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SMILE

Smart Island Energy Systems

Deliverable D6.6
SMILE business cases and financial mechanisms

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1 Introduction

The overall scope of SMILE project is to demonstrate, in real-life operational conditions, a set of both technological and non-technological solutions adapted to local circumstances targeting distribution grids to enable demand response schemes, smart grid functionalities, storage, and energy system integration with the final objective of paving the way for the introduction of the tested innovative solutions in the market in the near future. To this end, three large-scale demonstrators have been implemented in three island locations in different regions of Europe with similar topographic characteristics but different policies, regulations, and energy markets: Orkneys (UK), Samsø (DK) and Madeira (PT).

The present deliverable D6.6 has been developed in the framework of SMILE activities dealing with market analyses, business cases and financial mechanisms.

The main purpose of this Deliverable is to provide a number of insights and reflections on the possible business cases which could be applied to SMILE demonstration sites or eventually to replication sites facing similar challenges, through the exploitation of the main technologies developed and tested during the project. The evaluation of the business cases is carried out through considerations related to potential business models, financial flows and business plans associated to technologies deployments and integrated with literature outputs. In some cases, it has been indicated the option to rely on financial incentives to improve the financial results associated to the specific business cases.
The analysis of business cases has been executed following an information collection process which lasted several months and involved representatives from each of the three demonstration sites. Data collection related primarily to expenses actually incurred in the project demonstration sites to develop and install the main SMILE technologies as well as the ancillary components necessary for a proper functioning of the solutions implemented. Furthermore, special attention has been paid on the outcome of the market analysis (D6.5). The monetary benefits for users were mostly, but not solely, associated to estimated savings realization. Multiple conference calls with project representatives from the three islands have been held in order to discuss on the potential business cases that could be developed. In addition, the present document builds upon the technical findings presented in SMILE public deliverables and insights emerged from the research activity carried out during the project, with the aim to provide a picture of potential business opportunities arising from those results.

The kind of analysis performed in each demonstration site reflected the local frameworks nature (which differs substantially in the three islands, both in terms of stakeholders involved and in relation to systems implemented) as well as the information availability. For this reason, different approaches have been adopted to carry out the analysis in the three pilots and this aspect is obviously reflected in the sections of the present document. For example, the Orkney demonstration site, discussed in the first main section of the present document, entailed the presence of a number of residential consumers and of electric vehicles charging stations which are linked together by a centralized load controller (aggregator platform) further connected with renewable generators located in the islands and with the local DNO. This framework led to investigate the business case associated to the overall system, exploring potential arrangements which can provide benefits to all the stakeholders involved as well as the suitable allocation of costs. In relation to the island of Samsø, addressed in the second main section of this document, since the focus of the demonstration site revolved around the installation, in one of the local marina, of photovoltaic modules integrated with a battery energy storage system, it has been investigated the cashflow associated to this system, in addition to the evaluation of the potential savings associated to deploying implicit demand response strategies either focused on the marina own operations or involving tourists visiting the site. Finally, regarding Madeira island section, it has been once again addressed a distributed system, involving multiple stakeholders

including local prosumers, electric vehicles charging stations and the island DSO. Differently from the Orkney case, since the central unit, the developed Energy Management System (EMS), provided diverse services to each stakeholder categories, after an evaluation of the overall system business case, it has been chosen to focus on the assessment of the financials of individual prosumers for which it has been possible to estimate potential annual savings brought by the SMILE solution.
In each of the sections, it has been included a set of considerations on commercial opportunities for SMILE technology providers unlocked by the replication of the business cases, developed in the context of the SMILE environment, in other sites.

2 Orkney

The Orkney distribution network is not a fully isolated network as it is connected to Scotland through two 33 kV submarine cables that allow energy import/export between the two areas. The islands are characterized by significant renewable energy generation capacities (especially associated to wind power) equal to about 57 MW in 2018. The islands large renewables generation that could ideally be exploited through export to the Scottish mainland is constrained by the cables limited capacity which implies the need to curtail part of the produced energy. Since expanding the connection capacity between the islands and Scotland would need the installation of a new cable requiring a high investment, maximizing the islands self-consumption potential became a key objective.

The island has introduced an Active Network Management (ANM) scheme which implies a "managed connections" concept where some generators are periodically restricted from injecting energy in the network. The ANM scheme that became operative in 2009, required only a fraction of the investment that would instead be required to strengthen the network installing a new submarine cable. A Last-In-First-Out (LIFO) principle of access is employed in the Orkney's network to establish the priority of the different generators. Though, the ANM scheme introduction does not fully resolve the curtailment issue as areas are still subject to substantial curtailment percentages[1]. In fact, the LIFO principles entails that the last generator that entered the ANM scheme is also the first that is going to be curtailed. It is a very simple approach that appears to have two major limitations:

- The principle might discourage further renewable generators to join the scheme in the case the frequency of curtailment events reaches levels that render operations unsustainable. A clear representation of this scenario is reported in the image below from Kane and Ault's study[2].

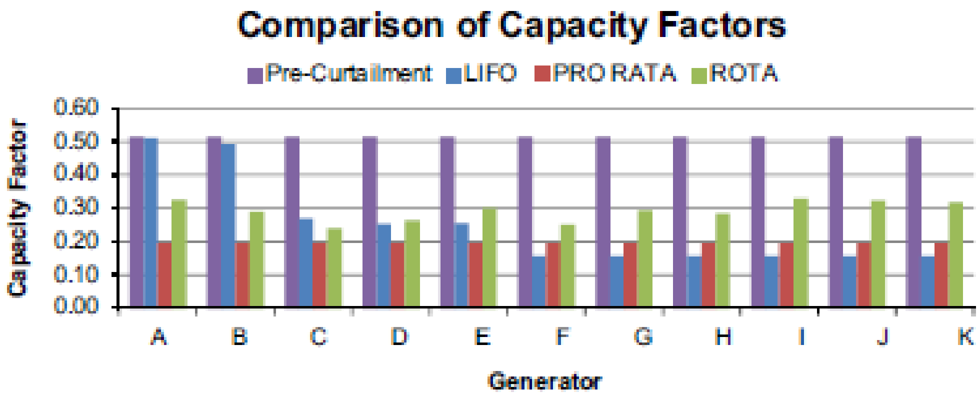

Figure 2.1: Comparison of Capacity Factors (for LIFO stack).
L. Kane, G. Ault[2] (2014)

The capacity factor of generators "A" and "B" (first and second in the LIFO principle stack) is substantially higher than the one of the subsequent generators (further decreasing from C to K) under a LIFO arrangement. It is worth recalling that the capacity factor is the ratio between the actual electric energy generated over a period of time and the maximum potential volume that could have been generated over the same period.

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[1] SMILE Project, Deliverables D2.1 / D2.4. Available at: https://cordis.europa.eu/project/id/731249/results/

- The principle does not foresee considerations on the localization of the curtailed generators which in turn might imply larger volumes of curtailed energy due to longer distances from the point of congestion[2].

In the U.K., there exists only one Transmission System Operator (TSO), namely National Grid Electricity Transmission. The transmission network in the North of Scotland (including the Orkney network) is owned and maintained by the Scottish and Southern Electricity Networks (SSEN). SSEN is also the island's Distribution Network Operator (DNO)[3].

The ANM scheme zone involved in the SMILE project is "Zone 1", where in the two islands of Rousay and Eday, two wind turbines are located (one 900-kW turbine on each).

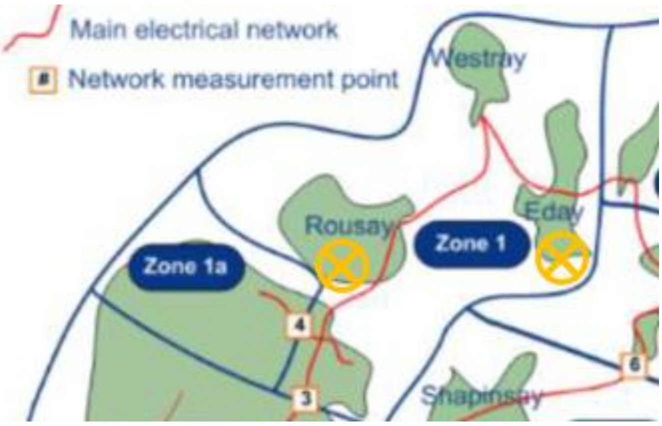

Figure 2.2: Orkney islands ANM scheme zone involved in SMILE project.

The 900-kW wind turbine located in Suorin district of Rousay, which started operation in 2011, is operated by the company named Rousay, Egilsay and Wyre Renewable Energy Development Ltd (REWIRED Ltd) which is fully owned by Rousay, Egilsay and Wyre Development Trust (REWDT). In this context, it is essential to highlight that the revenues realized through energy generation are devolved to a development trust which is an organization both owned and run by a community and whose main purpose generally refers to creating "social, economic and environmental renewal" and "tackling local needs and issues"[4]. In this sense, the income generated from the operation of the wind turbine are employed by REWDT for the funding of projects, grants and bursaries[5].

Mirroring the Rousay case, the 900-kW community wind turbine located on Eday is operated by Eday Renewable Energy Ltd (ERE), a wholly owned-subsidiary of Eday Partnership which employs the revenues generated by the turbine operation for the local community development[6]. In this context, it is essential to highlight that reducing curtailment events for the two wind turbines does not solely relates to increasing the efficiency of the system (essentially limiting energy wastage) but it also involves improving revenue-generation potential for the benefit for the local communities. In addition, it might be relevant to foresee that the projects to be funded through the revenues generated from

[2] L. Kane, G. Ault (2014) review and analysis of renewable energy curtailment schemes and Principles of Access: Transitioning towards business as usual, Energy Policy.
[3] SMILE Project, Deliverable D7.1. Available at: https://cordis.europa.eu/project/id/731249/results
[4] DTA Scotland (website). Available at: https://dtascot.org.uk/
[5] REWDT (website). Available at: http://www.rewdt.org/index.php
[6] BIG HIT project (website). Available at: https://www.bighit.eu/

energy sale might actually address smart heating systems in properties located within the islands communities under a quality-of-life improvement perspective.

Furthermore, it is essential to consider that in Orkney, renewables generators are not compensated in the case of curtailment. Load aggregation to provide flexibility and self-consumption appear to be available options to tackle the challenge posed by numerous curtailment events. In this sense, in the context of the SMILE project, the former solution has been pursued, deploying an aggregation platform (or Load Controller) provided by OVO Energy which connects households, generators (the two wind turbines) and the local DNOs (which provides the signal of curtailment events). The aggregation concept, implying exploiting the demand flexibility potential of a set of actors, has been coupled with energy storage devices. Hence, 42 residential sites have been equipped with energy storage systems (and heat pumps in a number of cases), providing a total of 234 kW of controllable demand. The four types of installations that have been deployed are briefly described below (please refer to deliverable D2.4[1] for the complete description of the systems architecture).

1. Type 1: Sunamp phase change material (PCM) based Heat Batteries have been installed and connected to the existing heating systems.
2. Type 2: Sunamp PCM based Heat Batteries have been installed and connected to heat pumps substituting the existing heating system.
3. Type 3: Hot water cylinders have been installed and connected to a heat pumps substituting the existing heating systems.
4. Type 4: Lithium Balance electrical batteries (lithium-ion battery) have been added to the previous architecture and connected to the heat pumps.

Heat Batteries, heat pumps and the hot water cylinders have been equipped with control devices, while the electrical batteries control is performed via cloud. The need for remote control of these devices relates to the introduction in the scenario of the aggregating “Kaluza” platform, which is provided by the company OVO Energy (the remote control is automatized). Such platform entails the installation at households’ premises of a gateway allowing remote control of devices and providing data to the platform. Other components such as VSCON have been installed on the wind turbines sites to allow data from the turbines to be recovered by OVO Energy; this includes power generation, wind speeds and curtailment power set points.

Moreover 66 additional households have been added to the demonstration site, providing further 290 kW of controllable load (through Kaluza platform). These 66 properties come from a project called Heat Smart Orkney, which aggregated the power demand of electric storage heaters and hot water cylinders to offset curtailment. Finally, additional 195 kW of manageable load is provided by the installation of 27 EV smart slow chargers; in this scenario, in fact, EVs batteries are treated as flexibility providers as the aggregating platform can manage the charging point and thus control the charging process. The presence of controllable demand enabled by the installation of energy storage, heat pumps and EVs is essentially enabling load management. Other ancillary elements, additional to those briefly outlined here, have been added to the system whose overall cost will be discussed later in this document.

A further remark regarding the technologies deployed in the demonstration site is necessary: while energy storage devices charge and discharge are not causing any discomfort to households, generally speaking the external control of switchable devices might instead bring inconvenience to consumers. In the context of the SMILE project, being the devices remotely controlled by the aggregating platform energy storage devices and heat pumps, which can be considered "flexible appliances[7]" not causing major discomfort, the comfort-related issue might be limited or not applicable.

2.1 The principles behind energy aggregation

Before further discussing the demonstration site context, it is worth to investigate the aggregation concept.
As in the Orkney scenario, when the electric network relies heavily on renewable energy sources such and wind and solar, which are characterized by intermittency and whose energy output cannot be controlled if not via curtailment, providing load balancing solutions and alleviating distribution and transmission grids congestion become essential. Managing demand appears to be a viable solution when investments to strengthen the distribution and/or transmission grids are excessively high, as in the case of Orkney submarine transmission cable. Energy demand management can be effectively deployed through demand response (DR) strategies. DR is concretely implemented through programs where energy consumers adapt their consumption responding to inputs from external actors. DR programs can be categorized as follows (the categories definition has been extracted from SMILE deliverable D6.5):

1. Explicit DR refers to programs where flexibility offered by consumers can be contracted either directly or through aggregation (that may occur, depending on the regulatory framework, through energy suppliers and/or independent aggregators) and subsequently traded in the market. Flexibility might be purchased, in the market, for example, by systems DSOs (and other parties) and resembles somehow generation. Long-term bilateral agreement for trading flexibility is also an available option (Okur et al., 2021). Flexibility providers are compensated for their service. It must be added, in this context, that adaptation of consumption (energy demand from the site) might be either automatized or occur through manual intervention.
2. Implicit DR refers to those programs where consumers adjust their consumption either manually or automatically to price signals in the presence of time-varying energy prices and/or network tariffs. No compensation from external party is foreseen but the financial incentive for consumers is connected to the realization of energy savings.

Considering the nature of Orkney demonstration site entailing the presence of Kaluza aggregating platform, this section of the document will focus on explicit DR strategies. The trading of flexibility in explicit DR can occur in different electricity markets: the wholesale energy market, the balancing market, the reserves and system support market[8]. While energy consumers with large loads (thus providing a large controllable demand) can directly trade their flexibility in the energy markets, the access to the market for consumers with limited loads is generally restricted in European countries (a threshold of 1 MW bid is set in Belgium, Denmark, the Netherlands and the U.K.[9] for example). In this context, aggregators assume a primary role in enabling DR programs and granting access of residential and small commercial sites to the energy markets. Leutgöb et al.[8] 2019's paper assesses the

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[7] Ö. Okur, P. Heijnen, Z. Lukszo (2021), Aggregator's business models in residential and service sectors: A review of operational and financial aspects, Renewable and Sustainable Energy Reviews.
[8] K. Leutgöb, C. Amann; D. Tzovaras, D. Ioannidis (2019), New business models enabling higher flexibility on energy markets. Available at: https://www.delta-h2020.eu/wp-content/uploads/2019/06/New-business-models-enabling-higher-flexibility-on-energy-markets.pdf
[9] SMILE Project, Deliverable D7.4. Available at: Available at: https://cordis.europa.eu/project/id/731249/results

applicability of two business models associated to explicit DR on small and medium-sized prosumers whose flexibility potential is bundled by an aggregator. The "Explicit DR as stand-alone service" business model relates to the most standard scenario where the aggregator manages and trades a set of consumers' flexibility potential in order to provide services in the energy markets which are eventually purchased by DSOs, TSOs or BRPs. A share of the revenues generated from the trading is subsequently transferred to flexibility providers according to the existing contractual agreement with the aggregator. A representation of the standard business model for the aggregator from Ma et al.[10] (2017) is reported below.

<table>
<tr>
<td rowspan="2">Partners
Regulators
BRPs
DSOs
TSOs
Control system providers
Energy suppliers (retailers)</td>
<td>Activities
• Access customers via energy suppliers or other channels
• Provide consulting and analysis of customer demand pattern
• Participate in the DR market (wholesale, balancing or ancillary market)
• Control customers' appliances
• Payment to customers for energy flexibility</td>
<td rowspan="2">Value Proposition
Direct payment by participating in the explicit DR market via aggressors</td>
<td>Customer relation
• Payment system
• Incentives by regulation, TSOs, and DSOs
• Consulting service (e.g. training, building energy behavior analysis)
• Control system operations and maintenance
• Reduce risk and provide reliability</td>
<td rowspan="2">Customers
Buildings (who are small energy consumers)</td>
</tr>
<tr>
<td>Resources
• Local control system
• Customer data (demand pattern)
• Market information
• Customer access via energy suppliers</td>
<td>Channels
energy consulting directly by aggregators access customers via energy suppliers (retailers)</td>
</tr>
<tr>
<td colspan="3">Cost Structure
DR control system (customer side and aggregator side)
Payment to customers
Tariffs to DSOs and TSOs
Payment/compensation to BRPs
Market access fees to the DR markets</td>
<td colspan="2">Revenue Streams
Payment from the DR market (including reserve capacity payment from TSO)
Incentive from TSO/DSO and regulators</td>
</tr>
</table>

Figure 2.3: Aggregator standard business model.
Ma et al[10]. (2017)

Interestingly, this business model canvas identifies as the only customer segment addressed the energy consumer one (prosumers might eventually be added as customer category), considering instead DSOs, TSOs or BRPs as "Partners" while revenues streams are generated providing these parties with flexibility-related services. Such choice might relate to the fact that also "Tariffs to DSO and TSOs", as well as payments to BRPs (which is the case for the French energy market), are included in the cost structure section of the canvas and DSOs and TSOs are generally served through energy market mechanisms, while a more direct interaction is required in the case of energy consumers. What is relevant to notice is the presence of "Regulators" within the Partners section, highlighting the essential role played by the evolving regulatory framework of energy markets. The general business model portrayed in the canvas can actually be further detailed considering how the aggregator interacts both with the energy market and with the energy consumers (which are two interrelated elements). Insights on this aspect are provided by Okur et al (2021) referring to the Dutch market context. In particular, flexibility trading is investigated firstly in the case where the aggregator operates in the day-ahead market, in which it can either pursue profit maximization in the trading activities

[10] Z. Ma, Joy D. Billanes, B. N. Jørgensen (2017), Aggregation potential related to business models.

(exploiting price fluctuations in the market) and offering financial compensation to consumers (following different schemes) or pursue energy savings optimization on behalf of consumers and eventually matching financial savings with rewards, in the case flexibility is exploited to limit aggregators' imbalances payments (in the intra-day balancing market). It must be highlighted that the latter option departs substantially from the business model canvas reported earlier in this document as the value proposition to consumers would relate to energy savings (consisting in the reduction of the energy bill) and thus not to financial rewards.

In the case of intra-day trading, the aggregator can either aim at minimizing imbalances-related expenses (even through aggregator's portfolio balancing) or once again pursue profit maximization in the market (rewarding consumers). Furthermore, operating with reserves appears a valuable option especially considering the energy storage technologies, heat pumps and EVs. Aggregators can operate in all the three markets for reserves (primary, secondary, tertiary) generating income both through capacity and activation remuneration; these options entail once again rewarding consumers in exchange for the control over their demand. Finally, the paper considers the opportunity to employ flexibility potential to address system congestion. This option appears particularly relevant in the case of the Orkney scenario as transmission system congestion appears to be the main issue affecting renewables generators operation in the islands. The aggregator may pursue either peak-shaving or interact directly with the DSO through market-based mechanisms supporting the management of foreseeable congestion issues. Obviously, these options can coexist and be integrated as the aggregator can operate, in principle, in all these energy markets. In addition, how energy consumers may be compensated for the provided flexibility can follow diverse logics; fixed or time-varying payment schemes, as well as more sophisticated solutions, can be adopted. It is worth to underline that aggregation most often requires the installation (as in the case of the Orkney demonstration site) of hardware devices which enable the automatic remote control of energy demand at customers' premises. In this context, in the standard aggregator business model, the aggregation platform management and maintenance and the installation of the control devices are often free-of-charge[11] for energy consumers/prosumers. In this way, the aggregators revenues from flexibility trading must cover both the platform deployment and running costs and the consumers' rewarding aspect.

Four major challenges to the deployment of the figure business model for small and medium-sized prosumers are identified in the Leutgöb et al[8] paper, especially relating to: the capability of the software solution to be able to aggregate a large number of distributed sites with small loads, the presence of a sufficient number of switchable devices, the attractiveness of the DR programs for consumers and the financial sustainability of the arrangement for the aggregator. The first two reported challenges might be less relevant for the SMILE project Orkney demonstration site (in the case such business model would be suitable) as an aggregating platform working with distributed small loads was developed and put in place and the installed energy storage systems provide larger flexibility potential with respect to a scenario where only switchable devices are available (e.g. electrical appliances, AC units, heat pumps, etc.). With regard to the latter two challenges, irrespective of the kind of business model, they must be addressed in the analysis of the demonstration site in order to define the financial sustainability of the SMILE solutions from the point of view of the energy consumers (assessing whether the compensation for the provided flexibility legitimates the necessary investments) and of the aggregator (evaluating the costs of running and maintaining the platform and delivering the aggregation service). To overcome the limited attractivity that the discussed business model might offer to energy consumers, it is also evaluated[8] the opportunity of coupling explicit DR

[11] D. Brown, S. Hall, M.E. Davis (2019), Prosumers in the post subsidy era: an exploration of new prosumer business models in the UK, Energy Policy.

with energy efficiency services. In this case, the scenario appears more complex as two competing objectives, i.e. realizing energy savings and managing energy consumption to enable sellable flexibility, must coexist. In this context, it was suggested[8] prioritizing the former objective while DR would be regarded as an ancillary element which can complement the value of energy savings generated by energy service companies (ESCOs) with additional revenues provided by flexibility aggregation and trading. Considering the nature of the Orkney demonstrator where no ESCO has been directly involved in the scenario such option had not been tested but it might be considered a viable alternative in the case households' revenues from aggregation would prove being limited to achieve financial sustainability. However, it must be highlighted that it was specified that such business model is suitable for sites with annual energy expenses exceeding 20,000 € which might not reflect the case of standard residential sites.

As it has been indicated so far, in this document, generally, flexibility "users" are DSOs, TSOs, BRPs. The following table reports how these parties can eventually exploit flexibility[12,13].

User	Flexibility utilization
Distribution System Operator (DSO)	Flexibility is exploited to enable distribution network congestion management. It allows to defer investments in network upgrades and to ensure network safety. Flexibility enables voltage control and the possibility to address uncertainty and unexpected changes.
Transmission System Operator (TSO)	TSOs need flexibility to manage frequency when imbalances arise, through: 3. Containment reserves 4. Restoration reserves 5. Replacement reserves In addition, flexibility is necessary to address congestion management and to provide reactive power when needed. Finally, flexibility can be used to reduce grid losses.
Balance Responsible Party (BRP)	BRPs exploit flexibility to balance their own portfolio, adjusting demand and supply and thus reducing their imbalances-related expenses.

Table 2.1: DSO, TSO, BRP flexibility utilization potential options.

It is necessary to underline that, as reported in the studies discussed above, it is generally DSOs and TSOs (and BRPs) that compensate the aggregators for the flexibility provided, which in turn, as extensively reported earlier in this chapter, reward flexibility providers. While this framework applies to standard cases, the scenario for the Orkney demonstration site appears slightly diverse.

[12] EDSO for Smart Grids (2014), Flexibility: The role of DSOsin tomorrow's electricity market. Available at: https://www.edsoforsmartgrids.eu/wp-content/uploads/public/EDSO-views-on-Flexibility-FINAL-May-5th-2014.pdf

[13] Smart Grid Task Force (2015), Regulatory Recommendations for the Deployment of Flexibility. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/EG3%20Final%20-%20January%202015.pdf

2.2 Specificities of the Orkney business case

The main objective for the Orkney demonstration site relates to the possibility of integrating larger renewable energy generation in a scenario which is constrained by a limited export capacity, limited self-consumption opportunities and disadvantages associated to the LIFO principle of access which penalizes a set of generators. In this sense, it appears clear that the introduction of DR practices and storage systems in the SMILE demo will not address only DNOs and TNOs needs (reported earlier in this document, especially in relation to congestion management) but it is expected to benefit primarily generators and subsequently to bring benefits to the overall system. In this context, a preliminary framework has been discussed in order to provide a representation of the scenario and of the logic that could legitimate the integration of storage systems (together with control and other devices) at households' premises. It must be highlighted that in the Orkney demonstration site, also EVs are "exploited" as electricity storage systems which bring further flexibility to match curtailment events penalizing turbines operation and their revenue generating potential.

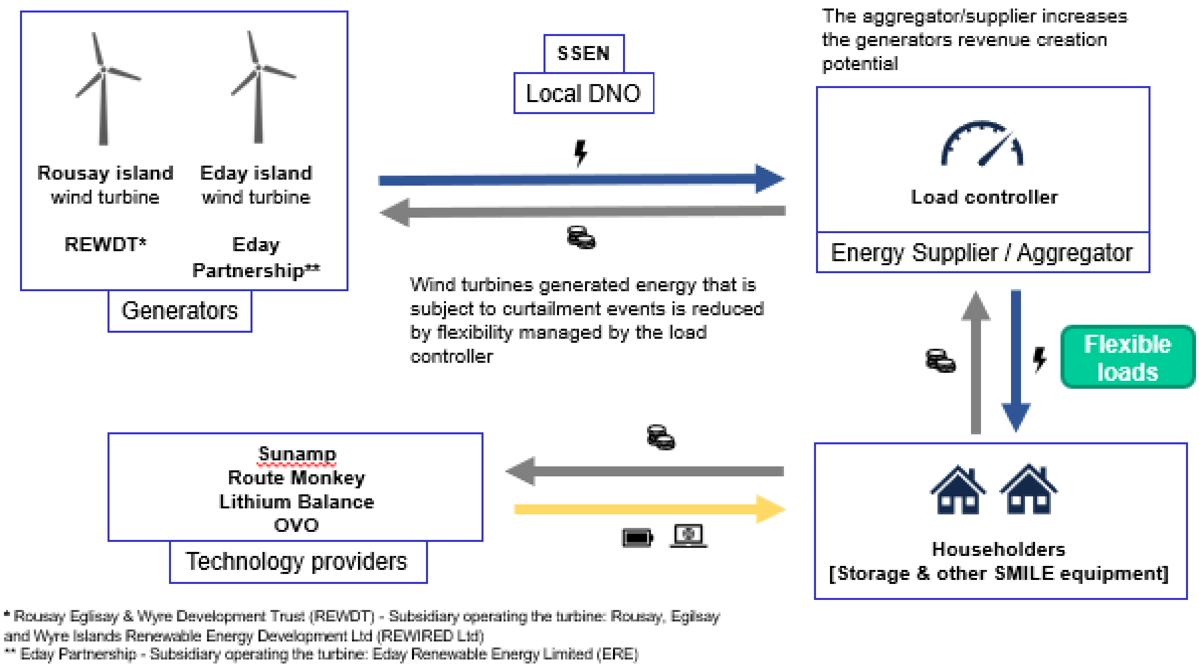

Figure 2.4: Preliminary business case framework representation.

The initial business case framework reported in the figure, refers to an early phase of the study, where it was being discussed that, in an ideal replication of the demonstration site scenario outside SMILE project context, households and EVs charging stations owners would invest in SMILE technologies expecting monetary and non-monetary benefits from supporting the system tackling curtailment events at generators level. These might relate to financial rewards/incentives provided by the other parties involved in the SMILE solution framework, involving the other stakeholders reported in the figure above(this aspect is further discussed below in this document), while in relation to non-financial aspects, environmental-related benefits associated to energy waste reduction and increasing RES penetration are relevant factors to be considered. In addition, it should be highlighted the community development objective of the development trust owning the generation infrastructures and thus the connected social value associated to curtailment impact reduction with the aim to tackle curtailment events occurring at generators level. Once energy storage systems are installed in residential sites, together with heat pumps, the load controller (Kaluza aggregator platform) can remotely and automatically control their charging strategies (obviously following the installation of the necessary

control devices discussed earlier). The loading of the storage systems would occur in order to reduce the quantity of generated electricity (produced by the generators involved in the demonstration sites and eventually others experiencing similar challenges) that is subject to curtailment. Essentially, activating energy storage charge command leads to the purchase of energy by households increasing the consumption at the specific moment in time, subsequently reducing the curtailment event impact/extent. This automatic purchase of energy might increase households' electricity bill in the case the buying signal would occur during peak-price periods in the context of a ToU tariff. With regard to this point, it must be pointed out that such potentially negative effect is expected to be fairly limited as curtailment events generally occur for a limited period of time. Whereas in case the household is subject to the single tariff scheme, such issue does not apply.
The main technologies required at residential level, to which it is associated remarkable business opportunity for those technology providers involved in the SMILE project in the context of a replication of the overall solution, are the following:

1. Sunamp Heat Batteries, installed in a number of households, which are energy storage systems relying on phase-change material technologies that can eventually substitute, in residential sites, hot water cylinders. The installation designed and implemented in the SMILE project is made up of multiple Heat Batteries serving daily space heating and hot water needs, but simultaneously, the batteries system can be employed to respond to curtailment events. Interestingly, it has been found, during the solution testing, that heating through Sunamp heat battery discharge is faster than heating employing solely heat pumps.

2. Lithium Balance lithium-ion batteries, installed in a number of households, are energy storage systems which have been developed and installed in the context of the SMILE project solely to address curtailment events. In this sense, the battery mounted at households' premises charges when curtailment events occur, enabling purchase of electricity from the public grid and its subsequent storage for future use (through discharging to meet daily energy demand).

3. Heat pumps have been installed in most of the residential sites involved in the SMILE project as they represent both switchable devices which can offer flexibility without providing discomfort to house occupants and key devices enabling the exploitation of energy stored by either Sunamp Heat Batteries, Lithium Balance lithium-ion ones. In addition, heat pumps are necessary to replace houses existing oil-based heating systems thus enabling electricity-based heating.

4. Controllers are critical elements in the deployment of the overall solution as they allow the communication between storage systems and the load controller. They include the QController developed by Sunamp, the VCharge Dynamo from OVO Energy (employed in installations exploiting hot water cylinders as storage devices), Lithium Balance cloud battery controller.

As explained earlier, the SMILE solution is also relying on the load controller/Kaluza aggregator platform provided by OVO Energy, which essentially enables to manage the controllable assets. In the framework represented in the figure above, Kaluza platform is either managed by an aggregator (also named "balancing service provider") or by an energy supplier which also operates as an energy aggregator.

Let us assume a scenario with an independent organization owning and managing Kaluza platform, and essentially operating as a local aggregator. In a real scenario, such role might be played by OVO which would be responsible for both providing and operating the load controller. It is thus expected to enter into contractual agreements with a set of householders willing to provide flexibility through energy storage systems and heat pumps (these householders maintain their existing energy supply contract with their respective suppliers). By considering an average 20 kWh heat pump daily consumption of householders in the Orkney it has been estimated that between 10 kWh and 15 kWh of the total figure may be potentially available for flexibility.

Through the SMILE solution implementation, it is essentially increased the share of generated renewable energy that is consumed over a year, which, in turn, leads to an increase of the generators' annual revenues by reducing the curtailment events. The aggregator thus operates with the objective of maximizing the generators' revenues as it is expected to be compensated for this service. For the sake of completeness, it is essential to highlight that, in principle, every generator has a set of long-term contracts with a number suppliers and each MW of renewable energy generated is compensated through a feed-in tariff and the price established in the wholesale market.

Since, as a preliminary option for the SMILE business case in the Orkney demonstration site, it has been assumed that in the scenario where no external financing is available, households would invest in the storage (and connected) technologies, it has been extensively discussed which kind of benefit and financial motivation would incentivize these stakeholders to acquire the necessary devices, which, in the current market conditions, appear expensive.

In this scenario, households are inevitably expected to be entitled to a financial reward for the flexibility provided so that the purchase of the technologies would appear financial sustainable and legitimate in a realistic replication environment. The definition and design of this financial flow and of the incentive represents a major challenge in the identification of a suitable business case. This is especially due to technical constraints associated to the SMILE installation in residential sites which appear to prevent to determine in an accurate way the exact amount of energy that is actually purchased by householders to match curtailment (except for the system architecture including the lithium-ion battery which charges solely when activated by the signal of a curtailment event coming from Kaluza platform). In fact, in the cases where Sunamp devices are installed, a set of Heat Batteries are mounted to satisfy either space heating or water heating needs. The system is not solely devoted to match curtailment, but it is operating to meet daily demand from the occupants. This is a relevant feature of the SMILE solution, as it ensures that no discomfort is caused to householders as they have constant access to heating and hot water irrespective of the occurrence, or not occurrence, of curtailment events. At the same time, this aspect, prevents the possibility to base the incentive value on the actual flexibility that is provided by each stakeholder.

Furthermore, considering the need to avoid requiring any effort from households, the SMILE solution does not expect them to intervene in any activity associated to activating/deactivating storage systems, consequently they have no access to the deployed devices state of charge.

In the context of a pilot application of this business case, seeing the impossibility to accurately establish the additional revenues created for generators through flexibility provision (through a dynamic measurement of the additional energy purchased by consumers at specific points in time), a set of solutions are being discussed:

1. The relationship between the aggregator and the generators is foreseen to be regulated following a long-term contract (e.g. a year-long contract). An initial evaluation of the potential increase in revenues for the generator is estimated by the aggregator, considering the annual average time of curtailment events, the extent of the demand that is manageable, etc. In this sense, a fixed

compensation amount for the aggregator is established. At the end of the year, eventually the effectiveness of the service provided by the aggregator can be assessed and actions taken (the contract may even foresee a fixed component and a variable one that is settled periodically, after the effectiveness evaluation). A share of the compensation is passed down to households who should expect a periodical (for example monthly) incentive/financial reward from the aggregator, seeing the relevance of the investment in energy storage and other equipment that is required to enable the business case deployment. A simplified representation of the aggregator's role in the business case is reported below.

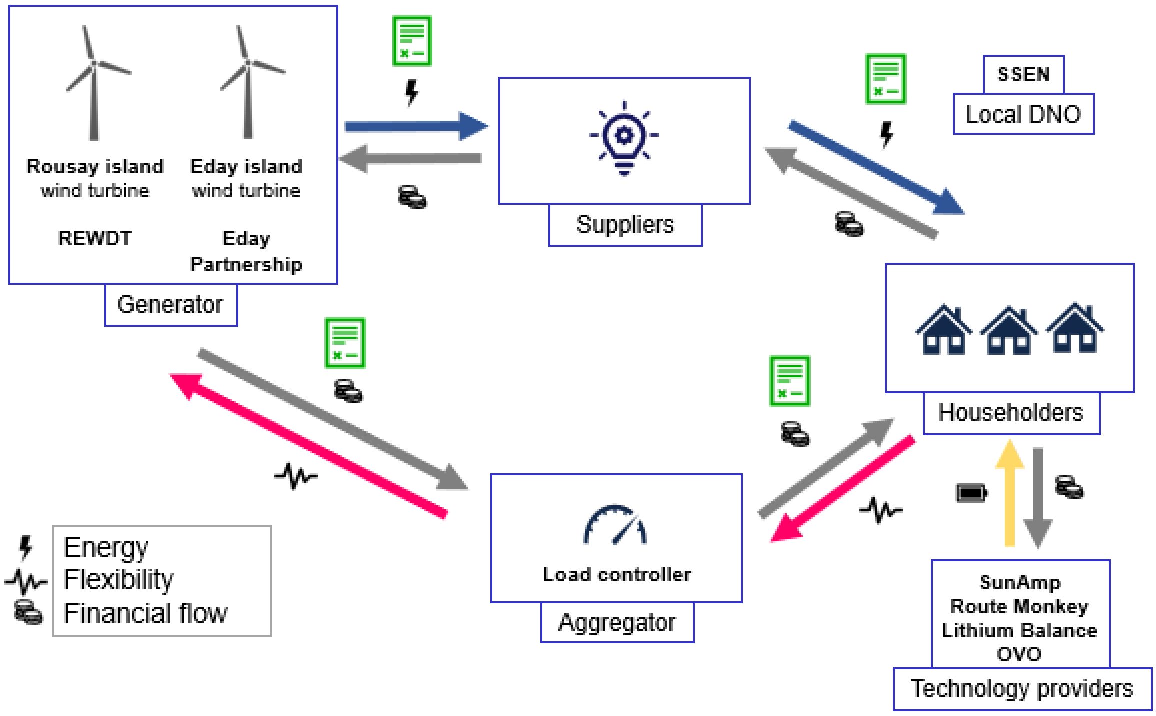

Figure 2.5: Simplified representation of the business case where the aggregator provides flexibility to generators and reward householders which invested in storage technologies.

As highlighted in the figure above, in the business case, generators retain their contractual agreement with energy suppliers which in turn retain their electricity supply contract with householders. Parallelly, the independent local aggregator is entering into long-term (for example, 1-year) contracts with both the generators and households (with installed SMILE equipment, irrespective of the system architecture mounted). The aggregator essentially manages the householders' available flexibility to increase the generators revenue potential and it is simultaneously the party which deals with monitoring of the installed equipment, interacts with customers and rewards them for the service provided. The incentive to invest in technologies can be associated as a suitable share of the additional revenues created by the generator and passed down to householders so that the payback period of the investment would result having a reasonable duration.

2. Considering the limited size of the demonstration site, requiring the aggregator to directly compensate households might not be a feasible solution from an operational perspective (it might instead apply to a context where a larger number of sites is involved). In this sense, following the

Heat Smart Orkney[14] (HSO) model, it might be considered the possibility to create a subsidiary company of the development trust (owning also the one operating the turbine) which might take care of the interaction with householders (together with ensuring the equipment monitoring and maintenance) and deal with their financial reward for the flexibility provided to the system. A major technical feature differentiates the SMILE solution with respect to the HSO one, it relates to the fact that the former affects the primary heating system, while the latter was solely involving households' secondary heating systems installed in the context of the project, namely: "storage heaters, flow boilers, hot water cylinders and immersion elements" [15]. In this sense, it was possible, through specific meters, to measure the exact amount of energy bought to operate the secondary heating systems (working as energy storage devices) as they were activating specifically to meet curtailment. In this context, generators were directly rewarding householders in the form of a rebate (periodically, for example quarterly) while the aggregator was compensated on a yearly basis for the maintenance of the aggregating platform. The SMILE project might adopt a similar framework only for those residential sites in which a lithium-ion battery was installed, in fact, as explained earlier in this section, it is the only device which charge only when a curtailment events signal is received. But even in this case, consumers would need to have access to information on the battery, in order to communicate the necessary data on consumption to the development trust subsidiary organization which would compute the rebate amount. While the specific HSO financial reward framework might not fully apply to the SMILE context, it must not be excluded the option that the aggregator's role is played by an organization that is solely maintaining and managing the load controller while the interaction with householders and their compensation is carried out by an organization acting on behalf of the generator. In this scenario, the party owning and managing the load controller might be entitled, as shown in the figure below, of a (fixed) compensation from the generators to cover Kaluza platform operation, maintenance and update.

[14] Community Energy Scotland (webpage). Available at:https://www.communityenergyscotland.org.uk/projects-innovations/heat-smart-orkney/

[15] REWDT (webpage), Heat Smart Orkney Ltd. Available at: http://www.rewdt.org/HSO.php

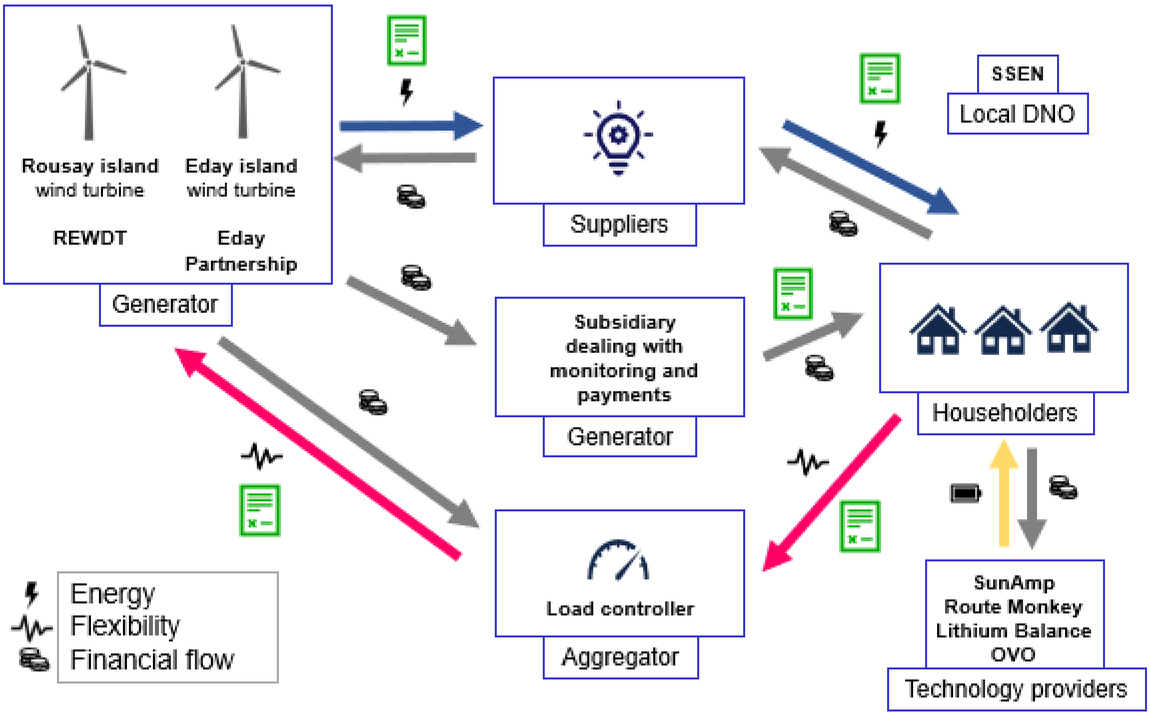

Figure 2.6: Representation of the business case where a development trust subsidiary is created to monitor installed equipment, interact with householders and reward them.

As shown in the figure above, while the aggregator retains its role as provider of flexibility, “originated” at householders’ level (and by EVs charging station owners) and exploited at generators level, no financial flow from it, directed towards householders, is represented. In this sense, differently from the previous business case, a subsidiary organization of the development trusts (which is indicated for the sake of simplicity as being part of “Generator”), deals with the latter financial flow. In both this and the previous business case, technology providers are expected to deal directly with householders which will invest in technologies purchase and installation and will have to incur in maintenance expenses over the years. As explained earlier in this document, the standard business model associated to the provision of aggregation services foresees that the aggregator acquires and deploys control devices. Once again, the incentive for householders to legitimate their investment on energy storage and associated technologies relates to a share of the additional revenues created at generation-level.

3. The two previously discussed business cases rely on the assumption that the financial flows directed towards householders are sufficient to justify their investments on the SMILE technologies. Since at current market prices, such devices appear expensive, and despite prices are expected to decrease in the short to medium term[16], the size of the financial reward to householders should be substantial to ensure the financial sustainability of the investment in technologies. It must be highlighted that the residential sites involved in the SMILE project are not prosumers which might exploit storage systems to improve their individual renewable generation self-consumption, but the technologies deployment is carried out exclusively to enable flexibility

[16] SMILE Project, Deliverable D6.5. Available at:https://cordis.europa.eu/project/id/731249/results

provision. In the case a suitable financial reward size to householders cannot be achieved due to market conditions and eventual other barriers, it must be foreseen the option that other stakeholders involved in the business model will invest in technologies installed at households' premises. The most suitable situation appears to relate to the aggregator acquiring and installing the necessary devices in residential sites (this would apply also to EVs charging stations). In this context though, householders are not entitled to a substantial financial reward, but a limited compensation associated to the electricity they are "forced" to purchase at specific points in time, to match curtailment, might be foreseen (this would be similar to the rebate system deployed in HSO project) as well as for allowing the remote control of the installed devices. In this context, while for the generator there is no major difference in operational and financial terms, the local aggregator will benefit entirely or almost entirely of the financial flow directed to it from the generator.

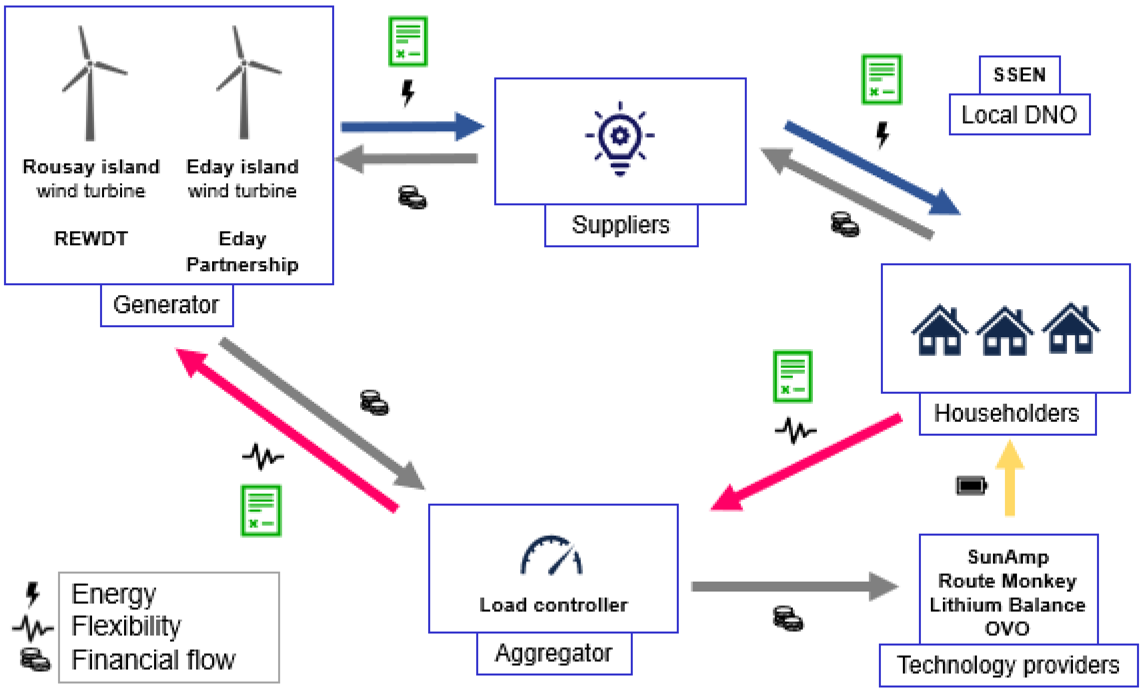

Figure 2.7: Representation of the business case where the local independent aggregator acquires and deploy the necessary SMILE technologies to be installed in residential sites and EVs charging points.

This business model represents a viable alternative to the ones discussed earlier but also an attractive option for the technology providers involved in the SMILE project. Indeed, in this framework, they do not need to deal directly with each individual household, but they can interact with a central party which might require the simultaneous acquisition and installation of multiple devices in a number of properties. In this sense, the time-consuming activity of recruiting and counselling householders on the most suitable technologies to be installed is executed by the organization managing the load controller which is also expected to have a more comprehensive knowledge of the requirements to be met to ensure the optimal functioning of the SMILE solution. Indeed, individual technology providers, while being naturally able to offer the aggregator the individual technologies critical information to enable the system proper functioning, they might lack the full view of the overall SMILE solution needs. At the same time, it must be highlighted that the fact that a single party is both providing and managing the infrastructure necessary for the system functioning, it might ease the potential replication of the overall SMILE framework deployed in the Orkney demonstration site in other contexts facing similar challenges. In this sense, since SMILE solution has proved its technical suitability in Orkney demonstration site, technology providers might approach other markets to replicate the solution as a sort of consortium led by the organization managing the load controller, achieving cost-efficiency and optimal coordination.

4. An additional option that departs substantially from those portrayed earlier relates to the replication of a framework similar to the one developed by some projects developing complementary solutions, like for instance TraDER[17,18]. It developed a real-time responsive marketplace where flexible assets are exploited, just as in the SMILE case, to match curtailment events, thus reducing the negative impact of those challenges typical of congested grid. The TraDER solution, which has also involved HSO properties where storage systems were already available, allows for real time matching between the need for curtailment mitigation of renewable generators and the flexible demand available at the same point in time (associated, for example to the presence of energy storage assets and switchable devices). By matching "activable" energy consumption supply and curtailment mitigation actions demand, flexible assets owners/managers gain the opportunity to generate revenues[19] in this market-based approach. In this sense, the SMILE solution, that initially did not foresee the creation of any market-based scheme and thus it has not been addressed during the project, might rely on a similar market framework which might involve all the wind turbines and other renewable energy generators included in the Orkney ANM through a centralized marketplace. Just as in the other business cases discussed earlier in this document, financial benefits for either the aggregator deploying and owning the SMILE solution storage technologies or the householders and EVs charging points owners investing in those same technologies, would need to lead to reasonable investments payback periods and eventually to further revenue generation opportunities. In this sense, for example, the business case of householders investing in SMILE technologies might still require financial incentives from the aggregator controlling SMILE assets which would instead be operating in the local marketplace described above.

[17] Electron (2020), Electron led consortium announce BEIS award to develop a new exchange for flexibility (press release). Available at: https://electron.net/electron-led-consortium-announce-beis-award-to-develop-a-new-exchange-for-flexibility/

[18] Current + - (202O), Project TraDER hits milestone that could have 'profound impact' on energy network. Available at: https://www.current-news.co.uk/news/project-trader-hits-milestone-that-could-have-profound-impact-on-energy-network

[19] Electron (2021), Project TraDER report: a first-of-its-kind local flexibility marketplace (press release). Available at: https://electron.net/results-project-trader-local-flexibility-marketplace/

2.3 Business model for the SMILE aggregator

Since in three out of four of the business cases which has been proposed in the previous section imply the presence of an independent organization acting as the local energy system aggregator it has been deemed useful to develop optimal business models associated to this party role. While some of the business model features should vary in order to reflect the specificities of each of the three business cases discussed, most of the essential elements building the general model framework, adapted to the SMILE project, are essentially common to the three proposed solutions.
It has been deemed suitable to adopt the business model canvas approach[20] being a proven tool for the development and the effective visual representation of business models. It is made up of nine building blocks containing key information associated to the essential aspects required to build a suitable and comprehensive model. The perspective on which the following models have been built refers to the one of the independent organization acting as aggregator and providing the aggregation service through the load controller operation.
With regard to the first business case discussed, relying essentially to a long-term contract between the aggregator and generators and to a further contract between the former and consumers (households and EVs charging stations owners) retaining their existing energy supply contracts with energy retailers, it has been deemed suitable the business model represented in the figure below.

Key Partners	Key Activities	Value Proposition	Customer Relationships	Customer Segments
- DSO and TSO (constant communication with system operators is essential to receive curtailment events signal) *- Technology providers of: heat pumps, heat batteries, lithium-ion batteries, EVs charging stations* *- Providers of control and charging algorithms* *- Regulator (enabling regulatory environment and eventual additional monetary incentives to support consumers investments)*	*- Reduction of the impact of curtailment events affecting renewables generators* *- Remote control of energy storage systems, switchable devices and EVs charging points* *- Provision of financial rewards to consumers* *- Provision and maintenance of software and hardware components of the system* *- Upgrade of algorithm and forecasting capability* *- Provide evidence to consumers of contributing to socio-environmental objectives*	*- Financial incentives to consumers/prosumers coupled with socio-environmental objectives that relate to boosting RES penetration, reducing energy waste and optimizing the income of the local development trusts* *- Financial incentives to EVs charging stations owners* *- No discomfort caused to house occupants/EVs* *- No intervention required to house occupants to activate/deactivate storage systems and other SMILE solution devices* *- Generators' revenues increase*	*- Contract between aggregator and consumer* *- Contract between aggregator and EVs charging points owner* *- Contract between aggregator and generator*	*- Small/medium-sized energy consumers (for example residential and small commercial sites)* *- EVs charging stations owners* *- Local renewables generators affected by curtailment events*
	Key Resources *- Aggregation platform (Kaluza)*		**Channels** *- Customer service enabling quick communication with*	

[20] Alexander Osterwalder, Yves Pigneur, Tim Clark (2010), Business model generation: a handbook for visionaries, game changers, and challengers.

	- *Control devices installed in consumers' sites and generators' sites (Kaluza)* - *Control algorithms* - *Switchable devices and energy storage technologies* - *EVs charging stations* - *Developers and IT personnel*		*households, EVs charging points, generators in case they are experiencing issues associated to the system* - *Communication in the form of reports regarding incentives, environmental related benefits, etc. providing visibility over the benefits of the solution*	

Cost Structure	**Revenue Streams**
- *Cost of the software platform* - *Cost of control/communication devices* - *Financial reward to consumers/EVs charging points owners* - *R&D and maintenance activities*	- *Compensation from generators*

Figure 2.8: Business model canvas representing the aggregator perspective in the first SMILE business case.

In the context of the canvas reported above and of the associated business case, it is essential to underline that energy consumers are expected to invest in storage technologies and other SMILE solutions (for example the smart charger to be deployed for EVs charging stations). In this sense, the value proposition must focus on providing relevant financial incentives to this customer segment so that the investment in SMILE technologies is perceived as financially sustainable (it requires an initial notable disbursements). At the same time, considering the relevant cost of storage systems under current market conditions (which will be extensively discussed later in this document), within the "Key Partners" section, it has been included the possibility to receive further financial incentives from governments (indicated as "Regulator") until the market for storage systems will show further cost reductions.

Indeed, since the SMILE solution at residential level required, in most cases, the installation, in addition to the storage systems, of heat pumps and in some cases the replacement of radiators, together with the installation of other ancillary components, the extent of the financial incentives required must be substantial. The control/communication devices necessary to connect distributed sites to the central Kaluza platform are instead reported in the "Cost Structure" section of the canvas as, in line with the literature discussed earlier in this document, this expense is covered by the aggregator. Another relevant aspect in the canvas relates to the technology providers identified as "Key Partners" which include both hardware and software components providers. Finally, the value proposition addresses generators as indeed they are expected to improve their revenues creation capability with respect to the situation prior SMILE technologies implementation. In addition, the same canvas building block includes the provision of visibility to consumers (eventually it might involve also other stakeholders) on the environmental and socio-economic benefits created through the SMILE solution.

The second business case, discussed in the previous section of the document, foresees a limited role for the aggregator as the generator, or its subsidiary company, handles the interactions with customers, both in terms of customer service and in relation to financial rewards. Indeed, the only customer segment relates to generators experiencing curtailment events, while energy consumers become "Key Partners" in the model. A contractual agreement should anyhow be foreseen in order to enable the remote control over assets (and the installation of control/communication devices). The "Cost Structure" for the aggregator does not include anymore any disbursement to reward energy consumers as the generator is responsible for their compensation. Most of the other building blocks are instead similar to the ones associated to the canvas of the previous business case.

<table>
<tr>
<td rowspan="2">Key Partners

- DSO and TSO (constant communication with system operators is essential to receive curtailment events signal)

- Technology providers of: heat pumps, heat batteries, lithium-ion batteries, EVs charging stations

- Providers of control and charging algorithms

- Regulator (enabling regulatory environment and eventual additional monetary incentives to support consumers investments)

- Household consumers (contractual agreement limited to managing assets)

- EVs charging points owner (contractual agreement limited to managing assets)</td>
<td>Key Activities

- Reduction of the impact of curtailment events affecting renewables generators

- Remote control of energy storage systems, switchable devices and EVs charging points

- Upgrade of algorithm and forecasting capability

- Provision and maintenance of software and hardware components of the system</td>
<td rowspan="2">Value Proposition

- Generators' revenues increase

- No discomfort caused to house occupants/EVs (part of generator value proposition to consumers but enabled by Kaluza platform)

- No intervention required to house occupants to activate/deactivate storage systems and other SMILE solution devices (part of generator value proposition to consumers but enabled by Kaluza platform)</td>
<td>Customer Relationships

- Contract between aggregator and generator</td>
<td rowspan="2">Customer Segments

- Local renewables generators affected by curtailment events</td>
</tr>
<tr>
<td>Key Resources

- Aggregation platform (Kaluza)

- Control devices installed in consumers' sites and generators' sites (Kaluza)

- Control algorithms

- Switchable devices and energy storage technologies

- EVs charging stations

- Developers and IT personnel</td>
<td>Channels

- Providing generators with the necessary information on distributed assets as well as on platform performance</td>
</tr>
<tr>
<td colspan="3">Cost Structure

- Cost of the software platform

- Cost of control/communication devices

- R&D and maintenance activities</td>
<td colspan="2">Revenue Streams

- Compensation from generators</td>
</tr>
</table>

Figure 2.9: Business model canvas representing the aggregator perspective in the second SMILE business case.

The third business case entails a further modification of the business model canvas. While the relationship with generators does not change with respect to the model associated to the first business case, the interaction foreseen with energy consumers changes substantially. They will be equipped with SMILE technologies provided by the aggregator (the technologies acquisition becomes a substantial item in the "Cost Structure") which will also perform maintenance activities. In this sense, despite they remain part of the "Customer Segments" section, they are entitled with a limited financial reward since they are not expected to incur in any major investment. However, their role remains crucial as enablers of the deployment of the overall SMILE solution, so a financial compensation is essential to attract and retain consumers within the system.

<table>
<tr>
<td rowspan="2">Key Partners

- DSO and TSO (constant communication with system operators is essential to receive curtailment events signal)

- Technology providers of: heat pumps, heat batteries, lithium-ion batteries, EVs charging stations

- Providers of control and charging algorithms

- Regulator (enabling regulatory environment)</td>
<td>Key Activities

- Reduction of the impact of curtailment events affecting renewables generators

- Remote control of energy storage systems, switchable devices and EVs charging points

- Upgrade of algorithm and forecasting capability

- Provide evidence to consumers of contributing to socio-environmental objectives

- Acquisition and maintenance of storage systems and other SMILE technologies to be installed at consumers' premises</td>
<td rowspan="2">Value Proposition

- Financial incentives to consumers/ prosumers/ EVs charging stations owners associated to installation and remote control of devices and to "forced" energy purchase

- No discomfort caused to house occupants/EVs

- No intervention required to house occupants to activate/deactivate storage systems and other SMILE solution devices

- Generators' revenues increase</td>
<td>Customer Relationships

- Contract between aggregator and consumer

- Contract between aggregator and EVs charging points owner

- Contract between aggregator and generator</td>
<td rowspan="2">Customer Segments

- Small/medium-sized energy consumers (for example residential and small commercial sites)

- EVs charging stations owners

- Local renewables generators affected by curtailment events</td>
</tr>
<tr>
<td>Key Resources

- Aggregation platform (Kaluza)

- Control devices installed in consumers' sites and generators' sites (Kaluza)

- Control algorithms

- Switchable devices and energy storage technologies

- EVs charging stations

- Developers and IT personnel</td>
<td>Channels

- Customer service enabling quick communication with households, EVs charging points, generators in case they are experiencing issues associated to the system

- Communication in the form of reports regarding incentives, environmental related benefits, etc. providing visibility over the benefits of the solution</td>
</tr>
<tr>
<td colspan="3">Cost Structure

- Cost of SMILE technologies to be installed at consumers' premises

- Cost of the software platform

- Cost of control/communication devices

- Financial reward to consumers/EVs charging points owners

- R&D and maintenance activities</td>
<td colspan="2">Revenue Streams

- Compensation from generators</td>
</tr>
</table>

Figure 2.10: Business model canvas representing the aggregator perspective in the third SMILE business case.

3 SAMSO

In order to provide a suitable introduction to the business case that has been discussed and developed reflecting Samsø specificities and challenges, it is worth reporting, as it has been carried out for the Orkney demonstration site, the island key features in relation to its energy system. This will eventually allow other sites located in different regions and facing similar challenges to gain insights on the effectiveness and feasibility of the solutions deployed with SMILE project.

Samsø is an island located in the Kattegat sea area, in Denmark. The island presents a large generation capacity of renewable electricity, especially arising from wind turbines (99%), implying production exceeding local electricity demand. A cable connects the island to the Danish mainland but seeing the excess generation capacity, it is mostly used to export energy. With regard to heating, the district heating made up of three straw-based heating systems and a plant exploiting woodchips and solar energy, covers about 40% of the demand and it is complemented by residential renewable heating solutions (70% of the heat is generated through renewable energy sources). An ambitious objective of phasing out fossil fuels in the island by 2030 has been set[21]. SMILE project consists in a further step toward this goal by addressing the optimization of renewable energy self-consumption in the island through demand-side management strategies and energy storage technologies deployment. The demonstration site in Samsø involves one of the four marinas located in the island, Ballen Marina. The marina context is relevant as it might apply to other scenarios within Samsø (considering for example the other marinas) and in other regions. Concerning electricity demand, Ballen Marina area comprises several sockets, located in the pier, for boats to connect to recharge and for the occupant electricity use, streetlights, heat pumps, a service building where a sauna (with electric heating) is located, and the harbormaster's office (which includes a socket for the charge of the harbormaster EV). It must be pointed out that all the elements reported are located behind the public network meter. From a regulatory point of view, Ballen Marina system legal status does not appear to be included in any category foreseen by the Danish regulatory framework and it is actually identified as an "internal grid" which is a concept that is actually contemplated in case laws. The concept encompasses a grid, as well as energy generation and storage capabilities behind the public network metering point[22]. The local municipality owns both the marina and the cable connecting the marina with the public network. The default utility providing energy to the marina is NRGi which actually owns also the island DSO, Konstant. Energy consumption in Ballen Marina is subject to substantial fluctuations both at annual and at daily levels. Tourism flows which are especially occurring in the summer season and during holidays and weekends in April, May and June lead to peaks in the annual electricity demand[23]. At the same time, in the periods with high touristic flows, fluctuations occur at daily levels, with peaks that tend to arise in the morning between 6:00 and 10:00 and in the afternoon/evening between 15:00 and 21:00[24]. In this context, electricity prices for the marina are relatively high, being, on average, equal to roughly 0.21 €/kWh. The final price charged to Ballen Marina is actually subject to fees (the utility company fees) and taxes (especially those associated to the use of the transmission and distribution grids), that could represent up to 85.7% of the electricity buying price[24], while a limited share reflects the Elspot price (day-ahead wholesale energy market of Nord Pool). Interestingly, a 2021 paper[24], highlighted

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[21] Renewables Networking Platform, 100% renewable energy island (webpage). Available at: https://www.renewables-networking.eu/documents/DK-Samso.pdf

[22] SMILE Project Deliverable D7.1.

[23] SMILE Project Deliverable D3.1.

[24] D. Jozwiak, J. R. Pillai, P. Ponnaganti, B. Bak-Jensen, J. Jantzen (2021), Optimising Energy Flexibility of Boats in PV-BESS Based Marina Energy Systems, Energies.

that, in 2019, during the week where it has been recorded the highest energy demand from boats, the average daily demand fluctuation was approximatively matching the Elspot wholesale price peaks and valleys for the same period. In this sense, high energy demand appears somehow synchronous with high electricity price periods, highlighting the need for investigating opportunities for the Ballen Marina to limit its dependence on the public grid (seeing the relevance of the buying price) and to manage boats electricity demand to shift surges to non-peak price periods. The synchronization aspect associating Elspot price fluctuations to the energy demand pattern from tourists' boats might depend on a series of factors including, for example, Ballen Marina checkout time at 12:00. This leads to a concentration of energy demand prior that time, coming from boats leaving the marina, and to a further increase in demand in the early afternoon, associated to new arrivals.
The annual energy demand of the marina is about 105,000 kWh and the maximum electricity injection to the grid, which is allowed by the DSO, is 49 kW[25].

A final remark before discussing the SMILE solution deployment and the related business case is necessary: due to the Danish regulatory framework, the energy consumed by boatowners connected to the piers was not measured and proportionally billed prior the project start and this option might require further clarifications according to SMILE Deliverable D7.1[26]. In this sense, boatowners were actually charged a lump-sum expected to cover also electricity expenses.

3.1 The SMILE solution

To deal with the challenges that have been portrayed, a solution encompassing the installation of renewable energy sources, energy storage systems and a demand-side management system has been developed in the context of the SMILE project. In this sense, it is worth to report the devices that have been installed in the demonstration site. The local municipality invested in the purchase and installation of a set of photovoltaic (PV) modules which have been located respectively in the service building, the warehouse, the harbormaster's office building and on a fence protecting the dock. To consult the requirements established by the municipality for the tender launched for the purchase of the PV modules (together with PV modules, inverters have been installed) as well as additional technical characteristics of this and other devices installed, please see SMILE deliverable D3.4[27]. The total installed solar capacity corresponds to about 56,260 kWh/year[27] (60.17 kW nominal power installed), which it has been estimated would cover roughly 54% of the annual marina electricity demand in the case all the generated energy would be consumed locally. The remaining share of the annual demand must be met purchasing energy from the utility. It must be highlighted that, in a scenario where a BESS would not be coupled with the installation of the PV modules, a relevant share of renewable energy generated via PV in the marina would not be locally consumed and it is thus exported to the grid (this situation arises from the intermittent nature of solar power whose production is strictly dependent upon meteorological conditions and time of the day and it might not match the energy demand). It appears that the selling price of the energy generated locally corresponds to a fraction of the buying price, being equal to Elspot wholesale price (thus excluding fees and taxes applied at purchase) that is averagely equal to 0.03 €/kWh. In this scenario, in presence of such a substantial difference between the buying and selling price of energy from/to the utility (0.21 €/kWh compared to roughly 0.3 €/kWh) it appears not economically advantageous to rely on energy

[25] Samso Energy Academy (2020), SMILE, Ballen, Samsø (factsheet).
[26] SMILE Project, Deliverable D7.1. Available at: https://cordis.europa.eu/project/id/731249/results
[27] SMILE Project, Deliverable D3.4.

export when supply surplus occurs. In addition, electricity generated from RES that is consumed locally, is not taxed, so there existed a clear need to increase the share of electricity generated by the PV plants that is consumed by the marina. In fact, the installation of the PV modules has been carried out together with the introduction of an energy storage solution.

Indeed, the context appeared optimal for the development, installation and testing in the framework of SMILE of a lithium-ion battery, integrated with the PV system, and which can increase the self-consumption capacity of the marina as well as its flexibility potential which is essential to enable demand-side management. The BESS has been developed by Lithium Balance. The battery, with 237 kWh capacity whose accessible share is 211 kWh[28], is located in a custom built cabin inside the warehouse building of the marina. The cabin hosts also the energy storage inverter enabling energy exchange between the battery and the grid. The presence of the battery energy storage system (BESS) enables to improve the degree of self-consumption of the energy generated from the installed PV modules, bringing the indicator value (the ratio of self-consumption) from 45%, representing the situation in which PV modules would not be integrated with a BESS, up to about 89%, representing the actual Samsø demonstration site scenario where PV modules and BESS were deployed simultaneously. In the context of the SMILE project, a controllable heat pump has been installed to substitute a radiator in the harbormaster's office building, three others have been installed in the service building while a fifth has been mounted in the warehouse [28]. The presence of switchable devices such as heat pumps, which can be controlled centrally and remotely, provides further flexibility potential to the system. Finally, a total of 340 "smart" sockets distributed on a set of 42 posts has been installed on the pier to enable measuring the actual electricity consumption of boats.

3.2 Implicit DR principles

While in the chapter devoted to the Orkney demonstration site a focus on explicit DR and aggregators has been provided, seeing the nature of the Samsø demonstration site (especially considering the "correspondence" between demand surges and Elspot price peaks highlighted earlier) it has been deemed worthwhile discussing implicit demand response strategies and the related business model in order to provide a clear picture of the opportunities and challenges for the Ballen Marina. In addition, the reason why no explicit DR strategies are explored in the Samsø demonstration site business case relates to the fact that no aggregator has been operating in the island so far. Seeing the high electricity prices charged to the Ballen Marina by the utility, it might appear relevant to consider the possibility to manage (and shift) the periods in which energy is imported from the grid. It must be in fact highlighted that the marina can control the BESS, adopting charging and discharging strategies reacting to Elspot day-ahead market prices[29], limiting electricity imports when energy prices are high. At the same time, together with many diverse strategies, the battery might be employed as a "buffer" which implies charging using PV excess power and discharging when solar generation does not fully meet demand (BESS "greedy" strategy). Let us first consider the former option. It actually reflects an implicit DR strategy deployed through a time of use (ToU) tariff which implies an energy consumer/prosumer's (Ballen Marina in this case) reaction to energy market price signals[30] (Elspot price). For the sake of

[28] J. Jantzen (2021), SMILE, Ballen, Samsø (factsheet).
[29] Nord Pool Elspot prices are available at: https://www.nordpoolgroup.com/historical-market-data/
[30] IRENA (2019), Innovation landscape brief: Time-of-use tariffs, International Renewable Energy Agency. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_ToU_tariffs_2019.pdf?la=en&hash=36658ADA8AA98677888DB2C184D1EE6A048C7470

clarity, ToU can, in principle, be deployed both following a static pricing scheme where for specific times of the day specific rates are preliminarily set, or a real-time pricing. Other schemes exist such as variable and critical peak pricing tariffs. Different local regulatory frameworks might either enable or prevent the adoption of the tariff schemes that have been mentioned. A standard implicit DR business model, built representing the perspective of the electricity supplier providing the opportunity to energy consumers, is reported below (from Ma et al.[10], (2017)).

Partners	Activities	Value Proposition	Customer relation	Customers
Regulators Market operators Billing company Datahub	Customer analysis to provide different DR offers; Customer education to promote the offers Customer consulting due to customer constraints Billing system integration Staffs/expert recruitment	Receive a lower bill	Different DR offers due to buildings' own preferences and constraints Increase customers' satisfaction rate due to the lower bill	All buildings
	Resources Price signal Regulators' support		**Channels** Part of the supply contract	
Cost Structure Integration of DR offers into supply contract (which might need DR experts and facility purchasing) Price signal sending to customers (facilities and staffs)			**Revenue Streams** Customer loyalty New customers due to a competitive offer	

Figure 3.1: Implicit DR standard business model.
Ma et al. (2017)

It is worth to highlight that in the business model canvas reported above, the value proposition corresponds to the chance for the energy consumers (indicated as "All buildings" in **Figure 3.1**, in the canvas section named "Customers") to realize monetary savings, which is substantially different from the concept of financial reward that has been investigated earlier in this document. The "Cost Structure" section of the above canvas, addressing the energy supplier expenses and required investment to deploy implicit DR, is not relevant in this document analysis as the Ballen Marina had already the option to purchase electricity from the utility company following a "by-the-hour" model[31] (accessing the hourly prices a day in advance). A consideration that does not transpire from the canvas relates to the fact that ToU tariff has the potential to support congestion management as indeed the ToU model might be applied also to distribution network-related fees[32]. Potentially, this option would be extremely relevant in Samsø demonstration site scenario being transportation fees in the order of 0.03 €/kWh[24]. In this sense, **ToU network tariff** would open up further opportunities to generate savings when energy must be imported from the grid. In particular, assuming the average final buying electricity price equal to 0.21 €/kWh for the marina, in which, on average, 0.03 €/kWh (representing about 14% of the total amount) is subject to real-time pricing in Elspot market, offering saving opportunities, and 0.03 €/kWh representing energy transportation cost that would be similarly subject to varying network tariffs, the extent of the cost reduction enabled by implicit demand response would increase substantially (in practice a further 14% of the 0.21 €/kWh average energy import price would

[31] SMILE Project, Deliverable D3.4.
[32] Eurelectric (2016), Network Tariffs: A Eurelectric position paper. Available at: https://cdn.eurelectric.org/media/2012/network_tariffs__position_paper_final_as-2016-030-0149-01-e-h-5AF7DC88.pdf

be subject to variability and could offer further savings opportunities). In Denmark, the regulatory framework allows, in principle, the differentiation of prices addressing the improvement of the grid efficiency and its safety, however the dynamic ToU network tariff does not currently apply to Samso, so the business case must demonstrate its financial sustainability solely relying on the exploitation of the variability attached to the Elspot wholesale market price.

A further option which has been investigated in the context of the SMILE project, which is still associated to the ToU tariff logic, relates to the opportunity to differentiate boatowners electricity costs deploying a static pricing-scheme. It relates to the chance to manage boats-related load (which represents the largest demand share in the marina) so as to move a component of their daily consumption (the one associated to boats battery charging) during non-peak price periods. In this way, basing on the observation of the average hourly prices charged by the utility to the marina, a model has been drawn, implying the presence of time slots with differing price (€/kWh) to induce boatowners to adapt their energy consumption in reaction to the rate charged. The model time-slots are the following[24]:

Time slot	Electricity price to boatowners
6:00 – 10:00	0.40 €/kWh
10:00 – 15:00	0.34 €/kWh
15:00 – 21:00	0.40 €/kWh
21:00 – 6:00	0.22 €/kWh

Table 3.1: Jozwiak et al. (2021) simulation timeslots and with pricing.

The model simulation, which might be compared to a situation where a flat tariff equal to 0.34 €/kWh is applied, **relying on a set of assumptions**, highlighted a number of results that are essential in outlining a suitable business case for the Samsø demonstration site:

- In the **periods where the main touristic flows occur**, with the BESS being underutilized, considering that PV generation is lower than electricity demand and it is thus entirely consumed (the BESS would charge only in case of excess renewable electricity production), the **optimal adaptation of boatowners behavior to the ToU tariff** would bring **limited cost savings** to both the marina and the tourists. Both the adaptation of the battery control algorithm to optimize cost savings for the marina (implying a change of the battery strategy which would be charging with electricity bought from the grid) and the integration of DR and BESS control addressing the simultaneous optimization of tourists and the marina's cost, would not improve substantially the results.
- In the **periods where touristic flows are limited**, such as late summer weeks and late autumn weeks, coupling DR and the utilization of the BESS (charging only when excess PV production is available) lead to optimal results for the marina. Energy import is brought to 0 (in both the weeks in which the simulation was carried out), energy export is either reduced, in late summer, or zeroed, in late autumn. These results imply no energy cost for the marina (and an increase in revenue due to export to the grid in the former case) but very limited savings are offered to boatowners.

Two major considerations must be reported:

- The insights from the conducted study that are briefly summarized in this document are the result of a set of simulation carried out assuming a full participation of the docked boats to the DR program. In addition, as the authors clarified, load shifting might also involve components

other than boats which are located in the marina area but that were not included in the simulation.
- It is essential to recall that under current regulatory framework, billing boatowners for their actual electricity consumption seems needed to be clarified according to deliverable D7.1[22].

Taking into account the above-mentioned considerations, the insights produced by the study, from a purely commercial point of view, provide an invaluable information which relates to the fact that the savings offered by implicit DR programs to boatowners are significantly limited even with an assumed optimistic full participation by tourists. In this sense, it seems even more essential to address the business case focus toward a solution which does not require billing boatowners for their actual consumption. At the same time, the value of DR for the marina might be relevant if projected to a year-long scale (as indicated, relevant savings can be realized during non-tourism seasons), that is why, the promotion of DR practices for boatowners in Ballen Marina might have to drift apart from the financial incentive argument and subsequently focus on others, including the environmental one. In this sense, it might be relevant to stress the "100% renewable energy island" concept which might actually appeal, at least a share, of the tourists visiting Samsø.

Furthermore, it might be underlined that cost-savings enabled by the voluntary adaptation of boatowners behavior are anyhow benefitting the marina, which is owned by the local municipality, and thus benefits are directed to the local community, in a not-for-profit perspective. Regarding the "environmental" argument that might be exploited in this scenario, research has found that the "informational strategy" addressing the increasing awareness of the impact of the individual's behavior might actually be effective when the desired behavior is not excessively costly[33]. In this context, also an increase in the individual's effort is regarded as "cost". The extent of the effort required to boatowners to change their consumption pattern to enable the marina cost-savings, which can be associated, for example, in off-season periods, to avoid energy imports from the grid, should thus be evaluated. In some circumstances, actually, the environmental argument may be proving effective and compete with the financial-related one (in presence of a scenario where the financial benefit offered is limited, as in the case of the single boatowner during a week-stay in the marina) especially in situations when the sustainable behavior may affect the individual's self-concept[34].

The automatic and remote control of boats charging strategies (not manual) is excluded from the possible options in relation to the inconvenience, in terms of discomforts, that this practice might cause to boatowners (however, electric fuses would cut off supply in the case the required rise in consumption would exceed the marina permitted safety levels). In this sense, promoting the voluntary participation highlighting the environmental benefits brought to the activity appears a more reasonable option.

In this context, the primary objective of the 340 smartened sockets measuring the actual consumption of boats that are plugged-in shifts from DR enablers to a data-collection device which enables the local municipality to review and re-design the tariff applied to boatowners, in the form of a fixed lump-sum for a package of services by taking into account the outcome of D7.1. It is crucial to take into account that factors such as the boat size and the number of occupants dramatically affect the electricity that

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[33] L. Steg, C. Vlek (2008), Encouraging pro-environmental behaviour: An integrative review and research agenda, Journal of Environmental Psychology.
[34] J.W. Bolderdijk, L. Steg, E. S. Geller, P. K. Lehman, T. Postmes (2012), Comparing the effectiveness of monetary versus moral motives in environmental campaigning, Nature Climate Change.

is consumed by the boat. In this sense, the solutions developed in the framework of SMILE, can enable a more sophisticated tariff setting which might be able to cover in a more consistent way the costs incurred by the marina for electricity provision.

3.3 Additional options

To further the discussion on the mechanisms that may be able to render the Samsø demonstration site business case financially sustainable, it is essential to explore the scenario where boatowners are not involved in DR programs. A strategy operating the BESS, reflecting a demand response model (with dynamic pricing), based on load and weather forecasting has been developed and tested in the Marina environment. Forecasts results combined with other parameters should ideally define an optimal strategy which exploits insights on PV generation and the Marina demand foreseen patterns and expected Elspot prices, to maximize savings on the energy bill (revenue generation through energy export might be an additional factor contributing to financial sustainability despite the very limited selling price). However, the strategy proved not suitable in the case of the Ballen Marina due to challenges in properly forecasting weather and load profile for the following day on an hourly basis. In an eventual replication site of the SMILE solution, where local weather is subject to a lower degree of variability, the strategy relying on that kind of forecasts might prove more effective. In this context though, it is worthwhile to highlight that SMILE solution demonstrated in Samsø may actually adapt to a variety of replication sites with different operational conditions as demonstrated by the possibility to test a number of algorithms in the same pilot environment. This aspect clearly opens up a range of commercial opportunities also for the technology providers involved in Samsø demonstration site.
A further feature which characterizes the Samsø island and simultaneously might prevent the inclusion of forecasting algorithms relates to the fact that, as reported earlier in this document, the Ballen Marina is subject to substantial fluctuations in terms of energy demand across the year (tourism/non-tourism seasons and periods) and that might add further challenges to the effectiveness of the strategy. In sites where more regular daily and yearly energy consumption patterns could be identified, the use of load forecasting algorithms tested in the pilot might appear more suitable and actually bring substantial savings on the electricity bill.

A further attempt to deploy an implicit DR strategy through the BESS control relates to the optimization of charges and discharges commands reflecting Elspot prices fluctuations across the day (removing the forecasting component of the strategy described above). However, this strategy proved that the monetary benefits achievable through its implementation are not too dissimilar from those brought a battery control algorithm targeting maximum self-consumption. This outcome is mainly due to the fact that fluctuations in daily Elspot prices are of limited extent such that exploiting differences in hourly rates does not bring significant monetary benefits, and not when charging and discharging is associated with electrical losses. Moreover, as highlighted earlier in this document, the buying price in Samsø is largely affected by fees and tariffs while Elspot price represents just a fraction of the electricity cost per kWh incurred by the Ballen Marina. In this sense, the share of the final buying price which is somehow variable and thus manageable (controlling purchase times) is limited.
The sub-optimal strategy for the operation of the BESS installed in the Marina, which at the same time appears to be the most cost-effective, relates to the “greedy” or “buffer” function, which address self-consumption maximization. On top of the savings generated maximizing self-consumption, the access to day-ahead prices in Elspot, at this point, might occasionally bring further benefits not through automatic operation of the BESS but through careful planning from the marina side. As emerged in a discussion with Samsø Energy Academy, SMILE project partner, the easiest example relates to a situation in which it is fairly certain that the following day would be cloudy, entailing scarce PV production, and energy demand (for instance from tourists’ boats) is expected to be high; in this

scenario, energy import from the grid can be booked for the following day at specific off-peak times (for instance during the night where prices are expected to be lower) in order to charge the battery which otherwise would most probably not be in operation due to high energy demand and low solar irradiation. So, savings can be effectively generated by avoiding peak prices. In this way, a greedy strategy operating the BESS coupled with an occasional adoption of implicit demand response exploiting Elspot prices limited variability, appears, at this point, the most suitable solution from a business perspective.

A further advantage associated to the buffer strategy, relates to the practicality and straightforwardness of the algorithm controlling the BESS. Indeed, it requires limited software related work and maintenance which is a key factor that must be considered when dealing with a small organization such as the Ballen Marina and the municipality. In fact, their investment capacity in software development and maintenance, outside SMILE demonstration environment, is limited. This is a key aspect to be considered for the eventual replication of the SMILE solution in different sites.
In this context, it is provided an evaluation of the main costs and associated monetary benefits attached to the PV+BESS business case for the marina. It must be highlighted that the assessment has been carried out building on initial assumptions provided by Samsø Energy Academy and assuming that the BESS is operated following the "greedy strategy" (no assumption has been made to include the occasional use of implicit DR or the exploitation of different charging algorithms).

3.4 PV+BESS Model financial evaluation

The evaluation of the business case is based on a set of assumptions that are discussed hereafter. Computations refer to a 25 years' period, from 2019 to 2043, while in 2018 it has been assumed the purchase and installation of the PV and the BESS starting functioning the following year. In the context of the simulation, it has been considered the investment required to purchase and install the necessary PV modules (comprising inverters), the one associated to deploy the battery developed in the SMILE project environment, including the connected inverter. PV panels have been associated with a lifespan corresponding to 25 years (reflecting the simulation chosen duration) while the BESS, adopting a prudential approach, has been foreseen to have a lifespan equal to 15 years[35,36].
With regard to the annual electricity demand from the Ballen Marina, it has been employed the value of 105,000 kWh/year, while the maximum annual PV production equals 56,000 kWh. While the former data has been kept constant for the whole 25-years' period, the latter has been assumed to be subject to a 0.63% annual degradation rate affecting PV panels. The self-consumption rate, assumed constant for the period, equals 81% and corresponds, in the first year, to about 45,150 kWh. Concerning electricity prices, as discussed earlier, 0.21 €/kWh corresponds to the purchase rate while 0.03 €/kWh corresponds to the selling rate (these are average starting prices). Both rates are subject to a 0.25% annual increase, reflecting Elspot price behavior in the period 2013-2017[23]. Finally, a loan covering the entire initial CAPEX considered has been assumed to be taken by the municipality. For reasons of simplification, the loan relates to a 15 years' period and an interest rate equal to 1.61% is adopted (consistent with Samsø demonstration site initial assumptions[23]). With regard to OPEX, the main

[35] L. da Silva Lima, M. Quartier, A. Buchmayr, D. Sanjuan-Delmás, H. Laget, D. Corbisier, J. Mertens, J. Dewulf (2021), Life cycle assessment of lithium-ion batteries and vanadium redox flow batteries-based renewable energy storage systems, Sustainable Energy Technologies and Assessments. Available at: https://www.sciencedirect.com/science/article/pii/S2213138821002964
[36] PV Magazine (2021), How long do residential energy storage batteries last? Available at: https://pv-magazine-usa.com/2021/09/21/how-long-do-residential-energy-storage-batteries-last/

figures considered relate to the PV modules and the BESS operation and maintenance expenses. Obviously, it is also included in the evaluation, among annual expenses, the electricity purchase value. To these cost items, it is added the debt interest rate payments and the PV inverter replacements (whose cost has been set to decrease in time, reflecting an assumed 44% cost decline in the first 10 years of the simulation and of further 20% in the following decade) in Year 11 (2029) and Year 21 (2039). The battery replacement cost in Year 16 (2034) has been attributed with a prudentially estimated value equal to 100 €/kWh following a set of references[37,38,39]. Concerning components replacements, as these investments are of a limited size compared to the one required at the beginning of the project, it has not been considered the need for further loans. The battery nominal capacity, reflecting the one actually developed and installed in Samsø, equals 237 kWh. Residual values for those assets deployed in the pilot environment whose lifespan exceeds Year 25 (2043) have been included in the cashflow computation.

From the elaboration of input data, it has been firstly evaluated the "Base case" situation associated to the scenario where no investment to purchase PV modules and BESS is made. In this context, Ballen Marina would rely entirely on the public grid to meet its energy needs thus the sole expense taken into account would consist in the electricity import. Since electricity cost has been simulated to slightly grow in time, the base case resulting annual cashflows reflect a decreasing trend (as electricity consumption has been assumed constant). A representation of the base case and of the PV+BESS system associated cashflows is reported below.

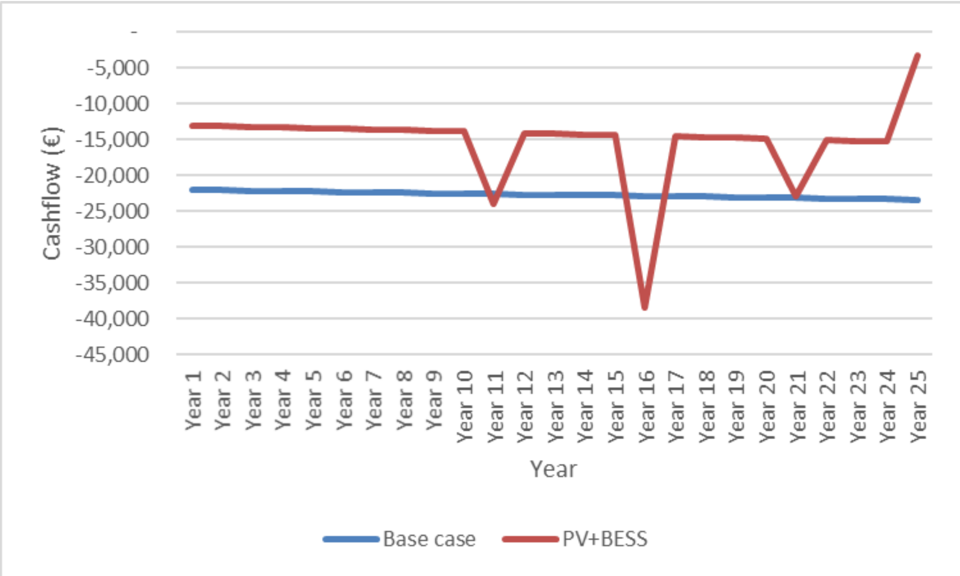

Figure 3.2: Cashflows comparison for the period 2019-2043.

Obviously, since it is not considered any change in any of the Marina main revenue sources (which have been excluded from the simulation), both cashflow representations appear negative (essentially,

[37] Energy Monitor (2021), Reducing battery cost is essential for a clean energy future. Available at: https://energymonitor.ai/tech/energy-storage/reducing-battery-cost-is-essential-for-a-clean-energy-future
[38] IRENA (2017), Electricity storage and renewables: Costs and markets to 2030. Available at: https://www.irena.org/publications/2017/oct/electricity-storage-and-renewables-costs-and-markets
[39] BloombergNEF (2020), Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh. Available at: https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/

it has been carried out a costs comparison, pursuing as main objective the realization of savings through PV+BESS introduction). Indeed, the only item with a positive sign which has been included in the graph elaboration relates to a limited annual revenue associated to energy export to the grid. As discussed extensively earlier in this document, the impact of that revenue source is bound to remain limited as export price to the public grid is significantly low. It has not been included in the representation Year 0 investment in PV+BESS system, in order to allow a year-to-year comparison. In this way, it is visible how the investment in generation and storage systems enables substantial annual savings comprised between 8,000 € and 9,000 €. Those valleys associated to the PV+BESS cashflow curve relate to the components replacement mentioned before in this section, while the final year spike relates to the inclusion, in the cashflow, of the system residual value. It must be pointed out that the PV+BESS cashflow does not include, as a positive item, the savings generated through reducing the energy import from the public grid. This choice has been made to enable a clear comparison between the two scenarios cashflows. In fact, the key objective pursued by the introduction of the PV+BESS system relates to achieving significant savings for the marina, minimizing energy imports from the grid, thus it has been reasonable to carry out a comparison between the base case-related cashflow and the one associated to the investment in generation and storage capacity.
A representation of the two cashflows difference for the period 2019-2043 is reported in the figure below.

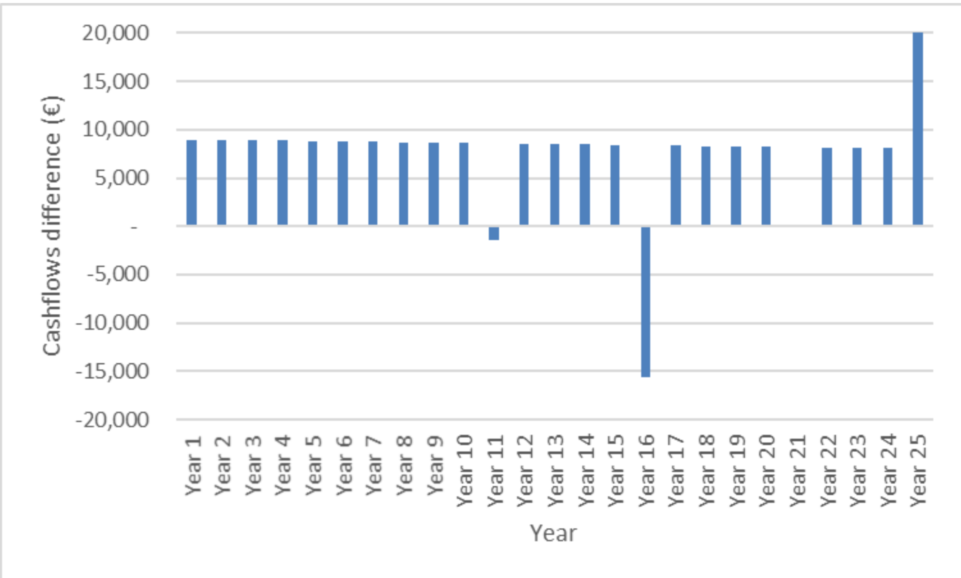

Figure 3.3: Cashflows difference representation for the period 2019-2043.

Considering the cumulative cashflows difference, to obtain a positive value at the end of the 25 years' period, it is necessary to consider a BESS initial cost which is at least equal to about 416 €/kWh. With this value, keeping all the other parameters unchanged, in year 2043 (Year 25), the cumulative cashflows difference becomes positive. It must be specified that such result relies also on the presence of the technologies residual value allocated in the last year of the analysis. To obtain instead the same outcome but excluding the impact of residual values, the BESS cost should be roughly equal to 365 €/kWh. It is worth to underline that this price includes also the BESS inverter.
By further decreasing the BESS cost, it is possible to achieve a cumulative difference of the two cashflows earlier in time. For example, assuming the BESS unit cost as equal to about 250 €/kWh, it is possible to achieve a positive cumulative cashflows difference in Year 22 as shown in the representation of the cashflows cumulative difference related to the last 15 years of the analysis.

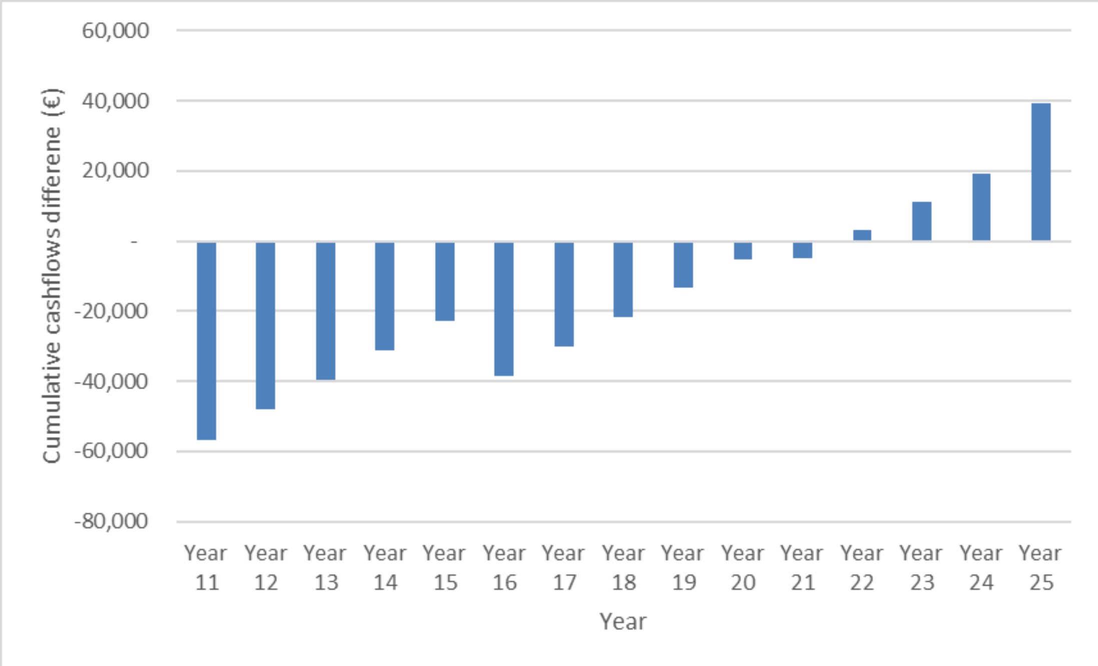

Figure 3.4: Cumulative cashflows difference for the period 2029 – 2043 assuming a BESS cost (including inverter) equal to 250 €/kWh.

Moreover, it has been observed that it is possible to reach a positive cumulative cashflows difference in Year 15, just before the year in which it has been foreseen the substitution of the BESS, by assuming a storage systems initial cost equal to about 154 €/kWh. However, the cashflows difference, assuming that initial rate, would still be negative in Year 16 due to the BESS replacement-related expense.

At the same time, it must be highlighted that the variation of parameters other than the BESS cost might significantly affect the simulation; for example, financial results improvement might be associated to changes in the energy export (to the public grid) and import price or to a reduction of the investments necessary for PV modules or even to an increase of BESS lifespan.

Let us, for example, consider, keeping the other initial input discussed at the beginning of this section constant, an increase in Year 1 energy price (both import and export) for the marina of 10%. This would entail a buying price equal to about 0.23 €/kWh and a selling price still corresponding to about 0.03 €/kWh (a 0.25% annual rate increase still applies to the simulation). Such assumed slight variation would already entail a positive cumulative cashflows difference between the two scenarios (base case and PV+BESS) in Year 24.Electricity price appears to be a critical variable affecting the financial advantage associated to the PV+BESS system investment. Indeed, a change in this variable acts parallelly on two elements of the cashflows:

- It increases the value of energy export towards the public grid, despite this revenue source retains a limited impact on the overall financials evaluation in Samsø case. However, in contexts with higher export tariffs, this effect would acquire a much larger relevance.
- It increases the cost of importing energy from the grid for both scenarios cashflow, but a much larger impact is associated to the base case since the reduction in the degree of dependence from the public grid, given by the presence of generation and storage capacity on site, partially isolates the marina from the impact of the rise in price (in the PV+BESS system investment scenario).

It is reasonable to conclude that the business case for PV+BESS systems does not only heavily depend on the required initial investment, but electricity price represents another essential variable determining the financial sustainability of the technologies deployment. Please refer to the figure below for the representation of the cumulative cashflows difference during the last 15 years of the simulation.

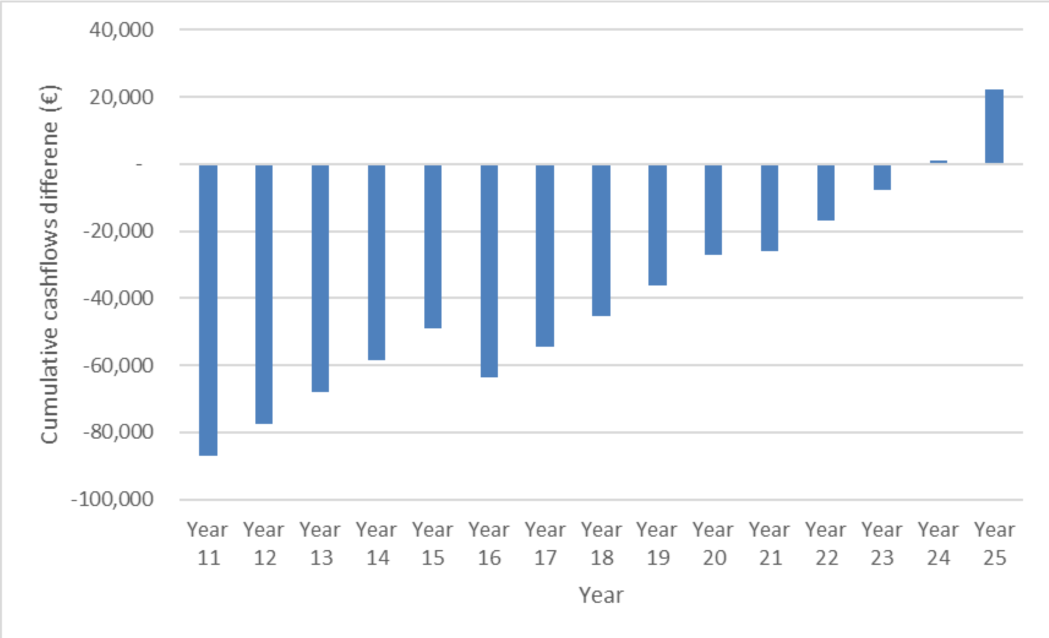

Figure 3.5: Cumulative cashflows difference for the period 2029 – 2043 assuming an initial electricity price 10% higher with respect to that indicated in the initial simulation input.

Finally, it should be pointed out that the presence of incentives might be foreseen to improve the financials associated to the PV+BESS system under current market conditions.

4 Madeira

A key feature differentiates the scenario and the challenges of Madeira from those of the other two SMILE demonstration sites as the Portuguese island is located over 1.000 km away from the European continent, implying no electricity network connection with it. In this sense, the electricity grid of the island must operate autonomously to accommodate local energy demand and generation, while a local organization, the publicly owned utility company Empresa de Electricidade da Madeira (EEM) is simultaneously operating as the island DSO, TSO and energy supplier[40]. In this respect, the autonomous region of Madeira, seeing its isolated location, benefits from derogations with respect to the liberalized market rules[41]. Madeira, just as other islands whose energy grid is completely isolated, is dependent upon fossil-fuel imports. As reported in D4.1, the island average energy mix in a one-year period comprised between 2016 and 2017 was reliant, for over 54% on a diesel-powered thermal plant while renewables accounted for just over 30% of total consumption. The latter percentage was expected to reach 50% between 2022 and 2023, implying a substantial growth of the share in just a six-years' time. This objective was expected to be reached through addition in pump hydro storage systems capacity, wind power and solar power generation capacity, and refurbishment of hydro power stations[42] (to increase the network flexibility). Moreover, by increasing the number of storage stations, the renewables share might reach 70% in the coming years[43]. In 2021, in the period January-August, electricity generation in the Madeira region relied still heavily on fossil fuels, almost 39% of the total generation and just over 21% was coming respectively from diesel and natural gas-powered plants. Almost 39% of generation was associated to renewables[44] (about ten percentage points away from the objective).

[40] SMILE Project, Deliverable D4.1. Available at: https://cordis.europa.eu/project/id/731249/results
[41] SMILE Project, Deliverable D7.1. Available at: https://cordis.europa.eu/project/id/731249/results
[42] Energynautics (webpage), Power System in Madeira & Porto Santo. Available at: https://hybridpowersystems.org/power-system-madeira-porto-santo/
[43] European Commission (2021), In focus: EU islands and the clean energy transition. Available at: https://ec.europa.eu/info/news/focus-eu-islands-and-clean-energy-transition-2021-jul-15_en
[44] APREN (webpage), Production. Available at: https://www.apren.pt/en/renewable-energies/production

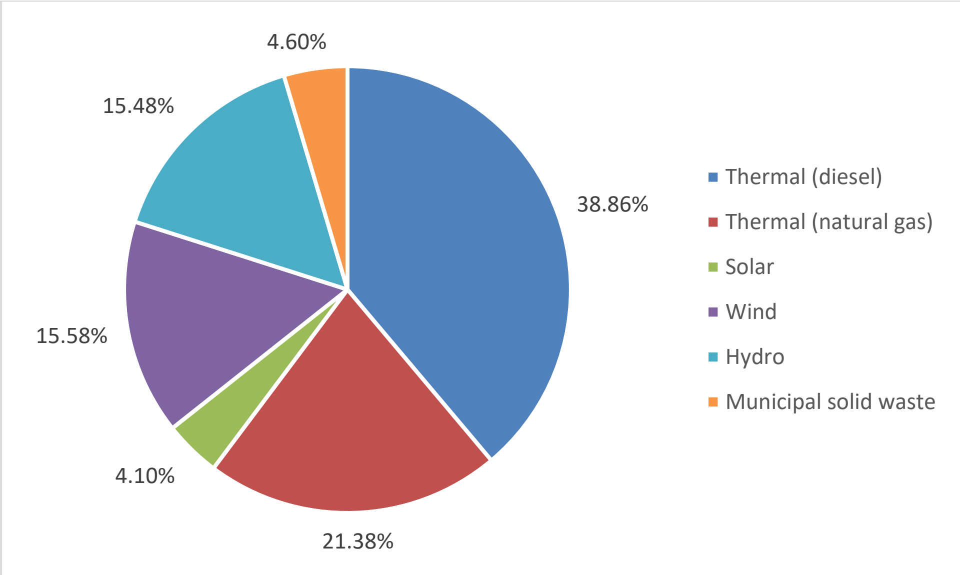

Figure 4.1: Electricity generation in Madeira Island Region (January-August 2021). Adapted from APREN 2021 data[44].

In terms or energy demand in the island, considering provisional values from the year 2019[45], showed that the main load categories relate to non-domestic and domestic demand while industry accounts for a limited share of the total (11.5% of the total). In the figure below, the provisional breakdown for the year is reported.

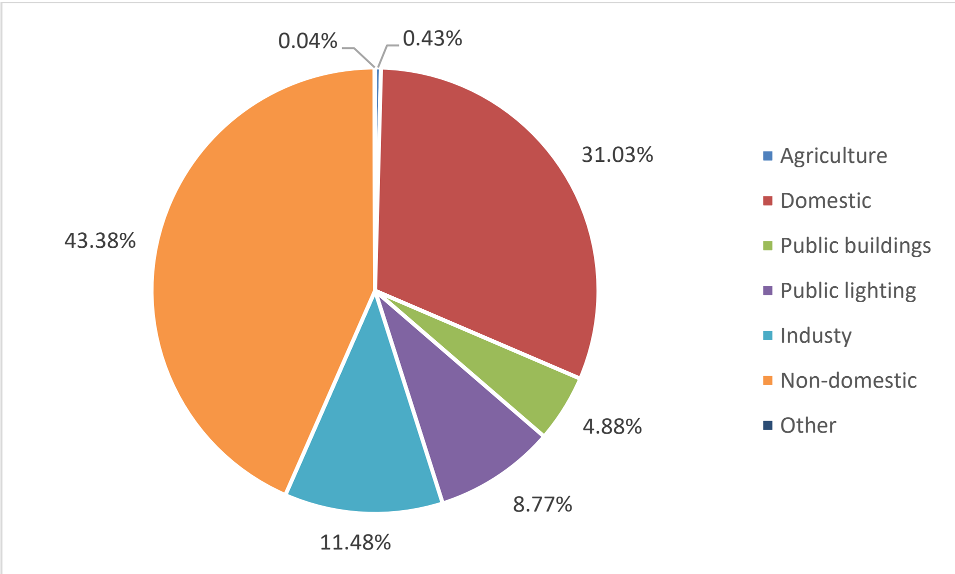

Figure 4.2: Electricity consumption per sector in the Autonomous Region of Madeira. Direção Regional de Estatística da Madeira 2020 data[45].

[45] Direção Regional de Estatística da Madeira (2020), Energia Elétrica na Região Autónoma da Madeira – 2019 (spreadsheet). Available at: https://estatistica.madeira.gov.pt/download-now/economica/energia-pt/energia-ee-pt/energia-ee-quadros-pt/energia-ee-quadros-geral-pt.html

In the context of the SMILE project, both domestic loads (a set of residential sites) and non-domestic ones (commercial sites and EVs charging stations) have been included in the solution deployed. For the sake of clarity, residential and commercial sites involved can actually be identified as prosumers as they generate energy through PV modules and are simultaneously identified by the Portuguese legal framework as UPACs (Unit Production for Self-Consumption). At the beginning of the SMILE project, and during the most if its duration, UPACs were, in general, prohibited to inject excess generation into the public grid[40] (this was not the case for UPACs involved in the project as a derogation has been granted to evaluate the amount of energy which was generated by the prosumer but not self-consumed). A major update in this respect relates to a 2021 regional legislative decree[46] enacted by the Regional Assembly which entitles UPACS to export energy generated to the public grid. In this sense, it must be highlighted that SMILE technologies deployments were thus addressing self-consumption maximization in UPACs, neglecting the option relating to the injection of the energy produced in the grid (which is remunerated). At the same time, as indicated in the information platform, developed within the SMILE project, self-consumption is still suggested to be regarded as the main objective for individuals evaluating the opportunity to install PV modules and to subsequently become UPACs as compensation for injection might not offer a significant revenue potential[47]. Indeed, a feed-in tariff coupled with fiscal incentives was available since 2009 for micro and mini production PV installations. It has been gradually reduced until 2015, when injection in the grid has been prohibited. The gradual reduction of the financial incentive for export to the grid was reflected by a slowdown of new solar installations[48]. In this sense, since a low financial incentive reduced the attractiveness of PV installations, addressing self-consumption as primary strategy appears a reasonable solution.

The objective to generate half of the energy consumed in Madeira from RES poses a challenge to EEM operations, due to the intermittent nature of solar and wind power. In this respect, in addition to the investigation of UPACs self-consumption optimization options, SMILE project addressed smart-charging strategies for EVs (which enable flexibility) and the voltage and frequency control potential (together with peak-shaving capabilities) offered by the installation of a BESS in a distribution point with a number of connected micro-producers. A key element which characterizes the SMILE solution relates to the presence of a centralized Energy Management System which communicates and coordinates the main components developed and installed in the context of the project.

4.1 UPACs

The Lithium Balance residential BESS has been developed and installed in the SMILE residential UPACs after the evaluations of parameters including: the degree of self-consumption prior energy storage installations which is relevant to determine the self-consumption optimization potential brought by the battery, the BESS capacity, the presence of previously installed energy storage systems and other factors that might have affected the testing[49,50]. The first consideration appears essential in the assessment of the monetary benefits brought by BESS installation to optimize self-consumption as in

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[46] Região Autónoma da Madeira - Assembleia Legislativa (2021), Decreto Legislativo Regional n.° 1/2021/M, article 7 “Direitos do autoconsumidor”. Available at: https://dre.pt/web/guest/home/-/dre/153013708/details/maximized

[47] Energias Madeira (webpage), Principais aspetos a considerar. Available at: https://energiasmadeira.pt/por-onde-comecar/#aspetos

[48] D. Garigali Pestana, S. Rodrigues, F. Morgado-Dias (2018), An overview of the Solar Photovoltaic policy in the Region of Madeira.

[49] SMILE Project, Deliverable D4.5. Available at: https://cordis.europa.eu/project/id/731249/results

[50] SMILE Project, Deliverable D4.7. Available at: https://cordis.europa.eu/project/id/731249/results

the case PV daily generation somehow matches the household's electricity demand (both in terms of generation capacity and consistency with the consumption pattern), the business case associated to the introduction of the battery might prove financially unsustainable seeing the substantial investment needed for the purchase of the equipment and the limited savings achievable in such scenario.

Irrespective of the installed PV capacity, it is worth assessing the initial degree of self-consumption and the share of electricity purchased from the grid which may be addressed by the BESS which was preliminarily projected during the SMILE project. The information has been extracted from the public deliverable D4.7[50]. The residential UPACs in which it has been chosen to install the storage systems, following a preliminary testing phase prior the installation, showed very different initial self-supply rates comprised roughly between 14% and 48%, corresponding to self-consumption levels ranging between 78% and 29%. Interestingly, the highest self-consumption rates were generally found in those sites with low self-supply rates and vice versa. In this sense, it should be highlighted the initial situation, prior Lithium Balance BESS installation, might have appeared suboptimal in a set of sites where existing PV modules were either over-sized or under-sized with respect to the residential site daily consumption patterns. In the context of this preliminary self-supply and self-consumption rates evaluations, it has been projected the maximum potential self-supply rate which could be eventually achievable through the introduction of the storage system. In principle, those UPACs showing already high self-consumption rates would potentially have smaller room for improvement in terms of self-supply performance with the introduction of the BESS (the amount of initial unused energy which is potentially captured in the storage system is limited). The opposite generally applies to sites where large PV generation is available, but it is, in the initial situation, not exploited. In fact, the introduction of the BESS could potentially improve substantially the performance of those sites with low initial self-consumption rates. Indeed, in an optimal scenario, those UPACs showing initial low levels of self-consumption, close to 30%, might eventually reach a maximum self-consumption level equal to about 100% or even exceed the full self-consumption rate. This would mean that, in addition to be able to fully satisfy domestic energy needs, a share of the UPAC renewables generation could be eventually exported to the grid.

Of course, in reality, the systems deployed (through the introduction of the battery and of the ancillary components required) face multiple challenges posed by system failures, the charge/discharge strategy adopted, fluctuations in demand and generation, etc.

When residential sites are subject to a single-rate tariff as number of UPACs in Madeira[51], in principle, it is undermined the chance to employ BESS to exploit implicit DR by deploying a charging strategy that avoids peak-pricing periods and takes advantage of those times of the day in which electricity price is lower. On the other hand, in the case of UPACs involved in the demonstration site in Madeira for which a dual ToU tariff contract is available, the generation of savings on the energy bill through the adoption of DR strategies has been evaluated.

Irrespective of the type of tariff which depends on the contractual arrangement between the prosumer and the energy supplier, since the regional objective consists in further increasing the share of RES in the island energy mix, an evaluation of the business case triggered by installing BESSs is necessary as it might foster further PV modules installations.

[51] SMILE Project, Deliverable D4.3. Available at: https://cordis.europa.eu/project/id/731249/results

4.2 PV+BESS System

The largest concern attached to batteries installation in residential and small commercial sites might relate to the high investment required to acquire the necessary equipment. Indeed, while PV modules experienced a 90% decrease in price during the decade 2009-2019[52], batteries still require substantially high capital expenditure. The evaluation of research outputs in contexts that somehow relate to the SMILE project one appears essential for deepening the understanding of the residential PV+BESS system framework. A recent study[53], from 2019, addressing various self-consumption business models in Germany, found out that actually residential energy storage, differently from district battery storage (which in the country, due to the regulatory framework, is undermined by the application of taxes and fees, despite presenting lower CAPEX values) might be currently profitable, without feed-in tariffs and only for systems of limited size (around 2 kWh); however, also in the case the investment appears profitable, it still presents a net present value that is lower than the situation where no storage is installed. The study employed an initial 1000 €/kWh value for CAPEX projected in the year 2017. It is also simulated the scenario in 2025, where the initial CAPEX value employed is reduced by 40% (600 €/kWh). Such simulation actually led to interesting results as the business model related to the installation of home battery storage, with the battery working as a buffer for PV generation, increases its profitability to such an extent that the associated NPV exceeds the one connected to the "no energy storage" scenario. It must be finally highlighted the fact that despite low or no profitability, at that time, attached to the home battery storage business model, installations of batteries in residential site was growing (in Germany), probably due to reasons associated to the value perceived in self-sufficiency and in consuming renewable energy.

A further study[54] from 2018, evaluating the profitability of coupling PV installation with residential BESS (adopting reference values based on the Greek market) led to similar conclusions. Indeed, it appears that, at that time, the NPV associated to the system "PV+BESS" is generally lower that the one referred to the scenario with no energy storage in place (as an initial value for the battery-related CAPEX, 600 €/kWh has been employed, assuming no battery substitution in the twenty-years' time of the simulation). It must be highlighted that the battery charge/discharge strategy assumed in the simulation relates to the energy storage system acting as a buffer to PV generation. A scenario in the simulation reflects Madeira's demonstration site case in which no compensation is provided for excess production and export to the grid. While the initial situation with a 600 €/kWh CAPEX excludes the possibility to achieve a positive NPV, by reducing the BESS cost to 400 €/kWh and assuming a battery size comprised between 4 kWh and 7 kWh positive results are achievable. In this way, a further cost decrease improves the business case. It must be highlighted that the scenario with no compensation of excess renewable production represents the worst case in the simulation performed by the study. When compensations for injection in the grid are introduced in the scenario, results appear to improve substantially, especially in the case of the NEM (Net Metering) policy, which implies that the prosumer pays for the net difference between energy consumed and energy exported to the grid over a period ("netting period"), irrespective of when consumption and generation occur along the period. This solution, in the simulation proposed in the study appears particularly promising as it leads to obtain generally positive NPV irrespective of the battery size (capacity expressed in kWh).

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[52] IRENA (2020), Renewable Power Generation Costs in 2019. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf

[53] B. Idlbi, D. Stakic, M. Casel, D. Graeber, G. Heilscher, M. Fiedler (2019), Business Models and Grid Impact of Energy Storages and Controllable Loads for PV-Self-Consumption at Prosumer Level.

[54] A. I. Nousdilis, G. C. Kryonidis, E. O. Kontis, G. K. Papagiannis, G. C. Christoforidis, I. P. Panapakidis (2018), Economic Viability of Residential PV Systems with Battery Energy Storage Under Different Incentive Schemes.

Two further studies, with results consistent with those that have just been discussed, have been conducted specifically on the Madeira island context, in the scenario where no export of excess renewables generation to the public grid is simulated. The former[55] conducted a simulation starting from real data on two UPACs with PV modules installed (one with a limited size PV installation, granting substantial self-consumption levels, about 68%, but relatively low self-supply percentage, almost 27%, the other with a larger PV installation enabling a notably higher self-supply percentage, 40%, but, at the same time, a lower self-consumption percentage, 51%). In this context, the simulation which entailed the introduction of a battery (whose size was varied, together with the size of the inverter) led to the conclusion that high battery-related investments undermine the financial sustainability of the business case associated to coupling existing PV modules with BESS (also in relation to long payback period due to limited savings offered by BESS despite improvements in self-supply and self-consumption percentages). In the context of the study, it is proposed a set of options that could improve the PV+BESS business case for residential UPACs; these include, the possibility to reduce the fixed component of the electricity tariff (thanks to the BESS presence which might reduce electricity import from the grid during high demand-periods) by decreasing the peak consumption foreseen in the electricity supply contract, the chance to develop a battery strategy which exploits ToU tariff periods and the situation in which excess generation is exportable to the grid and rewarded. This last point has been actually considered in the latter study[56] addressing PV+BESS model in Madeira, which also reported how the feed-in tariff is computed:

Feed-in Tariff (month m) = Average daily closing prices in the electricity market (month m) * 0.9

However, it is also clarified that since the resulting feed-in tariff for the period in which the research was being conducted was equal to just a fraction of the buying price, it was reasonable to focus on self-consumption in the simulation. Even in the case of the latter study, actual year-long generation and consumption data on UPACs equipped with PV modules represented the starting point on which the subsequent simulation has been carried out. Differently from the previous studies, it has been considered, in addition to the battery "buffer" strategy for UPACs with single-rate tariff electricity supply contract, the dual ToU tariff case where the BESS charging and discharging commands may follow more sophisticated strategies. The implicit DR option is thus pursued exploiting lower electricity prices during non-peak periods to import energy from the grid while during peak times the buffer strategy is once again adopted and only then the battery is eventually discharged (to meet demand). A comparison of the results from the simulation of the two strategies lead to a set of key conclusions with essential implications for PV+BESS business case:

- The scenario where dual ToU tariff is applied appears more profitable than the case where the single-rate tariff is adopted. In the following sections of the documents a comparison between the two cases is outlined.
- The best strategy in terms of profitability relates to implicit DR but the associated financial advantage undermines the sustainability aspect (the optimization of the level of self-consumption which entails the minimization of renewables generation curtailment), as in fact the strategy implying pre-charging the battery during off-peak periods tends to reduce the

[55] L. Pereira, J. Cavaleiro (2019), On the Value Proposition of Battery Energy Storage in Self-Consumption Only Scenarios: A Case-Study in Madeira Island.
[56] L. Pereira, J. Cavaleiro, L. Barros (2020), Economic Assessment of Solar-Powered Residential Battery Energy Storage Systems: The Case of Madeira Island, Portugal, Applied Sciences.

self-consumption percentage which is instead generally higher in the case where the buffer strategy is adopted. In relation to this conclusion, it is suggested that a possible solution relates to making self-consumption the most profitable option through modifications of the local legislative framework. In this context, it is suggested the NeM option which has been briefly discussed earlier in this document, in relation to a study findings[54].

- The ten-years projection of the simulation, with the average basic investment cost employed in the study for the battery, equal to 313 €/kWh, shows that also in the most favorable case a payback period of over 10 years is required (with cases showing significantly higher periods). In this sense, as concluded also in the studies previously discussed, a drop in the cost of BESS is essential to increase the attractiveness of the PV+BESS system in Madeira.

The conclusion that associates the best results (from a financial viewpoint) to the scenario where a ToU tariff is included in the simulation and that implies a more sophisticated strategy where together with the buffer function the battery also pre-charges during off-peak periods, has been confirmed by recent findings in the context of the SMILE project.

At this point it is worth assessing UPACs performance in detail.

4.3 UPACs performance

During an over three-years' long period, starting from June 2018 until August 2021, it has been carried out a data collection and evaluation process on residential load and PV production and consumption allowing to assess the self-supply and self-consumption performance on UPACs involved in the SMILE project. With regard to those UPACs that have been subsequently equipped with a BESS, as mentioned earlier in this document, it has been possible to carry out a comparison between the scenarios prior and after the energy storage system integration. In this way, it has been possible to determine the true contribution of the installation of the BESS, developed by Lithium Balance, integrated with previously existing PV modules. In the context of the analysis on residential UPACs, performed in this section, whose results will be further employed in the following ones, it has been considered a 12-months' period starting from February 2020 until January 2021. It must be highlighted that the results that will be discussed refer to a scenario where the battery works as a buffer to PV generation (greedy strategy), and in the context of electricity supply single-tariff contracts. Self-consumption and self-supply levels (percentages) for each residential UPAC, have been computed, for the sake of simplicity, considering the total yearly residential sites load, PV production, consumption and export to the public grid. It must be pointed out that, in reality, monthly self-consumption and self-supply performance tend to vary substantially during the year.

Especially in the case of UPACS with initially low self-consumption levels, it appears notable the improvement that has been achieved through the introduction of the energy storage systems in the scenario, as the initial percentage rates of self-consumption and self-supply has, for example, doubled in one case. Self-consumption experienced a shift from initial levels comprised between 20% and 30% to final rates in the range of 45% and 50%. However, considering 45% as a final result, the self-consumption percentage remains limited, implying, in a situation where no export to the public grid is allowed, a relevant level of renewables generation curtailment. In this case, despite the large improvement in absolute terms, from a sustainability perspective, the self-consumption upgrade appears narrow (due to the notable amount of renewable energy generated which would essentially be wasted). This aspect, as emerged from the study conducted, might be due to the oversizing of the PV modules installed in properties. At the same time, those UPACs which experienced substantial improvement in self-consumption percentages, also achieved remarkable results in terms of self-supply performance, reducing significantly their dependence on the public grid. Indeed, from initial self-supply levels equal to about 40%, a value equal to 67% and another substantially over 80% have been achieved. The percentage change recorded in these cases for both self-supply and self-consumption performance exceed 70% in a case and over 100% in another.

On the other hand, those UPACs whose initial self-consumption value was higher, experienced smaller improvements of this indicator, shifting from initial values comprised between 45% and 52% to final results equal to 81% and 72%. Although these improvements are of a limited extent compared to those reported earlier, from a sustainability viewpoint, the PV+BESS system in these UPACs appears to be well-performing, limiting the risk of energy wastage in the case no export option to the public grid is available. Self-supply, in the same sites, grew significantly from values ranging between 28% and 31% to about 44% and 50%, hence, once again, the improvement appears narrower compared to that experienced by UPACs with initial low levels of self-consumption. Where high self-consumption rates are coupled with limited self-supply performance, it is reasonable to conclude that the existing PV installation was under-dimensioned to properly meet the domestic energy needs.
The evaluation of UPACs performance has been enabled by the presence of the centralized EMS which allowed the measurement of generation and consumption rates and their subsequent aggregation. In this sense, it must be pointed out that, even in a context where the individual UPAC is subject to a single-rate tariff and the mounted BESS operates to maximize self-consumption, the EMS plays a key role in providing each unit visibility over their generation and consumption patterns.

Considering the case where a ToU tariff is applied to the scenario involving a commercial site, it should be pointed out that, in principle, these sites might have different typical consumption patterns with respect to residential ones, as periods of peak solar energy generation might occur in correspondence of peak consumption times of the day. The evaluation of the commercial site performance in a 12-months' period comprised between March 2020 and February 2021 has been carried out in the context of a dual ToU tariff. The BESS developed and installed on site has been operated following a strategy which integrates the buffer function to PV generation with the exploitation of off-peak periods.
The results observed, in terms of self-consumption performance, show a slight increase of this indicator which shifted from an initial value of about 68% to over 81% (experiencing thus a 20% growth). In relation to the self-supply indicator, the commercial UPAC experienced a limited growth that brought the initial value equal to about 18% to roughly 22%. These resulting slight increases are obviously associated to the fact that the BESS does not operate, as in relation to the residential UPACs discussed earlier in this section, pursuing self-consumption maximization, but it targets the realization of monetary savings avoiding energy imports when the €/kWh rate is higher. Indeed, in this case, another indicator should be included in the discussion, the energy stored in the battery (for later use) during off-peak periods. Its value, during the 12-months' assessment was equal to almost 26% of the site total load. For the sake of clarity, it should be highlighted the fact that the assessment has been carried out on a three-phase PV+BESS system and the percentage values reported in this document relate to average figures from the three phases.

Finally, to conclude the evaluation of UPACs self-supply and self-consumption performance, it has been simulated within the SMILE project environment, the case where a domestic UPAC is subject to ToU tariff (the results discussed earlier in relation to residential sites were obtained in a context where single-rate tariffs where initially applied). Indeed, thanks to a simulation of the residential sites digital twin, it has been possible to project a set of results. The simulation which has been carried out considering the 12-months' period comprised between September 2020 and August 2021 (it is worth underlining that initial indicators value are different from those of the residential UPACs reported earlier as the simulation refers to a different period), shows an improvement of both the self-consumption and self-supply performance reaching respectively about 85% and 53%, from initial values roughly equal to 55% and 33%. The energy purchased in the 12-months' period during off-peak times for later consumption, in the simulation, corresponded to about 11% of the total annual load.

4.4 EMS-enabled business case for UPACs and other SMILE stakeholders

The increasing penetration of RES in Madeira island energy mix might not solely require a larger deployment of BESS across local UPACs but also require further adoption of EVs and eventually additional deployments of batteries at distribution level.

As mentioned earlier in this document, the SMILE solution entails the presence of a centralized Energy Management System (EMS) that has been developed by PRSMA during the project, which communicates with all the installations in residential and commercial UPACs as well as with the distribution station (where a BESS has been mounted) and the EVs charging points involved in the testing. In this context, assuming, outside SMILE testing environment, that an EMS is implemented and managed by an independent organization, it is reasonable to foresee that an expense associated to the software operation, maintenance and upgrade is required in order to obtain a financially sustainable business case for the EMS deployment. In this sense, each stakeholder is expected to pay a fee necessary to exploit the EMS functionalities that might vary depending on the user category and on the kind of services that the EMS provides to each user category (the main services provided to stakeholders are summarized later in this section). It has been concluded, basing on the experience gained during SMILE project implementation, that a substantial upfront cost would be required for the development of a local EMS in any eventual replication site, while relatively limited annual maintenance fees can be foreseen, especially associated to server maintenance, domain and ancillary external services such as irradiation forecasting. It must be pointed out that in the case the SMILE solution would be replicated in other sites as, for example, microgrids or isolated communities willing to increase RES penetration through the smart management of renewable generation, energy storage, EVs and load control at distribution level, the upfront EMS development cost might be substituted with a SMILE (PRSMA) EMS software acquisition cost (or licensing fee) since the SMILE developed EMS might be replicated and adapted to local conditions. Indeed, this element potentially opens up relevant business opportunities not only for PRSMA that could benefit from EMS sale or licensing but also for those technology providers involved in the SMILE project for which it could be foreseen an entire system replication, involving both EMS and the other software (Route Monkey Trackm8-related algorithms) and hardware components installed locally (Lithium Balance BESS) which have been tested during the project. A general simplified business case, involving all SMILE stakeholders, where key financial flows are reported, is represented below.

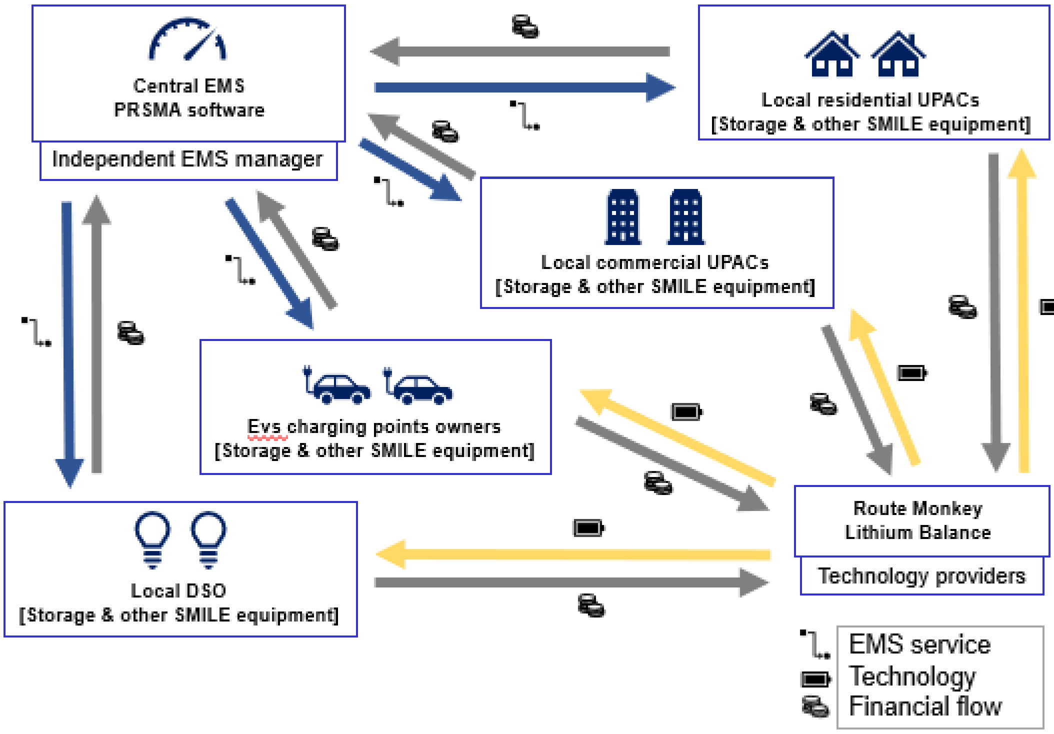

Figure 4.3: General business case representation involving all SMILE project stakeholders with identification of main financial flows.

In this scenario, EMS users are expected to be charged a fixed periodical fee (for example annual-based) that would ensure operating expenses coverage and revenues to ensure the financial sustainability of the independent organization owning and managing the system. As explained in SMILE Deliverable D4.10[57], the EMS consists in the central element which links together all those stakeholders portrayed in the figure above representing the solution to achieve improvements in grid performance. At the same time, as mentioned earlier in this section, it is providing a set of services to three main stakeholder categories:

1. UPACs, either residential or commercial, benefit from the EMS data collection capability on both consumption and generation, as well as on information related to those devices, such as energy storage systems (e.g. state of charge) which are installed at prosumers/consumers' premises. At the same time, the EMS has control over BESS charging and discharging strategies, which essentially relates to the main benefit offered by the SMILE solution. While in the case of single-rate tariffs contracts, UPACs might have to rely mainly on BESS greedy strategy, the EMS, in presence of dual or trial ToU tariff, enables implicit demand response strategies thus unlocking significant savings generation opportunities. In the following section of the document, insights on savings generation for both tariff frameworks will be provided. The EMS-enabled benefits at consumers/prosumers level might be further expanded being the system a flexible solution where additional services (also third-party ones) can be integrated and further BESS strategy can be tested and implemented to reflect local needs and conditions, even different from those experienced in Madeira. As concluded in a recent study[58] where self-

[57] SMILE Project, Deliverable D4.10. Available at: https://cordis.europa.eu/project/id/731249/results
[58] B. Rohrbach, M.E. Papaefthymiou, A. Schneider, C. Imboden (2019), Guidelines for business model innovation on the example of PV self-consumption optimization, Journal of Physics: Conference Series.

consumption optimization-related business models where investigated, adopting a fee-based approach for residential sites (such as residential UPACs in Madeira) could benefit from integrating the financial savings argument of the value proposition with social, ethical (comprising the environmental aspect) and emotional factors.

2. Local DSOs (and eventually TSOs) might benefit from multiple EMS services. In the SMILE project case the local DSO mainly benefitted from the EMS control over the BESS installed in a distribution substation which enabled peak-shaving thanks to the backup storage capacity offered by the battery to the grid. This element has key consequences in Madeira and eventually in other sites with similar operational conditions (e.g. total energy islands facing issues associated to the intermittent profile of RES and subject to derogation on DSO battery ownership): reaching higher grid safety levels through BESS deployment at distribution level and smart control unlocks the possibility to integrate further renewables generation into the local grid. In this sense, stationery batteries mounted at distribution level might also be an essential mean to defer distribution grid improvement investments further in the future[59]. While this might not be replicable for other system operators for which owning a BESS is not possible, in principle, all DSOs and TSOs might benefit from the EMS presence thanks to the information which it collects from sparse individual energy production and consumption units, enabling for example load forecasting opportunities and effective congestion management strategies. Seeing the value potentially offered by the EMS, it appears that DSOs and TSOs might be key users of its services. A technology provider such as Lithium Balance, seeing that the technical integration between its developed energy storage devices and the EMS has been extensively tested and demonstrated, might benefit from relevant commercial opportunities arising from an EMS replication in other contexts different from Madeira.

3. EVs charging points owners either at commercial or residential sites might benefit from smart charging strategies controlled by the central EMS. Just as in the case of UPACs, different strategies can be eventually tested and implemented, reflecting different users needs. At the same time, the user benefits from access to the information collected and aggregated by the EMS on generation and consumption at local and at system levels. In particular, SMILE EMS unlocks business opportunities associated to charging stations refitting, being a flexible solution compatible with multiple systems.

Finally, the financials of the centralized EMS business case could be substantially positively affected by considering that additional third parties might be willing to either integrate their services into the EMS software platform and/or exploit its data-collection capability.

4.5 UPACs business case

In addition to the EMS fixed annual fee, assuming that, in the presence of already installed PV modules, home and commercial units owners would individually invest in the battery system, it is essential to consider the main components affecting the financials of the battery introduction. Indeed, in addition to the BESS and its inverter (which entail the largest costs impact), it must be foreseen the purchase

[59] J. Wüllner, N. Reiners, L. Millet, M. Salibi, F. Stortz, M. Vetter (2021), Review of Stationary Energy Storage Systems Applications, Their Placement, and Techno-Economic Potential. Available at: https://link.springer.com/content/pdf/10.1007/s40518-021-00188-2.pdf

and installations of two energy meters (one for the measurement of PV generation and one addressing consumption), current breaker, residual current breaker, shucko plug and other ancillary components comprising aux box, cables, etc. In addition, the connection of the single UPAC with the central EMS requires the presence of a gateway to enable data flows. To the single components cost it must be added installations expenses from qualified staff. In relation to annual operational expense items, a general hardware maintenance fee is required (it is associated to an annual check of the system status in the individual UPAC by qualified staff) and a BESS-related maintenance/support fee must as well be foreseen. It has been assumed that the sum of the BESS support fee and the EMS-related yearly expense equal the annual hardware maintenance cost.
Considering these input costs, it has been possible to carry out a simulation of the typical residential and commercial UPACs potential business cases. Indeed, it has been considered the installation, in a standard residential UPAC where PV modules are already available, of an 8.6 kWh residential BESS together with the ancillary components indicated above. Just as in the simulation carried out earlier for Samsø, the BESS (together with the dedicated inverter) has been assumed to have a 15-years lifespan. The gateway mentioned earlier instead, has been assigned with a 10-years useful life, that is why it has been assumed this component substitution at the tenth year of the simulation which lasts 15 years in total (reflecting the BESS useful life). The other components, of which the two energy meters appeared to be the most relevant in terms of cost-impact, show longer estimated lifespans compared to the simulation duration, subsequently the cashflow computation has foreseen the presence of a (relatively) small final year residual value.

Coupling the Lithium Balance developed energy storage solution with the existing PV modules has shown significant savings realization potential during testing activities in Madeira demonstration site in all the involved residential UPACs. Savings generation is linked to the self-supply and self-consumption performance changes which have been discussed in the previous sections. The simulation of the business case financials related to the introduction of a BESS in a residential UPAC subject to single-rate tariff contracts, has taken into account the average of the individual UPACs annual load and PV production. Consequently, the annual load employed has been estimated to roughly 3,900 kWh and the PV production used in the simulation is equal to about 3,800 kWh/year. In addition, it has been chosen to consider the average self-consumption rates prior and after SMILE solution deployment, equal respectively to 35% and 59%. From these input values it has been possible to define each scenario (pre and post BESS integration) resulting self-supply, energy import from the grid and monetary value of savings brought by the SMILE solution. Savings have been computed considering the electricity flat rate equal to 0.1629 €/kWh while the average electricity price for households[60], in Portugal, is equal to about 0.21 €/kWh (including taxes and fees). The flat rate, has been adjusted to reflect a yearly 2.31% growth rate until Year 15 (2033). This average percentage value has been extracted considering the evolution of the energy price to households in Portugal for the period 2010-2021 including taxes and fees). The figure below reports the evolution experienced by the rate in the period.

[60] Eurostat (2021), Electricity prices for household consumers – bi-annual data (from 2007 onwards) (dataset).

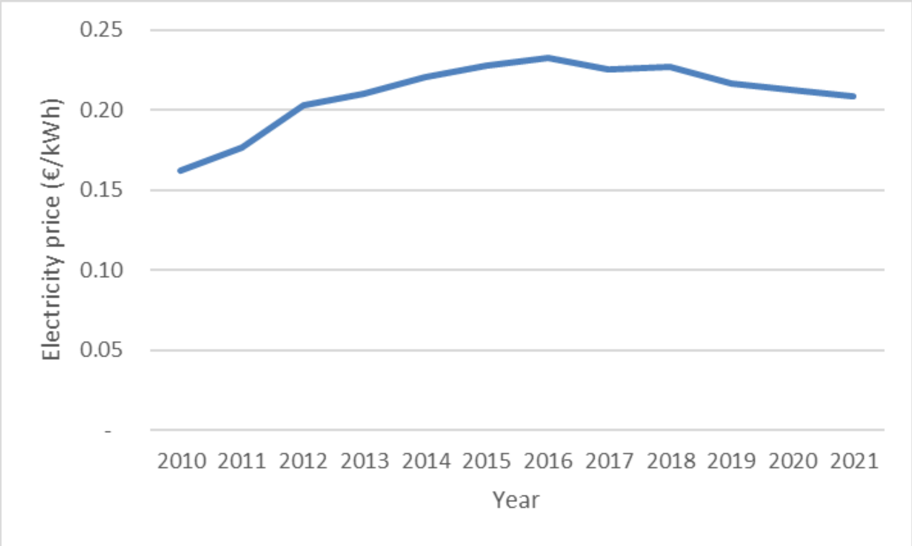

Figure 4.4: Householders electricity price (including taxes and fees) evolution in Portugal (2010-2021).

The initial (additional) yearly savings value adopted, relates to almost 160 € compared to the situation where just PV modules are installed in the property. These additional savings, associated to a self-supply value equal to about 59% (which in the case only PV would be installed, would be equal to roughly 35%), realized thanks to the deployed solution, have been treated as a reduction in residential site costs. It must be pointed out that testing in Madeira island have been deeply affected by Covid-19 pandemic as households daily consumption patterns changed substantially during the period, and in this sense, the estimated savings might be the result of sub-optimal testing conditions. Initially, no revenue source has been included in the computations. Applying an initial BESS-related CAPEX (including inverter) of over 1000 €/kWh, the obtained free cashflow showed that while additional savings might actually be able to cover the SMILE solution operating expenses, they appear not sufficient to allow the recovery of the solution investment. By applying, for example, as final self-supply value the highest achieved among the UPACs involved in the SMILE project (after the BESS introduction), corresponding to about 83%, and assuming a BESS cost reduction, thus employing the same approach adopted in the literature discussed in this section, to reach a BESS+inverter cost equal to about 280 €/kWh, it has been found that the cumulative cashflow becomes positive in the last year of the simulation.

A further reduction in BESS cost, reaching a value of about 140 €/kWh (still considering all the other expenses, comprising installation costs, unchanged) might actually lead to reach a slightly positive NPV for the 15-years' period cashflow. The discount rate applied in the computation of the NPV corresponds to the Re-frame[61] percentage indicated for PV systems in Portugal, oscillating between 6% and 7%. The average 6.5% value has been chosen. The 140 €/kWh rate would also bring a positive cumulative cashflow value already in Year 11, as shown in the graph below relating to the last 10 years of the simulation.

[61] Re-frame (webpage). Available at: http://re-frame.eu/portugal/

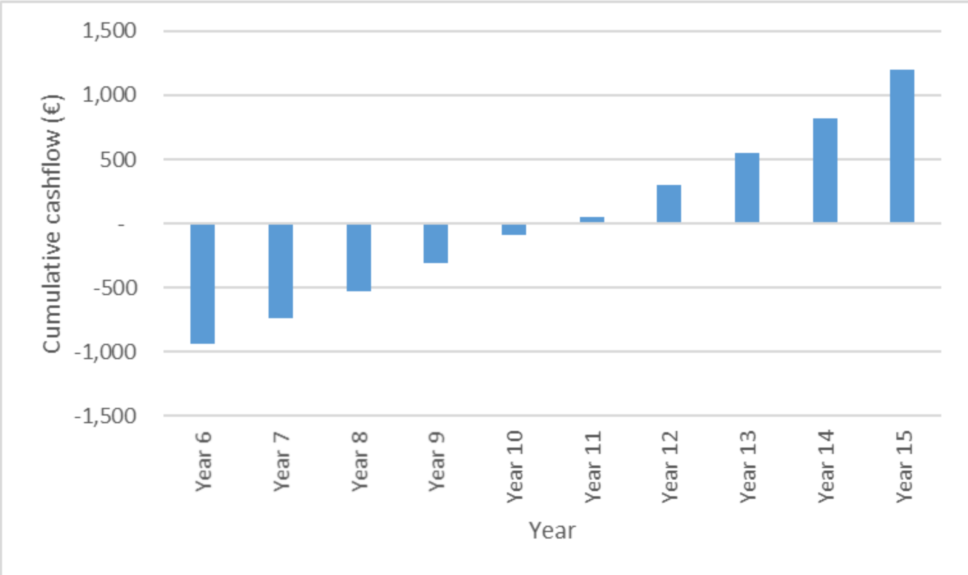

Figure 4.5: Cumulative cashflow from Year 6 to Year 15 in the scenario with BESS+inverter cost equal to 140 €/kWh and self-supply level equal to 83%.

Any further decrease of BESS+inverter system cost would improve the simulation resulting NPV and thus ensure an increase in the financial benefits brought by the SMILE solution to householders.
In the case where it is assumed that the deployment of the SMILE solution in residential UPACS would allow to reach the maximum self-consumption level, it has been found that a NPV equal to 0 (indicating a neutral situation with respect to the benefits and costs associated to the investment) could be already reached at a BESS+inverter system cost equal to roughly 243 €/kWh. In addition, it has been also tested the situation in which, instead of the flat rate, it is employed, in the simulation, the average electricity price for households in Portugal, equal in 2020, to about 0.21 €/kWh. The application of such rate would have a significant impact on the business case referred to the introduction of a BESS in a residential UPAC. Indeed, assuming a self-supply rate equal to 83% (as done previously), reached through the energy storage system integration, it would require a BESS-related investment (including inverter) of about 472 €/kWh to reach a positive cumulative cashflow value in the last year of the simulation period. While in the case a full self-consumption could be achieved through the SMILE solution deployment, an NPV equal to 0 would be already reached with a BESS-related investment equal to roughly 400 €/kWh.

With regard to revenues, to reflect the last developments in Madeira legal framework, it can be assumed that the UPAC excess renewable generation can be exported to the public grid and compensated through a feed-in tariff. The initial feed-in tariff value employed (from Year 3, 2021) corresponds to about 0.07 €/kWh (equal to the value recently recorded). The feed-in tariff reflects the same average annual percentage change in households' electricity prices applied to savings. For the sake of clarity though, it should be highlighted that in a situation where it is being considered the possibility to export energy to the public grid, within a feed-in tariff scheme, the introduction of the BESS+inverter under a single-rate tariff contract would reduce the revenue potential associated to the tariff compared to the situation where only PV modules are installed in the property. This is essentially due to the fact that the energy storage introduction improves substantially the self-consumption performance of the individual UPAC.

It appears that the negative NPV value is mostly associated to the initial investment required by the BESS and other components, as for the subsequent years, the solution is able to bring relevant savings that exceeds the annual costs presented above. The BESS high cost, at current market conditions, represents the largest barrier to achieve a positive NPV for residential UPACs subject to single-rate tariffs, confirming the findings discussed earlier in the section of this document devoted to Samsø SMILE demonstration site. An additional common conclusion relates to the effect of electricity price growth on the financials associated to the BESS introduction, scenarios entailing higher rates can foster the adoption of energy storage systems as the value of savings is substantially increased.

In the case it is considered, in the simulation, the scenario in which the household equipped with the BESS is subject to ToU dual tariff, the annual savings value increases substantially, reaching a difference, with respect to the scenario where only PV are installed, of about 244 €. It appears over 80 € higher with respect to the scenario where an individual UPAC is subject to a single-rate tariff and the BESS enables to achieve a 59% self-supply level; nevertheless, it should be pointed out that the two scenarios refer to different individual UPACs as the simulation of the ToU tariff case has been conducted only on one of the residential sites involved in the SMILE project.
Considering the same set of input proposed earlier, initial (additional) annual savings equal to 244 € (then adjusted reflecting the yearly growth rate indicated earlier in this section) would allow to reach a positive cumulative cashflow value in Year 15 of the simulation period only applying a BESS cost equal to about 137 €/kWh. The additional savings achieved through the energy storage deployment can be associated to both the improvement in self-supply and self-consumption levels (which grew both of about 55%-60%) and the share of energy consumed which has been purchased during non-peak periods. Obviously, just as it has been shown earlier, by assuming further improvements either on the self-supply/self-consumption performance or on the amount of energy purchased and stored when the rate is lower, the positive cumulative cashflow can be achieved much earlier during the 15-years' period even considering higher BESS-related investments. In general, as reported earlier, (small-scale) energy storage systems cost should experience a further decrease to improve the financials associated to their introduction in residential UPACs or incentive schemes could be foreseen to foster the investments on BESS until the evolution of market conditions will ensure a more robust business case.

With regard to the commercial UPAC, the input conditions change slightly with respect to those described for the residential ones. Indeed, three battery stacks are required in order to cover the commercial activity daily needs (that in normal conditions differ significantly from those of households). In this sense, a much larger investment has been foreseen, corresponding to roughly three times the BESS+Inverter value in residential sites. It has been estimated that substantial additional savings can be realized compared to the scenario where only PV modules are installed. The difference corresponds to about 278 € in Year 1. These additional savings are not sufficient to sustain, in a 15-years' period, the investment on energy storage systems at current market conditions. Nevertheless, it has been carried out a further simulation (of an improved scenario) which reported enhanced self-consumption and self-supply performance, reaching respectively 97% and 27% (the basic scenario entailed that the energy storage integration enabled to achieve 81% and 22%). The upgraded simulated scenario did not imply major changes to the share of energy purchased at lower price (during off-peak periods) and stored for later consumption. Anyhow, it enabled to reach a savings increase of about 604 € in Year 1. Such remarkable annual savings value would allow to reach a positive cumulative cashflow in Year 15 considering a BESS (and inverter) cost of over 284 €/kWh. It should be pointed out though that comparing the self-consumption rate which appears significantly high (over 80%) with the associated self-supply level (lower than 30%), by considering a scenario with a PV installation larger in size, it is reasonable to foresee substantially higher savings that would further improve the financials connected to the introduction of the storage system in the commercial UPAC.

5 Conclusion

The present document has addressed multiple aspects (including benefits and barriers) associated to the proposal of suitable business cases that reflect the SMILE solutions specificities and that could be replicated outside the project environment. They may represent viable options for contexts where issues connected with the intermittent profile of renewable energy sources, grid congestion, fuel poverty and high electricity costs are affecting local communities or individual consumers/prosumers. The analysis encompassed the main SMILE technologies whose application has been tested in the project environment, but which are already experiencing a growing deployment in energy markets across Europe, such as energy storage systems, EVs charging stations (considered in the context of this document as relevant flexibility providers), centralized energy management systems and aggregation platforms (or load controllers).
Following the experience acquired during SMILE project implementation in the Orkney Islands scenario, it has been possible to investigate a set of potential arrangements necessary to connect a series of distributed energy storage systems (EVs charging points have been exploited in this way as well) to a central control unit whose main objective relates to match curtailment events, creating benefits for generators and subsequently to the other stakeholders involved. Four main arrangements have been foreseen as feasible options:

1. The presence of yearly contracts, indicating a forecasted performance improvement, connecting generators with an aggregator, and the latter with energy consumers (with storage capacity). This relatively simple approach faces the fact that, since in the SMILE project is focused only on one of the ANM scheme zones, the aggregator might not find cost effective to simultaneously provide aggregation services and deal with consumers financial rewards. In this context, considering that the generator is the main stakeholder benefitting from curtailment events impact reduction, a second option has been proposed.
2. The aggregator maintains its function associated to remotely control assets to enable curtailment matching but interactions with consumers and their compensation is handled directly through a subsidiary company linked to the generator.
3. Since the previous two options imply consumers' investment in storage and associated SMILE technologies, and, under current market conditions, that might require significant investments, it has been proposed an alternative approach where the aggregator is investing in the mentioned technologies. It has been also discussed how this option brings key advantages in terms of replication of the whole SMILE architecture.
4. A further last option refers instead to the deployment of a local, real-time marketplace, based on bids, that might involve all the Orkney ANM zone and that would enable the matching of available activable demand with generators needs (in terms of response to curtailment).

In relation to the first three options discussed, which entail the presence of an independent party acting as energy aggregator, it has been provided a set of customized business models adapted to the SMILE project scenario.

The development and testing activities carried out in Samsø demonstration site led to draw a business case focusing on the Ballen Marina challenges and opportunities. The local scenario appeared suitable for a profitable deployment of implicit DR strategies based on the hourly variable Elspot price. DR has been discussed in relation to boatowners flexibility and referring to the marina overall consumption. Specific factors affecting the local context led to consider as a suitable option, outside SMILE testing environment, the adoption of a BESS greedy strategy as the simplest and cost-effective alternative consistent with the Ballen Marina needs and spending capacity. Indeed, the scenario does not foresee the introduction of an independent aggregator for which it might be more feasible to develop, update and maintain more sophisticated BESS control algorithms (requiring substantial financial resources). The business case financials simulation led to conclude that the PV+BESS system unlocks significant savings compared to a base scenario where energy demand is fully covered by import from the public grid. It has been found that the PV+BESS system introduction brings more substantial savings in contexts with high electricity prices. Furthermore, a wider deployment of the PV+BESS system could be fostered by energy storage required investment reduction and/or by the presence of incentives ensuring the financial viability of the initiative in the medium-long term.

Madeira demonstration site allowed to draw considerations on the overall system made up of energy consumers and the local system operator, linked together through the presence of the EMS, and specifically on the individual UPAC context. It has been foreseen, similarly to the Orkney case, the presence of an independent organization responsible for the EMS operation and maintenance. The approach, however, differs from the load controller one since the EMS does not serve primarily one of the system stakeholders (e.g. generators in the Orkney) but multiple stakeholders providing diverse services. Relevant business opportunities for SMILE technology providers could be unlocked by the implementation of the EMS in different sites, both foreseeing the full or partial SMILE system architecture replication.

With regard to the individual residential UPAC context, the integration of a BESS with existing PV modules showed relevant savings realization opportunities, while a positive NPV would require a BESS cost equal to at least 243 €/kWh in case of UPACs subject to single-rate tariffs (in the case full self-supply could be granted by the presence of the storage system). In the case the simulation relates to a scenario where ToU tariffs are applied, annual savings amounts can improve substantially as in addition to self-supply and self-consumption enhanced performance, the BESS would allow to deploy implicit DR strategy implying the purchase and storage of energy during off-peak periods. Nevertheless, a reduction in BESS-related investments (or eventually an incentive mechanism) should be foreseen in order to improve the financials related to the energy storage integration in residential UPACs. A similar conclusion relates to commercial UPACs but it has been observed that there might be a considerable room for improvement, in terms of savings realization capacity, associated to a more consistent sizing of the PV+BESS system.