"Innovative Business Models for Market Uptake of Renewable Electricity unlocking the potential for flexibility in the Industrial Electricity Use"

Adapted methodology for optimal valorization of Flexible Industrial Electricity Demand

Deliverable 3.2
June 2016

IndustRE

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List of abbreviations and acronyms

ARENH	Accès régulé à l'électricité nucléaire historique
BELPEX	BELgian Power EXchange
BM	Business Model
BRP	Balancing Responsible Party
C	Capacity
CHP	Combined heat and Power
CIPU	Contract for the Injection of Production Units
CWAPE	Commision wallone pour l'Energie, Belgian regulator in Wallonia
DIP	Dual Imbalance Price
DRA	Demand Response Audit
DSMO	Demand Side Management Operator
DNO	Distribution Network Operator
DS	Dual Supplier
EC	European Commission
EDF	Electricé De France
EEG	Erneuerbare Energien Gesetz
EPEX	European Power EXchange
EU	European Union
FCR	Frequency Containment Reserve
FID	Flexibile Industrial Demand
FRR	Frequency Resoration Reserve
GME	Gestore Mercati Energetici
HTB	Haute Tension B
HV	High Voltage
N2EX	Nord Pool's UK power market
NBE	net balancing energy (NBE).
NEBEF	Notification d'Echange de Blocs d'Effacement
NRA	National Regulatory Authority
OMIP	Operador de Mercado Ibérico de Energia
OTC	Over The Counter
PP	Price Profile
R3DP	Tertiary Reserve Dynamic Profile, Belgian Reserve product
REE	Red Eléctrica de España, Spanish TSO
RR	Replacement Reserve
RTE	Réseau de Transport d'Électricité, French TSO
STOR	Short Term Operation Reserve, reserve product of the UK National Grid
SoC	State of Charge
TERNA	Italian TSO
ToU	Time of Use
TSO	Transmission system Operator
VRE	Variable Renewable Energy
VREG	Vlaamse Regulator voor Electriciteit en Gas, Belgian regulator in Flanders
VRES	Variable Renewable Energy Source

Executive Summary

The role of Flexible Industrial Demand (FID) in the energy system is recognized and supported by the EU. The Energy efficiency directive 2012/27/EC [1] is getting a number of supporting measures in place by specifying that regulators should encourage demand response to participate in the market and that network operators are not allowed to discriminate demand response providers in the context of contracting ancillary services.

In order to get industry actively involved in demand side participation, a number of questions have to be answered. This report relies on the previous analysis [2] of the regulatory context in the target countries and the most suitable business models identified, and goes a step further by giving answers to the following relevant questions: "How much and what kind of flexibility is available?", and "Is the local (country) price information available to calculate the real value of the flexibility?"

Deliverable D2.4 [2] concluded with 5 generic business models. They are: **Electricity Bill Reduction**, **System Service Provider**, **Electricity Supply Contract with off-site VRE**, **Balancing Service Contract with off-site VRE** and **Electricity Bill Reduction with on-site VRE**.

The above business model classification is general and its implementation in practice requires the definition of specific business model calculation methodologies. Therefore, 5 specific relevant business models that fit in the above classification are defined and described in detail.

Under Electricity Bill Reduction category, two specific business models are further considered: **Standard contract optimization** and **Day-ahead wholesale market optimization**. Under System Service Provider category, there is one business model of relevance: offering **Reserve capacity to TSO**. Under the umbrella of business models named Electricity Supply Contract with off-site VRE, the business model **Imbalance optimization** is further refined. Lastly, within the Electricity Bill Reduction with on-site VRE group, there is the business model **On-site VRE optimization**. In this business model category, it is assumed that the FID owner has an on-site VRE source. This business model is considered as very relevant for the FID but also challenging given the dependency on the specificities of the local framework.

This deliverable focusses on how to calculate a concrete business case for a FID owner. This requires 3 core elements: a flexibility model, a calculation method, and price information.

Collecting the required information happens by means of a Demand Response Audit (DRA) which is a generic approach for mapping flexibility of a FID. It consists of the following four

steps: identification, quantification, valorization and exploitation. The first step of the DRA is to **identify** the potential sources of flexibility on site in a non-quantitative way. The most important step during the identification is a site visit by a DRA expert. During the **quantification** step, the exact amount of flexibility per flexibility source is modelled. Once the flexibility of the relevant processes is quantified in flexibility models, the value of the flexibility can be calculated in the **valorization** phase. The results of the valorization phase may give ground for a financially attractive business case and the company may decide to **exploit** the flexibility in practice. In this report, the focus is on the quantification and valorization step of the DRA.

For most business models, the calculation method boils down to two calculations: a "reference calculation" and an "optimal calculation". In the "reference calculation", the flexibility is disabled or set to default behavior in order to calculate the energy cost without the flexibility activated. In the "optimal calculation", an optimizer is used which shapes the energy consumption profile within the constraints of the flexibility model to achieve the lowest energy cost. The difference between the calculated optimal and the reference cost is the maximal revenue which can be generated by the activation of the related flexibility.

All required information for the calculation of FID business model is brought together in an "implementation matrix", which is shown in Table 1.

The table summarizes all business cases with their viability and the regulatory framework in the target countries (●,●,●). For every business case it is indicated by means of a letter code (PP, DIP, etc.) which calculation method must be used and finally the availability of price information is indicated with another color code (▬,▬,▬). The implementation matrix shows that quite some business cases can be calculated with publicly available price information (▬). One of the most interesting and relevant business cases for the IndustRE project (On-site VRE business case), however, requires insight in the bilateral contracts between FID and VRE owner.

	Price information	BE	FR	DE	IT	ES	UK
1	TOU pricing	PP	PP	PP	PP	PP	PP
2	Day-ahead prices	PP	PP	PP	PP	PP	PP
1,2	Network charges	PP	PP	PP	PP	PP	PP
3	FC reserve prices	C	C	C	-	-	C
3	FR reserve prices	-	C/PP	C/PP	-	-	C
3	R reserve prices	C	C	C/PP	-	-	C
4	Imbalance prices	DIP	DIP	PP	DIP/PP	DIP	DIP
5	On-site VRE prices	DS	DS	DS	DS	-	DS

Legend

Code	Calculation method
PP	Price profile optimization method (energy + peak)
DS	Dual supplier optimization method (supplier + own production + peak)
DIP	Dual imbalance price optimization
C	Total costs optimization method (capacity only)
-	Business case impossible in current regulatory framework

1 Standard contract optimization
2 Day-ahead wholesale market optimization
3 Reserve capacity to TSO
4 Imbalance optimization
5 On-site VRE optimization

public price data available
bilateral price data estimates available
(bilateral) price data not available

● business case is viable in exisiting regulatory framework
● business case limited viability/restricted in current regulatory framework
● business case impossible in existing regulatory framework

Table 1 Implementation matrix - a summary of business models (BM), calculation methods, and required price information across all target countries

1 Introduction: From flexible industrial process to FID business model

The role of FID in the energy system is recognized and supported by the EU. The Energy efficiency directive 2012/27/EC [1] is getting a number of supporting measures in place by specifying that regulators should encourage demand response to participate in the market and that network operators are not allowed to discriminate demand response providers in the context of contracting ancillary services.

In order to get industry actively involved in demand side participation a number of questions have to be answered. These questions have been partly answered in other reports developed within the IndustRE project, this report will contribute to fully addressing these, as summarized below.

What is the local regulatory context? Although the guidelines of the European Commission are clear, the member states are implementing them at a different pace. An extended overview of the regulatory status and differences of FID between the IndustRE target countries are identified and documented in [2]. Recommendations to further improve market uptake are presented in [3].

Which is the most suitable business model? The organization of the electricity market involves many stakeholders, such as electricity generators with or without VRE, balancing responsible parties, transmission and distribution grid operators, etc. All these stakeholders might have a certain interest in FID which is reflected directly or indirectly in their products and tariffs. Within the IndustRE project, a first classification of possible business models has been done in [5] which has been further refined in [4] after a stakeholder consultation.

How much and what kind of flexibility is available? Everything starts with the possibility of an industrial consumer to adapt its electricity consumption profile. Depending on the kind of industrial activity, the technical installations and production process, the kind and amount of flexibility can differ. The calculation of a FID business model requires a flexibility model. The definition of a flexibility model starting from technical installation details is part of this deliverable, see Chapter 3.

How are the local (country) market conditions? Remuneration of flexibility can take place in different ways. In some cases there is an explicit contract between the FID provider and the flexibility user, while in other cases the FID owner anticipates on varying market prices in order to valorize the present flexibility. In some cases the value of flexibility can be calculated based on publicly available price data, while in other cases the value depends on a bilateral agreement between the FID provider and the beneficiary. In this deliverable, the availability of price and market information for the IndustRE target countries will be documented.

This deliverable will bring all the above information together. Figure 1 shows how the above information will be combined in a FID business model selection and calculation methodology.

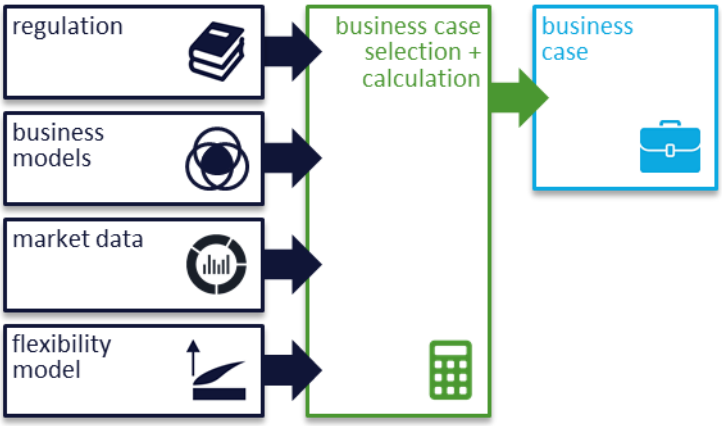

Figure 1: Top level information needed for the FID business model selection and calculation methodology.

This deliverable focuses on a methodology for the calculation of FID business models from the perspective of the FID owner/provider and is organized as follows: In Chapter 2, a top-level description of the business model calculation methodology is found. The chapter starts with a mapping of the generic business models of D2.4 [2] into more specific business models which will be worked out further in this document. The concept of flexibility models and calculation methods will be introduced followed by the implementation matrix which brings everything together. These concepts will be worked further out in the next chapters.

Chapter 3 explains the flexibility modelling part and chapter 4 explains all implemented calculation methods. Chapter 5 gives an overview of how the business models can be implemented for every target country which forms the rationale behind the implementation matrix.

It is important to mention that, while the overall focus of the project is on creating win-win situations between the European industry and the renewable energy generators, the presented methodology only focuses on cases where FID is involved. Some business models, as for example long-term electricity supply contracts between industrial electricity customer and VRE generator, will also work without the presence of flexibility. In those cases, the presented methodology cannot be applied. The other way around, however, in the cases where the valorization of the flexibility is not directly coupled with VRE, the developed methodology is easily applicable.

Offering flexibility to the electricity system can have some organizational consequences and costs. For example, slowing down (or shutting down) a production line for a couple of hours when electricity prices are extremely high might be profitable from an energy cost point of view, but might result in production loss, not optimal use of resources, like staff time and other costs which many companies call the opportunity costs. These costs vary from case to case and are difficult to generalise. The methodology presented in this document only includes the electricity related revenues and costs and does not include the opportunity costs.

2 Business model calculation methodology overview

2.1 From generic business models to specific business models

Deliverable D2.4 [2] concluded with 5 generic business models. A business model is considered as a set of flexibility business strategies which can be used by a FID owner in order to adapt its electricity consumption to generate an economic benefit. An overview of the identified business models is found in the figure below:

		Available tools		
Saving/Revenue sources		Flexible demand only	+ Contract with VRE generator	+ On-site VRE generation
Savings	Energy costs	Supplier price response; Market price response	Long-term	electricity supply
	Network and other regulated charges	Capacity network tariff response		Volumetric network tariff response
Revenues	System services	Balancing service provision; Other services provision	Bilateral balancing service provision	

Figure 2: Top level information needed for the FID business model selection and calculation methodology.

I. **Electricity Bill Reduction:** Combination of all strategies where the FID owner adjusts consumption in reaction to the entire electricity price (energy, network component and charges)
II. **System Service Provider:** Combination of electricity bill reduction and additional services to the grid.
III. **Electricity Supply Contract with off-site VRE:** Long term bilateral contract between VRE and industrial customer
IV. **Balancing Service Contract with off-site VRE:** FID owner offers balancing services in order to reduce the VRE's imbalance position.
V. **Electricity Bill Reduction with on-site VRE:** In some target countries, certain charges can be avoided in case of on-site VRE generation.

The above business model classification is general and its implementation in practice requires the definition of specific business model calculation methodologies. In this section, a number of very relevant business models that fit in the above classification will be described. The main criteria for the definition of the business models are:

- Pragmatism (reality check): Some business models suggest combinations of underlying business strategies which are possible in theory, but not applied in practice for various reasons.
- Solvability: The aim of this deliverable is the calculation of the economic value of FID. For that reason, focus is only on cases where the cost and revenue flows are sufficiently clear to define a calculation method.
- Relevance: Business models, with a high relevance for the project (FID supporting integration of VRE) are worked out even when they are not profitable or realistic yet today.

Based on the above criteria, 5 specific business models are defined, which are described below, classified under the five generic business models presented above.

I. Electricity Bill Reduction

In this business model category, two specific business models will be considered: "Standard contract optimization" and "Day-ahead wholesale market" optimization. Long term wholesale markets are not considered because the time line is not really relevant for FID.

1. Standard contract optimization

In this business model, a standard electricity contract with time of use energy price (typically peak, off-peak, weekend price) is combined with time of use network charges. Also an installed capacity of measured peak price component is included in this business model. This is a realistic business model in all target countries.

2. Day-ahead wholesale market optimization

In this business model, the dynamic price of the day-ahead wholesale market is combined with time of use network charges. Also an installed capacity or measured peak price component for network charges is included in this business model. In all target countries this is a realistic business model. It is assumed that the day-ahead prices are known when the business model is calculated. This probably overestimates the value of the FID but defines a clear upper limit of the economic value. The calculation will be performed based on historical day-ahead market prices.

II. System Service Provider

3. Reserve capacity to TSO

In principle, business model category II combines the underlying business strategies of electricity bill reduction with additional services to the system. In practice, however, most of the existing services are capacity based services with binding contractual availability. Once the FID is contractually allocated for these services, they cannot be used for additional business strategies. For that reason system services are considered without additional savings from energy cost, network and regulated charges. The most relevant system services today are associated with various forms of reserve offered to the TSO. Other services exist, but they are highly diversified over the different target countries (see [4]) and are not studied in detail in this deliverable. They will be considered *ad hoc* during the implementation of the case studies in the next stage of the IndustRE project, where relevant.

III. Electricity Supply Contract with off-site VRE

As mentioned in the introduction, this deliverable focuses on the role and value of FID. Due to the long time scale, FID has no significant influence on the financial viability of long-term electricity supply contracts between the industrial electricity customer and the VRE generator. For that reason, this business model category will not be worked out in this deliverable.

IV. Balancing Service Contract with off-site VRE

In this business model category, the FID owner supports the VRE generator in improving its imbalance position. In practice this can be done by means of a bi-lateral contract between the (VRE) generator and the FID owner: FID will be activated on demand by the generator when the size of imbalances becomes significant. However, it is very difficult to estimate how these contracts are set up technically as well as the related remuneration scheme. It is reasonable to assume that the remuneration is somehow related to the actual cost the generator has to pay for its imbalances and the historical imbalance prices are publicly available in all target countries.

4. Imbalance optimization

In this business model, the FID is used to minimize the imbalance of a certain portfolio. The official imbalance prices are used in order to calculate the economic value of the FID. It is assumed that the imbalance prices are known when the business model is calculated. This probably overestimates the value of the FID but defines a clear upper limit of the economic value. The calculation will be performed based on historical imbalance prices.

V. Electricity Bill Reduction with on-site VRE

5. On-site VRE optimization

In this business model category, it is assumed that the FID owner has an on-site VRE source. This VRE source can be the property of the FID owner or a third party. Due to the fact that the VRE source is on-site, network charges can be avoided or reduced depending on the regulatory framework of the country. Further, the industrial site has a grid connection to buy electricity from the main grid when the VRE is not producing enough electricity or sell electricity to the main grid when the VRE production is higher than the industrial site consumption. The calculation of this business model requires a good understanding of the local regulatory conditions and the impact on grid fees, taxes, charges and incentive schemes. This business model is considered as very relevant for the IndustRE project but challenging given the dependency on the specificities of the local framework.

2.2 Business model calculation

In the previous section, five specific business models were defined. This section explains the top-level approach of the business model calculation.

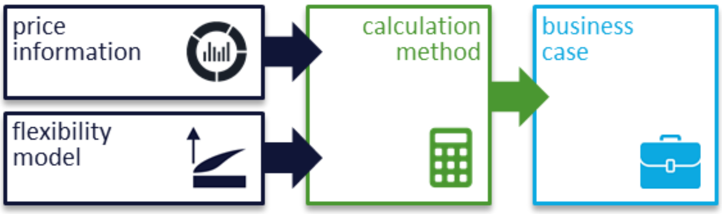

Figure 3: Top level information needed for a business model calculation.

Figure 3 shows the three core elements of the business model calculation: a flexibility model, a calculation method, and price information.

Flexibility model

Essentially, a flexibility model contains two sorts of information.

- It describes the relationship between actual industrial production characteristics and the electricity consumption. (E.g. polypropylene pelletizer runs at 10ton/h with an energy consumption of 5MWh/ton).
- It describes the constraints of the industrial production properties. (E.g. the physical limits of the pelletizer are between 5 and 10 ton/h, the overall production should be 150 ton/h, the pellet bagging machine needs a continuous influx of 8 ton/h, between the pelletizer and the bagging machine is a 50 ton storage buffer).

Once the flexibility model is in place, it can be used to calculate all different business models. Chapter 3 gives more details on the construction of flexibility models.

Calculation method

For most business models, the calculation method boils down to two calculations: a "reference price calculation" and an "optimal price calculation". During the "reference price calculation", the flexibility is disabled or set to default behavior in order to calculate the energy cost without the flexibility activated. During the “optimal price calculation” an optimizer is used which shapes the energy consumption profile within the constraints of the flexibility model to achieve the lowest energy cost. The difference between the calculated optimal cost and the reference cost is the maximal revenue which can be generated by the activation of the related flexibility.

The way in which the calculation method is implemented depends on the “business model”, on the “local market design”, and eventually also on the price information. Calculation methods are described and discussed in Chapter 4 of this document.

Price information

Activation of flexibility in FID can result in cost savings or generate extra revenue, under the condition that there is price variability. The required price information depends on the type of business model which must be calculated. A “standard contract optimization” business model requires time of use energy and network tariffs, whereas an “imbalance optimization” business model requires historical imbalance price data. Price information for business model calculation in the IndustRE target countries is collected and presented in Chapter 5 of this document.

2.3 The implementation matrix

	Price information	BE		FR		DE		IT		ES		UK	
1	TOU pricing	🟢	PP	🟡	PP	🟢	PP	🟢	PP	🟢	PP	🟡	PP
2	Day-ahead prices	🟢	PP	🟢	PP	🟡	PP	🟢	PP	🟢	PP	🟡	PP
1,2	Network charges	🟡	PP	🟡	PP	🟢	PP	🟡	PP	🟡	PP	🟢	PP
3	FC reserve prices	🟢	C	🟢	C	🟡	C	🔴	-	🔴	-	🟡	C
3	FR reserve prices	🔴	-	🟢	C/PP	🟡	C/PP	🔴	-	🔴	-	🟡	C
3	R reserve prices	🟢	C	🟢	C	🟡	C/PP	🔴	-	🔴	-	🟡	C
4	Imbalance prices	🟢	DIP	🟡	DIP	🟢	PP	🟡	DIP/PP	🟡	DIP	🔴	DIP
5	On-site VRE prices	🟢	DS	🟢	DS	🟢	DS	🟡	DS	🔴	-	🟢	DS

Legend

Code	Calculation method
PP	Price profile optimization method (energy + peak)
DS	Dual supplier optimization method (supplier + own production + peak)
DIP	Dual imbalance price optimization
C	Total costs optimization method (capacity only)
-	Business case impossible in current regulatory framework

1	Standard contract optimization
2	Day-ahead wholesale market optimization
3	Reserve capacity to TSO
4	Imbalance optimization
5	On-site VRE optimization
(green)	public price data available
(orange)	bilateral price data estimates available
(red)	(bilateral) price data not available
🟢	business case is viable in exisiting regulatory framework
🟡	business case limited viability/restricted in current regulatory framework
🔴	business case impossible in existing regulatory framework

Table 2 Implementation matrix - a summary of business models (BM), calculation methods, and required price information across all target countries

In the previous section, it was explained that the business model calculation methodology requires a flexibility model, a calculation method and price information. Where the flexibility model heavily depends on the technical installation properties of the company, it can be used in all business models for all target countries. Calculation method and price information, however, depend on the business model and the target country, so in principle a lot of combinations are possible. The “implementation matrix” in Table 2 brings all information together.

The table shows all specific business models (column 1) as they are described in section 2.1 with the required price information (column 2). The viability of the business model and the regulatory framework in the target countries is indicated with a ranking (●,●,●) which is derived from the conclusions of D2.2 [4].

Per business model and per country, it is indicated which calculation method must be used with a letter code (PP, DIP, etc). In some particular there are still business case variants which require different calculation methods (e.g. C/PP). The details of the calculation methods can be found in Chapter 4.

The implementation matrix also contains a color code indicating the availability of price information. In some cases (e.g. day-ahead, imbalance prices), price information is publicly available (▬), but in many cases prices are negotiated bilaterally between the flexibility provider and the beneficiary. This means that the exact value of the flexibility can only be calculated in cooperation with a flexibility provider which is prepared to share the price information (▬). For some common business models (e.g. TOU, reserves), the price information is in principle private information, but typical market prices are available (▬). Chapter 5 explains where the price information can be found, it explains why the availability was set to red, green or orange and it explains why a specific calculation method is selected. The organization of all data in an implementation matrix results allows to analyse potential business cases in a quick way.

Example “On-site VRE optimization”: The implementation matrix shows that this business case from regulatory point of view is allowed in BE, FR, DE and UK but not in IT and ES. The business case is calculated in the same way by means of the “Dual supplier optimization” calculation method. For Belgium, rough price information is available in order to perform the business calculation but for GE, FR and UK the price information is “hidden” in bilateral contracts. The details of these contracts are needed in order to estimate the business case value.

3 Flexibility modelling

3.1 Introduction

As mentioned in chapter 1, everything starts with the possibility of an industrial consumer to adapt its electricity consumption. The available flexibility varies depending on the kind of industrial activity, the technical installations, the production processes and the objective perceptions, preferences and requirements of the FID owner. In order to quantify the available flexibility, the technical installations and production processes need to be modelled. However, developing a flexibility model is a very complex and time consuming activity, therefore a Demand Response Audit (DRA) is carried out first to identify the high-potential processes. Hereby it is possible to reduce the flexibility modelling cycle by excluding the installations with low or no potential. In this section, the generic approach of a DRA is elaborated on; thereafter the actual flexibility modelling is discussed.

3.2 Demand Response Audit

A Demand Response Audit (DRA) is a generic approach for mapping flexibility of a FID. It consists of the following four steps:

1. Identification
2. Quantification
3. Valorization
4. Exploitation

Identification

The first step in the DRA is to **identify** the potential sources of flexibility on site. The most important step during the identification is a site visit by a DRA expert. During the site visit, the following topics typically are addressed:

- Discussion of the electricity contract(s): The value of flexibility heavily depends on the financial details in the electricity contract(s). E.g. a flat fee electricity contract doesn't generate any incentive to shift electricity consumption from one time step to another while dynamic pricing will.
- Analysis electricity consumption profile: The value of flexibility also depends on the current electricity consumption profile. The consumption profile will be analysed by means of a pattern analysis in order to identify repetitive patterns.
- Discussion/overview of the site activities and processes: Together with the energy manager and production manager, the main production processes and activities are

discussed with a focus on the amount of electricity consumption and potential flexibility in the processes.

- Discussion/overview of local electricity production facilities (e.g. CHP, Photovoltaic, wind): The presence of on-site production facilities is discussed with focus on the cost structure, constraints with a focus on the potential flexibility they can introduce on site.

The identification process results in a shortlist of processes and installations which are considered as "*relevant*" sources of flexibility for the company under audit. By "*relevant*" we mean that a financial benefit is expected by the activation of their flexibility within the existing contracts and usage patterns. The relevance is decided in a discussion between the DRA expert, energy manager and production manager. Information of the relevant installations is collected for further analysis. The identification process is visually represented in Figure 4.

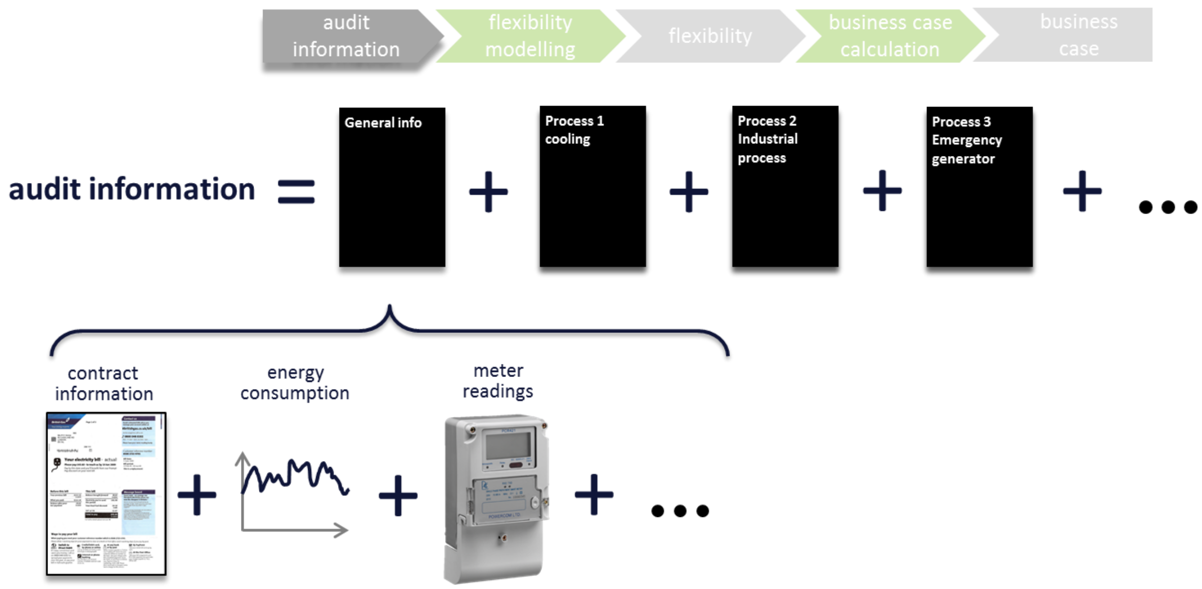

Figure 4 The first step of DRA: identification of flexible processes and their properties.

Quantification

During the identification step, the relevant processes are identified in a non-quantitative way. During the **quantification** step, the exact amount of flexibility per flexibility source is modelled. In general, the flexibility can be quantified through the following characteristics:

1. *Energy [kWh]:* the minimum/maximum energy storage capability of a unit. This doesn't have to be direct electricity storage but for intermediate bulk products can have an associated energy content as well.
2. *Power consumption [kW]:* the (modulating) minimum/maximum power consumption of the unit;
3. *Time [s]:* the time frame in which the above characteristics can be modified.

The most accurate way to quantify flexibility of a given process is to model it in detail. An approach and conceptual explanation on detailed modelling of flexible processes is further described in section 3.3.

Under certain conditions, the identified flexibility can be represented by means of flexibility graphs (or flexgraphs). Flexgraphs have a number of advantages especially when lots of different flexibility sources are present. The concept of these graphs is explained in more detail in section 3.4.

An outcome of this step is a distinction of total FID consumption into flexible and non-flexible electricity consumption of FID, as can be seen in Figure 5.

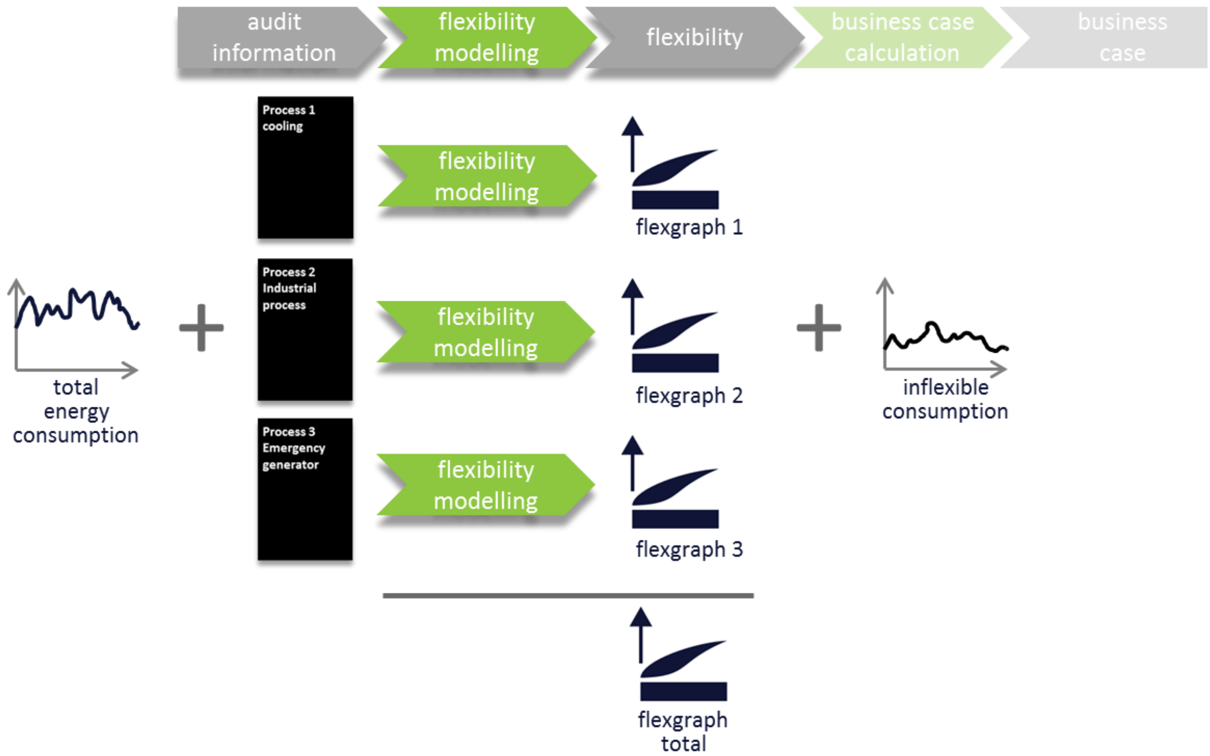

Figure 5 The second step of DRA: quantification of identified flexibility.

Valorization

Once the flexibility of the relevant processes is quantified in flexibility models, the value of the flexibility can be calculated in the **valorization** phase.

As stated in chapter 2, multiple business models are identified to exploit the available flexibility. In the valorization phase, these business models are applied to the selected processes to enable the company to select the optimal scenario for exploiting their flexibility. In order to perform this step, it is necessary to develop more detailed models of the chosen installations which we will discuss in section 0.

Exploitation

In general, the simulation results in the valorization phase may result in a financial attractive business case and the company may decide to exploit the flexibility in practice. This requires a control and decision strategy which adapts the electricity consumption of the flexible installations according to the business case goals. The exploitation complexity depends heavily on the characteristics of the installation, the details of the process and the chosen valorization scenario. A trade-off exists between this exploitation complexity and the percentage of flexibility that can be valorized. Sometimes a relatively simple solution can valorize already 80% of the flexibility, while a complex solution is needed to get the final 20% out. Therefore a trade-off between complexity and valorization percentage has to be made when choosing the final exploitation solution.

In this deliverable, the focus is on the **quantification** and **valorization** step of the DRA. Flexibility modelling is the most important and time consuming phase in the quantification step. This is further worked out in section 0. The details of the business case calculation in the valorization step will be refined in chapter 4, “Calculation methods”.

Identification of flexibility will be part of the case studies in WP4. Since the IndustRE project is focusing on business cases, there is only limited attention to the **exploitation** step in this project.

3.3 Flexibility models

Once the high-potential installations are chosen, by using the information from the DRA, further modelling is needed to enable the application of different valorization scenarios using the flexibility of the chosen production processes. Developing these detailed models of the installation is very time-consuming and is therefore generally only done for these shortlisted installations.

There are no generic techniques for development of flexibility models. In the majority of the cases, the information acquired from the DRA by interviewing the FID provider is not sufficient to develop the detailed model of the installation. Hence, it is important that the model is developed in close cooperation with the technical expert of the installation. Small subtle details which are rudimentary for the expert can have major consequences on the flexibility model and results of the applied valorization scenario.

In order to reduce the computational complexity of the optimization, the aspiration must be to keep the model as simple as possible with limited loss of accuracy. Obtaining simple but accurate models will drastically reduce the computation time of the calculation methods explained in chapter 4.

3.4 Flexgraphs

Under certain conditions, flexibility can be represented by means of a generic concept called flexgraphs. A flexible installation or process has several options in time to convert energy, e.g. consume/produce electricity. These different options can be seen as possible 'paths' within the electricity consumption/generation plane. A flexgraph is the visualization of the area between the highest and lowest path of this plane, this concept is described in [6] for thermal energy storage and applied to a fleet of electric vehicles in [7]. Figure 6 shows four generic examples of a flexgraph: the flexibility itself is indicated by the grey area, dashed lines are drawn as possible paths to cross the flexgraph. These graphs can be created based on the identification step of the DRA, e.g. the information obtained from the FID provider about the installations and processes:

- Energy consumption/production: annual electricity consumption/production
- Power consumption/production
    - Minimum/maximum power
    - Modulating options
    - Power cycle information
    - Power shifting potential
    - Ramping constraints

- Number of operating hours
- Regulating/control options

By means of the above characteristics of the installations the graphs shown in Figure 6 will be created.

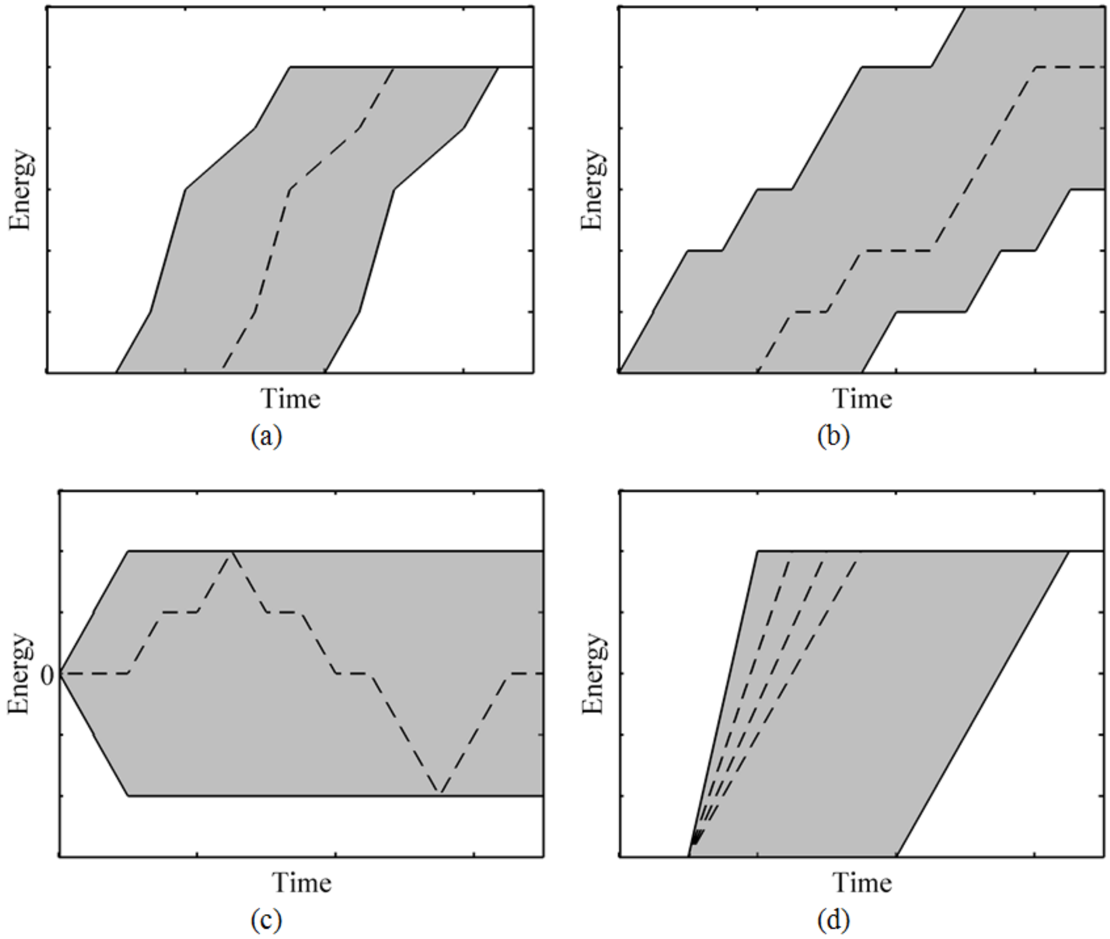

Figure 6: Four illustrative flexgraph examples, the grey area indicates the flexibility and the dashed lines indicate possible paths to cross the flexgraph. a) a shiftable unit; b) an electric hot water heater with thermal storage; c) a battery; d) a modulating unit.

The number of possible paths within the graph and the shape of the graph are installation/process specific. Figure 6(a) shows the profile of a shiftable unit which can delay or bring forward its consumption/production. Figure 6(b) shows the flexibility of an electric hot water heater with thermal storage: the power consumption of this device can be interrupted, depending on the heat demand. Figure 6(c) shows the profile of a battery: when the battery charges, its power is positive, indicated by a path going up, while when the battery discharges, its power is negative, indicated by a path going down. Figure 6(d) shows the profile of a power modulating unit: the profile has a number of possible paths with a different slope. The number of possible paths within the flexgraph is a measure for the potential to shift its consumption/production, and thus gives an indication of how much flexibility the installation offers. A unit without flexibility only has one unique path to cross the energy consumption plane, so its flexgraph is just one path. The area of the graph gives an indication of how much energy can be shifted. A flexibility profile with a large area and many paths within indicates that the device can shift a large amount of energy in a lot of different ways. The upper boundary of the graph represents the path in which the energy is consumed as soon as possible; the lower boundary of the graph represents the path in which the energy consumption is delayed as long as possible.

Figure 7 shows an applied example of a flexgraph of a battery system; the top figure represents the energy consumption/production of the battery whereas the bottom figure displays the power consumption/production. The blue and red dashed lines respectively show the lower and upper boundary of the flexibility, the green area shows the flexibility itself and the black lines show the consumption/production of electricity. The figure shows the state of the battery on a specific moment in time, namely in between 0.5 and 0.6 days. In the energy plane it is shown that, at that time, the battery can charge and/or discharge 100 kWh. The power plane shows at which power this energy can be charged and discharged. By looking at the upper and lower boundary in the graphs it is apparent that the battery can charge at 18 kW and discharge at 15 kW at this specific moment in time. Implicitly, this is also shown in the top graph by the slopes of the solid red (charge) and solid blue (discharge) lines because energy represents the integral of power over time. These two graphs point out that at each moment the flexibility depends on the state of charge (SoC) of the battery together with the minimum and maximum charge/discharge power.

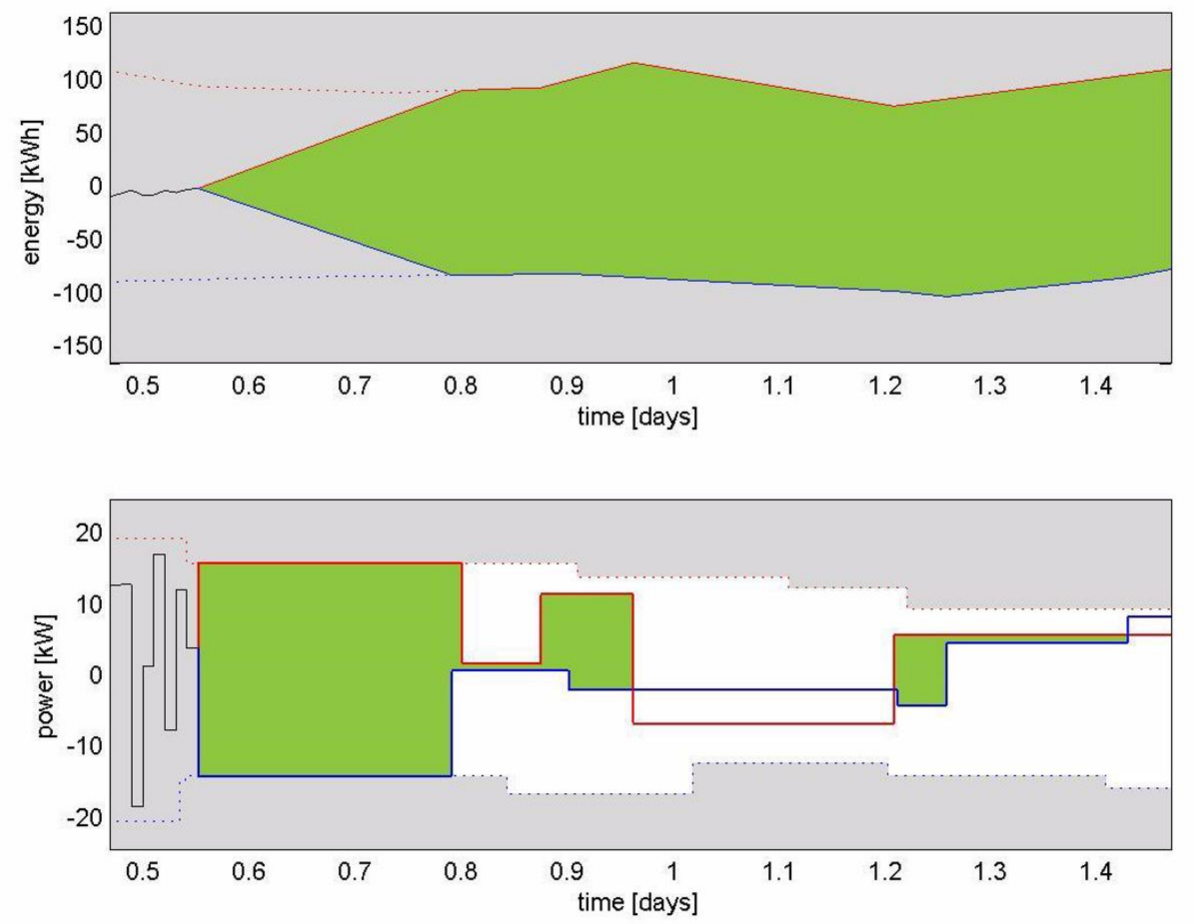

Figure 7: Flexgraph example of a battery with the energy consumption/production plane on top and the power consumption/production plane at the bottom; Dashed blue line is the lower boundary of the flexibility, dashed red line is the upper boundary of the flexibility

The flexgraph is a generic concept independent from the type of installation; hereby it is possible to aggregate multiple flexgraphs originating from different types of installations resulting in the overall flexgraph of a device cluster. This is illustrated in Figure 8, where the flexgraphs of two individual installations (light grey) are aggregated and their resulting total flexibility is represented by the flexgraph coloured in dark grey.

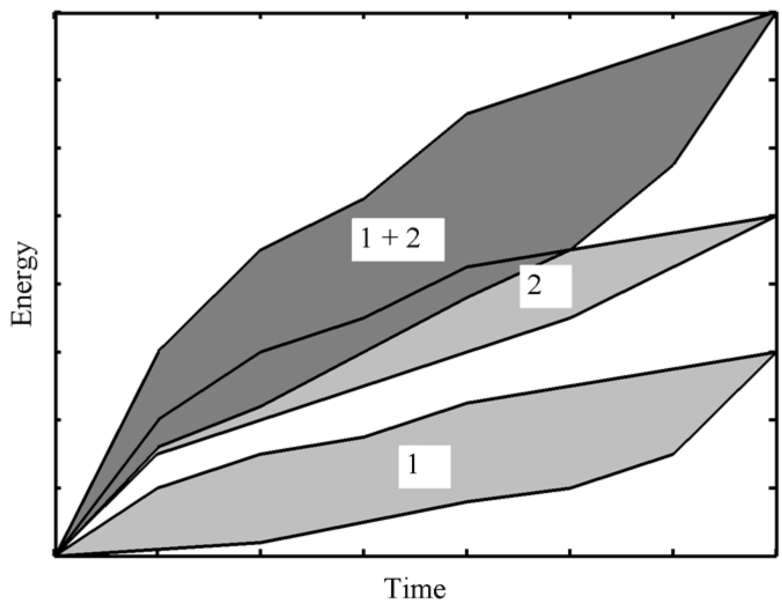

Figure 8: Aggregation of two flexgraphs, the dark grey area is the sum of the two light grey areas

The main advantages of using flexgraphs are *(i)* the simplified quantification of flexibility, *(ii)* the ease of aggregation, and *(iii)* the abstraction of specific information related to processes/installations. That is why this concept can be used to identify the high-potential flexible installations during the quantification step of the DRA.

4 Calculation methods

In this section, the developed and implemented calculation methods to find the economic value of flexibility are described in more detail. All the calculation methods are developed so that they can easily be applied to different flexible processes, i.e., so that they can easily incorporate different flexibility models, some of which were explained in the previous chapter.

4.1 Definition of a calculation method

The approach to quantify the value of flexibility in different business models is, for the majority of business models, based on optimization techniques.

Figure 9: Representation of the flexible power consumption by FID.

A representation of a flexibility model, i.e., of the flexible power consumption by flexible industrial demand (FID) is given in Figure 9. A flexibility model is, in broadest definition, a set of constraints describing the industrial process. The input electricity power *p(t)* is the variable power that can be adapted within the flexibility model constraints to achieve a given goal. In other words, based on such a flexibility model, it is possible to change/adapt the power consumption of the FID in order to optimize the energy costs according to a certain goal defined by the business model.

The result of the calculation method is the value of flexibility of a given flexible industrial demand process. This value is obtained as the difference of the optimal case and business-as-usual case. In the optimal case, the flexibility is optimally utilized, and in the business-as-usual case, the FID operated under the nominally scheduled consumption pattern, and no flexibility is employed.

An optimization procedure in the calculation method is defined by the cost function, input data and/or input parameters, and additionally by the constraints. Input data typically varies over time (e.g. temperature, price, production numbers…), parameters are typically fixed for a specific installation (e.g. electricity consumption factor kWh/ton, ramp-up rate…), and constraints typically describe operational limits (e.g. maximum production rate, minimum production levels…) of the flexible process.

The flexible industrial demand process is described by a set of constraints that describe its flexibility model, as discussed in chapter 3. Selection of the business model defines the cost function and the necessary input data. To capture the business models defined in task 2.4, the following calculation methods are developed:

Code	Calculation method
PP	Price profile optimization method
DS	Dual supplier optimization method
DIP	Dual imbalance price optimization
C	Capacity reservation price method

The implemented calculation methods have an abbreviation code (PP, DS, DIP and C) which will be used further in the document.

PP method is used for the following business models: Day-ahead prices, Network charges, and TOU pricing in all considered countries, DS method for On-site VRE prices DIP for imbalance prices in Spain, and finally C method for FCR and RR business models.

The developed business model calculation method as presented here utilizes different input time series. The input data can for instance be a price profile for a certain product, or the realized production of VRES. Data availability and sources are discussed in detail in chapter 5. Depending on this data input, different flexibility values can be obtained. In this work package, there are two relevant assumptions made. Firstly, the price profiles are assumed to be known in advance. Secondly, the provider of flexibility (FID) is assumed to be of such a size in the overall market that its individual actions do not have an impact on the market price, i.e. it acts as a price taker and not a price maker. Under these assumptions, the obtained flexibility value from the calculation method is the best case value, and provides the upper bound on the maximal achievable flexibility value for the given business model.

4.2 PP Method: Price profile calculation method (energy + peak)

In the PP method, the energy consumption is optimized over a given time horizon *T* so that the energy costs are minimized for the given price profile and flexibility model. Energy consumption could be priced based on:

(a) a peak over a well-defined period of time (day, week, month, year), e.g. as in Network charges business model, or

(b) an hourly energy price, e.g. in Day-ahead prices business model, or

(c) a combination of the two.

Therefore, the cost function *J* of this optimization method is defined as the combination of the two cost terms:

$$J = \lambda_C |p(t)|_\infty + \sum_{t=1}^{T} \lambda_E(t) p(t) t^{res}, \quad (1)$$

Where

- $p(t)$ [MW] is the power consumption of the flexible process in time
- $|\cdot|_\infty$ is the $\mathcal{L}_\infty$norm, which correspond to the maximum element in the vector for the considered type of dynamic profile (time series),
- *T* is the length of the considered period of time (e.g. day, week, month, quarter of a year, year),
- t^{res} is the time resolution (e.g. one hour, half-hour etc.),
- λ_C [€/MW] is the price for consumption peak, and
- λ_E(t) [€/MWh] is the energy price over time.
- The formulation (1) includes the energy consumption peak over the total considered time horizon but it can straightforwardly be extended to including a series of peaks over the considered time horizon, e.g. 12 monthly peaks in a year. A typical ToU price optimization would result in a variable price profile in λ_C.

In this optimization problem, the power consumption of the flexible process $p(t)$ is the decision variable to be optimized, and the prices λ_C and $\lambda_E(t)$ are parameters, i.e., given inputs.

By setting the energy price to zero, i.e., by selecting $\lambda_E(t) = 0, \forall t$, the cost function reduces to

$$J = \lambda_C |p(t)|_\infty, \quad (2)$$

and the optimization can be used for minimization of the peak consumption only.

Similarly, by selecting the peak price to be zero, $\lambda_C = 0$, the objective function reduces to

$$J = \sum_{t=1}^{T} \lambda_E(t) p(t) t^{res}, \quad \textit{(3),}$$

and the calculation method can be used for energy optimization only. The choice of the price $\lambda_E(t)$ is determined by the business model. For the Day-ahead prices business model, the price will change with every time step, and for TOU, the price will be constant over several hours.

In the price profile optimization method (PP method), the cost function *(1)* is minimized subject to the constraints, which define the flexible process. As a result, the optimal power consumption profile $p^*(t)$, and the minimal cost J^* are determined, where *** symbolizes the optimal values. Next to it, costs of energy consumption over the same time horizon are calculated for the business-as-usual case. The value of flexibility can be easily deduced from the difference between these two calculated costs.

The price profile optimization method (PP method) is developed for the following business models across all considered countries: Day-ahead prices, Network charges, and TOU pricing. Next to these, this calculation method is applicable to the imbalance pricing business model in countries with single pricing system (Germany).

4.3 DS Method: Dual supplier calculation method (supplier + own production + peak)

The dual supplier optimization method is developed for the business model with two possibilities for energy supply of the flexible process: (a) energy produced elsewhere in the network, e.g., from a standard energy supplier; and (b) energy produced from a local VRE supplier with limited supply capabilities. Energy produced elsewhere in the network can be priced arbitrarily e.g., under a dynamic price profile or TOU pricing. The energy produced from a local VRE supplier is typically provided for a lower price, as the network charges are avoided.

Figure 10 shows an illustration of a FID connected to a VRES. VRES is shown in the most left side of the figure. Both FID and VRES are connected to the network via a single connection, which is in the figure represented by two energy streams, p_2 and p_3.[1] Energy flow p_2 represents the energy bought from the network for supplying the FID. Locally produced energy from VRES can either be directly consumed by any part of FID process (p_5), or can be injected in the network (p_3).

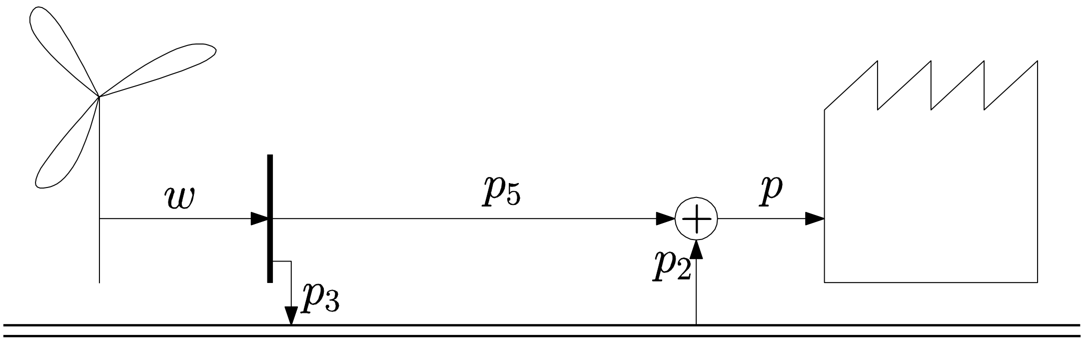

Figure 10 Illustration to define the Dual supplier business model calculation method

For the calculation of this business model, it is assumed that the following information is available over the considered time horizon:

- wind energy production of the locally available VRES *w(t),*

[1] Note that this is an artificial split of a physical signal into two always positive powers, where at any time instance, at least one of the two power streams is 0. This distinction will prove useful later in the computation method.

- price for VRES energy if locally consumed, $\lambda_W(t)$
- price for energy from a standard supplier $\lambda_E(t)$
- required energy for the FID process that can be adjusted/optimized, *p(t),*
- and possibly, price for injecting the VRES energy to the network (energy not locally consumed), $\lambda_S(t)$.

With the convention as in Figure 10, the required energy for the FID process that can be adjusted/optimized, *p(t)* is defined by

$$p(t) = w(t) - p_3(t) + p_2(t), \qquad (4)$$

where $p_3(t)$ represents the locally produced energy exported to the network, and $\mathrm{p}_2(\mathrm{t})$ the energy bought from the standard supplier.

The energy costs that are optimized in this calculation method are defined as

$$J = \sum_{t=1}^{T} \lambda_W(t)p_5(t) + \lambda_E(t)p_2(t) - \lambda_S(t)p_3(t) \ . \qquad (5)$$

In addition to the constraints describing the flexibility model, next to the definition of *p(t)* from equation (4), the following constraint has to be satisfied in the optimization problem:

$$w(t) = p_5(t) + p_3(t) \qquad (6)$$

In the dual supplier optimization method, the cost function (5) is minimized subject to the constraints that define the flexible process, and subject to (6)-(7). As a result, the optimal energy consumption profile $p^*(t)$, and the minimal cost J^* are found. Next to it, costs of energy consumption over the same time horizon are calculated for the business-as-usual case, with the presence of an on-site VRES, but without employing of flexibility from FID process. The value of flexibility is easily deduced from the difference of these two calculated costs.

The DS method is applicable for the business model On-site VRES.

4.4 DIP Method: Dual imbalance price calculation

In the dual imbalance price calculation method, flexibility from FID is utilized to correct the real-time imbalance in countries in which the dual imbalance price system is implemented. In dual imbalance pricing, different imbalance prices are applied to a balance responsible party (BRP) having positive and negative imbalances in a considered imbalance settlement period, depending on the sign of the system imbalance and the sign of the BRP imbalance. This BRP could be the FID itself (in case it is large enough to directly participate in the market and not through a supplier) or a different portfolio. In both cases, the historic imbalance prices and volumes will be used, as these prices will be reflected in the prices the FID gets either from the system operator or from the flexibility beneficiary party.

To calculate the flexibility value in this business model, the following assumptions are made:

1. Energy position of FID as a result of trading in day-ahead markets, the so-called base-line position, is known and fixed.
2. Energy position of FID within each imbalance settlement period, compared to its base-line position based on the day-ahead or intra-day market trading, is known in real time.
3. System net imbalance and system imbalance prices are known at the moment of calculation.
4. FID volumes are sufficiently small so that influence on the settled imbalance prices due to activation of FID can be neglected. In other words, FID is a price taker.

The first two assumptions are needed to create appropriate input data for the calculation method. Same as for the other business models, such assumptions have as a consequence that the obtained flexibility value is only the upper bound of the real flexibility value.

In this business case, the goal is to steer FID optimally so that when the system imbalance is positive (the system is long), it increases the nominal electricity consumption, and when the system imbalance is negative (the system is short), it decreases the nominal electricity consumption. To simplify the notation, we introduce the following two synthetic signals $p_{\mathrm{IMB}}(t)$ for the imbalance volumes, and $\lambda_{\mathrm{IMB}}(t)$ for the imbalance prices. These signals are based on the publicly available imbalance information for positive and negative net imbalance volumes p_{IMB}^{+}, p_{IMB}^{-} and the settled positive and negative imbalance prices, λ_{IMB}^{+}, λ_{IMB}^{-}:

$$p_{IMB}(t) \triangleq \begin{cases} p_{IMB}^{+}(t), & if\ p_{IMB}^{+}(t) \geq 0,\ p_{IMB}^{-}(t) = 0, \\ p_{IMB}^{-}(t), & if\ p_{IMB}^{-}(t) \leq 0,\ p_{IMB}^{+}(t) = 0. \end{cases} \tag{7}$$

$$\lambda_{IMB}(t) \triangleq \begin{cases} \lambda_{IMB}^{+}(t), & if\ p_{IMB}(t) \geq 0, \\ \lambda_{IMB}^{-}(t), & if\ p_{IMB}(t) \leq 0. \end{cases} \quad (8)$$

The sign of the synthetic price signal $\lambda_{\mathrm{IMB}}(t)$ is chosen in such a way that it is positive if the money flow goes from the flexibility beneficiary to FID, and negative otherwise.

With the definitions introduced in (8) and (9), it is now possible to define the objective function of the optimization method for optimal utilization of FID as

$$J = \sum_{t=1}^{T} \lambda_{IMB}(t)\big(p(t) - p'(t)\big) + \sum_{t=1}^{T} \lambda_{E}(t) p'(t), \quad (9)$$

Where $p'(t)$ represents the base-line position (the electricity consumption of the FID that is traded on ahead markets and is a combined result of all day-ahead markets, e.g., day-ahead, intra-day, long term markets), and $p(t)$ is the corrected electricity consumption that is a result of providing FID for solving the (portfolio) balancing problem in real time. Similarly as in the previously defined methods, in this method, the goal is to optimize $p(t)$.

According to the assumption 1 of the method, $p'(t)$ and also $\lambda_{\mathrm{E}}(t)$ are known and fixed, so the terms of the cost function (10) related to these constants have no influence on the optimal value of $p(t)$. Hence, instead of writing objective function (10), one could write

$$J = \sum_{t=1}^{T} \lambda_{IMB}(t) p(t), \quad (10)$$

with the same definitions as above.

This objective function is to be optimized subject to the flexibility model constraints, and additionally to the following constraint

$$p(t) - p'(t) \leq p_{IMB}(t). \quad (11)$$

This constraint expresses that the adaptation in the FID consumption should not exceed the size of the observed (system or portfolio) imbalance.

Similarly as in the previous business models, the value of flexibility is easily deduced from the difference between the optimal and business-as-usual computed costs.

The price dual imbalance price calculation method (DIP method) is developed for the following business models across all considered countries: Imbalance pricing in countries with dual pricing system (Belgium, France, Italy, Spain, UK).

4.5 C Method: Capacity reservation price

The capacity reservation price method (C method) is developed to compute the benefits of providing system balancing reserves, and concerns the business models FCR and RR.

As the first step of the method, an amount of capacity $p(t)$ that can be made available to the system is determined from the flexibility model. This amount of capacity can vary in time over the considered time horizon. Next, from this volume, and from the either historical or contracted reserve prices $\lambda_{\mathrm{RES}}(\mathrm{t})$, which are known input parameters to the method, the value of flexibility over the considered time horizon is found as

$$\sum_t p(t)\lambda_{RES}(t). \qquad (12)$$

Although the calculation method itself is straightforward, the difficulty lies in determining the volume of capacity that can be offered. Moreover, the terms and conditions of reserve provision are typically the main factors determining the business model. FID processes with a shiftable/sheddable process that is almost always turned on or almost always turned off are expected to achieve the highest benefits from this business model.

This method is applicable for many reserves business models FCR, FRR and RR.

5 Business model implementation

The implementation matrix of the business calculation methodology was introduced in Table 2. This matrix gives an overview of how the different calculation methods, described in the previous chapter, are mapped to the business models in the target countries. The implementation matrix also indicates the availability of relevant price and/or additional economic data by means of a green, orange and red color coding. This chapter explains the rationale of the choices presented in the implementation matrix. For the sake of clarity for the reader, the implementation matrix is repeated below, followed by the country rationale in the next sections.

	Price information	BE	FR	DE	IT	ES	UK
1	TOU pricing	● PP	● PP	● PP	● PP	● PP	● PP
2	Day-ahead prices	● PP	● PP	● PP	● PP	● PP	● PP
1,2	Network charges	● PP	● PP	● PP	● PP	● PP	● PP
3	FC reserve prices	● C	● C	● C	● -	● -	● C
3	FR reserve prices	● -	● C/PP	● C/PP	● -	● -	● C
3	R reserve prices	● C	● C	● C/PP	● -	● -	● C
4	Imbalance prices	● DIP	● DIP	● PP	● DIP/PP	● DIP	● DIP
5	On-site VRE prices	● DS	● DS	● DS	● DS	● -	● DS

Legend

Code	Calculation method
PP	Price profile optimization method (energy + peak)
DS	Dual supplier optimization method (supplier + own production + peak)
DIP	Dual imbalance price optimization
C	Total costs optimization method (capacity only)
-	Business case impossible in current regulatory framework

1 Standard contract optimization
2 Day-ahead wholesale market optimization
3 Reserve capacity to TSO
4 Imbalance optimization
5 On-site VRE optimization

public price data available
bilateral price data estimates available
(bilateral) price data not available

● business case is viable in exisiting regulatory framework
● business case limited viability/restricted in current regulatory framework
● business case impossible in existing regulatory framework

5.1 *Standard contract optimization*

Standard contract optimization entails the generation of profit from flexible energy tariffs and the reduction of grid utilization costs. The former targets the commodity price element of energy costs, i.e. the price per kWh consumed in a certain period. In several countries, time-dependent energy tariffs (TOU) are already being offered for business consumers. For the decrease of network charges the focus is placed on the charge for grid usage by the system operators, i.e. the capacity remuneration. Systematically reducing maximum load by shaving off load peaks leads to savings in the capacity price. In order to calculate the value of the flexibility, it is more important to know the price differences between the different time zones (e.g. difference between day and night tariffs) than the average price.

Belgium

Price availability : For the commodity price element within this business model, time-differentiating energy prices (e.g. TOU, day, night, peak) are typically negotiated with the supplier and are not publically available. Average electricity prices can be found on the Eurostat website[2]. The industrial customers are categorized in 7 energy bands from <20MWh to >150GWh. More detailed information on the Belgian electricity tariffs for industrial consumers can be found in the report from the federal regulator [3].

Transmission and distribution network charges are publically consultable. Transmission grid fees available via the Elia website, the Belgian TSO [4]. Distribution grid fees are subjected to regional differences and can be accessed through the relevant regional regulator, i.e, VREG for Flanders [5], CWAPE for Wallonia [6] and Brugel for the Brussels Capital Region [7].

Calculation method **PP**: For the elaboration of the standard electricity contract optimization the price profile calculation method is applicable. Grid fees are calculated based on the subscribed capacity. Herewith, reference is made to the capacity made available, determined on the basis of the maximum power quarter-hourly recorded, consumed over

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[2] http://appsso.eurostat.ec.europa.eu/nui/show.do

[3] http://www.creg.info/pdf/Studies/F1453NL.pdf.

[4] http://www.elia.be/en/products-and-services/access/access-tariffs

[5] http://www.vreg.be/nl/distributienettarief

[6] http://www.cwape.be/?dir=7.3.2

[7] http://www.brugel.be/nl//distributietarieven/de-distributietarieven-2015-2019

the last 12 months, including the billing month. The calculation can be performed with the price profile method by setting the energy price to 0 and only optimizing on the peak component reduction.

France

Price availability: Time-differentiating prices are in principle negotiated with the supplier and are not public information. France has a long tradition of integral regulated tariffs for different types of consumers. Depending on the connection capacity, grid users are classified into three categories (i.e. Blue tariff P < 36 kVA, Yellow tariff 36 kVA < P < 250 kVA and the Green tariff p > 250 kVA). By the end of 2015, the regulated Green and Yellow tariffs were phased out thus the relevant grid users are offered time varying prices by suppliers.

Although the consumers with a grid capacity exceeding 36 kVA are obliged to enter the liberalized electricity market, large industrial consumers have the possibility to purchase part of their electricity under the ARENH mechanism[8]. The regulated ARENH price, frequently under the market price, is set by the government for baseload nuclear electricity generated by EDF and sold to alternative suppliers. In 2012 the government has set the ARENH price at 42 €/MWh and it has not been changed since.

Furthermore, average electricity prices can be found on the Eurostat website[9], but no price differences are available.

The grid tariffs applicable in France are rather complex but the methodology to calculate them is publically described. There is time differentiation with 5 temporal classes for voltages lower than 350 kV. Three kinds of differentiation exist: summer/winter, mid-peak/off-peak, and peak hours only in January, February and December. Tariff for higher voltages remains only based on usage duration.

The tariff relating to the highest voltage levels (HTB, V ≥ 50 kV), or the public electricity transmission user tariff, "TURPE 4 HTB", came into force on 1st August 2013 and is applicable for a period of 4 years[10].

[8] https://clients.rte-france.com/lang/an/clients_producteurs/services_clients/dispositif_arenh.jsp

[9] http://appsso.eurostat.ec.europa.eu/nui/show.do

[10] https://clients.rte-france.com/lang/an/clients_producteurs/services_clients/tarif.jsp

The French government introduced a reduction of 50% in transmission costs for those consumers whose energy rate was larger than 10 GW/h and their consumption overtakes the 7000 hours/year.

The transmission tariff for HV consumers (TURPE 4 HTB) is composed by a capacity charge and time differentiation for the volumetric charge but it is unlikely that it provides a sound incentive for peak load reduction as it accounts for a small share of the final electricity price for this consumer group. Small industries may expect more benefits from adapting their consumption profile to reduce their transmission charge.

Calculation method **PP**: For the standard optimization of the electricity contract a price profile calculation methodology suffices.

Germany

Price availability : Electricity prices are not regulated, but in principle negotiated. These bilaterally agreed tariffs are not published. Whether and to what extent time-differentiating prices (TOU/day/night/peak) are offered depends on the supplier and the concrete negotiations. Depending on the supplier, several different products may exist, possibly even down to hourly tariffs. Latest information on the average electricity prices charged to industrial consumers can be found on the VEA website[11]. An overview over the electricity prices on the spot market, their development and "typical" time-differentiating prices can be found on the EPEX website[12]. It can be stated that the prices on the day-ahead market no longer fluctuate that much, the difference between rush hour and off-peak is maximally 10 EUR/MWh. Furthermore weekend prices are approximately 20 EUR/MWh lower than the market price on weekdays.

Concerning the network charges, German law provides that grid operators have to offer reduced network charges in case the peak demand of a consumer differs in a predictable manner and at a significantly different moment in time compared to the average annual peak demand of all consumers connected to the grid. In such cases, it is assumed that the consumer can contribute to the grid stability. Lowering such peak demand is not required. However, the demand must differ by at least 30% in the low voltage, 20% in medium voltage and 10% in high voltage, with a minimum of 100kW. The network charges may then be reduced up to 80%.

[11] http://www.vea.de/leistungen/vea-strom-gaspreisindex/

[12] https://www.epexspot.com/de/marktdaten/dayaheadauktion

Network charges for both the transmission[13] and distribution[14] grid are public information. However, what the industrial consumer actually pays – under the pretext of having applied for reductions – depends on several factors (consumption, location,…).

Calculation method **PP**: For the German market, a price profile optimization methodology is designated. With this calculation strategy an energy price optimization is implemented, including a peak over a well-defined period of time.

Italy

Price availability : Large energy consumers enter the liberalized market to engage into an energy contract with a supplier based on flat rates, TOU tariffs or more dynamic offers. An indication of average electricity prices can be found on the Eurostat website[15].

Transmission and distribution grid fees are regulated[16] and public information. The grid fees for each type of consumer are available via the SET website[17].

Calculation method **PP**: In order to perform an optimization of the relevant electricity contract, a price profile calculation method will be used.

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[13] Amprion: http://www.amprion.net/sites/default/files/pdf/Entgelte%20Amprion%202015%20deutsche%20Version.pdf

TenneT: http://www.tennet.eu/de/fileadmin/downloads/Kunden/Netzentgelte/141211_TenneT_Netzentgelte_fuer_2015_Deutsch.pdf

50Hertz: http://www.50hertz.com/Portals/3/Content/Dokumente/Anschluss-Zugang/Netzzugang/Netznutzung/141204_Preisblatt%202015_final.pdf

Transnet: https://www.transnetbw.de/downloads/netzzugang/entgelt/Preise_Netznutzung_2015.pdf?v2.

[14] Westnetz: http://www.westnetz.de/web/cms/mediablob/de/2290308/data/1625968/9/westnetz/netz-strom/netzentgelte/preisblaetter-2015/Netznutzungspreise-gueltig-vom-01.01.15-bis-31.12.15-.pdf

WEMAG: http://www.wemag-netz.de/export/sites/wemagnetz/entgelte/Preisblaetter_2015_141015.pdf.

Bayernwerk: https://www.bayernwerk.de/cps/rde/xchg/bayernwerk/hs.xsl/5710.htm

[15] http://appsso.eurostat.ec.europa.eu/nui/show.do

[16] http://www.autorita.energia.it/allegati/docs/11/199-11TITnew.pdf

[17] http://www.set.tn.it/content/tariffe-per-i-servizi-di-trasmissione-distribuzione-e-misura-dell-energia-elettrica

Spain

Price availability : Time differentiating prices are typically negotiated with the supplier and are not public information. An indication of average electricity prices can be found on the Eurostat website[18].

Regarding network fees, the so-called "access tariffs" in Spain have a higher impact on the final price of small electricity consumers than for large industrial consumers. Hence, there is a lower incentive for adjusting contracted power or time of consumption in relation to this access tariff.

The specific values of the access tariffs for each year are calculated based on the annual allowed revenue of transmission and distribution activities plus the addition of other regulated costs. Those for 2015 are established in the Order IET/2444/2014, of 19th December[19].

The final access tariff is made up of three types of charges: a capacity charge, an energy charge and a reactive energy charge. The values for the energy and the capacity charges for 2015 can be consulted via the websites of the different energy companies, e.g. Iberdrola[20].

Calculation method **PP**: For the Spanish elaboration of the standard electricity contract optimization the price profile calculation method is applicable.

United Kingdom

Price availability : Concerning energy prices, average prices per I&C customer for electricity are given by Department of Energy and Climate Change[21]. All I&C with half hour metering power contracts are privately negotiated between supplier and customer.

Transmission charges are charged based on the 3 highest demand periods of the years[22]. They vary regionally. Distribution charges are site specific and depend on voltage levels and each DNO calculates its own charges[23].

[18] http://appsso.eurostat.ec.europa.eu/nui/show.do

[19] http://www.boe.es/diario_boe/txt.php?id=BOE-A-2014-13475

[20] https://www.iberdrola.es/02sica/gc/prod/es_ES/hogares/docs/Triptico_tarifas2015.pdf

[21] https://www.gov.uk/government/statistical-data-sets/gas-and-electricity-prices-in-the-non-domestic-sector

Calculation method **PP**: In order to determine the business model for standard contract optimization a price profile optimization is the designated calculation method.

[22] http://www2.nationalgrid.com/UK/Industry-information/System-charges/Electricity-transmission/Approval-conditions/Condition-5/

[23] http://www.energynetworks.org/electricity/regulation/distribution-charging/distribution-charges-overview.html

5.2 Day-ahead wholesale market optimization

Energy exchange markets operate spot and derivatives market platforms for trading energy and energy-related products. Participants can use the different markets to buy and sell electricity on short term and/or long term. On the short term spot market, the Day-ahead market provides standardized products (hourly or multi-hourly) to sell and purchase electricity to be delivered the day after. Given a shiftable energy demand and/or a flexible electricity production, the stock market price on the short term wholesale market can be used to minimize the costs for the energy needed or to optimize the revenues from own generation.

Belgium

Price availability : Day-ahead prices of the Belpex spot market are public information. The relevant prices can be consulted via the Belpex website[24].

Calculation method **PP**: For the optimization of consumption in response to wholesale electricity prices by acceding directly to the market or through a supplier/aggregator, a price profile calculation method can be used.

France

Price availability : As already stated, electro-intensive industries can benefit from the access to electric energy at a regulated price (ARENH) which incentivizes a flat consumption profile. Wholesale electricity price data can be found via the Epex website[25].

Calculation method **PP**: With a view to invoke flexibility in function of hourly wholesale energy prices the price profile calculation method is assigned except in case a regulated fixed price (ARENH) is used. In that case there will be no business case for the use of FID.

Germany

Price availability : For an overview of the electricity prices on the spot market and the price signals in the day-ahead market the Epex website can be consulted[26].

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[24] https://www.belpex.be/

[25] https://www.epexspot.com/en/market-data

[26] https://www.epexspot.com/de/marktdaten/dayaheadauktion

Calculation method **PP**: In order to optimize towards the stock market price on the short term wholesale market a price profile calculation method will be used.

Italy

Price availability: Day-ahead GME prices are public information, available at the GME website (monthly reports)[27].

Calculation method **PP**: For the optimization towards hourly energy prices, the price profile calculation method will be used.

Spain

Price availability: Day-ahead hourly prices are available at the website of the market operator OMIE[28].

Calculation method **PP**: Analogously to the other target countries, also for the Spanish day-ahead wholesale market optimization the price profile strategy is preferred.

United Kingdom

Price availability: Within the UK market, OTC trading represents 82% of total trading and thus prices are obtained through energy brokerage platforms. The APX[29] exchange is usually associated with intraday trading, while the N2EX[30] exchange sees the bulk of Day-Ahead and future trading.

Calculation method **PP**: The price profile calculation method is designated to perform the optimization.

[27] http://www.mercatoelettrico.org/It/download/DownloadDati.aspx?val=MGP_Prezzi

[28] http://www.omie.es/files/flash/ResultadosMercado.swf

[29] https://www.apxgroup.com/market-results/apx-power-uk/dashboard/

[30] http://www.nordpoolspot.com/Market-data1/N2EX/Auction-prices/UK/Hourly/?view=table

5.3 Reserve capacity to TSO

In order to stabilize the grid frequency at 50 Hz and to be able to respond to substantial frequency deviations, TSOs are required to contract (in advance) certain volumes of reserve capacity. Both positive and negative reserve capacity is needed to be capable of compensating deviations in both directions. Open and transparent market platforms exist, where providers of reserve capacity can place contingents of positive and/or negative reserve capacity in auctions.

Markets for reserve capacity are divided according to the three types of reserves (primary (FCR), secondary (FRR) and tertiary (RR)) and can have separate national rules and regulations for each type. Moreover, the remuneration for the offering of reserve capacity is very country specific.

Belgium

Price availability FC : For Belgium, average FC reserve prices are public information which is available at the transmission grid operator website[31]. A couple of FC products are available: 2 symmetric products (100mHz and 200mHz) and 2 asymmetric products ("Load" and "Down"). The remuneration of a symmetric 200mHz product around 18 €/MW/h and higher than the asymmetric products (5…10 euro/MW/h). An interesting business model in Belgium for aggregators is aggregating complementary asymmetric products into a high value symmetric product.

Price availability FR -: For FR reserves, the transmission grid operator focuses mainly on traditional gas power plants for sourcing this type of reserves. Structural contribution to FR reserves is organized in monthly auctions which are only accessible for BRP's generators with a CIPU interface. CIPU can be seen as a very advanced real time control system which only makes sense for generators and is not open for FID.

Price availability RR : Within the RR product category, the Belgian transmission grid operator has 2 products which are suitable for this business model; ICH for transmission grid connected customers and R3DP which is also accessible for distribution grid connected customers.

31 http://www.elia.be/en/suppliers/purchasing-categories/energy-purchases/Ancillary-Services-Volumes-Prices

Average prices for ICH and R3DP services are public information which is available at the transmission grid operator website[32].

Additionally, there is a possibility to offer capacity in so called "free bids" in a day-ahead market. BRP's are allowed to combine small generation units without a CIPU interface and this is in principle open for FID. Once the offer is placed as a free bid, it will be put in the merit order. Depending on the required reserves on the next day and the price, the unit might be activated on request of the transmission grid operator. The value depends on very variable free bid prices in combination with a probability to be selected.

Calculation method (FC & RR) **C:** In the framework of calculating the business model for offering reserve capacity to the transmission system operator, only the FC and R reserves are to be taken into account and a fixed capacity price is the basis.

Calculation method (FR) **- :** Due to the limited probability that FRR products will be accessible for FID, this type of reserves is omitted from the optimization.

France

Price availability (FC, FR & R) : FID offering reserve capacity, either directly or through an aggregator, by shedding load is possible since 2003 in France and its relevance has been growing significantly in recent years. The TSO procures the balancing services through different calls for tenders, where industrial customers or distributed load shedding submit their capacities offers. The TSO is also carrying out measures to open frequency response reserves, such as FCR and FRR, to demand side. Information on the prices for these services can be found via the RTE website[33]. France also has a capacity mechanism which is described on the RTE website [34]as well.

Calculation method (FC, FR & R) **C/PP :** The Automatic Reserve Requirements issued by RTE give place to a fixed remuneration from RTE. Contracting of the RR is made following a yearly tender with the balancing market players. Contracting guarantees a fixed annual volume of Manual Frequency Restoration Reserve. In return for their contractual commitment to make capacity available on the balancing mechanism, the balancing players

[32] http://www.elia.be/en/suppliers/purchasing-categories/energy-purchases/Ancillary-Services-Volumes-Prices

[33] http://clients.rte-france.com/lang/an/visiteurs/vie/reserve_ajustement.jsp

[34] http://clients.rte-france.com/lang/fr/clients_traders_fournisseurs/services_clients/dispositif_mecapa.jsp

receive an annual bonus based on the offered volume and the activation time. The price per half-hour displayed by RTE, corresponds to the average half-hour price for the month in question and paid to the contracting parties. For R reserves a pure capacity remuneration mechanism is used (C).

Germany

Price availability (FC) : For primary reserve capacity, the price is based only on the capacity. Prices of past auctions are published[35].

Price availability (FR & R) : The German transmission grid operators maintain a common platform for auctioning for balancing energy.

Calculation method (FC, FR & R) **C/PP:** To compute the benefits of offering ancillary services to the TSO, the capacity reservation price optimization method will be used in combination with an activation price in some specific cases.

Furthermore, Germany is about to implement a strategic reserve as capacity and climate reserve. While the latest drafts for the law to change the Energiewirtschaftsgesetz (EnWG) already contain some provisions showing what the reserve will look like, the details will only be set out in a regulation. What is clear, however, is that installations participating in the reserve cannot participate in the market for electricity by at the same time offering their production there, and may not return to the electricity market. Prices will be determined in auctions, but no information is available yet.

Italy

Price availability & calculation method (FC, FR & R) **-** : In Italy demand side sources do not have access to the balancing market, nor to ancillary services. Thus this business model is not applicable in the current Italian regulatory framework. Moreover the role of an aggregator is not defined in the present dispatching regulation.

In Italy, interruptibility services have traditionally been regulated by contracts between TERNA and the service providers which were monthly auctioned. The resolution of 20 June 2014, from the NRA established a new discipline for interruptibility services starting from 1 January 2015, by which 75% of interruptibility services are purchased through multi-annual auctions, and 25% through annual auctions. Moreover, industries have the possibility to buy

[35] https://www.regelleistung.net/ext/tender

back (permanently or only for a predefined period) the interruptible capacity from TERNA once one-third of the total duration of the contract has passed. The Italian regulation foresees a premium of 135 000 €/MW/year for production units which allow instantaneous interruptions and a premium of 90 000 €/MW/year for production units which allow emergency interruptions (within few seconds).

For the determination of the profit generated by providing interruptibility services to the TSO, the optimization towards the capacity reservation price is the key.

Spain

Price availability & calculation method (FC, FR & R) **-** : FID offering reserve capacity, either directly or through an aggregator is not possible. Consumers are not allowed to provide any kind of balancing services.

Large FID can, however, provide interruptibility services to TSO for emergency situations. The TSO activates the interruptibility service by ordering the provider (i.e. FID) to lower its active power demand to a predefined value. The service is remunerated for available capacity, according to the results of the auction, and energy effectively interrupted, based on the reference price calculated every trimester and published by the Directorate General of Energy Policy of the Ministry of Energy.

According to the results of the latest auction in November 2014, the 2000 MW for 2015 were sold to the Spanish TSO, REE, for M€ 352, i.e. for 176 339 €/MW on average for the whole year[36].

The reference price for the settlement associated to a power reduction order in this service to be applicable in the first trimester of 2015 is calculated as the average wholesale electricity prices in the day-ahead market during the last trimester of 2014 and the forward market operated by OMIP for the first trimester of 2015, resulting in 48.20 €/MWh[37].

United Kingdom

Price availability (FC, FR & R): Concerning the different types of reserve capacity, there are a number of products accessible, namely: Short Term Operating Reserve (STOR), STOR Runaway, Enhanced Optional STOR, Fast Reserve, BM Start-up and Demand Turn Up.

[36] http://www.esios.ree.es/web-publica/ , *Servicio de Interrumpibilidad > Resultados.*

[37] http://www.boe.es/boe/dias/2015/02/09/pdfs/BOE-A-2015-1221.pdf

Detailed prices, procurement process and historic volumes can be found on the National Grid website[38]. More detailed information on activation price (hourly) data are also published[39].

The various products available are all associated with a utilization payment which remunerates the service providers for the energy delivered to the system operator after an instruction has been issued. In addition to this, with the exception of Enhanced Optional STOR, all the remaining services also consider an availability payment which remunerates service providers for making their units available to the system operator. Moreover, in the particular case of Fast Reserve, availability payments can also be split into two parts: availability fee and positional fee which are differentiated according to the commitment level of each unit, e.g. positional fees are paid when units are instructed one day ahead to delivery, if this does not occur, service providers are only paid the availability fee.

Some of the products are designed to be provided specifically by demand response units. This is the case for Demand Turn Up and STOR Runaway, the former associated with high frequency events and therefore requires service provides to increase consumption (or decrease on-site embedded generation) and the latter associated with low frequency events and thus reduction of consumption. Although the two aforementioned services are designed specifically for demand response, other services can also be provided by demand response units as long as technical requirements are met.

Additionally, there is a capacity market that demand side can participate[40] in the UK. There has only been one auction to date with prices equal £19.40/kW/Year. The first date that this payment will be made is winter 2018. Every year there will be an auction so prices will be changing for subsequent delivery years.

Price availability & calculation method (FC, FR & R) **C** : For the assessment of the potential of offering flexibility towards the TSO as reserve capacity the capacity reservation price is used as guidance. Although in this business case, the flexibility is remunerated for the majority of products for both availability and utilization, the only certain payment is based on the availability fee, i.e. offered capacity. The business case has to be financially feasible already on basis of this capacity payment, and hence, the capacity method is applied. The utilization

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[38] http://www2.nationalgrid.com/UK/Industry-information/Electricity-transmission-operational-data/Report-explorer/Services-Reports/

[39] https://www2.bmreports.com/bmrs/?q=balancing/pricesofprocuredbalancing

[40] https://www.emrdeliverybody.com

payment is an uncertain bonus that is mostly used to cover for operational costs of offering flexibility, and is considered not the crucial factor that assures the financial attractiveness of the business case.

5.4 *Imbalance optimization*

The principal function of the Balancing Responsible Party (BRP) is to assist the TSO in balancing supply and demand close to or during time of delivery. Within this context, the BRP is in charge of making a day-ahead forecast for the demand and/or production within his portfolio. When deviations occur from the nominated position, balancing energy has to be used by the TSO to stabilize the net frequency at 50 Hz. In the clearing process, the BRP is held accountable and is required to pay imbalance costs.

By controlling and shifting the FID in order to reduce the deviation from the day-ahead forecast, the imbalance costs for the BRP can be reduced. Within the optimization, it is assumed that the FID owner is responsible for own nominations. Subsequently, the FID owner can deviate from the forecasted profile and is remunerated with the official imbalance price.

Belgium

Price availability: Belgian imbalance prices are public data, available at the website of the Belgian transmission grid operator Elia[41].

Calculation method **DIP**: The Belgian imbalance market is double-sided, i.e. the imbalance price is different depending on the position of the balance responsible compared to the system position. Hence, the optimization is performed via the DIP calculation method.

France

Price availability: Concerning the French imbalance settlement process, for a given half hour, if the balancing mechanism trend is the reverse of the results of the Balance Responsible, the Settlement Price of the Negative Imbalances (resp. Positive) is the Average Weighted Price of the Balancing carried out Upwards (resp. Downwards) over this same period, adjusted by a multiplier (i.e. 1,08). Otherwise, the EpexSpot price is the one that is applied, see Figure 11. The current imbalance prices are published by RTE[42]. Historical imbalance prices are also available[43].

[41] http://www.elia.be/en/grid-data/data-download

[42] http://clients.rte-france.com/lang/an/visiteurs/vie/mecanisme/jour/prix.jsp

[43] http://clients.rte-france.com/lang/an/visiteurs/vie/mecanisme/histo/tendances.jsp

	Case where the balancing trend is upward	Case where the balancing trend is downward	Case where the balancing trend is nil
Positive imbalances	EpexSpot price	AWPb / (1+K) *	EpexSpot price
Negative imbalances	AWPh x (1+K)**	EpexSpot price	EpexSpot price

* upper limit fixed at the EpexSpot price
** the EpexSpot price constitutes a ceiling

Figure 11: Imbalance settlement price France

Calculation method **DIP**: As the imbalance settlement process consists of a dual pricing mechanism the DIP method is applicable for the implementation of the optimization.

Furthermore, the NEBEF Rules 2.0 enable any consumer in mainland France to sell its electricity load reductions on the energy markets, either directly by itself becoming an Operator, or indirectly through a third party that is a DSMO (Demand Side Management Operator). The NEBEF mechanism (Notification d'Echange de Blocs d'Effacement, Notification of Exchange of Blocks of Load Shedding) establishes the transfer of an energy block from the BRP of the consumer's energy provider to the demand response service operator and then to the target markets. The contribution of this mechanism is to allow the bid of demand response offering on the energy market by a third operator distinct of the energy provider. The current NEBEF Rules give rise to a payment to be made by the DSMO to the suppliers of electricity to the consumers concerned and are displayed on the RTE website[44].

Germany

Price availability: The standard cross-control area balancing energy prices (reBAP) apply to all German control areas and are online available[45].

Calculation method **PP**: The imbalance settlement is based on a single price system: the imbalance price is the same, regardless the position of the balance responsible compared to

[44] https://clients.rte-france.com/lang/an/clients_traders_fournisseurs/services_clients/dispositif_nebef.jsp

[45] http://www.50hertz.com/en/Markets/Balancing/Balancing-group-settlement

the system position. The prices are calculated for each settlement period of ¼ hour. The price is the volume weighted average cost of the secondary and minute reserve which has been actually used (only the energy, since the cost due to the capacity payment is integrated in the network tariffs). The price is the same for positive and negative imbalances. The balance responsibles who are in a long position get paid by the TSO (they sell the surplus of energy); on the contrary, the ones who are in a short position pay the TSO (they buy energy to cover their deficit). Due to the single price system, a price profile optimization method will be used.

Italy

Price availability: Imbalance prices are public data, available at the website of the Italian transmission grid operator TERNA[46].

Calculation method **DIP/PP**: Concerning the pricing scheme for imbalance settlement, two systems exist.

1. Units enabled to participate to the Dispatching Services market: Dual price
   For every period and for every producing unit and consuming unit the 4 following formulas are applied (in Italy every power plant that injects or consumes energy from the network is responsible for its imbalances):
   - When the imbalance of the power plant is positive and the imbalance of the overall market zone (where the power plant is located) is positive: The power plant receives for its surplus of energy the minimum price between (PMSDbuy , PDAMsell)
   - When the imbalance of the power plant is positive and the imbalance of the overall market zone (where the power plant is located) is negative: The power plant receives for its surplus of energy the price of the Day Ahead Market PDAMsell
   - When the imbalance of the power plant is negative and the imbalance of the overall market zone (where the power plant is located) is positive: The power plant has to compensate the system operator for the deficit of energy with the Day Ahead Market price PDAMsell
   - When the imbalance of the power plant is negative and the imbalance of the overall market zone (where the power plant is located) is negative: The

[46] http://www.terna.it/it-it/sistemaelettrico/mercatoelettrico/settlement.aspx

power plant has to compensate the system operator for the deficit of energy with the maximum price between (PMSDsell , PDAMsell)

2. Units not enabled to participate to the Dispatching Services market: Single price
For every period and for every producing the 2 following formulas are applied:
   - If the sign of the overall imbalance of the market zone where they are located is positive, the imbalance is priced at the minimum price between (PMSDbuy , PDAMsell)
   - If the sign of the overall imbalance of the market zone where they are located is negative, the imbalance is priced at the maximum price between (PMSDsell , PDAMsell)

Code	
P	Price
MSDbuy	Price of the resources selected on the Balancing Market for downward regulation
MSDsell	Price of the resources selected on the Balancing Market for upward regulation
DAMsell	Day Ahead Market price

Table 3: legend

By the 25th day of the following month, TERNA calculates for every period (hourly) and for every dispatching unit the imbalance fees for both producing units and consumption units under the scheme described.

For the optimization it is expected that the DIP method will be applied.

Spain

Price availability : Within the Spanish power system, imbalances are settled within a timeframe of no more than one hour. A balancing perimeter is not defined as such (integrating at the same time generation and load). The classification of upwards and downwards imbalances refers to the sign of the net balancing energy (NBE). When the net balancing energy is positive, upwards imbalances are equal to NBE and downwards imbalances are opposite to NBE. On the other hand, when the NBE is negative, downwards imbalances are equal to NBE and upwards imbalances are opposite to NBE.

Calculation method **DIP:** A dual imbalance price is used for all imbalance volumes[47].

United Kingdom

The 'Cash Out' process penalizes generators and suppliers to the extent that an imbalance in their own contracted position contributes to an overall imbalance for a settlement period.

If generators and suppliers as a whole contract to deliver less electricity overall than required, the system is 'short'. Generators or suppliers contributing to the shortfall by being short in their own contracted position pay a System Buy Price to Grid for each unit of their own imbalance. The System Buy Price is higher than the market price and the difference represents a 'penalty' for a short party relative to its position if it had achieved a balanced contractual position through the market.

If generators and suppliers contract to deliver more electricity in total than required, the system is 'long'. Generators or suppliers contributing to the surplus by being long in their own contracted position are paid a System Sell Price to Grid for each unit of their own imbalance. The System Sell Price is lower than the market price and the difference represents a 'penalty' for a long party relative to its position if it had achieved a balanced contractual position through the market.

Generators and suppliers out of balance in the opposite direction to the overall system pay or receive the prevailing market price for their shortfall or surplus. They are therefore not penalized for their imbalance relative to their position if they had achieved balance through the market.

Price availability: Only limited imbalance price data is publicly available[48]. A subscription for the detailed price information is needed.

Calculation method **DIP:** For the calculation method, the DIP method will be applied.

[47] http://www.esios.ree.es/web-publica/

[48] https://www2.bmreports.com/bmrs/?q=balancing/imbalanceprice

5.5 On-site VRE optimization

Within this business optimization, on-site renewable energy is assumed. Hence, the focus is placed on the aptitude to shift consumption in function of the on-site VRE production. The optimization strategy is dependent on the agreement with the relevant energy supplier. A maximization of self-consumption can be pursued, which potentially engenders reduced energy costs and grid fees. Additionally, depending on the market signals or the supplier requests, and given the on-site VRE production, consumption is shifted.

Belgium

For Belgium, several implementation options are possible:

Application 1: The industrial customer invests in on-site VRE and the principle of "net-metering" is used. Excess electricity from the VRE source can be injected to the grid and sold to the supplier.

Selling electricity to a supplier is in principal a bilateral agreement. In practice a fixed price based on the long term ENDEX price or a variable price based on the day-ahead BELPEX prices will be used. Typically the agreed prices are lower than ENDEX and/or BELPEX in order to allow a margin for the supplier. Day-ahead BELPEX prices are public information, available at the Belpex website[49]. Moreover, long term ENDEX electricity prices are accessible[50] and visualized[51].

Application 2: The VRE source is installed on the industrial estate but not owned by the industrial customer. Depending on the technical and legal specifics, either a direct connection or a closed distribution system is created between the VRE source and the industrial customer. In this case, the price for electricity directly obtained from a VRE is also described by a bilateral agreement. In practice it generally concerns a price based on the ENDEX or BELPEX price, comprising a markup for buying and a markdown for selling.

Price availability : Although prices are not public, price indications are available.

Calculation method **DS:** For the calculation method, the DS method will be used.

[49] https://www.belpex.be/

[50] https://www.theice.com/products/27993084/Belgian-Power-Baseload-Futures/data

[51] http://be.scholt.com/marktprijzen/?utility=E&update

France

Self-consumption is allowed in France, with no additional taxes. Therefore, a flexible user might be able to adapt their consumption profile to the own on-site RES forecast, thus reducing the energy cost. On the other hand, excess generation can be fed into the grid remunerated at feed-in tariff scheme under certain circumstances.

Price availability : No public prices or price indications available.

Calculation method **DS:** For the calculation method, the DS method will be used.

Germany

This business model is difficult in Germany and one needs to carefully distinguish between different cases. However, in all cases we assume that the plant is located on the territory of the industrial consumer and the public grid is not used.

Application 1: The VRE is owned by the supplier. This business model has become less attractive in Germany and requires a complex legal framework nowadays, as the regulator (and some courts) seems to be of the opinion that in such a constellation the production from the VRE does not count as self-consumption, so that the full EEG-surcharge may become due.

It can however, depending on the consumption behavior of the industrial consumer, the exact set-up and depending on the contract negotiated with the supplier still be interesting, and may it be only for sparing network charges and certain other charges connected to them.

In this case, prices will be negotiated and will likely be subject to various factors, in order to make this model work for the parties. Inspiration may be found in the prices in the day-ahead market[52] as well as the market premium system under the German Erneuerbare Energien Gesetz (EEG)[53].

[52] https://www.epexspot.com/de/marktdaten/dayaheadauktion

[53] http://www.gesetze-im-internet.de/eeg_2014/

Application 2: The VRE is owned by the FID. If the VRE is located on the territory, owned by the industrial consumer, one may assume that the model counts for "self-consumption". This could mean that the industrial consumer benefits from a reduced EEG surcharge on the electricity consumed. If the plant is not using the public grid, then no grid charges will become due, and notably many of the charges on the electricity price in Germany will fall away.

This business model relies on the savings for the FID under self-consumption, and possibly on the income generated through the surplus production. Both will depend on the details and cannot be estimated. For the prices for the surplus production, the prices in the day-ahead market as well as the market premium system under the German Erneuerbare Energien Gesetz (EEG) may be of use.

Price availability: No public prices or price indications available.

Calculation method **DS:** For the calculation method, the DS method will be used.

Italy

In Italy there is a net-billing system in place (so called "Scambio sul posto"), as an alternative to net metering. The net billing mechanism, for generation units under 500 kWh, allows the producer to obtain a compensation for the generation. The remuneration is defined by 1) the economic value linked to the electricity produced and fed into the grid and 2) the theoretical economic value associated with electricity consumed in a different period from that in which the production takes place.

However, typical VRE producers are downhearted to be involved in such a net billing mechanism because it is not compatible with any incentive mechanism.

Based on this information, it was decided not to keep this model in scope.

Price availability: No public prices or price indications available.

Calculation method **DS:** For the calculation method, the DS method will be used.

Spain

This business model is not possible in Spain. On-site renewable energy is possible but the possibility of netting demand with self-generation is not allowed. In principle, injections and consumption are metered and rewarded, or charged, separately. The regulation of self-generation and consumption is under discussion.

Price availability: n.a.

Calculation method**:** n.a.

United Kingdom

In the UK, prosumers are exempted from paying any network and system costs on self-consumed energy, strongly incentivizing self-consumption among industrial consumers. Therefore, a flexible user might be able to adapt their consumption profile to the on-site VRES forecast, thus reducing the energy cost. In such a way, netting FID with on-site VRES will reduce the per MWh consumption of the FID. At the same time, excess generation can be fed into the grid, or additional demand for electricity can be obtained from the grid at the agreed price.

Price availability : No public prices or price indications available.

Calculation method **DS:** For the calculation method, the DS method will be used.

6 References

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