FlexiGrid

Project Acronym:	FlexiGrid
Project Full Name:	Enabling flexibility for future distribution grid – FlexiGrid
Grant Agreement:	No 864048
Project Duration:	3,5 years (starting 1 November 2019)

Deliverable 3.3

Process design for flexibility procurement and dispatch

Work Package:	WP3
Task:	T3.3
Lead Beneficiary:	LIST
Due Date:	31/10/2020 (M12)
Submission Date:	31/10/2020 (M12)
Deliverable Status:	Final
Deliverable Style:	Report
Dissemination Level:	Public
File Name:	D3.3_Process_design_flex_procurement_v_4

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 864048

Authors

Name	First Name	Beneficiary	e-mail address
Koster	Daniel	LIST	daniel.koster@list.lu
Nguyen	Phuong	TU/e	p.nguyen.hong@tue.nl
Haque	Niyam	TU/e	a.n.m.m.haque@tue.nl

Reviewers

Surname	First Name	Beneficiary	e-mail address
Antoniadou-Plytaria	Kyriaki	Chalmers	kyriaki.antoniadou@chalmers.se

Version History

Version	Date	Modifications made by
0.0	20200820	Basic version
1.0	20200915	Draft for internal review
2.0	20201010	Version ready for review
3.0	20201028	Final draft version
4.0	20201030	Final version

Figures

List of abbreviations

Abbreviation	Definition
AC	Alternating Current
AS	Ancillary services
BRP	Balance Responsible Party
CAPEX	Capital Expenditures
CHP	Combined Heat and Power units
DER	Distributed Energy Resource
DG	Distributed Generation
DLC	Direct Load Control
DSO	Distribution System Operator
DR	Demand Response
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
GOPACS	Grid Operators Platform for Congestion Solutions
ID	Intra-Day
IDCONS	Intraday Congestion Spread
IES	Integrated Energy Systems
LFM	Local Flexibility Market
LV	Low Voltage
mFRR	manual Frequency Restoration Reserve
MV	Medium Voltage
RES	Renewable Energy Sources
TOTEX	TOtal Capital and Operational Expenditures
TSO	Transmission System Operator
V2G	Vehicle-to-grid

Contents

Process design for flexibility procurement and dispatch

1 Introduction

The increased integration of renewable energy sources (RES) and distributed energy resources (DERs) into our electricity grids will result in several, continuously growing operational challenges. In addition to this, electricity consumption will be affected by the shift to a more electrified energy system in the future. To face such challenges, demand flexibility seems to be a promising tool for DSOs. With energy transition emerging especially at the local and regional levels of the electricity network, more and more flexibility can be unlocked from small-scale and industrial end-users. The demand flexibility can be very useful for both market and grid-oriented services. Under an operational framework, it is crucial to have a generic process for flexibility procurement in order to manage the flexibility in an efficient way. This report will present a suitable structural design to coordinate the associated process in the flexibility value chain. In this report, the design requirements for procuring and dispatching flexibility services will be specified. These include detailed specifications regarding the data flows among the actors concerning energy, price and incentives, as well as the interactions among flexibility service providers, end-users, market and network operators and regulatory authorities.

The results of the developed structural design will be assessed, mainly regarding the formulation of an interaction framework among stakeholders for flexibility procurement. Finally, the process flow for different types of flexibility services will be determined to provide a detailed road map for the efficient design regarding flexibility exchange and dispatch.

This task will be assisted by inputs from the Canadian project, NestNett and with the exchange of ideas and knowledge between the two projects.

1.1 Context Background

With energy transition in full swing, flexibility will play a crucial role in the energy system for facilitating the integration of renewable generation [1], reduction of operational costs of the energy systems [2], deferring capital cost on power systems [3], resilience and reliability improvement [3], and opportunities for innovative business models and market frameworks (e.g., transactive energy (TE) [4], smart contracts [5], local flexibility market (LFM) [6], peer-to-peer (P2P) energy trading [7], etc.). Key drivers for flexibility procurement in the electric power systems can be briefly summarized as follows:

- The intermittent and uncontrollable nature of the RES-based distributed generation (DG) units induces significant imbalance between the generation and consumption because of the increasing uncertainties. This poses a great challenge to the transmission system operator (TSO) for balancing and controlling the resulting frequency fluctuations. Adequate flexibility is needed by the TSO to cope with these type of balancing problems [8].
- Distribution networks are evolving into bidirectional, decentralized systems caused by the increasing share of DERs connected to the demand side. It results in an increased amount of reverse power flows, voltages level violations, congestion and network losses. Flexibility is significant on the demand side in order to enable the DSOs to address these challenges. Unlocking the demand side flexibility to solve the

operational challenges in the distribution networks are also highly encouraged by the policy makers at the European level [9], [10].

- Flexible consumers and local producers (also referred to as prosumers) are the potential providers of flexibility in the distribution networks. With the proliferation of intelligent solutions, the prosumers can provide flexibility services by managing their DERs and communicating with other stakeholders including fellow prosumers, energy suppliers, aggregators and the DSO. In return, the prosumers can benefit financially for the provided services [2].
- Integrated energy systems (IES) are being widely studied as promising solutions for the evolving energy systems hosting multiple energy vectors in a scalable setting. IES are regarded to offer immense opportunities for the power systems to provide cost effective flexibility services by capitalizing on synergies and complementary advantages of the interdependent energy vectors at various scales [11]–[13].

Within the project, FLEXI-GRID aims at the development and demonstration of integrated solutions which will allow the distribution networks to function in a secure and stable manner with large shares of variable renewables, while unlocking the flexibility from the demand side. In this deliverable, the generic process flow for flexibility procurement is outlined, considering market and network integration of the DERs. The process flow is crucial to determine the available flexibility for network support and to design how the flexibility can be valued and procured for different types of services. The deliverable supports the demonstration activities in relevant WPs, while outlining the basic specifications and functional requirements of the IoT platform.

1.2 Players and services offered from flexibility procurement

Uncertainty caused by distributed energy resources (DERs) urges for advanced grid operation regimes, among others transactive energy is emerging that “allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operation parameter” [14]. The bottom-line of this conceptual framework is to create a means for executing transactions through automatic control of the operating state of various DERs which allows flexibility resources to be harnessed bottom-up. The introduction of a local flexibility market (LFM) allows flexibility from distribution level resources to be used for different purposes; specifically, the scope of these flexibility services is threefold [18]:

- Grid-oriented services;
- Market-oriented services;
- System-oriented services.

Within the local market context, flexibility is considered as a commodity offered by a particular distributed energy resource to adapt its energy profile according to sudden (required) changes. This heterogeneous commodity is with multiple attributes [15], e.g. capacity, duration, or ramp rates, which allows an deviation from the baseline of the DER’s usual profile pattern, as illustrated in the following Figure 1-1.

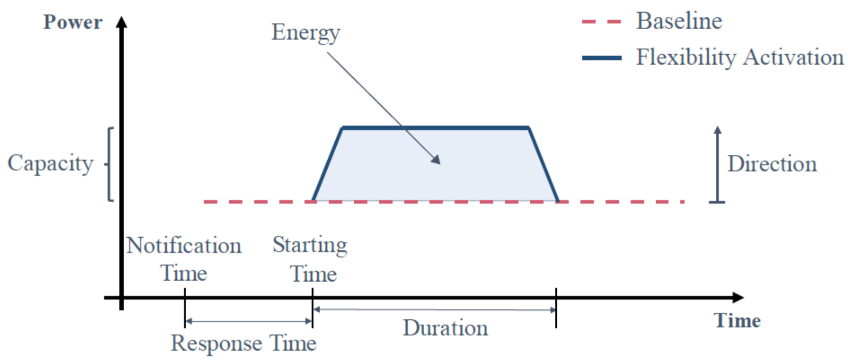

Figure 1-1: Flexibility activation with relevant attributes [10].

Acting as a marketplace, LFM allows potential buyers and sellers to engage in trading flexibility at local grid levels. Among others, three main players are active in LFM, including [16]:

- The **(independent) aggregator** who can provide the available flexibility from clusters of DERs. The aggregation of small and medium-sized DERs via this aggregator entity will enable an access for DER's owners to the market. The existing market entity such as energy suppliers might act also as an aggregator that has a certain benefit in coupling flexibility services offered at the local market together with adjusting the energy profile to participate in the wholesale market.
- The **distribution system operator (DSO)** who requests flexibility for grid-oriented uses. To maintain the security and quality of power supply to the consumers in an effective, sustainable, and affordable way, the DSOs can use the DERs' flexibility to solve local problems, such as feeder (or transformer) overloading issues or voltage band violations.
- **Balancing Responsible Party (BRP)** who trades flexibility for market-oriented use. To keep the supply and demand balance for a portfolio of producers (or consumers), the BRPs can use flexibility to correct unbalanced positions in their portfolios.

In particular setting of renewable energy communities [17], value-driven approaches might reveal new local players and services including collective self-consumption that couples to (local) balancing services. The large-scale impact would create flexibility value for system-oriented services in which the TSO would be benefitted from the coordination with the LFM and the involved stakeholders i.e. TSO-DSO interactions.

1.2.1 Stakeholders in the FlexiGrid Demos

Within the scope of FLEXI-GRID, four main demo sites have been proposed to validate potential flexibility services. Main players and tangible services to be demonstrated are listed in the following Table 1-1. Base on the preliminary requirements from the demo sites and involved partners, this report will specify on the design of flexibility procurement to enable potential services accordingly.

Table 1-1 Involved players and tangible services in FLEXI-GRID's demo sites

Demo sites	Aggregator	DSO	BRP	Tangible services
Chalmers campus site - Sweden	Akademiska Hus		-	• Grid-oriented services (advanced monitoring) • System-oriented services (self-consumption)

EnergyPolis - Switzerland	HES-SO	ESR	-	• System-oriented services (self-consumption)
OEDAS pilot site - Turkey	OEDAS			• Grid-oriented services (congestion management) • Market-oriented services (portfolio balancing)
Energo-Pro pilot site - Bulgaria	Energo-Pro		-	• System-oriented services (self-consumption)

2 Overview on the operational framework of LFM

As discussed in [10], the flexibility potential offered by DERs can be considered for tackling location-dependent problems (such as congestions) but also, if properly aggregated, for supporting the traditional flexibility sources at the transmission level. By unlocking flexibility values from small and medium-scale DERs, both market- and grid-oriented services can benefit from the demand flexibility. However, in order to manage the flexibility in an efficient way, an operational framework is crucial.

A suitable structural design for this operational framework needs to coordinate the associated processes of electricity flows together with market value and flexibility flows, as presented in Figure 2-1. These should include detailed specifications regarding the data flows among the actors concerning energy, price and incentives, as well as the interactions among flexibility service providers, end-users, market and network operators, and regulatory authorities.

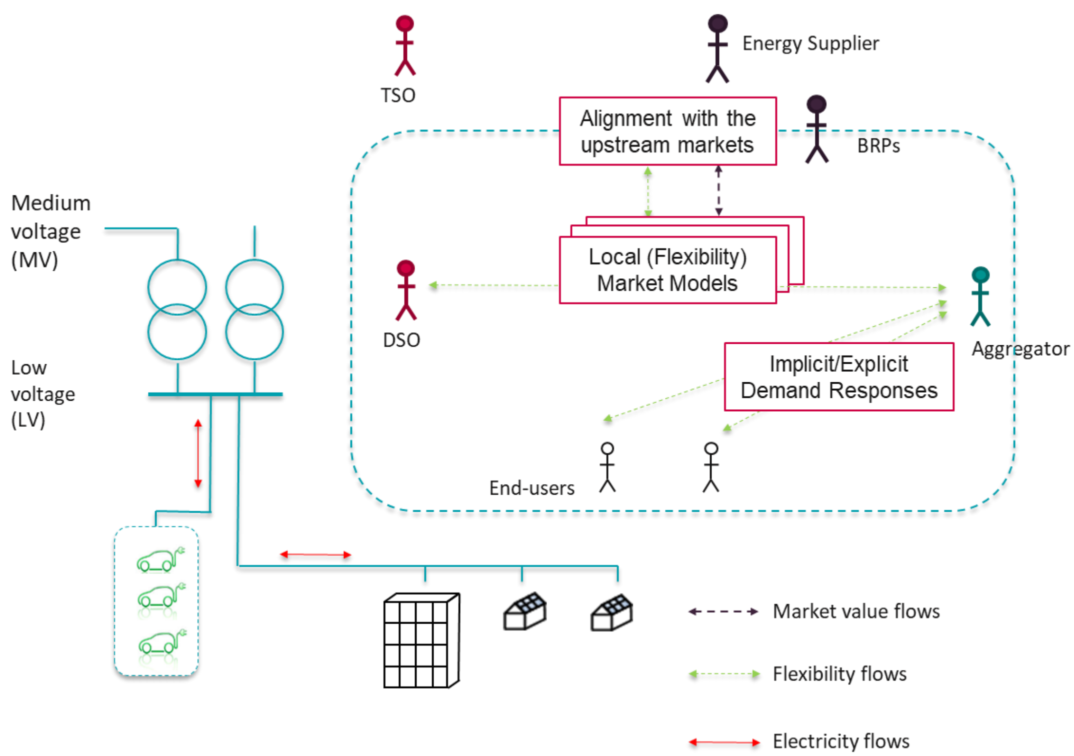

Figure 2-1: An operational framework for Local Flexibility Market.

Within this operational framework, some important aspects need to be addressed including:

- Crucial role of aggregator to unlock flexibility potential from DERs;
- TSO-DSO coordination to allocate flexibility to where it brings the highest benefit to the overall power system.

Coexistence of different flexibility services based on the interactions of the aggregator, TSO and DSO is important to provide fair access to all potential parties while ensuring appropriate compensation. Taking an evolution role of the DSO as an active network manager, these main design challenges for LFM to enable the procurement process of flexibility will be discussed in detail in the following sub-sections.

2.1 Crucial role of aggregator

The (independent) aggregator is the key enabler for flexibility services due to its benefit on economies of scale, i.e. minimizing the fixed costs of market participation and communication infrastructure, as well as higher certainty of available flexibility, i.e. mitigating the risk of forecasting errors. The aggregator will play the role to aggregate and value flexibility for different markets (local and wholesale). Possible interactions of the aggregator with existing wholesale markets includes the day-ahead (DA) market and intra-day (ID) market, to provide market services and might further include ancillary service (AS) markets to provide system services.

Although it could be considered that a DSO-based flexibility platform could be run without the aggregator as an independent, third party between the flexibility provider and the market operator or even that the platform is also operated by the DSO, this model is not further considered here. Although not excluded, this role could be seen problematic from a regulatory perspective, separating regulated and non-regulated business and the independence of the marketplace would be lost (a requirement of the EUs' electricity directive). While the aggregator role can be carried out by an existing market entity such as the energy suppliers, an independent (or third-party) aggregator is a new actor who can manage DERs' flexibility with a separate contract with the DERs' owner. Enabling such a contract without having a pre-agreement with the energy supplier and its associated BRP, might create deviations from the schedules, that urge for a compensation scheme for relevant parties. The below Figure 2-2 shows the implications of a third-party aggregator having a separated contract with the prosumer. Examples on how this rebalancing is solved in existing market platforms are described under 2.2 and 3.2.

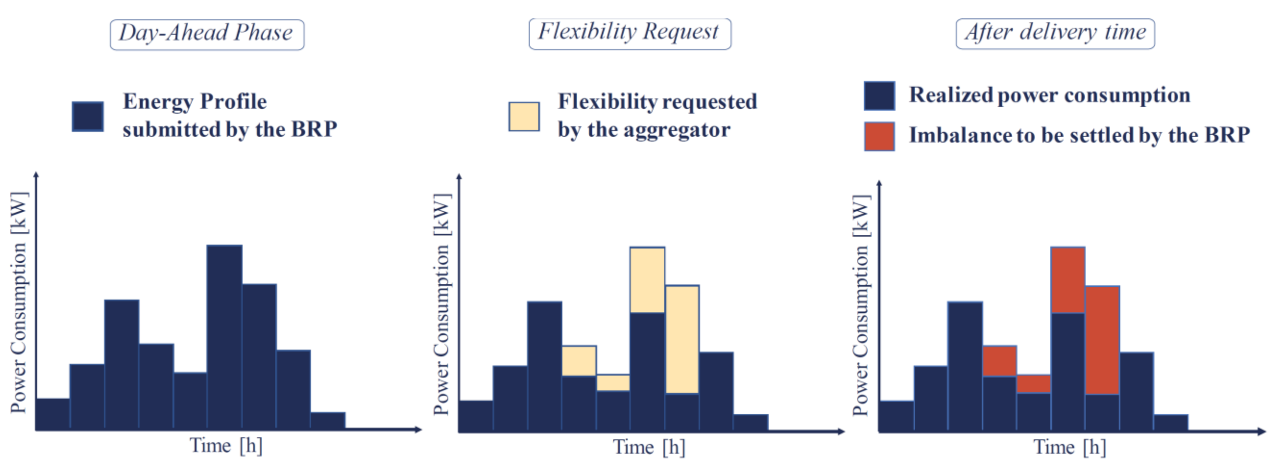

Figure 2-2: An example of possible impact of flexibility activation by an independent aggregator on the Balance Responsible Party (BRP) energy program [10].

Along with the design process for flexibility procurement, it is important to create a level-playing field for players in the LFM, in which the role of the DSOs can be more related to procure flexibility. Some examples in Belgium and Germany include operational schemes, under which newly installed generation units' profit from reduced network tariffs, by allowing the DSO to curtail their power output if necessary. For such grid-oriented use, the DSO is the single buyer while flexibility aggregators can compete on the seller side.

The aggregator can mobilize flexibility values from the DER owners via, either implicit or explicit response mechanisms [18]. While the implicit mechanism is price-based to reflect the variability of network costs and market prices, the explicitly one is defined as one or more products on the energy and/or ancillary service markets and traded as such. In this case, remuneration depends on the (explicit) delivery of the product flexibility [19].

2.2 TSO – DSO Flexibility trading

TSO–DSO coordination is essential to ensure an effective exploration of flexibility resources, that can be traded in different markets (local and wholesale). An integrated approach is expected to maximize the value from flexibility resources, minimize the number of different bidding processes for procuring ancillary services. This aims also to prevent any market party from creating voluntarily a local problem and being paid afterwards for solving it. Hence, the design of the local market should consider this TSO–DSO interaction in a way, that the transactions at the local level should be reported to the TSO.

Besides sharing data and information to counteract potential deviations from the schedules between the TSO and DSOs, creating a single marketplace would reduce the number of different bidding processes and limit the possibility of arbitrage between different markets. A challenge is to create a common ground for both, the TSO's needs (balancing, frequency regulations) and DSO's needs (local congestion management, voltage limit violations).

An example for this TSO-DSO flexibility trading is the Grid Operators Platform for Congestion Solutions (GOPACS)[1] which is a joint force among the Dutch DSOs (Stedin, Liander, Enexis and Westland Infra), TSO TenneT and the intraday trading platform ETPA (Energy Trading Platform Amsterdam). Based on price spreading between buyers and sellers (BRP) in the intraday market, as well as (local) connection specification, GOPACS can combine (optimize) the orders to solve congestion problems in a so-called intraday congestion spreads (IDCONS), as illustrated below [20].

[1] https://gopacs.eu/

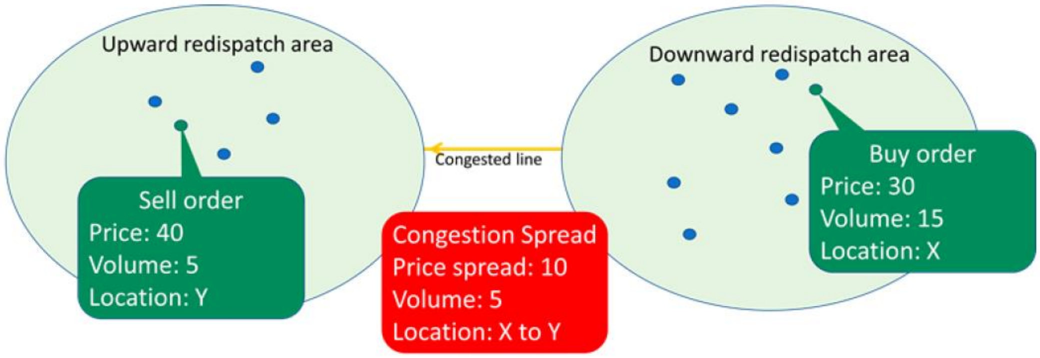

Figure 2-3: Illustration of a congestion spread in GOPACS.

The grid operators can activate intraday bids with a specific connection point to solve a congestion problem.

3 Local flexibility markets: scientific and industrial strides

The development of LFM is considered as a different form of market-based re-dispatch, i.e. local markets for flexibility, using balancing products for congestion management, locational intraday order book etc. In this section, associated development activities are briefly discussed from the scientific and industrial perspectives.

3.1 Scientific state of the art on flexibility procurement

With the growing fluctuation in supply and demand at the residential level, demand flexibility plays a significant role in the energy transition. That is to say, consumers need to be more flexible in their energy consumption to accommodate more variable generation and to alleviate the network peak demands [21], [22]. To this end, an extensive body of literature has been developed focusing on the flexibility of residential and commercial end-users, incorporating flexibility arrangements with diversified scopes, architectures and involved actors. On the one hand, these include centralized methodologies for residential or neighbourhood energy management [23], system balancing [8], distribution congestion management [24], [25] and voltage control [26], [27]. On the other hand, distributed frameworks have also been widely studied involving agent-based architecture and local flexibility markets [28], [29], combined with efficient computational intelligence. Centralized approaches determine control actions based on data gathered at a central location and have the advantages of taking the whole network into consideration. However, these approaches are not particularly scalable, due to data transfer and computational limitations. Moreover, they are vulnerable to technical failures, since control actions are performed from a single controller. On the contrary, decentralized or distributed approaches aim at dividing the task into several smaller ones and exploit locally available information with limited communication. As the intelligence is distributed among different points in the network, these approaches are more robust to failures. Thus, distributed approaches can be particularly suitable for large-scale problems with scalability issues. Nonetheless, the distributed controllers lack the global view of the system, and hence may not be able to reach the global optimum solution [30], [31].

From the network operator's perspective, exploiting flexibility can be an efficient and cost-effective alternative for large-scale network reinforcements. In liberalized electricity markets, small-scale consumers and producers can offer flexibility by participating in the energy market through market entities like aggregators. The offered flexibility is traded in different price or incentive-based market settings and is incorporated in demand response (DR) programs.

Conventionally, the concept of DR expresses the price elasticity of the electricity demand and facilitates shifting of demand, based on certain price changes. According to the US Department of Energy, DR can be defined as *changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized* [32]. In this report, DR is *the changes in consumption or generation behaviour of the end-users in response to price signals or incentives sent by market entities and network operators upon violation of specific network constraints*.

It is important to note that, network issues such as thermal overloading and voltage limit violations are related to particular network assets and are therefore confined within certain areas. On the other hand, in liberalized electricity markets, aggregators or energy suppliers are not limited by geographical boundaries, since the end-users are free to choose their respective suppliers. In addition, all stakeholders of the smart grids have various optimal strategies and behaviours to operate their generation sources and consumer appliances. While a DSO may put forth effort to reduce the power losses and capacity issues, the energy supplier/retailer may encourage the customers to maximize the demands; in-turn the consumers may be sensitive to the price signals from the power market to accordingly adjust their power consumption or even production. Thus, DR programs that aim to resolve operational challenges of the network must be designed considering the conflicting interests of the involved actors as well as by addressing the locational issues [33], [34].

3.1.1 Market-controlled DR

Since the regulatory framework inhibits DSOs to influence small-scale end-users, market-controlled DR programs are used to procure flexibility through market parties like aggregators, using different price signals. Such market-based DR programs employ a variable electricity tariff for different times of the day, while consumers are expected to manage domestic energy consumption, considering the varying levels of the price. These mechanisms inherently influence load shifting from peak hours to less congested time intervals during the day and thereby facilitate peak shaving for network operators. The price levels may differ at predefined time periods or dynamically throughout the day. For instance, in many European countries, day-night tariff schemes have been implemented with a lower price during the nights and weekends. Since the price levels are adjusted in order to invoke demand flexibility, market-based DR programs are often termed as 'price-based DR schemes.' Variants of such price-based schemes include time-of-use (ToU) pricing, critical peak pricing (CPP), day-ahead dynamic tariffing, real-time pricing (RTP) etc [35]–[37].

Price-based DR programs can be easily scalable and do not usually hamper consumer privacy. However, controversies exist concerning the fairness of such mechanisms, as the same price levels are provided to the consumers with different consumption levels. A lower price level also encourages the switching of more loads, which may result in overloading network components [36], [38]. Furthermore, most of these market-oriented approaches aim to resolve market issues and hence have effects on a global scale. Therefore, addressing local network issues through varying price levels requires additional complexities in terms of determining the price elasticity, locational dependence and other factors.

3.1.2 Incentive-based DR

Incentive-based DR programs encourage end-users to alter energy consumption following flexibility requests or contractual agreements, coupled with monetary compensations. In most cases, a centralized entity is responsible for the determination of appropriate flexibility requests and corresponding incentives. The program administrator is usually provided with some degrees of authority to regulate the power flow at the connection points according to their preferences. Such incentive-based DR programs include direct-load control (DLC), interruptible tariffs, demand-bidding programs, etc [36], [39].

Active power curtailment is a popular DLC solution for peak load reduction and voltage constraint management in the distribution networks. Centralized or distributed algorithms are employed to determine the curtailment locations considering certain criteria [40], [41]. While some load control methods use partial load-shedding schemes [42], [43], smart load management methods have also been developed incorporating remotely controlled switches enabling a flexible consumption level at the connection points [44], [45].

Direct control mechanisms have been applied extensively for controlling power injected by DG units in MV and LV distribution networks. Traditionally, reactive power control methods of DG units have been used to control voltage levels at the connection points. However, distribution networks, predominantly comprising of underground power cables, introduce higher resistance compared to overhead lines. This means that the reactive power consumption/injection has a significantly lower impact on the voltage levels in radial distribution networks. Consequently, active power curtailment becomes necessary in order to accommodate more RES-based DG and to maintain the power quality of the networks [46], [47]. For instance, solar PV systems are widely being equipped with integrated droop-control functionality, that curtails active power injection when voltage levels exceed certain threshold values. Nevertheless, the regulatory frameworks for curtailment and related financial compensation largely vary depending on regional and national legislations. In most of the European countries, DG units with a certain installed capacity are obliged to curtail active power injection upon request from the DSO [48], [49].

However, several factors play a crucial role for the limited application and acceptance of the approaches. First, such direct methods are inherently invasive, as the end-users perceive a lack of control over their energy consumption and disruption of their comfort [36], [50], [51]. Second, the transmission of the control signal is hindered by technical difficulties [52]. Next, distrust and scepticism exist among the end-users due to the privacy concerns [51]. Finally, most of the direct approaches suffer from the system scalability issues for wider applications [36].

3.2 Existing market platforms

Beyond the developments in the academic area, several initiatives, demo projects as well as first small-scale implementations deliver valuable experiences with the establishment of local flexibility markets in the energy industry [53]. Some of these examples are:

- **Enera *(Germany)*** – is a common project of utility EWE AG and EPEX SPOT, in cooperation with the DSOs Avacon Netz, EE NETZ and TenneT. The Enera flexibility market focuses on solving grid congestion, using locational order books that collect the flexibility to be used by DSOs and the TSO [54].
- **GOPACS *(Netherlands)*** – is the cooperative market platform of Dutch TSO TenneT and most of the Dutch DSOs. The objective is to mitigate capacity shortages in the electricity grid (congestion) by active collaboration between the Dutch national grid operator, using local flexibility.
- **NODES *(Germany / Norway)*** – has been established in 2018 as joint venture of the Norwegian utility Agder Energi and the operator of the European power exchange market Nord Pool. NODES will cover load- and generation-related congestions and balancing purposes, from HV to LV level.
- **IREMEL *(Spain)*** – launched as a project of the Spanish spot market operator OMIE and the Institute for the Diversification and Saving of Energy (IDEA – part of Ministry for the Ecological Transition), incl. fife

demos in different Spanish areas to test a market model for the use of DER to solve local congestions and to serve DSOs needs.

- **Piclo Flex *(United Kingdom)*** – this independent flexibility platform has been developed by the software company Piclo and involves currently six different DSOs across the UK. On this platform DSOs place flexibility tenders and flexibility providers register their offers, streamlining the procurement process.

The ***operability*** of the different initiatives reaches from individual local demos to implementations on full national scale: GOPACS and Piclo Flex are widely implemented on their respective geographic areas, depending on the participation of the individual DSO. IREMEL, NODES and Enera established local demos, so far, but are active on different voltage levels and serve versatile purposes of flexibility use. Concerning the operability of different functionalities, the initiatives are hard to compare and on some (specifically IREMEL) it is difficult to find specific information. Anyhow, NODES, Enera, GOPACS and Piclo Flex report (sometimes historic) data on actual trades via their respective platforms and are proving their functionality in real application cases currently.

The ***independence*** of the market platform from any market actor is not a legal requirement but can be seen as a key success factor on long term, to attract further market players to become active on the platform. In the current stage, as most of the existing initiatives originate from demo projects, this independency is often not yet fully given. EPEX SPOT serves in *Enera* as independent controlling and transparency granting organisation, but EWE remains involved with its different entities from grid operators and utility side. Dutch TSO TenneT seems to have a central role in GOPACS, which can be seen as neutral market player towards DSOs and other payers involved, but it can still be argued weather they can be considered the right operator of such market scheme. Agder Energi has announced to pull out of NODES, at a later stage, to assures this independence, while IREMEL remains unclear regarding this aspect. Piclo Flex, on the other hand, is a platform, developed and operated by an independent software company.

The actual ***flexibility use case*** behind each individual local flexibility market can be very different and some, like NODES, even cover several purposes using similar platforms. NODES reported in their market design white paper [55] two different use cases: In Northern Germany, local flexibility is used to avoid costly emergency measures at a potentially overloaded 110 kV line, due to RES generation, while in Norway the NODES platform is used by the DSO to buy flexibility under a potentially overloaded 132/22kV transformer (load related). Meanwhile, further uses cases are reported (planned or operational) which include a) to secure power supply of remote and weakly connected places (Norway), b) use of locally offered flexibility on TSO level (mFRR in Norway) , c) automated imbalance mitigation functionality (UK), d) operate long term, bilateral flexibility agreements via the same platform and e) improve TSO-DSO coordination and the integration into TSO´ mFRR market (Sweden).

Piclo-Flex does not specify directly which use cases their platform currently supports, but reinforcement deferral is mentioned frequently in their currently running competitions. Anyway, Piclo-Flex serves rather as agent to connect potential flexibility providers to DSOs requesting flex and is not active on the operational level.

Within Enera, the demo region in the North-West of Germany is faced with a RES share of 235% of its demand. Flexibility is being use to defer grid reinforcements and to avoid curtailment of RES, especially wind power. The usage of the GOPACS platform is targeting grid congestions, purely. While, IREMEL mentions the demonstrations in 5 very different pilot areas, facing varying participants and conditions, without further specifications on the actual use cases.

The ***locational granularity*** in these markets will in the existing initiatives be defined by the grid operators and needs to be in line with the uses cases requirements, hence the purpose of the flexibility use. For example, in Enera, targeting mainly the integration of huge wind power feed-in, the so-called locational order books are setup for 23 individual market areas in the full demo region. These market areas are the smallest granularity foreseen and represent grid topological areas, where the assigned flexibility resources would have similar sensitivity to tackle a potential congestion in that area.

The ***integration with existing market levels*** is key to ensure that flexibility providers can serve the requests from different market levels and stakeholders, wherever they could fulfil the requirements. This leads to higher liquidity in the markets, increased cost-efficiency and could (indirectly) facilitate market access of small-scale flexibility resources to up-stream market levels.

Some of the existing initiatives collaborate with operators of upstream markets, such as Nord Pool in NODES, EPEX SPOT in Enera, OMIE in IREMEL and also GOPACS has a collaboration with an intraday market platform (ETPA) ongoing.

In the NODES framework, the platform will serve as gateway to other marketplaces, at times where the value of this flexibility is higher there than on local level – namely on the ID market for BRPs or serving the TSO for balancing purposes. Although, if there is need for flexibility locally, NODES expect the ID price to be cheaper since on local level, there will be much fewer alternative offers. Further, flexibility providers may differentiate in NODES whether they wish to sell locally or to a central marketplace.

The Enera scheme is much less specific to that respect: the link to the ID market is used for rebalancing purposes and the market design is designed inline with the ID market, but a full integration in a sense that the flexibility offer could be placed on other market levels in parallel is not described. A similar logic is followed by the developers of the GOPACS platform, using the ID market link for rebalancing, which is explained in the next paragraph.

The approach in IREMEL differs from the other initiative with regards to the creation of a local market, only “upon demand”. The DERs, offering flexibility, would participate in ID and DA markets in periods where there is no restriction set by the respective DSO. Just in case DSOs identify and report restrictions to OMIEs market platform, the DERs would be associated with the local market platforms.

Further differences between the existing initiatives can be identified regarding ***rebalancing:*** The term rebalancing describes the compensation of the imbalance that would result from the activation of positive or negative flexibility on a local market. Hence, each e.g. positive flexibility activation on a local market, needs to be compensated by negative flexibility outside this local market.

This process of rebalancing is intrinsic part of the GOPACS scheme, as each flexibility activation needs to be combined with an opposite order outside the congested area and a further check is foreseen to exclude that this measure is not causing additional issues.

Under NODES, the rebalancing can either be done via a similar opposite trade on ID market or could be compensated by the seller own portfolio. Also, Enera mentions a “compensating trade” via the ID market.

Under IREMEL and Piclo Flex, the topic of rebalancing is not addressed specifically.

3.3 Examples - Procurement and dispatch in USEF and NODES

Process flows for flexibility procurement can vary in real-life based on local market regulations, interaction among different actors, time horizon and scope of services. In order to shed some light on industrial practices, in this section, the generic processes for flexibility procurement in USEF and NODES are briefly discussed.

3.3.1 Universal Smart Energy Framework (USEF)

USEF provides a model of extended markets revolving around localized flexible energy use. This type of market model allows active market participation of all players, such as the DSO, aggregator(s), BRP(s), prosumers, etc. The framework includes a market structure and the associated rules and tools required to integrate flexibility resources. It fits on top of most energy market models, extending existing processes to offer the integration of new services and flexibility provisions.

In a USEF compliant distribution network management scheme, expected congestion points are published by the DSO in an open access database and forecasting is mandatory for the aggregator concerning the published congestion points. Congestion management is performed by issuing flexibility requests to aggregators that are active in the relevant network areas in advance. The volume and price of the flexibility offered by aggregators is negotiated with the DSO in an iterative process, where the designed program of the aggregator is validated. The DSO is obliged to procure the offered flexibility at the designated price [56].

USEF mobilizes the provision of implicit and explicit demand response mechanisms through dynamic pricing and aggregators. In order to trigger the implicit demand response, time-of-use (ToU) price signals are provided to the prosumers by the DSO and the suppliers. Based on these signals, the prosumers are expected to alter their energy consumption and unlock the demand flexibility. The role of energy service companies (ESCos) has been highlighted to coordinate the process for the prosumers through control signals and recommendations. On the other hand, for triggering the explicit demand response, USEF recommends the aggregator to assume a central position in the so-called Flexibility Value Chain (FVC). The aggregator acts as a retailer of flexibility between the prosumer and the Flex Requesting Parties (FRP), i.e. the Balance Responsible Party (BRP), DSO and Transmission System Operator (TSO). The aggregators are responsible for acquiring flexibility from prosumers through aggregation in their portfolio. The aggregator is incentivized for the offered flexibility services, which is subsequently shared with prosumers for the provided flexibility. More information about the framework and market interaction can be found in [57].

3.3.2 NODES Marketplace

NODES is an independent marketplace for a sustainable energy future, decentralized flexibility and energy. Currently in its pilot phase, NODES is a universal platform with features allowing connecting to other markets, so that grid operators, producers and consumers of energy can trade on local and flexible electricity markets. Initiated by Nord Pool, Europe's leading power market and Agder Energi, NODES aims to offer a flexibility marketplace to provide scalable and optimal use of flexibility and a transparent view using multiple technological solutions. Different types of flexible loads and technical solutions can be integrated, including smart homes with solar PV systems and batteries, electric vehicles (EVs), and commercial and residential demand response programs [58].

In the NODES marketplace, the DSO participates in the flexibility market by placing offers to obtain flexibility and by providing network-related topological/geographical information. Different levels of granularity can be chosen in terms of topology at which the flexibility is required. Bids below that network level are aggregated in the marketplace to provide the required services. The DSO acquires load forecast and decision support data from internal grid systems and the marketplace. It then runs or obtains results from supporting data analytic tools to reveal any locations with potential overloading issues. The aggregators optimize the schedule of their resources that results in potential flexibility offers to be made in the marketplace. Main principles of the marketplace in relation to the distribution network have been defined as follows:

- Allow the DSO to export information about the physical distribution network to the marketplace.
- Allow the DSO to continually update the marketplace with information about local congestion.
- Allow all market participants to trade flexibility in accordance with the information provided by the DSO.

4 Process flow for different types of flexibility services

On a local level, flexibility can be defined as the alteration of generation and/or consumption behaviour in response to external signals (price levels or control signal) in order to facilitate services for the energy system. Flexibility can generally be characterised based on power variation, duration of operation, rate of change, response time, location and other factors. Aligned with grid, market and system-oriented services, as discussed in Section 1.2, three main uses of flexibility are recognized in the scientific and industrial domains [59], namely:

- **Portfolio optimisation**: Portfolio optimisation is exploited by market actors to meet their obligations originating from the markets at minimum costs by arbitrating between generation and demand response on different time horizons.
- **Balancing**: Balancing refers to the procurement of capacity services and activation of balancing resources by the TSO to maintain the balance between demand and supply through the market. This involves all actions and processes from the gate closure time of balancing market until real-time through which the TSOs continuously ensures the stability of the system frequency within predefined ranges.
- **Network constraint management**: Flexibility services will allow network operators to address violations of network constraints in different timescales, maintaining safety, reliability and quality of services and maximising the penetration of renewable based DERs.

4.1 Generic design requirements

In order to formalize the process of flexibility procurement involving multi-actor environments, several clear principles have been outlined in the Clean Energy Package [60], as follows:

- End-users need to be able to access all organised markets and products, either directly or indirectly (Electricity Market Directive (EU) 2019/944, Articles 5, 11, 15, 16, 17);
- Network congestion management activities should be carried out through market-based approaches and should be open to all generation technologies, all energy storage and all demand response service providers (Electricity Market Regulation (EU) 2019/943, Article 13);
- The provision of non-frequency ancillary services to system operators has to be made available via market- based frameworks (Electricity Market Directive (EU) 2019/944, Article 40 and Electricity Market Regulation, Article 59.1.d).

Aligned with the abovementioned requirements, several high-level principles can be summarized in order to facilitate the design and implementation of local flexibility markets.

- Transparent market platforms: A non-discriminatory access needs to be ensured for all market parties to be able to compete freely for flexibility services, through appropriate market-based platforms. This will enable competition, that ensures efficient allocation of resources, while reflecting the accurate value of flexibility to market participants. Contractual agreements between system operators and flexibility service providers should only be arranged if market-based schemes cannot procure enough flexibility.

- Operation of local flexibility market platforms by independent actors: Conflict of interests can be avoided only by allowing independent parties to operate the market, who are not active on the market. Trading of services and price formation in local flexibility markets should be operated by independent third parties, while maintaining TSO-DSO coordination in a regulated environment. This also provides additional advantages in terms of different levels of unbundling at the DSO level.
- Access for all resources: All types of distributed resources should have the access to the local market for providing flexibility services. These include local RES-based DG units, flexible thermal loads, power-to- gas technologies, energy storage systems etc. For practical reasons, aggregators can be encouraged to represent the resources in the market. In addition, aggregators of industrial loads can also participate in local flexibility markets, considering their characteristics, impact and marketable services.
- Product design: Relevant stakeholders need to be involved in the design process to ensure that the products are defined to allow all technologies and services to compete fairly and are not limited to specific types or to the needs of certain providers. It is also important to allow the markets to evolve and grow through stepwise innovations, in terms of product and service design and market mechanisms.
- Addressing local needs: Local flexibility markets need to respond to needs of flexibility in very specific locations of the power and energy system. Therefore, such markets have to be set up for each identified local area, facilitating locational price signals for congestion management and redispatch of resources by aggregators, TSOs and DSOs.
- Integration with the existing market: The Clean Energy Package demands a framework for the trading of products and services, that sufficiently reflect the integration of DERs and DR programs in different market and network segments. To this end, local flexibility markets, addressing very specific local needs, have to be compatible with and be able to connect to existing wholesale short-term markets.
- Clear rules for the operation of resources: Unbundling of market assets infers a distinction between regulated network assets, owned by the TSOs or DSOs, and commercial assets owned and operated by the market actors. Aligned with the Electricity Directive, this approach is necessary for the efficient functioning of the market by guaranteeing fair access of the actors to the assets, while maximizing the utilization at different levels.
- Incentives for efficient management: System operators, both DSOs and TSOs should be sufficiently incentivised to procure flexibility from the local markets as an alternative to network reinforcements. Incentive schemes and structures should represent the general perspective on overall costs, including the transition from the CAPEX based approach to total capital and operational expenditure schemes (TOTEX) [53], [61].

4.2 Generic process flow for constraints management service

In this section, a generic process flow, as shown in Figure 4-1, is conceptualized for flexibility procurement in order to resolve congestion in distribution networks. Based upon the developments in the NODES Marketplace and USEF interaction model, it aims to show how the demand flexibility can be optimally used for congestion management. Following sections discuss the processes more in detail.

4.2.1 Phases of operation

This section describes the steps of each phase including the interactions among the stakeholders. The operation involves declaration of congestion points in the network, predicting the network load and imminent overloading issues, identification and procurement of flexibility services and remuneration of relevant stakeholders for the provided services. Depending on the time of execution, the whole process has been divided into the following four phases:

- registration,
- planning,
- operation, and
- settlement.

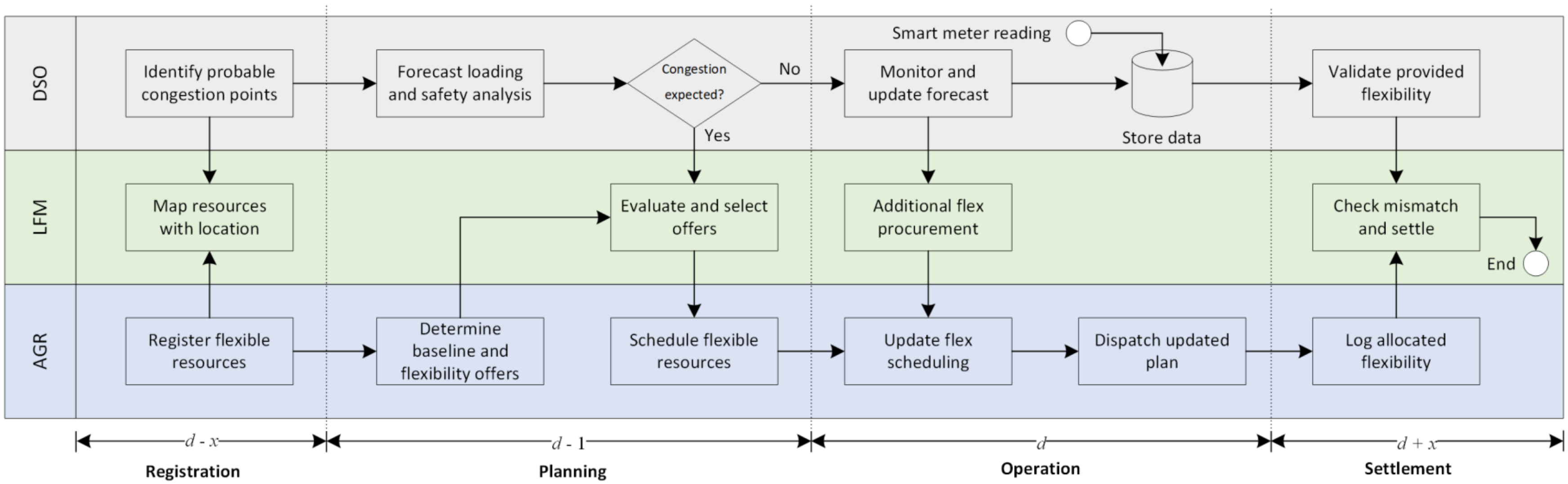

Figure 4-1: Generic process flow for procuring flexibility in order to resolve congestions in distribution networks. Tasks are identified for the relevant stakeholders - DSO (Distribution System Operator), LFM (Local Flexibility Market) and AGR (Aggregator).

Registration: The process begins with the registration phase, when the DSO denotes a point in the network as a potential congestion point. A congestion point can be a transformer or a line section, where the power flows are most likely to exceed the thermal capacity of the asset. Upon identification, the DSO publishes these congestion points to the LFM for solving the congestion. At the same time, relevant aggregators register the resources connected to the respective congestion point with the LFM (e.g. household prosumers, DG or storage units, EV charging points, etc.).

Planning: The planning phase is carried out on the day before real-time operation (d-1), when the DSO estimates the loading conditions in the congestion point, based on historical loads or an analysis of the trends in energy flows for the price levels. Upon detecting an expected congestion, the DSO sends a request to LFM to order flexibility from the aggregators involved in that network area. Based on the request from the LFM, the aggregators create flex offers with relevant costs for solving the congestion issues. In order to quantify the offered flexibility services, each aggregator needs to generate a baseline of loading conditions of contracted end-users. The offered flexibility is subsequently determined from the deviation of actual loading from the baseline.

The LFM selects the most suitable flexibility offer by matching the ordered and offered flexibility to solve the congestion. Based on the selected profile, LFM informs the aggregators to schedule the flexibility resources accordingly (e.g. EV charging points). At the same time, the DSO performs a network safety analysis considering the selected flex offers to validate the plan.

Operation: The operation phase denotes the intra-day operation (d). The schedules adopted during the planning phase are implemented by dispatching the resources according to the set points. The DSO uses sensor and measurement devices to observe network loading and estimates loading scenarios in upcoming time steps. The measured values need to be stored in secure databases for further calculations and settlement purposes. In case of probable congestions within the intra-day time frame, the DSO requests for additional flexibility from LFM. Upon this request the LFM initiates a new round of trading with the aggregators to solve the congestion. The aggregators may need to change and update the schedules of the flexible resources to procure additional flexibility. Based on the altered schedules, the aggregator dispatches a flexibility plan with adjusted set points for the resources.

Settlement: The aggregators submit the quantity and associated cost of provided flexibility to the LFM within the day by calculating the deviations from the baseline and the purchased flexibility offers. Based on the measured data in the network and smart meters of the end-users, the DSO verifies the provided flexibility in relevant time periods and submits the information to the LFM. The LFM checks for mismatches between the procured and provided flexibility and remunerates the aggregators accordingly.

4.3 Interaction model for flexibility procurement

Flexibility markets and associated trade initiate new services and propositions to the stakeholders in smart energy systems. In this section, a generic interaction model, as shown in Figure 4-2, is presented, that shows the relationship among various actors active in the system. In order to keep the discussion and depiction clear and concise, while ensuring that no details get lost, all relationships are presented as 1-to-1 relations. However, most of these are 1-to-N relationships as follows:

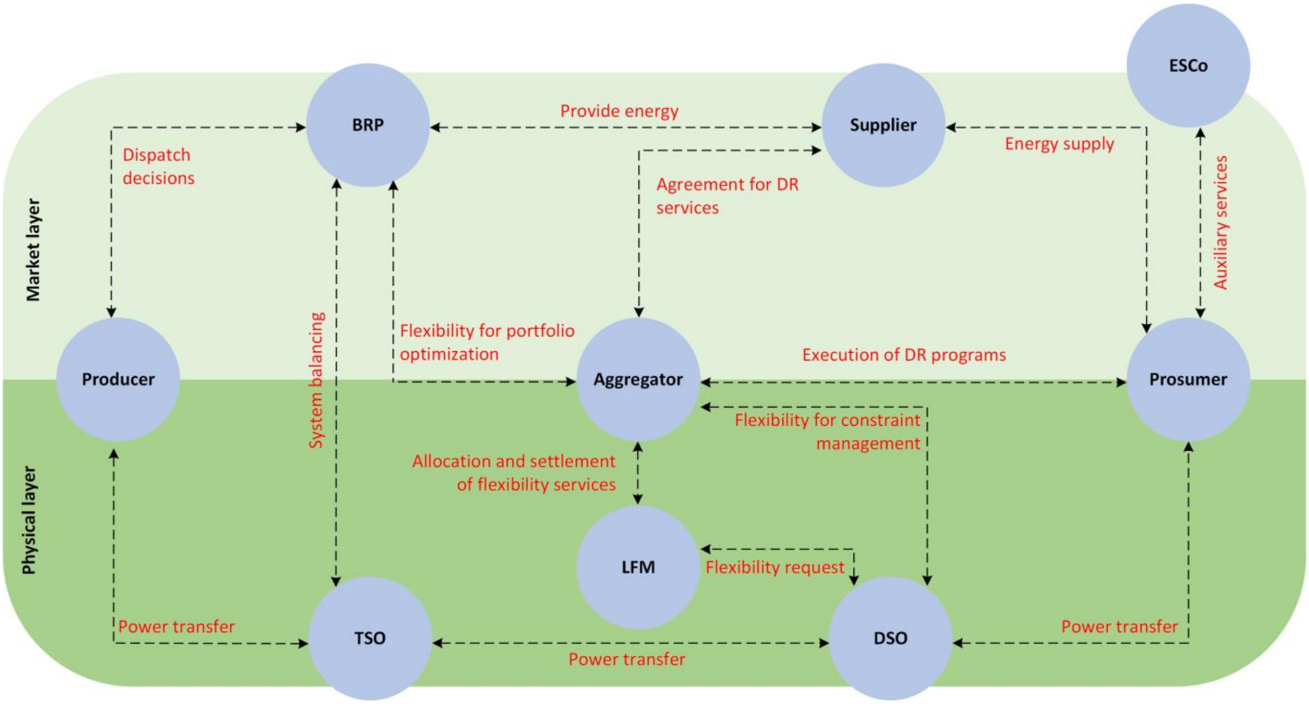

Figure 4-2: Interaction model for flexibility procurement involving different actors in the energy value chain.

- Supplier and Prosumer (1-to-N): The contract for the supply of energy to the prosumers and vice versa need to be arranged between the supplier and prosumers. The contract should ideally state the operating conditions for the demand response program executed by the aggregator on behalf of the supplier. Formal details of contractual agreements and the responsibility for billing or reimbursing flexibility can be agreed between the supplier and aggregator for individual or a group of prosumers. It should be noted that, the participation in any demand response program remains solely under the discretion of each prosumer.
- Supplier and Aggregator (1-to-N): The supplier and aggregator arrange a framework contract for all prosumers in the portfolio of the aggregator. This contract outlines the operating conditions for the demand response programs, executed by the aggregator and reflects the conditions agreed between the supplier and prosumers.
- Aggregator and Prosumer (1-to-N): The aggregator registers flexible resources of the prosumers for flexibility services. The aggregators are recommended to start the process with forecasting the local generation and consumption profiles of the contracted prosumers. To this end, it is important to estimate the behaviours considering different sources of uncertainties including switching actions, weather conditions, price levels and social events. Based on the forecast, the aggregator prepares the baseline and flexibility offers for network support services.
- BRP and Supplier (1-to-N): The supplier needs to formalize a contract with the BRP that outlines the viable conditions under which the BRP can procure the flexibility from the portfolio of prosumers under contract with the supplier. Such contracts already exist in liberalized market scenarios throughout Europe.
- BRP and Aggregator (1-to-N): The Aggregator and BRP agree on formal processes to mutually optimize respective portfolios and find the lowest operational costs. Flexibility offers traded on LFM must be checked and validated by the BRP that provides energy to the supplier that the aggregator has a

framework agreement with. For operational reasons, an aggregator should have agreements with a single BRP.

- BRP and Producer (1-to-N): Based on the portfolio optimization, the BRP determines the most effective way to balance its portfolio of supply and demand. This process is currently practiced in European energy markets and no fundamental changes are necessary in this regard. This process calculates the amount of energy that needs to be produced by the power plants in the upcoming periods. The BRP requests the producer to dispatch the required energy or purchases it on the market. In the Operation phase, the BRP may request the producer to change the original plan in order to ensure the balance.
- TSO and BRP (1-to-N): The TSO validates the E-program of the BRPS to ensure safe and reliable transmission of power. The TSO monitors the network states continuously and procures regulating power from the BRPs to balance the system in case of imminent imbalances.
- TSO and DSO (1-to-N): The TSO checks and endorses the T-programs of the DSOs for the expected power transfer in the grid connections.
- DSO and Supplier (1-to-N): Aligned with the contemporary electricity market design, multiple suppliers can provide energy in a network area of DSO. The DSO is responsible for maintaining the network to ensure the safe and reliable distribution of energy provided by the suppliers, and for managing the associated administrative issues.
- DSO and Prosumer (1-to-N): The DSO provides access of energy to/from the prosumers, and other parties. The DSO does not directly interact with the prosumer for altering the behaviour for flexibility services through the market. However, in order to address capacity issues with high impact, DSOs can have contractual agreements with prosumers to dynamically limit network access for active power curtailment. Example of such cases can be found in [62].
- DSO and Aggregator (1-to-N): In order to resolve congestion in certain network areas, the DSO will procure flexibility from all aggregators active in that area. The flexibility offers from all aggregators are evaluated by respective LFMs responsible for each congestion point.
- ESCo and Prosumers (1-to-N): The ESCo can provide energy-related services including insights to prosumers about energy conservation, cost reduction, remote maintenance and recommendations for flexibility services.

4.4 Adaptation for demo sites

In this section, recommendations for possible adaptation and reconfiguration of the demonstration sites are briefly outlined in order to facilitate flexibility procurement involving multiple actors considering their interactions and market roles.

4.4.1 Chalmers campus site - Sweden

The demonstration site in Sweden will host a range of tests including exploitation of supervisory control and data acquisition (SCADA) control system and other innovative tools for enhanced grid observability and controllability, real-time clustering of resources, formation of islanded microgrids under extreme operating conditions, formation of flexible grid structure according to existing conditions and market signals and operation of a centralised market for energy and grid services exchange with seamless transition between them. The site is owned and operated by Akademiska Hus, who will act as both DSO and Aggregator for the demonstration activities. The site is in Gothenburg, Sweden and facilitates the supply of electrical and thermal demand of the Chalmers University of Technology campus. The 12kV distribution network of Chalmers includes four distribution network areas that are suggested for microgrid implementation, while the DERs and controllable devices include solar panels (831 kWp), batteries (300 kWh), 35 plug-in EV charging points at 32

A/22 kW and 16 A/3.7 kW level, which located at two different charging stations , a combined heat and power (CHP) plant with 9000 kW thermal capacity and up to 1 MW electrical capacity, building controllable devices (to control temperature, air flow, heating & cooling, and ventilation), heat pumps and a SCADA monitoring system.

Since the site will accommodate both grid-oriented and system-oriented services, the following key transformations and improvements are necessary:

- Advanced monitoring: The site is already equipped with SCADA-based monitoring system including building automation technologies for flexibility resources. However, advanced sensors will have to be implemented to enable a fast and reliable state estimation algorithm that enables a more reliable and robust operation of the whole system. A more advanced monitoring methodology needs to be incorporated to execute demonstration activities accordingly. In addition, the monitoring system needs to include the possibility to cluster resources and network areas in a dynamic way to facilitate flexibility services based on market signals and network contingencies.
- Self-consumption: An operational algorithm currently optimizes the schedule of the battery energy storage systems considering uncertainties in price and weather conditions. The algorithms need to be improved in order to consider wider scopes of the energy system including higher ratio of self-consumption of energy for system support. This will also make use of the advanced digital monitoring and control abilities implemented throughout the network and distributed resources.

4.4.2 EnergyPolis - Switzerland

EnergyPolis is an academic campus shared by the HES-SO VS and EPFL-VS, grouping 3 new buildings and representing approximately 30,000m^2 of floor area, located at Sion. The site comprises of solar panels (400 kWp), battery storage, flexible EV charging, facilities for power-to-heat (heat pumps) and power-to-gas (conversion of surplus electricity into methane) conversion, fuel cells, advanced building automation system, and associated monitoring and control installation. The local DSO (ESR) will partner with HES-SO for the execution of the demonstration activities at this site. These activities will include tests for provision of positive and negative flexibility to the local DSO (ESR), injecting local PV production, shifting electrical loads within the buildings (including charging of electric vehicles and local battery storage), activating power-to-heat and power-to-gas facilities, with particular interest on power-to-gas technologies based on a solid oxide electrolyzer cell (SOEC), a solid oxide fuel cell (SOFC) and methanisation technologies.

Since the demonstration activities will mostly focus on the system-oriented services, special attention needs to be paid for enhancing the self-consumption of the locally produced energy. In order to achieve that, the coordination mechanism between the DSO and aggregator needs to be formally organized considering the boundary conditions, system constraints and characteristics of the resources. The generic interaction model, as discussed in Section 4.3 can be considered as a starting point for determining the interaction among the actors. Additionally, the interoperability issues of the resources for providing flexibility services need to be clarified and standardized.

4.4.3 OEDAS pilot site – Turkey

OEDAS is one of Turkey's biggest distribution companies (1.7 million customers, 6.1 TWh distributed energy, 49.000 km^2, 24.000 km MV lines, 22.000 km LV Lines). OEDAS is responsible for the power distribution of five cities with a variety of network structures, customer types, and customer energy consumption profile. It has 600 MW RES installed, mostly in rural areas (expected 2GW to be connected in 3 years), EVSE and power-to-X mostly established in city centers, a 100–150 kWh lithium-ion energy storage unit, 5 x 22 kVA AC chargers and

6 EV (Renault Zoe, BMW i3) cars. The infrastructure is controlled by the OEDAS SCADA system. Tests in this site will include SCADA system use for equipment and system integration, RES use for flexibility and load levelling, EV charging management platform and EV mobile application, V2G solutions with various tariffs and usage of energy storage technologies to reduce conversion losses.

Since the site will accommodate both grid-oriented and system-oriented services, adaptations will be required for two main types of services:

- Congestion management: MV and LV distribution networks will be closely evaluated for selection in order to demonstrate solutions for congestion management. In this regard, formal agreements need to be realized between the DSO and the flexible resources, considering the characteristics of the resources and boundary conditions of the emulated network issues. In the absence of a formal aggregator, local market regulations need to be carefully assessed in order to ensure replication potential for the demonstrated solutions. In addition, wider monitoring and real-time control ability will play a significant role for the switching of flexible resources to resolve congestion.
- Portfolio balancing: Portfolio balancing will be tested through the application of RES-based resources for load levelling, innovative storage solutions through EVs, V2G solutions. In this regard, advanced communication and real-time control will have to be realized among the involved resources and central coordinator or the SCADA system.

4.4.4 Energo-Pro pilot site - Bulgaria

ENERGO-PRO is a large utility in Bulgaria, owning generation assets, distribution business and electricity trading business with activities including operation of installed RES (mainly wind and solar power), distribution of electricity (ENERGO-PRO Grid AD) and electricity supply (ENERGO-PRO Sales AD).. ENERGO-PRO Grid is holder of a license for the distribution of electric power. The licensed territory of ENERGO-PRO Grid AD is nearly 30,000 km^2 wide and covers 9 districts. The company operates and maintains electricity distribution grids with length totalling to 42,185 km and 26 substations. The company is involved in electricity trading and coordinator of standard balancing group (ENERGO-PRO Energy Services EOOD).

The demonstration activities will mainly focus on the system-oriented services. To this end, the activities will be centred around enhancing the self-consumption of the locally produced energy in different levels of the networks. In principle, the coordination mechanism between the DSO and the aggregator in such cases, needs to be formally organized considering the boundary conditions, system constraints and characteristics of the resources. However, in the absence of an aggregator as an independent entity, virtual actors need to be implemented to emulate the interaction in real environments, to make the results replicable in real-world settings. The generic interaction model, as discussed in Section 4.3 can be considered as a starting point for determining the interaction among the actors. Additionally, the interoperability issues of the resources for providing flexibility services need to be clarified and standardized.

5 Conclusions

This report introduces the operational framework to explore flexibility values with the highlights on the role of the aggregator and interaction between TSO-DSO. This lays the foundation to ensure that the deployment of local (flexibility) market mechanisms will not jeopardize the co-existing market settings upstream. A comprehensive review on the development of local flexibility markets, both from the scientific and industry perspectives, have been conducted. Especially, this report presents a detailed discussion about the procurement and dispatch approaches from the two widely adopted frameworks, USEF and NODEs.

Base on the common ground of above operational frameworks for flexibility mechanisms and specification requirements from FLEXI-GRID demo sites, a generic process flow for different type of flexibility services has been developed. This reflects on constraints management services as well as detailing out interactions between involved players along the flexibility procurement. Necessary adaptions of this generic process for flexibility procurement to specific demo sites of FLEXI-GRIDs are also proposed.

This deliverable creates a bottom-line to link different tasks of WP3, including T3.1, T3.2, and T3.4, together, as illustrated in the following Figure 5-1. Please note that there is a direct connection of this T3.3 to the on-going development in T2.3 of WP2 (which will be finalized 12 months later).

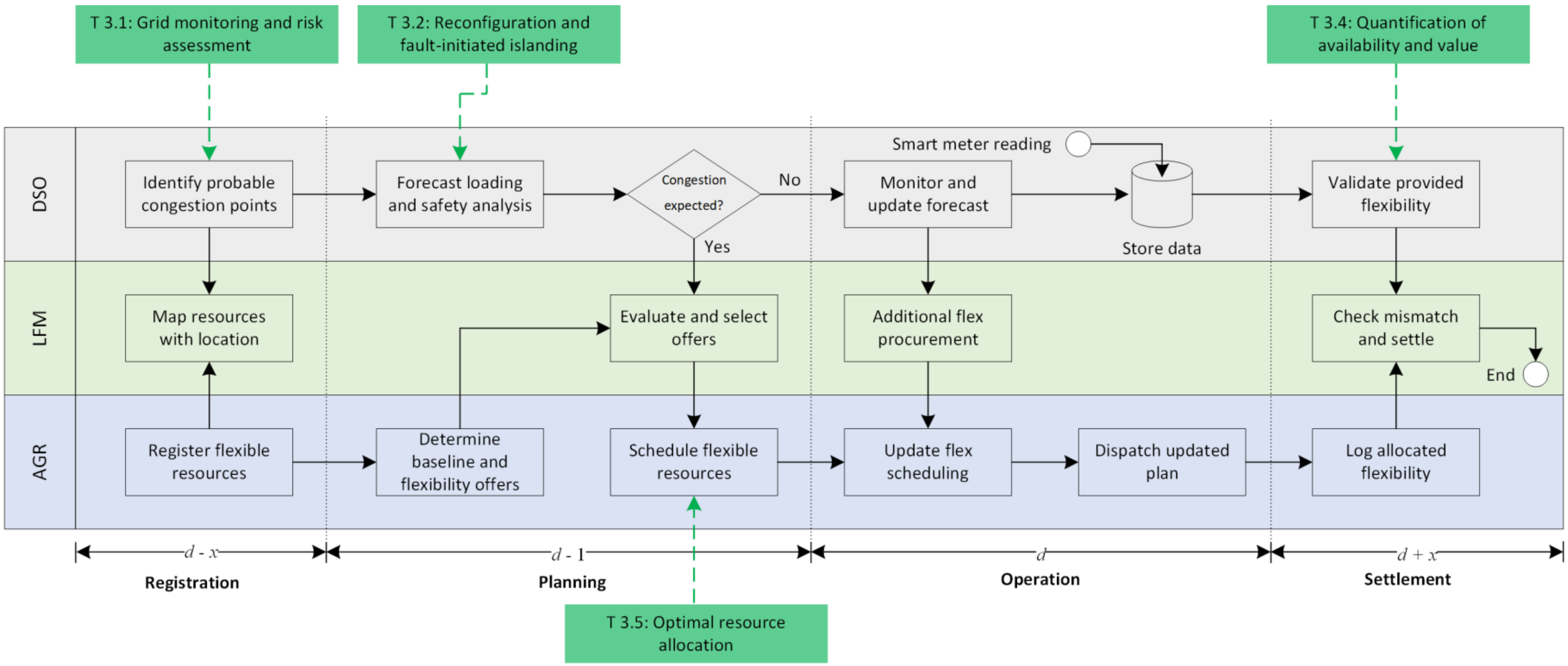

Figure 5-1: Connections from different tasks from WP3 to the generic process flow.

References

[1] X. Jin, Y. Mu, H. Jia, J. Wu, X. Xu, and X. Yu, “Optimal day-ahead scheduling of integrated urban energy systems,” *Appl. Energy*, 2016.

[2] X. Jin, Q. Wu, and H. Jia, “Local flexibility markets: Literature review on concepts, models and clearing methods,” *Appl. Energy*, vol. 261, no. August 2019, p. 114387, 2020.

[3] Y. Lei *et al.*, “A new reliability assessment approach for integrated energy systems: Using hierarchical decoupling optimization framework and impact-increment based state enumeration method,” *Appl. Energy*, 2018.

[4] J. Hu, G. Yang, H. W. Bindner, and Y. Xue, “Application of Network-Constrained Transactive Control to Electric Vehicle Charging for Secure Grid Operation,” *IEEE Trans. Sustain. Energy*, 2017.

[5] L. Thomas, Y. Zhou, C. Long, J. Wu, and N. Jenkins, “A general form of smart contract for decentralized energy systems management,” *Nat. Energy*, 2019.

[6] M. Khorasany, Y. Mishra, and G. Ledwich, “Market framework for local energy trading: A review of potential designs and market clearing approaches,” *IET Generation, Transmission and Distribution*. 2018.

[7] C. Zhang, J. Wu, Y. Zhou, M. Cheng, and C. Long, “Peer-to-Peer energy trading in a Microgrid,” *Appl. Energy*, 2018.

[8] A. N. M. M. Haque, A. U. N. Ibn Saif, P. H. Nguyen, and S. S. Torbaghan, “Exploration of Dispatch Model integrating Wind Generators and Electric Vehicles,” *Appl. Energy*, vol. 183, pp. 1441–1451, 2016.

[9] European Commission, “Clean Energy For All Europeans,” Brussels, 2016.

[10] S. Minniti, N. Haque, P. Nguyen, and G. Pemen, “Local markets for flexibility trading: Key stages and enablers,” *Energies*, vol. 11, no. 11, 2018.

[11] A. Fleischhacker, G. Lettner, D. Schwabeneder, and H. Auer, “Portfolio optimization of energy communities to meet reductions in costs and emissions,” *Energy*, vol. 173, pp. 1092–1105, 2019.

[12] G. Reynders, R. Amaral Lopes, A. Marszal-Pomianowska, D. Aelenei, J. Martins, and D. Saelens, “Energy flexible buildings: An evaluation of definitions and quantification methodologies applied to thermal storage,” *Energy Build.*, vol. 166, pp. 372–390, 2018.

[13] S. Schwarz, H. Flamme, G. Gurses-Tran, M. Cupelli, and A. Monti, “Agent-based Power Scheduling Framework for Interconnected Local Energy Communities Incorporating DSO Objectives,” in *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*, 2019, pp. 6642–6648.

[14] W. Richland, “Gridwise transactive energy framework version 1.0,” 2015.

[15] L. Boscán, “Flexibility-Enabling Contracts in Electricity Markets,” 2016.

[16] S. S. Torbaghan *et al.*, “A market-based framework for demand side flexibility scheduling and dispatching,” *Sustainable Energy, Grids and Networks*. 2018.

[17] REscoop, “What local energy communities need from the Clean Energy Package,” p. 9, 2015.

[18] “Explicit and Implicit Demand-Side Flexibility,” 2016.

[19] R. Fonteijn, P. H. Nguyen, J. Morren, and J. G. Slootweg, “Demonstrating a generic four-step approach for applying flexibility for congestion management in daily operation,” *Sustain. Energy, Grids Networks*, vol. 23, p. 100378, 2020.

[20] L. Hirth and S. Glismann, “Congestion Management: From Physics to Regulatory Instruments,” *ZBW – Leibniz Inf. Cent. Econ. Kiel, Hambg.*, pp. 1–23, 2018.

[21] G. Schuitem, L. Ryan, and C. Aravena, “The Consumer’s Role in Flexible Energy Systems,” *IEEE Power Energy Mag.*, no. February, pp. 53–60, 2017.

[22] A. N. M. M. Haque, “Smart Congestion Management in Active Distribution Networks,” Eindhoven University of Technology, 2017.

[23] N. G. Paterakis, O. Erdinc, I. N. Pappi, A. G. Bakirtzis, and J. P. S. Catalao, “Coordinated Operation of a Neighborhood of Smart Households Comprising Electric Vehicles, Energy Storage and Distributed Generation,” *IEEE Trans. Smart Grid*, pp. 1–12, 2016.
[24] R. Verzijlbergh, C. Brancucci Martínez-Anido, Z. Lukszo, and L. de Vries, “Does controlled electric vehicle charging substitute cross-border transmission capacity?,” *Appl. Energy*, vol. 120, pp. 169–180, 2014.
[25] Y. Huang, C. Guo, Y. Ding, L. Wang, B. Zhu, and L. Xu, “A Multi-Period Framework for Coordinated Dispatch of Plug-in Electric Vehicles,” *Energies*, pp. 1–16, 2016.
[26] A. Zakariazadeh, O. Homaee, S. Jadid, and P. Siano, “A new approach for real time voltage control using demand response in an automated distribution system,” *Appl. Energy*, vol. 117, pp. 157–166, 2014.
[27] S. Hashemi and J. Østergaard, “Methods and Strategies for Overvoltage Prevention in LV Grids with High PV Penetration,” *IEEE Trans. Smart Grids, Under Rev.*, vol. 11, pp. 205–214, 2017.
[28] A. N. M. M. Haque, P. H. Nguyen, F. W. Bliek, and J. G. Slootweg, “Demand response for real-time congestion management incorporating dynamic thermal overloading cost,” *Sustain. Energy, Grids Networks*, 2017.
[29] L. A. Hurtado Munoz, “Uncovering Demand Flexibility in Buildings,” Eindhoven University of Technology, 2017.
[30] A. Kulmala *et al.*, “Hierarchical and distributed control concept for distribution network congestion management,” *IET Gener. Transm. Distrib.*, vol. 11, no. 3, pp. 665–675, 2017.
[31] D. I. Koukoula and N. D. Hatziargyriou, “Gossip Algorithms for Decentralized Congestion Management of Distribution Grids,” *IEEE Trans. Sustain. Energy*, vol. 7, no. 3, pp. 1071–1080, 2016.
[32] U.S. Department of Energy, “2014 Smart Grid System Report,” 2014.
[33] A. N. M. M. Haque, T. H. Vo, and P. H. Nguyen, “Distributed intelligence: Unleashing flexibilities for congestion management in smart distribution networks (Invited paper),” in *IEEE International Conference on Sustainable Energy Technologies, ICSET*, 2017, pp. 1–7.
[34] A. N. M. M. Haque, T. H. Vo, P. H. Nguyen, J. G. Slootweg, and F. W. Bliek, “Smart real-time multi-node congestion management in active distribution networks,” in *IEEE Power and Energy Society General Meeting*, 2018, vol. 2018-Janua.
[35] P. Palensky and D. Dietrich, “Demand side management: Demand response, intelligent energy systems, and smart loads,” *IEEE Trans. Ind. Informatics*, vol. 7, no. 3, pp. 381–388, 2011.
[36] T. Haider, O. H. See, and W. Elmenreich, “A review of residential demand response of smart grid,” *Renew. Sustain. Energy Rev.*, vol. 59, pp. 166–178, 2016.
[37] N. Venkatesan, J. Solanki, and S. K. Solanki, “Residential Demand Response model and impact on voltage profile and losses of an electric distribution network,” *Appl. Energy*, vol. 96, pp. 84–91, 2012.
[38] A. N. M. M. Haque, D. S. Shafiullah, P. H. Nguyen, and F. W. Bliek, “Real-Time Congestion Management in Active Distribution Network based on Dynamic Thermal Overloading Cost,” in *2016 Power Systems Computation Conference (PSCC)*, 2016, pp. 1–7.
[39] M. Nikzad and B. Mozafari, “Reliability assessment of incentive- and priced-based demand response programs in restructured power systems,” *Int. J. Electr. Power Energy Syst.*, vol. 56, pp. 83–96, 2014.
[40] B. Qela and H. T. Mouftah, “Peak load curtailment in a smart grid via fuzzy system approach,” *IEEE Trans. Smart Grid*, vol. 5, no. 2, pp. 761–768, 2014.
[41] H. P. Simão *et al.*, “A robust solution to the load curtailment problem,” *IEEE Trans. Smart Grid*, vol. 4, no. 4, pp. 2209–2219, 2013.
[42] A. Arief, M. B. Nappu, Z. Y. Dong, and M. Arief, “Load curtailment strategy in distribution network with dispersed generations,” in *Universities Power Engineering Conference (AUPEC)*, 2011, pp. 1–6.
[43] A. Ahmadi and Y. Alinejad-Beromi, “A new integer-value modeling of optimal load shedding to prevent voltage instability,” *Int. J. Electr. Power Energy Syst.*, vol. 65, pp. 210–219, 2015.

[44] I. Bilibin and F. Capitanescu, “Contributions to thermal constraints management in radial active distribution systems,” *Electr. Power Syst. Res.*, vol. 111, pp. 169–176, Jun. 2014.
[45] A. N. M. M. Haque, T. Rahman, P. H. Nguyen, and F. W. Bliek, “Smart Curtailment for Congestion Management in LV Distribution Network,” in *IEEE PES General Meeting*, 2016, pp. 1–5.
[46] N. Etherden and M. H. J. Bollen, “Overload and overvoltage in low-voltage and medium-voltage networks due to renewable energy – some illustrative case studies,” *Electr. Power Syst. Res.*, vol. 114, pp. 39–48, Sep. 2014.
[47] R. Tonkoski and L. A. C. Lopes, “Impact of active power curtailment on overvoltage prevention and energy production of PV inverters connected to low voltage residential feeders,” *Renew. Energy*, vol. 36, no. 12, pp. 3566–3574, Dec. 2011.
[48] T. Sansawatt, L. F. Ochoa, and G. P. Harrison, “Smart Decentralized Control of DG for Voltage and Thermal Constraint Management,” *IEEE Trans. Power Syst.*, vol. 27, no. 3, pp. 1637–1645, Aug. 2012.
[49] Eurelectric, “Active Distribution System Management A key tool for the smooth integration,” 2013.
[50] M. J. Fell, D. Shipworth, G. M. Huebner, and C. A. Elwell, “Public acceptability of domestic demand-side response in Great Britain: The role of automation and direct load control,” *Energy Res. Soc. Sci.*, vol. 9, pp. 72–84, 2015.
[51] K. Stenner, E. R. Frederiks, E. V. Hobman, and S. Cook, “Willingness to participate in direct load control: The role of consumer distrust,” *Appl. Energy*, vol. 189, pp. 76–88, 2017.
[52] A. Arteconi, D. Patteeuw, K. Bruninx, E. Delarue, W. D’haeseleer, and L. Helsen, “Active demand response with electric heating systems: Impact of market penetration,” *Appl. Energy*, vol. 177, pp. 636–648, 2016.
[53] Smart Energy Europe, “SmartEn Position Paper - Design Principles for (Local) Markets for Electricity System Services,” no. September. 2019.
[54] “projekt-enera.de,” 2020. .
[55] NODES, “White Paper - NODES -A fully integrated marketplace for flexibility.”
[56] M. van den Berge, M. Broekmans, B. Derksen, A. Papanikolaou, and C. Malavazos, “Flexibility provision in the Smart Grid era using USEF and OS4ES,” in *2016 IEEE International Energy Conference (ENERGYCON)*, 2016, pp. 1–6.
[57] “Universal Smart Energy Framework,” 2020. [Online]. Available: https://www.usef.energy/. [Accessed: 07-Oct-2020].
[58] “NODES Marketplace,” 2020. [Online]. Available: https://nodesmarket.com/. [Accessed: 07-Oct-2020].
[59] Eurelectric, “Flexibility and Aggregation - Requirements for their interaction in the market,” 2014.
[60] Europex, “A market-based approach to local flexibility – design principles. Position paper,” Brussels, 2020.
[61] R. (et al. . HAFNER and European Commission, *Do current regulatory frameworks in the EU support innovation and security of supply in electricity and gas infrastructure ?* Brussels, 2018.
[62] A. Haque, M. Nijhuis, G. Ye, P. Nguyen, F. Bliek, and J. Slootweg, “Integrating Direct and Indirect Load Control for Congestion Management in LV Networks,” *IEEE Trans. Smart Grid*, 2017.