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Executive Summary

The overall aim of Work Package H has been to quantify the impact of a widespread deployment of Microgrids (MG) on the future replacement and investment strategies of the EU network infrastructures. In particular, while in Task TH1 general scenarios and modelling frameworks for Microgrids development have been discussed, relevant analyses have been conducted in Task TH2 to quantify the system value of Microgrids in different power system areas. A number of benefits have arisen from the studies, hinting that Microgrids could positively contribute to economic and efficient evolution of future power systems. However, the feasibility of Microgrids remain linked to the setup of adequate business models within suitable regulatory and commercial frameworks.

In this regard, the objective of this report is to illustrate the investigations carried out within *Task TH3: Business case for Microgrids*, with the aim of drawing relevant considerations on the key drivers enabling the market feasibility of Microgrids in different contexts. Different studies have thus been developed by Imperial, Siemens, INESC and NTUA regarding potential business cases for Microgrids, whose main findings are summarised below:

- The general framework for studying business models developed by Imperial shows that a suitable regulatory and commercial context acknowledging the external benefits (upstream network-related and environment-related, primarily) brought by Microgrids needs to be set up in order to make the Microgrid concept economically feasible on its own while delivering optimal network solutions.
- This reflects the need for recognising that the network use from DG and DER in general, as well as from loads close to local generation, is not the same as in conventional (centralised) systems, so that for instance competition on the wholesale market between DG and conventional generation cannot be based on a level playing field.
- The concepts of price (cost/benefit) reflectivity, time of use of the network and locational charges are the key points for developing an adequate framework for optimal network operation and development in the presence of distributed energy in general and Microgrids in particular.

- Building on this general framework, alternative business models have been analysed by Siemens. Potential business cases that are associated with Microgrids can be either external or internal in nature. In the former case, a Microgrid trades with external players as one entity, and Microgrid operator will attempt to maximize total system-wise benefit under a combined economic, technical, and environmental perspective, which has been covered in detail in the DG3 report. In the latter case (i.e., internal Microgrid business cases), a Microgrid operator or arbitrator will be further responsible for allocating the benefits obtained from external sources to different stakeholders. The studies performed in this report are primarily focused on the second type of business cases.
- However, in general depending on market transparency and regulatory support level, the amount of total available benefits to be recognised and allocated to a specific Microgrid could either comprise only local values or encompass both local and upstream benefits.

Although all categories of benefits have been widely explored between WPH and WPG, for exemplificative purposes and due to the general difficulty of identifying the exact economic transactions of different upstream benefit indices, the impact of upstream benefit inclusion over Microgrid has been modelled as more favourable buying and selling prices with respect to classical directional prices (in which case the Microgrid would sell energy at the wholesale price (or close to that) while buying energy at the retail price (or close to that)).

- Regarding Microgrid internal markets, two general types have been studies, namely, local retail market and local service market. The local retail market can be simply put as an 'over-the-grid' trading platform where MS units and local consumers attempts to avoid potential transmission and MV distribution-related grid charges by trading directly with each other within the physical threshold of a Microgrid. The local service market, on the other hand, mainly serves as a smaller version of ancillary service market established between DSO and potential sources of grid control power, namely, MS units, dispatchable loads, storage devices, and so forth. Obviously, settling prices in the local retail market will directly reflect the interest allocation results among consumer, MS unit(s), and DSO; while transactions in local service market can be inherently seen as the market realisation of trade-off optimization between economic and technical objectives.
- For both local retail and local service markets, the ownership model that a Microgrid could feature would impact over the overall market development results. In order to illustrate this point, three representative ownership models have been introduced: (i) DSO Monopoly, which leads to a local retail market but no service market; (ii) Prosumer Consortium, which leads to a local service market but no retail market; and (iii) Free Market, which enables both local retail and local service markets within a Microgrid.
- In addition, different Microgrid ownership models could also lead to large deviations of interest allocation results. In order to illustrate this point, both a simple case study Microgrid and a multitude of European-level simulation results have been examined to reveal ownership model impacts over interest allocation results.
- These cost/benefit allocation studies with the different business models reveal that complete MS ownership by either DSO (DSO Monopoly) or end consumer (Prosumer Consortium) can easily grant the owner with large or even full access to most of benefits, and prevent other stakeholders from sharing. Thus a free market ownership structure or trading mechanism seems more suitable to disseminate Microgrid benefits to a large number of stakeholders and according to a more fair and transparent scheme.
- Sensitivity analysis relevant to including also upstream benefits indicates that support measures based on identification of such upstream benefits can be extremely effective in the early stage of Microgrid development, but may gradually hold decreasing impact levels as the self-supply tendency of a Microgrid increases (benefits tend to arise more and more internally while Microgrids become more autonomous from the bulk grid).

- The cost/benefit analysis to be carried out within Microgrids and according to different business models is intrinsically a multi-criteria problem. Analyses in this respect, performed by INESC by adopting a number of advanced decision theory models, have shown that different trade-offs generally lead to different evaluations/rankings in each considered scenario, and within the set of possible solutions it is important to identify the range of trade-offs where the MG concept deployment turn out to be most favourable.

- For the specific studies carried out mainly from the DSO perspective it has emerged that large scale deployment of MS could be feasible in the future only under the MG concepts, whereas small MS penetration does not require adoption of sophisticated management and control structures. Therefore, only significant percentage of MS can make MG viable and economically interesting solutions.

- Among the external benefits acknowledged to Microgrids environmental aspects could play a key role owing to deployment of RES and CHP. However, only recognition of such a global (societal) value by internalising environmental benefits could likely support the delivery of efficient Microgrid-based energy systems. This has been practically exemplified by NTUA that has run studies with environmental and economic objective functions.
- The results show that trying to maximise the earnings from combined participation in energy and CO_2 emissions market provides significantly higher environmental and economic benefits compared to maximising the earnings from participating only in energy market and considering the CO_2 remuneration as an additional income.
- Therefore, developing adequate business models where participation in CO_2 emissions market is allowed in parallel with classical economic optimization can greatly increase the environmental and economic benefits achieved by distributed energy operators, with benefits for the overall society. On the other hand, if environmental benefits are not somehow recognised, then the economic competitiveness of MS decreases substantially.

Content

List of Abbreviations

MS	Micro-Source
DSM	Demand Side Management
DG	Distributed Generation
DSM	Demand Side Management
DSO	Distribution System Operator
FIT	Feed-in Tariff
FLH	Full Load Hours
RES	Renewable Energy Resources
PV	Photovoltaic
WT	Wind Turbine
CHP	Combined Heat and Power
MGCC	Microgrid Central Controller
UoS	Use of System
P	Active Power
Q	Reactive Power
nUB	no upstream benefit
wUB	With upstream benefit
DM	DSO Monopoly
PC	Prosumer Consortium
FM	Free Market

Country abbreviations

DE	Germany
DK	Denmark
GR	Greece
IT	Italy
MC	Macedonia
NL	The Netherlands
PL	Poland
PT	Portugal
UK	United Kingdom

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1 Introduction

The models and case studies developed within Task TH2 as well as in Work Package G have demonstrated that the impact on distribution networks from DG and DER operated within Microgrids is dependent on time of use of the network and location. Hence, network and more in general social benefits will arise, and negative impact will be minimized, only if proper economic signals are realized and taken into account during Microgrid operation. Similarly, the ability of Microgrids to displace conventional generation and to operate without the requirement for a large capacity margin of conventional generation to support system operation will depend on the correct signals being passed through to DG connected to and operating in the distribution networks.

In order to carry out cost effective integration of DER within Microgrids, and then of Microgrids within distribution networks (Multi-Microgrids – see also WPD for further discussion), there is therefore the need to develop new market frameworks for pricing and reward of DER that are capable of reflecting the long term impact or value of controllable systems at the distribution level and signalling the short term requirements of the physical system.

At present, there is a gap between the vision set by pan-European targets for the penetration of significant levels of DG and the realities of the present system arrangements, as clearly illustrated in the sequel, whereby small-scale generators are to compete with conventional generation without taking into account the network benefits brought by proximity to load and, in case, correlation with local demand. These system benefits of DG are not fully recognized, or not at all, within the present commercial frameworks. In contrast, ignoring these particular features in the derivation of the value of DG results in non-competitive markets in which DG cannot compete on an equivalent level with conventional generation.

Historically, DNOs have planned and developed the network in isolation from DG; charges (based on averaged costs that do not include the impact of users at different voltage levels and locations or time of use) were designed to recoup costs of system expansion rather than inform future investment decisions of users. Integrated pricing strategies are required for sustainable future networks to complement and facilitate the increasing trends towards active management and integration of non-network solutions for system planning and operation, whose characteristics and benefits have been illustrated in the analyses reported in Deliverable DH2.

In the short term, for DG to participate in system operation it must be able to react when and where the system is stressed. To do this it must be exposed to prices that reflect the physical system conditions, and not just market prices as for conventional generators. In fact, for transmission connected generation this is achieved through their interaction in the wholesale market and the physical system balancing mechanism/market. For DG at distribution level, in most instances it will be treated as negative demand and netted of total demand for an Energy Supplier. Most DG have thus currently power purchase agreements with a single supplier, effectively a tariff based agreement for purchasing energy output at a fixed price, regardless of location or time of output. This disconnection between DG and the wholesale market prices and physical network conditions is the same as that experienced by demand, disconnected from real time prices by a tariff based retail “market”. In the long run, this traditional approach to network operation and design will lead to suboptimal network operation and development and eventually hinder further integration of clean DER. This is primarily related to the inadequateness of the current regulatory framework to recognize the external costs and benefits arising from DER, beyond mere energy trading transactions.

Overcoming this separation of the physical system and small scale resources requires new market based control paradigms to facilitate increasing levels of distributed control. Whether it be through local price dissemination tools or agent based organisation of distributed resources, the emphasis of market based integration for utilisation of DG in a system support role is to expose the resource to correct locational and time of use signals, and to treat all system users, both generation *and* demand – as equal contributors to system operation and development, whether located in the distribution or transmission networks.

Within such a framework, the role of Microgrids is to enable the development of internal transaction mechanisms for correct allocation of costs and benefits among the involved agents, as well as enable the full recognition of all (also external) costs and benefits arising onto the system from DER operation. In this respect, this report completes the set of system-level assessment models and studies started in Task TH1 and developed across TH2 by illustrating a number of approaches for developing cost-reflective DER integration scenarios, eventually resulting in effective Business Cases for Microgrids.

The report is organized as follows:

- Chapter **Error! Reference source not found.** contains the general framework developed by Imperial for studying business cases for Microgrids and discusses the key issues as to what type of commercial and regulatory framework would be most adequate to deliver optimal network solution in the presence of Microgrids.
- Chapter 3 discusses and exemplifies a number of different business models, contexts and transactions types developed by Siemens, with focus on energy and ancillary services markets/transactions that take place both internally and (to a smaller extent) externally to the Microgrid.
- Chapter 4 summarizes the main findings on multi-criteria approaches and decision theory-based models developed by INESC Porto, whose details are reported in the Annex H3.A.
- Chapter 5 sums up the mixed economic and environmental studies carried out by NTUA, with allowance for participation of Microgrids in CO2 emission markets. Also in this case the details are reported in the Annex H3.B.
- Chapter 6 contains the final remarks of the work performed.

2 What commercial and regulatory framework for Microgrids?

2.1 Identifying the value of DER: the economic supply chain

Within the scope of the More Microgrids project, and more specifically of Task TH3, the key issue to address can be referred to as: "Once we have demonstrated that Microgrids are source of benefits to the system (network operators, society, etc.), how can costs and benefits properly be acknowledged and allocated, so as to make Microgrids economically attractive?". Answering this question implicitly means make Microgrids feasible, in the sense that while representing an enabling concept for DER technical integration, Microgrids can also function as enabling concept for economic integration. At the same time, the regulation-related question arises as to what framework is needed for DER to compete on a level playing field with conventional (centralised) energy systems.

As mentioned in the introduction, the starting point to carry out a comprehensive cost/benefit analysis, which would translate into assessing whether Microgrids can be cost-competitive with conventional systems on a holistic standpoint, is the need for identifying suitable models to *internalise* the actual *external* benefits (and costs) from DER and Microgrids onto the power system. Indeed, distributed energy boasts technical characteristics that are substantially different and somehow innovative relative to conventional systems, and this must be reflected on an economic outlook too.

In order to exemplify this concept, the high-level economic supply chain for different layers of power systems, from power generation to consumption, is shown in Figure 2-1. In the exemplificative illustration, electricity produced by centralised generation is sold in the wholesale market for around 2-3 €c/kWh. By the time this electricity reaches the end consumer it is being sold at a retail price of around 8-12 €c/kWh. This increase in value is driven by the added cost of transmission and distribution services to transport electricity from the point of production to consumption, including the cost of securely operating the system. At this stage, what's therefore the value of electricity that is produced at the consumer layer? This concept is explored below.

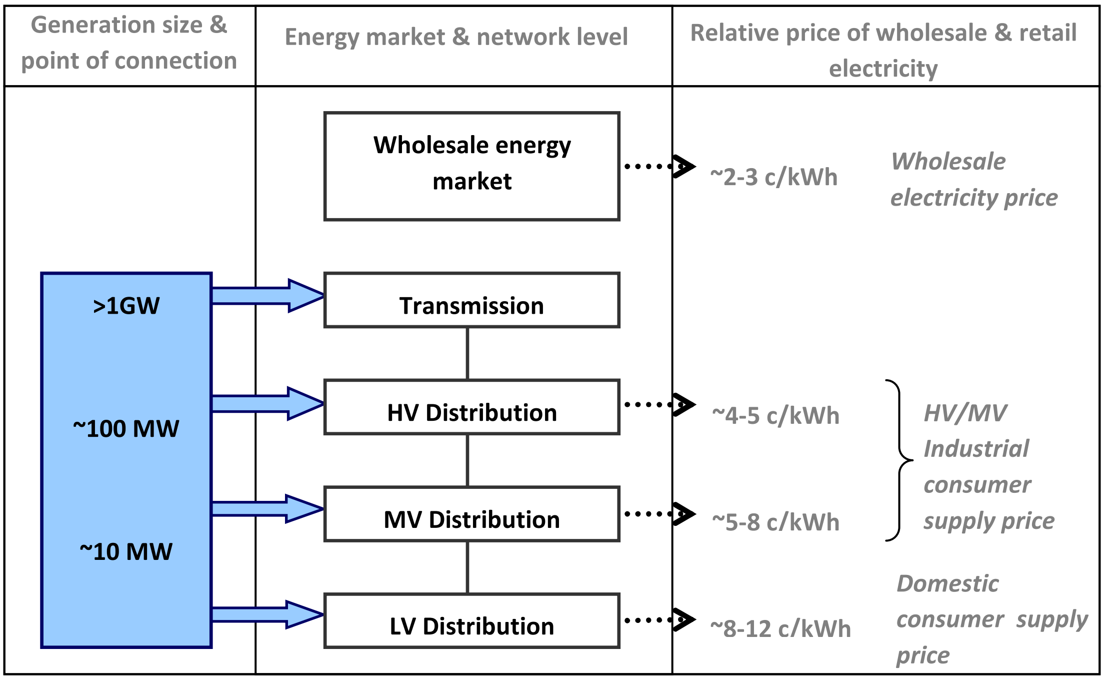


Figure 2-1 Value of Supply Chain

2.2 Is the current commercial and regulatory framework adequate?

With regard to the above value chain, it has to be considered that DG (and more in general DER), located close to demand, is delivering electricity "directly", with limited requirement for use of the network. This power may therefore have a higher value than that of conventional generation (e.g., an equivalent value of 4-10 c/kWh, i.e., the costs avoided by not using the network) due to the potential of DER to reduce the demand for distribution and transmission network capacity and corresponding costs.

However, this network cost reduction, generated by the favourable location of distributed generators, is not fully recognised within the present commercial and regulatory framework. As a consequence, non-conventional generation (DG) is competing with conventional generation in the wholesale markets at a price (2-3 c/kWh) that may be significantly lower than the true value of electricity delivered from a location close to demand (i.e. 4-10 c/kWh). On the other hand, often DG may not be able to produce electricity at a competitive price with conventional generation due to economy of scale, so that recognition of the (external) benefits brought to the network mainly owing to proximity to load becomes crucial for feasibility itself of DER.

In order to create an unbiased level playing field, then, network pricing arrangements should be able to recognise the impact that individual participants (and Microgrids, in the specific case) bear on the network according to their location and time of use. In this respect, as widely illustrated in WPG and WPH, the full value of DG and DER obviously depends on a number of factors such as, primarily:

- time of use and location;
- density of penetration;
- time correlation between network (peak) demand and production output.

Similarly, for *demand*, customers taking energy from the network at the right time and in the right location in the network (i.e., close to generation), have less requirement for network services. Instead, for most consumers all power is priced at fixed retail rate, occasionally reflecting differences in time of use, but never fluctuating in response to location and the distance between generation and the consumer.

It is therefore obvious that ignoring time of use and location results in sub-optimal network development because the full and true impact of the user (whether generation or demand) on the network is not adequately represented. This prevents new low-carbon generation and demand, specifically aggregated within Microgrids, from competing with incumbent generation. At the same time, no fair competition with traditional network solutions is enabled, which could instead guide optimal network development. As a result, the system must resort to increasingly expensive and unnecessary network reinforcements, and sub-optimal network support solutions. This was for instance widely explored in Deliverable DH2, where it was shown how a classical fit&forget (passive) approach would be more expensive with respect to alternative “intelligent” solutions with active management for integration of DG in distribution networks, which eventually would lead to hinder further connection of cleaner sources.

On the above premises, it can be summarised that some key characteristics that an adequate regulatory framework for DER integration should boast are:

- Recognition of ALL costs and benefits (internal and external);
- Recognition of the technical drivers for costs/benefits;
- Recognition of the conditions whereby costs/benefits arise;
- Adequate estimate of the value of costs/benefits relative to the specific conditions whereby they arise (e.g., cost reflective charges).

2.3 Microgrid value on both External and Internal levels

When we think of a Microgrid, with DG close to the consumers, “prosumers”, controllable loads, responsive demand, sotage systems, and so on, two levels of power flow interactions may be thought of, to which should correspond relevant economic transactions :

- Power generated and consumed within the Microgrid;
- Power imported from/exported to the upstream grid.

For the power exchanged within the Microgrid, from the above discussion it has emerged how the (fixed) cost of transportation from bulk generation should not be applied as it is. On the other hand, for the power exchanged with the upstream network, the Microgrid should be seen as an *equivalent prosumer* that time by time buys or sell electricity. In this case, then, the overall concept of price reflectivity expressed above for an individual network user should be applied to the Microgrid as a whole.

In both cases, namely, whether power is flowing through the upstream network or not, external costs and benefits arising from Microgrids operation should be taken into account for optimal network development. The models for and the outcomes from such an analysis are the ones already reported in WPG and WPH. Once all (internal and external) costs and benefits are acknowledged, these should be properly allocated within the Microgrid agents according to suitable mechanisms, in case market-based, driven by the cost-reflectivity principle. In particular, the Microgrid can also serve as an aggregator of costs and benefits in the interface with the bulk power system, so that it becomes not only a technical enabler but also an economic enabler, as mentioned above.

2.3.1 Example of external costs and benefits

From the studies performed in WPG and WPH, a number of (positive and negative) network impact types have been identified and quantified from both technical and economic perspectives. These impacts are not currently taken into account in most pricing strategies for DER, apart from network connection charges which can be more or less price reflective. In any case, positive impacts are not usually acknowledged. On the other hand, *positive externalities* may include for instance:

- Increased power quality and reliability (benefit to final user and DSO);
- Grid security to black-outs, external attacks, etc. (benefit to final user, network operators and society);
- Losses reduction in distribution networks (benefit to DSO, final user and society);
- Investment deferral in distribution networks (benefit to DSO);
- Voltage profile improvement in distribution networks (benefit to DSO);
- Congestion relief in distribution/transmission networks (benefit to system operator, final users and society);
- Capacity release in distribution transmission networks (benefit to final user and society);
- Provision of balancing services (benefit to system operator, final user and society);
- Conventional generation higher utilisation (benefit to generation operators, final user and society);

- Energy and environmental efficiency: marginal plants displaced by renewable or cogeneration plants (benefit to society);
- Security of supply: reduction of fossil fuel utilisation (benefit to society).

These benefits can of course be relevant to one (for instance, the network operator) or more (for instance, network operator and final user) actors involved in the business chain, also depending on how costs and benefits are allocated. For instance, a reduction of losses due to DG production can be beneficial to the DSO that can more easily meet predefined target of network efficiency as set by local regulation. On the other hand, the consequent cost reduction could be reflected into lower tariffs for the final user. Fewer losses would also mean decreased environmental impact, which all the society would inherently benefit of.

Negative externalities may of course occur as well, which may include, for instance:

- Additional losses in distribution networks (cost to DSO);
- Voltage rises (cost to DSO);
- Need for distribution/network reinforcements to accommodate DG, due to:
  - Thermal limits;
  - Voltage limits;
  - Short-circuit limits;
- Additional balancing cost (above all in the case of uncontrolled intermittent sources).

However, in the project it has been shown how operating DER within Microgrids can decrease their negative impacts on networks, so that also the economic value of these negative externalities could decrease.

2.3.2 Benefit allocation within the Microgrid and business models

Allocation of internal and external costs and benefits to the various agents involved in the Microgrid transactions may be a daunting task, but it’s a key precondition for correct cost-benefit analysis and business model development. In particular, in the case of externalities, it is crucial to understand who’s benefiting (e.g., the whole society, the network operator, the DG owner, etc.) from what (losses reduction, peak shifting, etc.). In particular, in principle relevant optimization studies could therefore be carried out relative to a specific objective function that takes into account internalization of parts of these externalities and maximises the benefits of a specific agent. This would also be reflected into specific business models, in which some agents may be more or less favoured by the economic transaction schemes that are implemented.

Regarding cost allocation, classical cash flow analysis addresses market-related transactions that occur internally to the Microgrid. In this outlook, the primary aim for developing business model studies is to analyse how different transaction models will affect different agents operating within the Microgrid, resulting in different allocation schemes of costs and benefits. These business models can generally related to two streams of economic flows, corresponding to the “commodity” being traded internally, namely:

- Local energy trade; and
- Local ancillary services trade.

In addition, a *cost-reflective* regulation should take into account the fact that also external costs and benefits are arising, as discussed above, so that in case the transactions for internal energy and services trading schemes can/should include properly internalised externalities in order to carry out an unbiased cost/benefit analysis. This leads to develop two possible generic sets of studies, namely:

- Business models internal to Microgrids *without* allowance for externality (upstream network impact);
- Business models internal to Microgrid *with* allowance for externality (upstream network impact).

These concepts are explored in the sequel.

3 Business case modeling for Microgrid internal and external energy and services transactions

3.1 Background Illustration

On the premises of the above sections, it can be seen how business conducts associated with a Microgrid can be roughly categorized into *external* and *internal* cases by nature, which respectively relate to the process of acquiring social recognition of economic, technical, and environmental values created by a Microgrid (mostly externalities) and the procedure of allocating incomes obtained in the first step to different internal players (classical transactions).

Such a distinction, however, is not necessarily visible in the daily Microgrid operation as both functionalities are likely to be assumed by one central operator or dissipated into the collective behaviors of individual controller agents. Nonetheless, for the purpose of identifying Microgrid business potentials, differentiated handling of external and internal transactions provides a convenient platform where Microgrid benefits based on external impacts and delivery of these benefits to beneficiaries under Microgrid internal environment can be decoupled and studied separately.

Therefore, the main purpose of the business case models studied in this chapter is to reveal the prospects of internal business opportunities within a Microgrid, while external sensitivities will be studied in terms of upstream benefit identification and successive allocation to Microgrid agents. In this sense, the construction of internal business cases can be seen as a follow-up of external market and regulation analysis, where the focus of study is turned from '*what kind of benefits can be expected?*' to '*how can the benefits reach to proper recipients?*'.

3.1.1 Economic transactions in brief review

The major form of interaction between Microgrids and upstream networks can be understood as a financial market for trading of electricity (emission trading, if applicable, can be seen as a part of it, as also explored in Chapter 6).

In a short retrospect, and referring to the nomenclature and the approach in Deliverable DG3, the most critical influencing forces from market (external to the Microgrid) and regulation settings can be summarized into three aspects:

(1) Whether or not *directional tariffs* (buy as *quasi-retail* and sell at *quasi-wholesale* level) apply to Microgrid as a whole;

(2) Whether or not *local 'over-the-grid' consumption* (direct trading between Micro-Sources (MS) and end consumer, with dedicated tariff or market scheme) is acknowledged by the regulating authority;

(3) Whether or not *real-time pricing* is introduced to energy trading between a Microgrid and upstream grid.

According to the findings in DG3, a likely enabling requirement for a Microgrid to become economically viable is the acknowledgement of local (internal) consumption when directional and time-invariant tariffs apply, which leads to an economically islanded Microgrid due to local MS cost advantage over buying price (thus no import initiative) and disadvantage over selling price (thus no export initiative). However, this would probably lead to a comparatively small profit margin (as seen from Figure 3-1) for the Microgrid as a whole, since both power flow selectivity and market price selectivity are minimum.

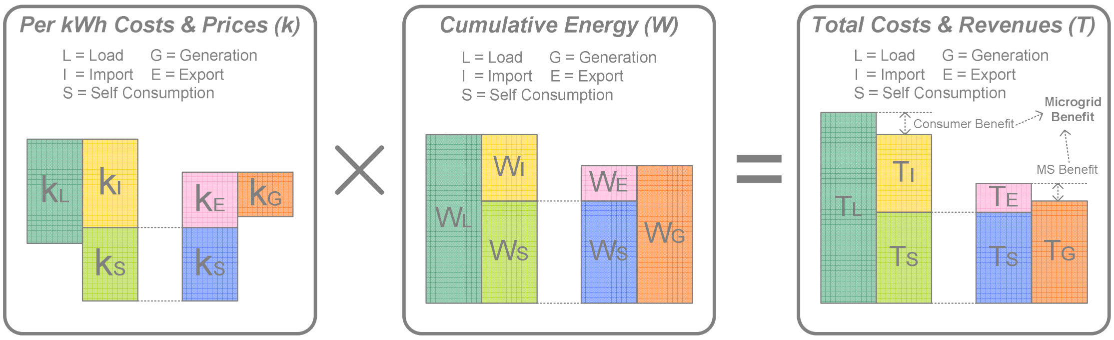


Figure 3-1 Financial and Energetical Balances of a Microgrid under Constant Pricing

On the other hand, once real time pricing scheme is introduced into a Microgrid, both local consumers and MS units will be able to make time-dependent trading choices to minimize opportune cost or to maximize opportune profit. In this sense (shown by Figure 3-2), average grid buying price over a year could probably fall below MS cost line while average grid selling price over a year could probably rise above MS cost line (exactly opposite to economic island condition), which would imply a considerable boost of Microgrid profitability due to increased trading opportunities.

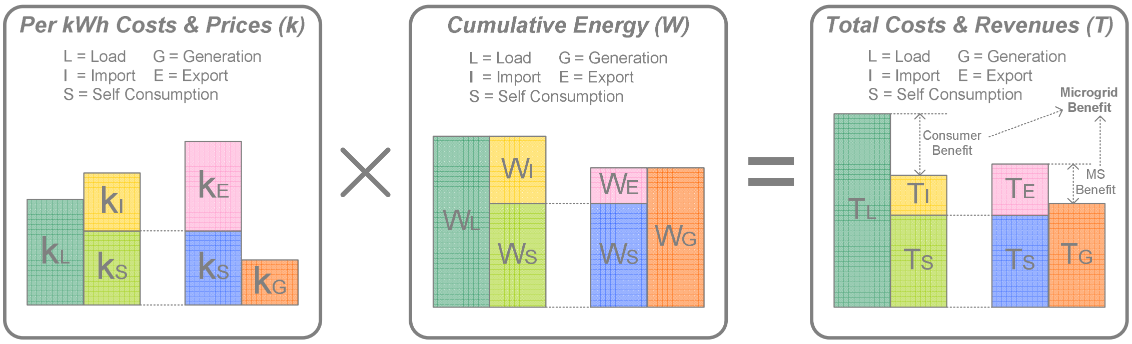


Figure 3-2 Financial and Energetical Balances of a Microgrid under Real Time Pricing

Although it is quite convenient to represent a Microgrid's economic value with summed benefits from both consumer side and MS side (as done in WPG), in reality a fair and transparent internal market mechanism is needed to ensure such benefits will be reasonably split and directed to proper receiving parties. Specifically, the internal market would be responsible for real time (if applicable) price setting for both MS units and end consumers. In case buying and selling price gap persists despite real time setting, the local ('over-the-grid') retail price would also need to be developed within the internal market.

The general motivation for applying real-time pricing mechanism to both MS units and end consumers from a technical standpoint has been discussed above in terms of representing cost-reflectively the impact on network. From an economic outlook, real-time pricing can also be motivated by the potential possibility of excessive market power on MS side or insufficient DSM motivation on end consumer side when constant price settings are applied. In addition, in the potential absence of a central operator or dispatcher (i.e. decentralized control), individual agents at load-side or MS-side will be forced to negotiate deals in real time and constant pricing will not be possible any more.

Allocation of carbon reduction credit within a Microgrid is closely linked with financial transactions both external and internal in nature. In case an effective carbon trading platform is in work, the emission related costs and remunerations can be seen as a derivative of cash flows within retail market, as also illustrated in the examples in the Annex H3.B.

3.1.2 External Service Transactions and Upstream Benefit Modelling

In addition to normal financial transactions based on energy flows between Microgrid and upstream network (external market or tariff prices), generally speaking the Microgrid presence is likely to lead to technical benefits for upstream networks (as from the results in WPH), whose major impact components can be summarized into the following aspects:

- Network losses reduction;
- Congestion relief and potential network upgrade deferral;
- Voltage quality improvement;
- Supply reliability improvement;
- Provision of balancing, spinning or standby reserve services from Microgrid to upstream networks.

Obviously, the majority of these upstream benefits will be received by the upstream grid operators or upstream consumers, while the contributing Microgrid(s) may not be aware or informed of these created values under the default (concurrent) infrastructure setting (which leads to the concept of externalities). In order to transfer a part of these upstream benefits to Microgrid side as a source of remuneration, a technical (ancillary) service market or other remuneration scheme need to be formed between Microgrids and upstream network operators in order to internalize the arising externalities.

In general, a suitable Microgrid concept could be related to developing free-trading models that allow the Microgrid to determine hourly import/export levels on its own to maximize opportune profit and then allocate the benefits to all the involved agents. On the other hand, this concept as it stands would also mean that Microgrid will behave as a self-regulating unit that does not provide full controllability to upstream network, unless opportune modifications to the relevant economic transaction framework are carried out. For instance, under a free market model internal to the

Microgrid with no allowance for upstream related signals, the upstream grid could not force (under liberalized market) the Microgrid to use its own MS units instead of importing all demand (in those cases of market prices being extremely low), so as to imposing certain operation constraints upon the Microgrid to improve MV or even HV level grid performance. Such upstream benefits would indeed be achieved, in this case, at the cost of Microgrid profitability, and a trade-off would thus form. On the other hand, if adequate price signals related to the need for upstream load flow release could be attached to the base energy price signals, which could for instance lead to a net benefit from local production, then MS production would be boosted again. Such a framework is indeed perfectly in line with the general discussion carried out in Chapter 2, and highlights the need for price reflectivity that can even go beyond classical real time pricing as from the wholesale market.

However, it is questionable whether grid operators or other entities would be willing to pay for this type of trade-off or attaching a sort of additional upstream-related premium rather than simply imposing the requirement to Microgrid as a grid code (and blame Microgrid as initiator of the problem in the first place). Economic evaluation (ensued by business cases) of technical benefits is indeed always tricky and difficult due to information transparency and the (un-)willingness of grid operators to actually acknowledge them. The potential reason for this type of reluctance can be in fact explained in that from an economic output, in order to maximize Microgrid appeal (even for getting services limited in time) the upstream network operators might suffer from reduced use of system charge due to local trading mechanism for the part of energy consumed within the Microgrid. In addition, also the upstream generators (both central ones and DG on MV level) might face a reduced demand level and smaller revenue potential. Regulation again should here step in.

Apart from the specific arrangements and willingness of the specific operators, under an effective regulatory setting Microgrids could be remunerated for their technical services provided to upstream network in two ways:

(1) Explicit participation in real time “ancillary” service markets, i.e., separated from cash flow in financial market.

(2) Implicit remuneration for maintaining a certain level of technical performance as additional revenue entries in financial market.

Due to the comparatively small sizes of Microgrids and Multi-Microgrids, direct service market entries in the first manner are comparatively difficult to implement, especially when Microgrid shares in the national network are low. In the scope of this report, the second type of remuneration is thus assumed, which could in turn lead to two types of revenue increments for Microgrids:

(1) Recognition of all locality values, i.e., full exemption of use of system charges for all self-consumed energy (i.e., also including MS units that rely on external support schemes to retain profitability) within a Microgrid. In WPG, this

corresponds to the addition of consumer-side locality benefits on top of the existing selectivity benefits.

(2) Application of better selling and buying prices, i.e., allow partial use of system charge exemption for both buying and selling of energy within a multi-Microgrid or between a Microgrid and neighboring consumer or DG unit. In WPG, this corresponds to the adoption of uniform price setting rather than directional (low export and high import) pricing schemes.

In this report, two basic scenarios are consequently examined:

(1) Business cases based on zero upstream benefit remuneration;

(2) Business cases based on ideal (maximum) upstream benefit remuneration (ideal externality internalisation).

3.2 Business cases inside Microgrids: Local Energy Retail and Service Markets

As already discussed in WPG, from an economic standpoint a major benefit of (and reason for setting up) a Microgrid is the provision of local ‘over-the-grid’ trading opportunity for end consumers and Micro Source (MS) units, thus allowing economically efficient MS integration. As a general base case, in the sequel it is assumed that the competitive production cost of a mature MS technology (thus not dependent on support schemes such as FIT in order to be commercially profitable) falls between the average wholesale and average retail prices (taxes and sales excluded) of a typical European country. Figure 3-3 then shows that the price gap between buying (import) and selling (export) behaviors of a Microgrid could in effect lead to a local retail market in which electricity is traded with higher prices than in the wholesale pool while grid charges are reduced due to the local nature of MS energy consumption.

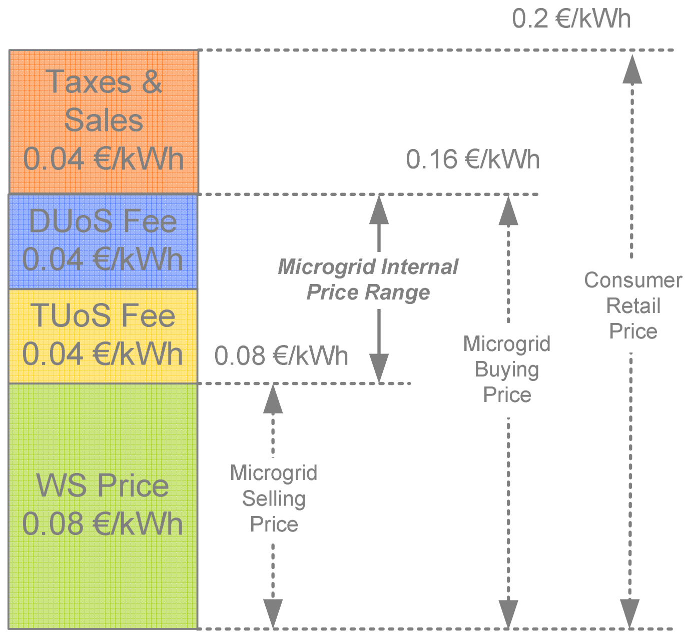


Figure 3-3 Example of Potential Tariff Structure for a Microgrid

As in general the power flows in distribution lines will be probably reduced within a Microgrid, the collected Use of System (UoS) charges may be consequently lowered for a Distribution System Operator (DSO). This potential drawback, however, can be compensated by the technical benefits offered by Microgrid operation. This can be mainly interpreted as steady-state performance improvements in terms of line loading, voltage variation, system losses, and supply reliability. In Table 3-1, the eligibility of both dispatchable MS and intermittent RES units for each suggested service entry has been examined in detail. This type of local service provision from MS units to DSO can be either performed on a compulsory basis (i.e., when the DSO does not benefit from local retail trading) or traded in a local service market (i.e., when the DSO controls the Microgrid).

	Dispatchable MS	Intermittent RES
Peak Load Support	Full	Partial
Voltage Regulation	Full	Partial
Loss Reduction	Full	Full
Reliability / Islanding	Full	None

Table 3-1 List of Potential Service Market Entries within a Microgrid

3.3 Microgrid Ownership and Impact on Local Markets

In WPG, three typical Microgrid ownership properties have been suggested, namely, the *DSO monopoly*, the *prosumer consortium*, and the *free market*. In Figure 3-4, Figure 3-5, and Figure 3-6, structure and cash flow features of these models are respectively shown.

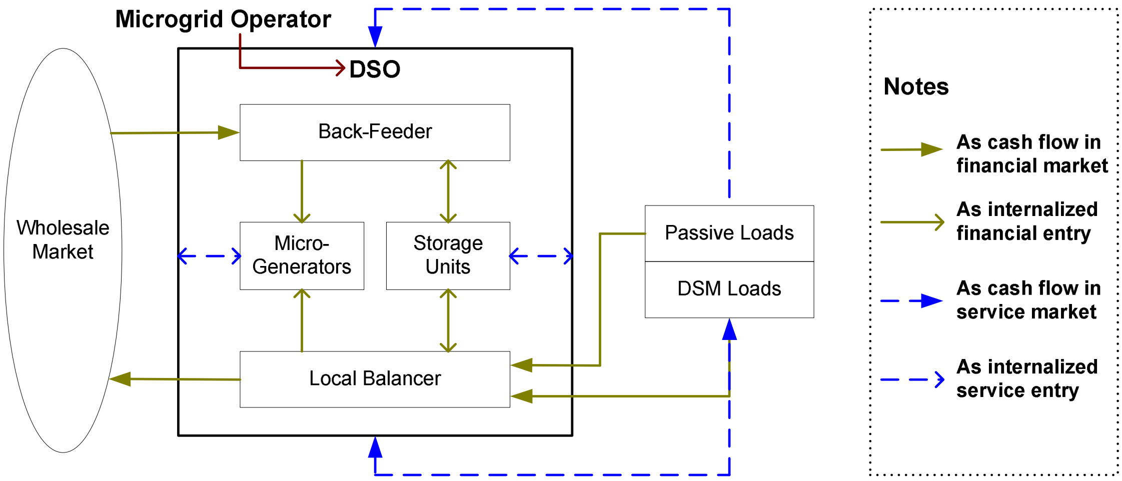


Figure 3-4 The DSO Monopoly Microgrid Model

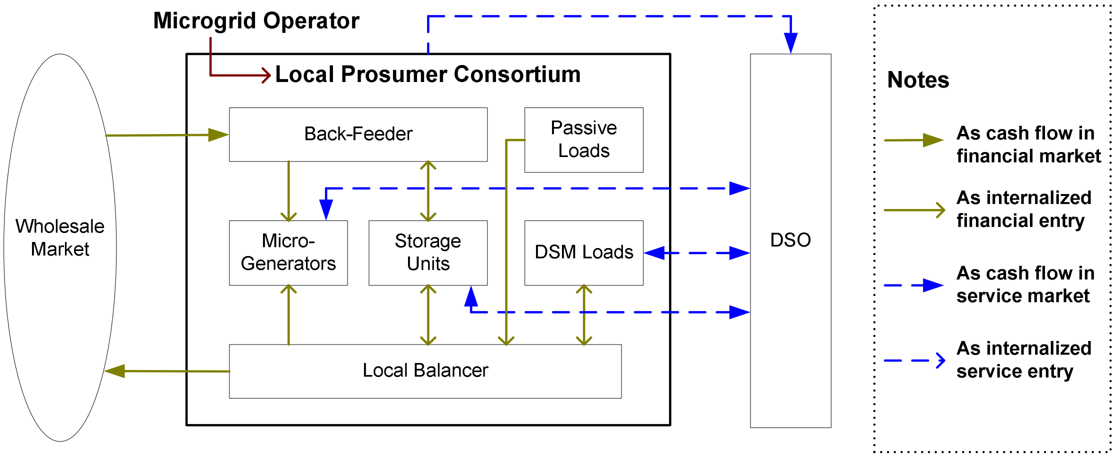


Figure 3-5 The Prosumer Consortium Microgrid Model

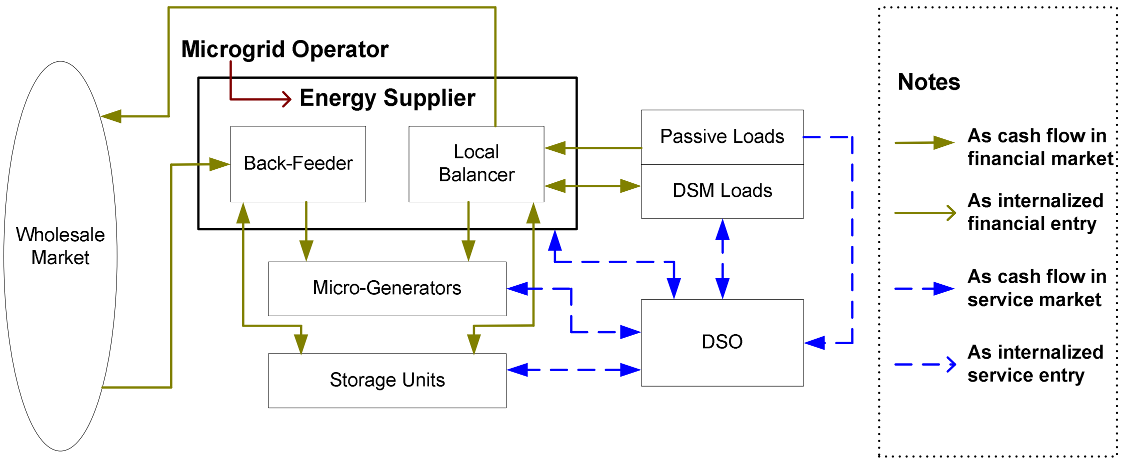


Figure 3-6 The Free Market Microgrid Model

A DSO monopoly Microgrid is mostly likely to be built upon a technically challenged distribution grid with aging, maintenance, and/or supply quality problems. The investment decision in MS units by a DSO (if allowed by market regulator) can be generally explained as an alternative to more expensive solutions to existing network problems (such as replacing overloaded lines to overcome thermal constraint). The potential profitability of selling MS energy to local consumers may or may not turn out to be an initial consideration; but once local value of MS energy is recognized properly, DSO will be very likely the sole beneficiary of such benefits. However, end consumers may or may not be informed of the fact that they are consuming local MS energy and consequently have very slim chances of benefiting from Microgrid operation.

A prosumer consortium Microgrid is most likely to be found in regions with high retail electricity price or high MS financial support levels (and both conditions are very likely to occur simultaneously). In this case, single or multiple consumer(s) will purchase and operate MS units to minimize electricity bill or maximize sales revenue from MS export (if export tariff is high). This type of Microgrid may find considerable barriers set by DSO, as by nature the consortium tends to minimize the use of distribution grid (which leads to a reduction of UoS revenue) and may neglect all network constraints (i.e., hosting capacity) during design of the Microgrid. DSO can only passively influence the operation of a prosumer consortium Microgrid via imposing requirements and charges upon the MS owners, but will not be able to benefit from the local trading process.

A free market Microgrid can be driven by various motives (economic, technical, environmental, etc.) from various stakeholders (DSO, consumers, regulator etc.), and the daily operation decisions will be dependent on real-time negotiations (i.e., interest arbitration) of all involved parties. In this case, a Microgrid Central Controller (MGCC) will be present to behave as an energy retailer that is simultaneously responsible for local balance, import and export control, technical performance maintenance, as well as emission level monitoring. The potential benefits of Microgrid operation will be thus splitted and directed to proper recipients on a level-playing basis.

In Table 3-2, the influences of Microgrid ownership model on local market development and potential interest allocation results are briefly summarized. As can be expected, the DSO monopoly model discards the necessity of local service market (although technical benefits still apply without need for identification), and the prosumer consortium model does not require any local retail market as the loads and MS units are owned by the same interest group. In addition, it is obvious that the DSO monopoly model will maximize DSO benefits, the prosumer consortium model will maximize consumer benefits, while the free market model will attempt to distribute Microgrid benefits to all players.

	DSO Monopoly	Prosumer Consortium	Free Market
Local Retail Market	Yes	No	Yes
Local Service Market	No	Yes	Yes
End Consumer Benefit	Low	High	Medium
DSO Benefit	High	Medium	Medium
Micro-Source Profit	High	Low	Medium

Table 3-2 List of Potential Service Market Entries within a Microgrid

3.4 Sample Study Cases for Transactions in Microgrid Internal Market

The objective of this section is to illustrate possible internal transaction mechanisms of a Microgrid based on a single-unit and one-hour scale with simplified market formulations — i.e., all taxes from regulators and sales entries from intermediary agents are ignored and the Microgrid is considered to receive real-time prices for both import and export. The regulatory setting for Microgrid is assumed to be friendly enough to acknowledge local 'over-the-grid' trading between MS units and end consumers.

3.4.1 Trading of Financial and Environmental Values in Local Retail Market

In WPG, four economic benefit indices of a Microgrid have been identified for both load-side and MS-side, as follows:

(1) Load Side Locality Benefit due to RES Self-Supply (Partial Exemption of UoS Fee);

(2) Load Side Selectivity Benefit due to Selection between MS and External Purchase;

(3) MS Side Locality Benefit due to Acknowledgement of Local Retail Market;

(4) MS Side Selectivity Benefit due to Real Time Price and Energy Optimization.

As locality benefits apply strictly to load only or MS only, there is no need for interest arbitration. The selectivity benefits on load-side and MS-side, however, actually refer to the same benefit created by minimizing the opportune supply cost via selection of local as opposed to external resources for energy trading. Thus the ideal load side selectivity benefit and ideal MS side selectivity benefit cannot be achieved simultaneously (maximizing one will reduce the other index to zero), and allocation of the total benefit (as shown by Figure 3-7) will be needed to ensure fairness and efficiency of the whole Microgrid.

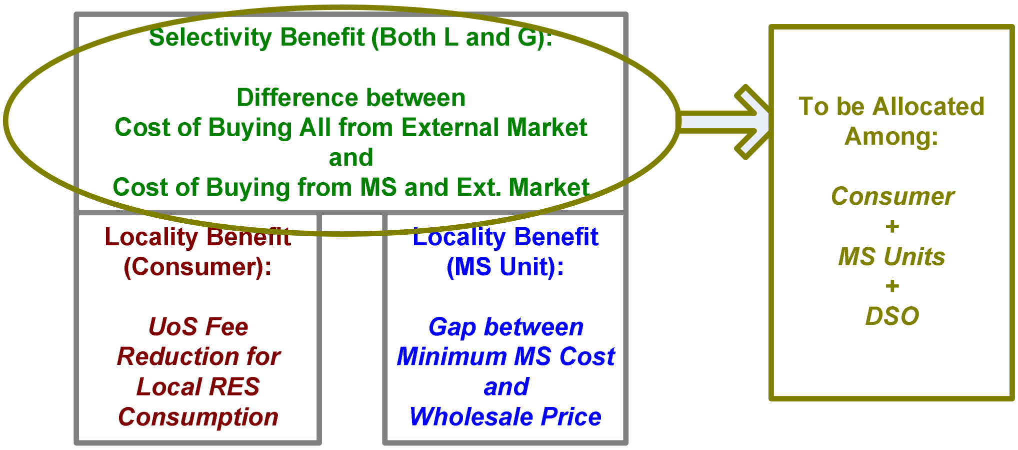


Figure 3-7 Microgrid Economic Benefit Indices and Need for Allocation

It should be noted that in the scope of this section, all MS units are expected to carve out their profits entirely from the price gap between wholesale and retail price levels and thus requires no external financial support for commercial launch of operation, as mentioned earlier. For MS technologies (typically intermittent RES) with basic generation cost above retail level, however, support schemes are needed on top of local sales revenue to ensure unit profitability, as shown by Figure 3-8. In order to achieve best controllability, premium (constant support on top of wholesale market price) rather than FIT (constant purchase price regardless of market price variation) schemes are recommended for dispatchable MS units that are in need of financial support.

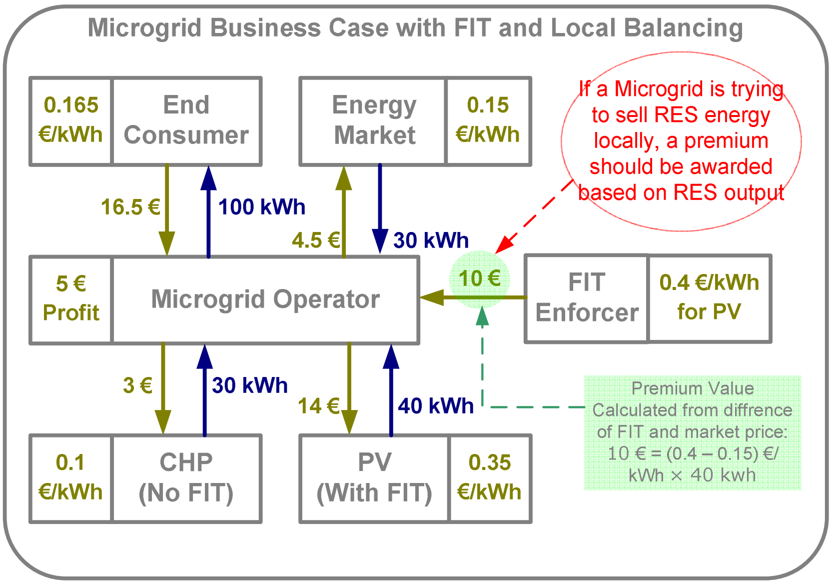


Figure 3-8 Operation of RES Support Scheme within a Microgrid

In Figure 3-9, the original base case used for retail market illustration is given. Assuming that the 0.04 €/kWh tax and sales cost (Figure 3-3) remains constant for end consumer, the net retail price will be 0.16 €/kWh while net wholesale price will be 0.08 €/kWh. We assume the 0.08 €/kWh grid charge is split evenly between the LV

DSO that is in charge of the Microgrid and overlaying HV TSO and MV DSO (represented as TSO only for simplicity).

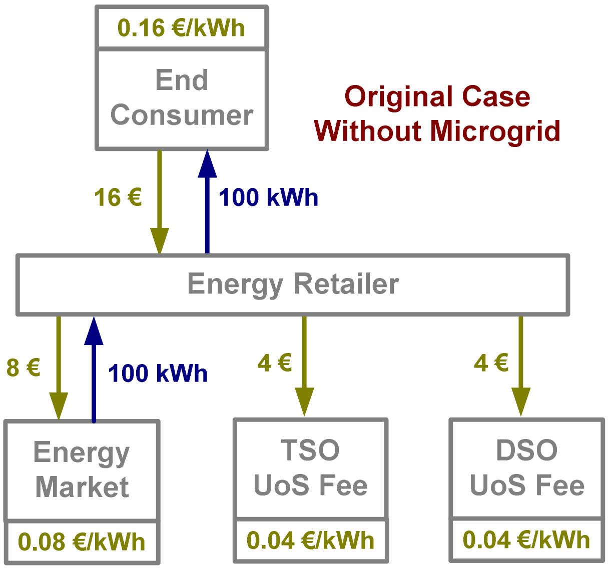


Figure 3-9 Sample Microgrid Local Trading: Original Case Without MS Units

With the original case (no Microgrid), the end consumer(s) need to pay 16 € (without tax and sales) for the 100 kWh consumption in one hour. Now we assume a MS unit with maximum output level of 70 kW and minimum generation cost of 0.1 €/kWh is connected and a Microgrid is formulated in consequence. Using the evaluation method of WPG, total economic benefit due to selectivity in this hour will be 4.2 €, as shown by Table 3-3. This can be translated into a cost reduction 0.042 €/kWh (i.e. from 0.16 €/kWh to 0.118 €/kWh) for end consumers if applied entirely to load side, or a sales revenue of 0.06 €/kWh (i.e. selling at retail price of 0.16 €/kWh) for MS units if the whole benefit is applied to MS side.

	€	kWh	€/kWh
Local MS	7	70	0,1
Import	4,8	30	0,16
Total	11,8	100	0,118
Reference	16	100	0,16
	€	All to load €/kWh	All to MS €/kWh
Benefit	4,2	0,042	0,06

Table 3-3 Summary of Selectivity Benefit in Sample Microgrid

Now that the total amount of benefits to be allocated is known, specific allocation results can be explored for different Microgrid ownership models. In Figure 3-10, the cash flow under DSO monopoly model is given for the sample Microgrid. It can be seen that end consumer under this condition still pays the same 0.16 €/kWh for electricity consumption regardless of using imported or local MS electricity. The DSO will be able to collect 0.054 €/kWh as UoS fee and sales revenue from MS units. The

4.2 € benefit now flows entirely to the DSO, while consumers experience no tariff change and MS units are compensated just for basic operating costs.

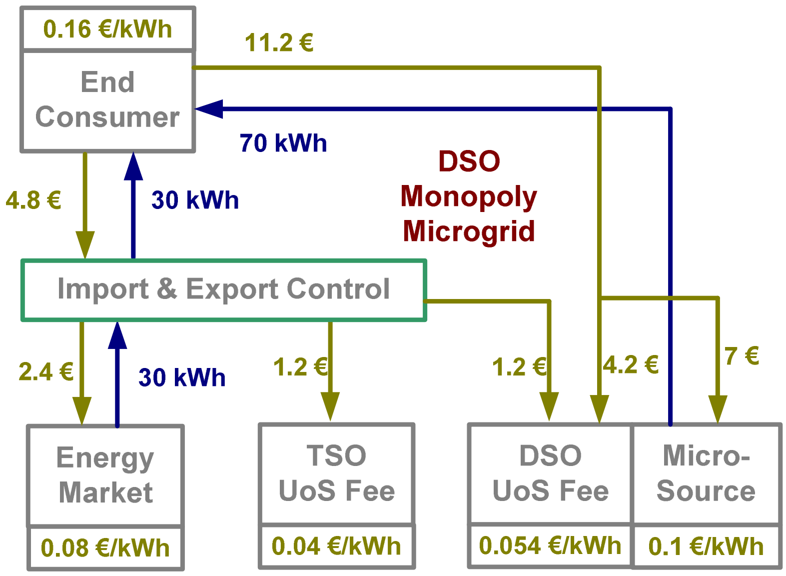


Figure 3-10 Local Trading in Sample Microgrid: DSO Monopoly Model

In Figure 3-11, the cash flow under prosumer consortium model is shown for sample Microgrid. Obviously, the supply cost of 7 € for 70 kWh electricity from MS units has been internalized, which is very probably 'invisible' to all grid operators and is thus not subject to any UoS charges. This makes it possible for end consumers to achieve the theoretical 0.118 €/kWh retail price calculated from Table 3-3, while the DSO can only collect an average of 0.012 €/kWh for the 100 kWh consumption of local consumer.

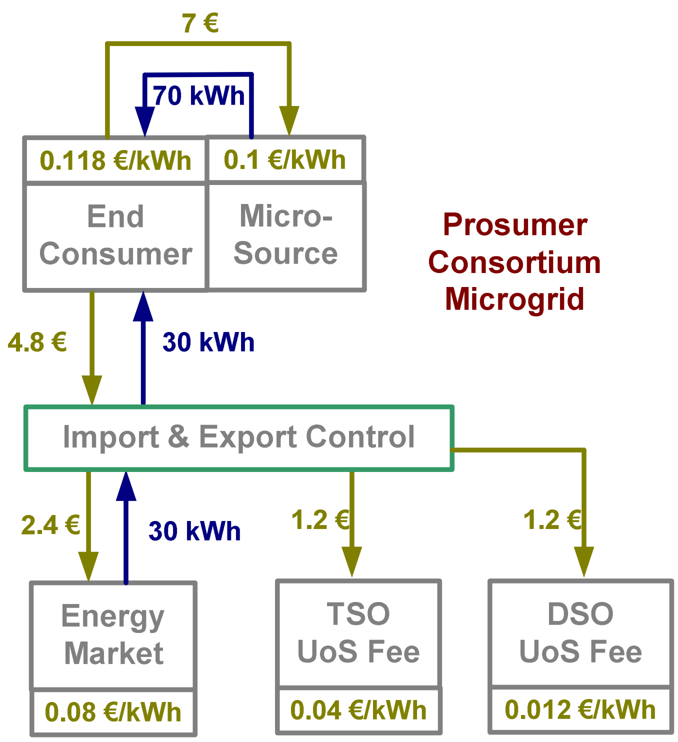


Figure 3-11 Local Trading in Sample Microgrid: Prosumer Consortium Model

Obviously, in Figure 3-10, end consumers do not benefit from Microgrid operation at all; and in Figure 3-11, the DSO suffers significant income reductions due to the lost opportune revenue from on-site energy consumptions. In reality, DSO (in the former model) or end consumer (in the latter case) might voluntarily leave out or be forced to leave out a proportion of the expected benefits to other parties so as to provide sufficient incentives for all players in the Microgrid. Such re-allocation procedures, however, would require effective regulatory measures to function properly and is highly dependent on the level of market liberalization in the distribution sector.

Finally, a potential interest allocation result under free market ownership model is shown in Figure 3-12. In this case, the end consumer enjoys a cost reductions of 0.014 €/kWh; the MS units are able to achieve a profit margin of 0.02 €/kWh; and the DSO now collects an average of 0.026 €/kWh for both local and imported energy flows. This allocation result corresponds to an even splitting of the 4.2 € benefit into three equal shares of 1.2 €/kWh to all three players. In reality, the allocation may not be even in nature, and equal shares are used here only for exemplificative purposes. In fact, DSO could get a larger share if retail liberalization is absent, MS units might receive larger shares under low market transparency, and consumers could take a larger share if political support for electricity price reduction is high. Nonetheless, the free market model offers maximum flexibility of interest allocation with an open platform.

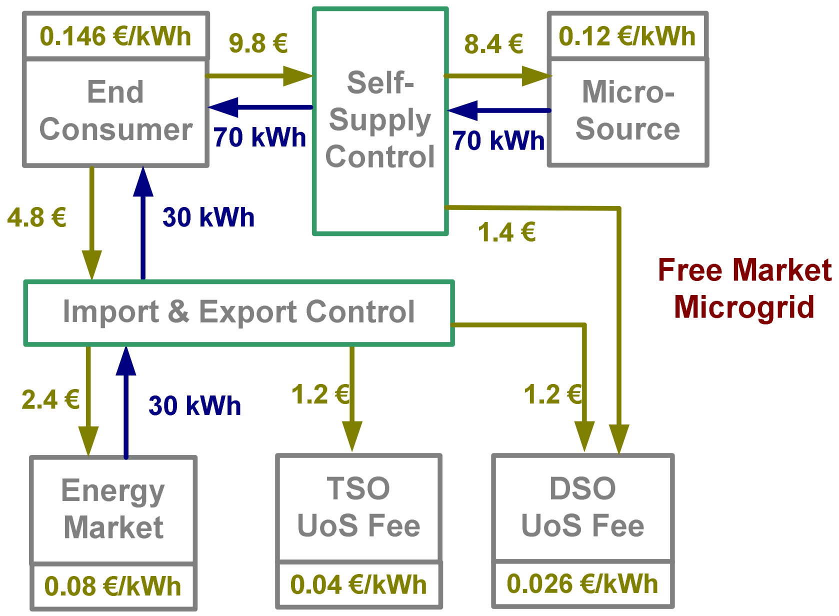


Figure 3-12 Local Trading in Sample Microgrid: Free Market Model

In Table 3-4, the interest allocation results of DSO monopoly, prosumer consortium, and free market models are summarized according to Figure 3-10, Figure 3-11, and Figure 3-12. As already stated before, results in this table are typical values that can be expected from these three ownership models, but they are not the only possible outcomes. Nevertheless, the allocation principles used in this section are considered as most likely to occur in reality and will be applied to analysis of European-level simulation data in ensuing sections.

	Consumer	Micro-Source	DSO	Total
DSO Monopoly	0 €	4.2 €		4.2 €
Prosumer Consortium	4.2 €		0 €	4.2 €
Free Market	1.4 €	1.4 €	1.4 €	4.2 €

Table 3-4 Ownership Model Impact on Sample Microgrid Interest Allocation

Up to now, the selectivity benefit used for interest allocation in sample Microgrid has been obtained on the basis of directional pricing (i.e., 0.08 €/kWh for export and 0.16 €/kWh for import), which corresponds to the case without upstream benefit consideration (as defined in section **Error! Reference source not found.**).

When upstream benefits are included and a uniform Microgrid price of 0.12 €/kWh is applied, the total selectivity benefit will be increased in the example from 4.2 € to 4.8 € as a result. However, interest allocation principles basically stay the same for all ownership models, as shown by Table 3-5.

	Consumer	Micro-Source	DSO	Total
DSO Monopoly	0 €	4.8 €		4.8 €
Prosumer Consortium	4.8 €		0 €	4.8 €
Free Market	1.6 €	1.6 €	1.6 €	4.8 €

Table 3-5 Sample Microgrid Interest Allocation with Upstream Benefit Inclusion

3.5 Trading of Technical Services in Local Service Market

In comparison with a local retail market, a local service market within a Microgrid might be much more difficult to build and operate mainly due to two reasons:

(1) DSO might lack willingness of remunerating MS units or DSM loads for potential technical service items, especially when such benefits cannot be translated directly into economic terms or faces large uncertainties due to MS operation decisions.

(2) Potential providers (mainly MS units) of technical services within a Microgrid might not be sufficiently aware or informed of their contribution to system performance, especially when the service is a by-product of normal daily operation.

Despite these obstacles, in this section we assume a local service market exists within a Microgrid. In the mean time, it is assumed that all ‘unconscious’ provision of technical performance improvements (e.g. peak load reduction due to normal MS trading behaviour) is not compensated in any form, which means the DSO is allowed to take advantage of such ‘shadow’ benefits to offset the potential revenue reductions from UoS charges.

The necessity of building a local service market is therefore mainly driven by the potential conditions where MS, storage, or consumer entities have to undergo a certain revenue loss or cost increment in order to achieve a certain level of technical performance at a given time instant, and such performance level should be transferrable to a visible economic benefit from the DSO side, so that in consequence paying willingness by the DSO arises.

Obviously, under a non-transparent market setting, the DSO could assign all such operating constraints (that could potentially create technical benefits) as compulsory grid codes and obtain the technical services completely for free, as mentioned above. This can be of course possible when the DSO was to suffer heavy losses from reduction of UoS revenue and was then to need “free” technical benefits to reduce operating costs. However, in those cases when the DSO turns out to be the dominating role in a Microgrid, a local service market could become a more effective interest allocation tool than simple regulatory measures.

As Table 3-1 suggests, non-dispatchable RES units can only provide partial service support in restricted areas (mainly reactive power control). Thus in the scope of this section, all service market entries are exemplified with dispatchable MS units as service provider.

In Figure 3-13, a peak shaving transaction is shown for a sample Microgrid with line thermal constraint problem. As the MS units could offer to run at partial load (thus reduced income) to maintain loading of an otherwise overloaded line below 100%, the DSO could use a part of avoided line upgrade fee to award the MS unit to achieve a win-win situation for both sides.

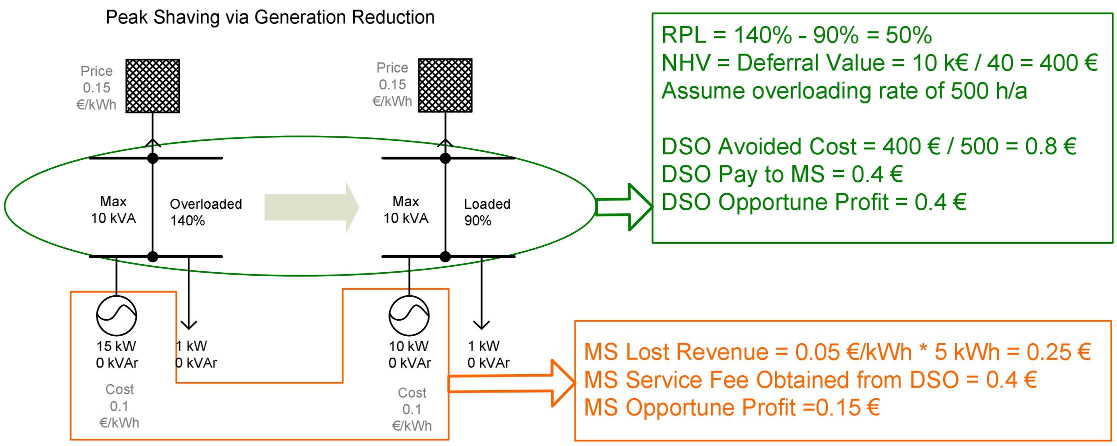


Figure 3-13 Peak Shaving Service Trading in Sample Microgrid

Similar to the case of peak load support, in Figure 3-14 a voltage regulation service trading example is given, where the DSO remunerates a MS unit for maintaining the voltage variation of its connected node within +/-10%. The MS unit should be potentially able to cover lost active power sales revenue and reactive power generation costs with such extra revenues.

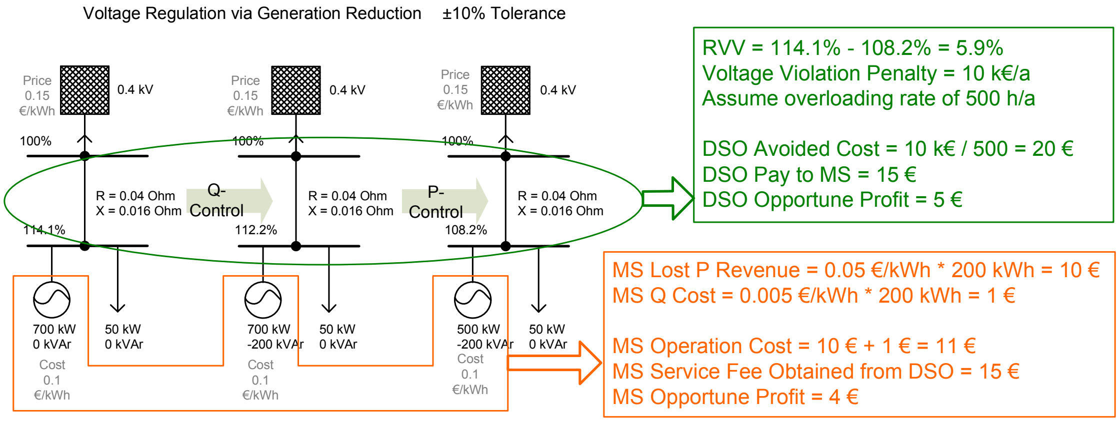


Figure 3-14 Voltage Regulation Service Trading in Sample Microgrid

There is however a serious recognition problem with both peak shaving and voltage regulation entries: DSOs could claim that potential overloading and voltage violation problems are created by the irresponsible operating behaviour of MS units in the first place and assign the output restriction and reactive power tuning requests to MS units as compulsory operating conditions. From the MS point of view, such requests may appear to be unfair as they may have seen none of these terms during interconnection process. It is therefore very important for both sides to achieve mutual understanding of what are expected (leading to compulsory terms for MS) problems and what are unexpected (leading to remunerated service by MS) problems so as to differentiate (in case) service market opportunities from required operating constraints.

In Figure 3-15, the potential losses reduction credit of a Microgrid is shown, which indicates that synergy of load and MS causes lower losses than either single resource.

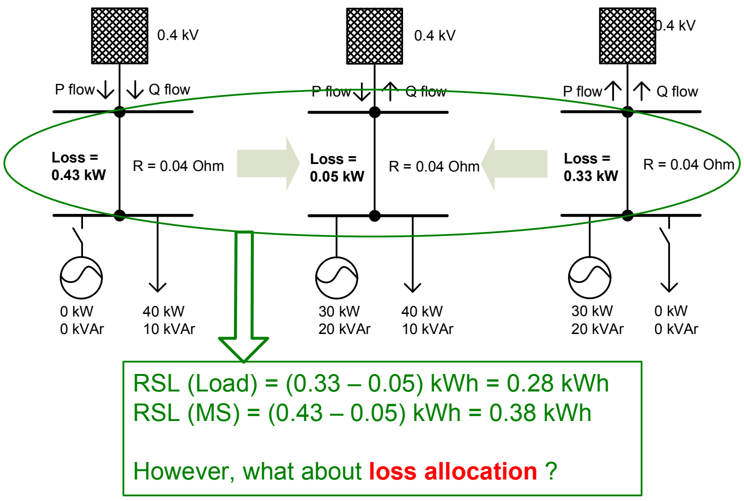


Figure 3-15 Loss Reduction Effect of a Sample Microgrid

Despite the relative convenience of loss reduction identification, the allocation of loss contribution to different consumers and MS units can become a very complicated issue due to the existence of bi-directional power flow in a Microgrid. For instance, losses allocation methods traditionally applied to transmission networks could be adopted as well here, which, however, in general face algorithm complexity or allocation fairness problems. In Figure 3-16, an allocation example is shown using the NtL load flow method (Technical Annex C of WPG) as a reference.

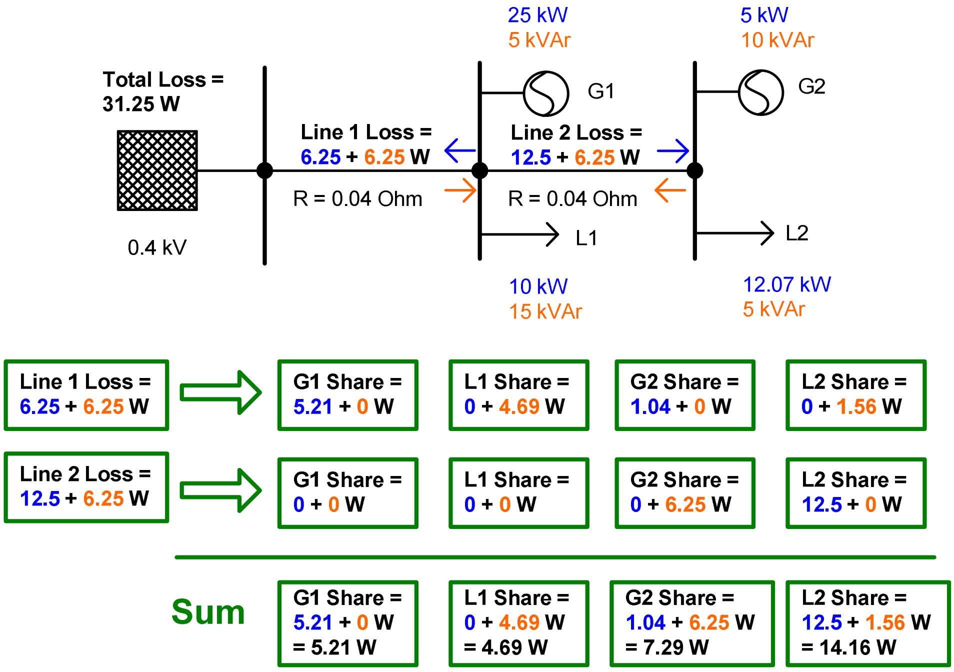


Figure 3-16 Loss Allocation with Load Flow Coefficients of a Sample Microgrid

Finally, one major contributor to a Microgrid's technical value is its capability of operating in complete or partial islanded mode during network disturbance or loss of main grid. As the potential cost of supply interruption normally exceeds by far the generation cost of MS units, the major economic criterion for deciding the economic value of a Microgrid's islanding capability will be the investment cost for storage units (assuming that storage units are only used during islanding condition). A sample islanding service value identification case is shown in Figure 3-17, in which storage investment cost is justified by the potential supply interruption loss without Microgrid islanding capability.

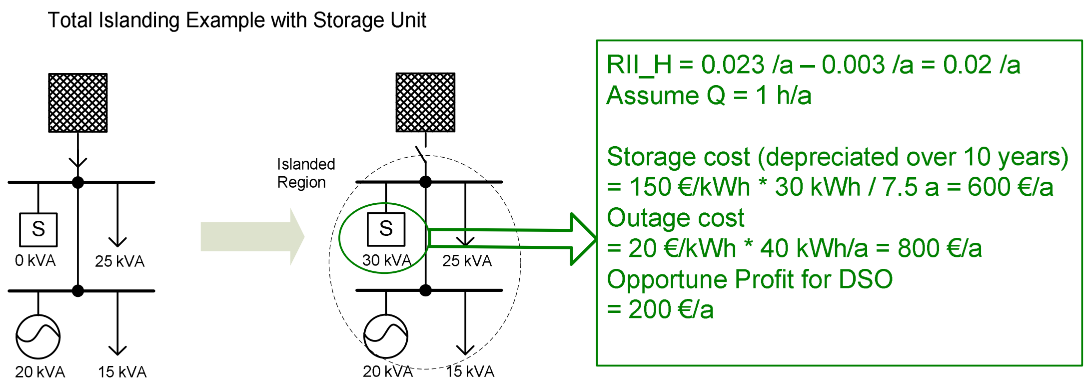


Figure 3-17 Islanding Service Evaluation of a Sample Microgrid

It should be noted that although the majority of technical service entries (except for energy loss) in this section are explained with DSO as payer of services, in the end it is quite likely that the DSO will transfer the service costs to some or all end consumers in one way or another. In this case, the market regulator is again responsible for determination of proper allocation of service costs between DSO and end consumers.

4 Application of business models to European countries

4.1 Application of Interest Allocation Models to European-Level Dataset

In WPG, the potential benefits of Microgrids have been summarized in benefit indices that include not just economic aspects but also potential technical and environmental impacts. In this section, actual Microgrid selectivity benefit values calculated from WPG are allocated among end consumers, Micro Sources (MS), and DSO using different ownership models as well as different external benefit levels.

4.1.1 Brief Summary of WPG Simulation Result under STC Condition

As already shown by Figure 3-7, the ideal selectivity benefit indices on consumer side and MS side are actually based on the same amount of economic value, but divided by different energy levels (total demand for consumer benefit, and total generation for MS benefit).

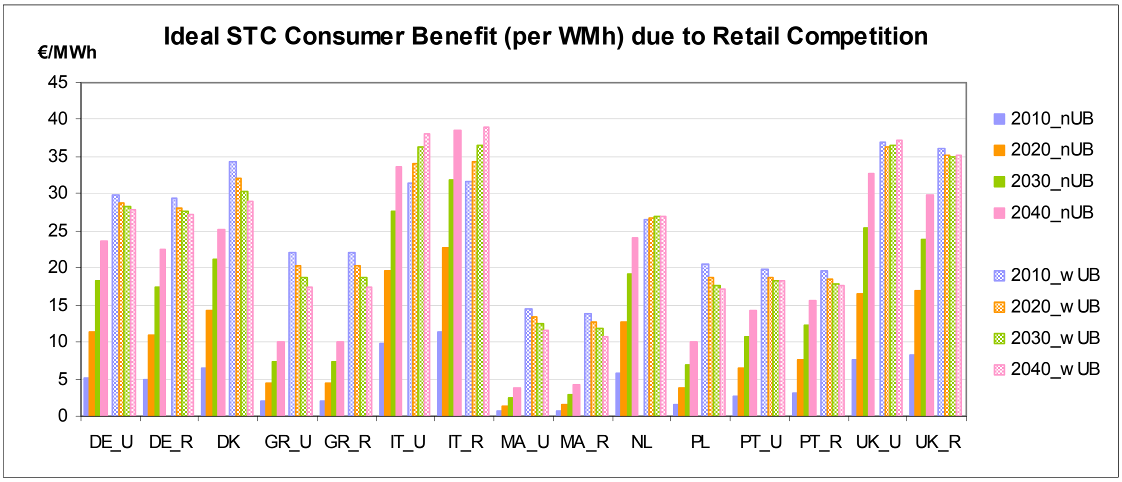


Figure 4-1 Ideal Consumer Side Selectivity Benefit under Standard Test Condition

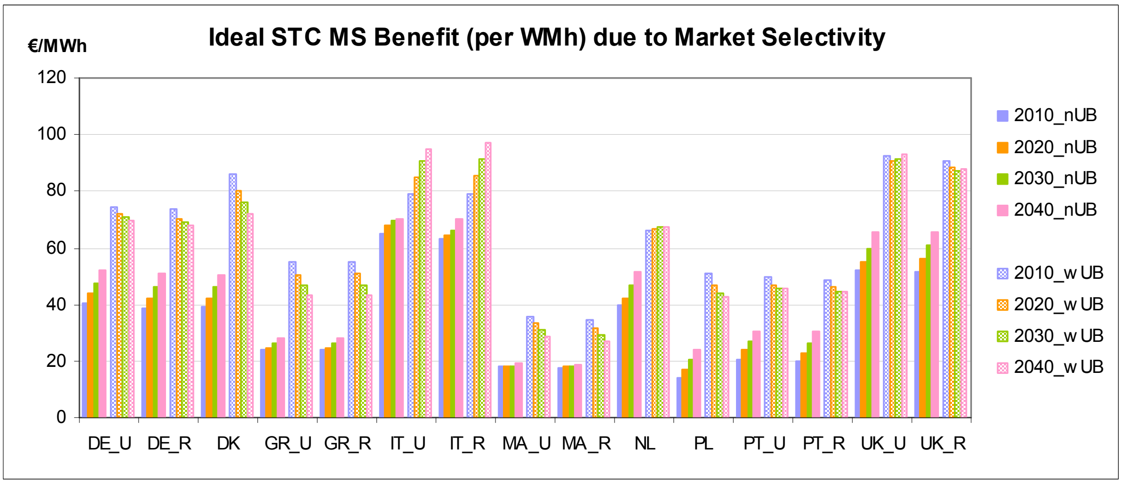


Figure 4-2 Ideal MS Side Selectivity Benefit under Standard Test Condition

In Figure 4-1 and Figure 4-2, the calculated maximum benefits on consumer side and MS sides are respectively shown. Consumer side benefit refers to per-kWh price reduction (compared to original retail price), while MS side benefit refers to per kWh profit (compared to generation cost). Obviously, Figure 4-1 corresponds to the ideal situation where consumers obtain all Microgrid benefits, while Figure 4-2 refers to the ideal case where MS units obtain all Microgrid benefits.

In both plots, nUB refers to no upstream benefit, while wUB refers to with upstream benefit. The conspicuous increment of potential benefits on both sides due to upstream benefit recognition can be seen as the consequences of locality value inclusion and introduction of more friendly pricing schemes (from directional to uniform pricing).

4.1.2 Allocation of Total Selectivity Benefits

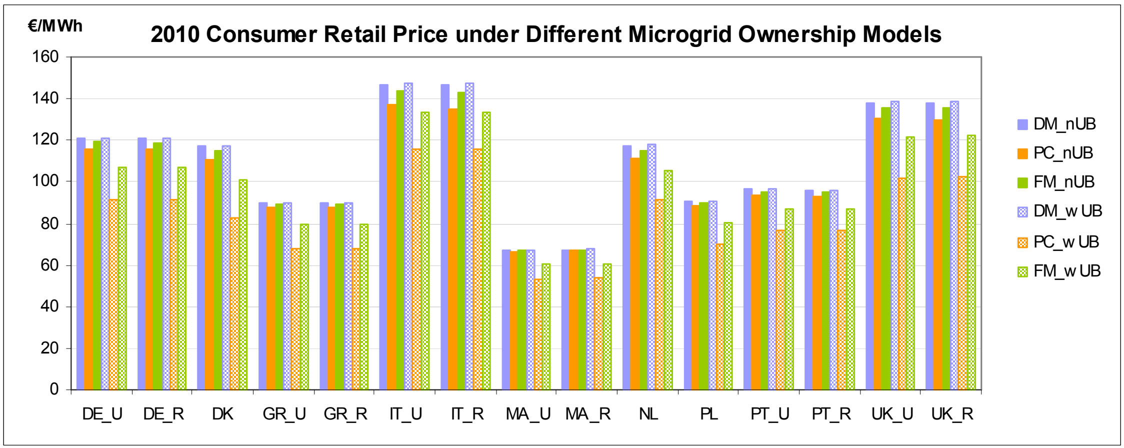
In Figure 4-3, Figure 4-4, Figure 4-5, and Figure 4-6, benefit allocation results are respectively shown for 2010, 2020, 2030, and 2040 case study scenarios (detailed scenario definition is given in WPG).

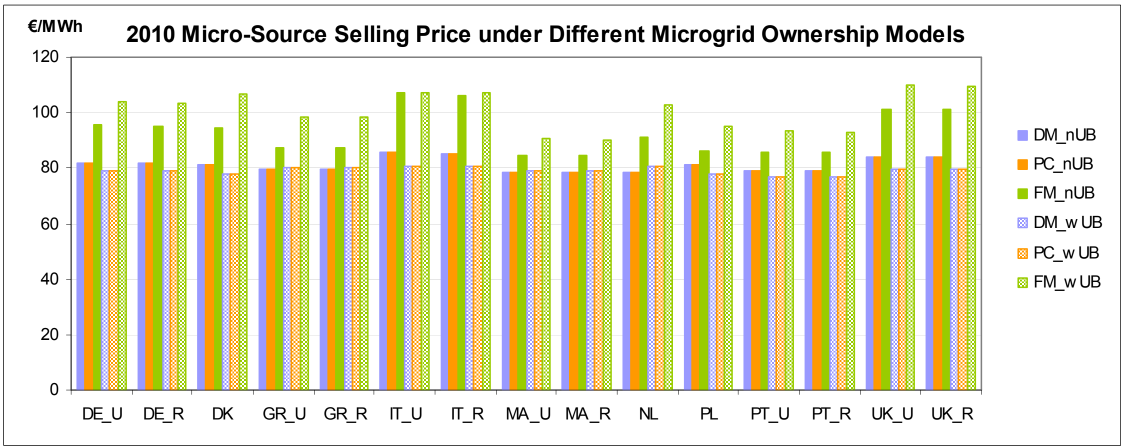
In all listed plots, DM refers to DSO monopoly, PC refers to prosumer consortium, and FM refers to free market. Again nUB refers to no upstream benefit, while wUB refers to with upstream benefit.

Study of the allocation results reveals that Microgrid benefits are most pronounced under a DSO monopoly model, where system operator could experience up to 100% revenue increase by owning and operating the MS units even under low penetration levels (i.e. 2010 case). Consumers receive naturally the highest amount of price reduction under prosumer consortium model, but the visibility of such benefits is comparatively low in the starting scenarios where MS-supplied energy ratio is low. Under free market condition, obvious compromises are made such that benefits are shared among all players.

Inclusion of upstream benefits turns out to be extremely effective for increasing consumer-side and DSO-side benefits under low MS penetration levels (e.g. 2010 case), which can be understood as the effect of regulatory support over the initial launching of commercial-level Microgrids. Eventually, however, the contribution of upstream benefits to total Microgrid value decreases as MS penetration level becomes higher (e.g. 2040 case) — this is of course caused by the high self-supply tendency of Microgrids with cost-competitive MS technologies, where more benefits are transferred from external side to internal side.

In both DSO monopoly and prosumer consortium scenarios, MS units are assumed to be operated under zero profit due to subsidiary ownership property. Under the free market setting, however, a comparatively consistent profit margin can be observed over the years with national differences mainly determined by average wholesale price level. Inclusion of upstream benefit obviously enlarges the potential MS profit margins for all examined cases, whereas actual increment depends on FLH values under operation.





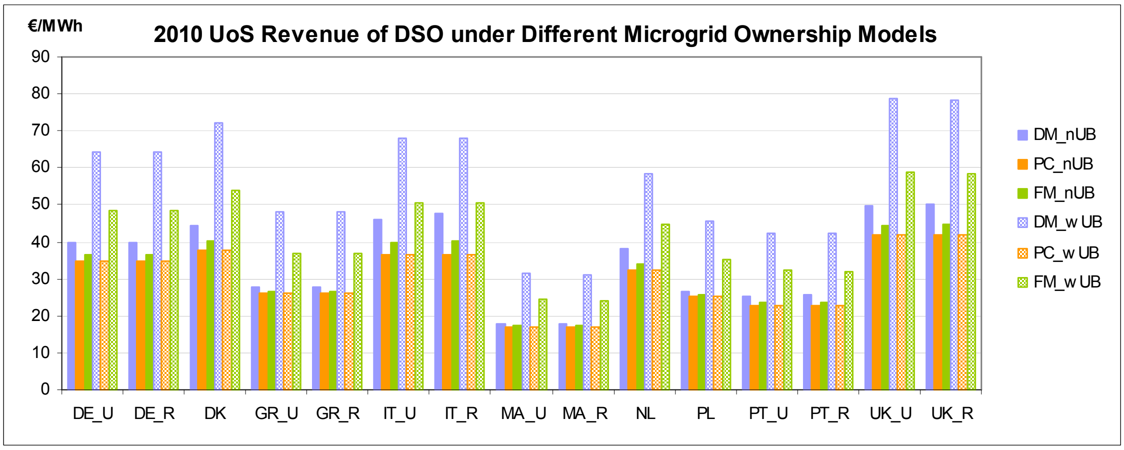
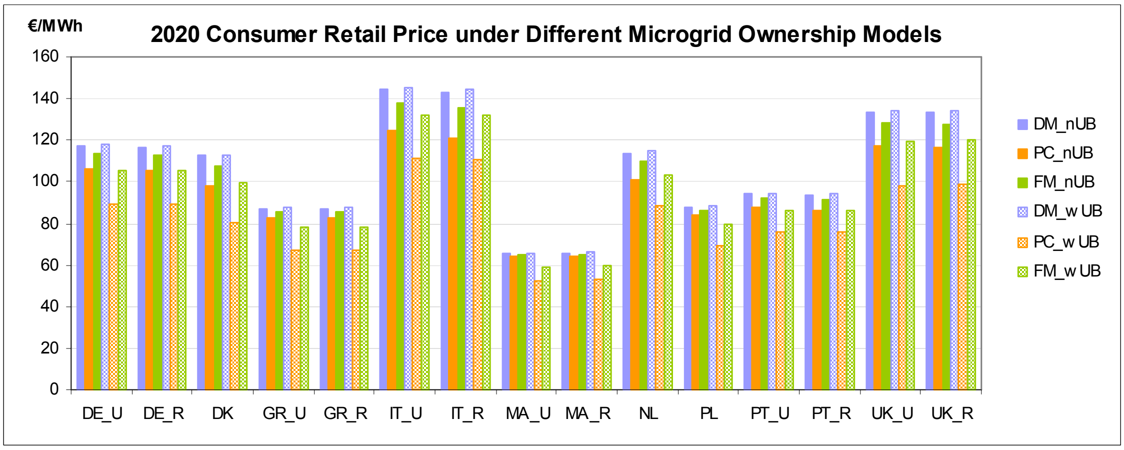
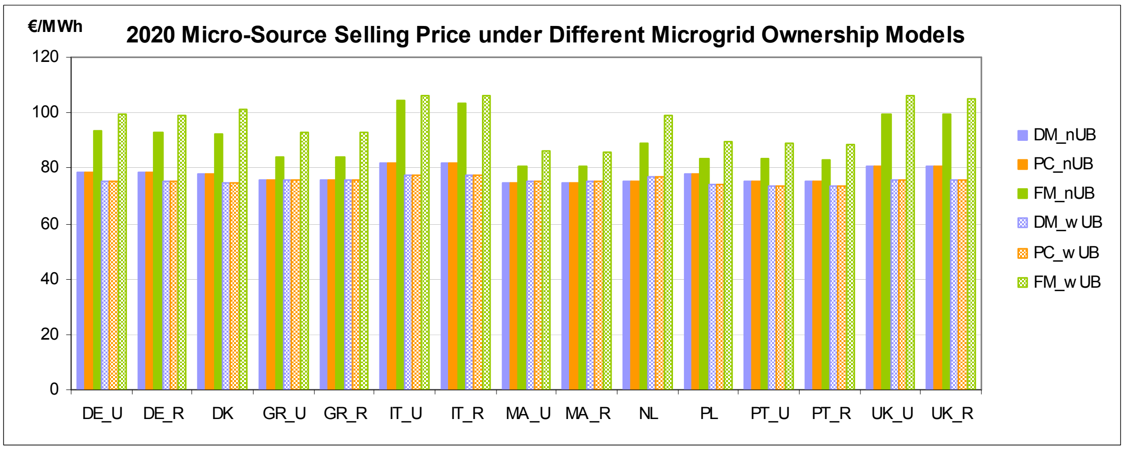


Figure 4-3 2010 Benefit Allocation Results under Different Ownership Models





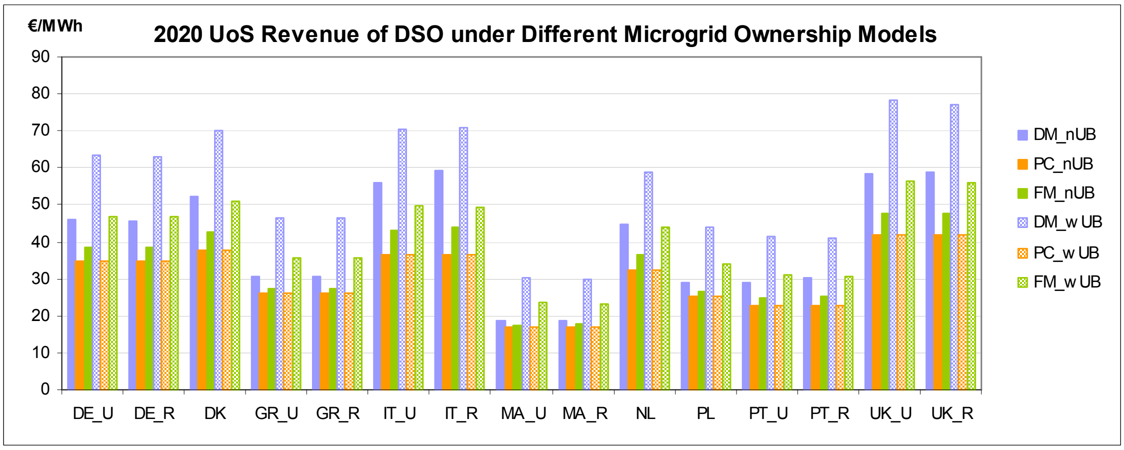
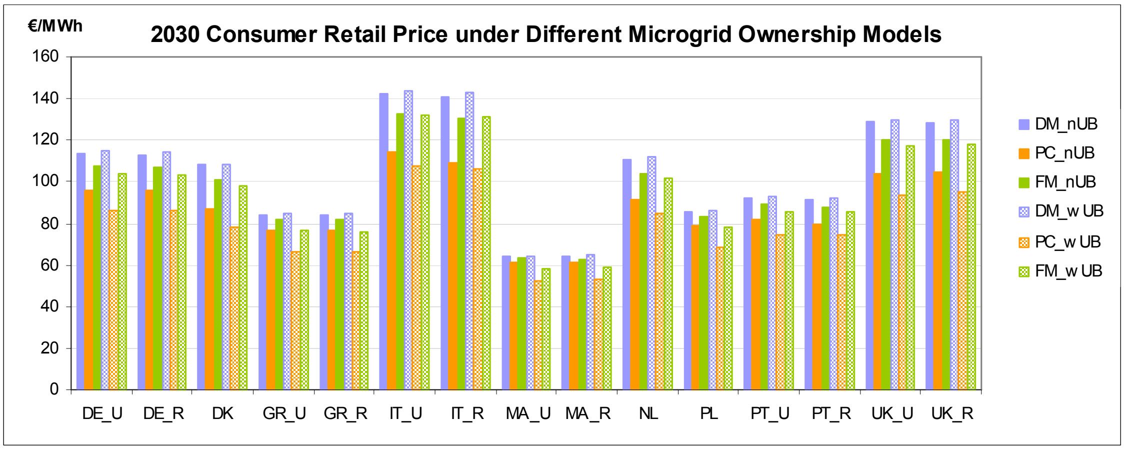
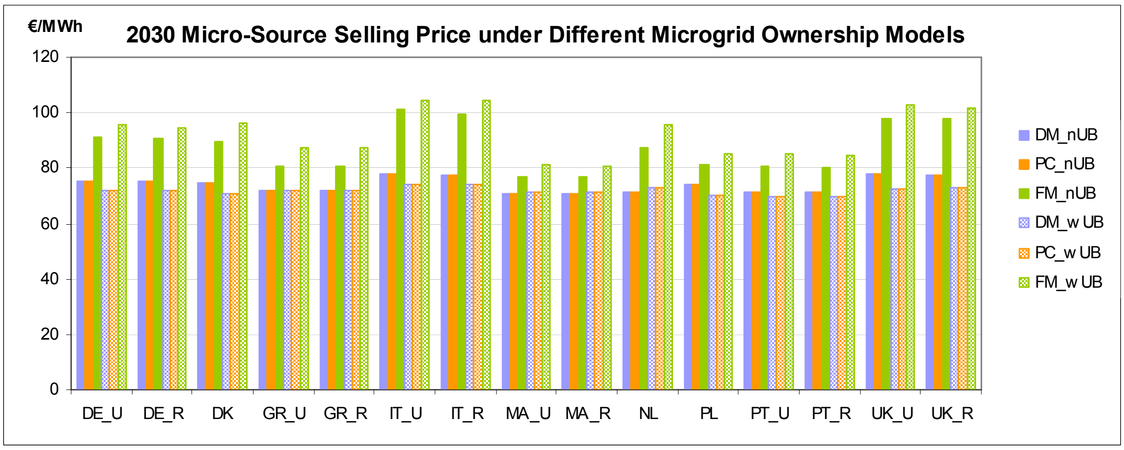


Figure 4-4 2020 Benefit Allocation Results under Different Ownership Models





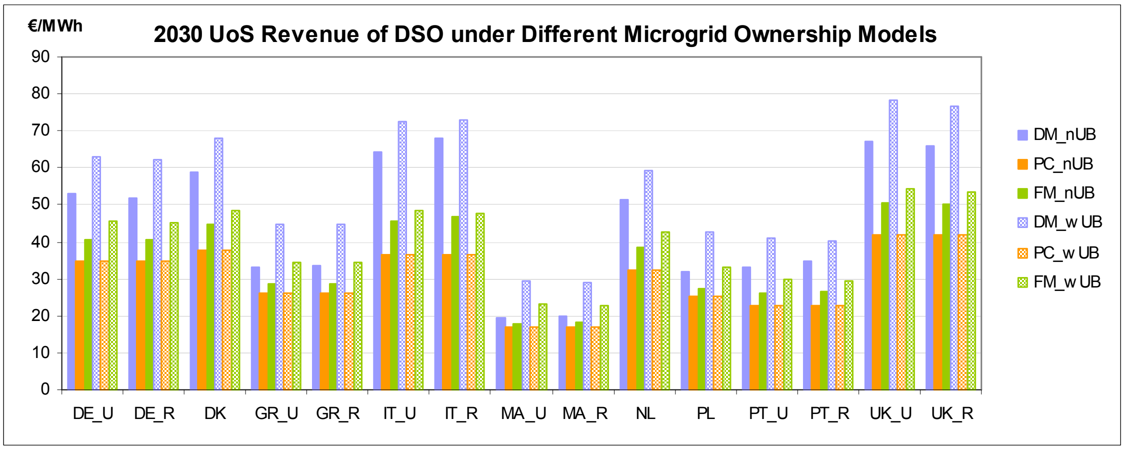
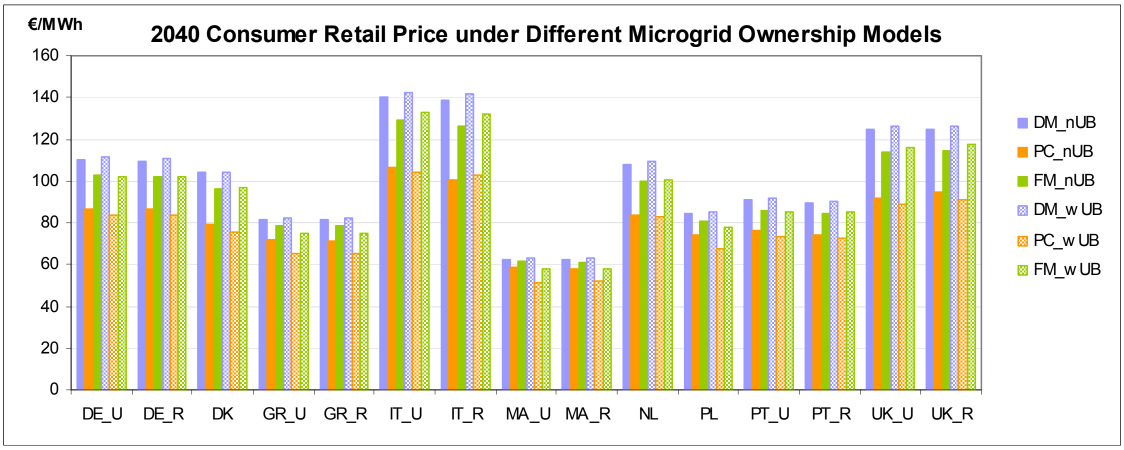
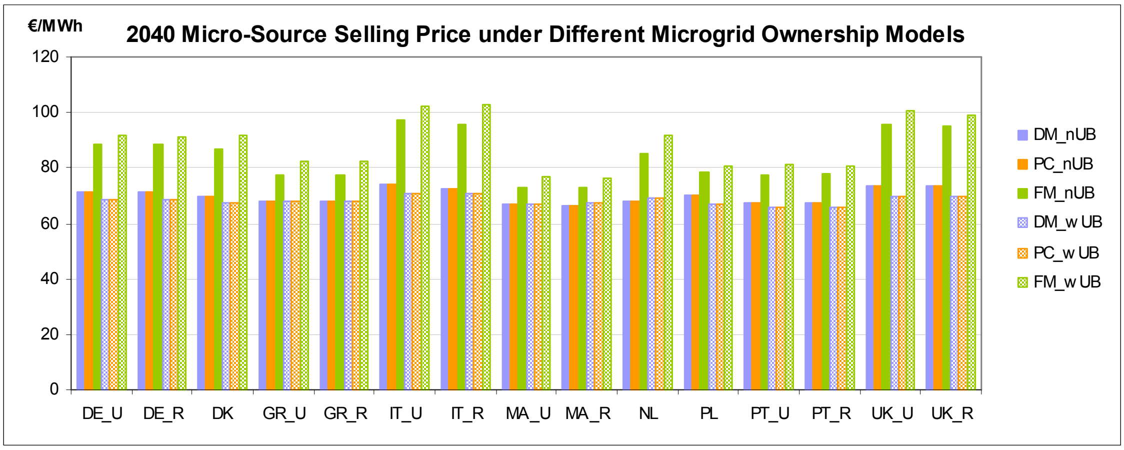


Figure 4-5 2030 Benefit Allocation Results under Different Ownership Models





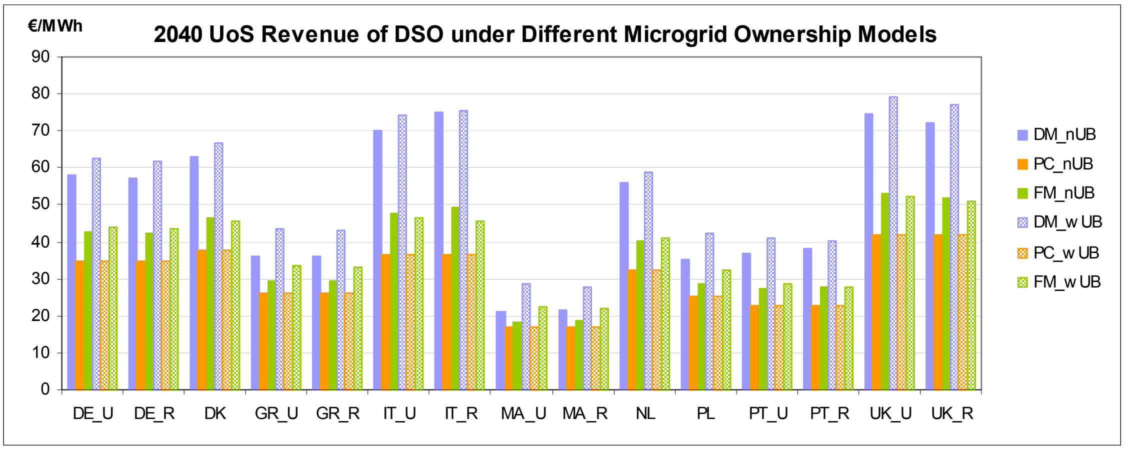


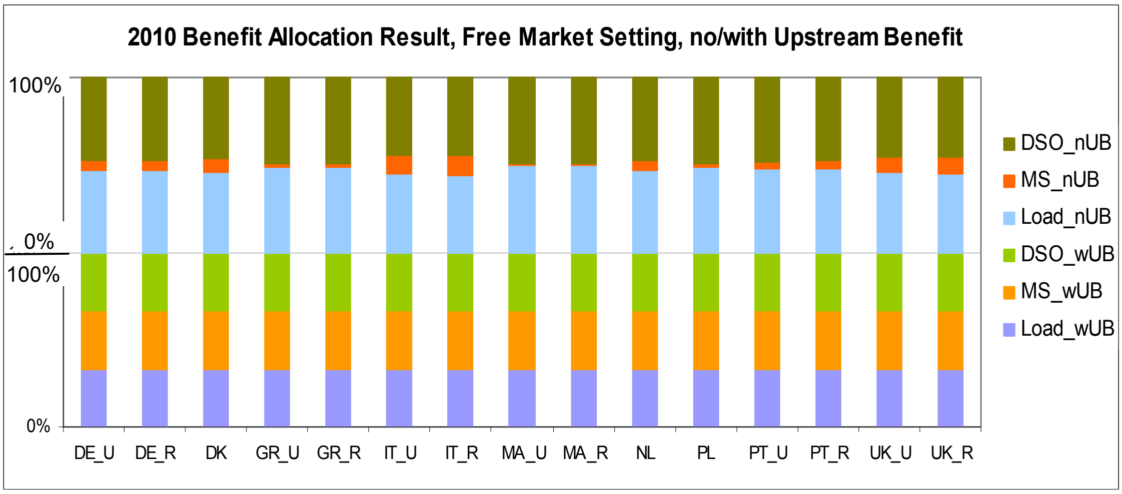
Figure 4-6 2040 Benefit Allocation Results under Different Ownership Models

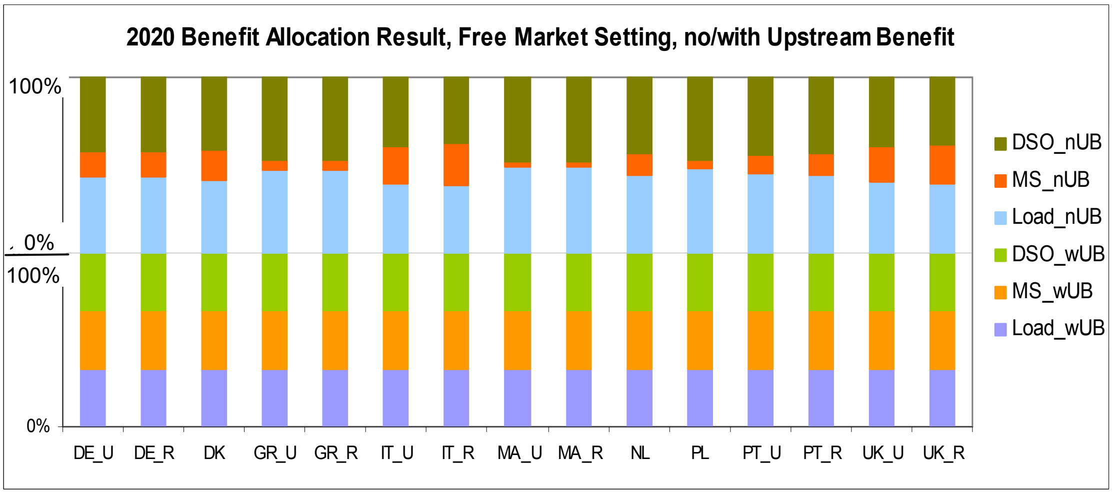
4.1.3 Benefit Allocation Ratios under Free Market Condition

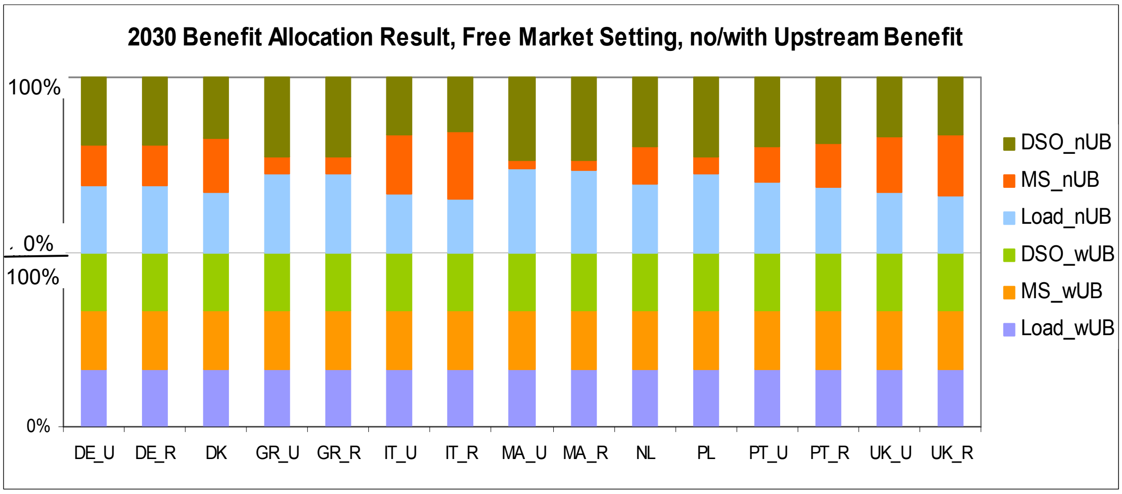
In Figure 4-7, the benefit allocation ratios of DSO, MS, and end consumers are listed under free market setting. Again nUB refers to no upstream benefit, while wUB refers to with upstream benefit.

While allocation strategy without upstream benefit recognition appears to be exactly even among all three parties for all examined countries and time settings, inclusion of upstream benefit changes this default allocation philosophy, which mainly applies a changing level of MS ratio of benefit according to its actual contribution to total system energy demand.

The reason behind a varying level of MS benefit sharing ratio under upstream benefit inclusion model can be explained as follows: the added upstream benefits are made up of economic values created by energy flows irrelevant with local MS production level (e.g. cheaper energy import from neighbouring DG in MV grid), thus the actual share that MS units can obtain from this total value is strongly dependent on their annual FLH levels—which justified the gradual increase of MS benefit share with time advancement.







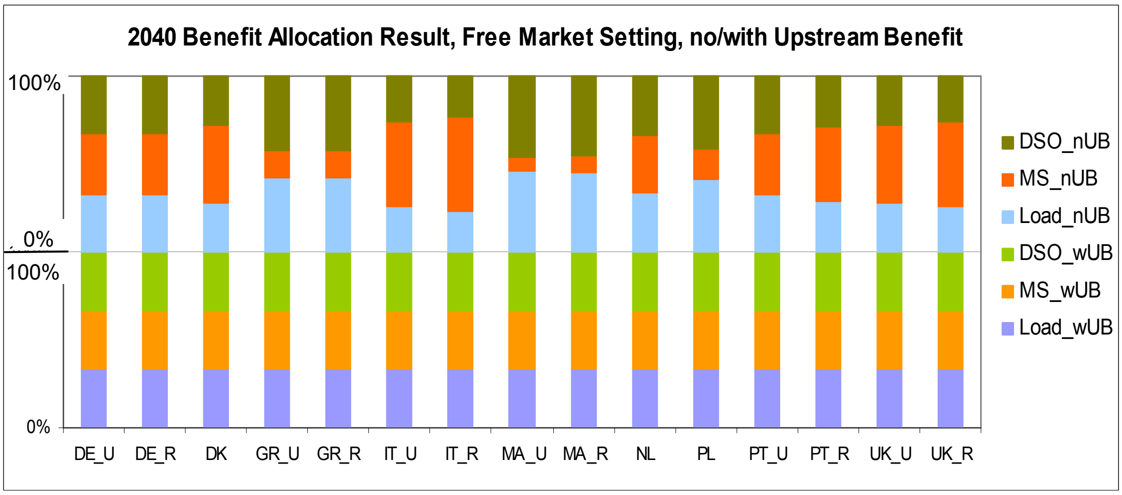


Figure 4-7 Comparison of Benefit Holding Ratios with and without Upstream Benefits

5 Decision theory models and analyses for Portuguese Microgrid business case studies: Annex H3.A

As illustrated above in this report and throughout the project, MS impact on networks will depend on several parameters such as, primarily: size, type and location of the new connections; pattern and timing of output; density of installations; rural/urban setting; proximity to the load; the state of the network and the overall amount of capacity; etc. However, in order to enable MS to act as an option for DSOs, the operational strategies which can be used when exploiting MS and DSM need to be considered in the planning exercise. In addition, focusing on infrastructure benefits, as illustrated in WPH the economic benefits of installed MS under the Microgrid (MG) and Multi-Microgrid (MMG) concepts to the utility could come from deferred generation and distribution investments, net of the costs associated with installing, operating, maintaining, administering, coordinating, scheduling, and dispatching MS units. Utilities that are not MS owners may as well offer capacity payments for units that can be dispatched during times of system need in order to ensure availability and to address their interests in performance guarantees, which is directly related to the business models for services provision described above.

In that regard, the impact that large scale MS operated under coordinated and controlled scheme using the MG and MMG concept could have on distribution networks could lead to different regulatory approaches by creating incentive mechanisms for DSO, MS owners and loads to accept the MMG concept and define adequate remuneration schemes. Therefore, identification and evaluation of significant, quantifiable economic, technical and environmental benefits and costs attributed to the MG and MMG deployment is a prerequisite for building a comprehensive regulatory framework in favour of easier integration and deployment of these concepts, as preliminarily discussed above.

Within this framework, INESC Porto has carried out extensive modeling and simulation exercises regarding Multi Criteria Decision Aid (MCDA) techniques, with the aim of evaluating the MG and MMG impact on LV and MV distribution networks and trying to capture different preference structures of the Decision Maker (DM) and to help in the evaluation of the cost-benefit relation resulting from the deployment of these concepts. Given the volume of the work, the results are illustrated separately in the Annex H3.A., which summarizes the findings on the evaluation of potential costs and benefits by deployment of the MG and MMG concepts using multi-criteria decision aid methods. More specifically, identification of multiple criteria and assessment of their attributes precedes the decision aid process, where different decision aid techniques are applied for capturing different the Decision Maker's preference structures. Starting with trade-off analysis, it is shown how different trade-offs normally lead to different evaluations/rankings in each scenario, and within the set of possible solutions it is important to identify the range of trade-offs where the MMG concept deployment turn out to be favourable. Further on, different Decision Maker's attitudes are translated into different value functions and applied in the analysis. As a further point, the uncertainties coming out from electricity market prices and load growth levels are dealt with by defining four mutually exclusive scenarios, so providing an overall sensitivity-based picture of all the possible results.

The main idea of the study was to evaluate the MG and MMG concept deployment as potential solution to deal with normal and stressed distribution network operating modes exploiting the controllability and active management potential of MG and MMG. What can be drawn as conclusion from these studies is that large scale deployment of MS may only be feasible under the MG and MMG concepts, whereas small MS penetration does not require adoption of sophisticated management and control structures. Therefore, only significant percentage of MS can make MGs and MMGs viable and economically interesting solutions.

Furthermore, the analysis made is from the DSO perspective, meaning identification of the cost and benefits attributed to the DSO (DSO-based business model). There is no doubt that some of these benefits are shared by MG/MMG consumers as well, and suitable business models such as the ones explored earlier should reflect this. Therefore, as a preliminary estimate an equal share of MMG installation costs, in terms of communication and control infrastructure cost, has been assumed for both consumers and the DNO. In any case, further identification and evaluation of benefits passed to the MMG consumers might lead to different share of the costs to be carried by MMG consumers rather than the DSO, so that different final conclusions could be achieved, particularly for what concerns the decision thresholds.

6 Greek Microgrid business case studies with environmental analyses: Annex H3.B

In order to exemplify business cases with internalisation of environmental aspects, NTUA has carried out extensive work that is reported in the Annex H3.B.

In this work, it is assumed that at least *two* aggregators compete in order to sign contracts for the optimization of operation of Microgrids. The first one, let's say Aggregator A, operates the Microgrid trying to maximize the benefits for the DG sources and his own income from a strictly economic standpoint. On the other hand, Aggregator B tries to increase his market share by taking advantage of participating in the emissions markets and sharing part of the additional benefits with the Microgrids stakeholders. Moreover, additional benefits will be created by losses reduction and emissions avoided by losses reduction, which, as widely illustrated in the project, is not negligible at all.

The studies carried out exemplify how, next to the potential environmental benefits of DER, their economic evaluation is critically influenced by the development of adequate CO_2 emissions trading markets that also affect production costs of electricity generated by centralised thermal units. In fact, the high efficiency of DG sources, especially CHP, and the operation of RES tend to reduce emissions substantially, while co-ordinated operation and control of DER can help obtain larger benefits from their operation. However, only recognition of this global (societal) value by internalising environmental benefits can support the delivery of such efficient Microgrid-based energy systems. In order to do so, the environmental benefits of the co-ordinated operation of DER is analysed under two different optimisation objectives, namely, minimising operating costs and minimising emissions. Moreover, the potential benefits from the participation of DER in the CO_2 emission trading markets are calculated, thus taking into account both emission reduction and increase of earnings.

The outcomes show how the most accurate results are obtained when emissions and operating intervals of the marginal units are available within a short time resolution (even hourly). Since this is not always the case, monthly or even yearly average emissions values can be used instead, producing however results of lower accuracy. When this is the case, although the goal of DER operation might be minimisation of CO_2, the error in the estimation of pollutants may not lead to achieving it, due to the fact that the average emission level leads to operation of DER during hours that are not actually environmentally better. Additionally, this error may lead to revenue reduction. Moreover, for power systems with low average CO_2 emission level, information on marginal units operation would lead to operation of DER during the hours that they can actually reduce emissions. Otherwise, it is possible that DER will not be committed at all. Operation aiming at maximum emissions savings may reduce DER earnings and thus can be unattractive for DER, unless sufficient remuneration for the emissions avoided is provided. Participation of DER in the CO_2 emissions trading can offset the reduction of DER earnings while reducing CO_2 emissions. It is proven that aiming at maximising the earnings from combined participation in energy and CO_2 emissions market provides significantly higher environmental and economic benefits compared to maximising the earnings from participating only in energy market and considering the CO_2 remuneration as an additional income. Therefore, as a general concluding remark it can be stated that developing adequate business models where participation in CO_2 emissions market is allowed in parallel with classical economic optimization can greatly increase the environmental and economic benefits achieved by distributed energy operators, with benefits for the overall society.

7 Concluding remarks

This report has illustrated the models and studies developed by Imperial, Siemens, INESC and NTUA regarding potential business cases for Microgrids. Summarising the main results, it is possible to say that:

- A suitable regulatory and commercial framework acknowledging the external benefits (upstream network-related and environment-related, primarily) brought by Microgrids needs to be developed in order to make the Microgrid concept feasible;
- This reflects the need for recognising that the network use from DG and DER in general, as well as from loads close to local generation, is not the same as in conventional systems, so that for instance competition on the wholesale market between DG and conventional generation would not be based on a level playing field;
- The concepts of price (cost/benefit) reflectivity, time of use of the network and locational charges are the key points for developing an adequate framework for optimal network operation and development in the presence of distributed energy in general and Microgrids in particular;
- Alternative business models have been analysed that take into account transaction internal to Microgrids (for both energy and system services) and external to Microgrids (ancillary services to the upstream network). These models are, namely, (1) *DSO Monopoly*, which leads to a local retail market but no service market; (2) *Prosumer Consortium*, which leads to a local service market but no retail market; and (3) *Free Market*, which enables both local retail and local service markets within a Microgrid.
- Cost/benefit allocation studies with the different business models have been performed for different entities and for different European countries, revealing that complete MS ownership by either DSO (DSO Monopoly) or end consumer (Prosumer Consortium) can easily grant the owner with full access to all benefits and prevent other stakeholders from sharing. Thus a free market ownership structure or trading mechanism seems more suitable to disseminate Microgrid benefits to a large number of stakeholders and according to a more fair and transparent scheme.
- The cost/benefit analysis to be carried out within Microgrids and according to different business models is intrinsically a multi-criteria problem. Analyses in this regard have shown that different trade-offs generally lead to different evaluations/rankings in each considered scenario, and within the set of possible solutions it is important to identify the range of trade-offs where the MG concept deployment turn out to be most favourable. For the specific studies carried put mainly from the DSO perspective it has emerged that large scale deployment of MS could be feasible in the future only under the MG concepts, whereas small MS penetration does not require adoption of sophisticated management and control structures. Therefore, only significant

percentage of MS can make MG viable and economically interesting solutions.

- Among the external benefits acknowledged to Microgrids environmental aspects could play a key role owing to deployment of RES and CHP. However, only recognition of such a global (societal) value by internalising environmental benefits could likely support the delivery of efficient Microgrid-based energy systems. This has been practically exemplified by running co-optimisation studies with environmental and economic objective functions. The results show that trying to maximise the earnings from combined participation in energy and CO_2 emissions market provides significantly higher environmental and economic benefits compared to maximising the earnings from participating only in energy market and considering the CO_2 remuneration as an additional income. Therefore, developing adequate business models where participation in CO_2 emissions market is allowed in parallel with classical economic optimization can greatly increase the environmental and economic benefits achieved by distributed energy operators, with benefits for the overall society. On the other hand, if environmental benefits are not somehow recognised, then the economic competitiveness of MS decreases substantially.

References

[1] Nikos Hatziargyriou, Antonis Tsikalakis, et al, *MicroGrid Central Controller Strategies and Algorithms*, MICROGRIDS Deliverable_DC1 Part 1, Contract No: ENK5-CT-2002-00610

[2] Christine Schwaegerl, Liang Tao, et al, *Definition of Future Microgrid Scenarios and Performance Indices*, Advanced Architectures and Control Concepts for More Microgrids, WPG DG1, November 30th 2008

[3] Konrad Purchala, *Aggregation of CHP units and Demand Response*, EU-DEEP FP6 Project: SES6-CT-2003-503516, Task Force 3, Jan 2009, rev 2

[4] Frits van Oostvoorn, *Overview of Progress, Barriers and Solutions for More DER Integration into Electricity Supply System*, SOLID-DER, WP4 Deliverable 4.5, March 2009

[5] Mary GILLIE, Jen CARTER et al, *Getting the Most from Community Generation—An Economic and Technical Model to Control Small Scale Renewable Community Generation and Create a Local Energy Economy*, CIRED 2009, Session 6, Paper 0190, June 2009

[6] Athanase Vafeas, *Three Aggregation Business Cases Validated by On Site Measurements and Extrapolated to Five European Countries*, EU-DEEP (FP6 Project: SES6-CT-2003-503516), WP 8, Deliverable D10, June 2009

[7] Liang Tao, Christine Schwaegerl, et al, *Advanced Stochastic Analysis of Massive DG Penetration—a Voltage Quality Case Study*, CIRED 2008 Smart Grid Seminar, Paper 0033, Frankfurt, June 2008

[8] Maciej Fila et al, *Flexible Voltage Control in Distribution Networks with Distributed Generation –Modelling Analysis and Field Trial Comparison*, CIRED 2009, Session 4, Paper 0411, Prague, June 2009

[9] Märtel, D; Wellßow,W.H, Die Qualität der Versorgung mit elektrischer Energie. Elektrizitätswirtschaft 95(1996), Vol.25

[10] Aris Dimeas, Antonis Tsikalakis, Nikos Hatziagyriou, Rachel Li, Nick Jenkins, Olimpo Anaya-Lara, *Requirments Specifications for Microgrid Control*, More Microgrids – Advanced Architectures and Control Concepts for More Microgrids, Contract No. SES6-019864, Work Package B, 24-July-2006

[11] Christine Schwaegerl, Nikos Hatziargyriou, Antonis Tsikalakis, Anestis Anastasiadis, *Data Requirements and Methods for The Evaluation of Economic and Environmental Benefits of Microgrids*, Advanced Architectures and Control Concepts for More Microgrids, Contract, WPG – Task TG2, March 2007