOPACS. Market parties with a connection in this area can then place a suitable buy order on a connected electricity market platform. However, a negative impact on the national balance of the electricity grid needs to be avoided due to this action. This is why the reduction of electricity production in the congestion area is combined with an opposite order from a market party outside the congestion area. The price difference between the two orders is paid by the grid operators. In this way, the two orders are matched on the market platform and congestion can be solved. GOPACS is implemented through ETPA - Energy Trade Platform Amsterdam.

Black start capability is defined as capability of recovery of a power-generating module from a total shutdown through a dedicated auxiliary power source without any electrical energy supply external to the power-generating facility (Schittekatte, et al., 2019). For example, some power generators can have small diesel generators which can be used to start larger generators, which in turn can be used to start the main generators. The way of remunerating this ancillary service varies widely over Europe, Figure 2.

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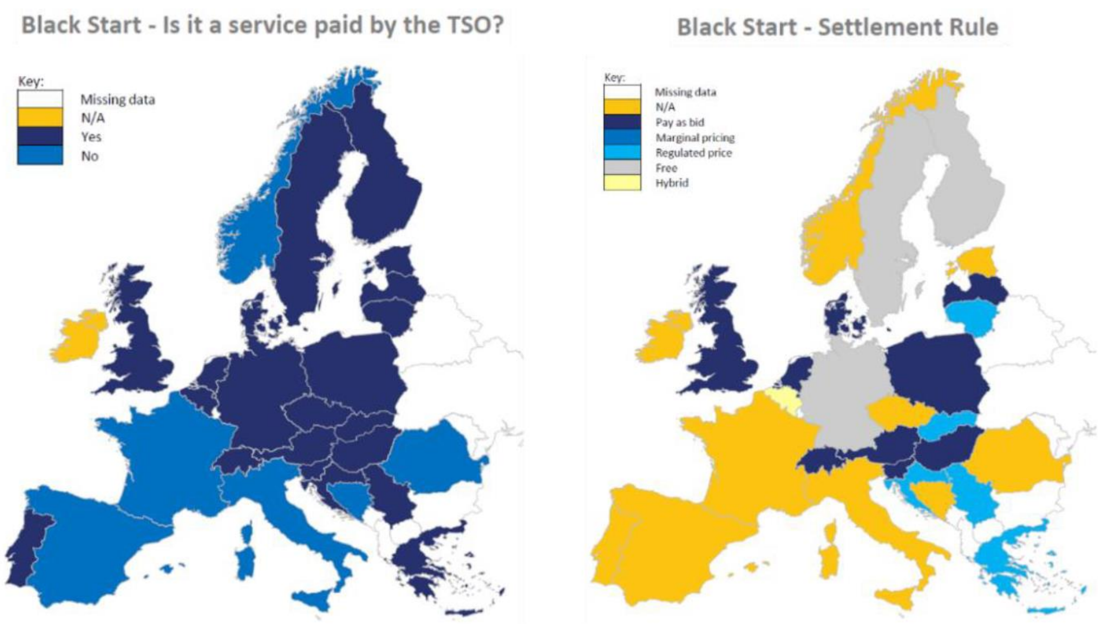

Figure 2: Black start remuneration in Europe, status in 2017 (Schittekatte, et al., 2019).

It is interesting to note that black start is a service that might be very suitable to be provided by (large) energy storage systems in the future. The coordination between loads and generators is needed during the black start because the infeed of intermittent RES such as wind and solar during the black start may create a new blackout.

3.2 Evolution of European energy markets

The increasing share of renewable energy sources and dispersed energy production are placing new challenges for maintaining the stability of the electrical grid. They represent considerable burden on grid balancing capacities.

This imposes novel approaches in grid balancing, in particular in terms of number of capacities and the response time. The forward period and the commitment period of the ancillary services are therefore gradually shortening. The trends of the reserve markets develop towards real-time markets of balancing capacities as evident from Figure 3.

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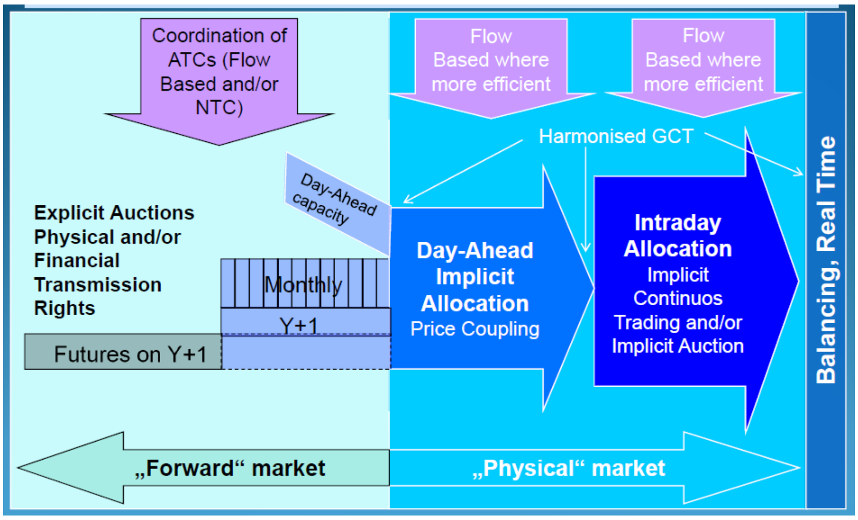

Figure 3: Target model of reserve markets (Supponen, 2018)

Market actors such as those who use and generate electricity at the same time (prosumers) need to be integrated in the technical and the market system. The challenges of modernizing the electricity grids in Europe lie in enabling increased flexibility of the European power system, efficiently providing increased transfer capacity and enabling active participation of users and new market actors by providing information, services, market architectures and privacy guarantees.

The broad trends of development of the energy production systems are ranging from centralized to decentralized generation and control, in parallel with market liberalization. A new paradigm in energy management is emerging: value is shifting towards the timing and location of consumption and generation, rather than the quantity. Hydrogen will play a vital role here as it is a unique solution for large scale and long-term energy storage. However, its distribution and handling through pipelines is difficult due to its thermodynamic and transport properties. This limitation can be overcome by integrating multiple hydrogen producers and consumers into a smart network of geographically distributed energy prosumers.

Our vision is to provide grid services through aggregation and automatic trading of flexibilities, which will enable active participation of several geographically distributed prosumers. The flexible energy will be traded between sellers (prosumers) and buyers (DSOs, BRPs) through local marketplace for energy flexibilities, taking into account several optimization criteria, such as location, price, amount, transfer costs, etc. Both the congestion management and the balancing market will be addressed, resulting in avoided costs of reinforcing the transmission capacities and in enabling the integration of cheap and green RES.

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The market in general will grow by increasing share of RES in the energy supply structure which will impose the need to increased grid balancing capacities. Flexibilities can find their market by 1) providing grid balancing services and 2) managing grid congestions. Due to the technical and regulative constraints these two options are interdependent.

Increasing shares of renewables are already presenting new challenges to grid operators. There is the need of new balancing products being identified by the TenneT TSO:

- Fast responding inertia: Due to lack of spinning reserves in RES dom-inant power systems, a quick responding technology is needed for a quick response to frequency deviations. Perhaps this could be provided by RES with advanced power electronics.
- Shaving the frequency deviations at ±5 min from full hour due to trading schedules. These are caused by the difference between energy trading markets and the system response. Each time change between CET and CEST represents a particular risk.

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4 FCH relevant market opportunities

Main FCPP features which represent value to the potential customer are as follows: zero emissions, noiseless operation, high efficiency & part load efficiency, durability, reliability and flexible operation via fast ramp-up/down rates. Hydrogen can be stored at any time scale and at big quantities provided that the tank of sufficient size is built.

Coupling the FCPP with an electrolyser and with a hydrogen storage unit would add a new dimension to the FCPP operational flexibility and would open a wide range of further possible revenue streams. Such system would represent a hydrogen prosumer with ability of providing extensive upward and downward reserves. The excess RES energy from the grid which would otherwise be curtailed can be stored in form of hydrogen. The roundtrip efficiency of a power-to-hydrogen-to-power process in the today's hydrogen systems is in the range 34–44%. The revenues can be generated from multiple sources, Table 2.

Table 2: FCPP revenue streams and benefits of possible extension to electrolysers.

Revenue stream	FCPP	FCPP with electrolyser and H2 storage
Selling electricity	(✓)*	(✓)*
Buying/selling electricity price difference	x	✓
Balancing services (frequency)	✓	✓✓
Balancing services (non-frequency):		
congestion management	✓	✓✓
island operation (microgrids)	✓	✓✓
black start	✓	✓✓
Selling heat	✓	✓

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UPS systems	✓	(✓)*
selling excessive hydrogen	x	✓
exploiting carbon levies	✓	✓

* possible but economically questionable

4.1 Balancing markets

Table 3 presents market prices for FCR and aFRR in selected European countries (FCH-JU, 2017). When providing FCR from the regelleistung.net bids, the Balancing Service Provider (BSP) receives remuneration only for the reserve capacity. The energy injected into the grid is not paid as it is assumed to be zero due to the symmetricity of the product. FRR is an asymmetrical product in German and Dutch markets and the BSP receives remuneration for both capacity and the delivered energy.

Table 3: Value to be captured from FCR and aFRR (FCH-JU, 2017).

	DE		FR		DK-West	GB	
	FCR	FRR	FCR	FRR	Primary Regulation (FCR)	FFR (FCR)	EFR (FRR)
Can be provided by loads	✓	✓	✓	✓	✓	✓	✓
Symmetric / Asymmetric Reserve	Sym.	Asym.	Sym.	Sym.	Asym.	Sym.	Sym.
Minimum bid size (MW)	1 MW	5 MW	< 1 MW	< 1 MW	1 MW	10 MW	1 MW
Maximum time for activation	30 s	5 min	30 s	15 min	30 s	30 s	1 s
Suitable for PEM	✓	✓	✓	✓	✓	✓	✓
Suitable for ALK	✗	✓	✗	✓	✗	✗	✗
Capacity price (k€/MW /y)	167.0	4.1 - 19.0	160.8	160.8	12.8 - 152.0	58.0 - 64.0	70.0-123.0
Activation price (€/MWh)	0	1103-1217	26.48	26.48	0	0	0

It is important to remember that the prices presented in Table 3 are average values. A thorough investigation conducted by Abengoa Innovacion showed that the business case of providing FCR against average yearly revenue of 167.000 € per MW capacity is deeply negative. This is the average price from the German market where the conditions are considered most favourable.

Average prices of providing a/mFRR in the German market in recent years are presented in Figure 4. Capacity prices are presented in the left while activation prices are in the diagram on the right hand side. It is evident that providing the positive aFRR (i.e. SRL+ in the diagrams) guarantees highest revenues, which is in scope of FCPP. Another observation is that the

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capacity prices have been continuously dropping in recent years while the activation prices have not been changing that drastically.

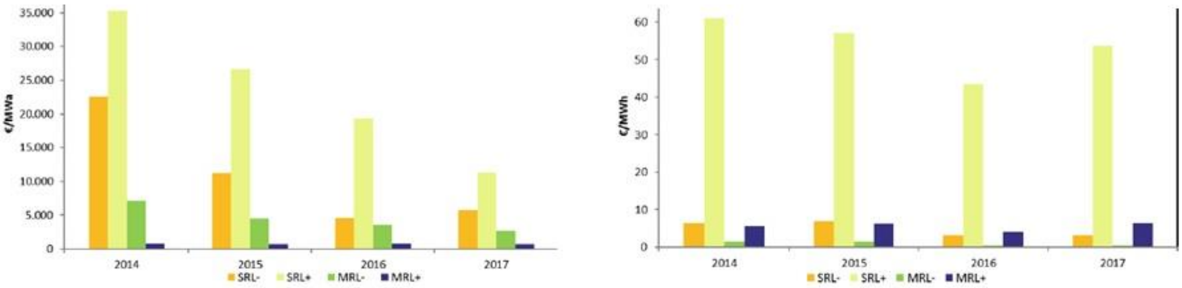

Figure 4: Historic price development of a/mFRR (i.e. SRL and MRL) in years 2014-2017 in German market. Capacity prices (left) and activation prices (right), (Fraunhofer ISI, Fraunhofer IEE, IKEM , 2017).

Presumably the negative price trends in recent years are caused by new players emerging in the markets who are able to provide the reserves. Introduction of emission trading allowances and the consequent phasing out the coal power plants in future may again increase revenues for the providers of the reserves, but the future trends are unclear.

The important players entering the FCR markets are batteries. The technology is cheaper than fuel cells and is able to provide response within milliseconds, so the FCPP cannot compete with batteries neither from the performance point of view nor pricewise. Moreover, as mentioned above, providing FCR would not be profitable for the FCPP.

Therefore the FCPP should focus on aFRR market. Batteries are not a competitive technology here as they are unable to provide their capacity for the time period required for the aFRR. The required response time is at least 5 minutes which is the criterion the FCPP can easily meet. The main competitors here at the moment are gas and coal fired power plants, which will gradually phase out and it will be easier to face them.

The business cases of providing reserves at average reserve prices are deeply negative. It is therefore important to analyse the price ranges of aFRR and to target the events with highest prices. The Dutch transmission system operator TenneT TSO keeps all historic bidding data publicly available in anonymised form which allows for the detailed analysis of the occurrence of such events.

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prices Eur/MWh	2014	2015	2016	2017
0-25	144	66	35824	207
25-50	138604	145766	119073	139856
50-75	54629	37676	15267	17260
75-100	5619	4736	4917	5591
100-150	9914	10668	6233	8972
150-200	3891	11661	3505	4315
200-250	931	2055	1689	2923
250-300	680	592	664	1968
300-350	595	548	826	1042
350-400	3702	2178	2992	1239
400-450	301	147	11	383
450-500	0	45	0	179
500-600	0	32	21	113
600-700	0	168	0	43
700-800	0	22	0	12
800-900	0	0	0	0
900-1000	0	0	0	10

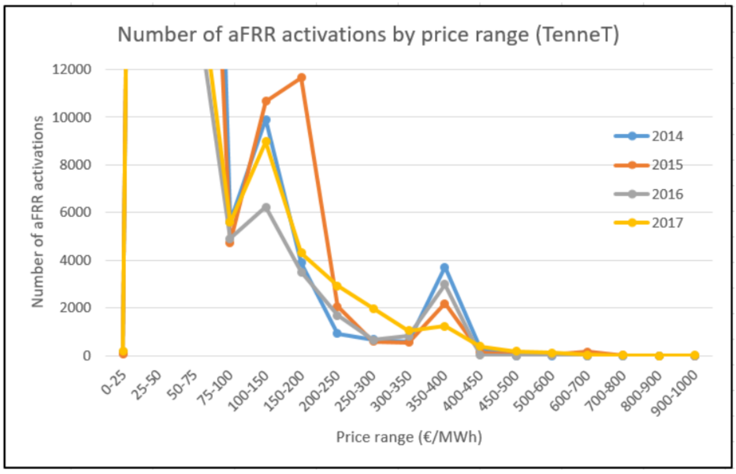

Figure 5: Number of annual aFRR activations in the Dutch grid (data from TenneT TSO).

Numbers of annual aFRR activations in the Dutch grid operated by TenneT TSO in years 2014 - 2017 are presented in Figure 5. The prices above 200 €/MWh should be targeted by the operating FCPP. The highest aFRR prices are probably caused by unpredictable events such as unfavourable weather conditions for the RES injection combined with high electricity demand. Such events may sporadically take place in some years but not in others. Compared to previous years, the number of aFRR activations in 2017 was higher with exception of the range 350-400 €/MWh. This provides a promising environment for the FCPP operation.

It is important to be able predict the events of highest aFRR prices in order to assure FCPP's readiness for operation at such events. The results of the preliminary analysis are presented in the diagram in Figure 6. Size of bubbles represents the number aFRR activations with price above 200 €/MWh in dependence of the daytime and the month of year. Weekly/holiday trends are neglected here but both the seasonality as well as daytime occurrence of the high aFRR prices are evident. Most events in 2017 took place in cold months of January and from October to December. Interestingly, there were many events in April as well. The events will most likely take place between 6 AM and 10 AM in the morning and between 6 PM and 10 PM in the evening.

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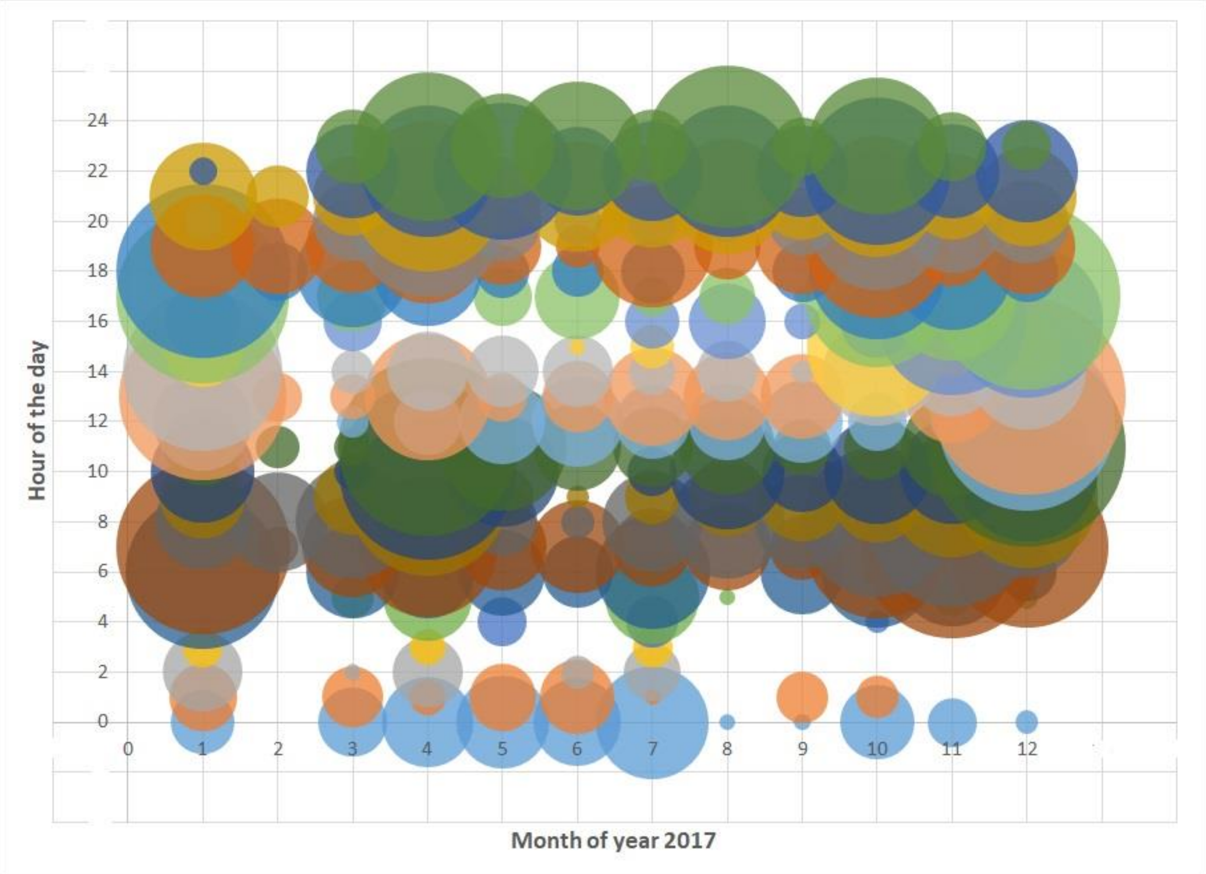

Figure 6: Distribution of aFRR reserve activations with prices above 200 €/MWh over year 2017. Data from TenneT TSO.

4.2 Selling heat

Heat and hot water accounts for 60–80% of final energy consumption in residential and commercial buildings across Europe (Staffell, et al., 2019). Emissions from heating need to be reduced rapidly and largely eliminated by 2050. The heat sector is proving hard to decarbonise. A particular challenge for low-emission heating in temperate countries is meeting winter peak heat demand. It is high and extremely variable which imposes highly flexible traditional solutions such as gas heating.

Complementary heating technologies have recently gained recognition, e.g. fuel cell Cogeneration of Heat and Power (CHP) systems can export electricity to the grid at the same time as heat pumps consume it; a UK case study found that a 50% penetration of fuel cell micro-CHP could completely offset the electrical demand from a 20% penetration of heat pumps (Staffell, et al., 2019).

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The FCPP presents an interesting solution to decarbonise heating. Fuel cell CHP systems have higher electrical efficiency and lower emissions than other CHPs. PEMFCs are the dominant technology with high efficiency, durability, reliability, rapid start-up and shut-down, part-load capability and operating temperatures of around 80 °C. Given their flexibility, PEMFC are mostly used in domestic systems and due to high power-to-heat ratio, they better fit into well insulated buildings with lower heat loads.

Since FC technologies are well suited for CHP applications, they have a great potential of use in built environments (houses, apartments, offices) where their advantages towards gas turbines would be clearly pronounced. Zero emissions, noiseless and flexible operation with high part-load efficiency are all attributes which make this technology unrivaled for the heat and power supply as decentralized generation in the built areas. This can help increasing air quality in urban environment where the pollution is already both an environmental and health hazard. With future development of hydrogen vehicles, the coupling with transport sector will be made possible with hydrogen being a single energy vector in such communities. Supplying the hydrogen to the location is the only item to be considered.

4.3 Microgrids - Capability to take part in island operation and black start capability

The ability of installing the FCPP in the vicinity to living environment is of high value as placing behind the meter is possible and no network fees incur. This is the motivation of creating the energy communities and microgrids.

According to (IRENA, 2018), the implementation of long-term storage via hydrogen in combination with intra-day battery storage may much faster become economically viable in isolated power systems (i.e. microgrids) than in usual networks. Hydrogen storage and fuel cells do not self-discharge. In contrast to batteries, they have a longer lifetime and a higher temperature tolerance, which is useful in more extreme climates. Where there is a need for larger amounts of energy compared to power (storing many hours of electricity supply), there might be a case of using FCPP. For premium tourist island locations, the reduced noise, odour and improved air quality could make the case for FCPP more attractive.

There is a big market potential for the FCPP with capability of microgrid operation. In Germany alone there are 400 DSOs, the so-called utilities. Many of them have less than 100.000 customers and represent the specific cases in the EU Clean Energy Package meaning that they may be in possession of storage capacities and may keep the infrastructure and the energy sales coupled. This is the opportunity for FCPP as a secure power supply and a grid service provider with automatic response, in particular in regions with high shares of RES. Coupling with electrolysers is essential for this.

It is important for the utilities with ambition of microgrid operation that the technology is black start capable (Gerhard Meindl, 2019). Black start is a part of system services and should be considered as a possible service to be provided by FCPP. It is the matter of power electronics, data collection and coordination with the grid. Again, coupling with an electrolyser would be of great benefit as it can represent a perfect load during the black start.

4.4 UPS and backup systems

Fuel cells can already play a role in applications of stationary power for uninterruptible supply or power backup systems for network equipment (telecommunication stations) and datacentres, and the supply of off-grid power in isolated regions or islands (IRENA, 2018). Power-only fuel cell systems (i.e. without combined heat and power) are gaining popularity in applications of Uninterruptable Power Supply (UPS) systems for data centers and servers, particularly with American technology firms and multinationals seeking a green image. The units deliver cheaper electricity than local utilities (8–10 c/kWh versus 14 c/kWh) and allow a move away from diesel engines as an UPS (Staffell, et al., 2019). By achieving the project target of CAPEX below 1500 € / kWe, the FCPP would be competitive in the market of UPS units (Joost Sandberg, 2019). The technology must meet the requirements on fast response and potential fast black start. Reliability is the key, rather than availability.

FCPP can thus replace diesel generators which require more maintenance. This makes them attractive for deployment in remote locations. According to (FCH-JU, 2017), variable costs of diesel generators would be up to 200 €/MWh which means that FCPP would absolutely be competitive in isolated, smaller systems.

4.5 Energy as service

With increasing shares of RES, the European power grids are in a big transition. Energy production is shifting from big, centralized units to small dispersed RES generation units such as solar and wind, in parallel with market liberalization. Introducing RES implies that no fuel costs incur anymore. On the other hand, intermittence of RES imposes new solutions in balancing

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the supply and demand, e.g. commissioning highly flexible power generation and storage units and changes on consumers' behaviour such as Demand Response (DR).

A new paradigm in energy management is emerging: value is shifting towards the timing and location of consumption and generation, rather than the quantity of energy. With other words; producing the energy doesn't represent high costs anymore, the challenge is to deliver it where is needed when it is needed.

New market players with new business models are accessing energy markets. In coming years, competition will come from non-traditional players such as GAFAMs (Google, Apple, Facebook, Amazon, Microsoft); energy equipment manufacturers (ABB, Alstom, GE, Siemens, etc.), telcos and electric car manufacturers (WEMO, 2018).

Trends in energy market development are going in direction of providing energy as a service, which is how customers avoid risks related to the technology. Insurance companies with their rich risk assessment- and data management capabilities are evaluating the scenarios to offer comprehensive services to homes: power would be offered in a bundle with heat, internet, maintenance, house insurance and other amenities (Sulzer, 2018). A new Italian player Europe Energy is already offering packages of power, gas, optical internet connection and cell phone services at very competitive prices. According to (WEMO, 2018), energy as a service and comfort as a service will be the top margin contributors in next years.

The GRASSHOPPER consortium is aware of these trends, however offering energy as service together with financial products would be a move away from the consortium's core business. There is ambition to act as a technology provider. Therefore it is important to follow up the evolution of energy market and to offer the technology to new players who are emerging on it.

4.6 RES technology suppliers

Technology suppliers for capturing renewables such as wind turbine producers or producers of photovoltaic panels have been previously focusing solely on sales of their technology. With increasing RES penetration in the grid and increasing grid instability, market rules are gradually changing, and the RES operators are becoming (financially) responsible for grid imbalance. This puts pressure to the RES technology providers to offer their technology in package with energy storage technologies.

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Vestas, primarily the wind turbine producer, offers hybrid power plants in its product portfolio where the technology is combined with PV panels and most importantly, with Li-Ion batteries to provide energy storage (Vestas, 2019). A hybrid power plant is being installed in Kennedy Energy Park, Australia with 60 MW of combined wind and solar capacity and a 2 MW / 4 MWh Li-Ion battery. A similar system of smaller size has already been in operation at Lemkaer, Denmark since 2012.

Before entering this market segment, a business agreement with technology providers of electrolysers must be established.

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5 Feedback to the European policy makers

According to the recommendations by the Advisory Board Members for the potential of FCH technologies to become an integral part of emerging new energy market concept for DSO/TSO operation, provided in Chapter 2 and accordingly the description of the FCH market opportunities, provided in Chapter 4, in order to ensure and increase the business potential of the GRASSHOPPER solution, some aspects still need to be considered and clarified.

In general, synchronization of the regulations within a Pan-European countries will simplify the procedures and easier the involvement of new technologies into the gird. Opening the balancing market and flexibility market for different players and relaxing the initial procedures for the potential players to get involved is essential. More preciously few points in that direction, that's worth mentioning would be:

- Development of local flexibility markets (allow and provide incentives to DSO/TSO to procure flexibility services).
- New grid codes for micro grids (local markets).
- Ancillary services open down to different device/loads level.
- Standards and open protocols. Standardization on different levels, interfaces, functions, communication protocols.
- Clear Flex Resource Register definitions (e.g., what an aggregation is etc.)

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6 References

ENTSO-E (2019). Proposal for standard products (draft)

ENTSO-E (2013). Supporting Document for Network Code on Load-Frequency Control and Reserves

ENTSO-E (2018). Proposal for mFRR and RR Standard Products - Supporting Document

ACER. 2014. *Demand Side Flexibility, The potential benefits and state of play in the European union, Final report for ACER.* s.l. : ACER, 2014.

Agora Energiewende. 2018. *The European Power Sector in 2017.* Berlin : Agora Energiewende, 2018.

CEN-CENELEC-ETSI, Smart Grid Group. 2012. Smart Grid Reference Architecture. *http://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_reference_architecture.pdf.* [Elektronski] 2012.

Commission Regulation (EU) 2017/2195 - guideline on electricity balancing. **COMMISSION, EUROPEAN. 2017.** 2017, Official Journal of the European Union.

D. Arnone, A. Rossi, M. Bertoncini, R. Proietto, D. Moneta, G. Tondi, C. García-Santiago. April 2014. *Energy Management In A Smart Grid-Integrated Hydrogen-Based Storage.* Chamonix, France : IARIA Energy 2014, April 2014.

E-Bridge, IAEW. 2015. *Impact of merit order activation of automatic Frequency Restoration Reserves and harmonised Full Activation times.* Brussels : ENTSO-E, 2015.

EFET/ebIX/ENTSO-E. http://www.ebix.org/documents/role_model_v2011_01.pdf. [Elektronski]

ENTSO-E. 2018. *Explanatory document concerning proposal from all TSOs of the Nordic synchronous area for the determination of LFC blocks within the Nordic Synchronous Area in accordance with Article 141(2) of the Commission Regulation (EU) 2017/1485.* s.l. : ENTSO-E, 2018.

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Expert Group 3 (EG3, 'Regulatory Recommendations for Smart Grids Deployment') of the Smart Grids Task Force. Regulatory Recommendations for the Deployment of Flexibility. *https://ec.europa.eu/energy/sites/ener/files/documents/EG3%20Final%20-%20January%202015.pdf.* [Elektronski]

Gerhard Meindl, SWW Wunsiedel. 2019. *Consultations with the GRASHOPPER project Advisory Board.* May 2019.

IEC. International Electrotechnical Commission. *http://www.iec.ch/smartgrid/standards/.* [Elektronski]

Joost Sandberg, Nouryon. 2019. *Consultations with the GRASHOPPER project Advisory Board.* May 2019.

Mussbacher, G., Bochmann, G.V. in Niu , N. Requirements Analysis and Specification.

regelleistung.net. 2019. FCR Cooperation Stakeholder Workshop on Harmonisation and Implementation of New FCR market Design. s.l. : regelleistung.net, 2019.

Schittekatte, Tim, Reif, Valerie and Meeus, Leonardo. 2019. *The EU Electricity Network Codes: Technical Report.* San Domenico di Fiesole : European University Institute, 2019.

Srnovšnik, T. 2019. Europe Has 9,133 MW Secondary Frequency Control Potential. *energetika.net.* [Online] April 16, 2019. [Cited: August 26, 2019.] https://www.energetika.net//eu/novice/trading/europe-has-9133-mw-secondary-frequency-control-potential.

Staffell, Iain, et al. 2019. The role of hydrogen and fuel cells in the global energy system. 2019, 2.

Sulzer, Matthias. 2018. *Why do we need ENERGY market desig instead of ELECTRICITY market design?* Lucerne : Grid Service Markets Symposium, 2018.

Supponen, Matti. 2018. *Legislative progress in the harmonisation of ancillary services markets in Europe.* Lucerne : Grid Service Markets Symposium, 2018.

TenneT TSO . 2018. *Market Review 2017: Electricity market insights.* Arnhem : TenneT TSO B.V., 2018.

WEMO. 2018. *World Energy Markets Observatory.* s.l. : Capgemini, 2018.

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