*Distributed Intelligence in Critical Infrastructures for Sustainable Power*

ENK8-CT-2002-00673

# Market-oriented online supply-demand matching


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# Document Description

This document gives an overview of current power markets and hierarchic grid architectures and the role of demand side and supply management therein. Then, a framework is presented for the application of new ICTs and agent technology for integrated Supply and Demand Matching in bottom-up high-RES distributed generation environments. Using this framework, four sample scenarios are defined, spanning a bottom-up approach for power distribution networks as well as for bottom-up markets. The document serves as an input for WP2-simulations and WP3-tests in the CRISP-project.

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# Acronyms and Abbreviations

| Acronym | Means |
|---|---|
| AMM | Automated Meter Management |
| AMR | Automated Meter Reading |
| APX | Amsterdam Power eXchange |
| BTM | Behind The Meter |
| BUSMOD | Business Modelling in a world of distributed generation |
| CHP | Combined Heat Power |
| CRISP | Distributed Intelligence in CRitical Infrastructures for Sustainable Power |
| COP | Coefficient Of Performance |
| DG | Distributed Generation |
| DER | Distributed Energy Resources |
| DRR | Demand Response Resources |
| DSM | Demand Side Management |
| FDD | Fault Detection and Diagnostics |
| HVAC | Heating Ventilation and Air Conditioning |
| IEEE | Institute of Electrotechnical and Electronics Engineers |
| IEC | International engineering consortium |
| IP | Internet Protocol |
| ISO | Independent System Operator (comparable to TSO in USA context) |
| IST | Information Society Technologies |
| OSGi | Open Software Gateway initiative |
| PLC | Power Line Carrier |
| PQ | Power Quality |
| SDM | Supply and Demand Matching |
| RES | Renewable Energy Systems |
| RUE | Rational Use of Energy |
| TSO | Transmission System Operator |
| PV | Photo Voltaic |
| W3C | World Wide Web Consortium |

# Executive summary

Current power distribution systems are operated in a top-down manner. Power production control and price formation take place on a central level on the basis of relatively static data from a data collection and dispatching network with a limited scope and granularity. When incorporating a more considerable fraction of small-scale producers on the basis of, for instance, renewable energy, operation of the distribution grid requires more data to be collected from a more extensive information and data communication network. Furthermore, increased local information flows, in the form of two-way communication with distributed computation techniques, enable a more dynamic adaptation in power supply and demand patterns paving the way to a flexible way of embedding of ill-predictable supply of some types of renewable energy sources.

DSM-programs have been in use in the utility sector for years now. In this document, first, current Demand Side Management (DSM) and Demand Response Resource (DRR) techniques are discussed; then, supply side management especially in a DG (Distributed Generation) context is treated. A framework of novel concepts and possible technology directions is presented subsequently and some preliminary scenarios are shown to illustrate these concepts. An overview of more flexible supply and demand matching schemes is given essentially based on four distinct types of SDM-clusters.

It appears, that it is possible to fulfil requirements for these distributed environments in terms of needed information and communication technology, ICT, if these are paralleled with the expected future penetration of ever-smaller scale data-exchange networks at power customer sites. Agent technology using algorithms from micro-economic market theory offers a promising possibility for managing the complexity of price formation and supply<>demand matching in these fine-grained bottom-up control distribution networks.

Implication of these technical developments in terms of market and business models, however, is that, possibly, different approaches for pricing and contracting will be necessary. These approaches mimic current developments in the telecom sector. Legislation, market design and business models for power delivery have to adapted as well to establish a level playing field for the integration and embedding of small scale RES in a distributed power network setting.

# 1. Introduction

## 1.1 Scope

Electricity distribution infrastructures are based on a hierarchical, top-down flow and distribution of power. Driven by liberalisation, power networks are being utilized with decreasing reserve capacity. These infrastructures were designed and economically validated with accounting models of energy companies typically having a time horizon of 20 to 50 year [ADL, 1999]. Currently, investment capital preferably has a much shorter investment time horizon. Therefore flexibly usable, middle-size distributed power generation is becoming more attractive in this respect. Standards are being developed for using information networks [P1547,2003] to couple a number of medium sized installations to a virtual power plant, which operates on the power market or has a contract for supplying power on demand driven by market prices. Given these facts and recent problems with power delivery in California, a renewed interest in distributed generation (DG) of power has arisen with a connection to a modern ICT-enabled distributed information infrastructure. This interest is also fed by recent large-scale power failures in the North-East of the USAand parts of Europe. The scope of power failure and the effects due to cascading effects, as were manifest there, inherently, in a DG-setting are much smaller provided the power quality and system balance are controlled locally.

Renewable energy systems in a distributed setting currently only use the power grid as a buffer; they have a limited role in the total power infrastructure in terms of maintaining uninterrupted operation and power quality aspects. The systems are more or less tolerated instead of being an active contributor to total grid stability. This also holds for the power pricing and market aspects. When introducing a more than substantial amount of RES (Renewable Energy Systems) in a DG setting these energy producing systems have to be "connected" in an intelligent way in view of the above aspects.

Optimising operation of a mixed power supply and demand infrastructure, for instance in the context of a residential area, requires access to operational information from more power network nodes more deeply in the hierarchy from the demand as well as from the supply side. Furthermore, the expectation is that, to satisfy these future needs, a more bottom-up than top-down architecture of physical future power distribution grids will be necessary, especially when an increasing amount renewables has to be embedded. A more dynamic balancing model, then, will be required, in which one of the main issues will be what real-time or expected demand urges what load to be inserted in the network. In the EPRI Electricity Technology Roadmap [EPRI, 1999] a new mega-infrastructure, containing a combination of, partly customer-managed, energy/information networks is envisioned to meet these challenges.

This document treats the implications of above-mentioned developments mainly in the light of the information and communication technology aspects, operational issues in the net with respect to supply-demand matching and their effects on market price formation and customer interaction. It serves as the context for part of the WP2 activities of CRISP in defining the broader context and scenarios for supply and demand matching.

## 1.2 Contents

An infrastructure as described above provides great challenges to power infrastructure design (security, protection and load shedding) but also to optimal and cost-effective operation of the grid in more real-time power markets.

In this document an inventory and framework is presented for managing such a grid from this new market optimisation perspective. Starting point is a description of current price formation and demand side management techniques. The market, as considered in this document, has to be compared with common power markets but on a more fine-grained scale of time and distribution level. The "market-price" is used as a metaphor to the value an amount of power has at a certain time at a certain place in the network. Special attention is paid to demand and supply matching in various cluster sizes and on various timescales. The scope in time considered are processes ranging from a few days ahead to a quarter of an hour ahead; more or less shorter-term issues like load shedding and protection are not considered. It has to be noted, that the main themes covered are the real-time market aspects of the development of distributed generation with embedded, small-scale renewable resources. Operating high-RES DG-grids from an electro-technical point-of-view and with respect to reliability and interruptability factors is not considered in this document but in other deliverables of the CRISP project. [D1.1,2003] and [D1.4,2003].

The recent progress made in the area of knowledge-based technologies and distributed intelligence on the Internet and Web is reviewed. Two major ongoing developments in distributed intelligence are discussed: (1) the next, intelligent WWW generation known as the Semantic Web; and (2) intelligent agents and multi-agents systems as a distributed software architecture particularly suited to new electronic applications in an inherently networked and decentralized environment. These ICT developments will strategically impact the energy industry sector, for example by enabling new electronic energy services. These issues are discussed also from the viewpoint of socio-economic issues related to new ICT advances, such as the development of new, networked business models.

Furthermore, an attempt is made to illustrate the added value of information and telecommunication technology as a key-enabler in these possible developments. To that end a new conceptual framework of SDM-clusters is introduced. Four possible instances of such a cluster are discussed as input to simulations and practical tests in the project.

# 2. Setting the scene in current, liberalised electricity markets

In order to be able to develop tools for supply and demand matching [Warmer,2003] it is mandatory to have a description of the grid layout and the normal process of energy metering, trade, balancing and distribution pricing as well as a picture from current demand side and supply side management techniques. In this chapter, therefore, a functional overview of a number of aspects of electricity markets operating at this moment and possibly future variants will be given. This provides the context within which scenarios for demand and supply matching will function.

## 2.1 Trade on current liberalised power markets

Liberalisation has paved the way to a market, where the roles in the delivery of power have been decoupled. This is illustrated in Figure 2-1.

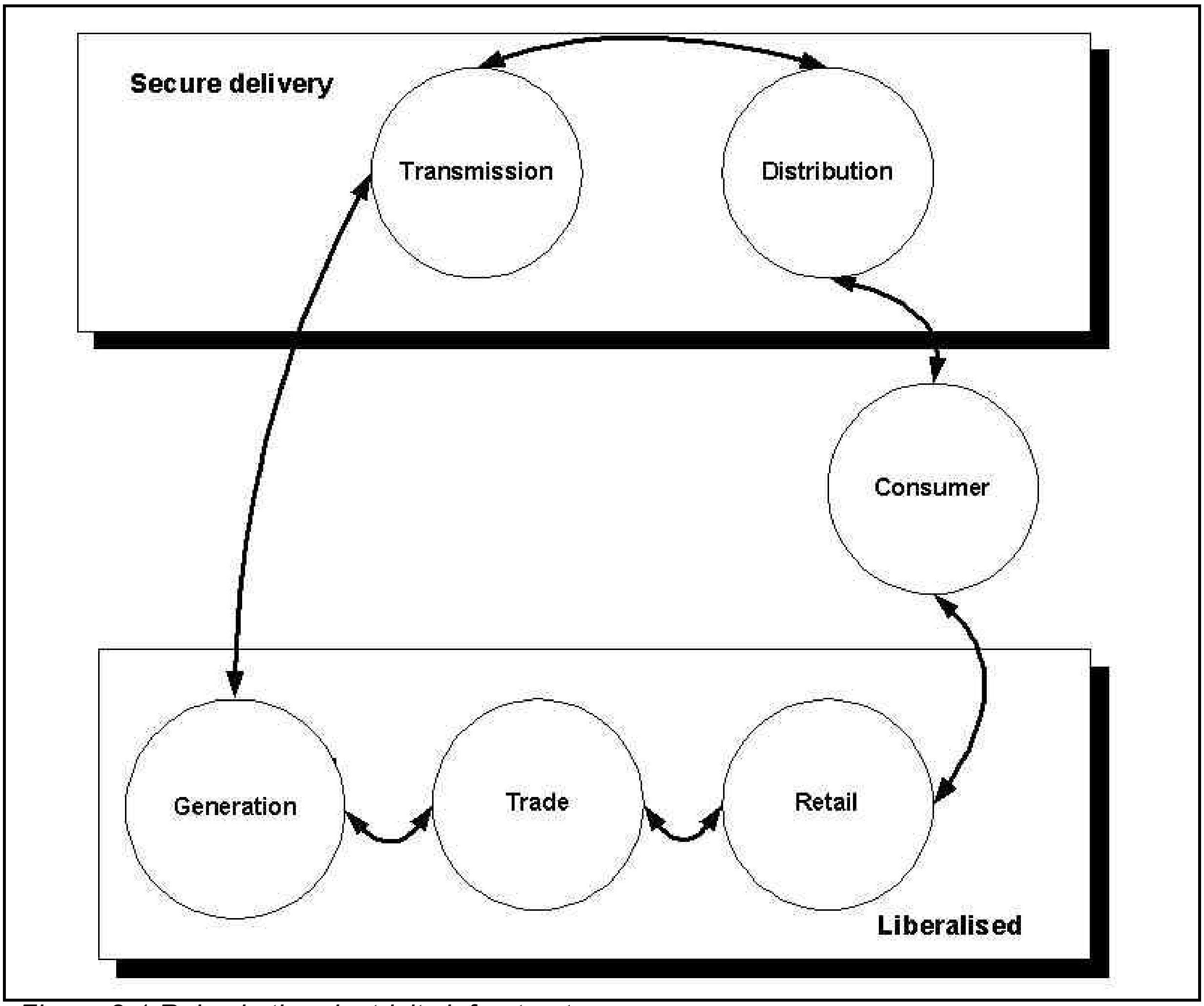


*Figure 2-1 Roles in the electricity infrastructure*

Transmission network operators managing the high-distance, high voltage network and distribution network operators are focussed on secure delivery with a minimum of outages.

In power trade, bilateral contracts, open day-ahead markets with multiple commercial parties for supply and demand and balancing markets with one party demanding/supplying and multiple parties supplying/demanding exist. These three mechanisms together constitute a mechanism for operating a power grid in a liberalised, unbundled setting
The legislator defines these roles in order to maintain a fixed reliability level in delivering power. On the other hand in the liberalised, re-regulated market a power generation trade and retail business (displayed in circles in the lower rectangle) has evolved operating from a distance of the physical power delivery process. A description of detailed mechanisms for this process for a number of European country settings have been the subject of one of the BUSMOD-deliverables [Busmod,2003].
In most European day-ahead liberalized electricity markets the planning of the amount of electricity demanded is done on the basis of time-of-year, meteorological prospects and feedback of historical consumption data. Based on this predicted amount, the long-term contracts between producers and consumers determine a base load. For the surplus, trading is done on a central market, the power exchange. This market also gives foreign producers the ability to import/export their electricity through the import/export transmission lines. An independent net authority (TSO: Transmission System Operator[1]) manages the process that the projected amounts can be transported and that sufficient distribution capacity is present. One hour before delivery of the electricity, delivery programme changes are accounted for and changed to adapt to the present situation. In some countries of Europe an hour-ahead market is operating for trading surpluses and deficits in capacity and demand. In other markets, this mechanism is not present, but there is a market for ancillary services. These services pertain to background power in the form of providing of capacity for a spinning reserve or for balancing. Derived markets, hedging positions of market players, are evolving in some countries as well. Such a derived market operates as an option market in traditional stock exchanges and allows risk mitigation for traders.

Power reliability and security of delivery is an item separated from the market aspects by law. The market and trading mechanism may in no way impair these aspects. For large customers, the financial transactions of the market mechanism based on the actually measured productions and consumptions is done on the basis of measurements on a small time-basis (minutes). For small consumers and producers financial implications are lumped and accounted in annual adaptations of contractual unit prices.

## 2.2 Pricing of power

When looking at the composition of prices for end users in 2001 and 2002 three elements are to be discriminated Figure 2-2 illustrates the build-up for the Dutch situation; the situation in other European countries however is not very much different.
Apart from a partially market dependent real-time APX-tariff (yellow/white), there is a time dependent net management tariff (brown/dark) and constant tax contribution (purple/grey).
The net management tariff is capacity related and essentially should be dependent on kW and not to kWhs. In various European countries the distribution/transmission component is not shallow but deep; i.e in the tariff infrastructure components from high voltage transmission and distribution lines are included. The price constituents are discussed in the following paragraphs.

[1] In the USA an ISO (Independent System Operator) in a different context fulfils this role.

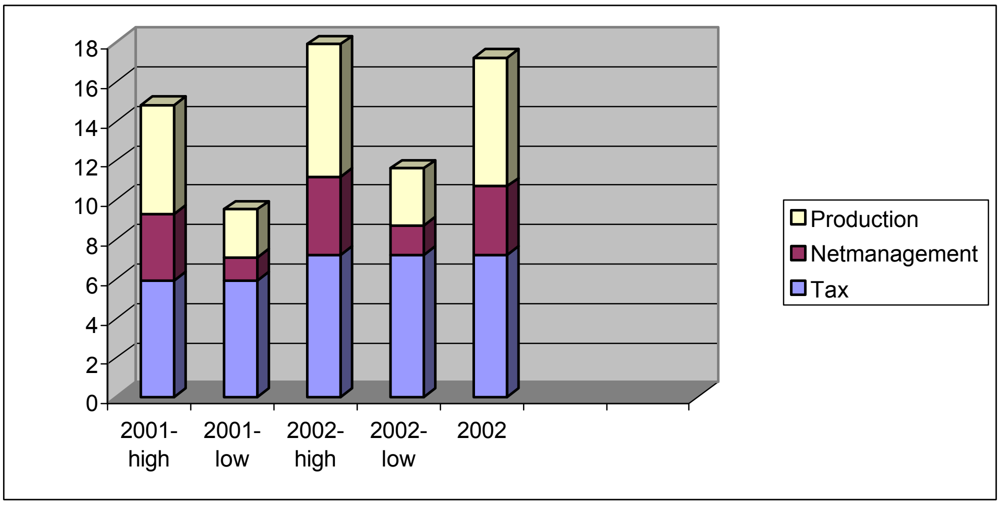


*Figure 2-2 Build-up of electricity prices*

As noted before, to the power consumer, the electricity market on one hand is liberalised, on the other hand the distribution and balancing aspects are strongly regulated in order to retain a high level of security of delivery. In the liberalised part of the market a large amount of transparency is achieved. In the perception of individual customer the new balancing scheme of the electricity infrastructure is difficult to imagine and it is hard to identify the separate roles of distributor or trader. Only the appearance of new energy trading companies on the market is the item a customer sees. The transparency of price formation and accounting also has the effect, that aggregation of consumer and producer alliances or brokers is possible with little reference to their locations in the physical power distribution grid. Such a transparency is not present in the physical “reregulated” power delivery network. Possibilities for the interchange or substitution of roles in supply or demand are limited. The role modern information and communication technology plays in the liberalised and the regulated context therefore is different. Especially a transparent communication technology as the Internet will be used very differently in both settings.

### 2.2.1 The dynamics of real-time prices

The schematic view of action of the power delivery system is shown in Figure 4-1. A base load contracted bilaterally between generating and trading companies is shown on the left. The day-ahead and hour-ahead markets act as multi-party, open markets with a larger number of players. In some countries, a auction-like balance market is operating in which bids for demand and supply are exposed to a limited number of parties.
At present, brokerage, wholesale and retail companies are becoming active on the energy market. Supply and demand meet each other bilaterally or on markets. Figure 2-3 gives an impression of the peaks in the APX (Amsterdam Power eXchange)-market. The short axis refers to the price development over a day; the long axis to days in 2002. In Figure 2-4 the volumes handled in the APX-market in 2002 and 2003 are shown. When looking at the price development of the APX-prices over a year, it can be seen, that substantial time-of-day and seasonal varying differences exist. It can be seen, that at peak prices the traded volumes are low as compared to early-morning volumes in December. The increasing trend in volumes traded in 2002 is not sustained in 2003. The APX mainly is used to bring market parties together, when prices are low; volumes at high price peaks are low. It is also remarkable, that the total volume can be seen to increase during 2002 and 2003. Figure 2-5

emphasizes the variability of the prices more fully by imposing a cut-off for too large peaks. The effect of the problems in the second half of august of 2003 with power supply, when code Red was issued, can be seen clearly. The market prices are dependent on the time-of-day and the time-of-year as shown in Figure 2-7 and Figure 2-8 in more detail.

It can be seen, that, in winter, peaks occur around 5-6 PM. In summer, the demand for cooling is becoming apparent in the first weak after summer holidays have ended. When cutting off the highest peaks a picture as shown in Figure 2-5 can be seen. The price landscape contains very characteristic seasonal and time-of-day dependent details. Apart from seasonal variations, the variability over days is large. The picture shows, that very large price variations may occur. This is further shown on Figure 2-7 and Figure 2-8. The individual variability per day is also noteworthy. The demand side picture, as far as small consumption end users are concerned, is also shown in Figure 2-6.
Currently, only a part, approximately 10-15 %, of electricity is traded on the APX-market. The rest is delivered according to longer-term contracts. Prices in these contracts are based on consumption demand profiles collected over a number of years. Using the contractual amounts and expected demands, on a day-ahead basis, the programme responsible parties make a "programme" for operation of the power producer and network distribution for the next day. Through instructions to large contracted generators, sometimes via the process of buying or selling on a one-hour ahead market, the net management authority does the adjustment to the real demand. Parties delivering more or less than the programmed amount are charged with a penalty proportional to the price formed the day before. There always is a reserve capacity the network operator can rely on. This capacity is charged on availability and actual delivery. Programme responsible parties are charged upon their surplus or deficit by the TSO and receive a fine/incentive as well according to the netcode, that is defined per country.

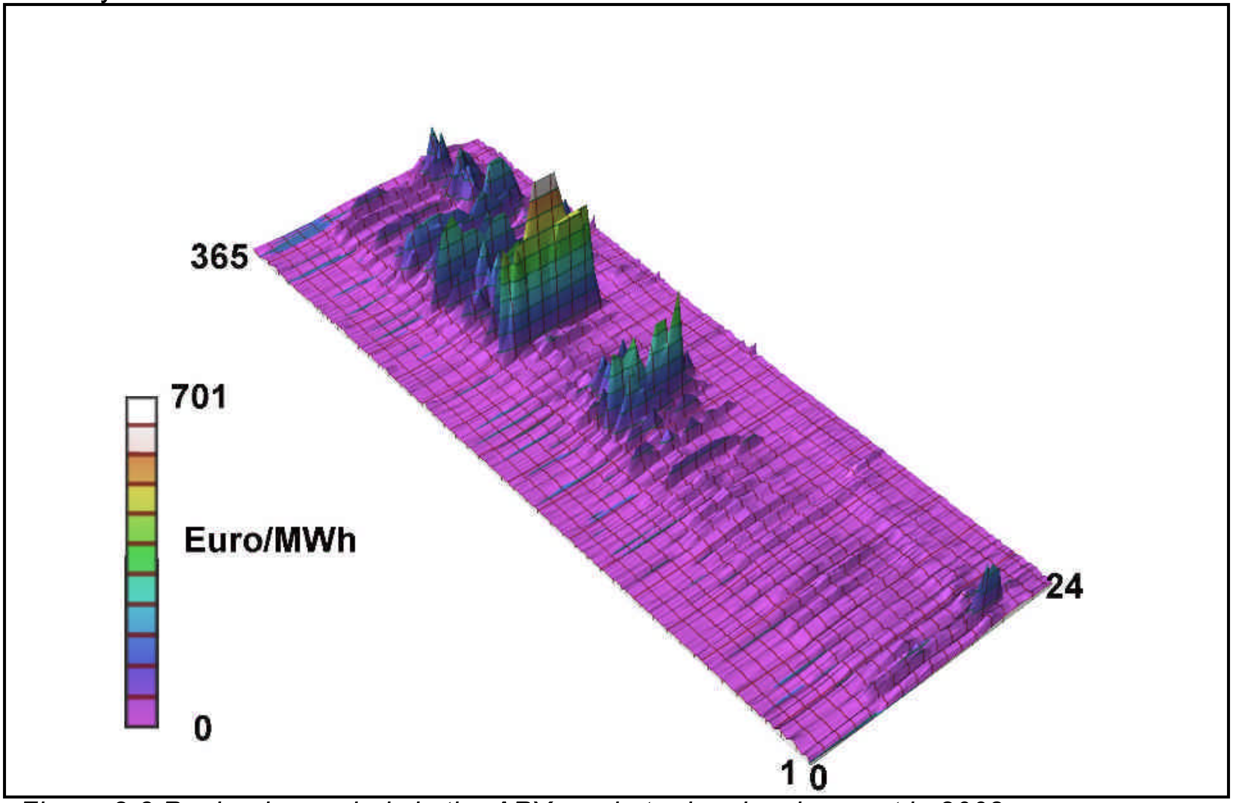


*Figure 2-3 Peak price periods in the APX-market price development in 2002*

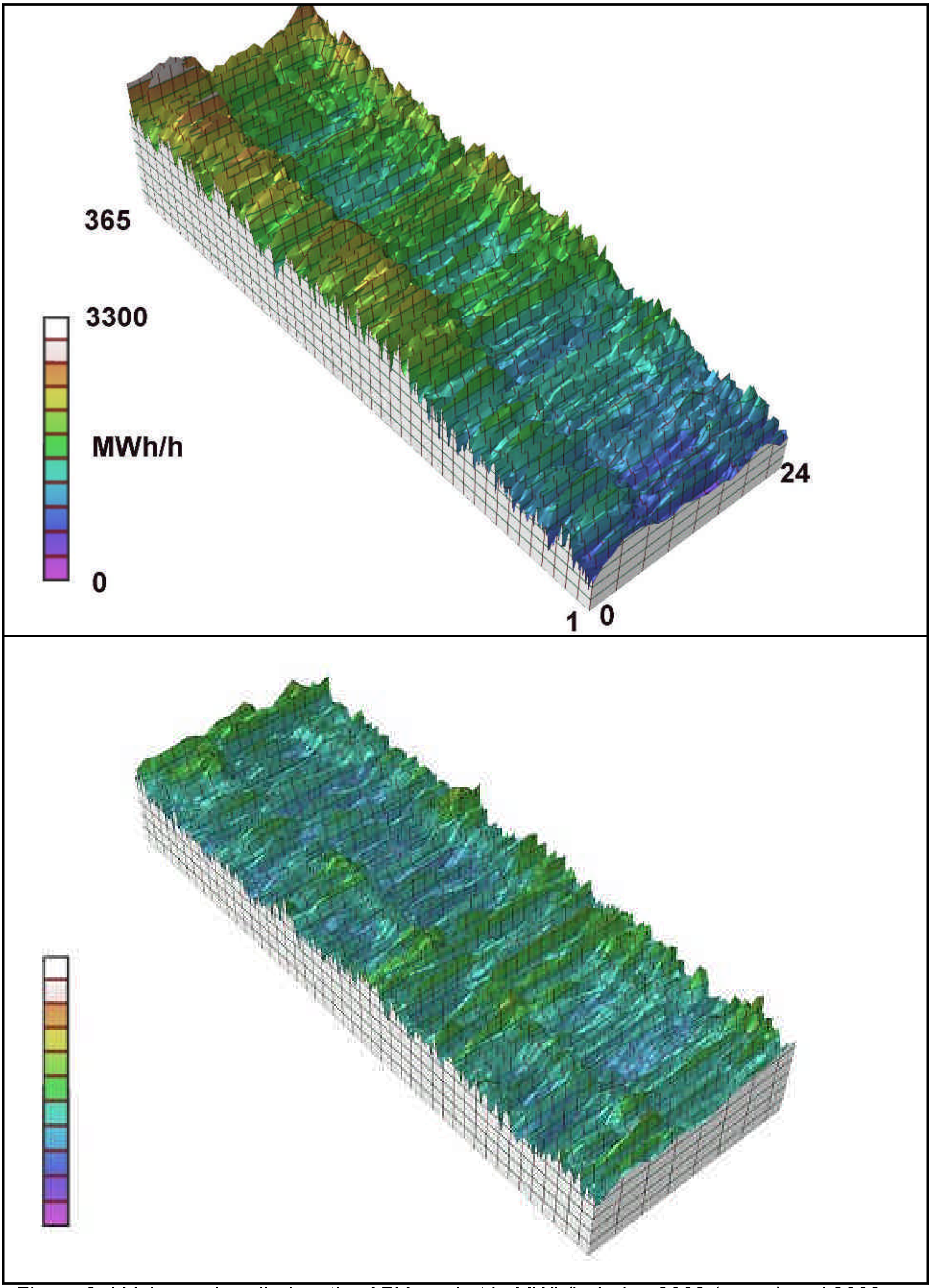


*Figure 2-4 Volumes handled on the APX-market in MWh/h during 2002 (upper) and 2003 (lower) graph (the right horizontal axis indicates the time of day; the left the daynumber*

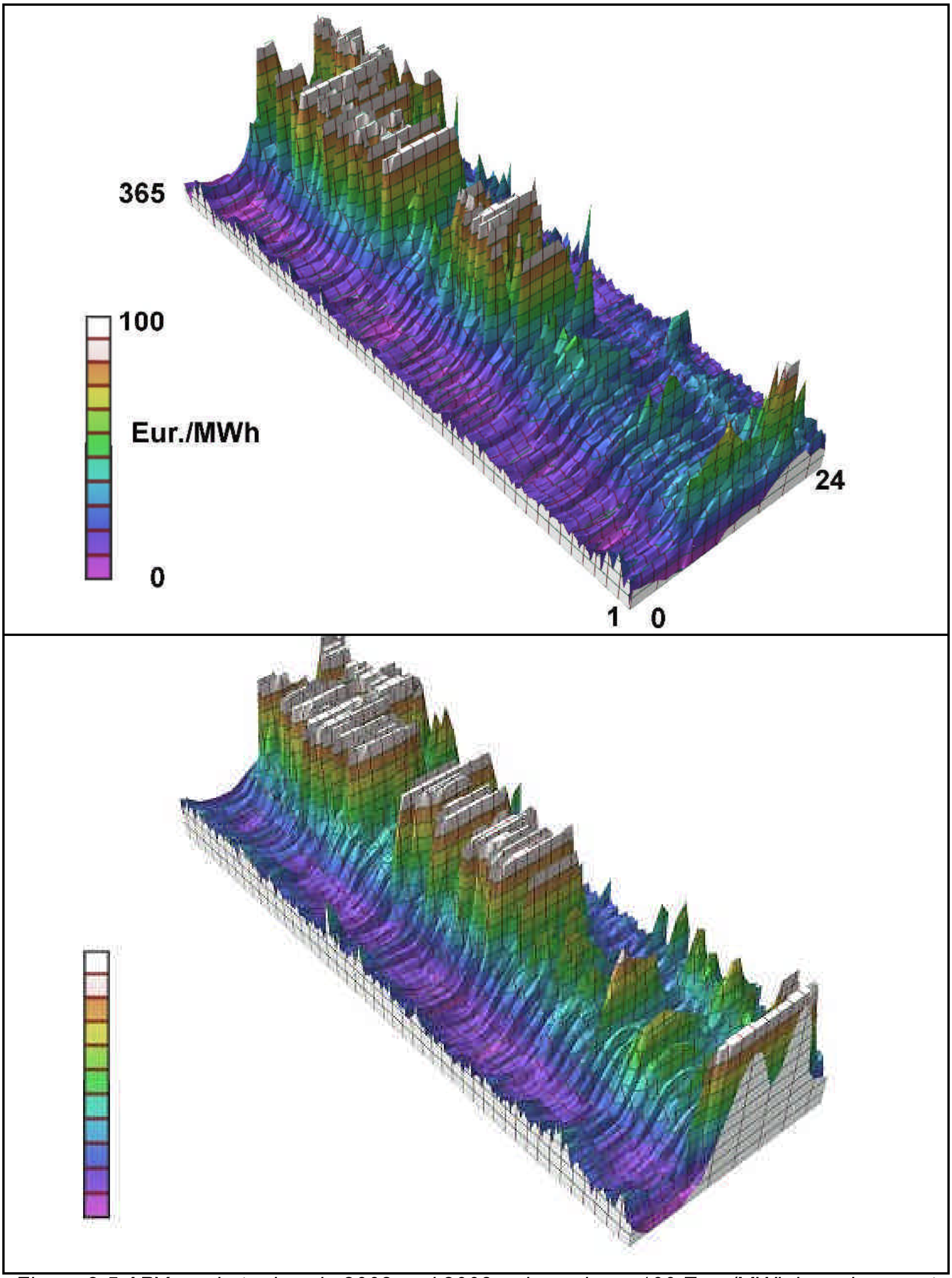


*Figure 2-5 APX-market prices in 2002 and 2003; prices above 100 Euro/MWh have been cut off*

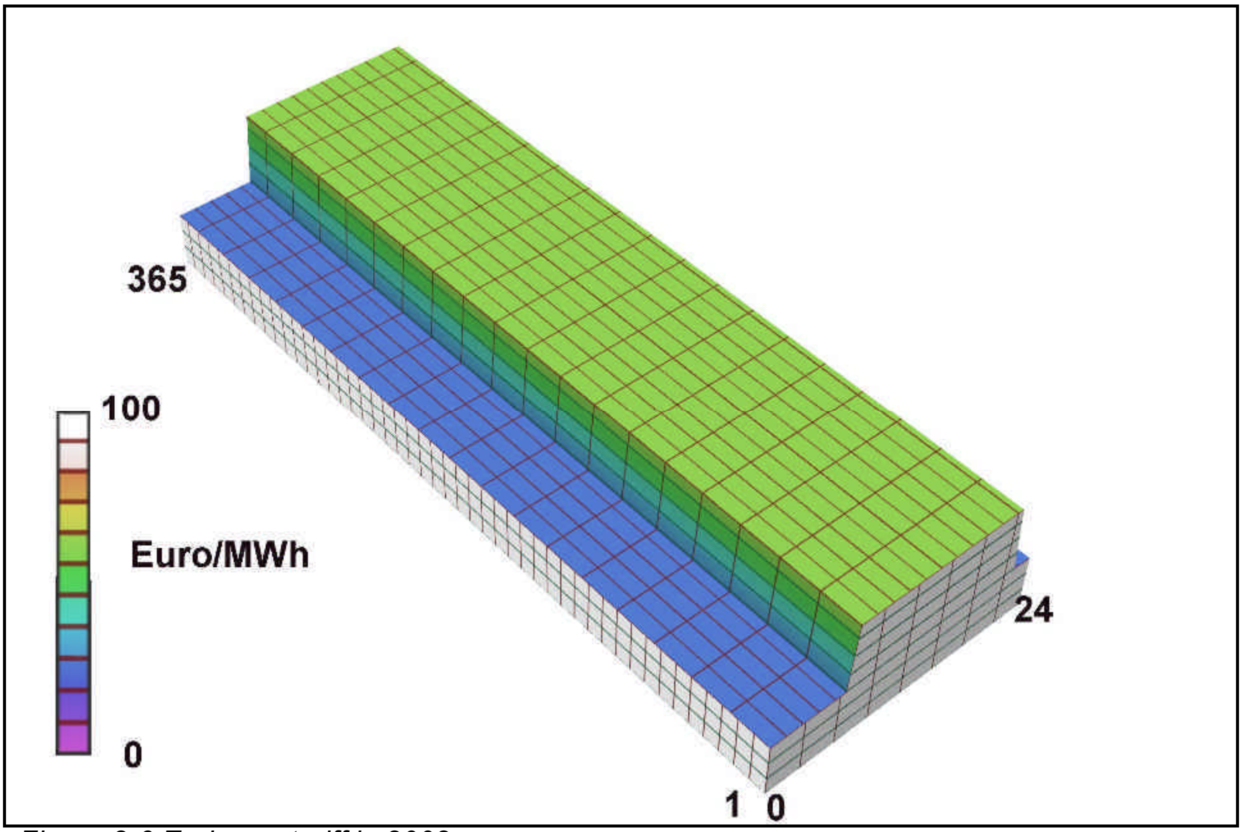


*Figure 2-6 End-user tariff in 2002*

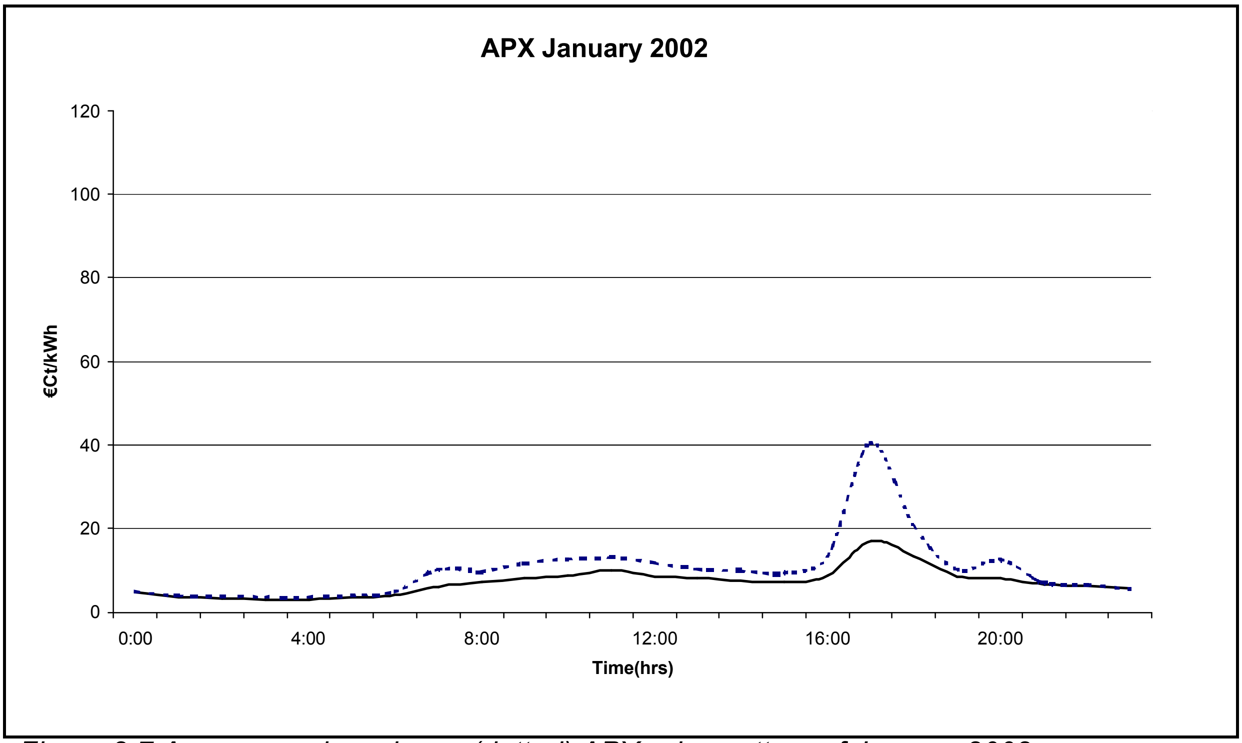


*Figure 2-7 Average and maximum (dotted) APX-price pattern of January 2002*

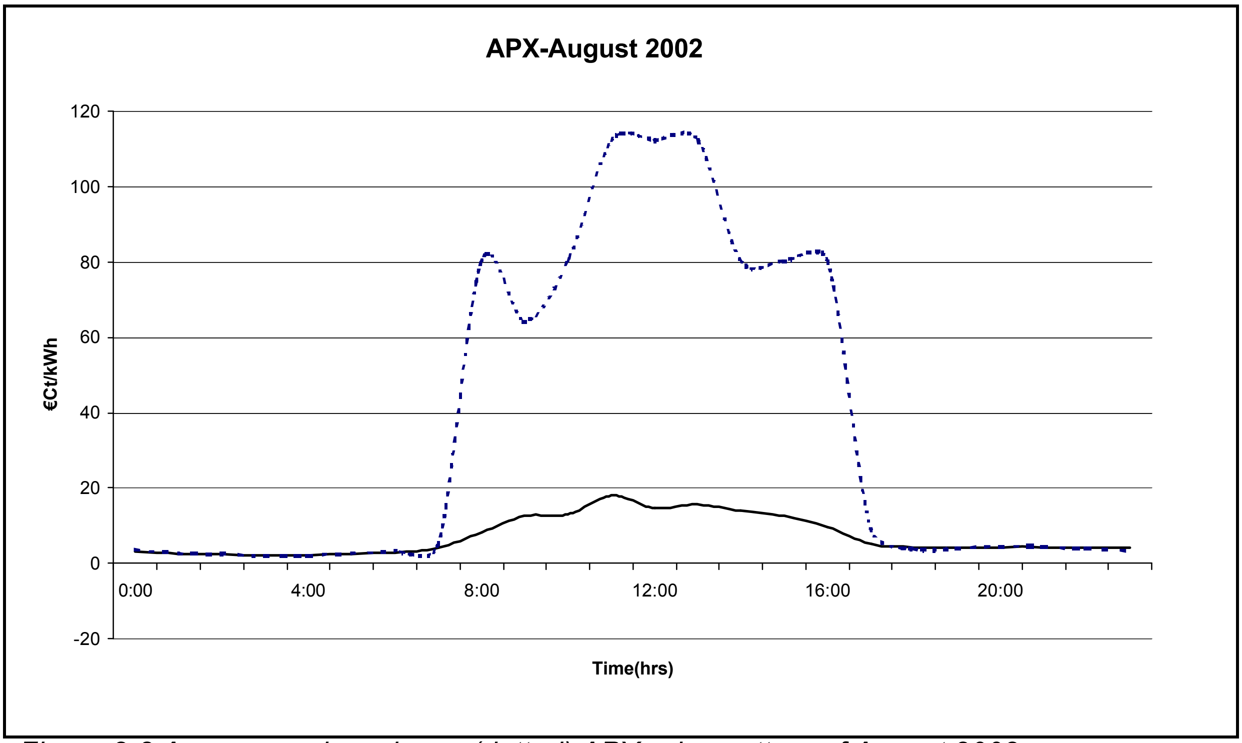


*Figure 2-8 Average and maximum (dotted) APX-price pattern of August 2002*

Looking at the APX-contribution to the prices (Figure 2-7) it can be seen, that due to the variability in load, when people arrive at home at 17-18 hours, there is a definite peak. The variability in the value of the peak over several days in January is considerable as well. The height of the peak on the APX-import market indicates, that only a small shift in the demand pattern might have tremendous consequences on the price, at which the last MWh have to be bought. In the utility sector, therefore, it is a rule of the dumb, that 20 percent of the generation capacity generates 80 percent of profit. Utilities having the ability to shift the loads of some of their large consumers would have a same opportunity. As mentioned before, apart from the day-ahead market, there are hour-ahead and/or balancing markets. On these markets, the net operating authority balances the last-minute shifts in contracts (surpluses and shortages). In some cases, prices paid here are higher than on the day-ahead market and producers sometimes do not sell their entire capacity one day-ahead, but keep some margin to sell on the hour-ahead market. Especially for renewables as wind energy this would be profitable. For the wind velocity, which is an important indicator for a wind turbine yield, the error margin in the day-ahead prediction [HIRLAM,2003], due to still existing error margins in weather models, is much higher than the margin for the hour-ahead prediction [Brand/Kok,2003] . For the cloud coverage prediction in moderate climate areas, which is important to PV-yield, the one-day ahead predictions do not perform better, than models based on persistence [Borg v.d.,2003]. Thus, as for part of the wind energy production, PV-energy could be more cost-effective, part of it being traded on very short-term markets.

### 2.2.2 Distribution network pricing

As can be seen in Figure 2-2, apart from market prices, there is are two tariffs in the price build-up for the distribution price. This price accounts for transmission and distribution

losses, investment cost and management of the infrastructures and metering. In high market price situations, the distribution component might increase due to added transport cost by import. Due to legislation, which stresses the importance of uninterrupted supply, no market forces are operative on the distribution market. Although the situation on liberalised markets varies somewhat, typically, electricity market authorities set a fixed profit on distribution activities based on general five-year government bonds with 1.5 % added. The distribution prices have been increased with the introduction of the liberalisation typically by 4-7 %.
Apart from the distribution cost, the distribution companies charge a fixed fee for rent of the meter. In a distributed setting with two-way communication, the role of the low-level distributor of power becomes richer, as apart from the distribution network an ICT-network has to be kept operational as well and the bi-directionality of the ICT-connection offers an opportunity for new services.

### 2.2.3 Energy source or delivery subvention schemes and tax-components

The way governments subsidize the usage of renewables, differs from one country to the other. The source investment of renewables may be sponsored or the delivery of green energy using "green labels" may be favoured. Until recently, in adjacent countries in Europe, energy companies could attain high profit margins by investing in wind parks in one country with source subsidy (feed-in tariffs) and delivering green energy (via tradable green-labels) in others with no taxes involved. At the moment the legislation on the European level is harmonized and source subsidies are the main RES-favouring instrument.

## 2.3 Energy monitoring and metering

In the liberalisation context, the process of metering is also decoupled. The market is open to independent certified metering companies. The projected revenues on simply selling electricity as a commodity with small margins are expected to decrease in the future. Therefore utility companies could also try to become more active on the metering market. In this respect, utilities might migrate from their traditional role of selling as much as possible of a commodity to advising their customers by using their metering data intelligently and in this way contributing to energy saving.

Currently the metering process strongly depends on customer size. Contracts range from simple lump sum power consumption over a year, via year-fixed time-of-day-dependent tariff groups, to very elaborate near real-time (15 minute resolution) pricing-schemes. This large variability is reflected in the metering process. Techniques range from meter reading and communication to the utility company by the end-user via the Internet using a WEB-browser interface to readings with a frequency of once every quarter of an hour with reporting via a RAM-mobile data network. A recent survey [Olsson, 2001] suggests, that small consumers certainly would favour more frequent meter reading and billing based on actual readings as a function of time. In Italy at the moment intelligent meters are rolled-out to as many as 27 million customers. These meters use an Internet connection to transmit meter readings. Reasons for introducing these meters on such a large scale were prevention of tampering/revenue protection and contract management in areas with a weak grid. The last point pertains to the fact, that above a certain limit per day power consumption is charged higher.

Apart from customers operating directly on the wholesale market, large (> 1 MWh) and medium size customers (> 100 kWh) have fixed metering procedures for their production and consumption of electricity. These procedures are supported by contract-defined mostly real-time prices. Metering typically takes place locally with one-hour resolution and daily data transfer to the metering company. Typical cost are 25-30 € per meter/month for AMR (Automated Meter Reading), data communication and balance statement.

Energy metering frequencies and protocols are standardized in European countries using EDIFACT/ISO9735-messages. In the protocol a MSCONS-message contains all information about energy use for a certain time period. Given current liberalisation it is expected required information streams involved in energy market operations will be surging. The metering chain is depicted in Figure 2-9.

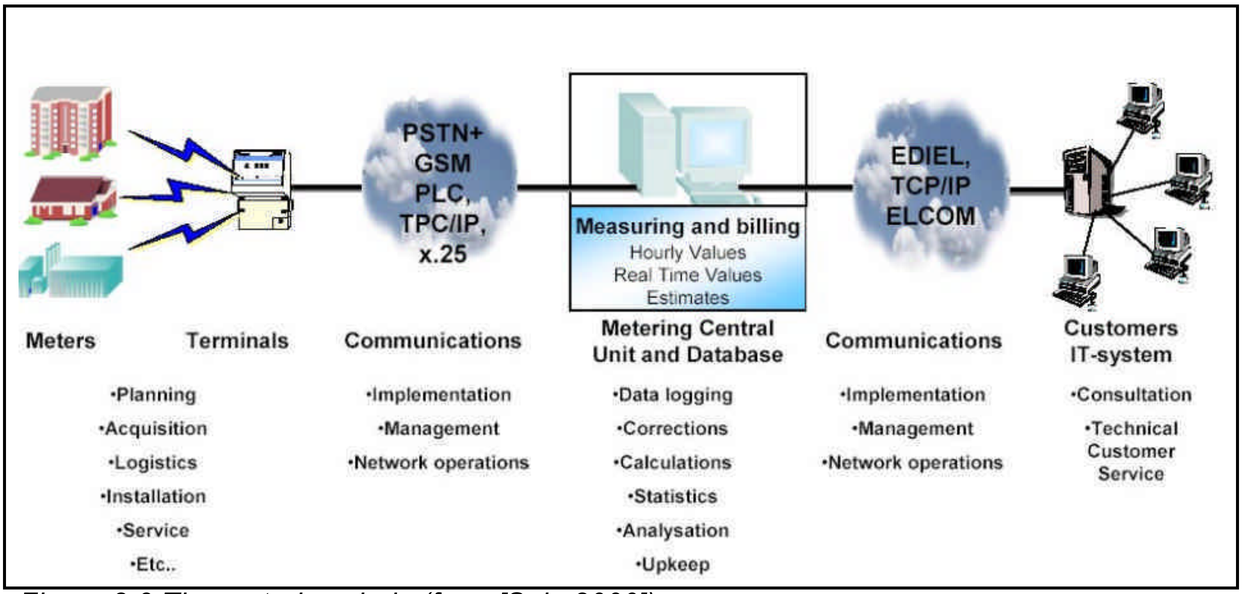


*Figure 2-9 The metering chain (from [Salo,2000])*

Typically, for small customers, meter reading the costs are in the order of 2-4 € per year. Mostly the customer actually does these readings. Feeding in into the database and control readings (5-10 € in urban areas and 12-25 € in rural areas) form the main fraction of this cost. In Finland, the GSM-network is used extensively for all kinds of payment including electricity [Salo,2000]. Similar data-collection, service functions and alarming services in combination with WEB-technology are considered to yield applications that might satisfy user needs and extend the profile of energy companies. A first application would be the introduction of real-time billing instead of estimate-based pricing as used so far in many countries. It is estimated that 50 percent of utility customer contacts have to do with correcting the estimates and the billing scheme in the estimate-based pricing scheme. So, apart from financial savings, AMR and real-time billing contributes to better customer contacts and an improved level of customer satisfaction. When used in conjunction with frequent meter readings, it also gives the opportunity to influence the demand side and settle demand side response contracts (see 3.3).

In Finland the effect of competition on electricity pricing has been a 20 % decrease for large users and a 13-20 % drop for households. However, the distribution prices have been increased by 4-7 %. Electricity market authorities set a fixed profit on distribution activities of general five-year government bonds with 1.5 % added. A similar situation is found in Norway [Saele,2000]. A study there suggested, that in a two-way communication gateway and automated metering an investment of a 100-200 hundred dollars is involved. Prices have dropped from 580 USD in 1993, via 325 USD in 1997 to about 200 USD. A way of clustering the metering process in an apartment block is shown in Figure 2-10. By the increase in scale of the metering process, economic viability is reached and a better contractual position is reachable.

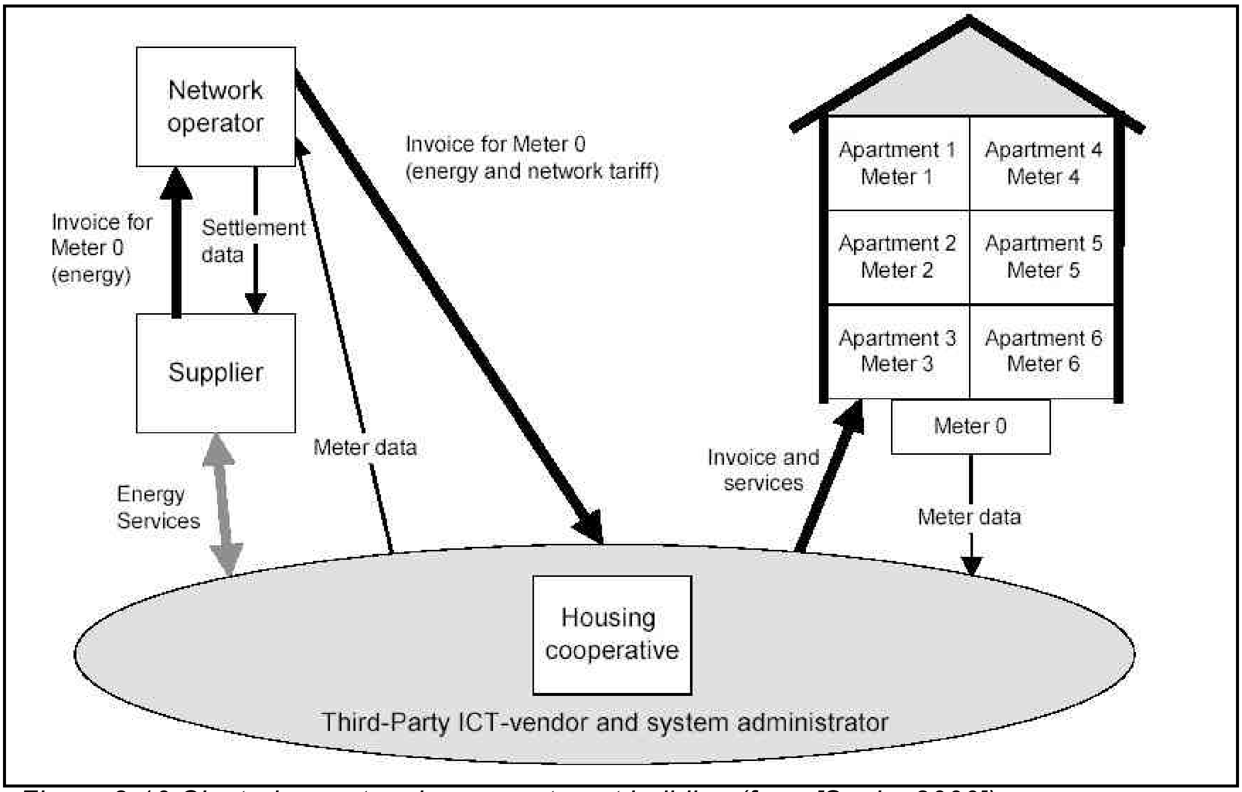


*Figure 2-10 Clustering meters in an apartment building (from [Saele, 2000])*

In Italy, a large (30 million) rollout of intelligent meters with bi-directional communication possibilities to end-customers is in the implementation phase now. In the Telegestore-project a total investment picture of 3.1 billion euro can be justified within a limited payback period. Prices per installation are in the order of 70 Euro in this particular case due to the economics of scale; apart from automated metering, additional benefits come from automation of back-office activities, obtaining real-time data for day-ahead estimations of power usage, reduced tampering and the possibility for extended service offerings. In the Italian configuration, the intelligent meters exchange data using power-line communication to near transformer stations. At these stations, the wireless GSM network further transfers the data. Significant in this respect is the partnering relation between the utility company, Enel, and the largest software provider in the world, IBM. Primary objectives of the project include a need to understand customers better, more accurate and timely billing, less disruptions and shortages and better monitoring of network availability and efficiency. Automated Meter Management (AMM) further opens the gate to a large number of utility operated on-demand customer applications using the back-office application information.

## 2.4 Energy management as a service

In other markets more flexible pricing schemes and payment methods are already used. Especially in wireless communication and ICT micro-payment methods are used. In order to effect mass-customisation, in these schemes, bundles of services are contracted to customers and payment is done real-time. In the distributed multi-media market, these schemes are also becoming more and more attractive. Using more differentiated metering for electricity would allow trade and calculation with real-time prices. In this respect, an "intelligent" meter would better give feedback to customers, while providing the utility with a better pricing strategy. Differentiated prices for categories of power quality (for instance in terms of reliability, dips and absence of harmonics) at the moment are becoming important to large customers.

Cost and earnings of time-dependent tariffs currently are at the risk of trading companies. In a commodity-market margins are becoming lower and lower. A discriminating factor might become the amount to which these risks are attributed to the customers by the electricity selling company. Another way to increase margins in the electricity selling business is extending service offerings. A service offering would be automated energy management for customers. This management requires a good definition of the energy impact on the primary processes of the user. Existing services [ISPLCS,2002], to which connection may be sought, in this respect may pertain to remote ICT-enabled building management. ESCO's (Energy Service COmpanies) are becoming more and more active in liberalized energy markets.

In energy contracts for larger customers more and more frequently dedicated, utility affiliated companies are involved in energy management. After an energy monitoring and evaluation trajectory, key energy conservation measures are identified. Energy management and monitoring trajectories in the utility building sector typically yield a cost and energy saving from 10 to 20 percent and even higher. In some cases the management activity is contracted on a no-cure no-pay basis, with the contracting company sharing a part of the revenues. These energy management systems currently are not always-on connected to central locations; mostly dial-up connections are used.

In these contracts operation of installations (mainly HVAC (Heating Ventilation and Air Conditioning) in buildings are also involved. Optimisation for energy use currently is only within the local building context. Historic energy monitoring data yield valuable information for establishing or updating energy contracts for larger customers. Commercial systems for load forecasting are already on the market to strengthen the position of these customers on the market.

In a wider context energy management could also be extended to supply and demand management. Currently the software models and hardware tools for these applications are evolving. The liberalization context now already forms a driving factor for a next generation of building management systems, which are coupled to the Internet and have access to external information such as meteorological expectations and real-time price developments [VV, 2002].

The possibilities to translate the dynamics of price formation in an optimal strategy for demand-supply side management by shifting loads or generation of electricity are increased by the liberalization developments. On the other hand the dynamics pose a problem to most renewable sources of energy, because of their unpredictable supply patterns. Studies on preventing situations as occurred on the Californian electricity markets in 2000 indicated, that temporarily switching off 1 to 2 percent of the load would have prevented blackouts [Borbely/Kreider,2002] and load reduction by using demand response would decrease price spikes by 50 %.

For small customers, at the moment, only a lumped sum of all energy used during a year is billed. The bill is only sent once a year and metering is done only once a year. This scheme is neither attractive for the utility company nor for the end-user. A large number of studies suggest [IVAM, 1995], that a more frequent feedback has an energy saving potential of about 10-15 % on end-user consumption. In the United States, an evaluation of 40 projects [Goldman,1996] involved in energy-near services, showed, that, at that time, there was a diverse market-entry philosophy from each stake-holder. Three important dimensions were the types of services to be provided, the communications system to deliver services and the way partnering with telecom companies takes place. Bottlenecks appear in forming complex teaming arrangements between partners involved and establishing enough critical mass. Especially time-of-use pricing with up to four tariff-zones appeared to be attractive to customers to tune their usage to real-time prices. The most interesting information service found in the survey was providing an itemized-bill. Typical installation cost start at 100-150 $ for wireless metering up to 1000-3000 $ per house for broadband. The latter category costs have dropped considerably in recent years. Utility benefits include summer peak reduction demand of 2-2.2 kW per household. Bill savings ranged from 7-15 %. As noted in the Dutch survey [Olsson, 2001] customers attribute a significant role to utility companies to reduce their cost and usage. Comparing the situation then and the increased broadband penetration, an opportunity window seems to exist for energy management services. Services wanted most in this study with 1800 end users are tabulated in Table 2-1.

| | **Service** | Average rank in question 5, when mentioned |
|---|---|---|
| 1 | Electricity at the lowest possible cost | 1,46 |
| 2 | Energy saving advice | 2,39 |
| 3 | Control of power use to cheaper periods | 2,43 |
| 4 | Low cost Internet through the power net | 2,69 |
| 5 | Green environmental energy | 2,76 |
| 6 | Electronic warning/ burglar alarm | 3,29 |
| 7 | See your energy consumption in real-time | 3,31 |
| 8 | Electronic bill | 4,03 |
| 9 | Remote diagnostics of appliances | 4,19 |
| 10 | Home automation and control | 4,34 |
| 11 | Remote control of heating system | 4,39 |
| 12 | Pay per use of washing machine/dishwasher | 4,52 |
| 13 | Remote control of appliances | 4,62 |

*Table 2-1 Ranking of energy-near services*

Delivering electricity at the lowest possible cost would be the major driving force for buying new services from energy companies. If a connection from energy services to selling of green energy could be made, then the study showed, that there is a bandwidth for even higher energy-prices. Some 25 % of the people are prepared to pay 5 to 10 % higher prices for their energy, if it has a green label.

In a number of EU-projects, e.g. ETHOS [David,1999], the opportunities evolving in case remote metering sensor-apparatus is enhanced with actuators influencing load are discussed and tested in a prototype environment. EA Technology developed the CELECT system, which is able to send out CRM's (Cost Reflective Messages), which have much more detail than the on/off availability messages sent in traditional load DSM-programs. CELECT internally uses EHS-PLC to transmit signals in the home network. In consumer field tests the local demand side power control network could be seen to reduce power in peak periods via the CRM's. CRM's were also shown to be very flexible in following the prices in pool markets.

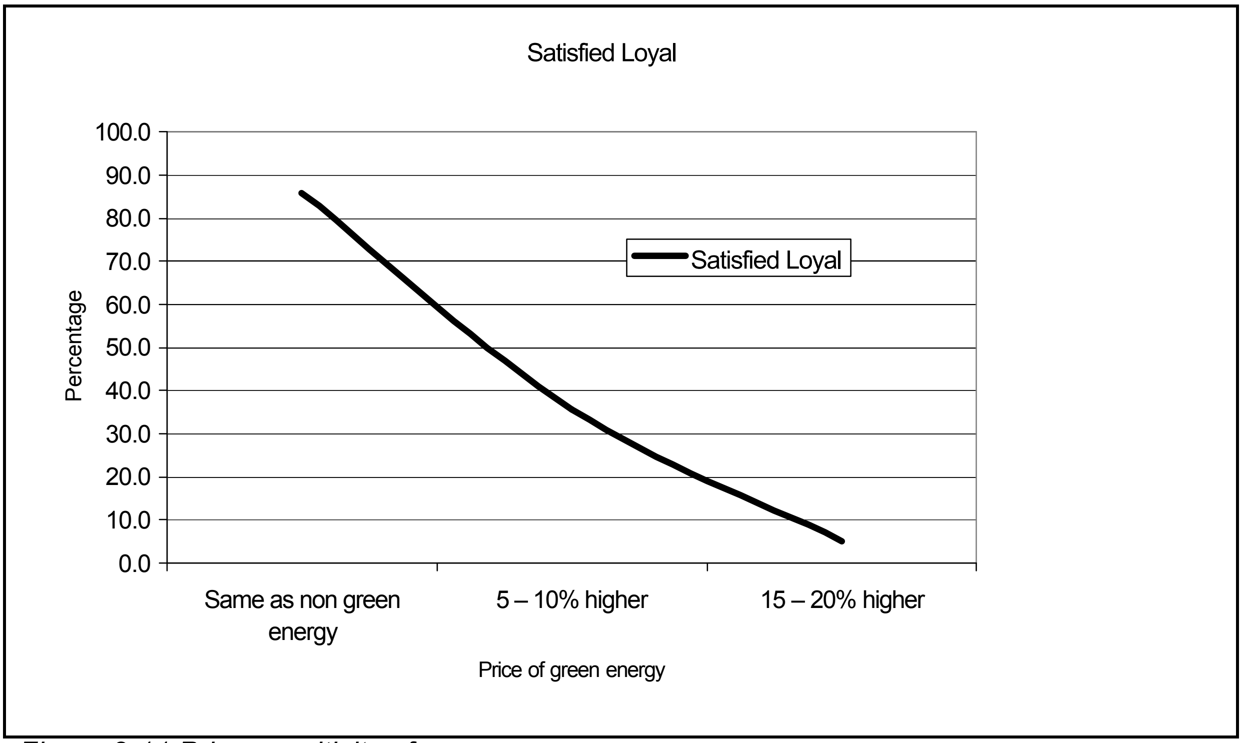


*Figure 2-11 Price sensitivity of green energy*

The role of small-scale ICT in the era of Utility deregulation and privatisation especially with respect to home automation and larger scale applications as surveillance and home security systems has been treated by [Parisot,1999]. A customer value increase appears to be the main driving factor, but small customers are hesitant in investing at the moment.

Apart from collecting metering data, two-way communication to customers increases the possibilities for fine-grained load control especially in periods of shortage of electricity. Remote cut-off (for defaulters), social cut-off (limiting consumption to a certain amount per day) and connection of customers, energy conservation incentives by more regular consumption and financial feedback, as well as the opportunity to reflect real-time market tariffs or more pricing groups to customers add to the potential of adding two-way communication to customers. Recently, in the Nordic countries, due to shortages on the power market, energy trading companies went broke and energy prices soared. By intelligent metering with more real-time tariffs, parts of the risk of buying energy at power markets can be transferred to individual customers instead of being taken by a trading company.

Paralleling the electricity market, the gas market, also, is in the process of liberalization. For gas contracts it is important to optimise for even usage of the distribution net. The connection capacity then is the most important factor in these contracts. The metering process of the gas usage has the same tariff-composition and regulatory issues as has the electricity metering process.

Business model development for DEG-RES has been treated in [Kartseva,2003]. In this paper the usage of the EEE($E^3$)-value methodology has been described mapped on business models for distributed generation. In these business models value-exchanges take place on the micro-level. These micro-transactions should be adequately followed by micro-payment schemes now arising in other service-sectors (especially telecom and the music industry) as well.

## 2.5 Electricity grids with a higher penetration of Distributed Generation

The current layout of the power market is top-down with a central task for market price formation and brokerage and management of transmission and distribution networks. Renewable energy sources generally are small scale and have a more or less unpredictable pattern of generation [ADL, 1999,Borbely/Kreider,2002].

Standards are currently being defined to smoothen the process of introducing DG and DG-RES in a more flexible way. In the IEEE-society, the P1547 standard is currently in the approval process. P1547 provides a uniform standard for interconnection and information exchange of distributed resources with electric power systems. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection [P1547,2003]. The CERTS Microgrid-concept [CERTS,2002] is extending these concepts to the adaptation of many small power producing apparatus to one larger entity, manageable as one item in the power distribution system. The low level electro-technical behaviour is tuned in this concept; not the matching of supply and demand. Advanced power electronics enable such an aggregated system to behave as "good citizen" in a grid less than as a load to be tolerated, as is the case for most renewable energy systems at the moment.

When comparing traditional electricity supply systems with future electricity systems with traditional electricity supply systems, new market entities appear. Small customers will have a role in DG-generation and conversion of primary energy sources. Furthermore, they might have options to act in the balancing and ancillary market. Network connections, then, will be dimensioned differently in those contexts and the flow of power will frequently be the opposite of flows now in power nets. Control of these future networks cannot be imagined without an adjacent ICT-network for optimal real-time operation.

# 3. Demand side management

## 3.1 Introduction

This chapter presents an aggregation of work done on demand side management. Not all power demand has the same characteristics; for certain applications the requirements on power delivery are different from others. Demand side management by utilities is a broad subject ranging from very static promotional activities of utilities to their customers to use less energy by buying energy conserving appliances to dynamic actions of utilities during power distribution to switch off customer loads temporarily to shave peaks. Recently, research efforts are being undertaken in demand response systems, in which price-driven responses of customer apparatus play a role.

The extent to which a user demand may be controlled, depends upon the quality attributes and the demand articulation. The first aspect covers the interruptibility of the power delivered to the device. Power used for feeding computer hardware has to be exactly at the right power level and should be uninterrupted. Power for heating water in washing processes has very limited quality demands and is interruptible. In this chapter, the different kinds of demand are first characterised. They form the basis for demand articulation functions, which will be discussed in chapter 5.

## 3.2 Influencing power demand

Power consumption is time-dependent and is triggered by external factors. Part of these factors may be influenced; others may not. In this section a categorization is made of power demand and primary processes are identified to which this demand is coupled.

### 3.2.1 Management of thermal comfort in buildings (HVAC).

Comfort management systems such as air treatment units (ventilators, cooling/warming devices) in homes and utility buildings account for about one third to one half of all energy consumption. In this total, electricity consumption forms a substantial part. It appears, that better adaptation of these systems to the life style of the building inhabitants leads to a better inner climate and lower cost [Jelsma, 2002]. A better adaptation can be reached by pre-emptive building management systems [ISPLC,2002]. This new generation of building management systems also provides an opportunity for introducing a link to the power market. In the Nordic countries this interest is increasing at the moment due to the fact that energy market prices have risen due to a shortage of hydro-energy whilst the pre-liberalisation grid-overcapacity has nearly vanished. The user interaction with comfort management systems is not well understood. Setting an adequate control strategy in well-isolated buildings is not simple. Effects of the control of inner climate control apparatus in these settings generally are more difficult to predict. On the other hand the good insulation properties of buildings offer an opportunity for storing energy. In summer for instance buildings can be pre-cooled in low energy-price hours. Renewable energy sources sometimes are coupled to the internal heat-load of a building. For instance a Stirling generator may utilize the excess heat of a heater to generate electricity more efficiently than a high-yield heating installation with heat-recovery. Control of these systems in variable market circumstances provides a large challenge but, because it is one of the most flexible loads in an electricity grid, is one of the critical success factors of the introduction of DG-RES. For residential houses, an architectural description of a C-Box, a comfort control box, managing the inner climate, has been given by [CBOX, 2002]. A C-Box features a demand articulation function (the dotted line in Figure 3-1) of a residential house with a typical demand pattern (solid line) shows, that the comfort management system allows shifts in the demand at certain times more reluctantly than at others. The graphs in the figure stem from a representative house in the Netherlands with a typical lifestyle of the inhabitants. The demand articulation indicates the necessity a demand has to be fulfilled within a certain time.

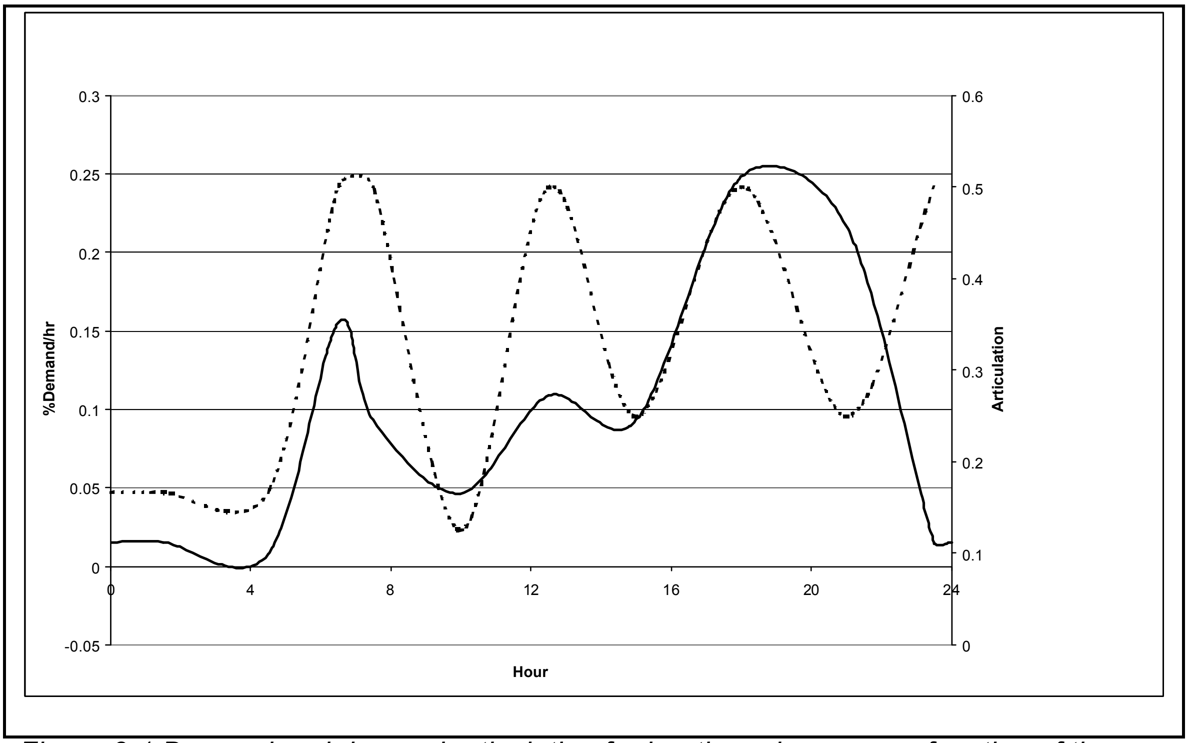


*Figure 3-1 Demand and demand articulation for heating a house as a function of time*

### 3.2.2 Rotating equipment and industrial freezing and heating loads

In this category loads like pumps and ventilators are to be defined. The demand elasticity is high for this kind of demand. On the small customer scale, the pump of a private swimming pool is an example. In the US, investment in this kind of apparatus is shown to be the most easily paid back application for cost saving. Large electricity consumers in this category include the building materials industry (concrete and cement production). Long-term food storage industries (cold stores) and the industries using industrial ovens to reach a constant high temperature level form another category of switchable loads. Currently control of these freezers and heaters is on an on/off basis with immediate delivery of power expected when a certain temperature bandwidth has been exceeded. New types of freezers have a continuous instead of an on/off control mechanism. These are the first that would benefit from appliance connectivity by induced control from price signals. In a rough approximation, the demand could be articulated in terms of an amount of power to deliver in a certain period. Configurations of these types of rotating equipment with heat or cold storage presents an opportunity for decreasing the load factor of these kinds of equipment in the grid. In large refrigeration cellars these mechanisms already are in the process of becoming introduced.

### 3.2.3 Loads composed of concerted operation of energy suppliers/consumers and/or buffers

These loads are to exemplified by a localized combination of, for instance, an electrical heatpump, air-conditioning apparatus and a buffering device. The operation periods are time shiftable locally without impairing resultant thermal comfort requirements. Several temperature levels of retaining heat may be covered. Principally, the electrical heat pump is also usable for cooling purposes. A similar combined load is the after-heating unit of a heatpump-boiler, which is needed to elevate the temperature from the maximum reachable by the heatpump to higher levels to be stored in the boiler reservoir.

### 3.2.4 Lighting loads

Lighting loads mostly are not switcheable (on/off) as they have an influence on the perceived visual comfort. In office environments, experiments conducted by the Lighting Institute [LI,2003] show, that a reduction of the lighting level by 30 % in case of power supply scarcity, did hardly impede the visual comfort for office workers. Lighting loads are switcheable in horticultural environments, when used for assimilation lighting. Here the total amount of lux delivered is more important than the exact times switches are set.

### 3.2.5 Hot tap-water generation and heat buffers

Hot water generated by an electric heater is one of the switchable loads, which have been used extensively for demand side management programs [Sidler, 1998]. Integrated systems would tune the buffer level for hot water production to the demand pattern in the recent past. PV-thermal with its integration of electricity generation using PV and hot water production using an integrated solar collector is an appliance from the supply side. Heat buffering also plays an important role in the horticultural sector, coupled to power production of (micro)CHP.

### 3.2.6 Electricity buffers

Direct storage of electricity in buffers would be a direct way to act directly to market signals. Currently redox flow cells are attracting most attention in this respect. These are also in the picture as a source of reserve capacity in power outage situations. Sodium bromide flowcells may have a capacity of up to 120 MWh. There is a large research interest [ISET,2002] in all forms of power storage with different duration ranging from the millisecond range in the form of super-capacitors to hours and days in water pumping installations between the two levels.

On the consumer level, charging units for electrical transport will be more frequently encountered. In future infrastructure scenario's all-electric traction or hybrid vehicles play a role. Charging these vehicles is time-changeable activity.

### 3.2.7 Power consuming PC's, audio/video and home automation equipment

In the operating phase this demand is hardly shiftable. The load is less predictable and strict real-time. Only the standby power consumption might be decreased in cases for instance when all apparatus in a building go to the minimum power position as a building is empty. The current trend in home automation may increase total power consumption; on the other hand intelligent management of the standby power may not only be a component issue but a centrally manageable item as well (i.e. on a home or building scale).

### 3.2.8 Washing and drying

Washing and drying processes have an opportunity for demand side management. On an industrial as well as on household scale several steps in the process are not time critical and can be pre-empted or postponed. In Figure 3-2 the time-dependent demand and the demand articulation for the washing process are shown. Some DSM-programs (Monday: washing-day) have been conducted to shave the peak in electricity consumption by giving a contractual advantage when washing on another day. On the other hand, washing and drying appliance manufacturers are in the process of introducing smart embedded systems into their machines to more exactly fit the amount of washing powder to the measured pollution level to decrease the environmental impact. This intelligence might also be used for DSM-purposes.

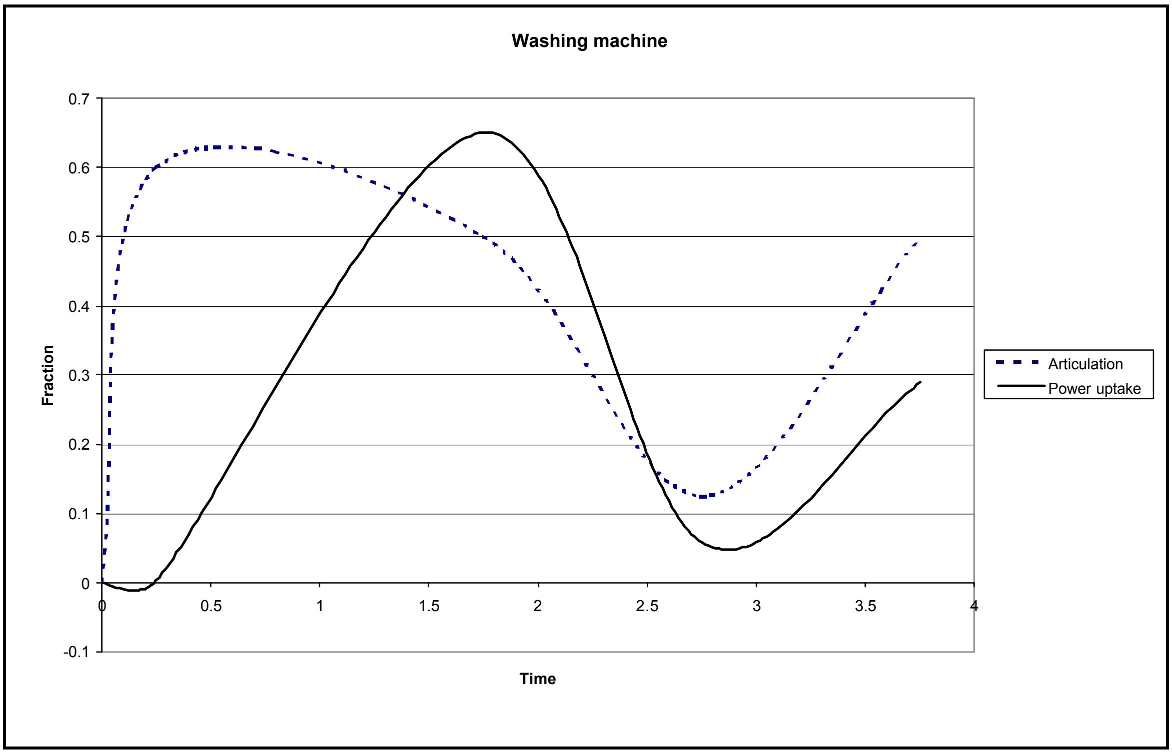


*Figure 3-2 Power demand and demand articulation for laundry washing processes*

### 3.2.9 An example: Demand side management in Sweden

On demand side management experience in Sweden an example is the Sydkraft experience. In the late ‘80s and early ‘90s Sydkraft made a substantial effort to develop demand side management and related knowledge. The interest stemmed from a need for generating capacity to cover peak load demand of a few hours a year. From this the question raised whether it would be not only possible to solve the peak load problem on demand side instead, but if this was an economical alternative too.

An overview of both Sydkraft experiences regarding the concepts of price reactive actors and full electronic markets is given in the annex to deliverable D 1.5 Intelligent Load Shedding [Carlsson,2003]. The overview concerns both supply – demand matching and intelligent load shedding. It appears, that most supply – demand matching techniques (involving demand side action) that have been developed in practice or in theory rely on estimations of the effect of a demand side action. Good estimates of the effect relies either on *(i)* a good personal knowledge and experience among involved personnel, or *(ii)* other knowledge based on consumption patterns of the involved consumer categories, etc. Sydkraft was involved in a large study on load patterns and load calculations published by Svenska Elverksföreningen in 1991 [Sweden, 1991], this (and similar) material is interesting as a base for calculations on effects of different load side actions.

## 3.3 Demand response resources used in elastic forward markets

Demand response resource (DRR) programs are the successors of Demand Side Management programs, which have been in the utility industry for some 20 years. A fundamental difference between DRR and DSM is the interaction with the consumer. In DRR-programs the emphasis is on consumer-action as opposed to utility control room action. An important aspect in the role of DRR is the associated information technology to settle contracts in liberalised markets.

Part of problems of liberalised markets, especially in the US, currently is the low credit rating of the energy generation sector. This means investments in the infrastructures are decreasing and have a short payback period. This trend has lead to a larger proportion of DG in the US. DRR is a comparable option to DG in this changing scene. DRR can be considered to be a means of selling something you do not want to consume immediately.

A second driver for DRR is the increase in the load factor of the power distribution network. DRR-programs as currently set-up in the USA are positioned on the wholesale market and have contracted capacities of up to 1000 MW. DRR-markets are currently in the construction phase. DRR-markets are examples of forward markets in which risks on traditional power wholesale markets may be mitigated in the same way as in other financial derivative markets futures are used to hedge risks. DRR involves "elastic" demand; demand of large installations with a certain flexibility. Apart from elasticity, articulation also plays an important role; the tendency a consumer is prepared to shed the demand at a certain point in time.

The mechanism of action of responsive demands is shown in Figure 3-3. The vertical line indicates the static demand; the curved lines indicate the price formation process, when the demand becomes more elastic. The ultimate bid price can be seen to decrease.

DRR-capacity may serve several roles in the power grid:

- Usage for power curtailment in emergency situations (low-probability/high-consequence events). Typical customer response times are in the order of a few hours. DRR-programs currently use a 500$/MW monthly availability price and a market price difference for the electricity not consumed. Typically, these DRR-contracts may not lead to any curtailment of power during years, but then sometimes may be effectuated more than one time during a year.
- Capacity driven; with the aim of avoiding congestion in the network. Using DRR, investments in transmission lines or in new large thermal plants can be deferred. Apart from the cost prevented, more time for planning procedures is available. Although the current 8/14 2003 power outage in the was not a result of congestion or emergency situations, but due to an operator misjudgement, power contracted in DRR-programs in NY facilitated start-up of essential power functions after the black-out.
- Usage to decrease price volatility (remove price-spikes). In these contracts, contracted amounts of power are switched-off in case short-term market prices reach certain levels. One of the problems here is, that DRR itself has an influence on price

formation and that financial profits not necessarily go to parties involved in DRR-contracts. Market simulations suggest, that a 5 % share of DRR may result in a 50 % decrease of prices in peak periods.

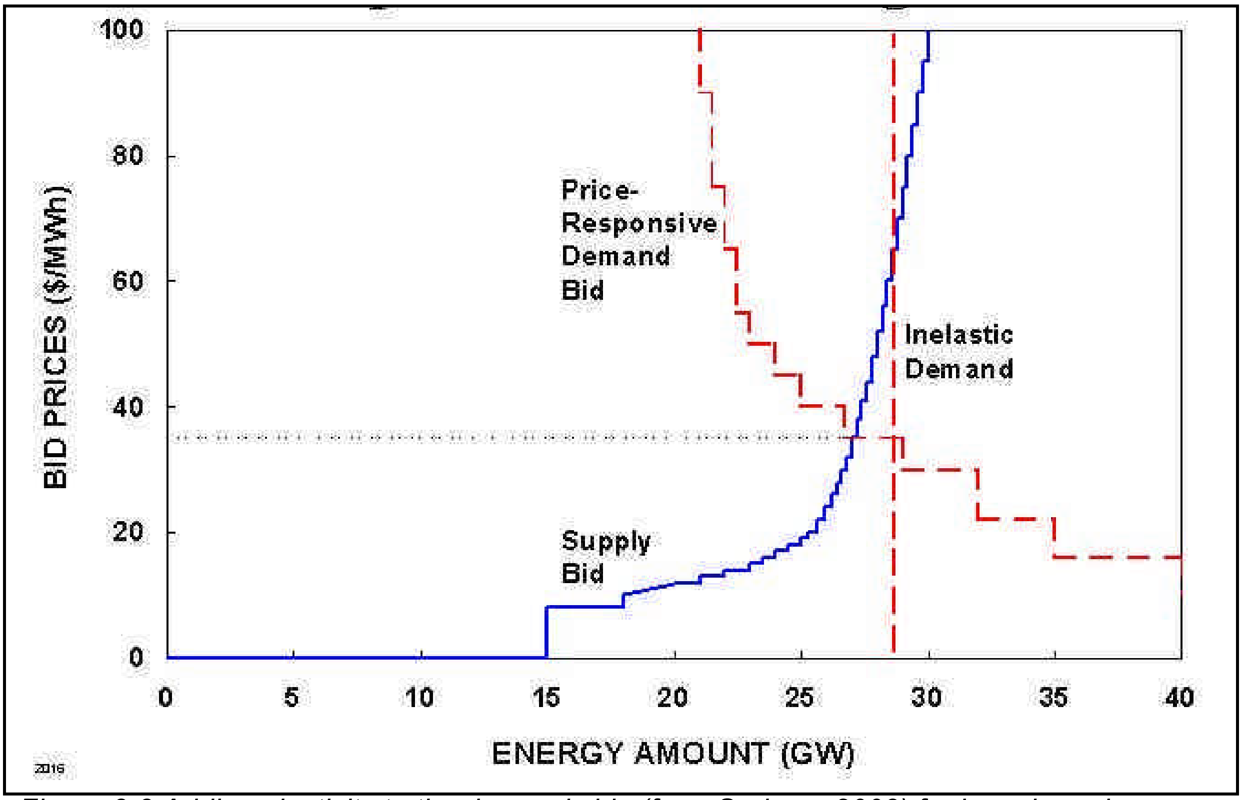


*Figure 3-3 Adding elasticity to the demand side (from Sedano, 2003) for lowering prices*

The firmness of DRR-contracts heavily depends on the type of application. Demand response may be voluntarily or certain fines may be involved. DRR for smaller customers is strongly linked to the metering process. In order to be able to settle the contracts, at least interval metering with periods of 15 minutes is necessary. Upload of metered data is also necessary with week or month periods. In the US, in the commercial segment of power markets, larger retail chains have installed technology for DRR and operate their aggregated switcheable load on the market. Switcheable load in these cases involves air conditioners and cooling devices. Due to the buffering effect of buildings the effects of load curtailment are hardly noticeable to customers. For DRR using office lighting experiments are on the way. A reduction of TL-light by 30 %, when gradually applied in 8 seconds, does not impair the perceived visual comfort perception of office workers. Current DRR-programs in the USA had an aggregated cost so far of $466 million.

On the hardware and system side companies in the USA like ITron, Comverge, Electricity City Corporation and RETX are developing products. Electric City promotes the VNPP-concept (Virtual Negative Power Plant). In this concept an ICT network is used to control a large aggregate of consumer devices demand. A company operating a VNPP is a curtailment service provider. The requested information technology and network connectivity for DRR-programs seems to be available and working at the moment. In a regulatory/legislative sense, DRR is becoming of some importance in the US. A locational marginal pricing scheme is under consideration now in a number of east-coast states in the US.

Experiences with DRR are being built-up at the moment worldwide; the largest programmes being in the USA (NYISO: 1531 MW with 1419 customers) and South-Korea. Furthermore, due to immanent power shortages, initiatives are being undertaken or investigated in Norway, Australia, Spain, Italy and New Zealand. DRR, making large customers aware of their time-dependent energy use, can be shown to increase the energy efficiency. In California, with the threat of power distribution grid capacity problems during summer, the amount of power that can be withdrawn from the grid is limited by a utility switcheable customer maximum load capacity. An IEA-subtask in the "Demand Side Management: Technology & Programmes"-task to further investigate the potential of demand response resources has found worldwide support.

## 3.4 Potential benefits of DSM

The benefits, costs, and problems of demand side management schemes differ from technique to technique. A number of benefits, costs, and problems are pointed out in the annex of deliverable D 1.5.

When it comes to environmental aspects of demand side management one could focus on a number of scenarios:

1. If action is taken to reduce the peak load of a supplier due to his delivery contracts, then the environmental impact of the action is small,
2. If action is taken to reduce overall peak load the momentary impact of the action is larger as it typically reduces the need to use production units with heavy environmental impact,
3. If action is taken as an alternative to enforcement of production and/or distribution capacity, the impact has to be evaluated with respect to the impact of new production or distribution units.

The link of DSM/ DRR in enabling a better embedding of DG-RES can be thought of in a number of ways:

1. Installations used for power generation in peak load situations are only used during a very limited period during a year and typically are the most polluting installations. DRR, then, will diminish the necessity of usage for these installations.
2. The intermittent supply patterns of small- or large-scale (DG-)RES can be compensated for by using the elasticity on the demand-side. Embedding of larger volumes intermittent DG-RES in the power infrastructure is facilitated having a flexibly controllable DRR-capacity.
3. The same distributed computing hardware and network technology for DG-control is usable for DRR-control.
4. Having added flexibility from the demand side increases the overall reliability of the power grid. Increasing the extent to which the demand-side resources are exposed to more real time prices improves market transparency of residual capacity in the net on a firm basis as opposed to an ad-hoc basis as during the recent imminent power shortage.
5. A market mechanism is introduced to compensate for current price-volatility risks in day-ahead power markets. In this respect DRR-markets decrease the price volatility on the day-ahead markets and offer a mechanism for managing the residual risk especially for intermittent, RES-supply-following producers.

The potential of demand side management is large in many countries, but the character of the potential differs from country to country due to variations in consumption patterns.

In Sweden approximately 40% of the total consumption of electric power (including some service) falls into the residential category. Furthermore, 40% of the small residential houses are electrically heated (directly or with a hot water heat distribution system). Heating of apartment blocks is mainly based on district heating [Stem, 2002]. Hence from a Swedish viewpoint, action in the residential sector is an alternative that ought to be considered.

A major drawback of involvement of residential loads in any demand side management scheme is that each unit is so small that investment cost need to be either low or give other surplus to participants that motivates the investment. Anyhow, the Sydkraft experience is that it is possible in the Swedish context with high penetration of both electrical building heating and electrical tap water heating to involve residential loads in an economically justifiable way.

The second largest sector (in energy use) is the industrial sector. It is much harder to estimate the potentials of this sector, since each customer has to be studied and treated separately. On the other hand, the potential of each unit that is found attractive to incorporate in a demand side management scheme typically is orders of magnitude larger.

Today e.g. industrial consumers in Sweden with alternative fuel possibilities that are buying (part of) their energy at dynamic prices act price reactive. There is typically no or weak knowledge on distribution side of what action is taken by these actors. Furthermore Svenska Kraftnät, the TSO of Sweden, has engaged a number of large industrial actors in a scheme for reduction of extreme peak load (see the annex of D 1.5). From the experience of both Svenska Kraftnät and Sydkraft we could deduce that there is a potential in the industrial sector that could be involved more in the future.

The experience within the current situation in Sweden is that when it comes to cutting the most extreme load peaks, the need for controllable load is in the order of a small percentage of the total load. On the other hand, the potentials of advanced load side action schemes are much larger and hence they open up for enhanced utilisation of the dynamics within power markets.

## 3.5 Demand side management and electronic power markets

There is over 20 years of experience in the field of demand side management already. DSM-programs have ranged from large to small customers. Protocols for communication between utility installations and load have been developed within IEC-870 [IEC,1996] and IEC-60870 and interfaces have been defined. In all these cases the utility is in control.

### 3.5.1 Large consumers

There is a division line between technologies where the control stays in the hands of the utility (as in the old Sydkraft set-ups) on one hand, and technologies where the control is in the hands of the end consumer or DG operator on the other.

In the latter case we have price reactive actors and electronic market approaches to the control problem (see the annex of deliverable D 1.5). Agent technology fits well with both of these approaches.

In this context software agents may be described as small (pieces of) programs that act on behalf of an actor within the power system, i.e. a consumer or DG operator (or DG unit), a supplier or any other party on the scene. As an example we could look at an agent responsible for indoor climate of a room. This room has certain thermal characteristics, it has limitations on maximum power consumption, and outside real-time and expected weather conditions it has limitations on minimum power consumption before becoming uncomfortable for the user – the agent has to take all this into account. Furthermore, forecasts on e.g. weather and prices are essential, and not least to mention preferences of the user(s), as shown in Figure 3-4. A goal for the agent is to optimise energy use with respect to user preferences and prices.

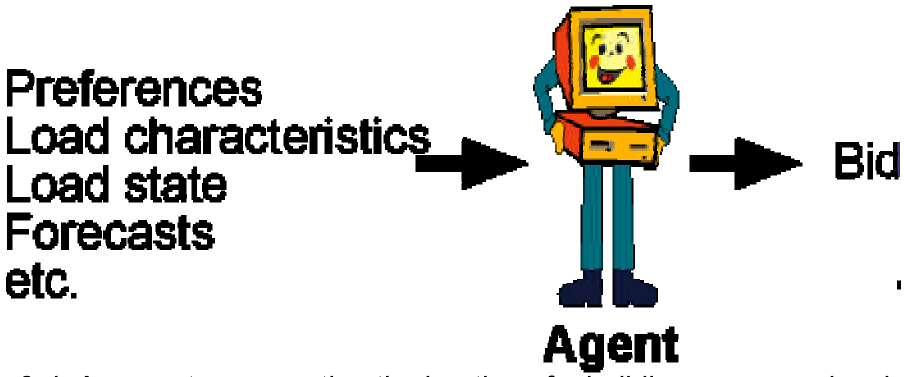


*Figure 3-4: An agent representing the heating of a building or a room in a building*

In a price reactive setting the agent could be described as an optimiser who takes all this, and system prices as input and calculates an optimal behaviour. In an electronic market setting the agent is the entity acting on the market, i.e. he constructs bids on behalf of the actor he represents and with these he acts on the (set of) power market(s). Market perspectives in focus here are from day-ahead markets or planning markets, down to markets that clear a few minutes before real-time.

### 3.5.2 End user level

As mentioned earlier, in a report of LBNL [LBNL, 1996] a large number of pilots and field tests with residential customer energy services are evaluated.

A large number of experiments with energy management in homes have been conducted in Europe [Sidler, 1998] and abroad [Goldman e.a., 1996]. The US-study extends to some 40 projects [Goldman, 1996]. In the USA legislatory regulations require more frequent meter reading than in Europe; apart from a reduction of the price of 0.5 to 1.0 dollar for one meter-reading further commercial gain was expected from an improved customer relationship. Applications and user response were investigated. Systems from that time were very much tailor-made to satisfy the metering and demand side management requirements. In general, these projects can be seen as early adopters of the technology. More frequent feedback of energy is seen to lead to a persistent saving in energy cost. In a survey conducted in 1995 in Amsterdam with 250 residential homes [IVAM, 1995] it appears, that monthly feedback and differentiation of tariffs leads to a persistent saving of 13 % on energy usage. This is confirmed by a market survey conducted in 2001 within the EU-project, PALAS, in 1800 house holds [Olsson, 2001] showing, that family heads in the Netherlands want more information from their energy company and at least a two-monthly bill. Also, a task is attributed to utility companies in demand control, if lower cost is achieved. In the current tariff structure for electricity time variability is confined to a peak and daytariff.

Especially in the Nordic countries a large number of pilot projects were conducted. Especially in the case of control of electric heating results achieved seem to be promising [Saele,1999]. In Norway the consumption per inhabitant has doubled since 1970 and amounts to 16000 kWh/yr and an average household used 25900 kWh/yr. Apart from this consumption increase, the consumption peak demand increased even more. This means the load factor of the network has decreased resulting in higher marginal losses. In the situation in Norway moving load from day to night reduce transmission and distribution costs. The system used in Norway had relay and sensor nodes. Relay nodes control water heaters and electrical heaters in the homes. The relay nodes worked locally: if an appliance is turned on, the switchable load is reduced by turning off some of the equipment. The load curves showed a clear reduction of 15 % in load-factor in the pilot and load-curves can be smoothed. User experiences in the test were positive; the appreciated the system, but were not willing to pay for it. Part of the financial gain and thus of the investment costs has to be brought up by the utility company.

In the USA experiments have been conducted and commercial systems are on the market to automate the analysis of real-time energy consumption [NIALMS, 2002]. By a precise analysis of small shifts in phase and voltage levels when power consumers switch on and off consumption can be directly attributed to appliances. A classical example of the use of this kind of information is heating the waterbed in an air-conditioned, cooled room. Systems operating on these secondary data have not found a widespread use due to a high initial investment.

In Europe in the Eureco-project [Eureco,2002] an end-use metering campaign in 5 countries was done and an assessment showed, that a rational use of energy potential existed of up to 30-40 percent for households.

Examples of demand side management with residential customers are currently implemented in Sweden and Italy. In Italy a large project, introducing intelligent metering and control gateways in 27 million households, is currently in the implementation phase. The main targets in this project are reducing tampering of power, contract management and improved customer feedback and more frequent billing. In Sweden, where energy prices are soaring, the creation of more possibilities for control of the power use, especially at a distance from second homes, promote the usage of intelligent, preferably wireless technology to manage power.

### 3.5.3 Embedding ICT and demand side management in the user environment and lifestyle

Adoption of modern information and network technology solutions in user environments is not easy [MC, 2001]. Mostly there is a mismatch between the user and designer perceptions of the systems. A considerable part of the long term European research agenda, however, is concerned with the ICT using small embedded processors in mobile, wireless networks. This research has the aim of extending personal networks with the other local wireless network infrastructures in order to add to the information value of both of them [Weiser, 1999]. Such pervasive computing environments in combination with an Internet repository may provide valuable information to energy management systems. In view of the current increasing density of always-on broadband connectivity this would add to functionality. Instead of involving the user with this kind of applications, which he/she is not interested in, these small devices may, not noted, organise processes in the background. These technological developments are valuable if they are able to create more reliable information from users than current classical user interfaces in a vanishing technology role [Olsson, 2001].

Problem with these network connections is a not well-developed articulation of user demands. Recent research suggests, that users see the importance of energy management applications, but can't easily build a consistent picture of possible applications. Defining applications therefore requires a good interaction between designers and developers.
Remotely operating monitoring and control systems, due to their hidden nature, may encounter scepticism due to falsely proactive actions and intrusion possibilities. Therefore the possibility of safe, autonomous operation, when not connected to network, is essential.

# 4. Supply side management

## 4.1 Introduction

In traditional grids, managing the supply of power, given a demand for a certain period ahead is done by a central independent organisation. The detailed operation of these organisations per country slightly differs [Busmod,2003] but uses the same basic principles.

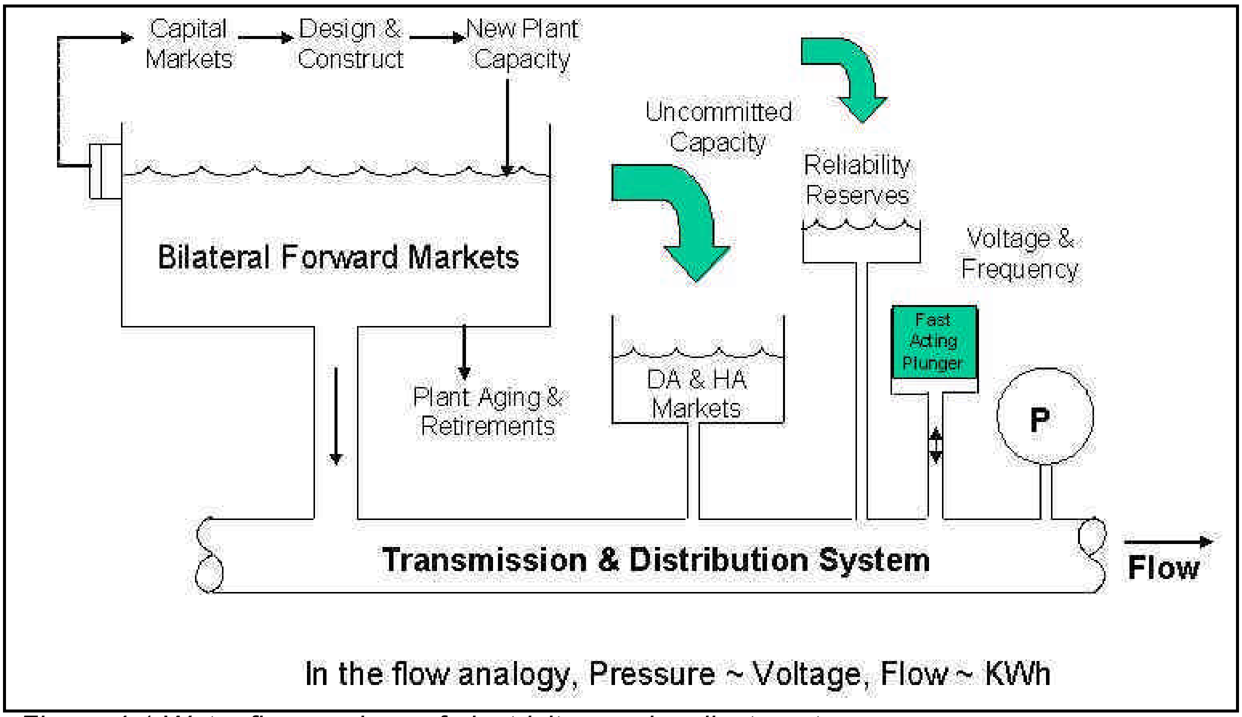


*Figure 4-1 Water flow analogy of electricity supply adjustment*

In Figure 4-1 the gradual transition from network planning attributes in time is shown going from left to right using a water flow analogy [Gilbert,2003]. The planning cycle for new generation capacity depends on the size of the generator and stretches from a few years for small installations to ten years for large ones. While turning to the right in the figure, the more real-time aspects can be seen, resulting in an even Voltage and kWh to the right at each moment in time.

In most countries a programme is defined [see 2.1], in which contracted volumes are incorporated. In a programme the amount of power generated as a function of time is fixed. Typically a programme is defined on a one day-ahead basis. As the time of delivery is nearing, slight updates and adjustments of the programme are contracted by the programme responsibles in order to adapt to actual power demand. Parties supplying too much or less power than contracted are penalized by the authority. Volumes of electricity to be traded for which this market is accessible are beyond the scope of current distributed generation units. However lumped units of different generation type may be actors on the market. For instance, owners of larger wind turbines are in the process of becoming one of the players on the electricity market.

Renewable energy sources like wind and PV have less predictable production patterns. Due to the decreasing size of cells in the on-land atmospheric measuring grids [HIRLAM,2003, Brand/Kok,2003, Borg v.d.,2003] and the increase of super-computing capabilities Navier-

Stokes techniques have become usable for accurately predicting meteorological parameters up to days-ahead. Parameters predicted most accurately are temperature and the wind direction and velocity; least accurate is the prediction of relative humidity, which is closely related to the expected cloud coverage. Wind power production capacity prediction margins are much closer to the realized values if the time ahead period is smaller. This means in some cases, that only a limited amount of expected production is sold as part of the 24-hour ahead programme to prevent the risk of underproduction. Given the increased accuracy in prediction with a smaller time-ahead and higher prices on smaller time-ahead period markets, then, would increase profits, but also leads to under utilisation of wind energy installations. For solar energy in the moderate temperature climates in Europe, there is no added value in predicting the direct and indirect solar radiation contributions. Persistence models here give comparable results.

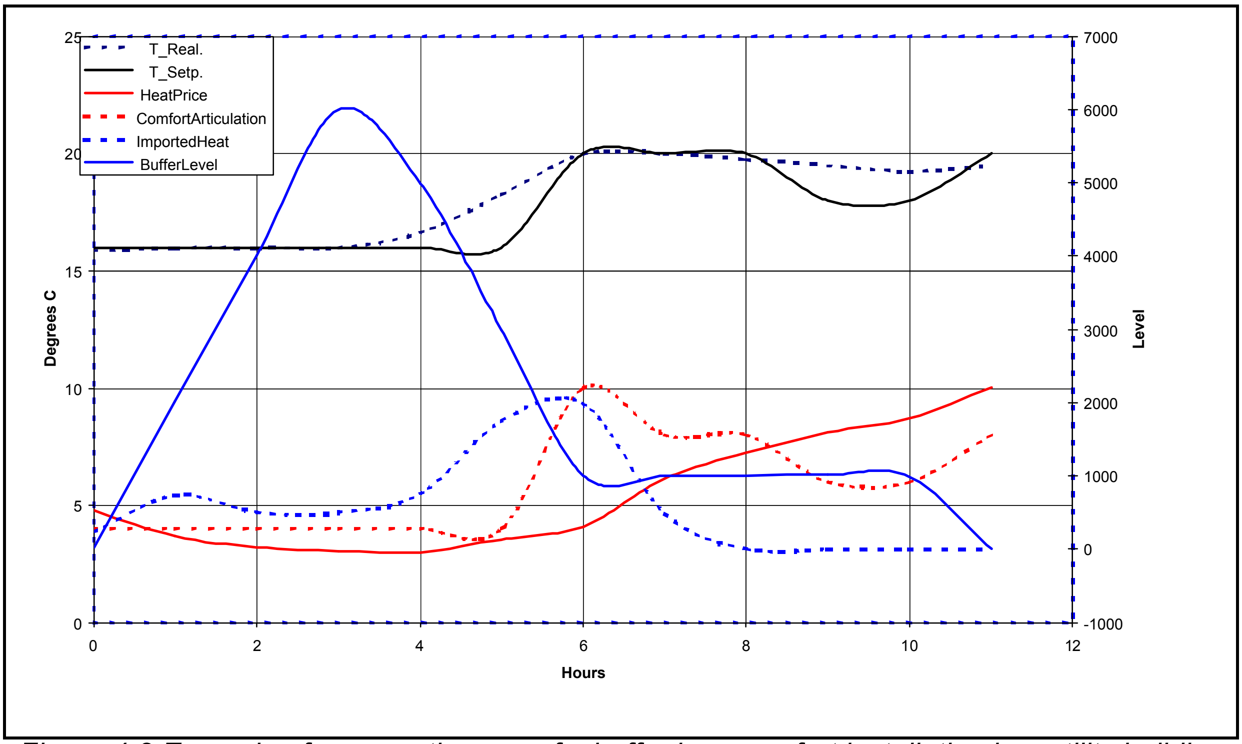


*Figure 4-2 Example of pre-emptive use of a buffer by a comfort installation in a utility building*

The PV-market is still one of the largest growing markets with a 30 % annual increase per year. The roof programme in Japan takes about a quarter of this volume. In Japan an extensive (wireless) monitoring network stretches over the country allowing the time-dependent production calculation of a 400 MWp network, distributed over 110000 rooftops. Additional data are collected with a grid of 800 measuring points, yielding a wealth of data to forecast an expected production.

Current DG and DG-RES energy supply systems use the grid as a background buffer. They also need the power grid to control power quality attributes. Dependency of the grid infrastructure, thus, is considerable in the current network topology. Islanding of DG-grids is even considered to be one of the causes hindering restoration of power after a failure in the large-scale power delivery network due to remnant small-scale power production. Introduction of a higher degree of RES in grids with a larger part of DG thus, urges, elasticity and articulation of certain types of demand and probably the use of extra electricity buffers. These buffers are needed to be able to balance the grid in real-time, but also to exert a role mimicking a spinning reserve as is present in current grids.

## 4.2 Controlling sources of energy supply

As for the demand side, energy supply systems may be dedicated completely to delivering electricity or be co-generating. In generation some environmental and operational constraints may be active as well. The co-generated resource may be most important in the primary process, that controls operation or be a by-product; electricity generation may be the primary process or not. Examples, in which electricity generation is the primary-process, are large thermal generation units, nuclear power plants, PV-cells and wind turbines. Examples, where energy generation is the secondary process are waste incineration/biomass plants linked to municipal heating systems, fuel cells. (μ-)CHP linked to greenhouses or homes. Examples of operating constraints are allowed cooling water inflows and duration of start/stop procedures. Furthermore buffers may exist for electricity itself or the by-product(s) and the valuation of products may be time-dependent (e.g. see Figure 2-5). At last, the supply pattern may be intrinsically intermittent. Therefore as for the power load side, the supply needs a large number of attributes to describe its behaviour sufficiently. In the IEC-community [IEC,2003] standards have been developed or are in the process of development to couple all kinds of power supplies to the power grid.

## 4.3 Price formation in DG-supply markets

Generally, the way the consumption price is built-up for end-users does not differ very much from the way retribution-prices for small-scale suppliers are formed. The power market price constituent is related to the "programme" responsibility on a day-ahead basis. Producers below certain limits do not have programme responsibility; above a certain limit, mostly a kind of insurance fee is paid to avoid penalties, if a certain amount of production is not attained. In the Netherlands, the tax-part per kWh is relieved for renewables dependent on the production method. The tax-reduction for biomass for instance, being less renewable than PV, is lower than for PV. In other countries similar feed-in tariffs are used. The high feed-in tariffs for wind-energy in Germany and Denmark in the 90's has given rise to a relatively large wind-potential in these countries and a innovative wind-turbine industry. Dependent on the position in the net a transport tariff is charged. In one of the deliverables of the EU-BUSMOD project a detailed account is given of country varying legislation and market mechanisms [Busmod,2003].

## 4.4 Opportunities for supply side management

Traditionally, owners of a distributed generation power plant have a fixed two-zone , time-dependent, tariff-scheme. In the Netherlands for instance, a relatively large percentage of power is generated by combined heat power (CHP) installations in the agricultural and utility building sector. These installations are driven by the heat demand, which depends on the primary process (realizing a certain temperature in a greenhouse or a building section). If a CHP has a capacity for buffering heat available, then apart from heat demand, control pre-empting expected price developments and changes in the operational context of the installation is possible. Currently even the residual carbon dioxide after burning natural gas has become a manageable resource, because it influences the photo-assimilation process in plants. For instance, in a greenhouse, in winter, when cloudy weather is expected with high ambient temperatures less heat and carbon dioxide has to be buffered in anticipation of low photosynthesis and heat demand than on a cold, sunny day. Due to the energy liberalisation process, where power prices have had an increase less than natural gas prices, heat demand and carbon dioxide reduction have gained more emphasis than the price for the generated electricity. CHP's for utility buildings have similar control strategies. Discrete simulation and optimisation algorithms provide a basis for designing an adequate control strategy for buffer usage given a pricing and demand articulation scheme. This is illustrated in Figure 4-2. Given a heat price, increasing as a function of time, a certain demand for delivering comfort (peaking 6 hours after the start of the simulation), the algorithm yields an optimal heat import and buffering strategy with minimum compromise to the realised temperature compared to the set-point. High-DG RES-networks are devoid of production capacity that compensates the inherently poor supply predictability within different time-spans for some renewables. Given the regional operation of these networks, errors in assumptions about demand and supply patterns, have a stronger influence on these local nets.

## 4.5 Buffer control

Buffering plays an important role in maintaining a satisfactory balance between demand and supply of energy resources in real-time. In the energy sector, intelligent control of intermediate storage of (converted) energy resources is becoming more and more attractive. Examples can be found in a number of business areas [Scheepers,2003].
In the horticultural sector in moderate climate regions, heat for warming greenhouses may be produced simultaneously with cogeneration of electricity or by direct conversion of the primary energy resource, gas or oil, to heat. In this sector, during nighttimes, when heat is requested, the price of co-generated electricity is low, while at daytimes, with higher outside temperatures and less heat required, the electricity price is higher. Buffering the heat produced in daytime hours, then, is a way to increase the yield of operating the whole installation on a day-by-day basis. Furthermore, apart from the time dependence of the price of the electricity produced, the price paid for the primary resource (mostly natural gas), may be volume dependent; there is a staged tariff with amounts above a certain limit charged higher. Finally, the carbon dioxide generated from burning the primary energy resource is used as additional manure for growing crops during lighting hours. Generating a cost effective strategy, thus, depends on many, partly time-varying, factors.
A second area, where buffering plays a role is comfort management of buildings. Within a number of research projects of ECN a comprehensive model has been developed [Kamphuis, 2001], that enables price driven control of elements of a building management system in close interaction with all actors involved in building management. The role of buffering of energy in utility buildings closely resembles the role depicted above for the horticultural sector. However, the possibilities for storage of heat or cold also pertain to the role a building may play using its mass. This heat/cold absorption capability may be optimized when energy prices are based on time-of-use. During summer this effect may be significant, because energy prices are highest during the afternoon due to the cooling demand of buildings. Finding a cost-effective control strategy, then, can be assigned a similar role as for the horticultural sector.
Apart from utility buildings, in residential buildings with facilities for storage of heat or electricity similar control strategy problems exist. Systems currently are under development for cogeneration on the scale of the individual house using fuel cells or Stirling-engine based concepts. Buffering heat at several temperature levels is becoming an option in zero-energy homes as well. The innovative E-Box [EBox, 2003] and C-Box [CBOX, 2002] concepts were developed at ECN to optimise operation of these kinds of devices. The E-box concept fulfills the role of local energy manager to optimally fine-tune energy demand and supply in time. Part of the E-box functionality already is concerned with scheduling fixed load times for the buffering strategy problem. The C-box concept defines the way in which an optimal comfort strategy may be defined in close interaction with users and the comfort installation. In this document some results of calculations with model for a B-Box (Buffer-box) will be discussed. The B-Box is a "box", which can be connected to a central control gateway, in order to exert optimal control of energy buffers. Due the ample network computation capabilities in operating a B-Box (a B-Box might have a Internet WEB-Service connection), control strategies may be optimized more extensively then current real-time localized control

systems. The B-Box's functionality makes it a candidate application for implementation of an energy management WEB-service application.

An abstract model of the control strategy problem of a B-Box is presented in Figure 4-3. A number of computational techniques for solving the strategy problem have been developed and an optimal algorithm is derived. The algorithm optimizes the buffer control strategy in time-of-use and volume-based pricing situations. The algorithm is scalable and may be used to calculate the strategy one day-ahead in 15-minute intervals within a short amount of computational time. The results of some "real-world" scenario calculations in residential and commercial settings are discussed for some DG-RES stuations.

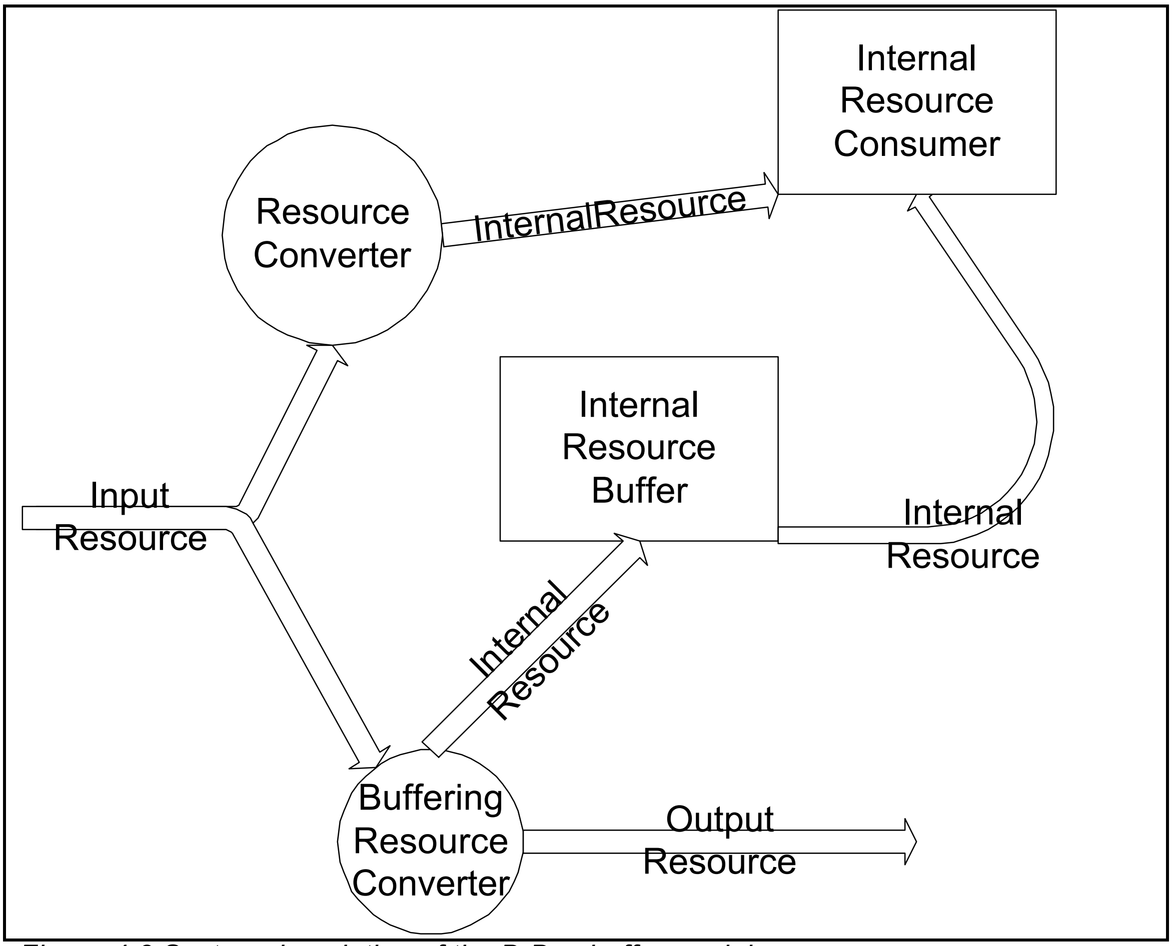


*Figure 4-3 System description of the B-Box buffer model*

### 4.5.1 Residential cogeneration

In Figure 4-4 the buffer control strategy is depicted for cogeneration in a residential setting. The resource needed is indicated by the dashed line and follows a heat demand approximately following the inhabitant's behaviour and the outside temperature in a winter situation. The InputPrice is based on consumption of natural gas. The InputAmount is the amount of gas used. The OutputPrice is taken from APX-data in November 2002 [Figure 2-5]. The input resource price is shown as the straight line below on the graph. The resource need is the heat demand [Figure 3-1]. In the following figures, the X-axis is the time in hours, the left Y-axis denotes amounts of resources (in GJ) and the right Y-axis the prices in

€ct/GJ. As might be expected, the buffer is filled during output price peak periods and emptied to fulfil the heat demand during the night.

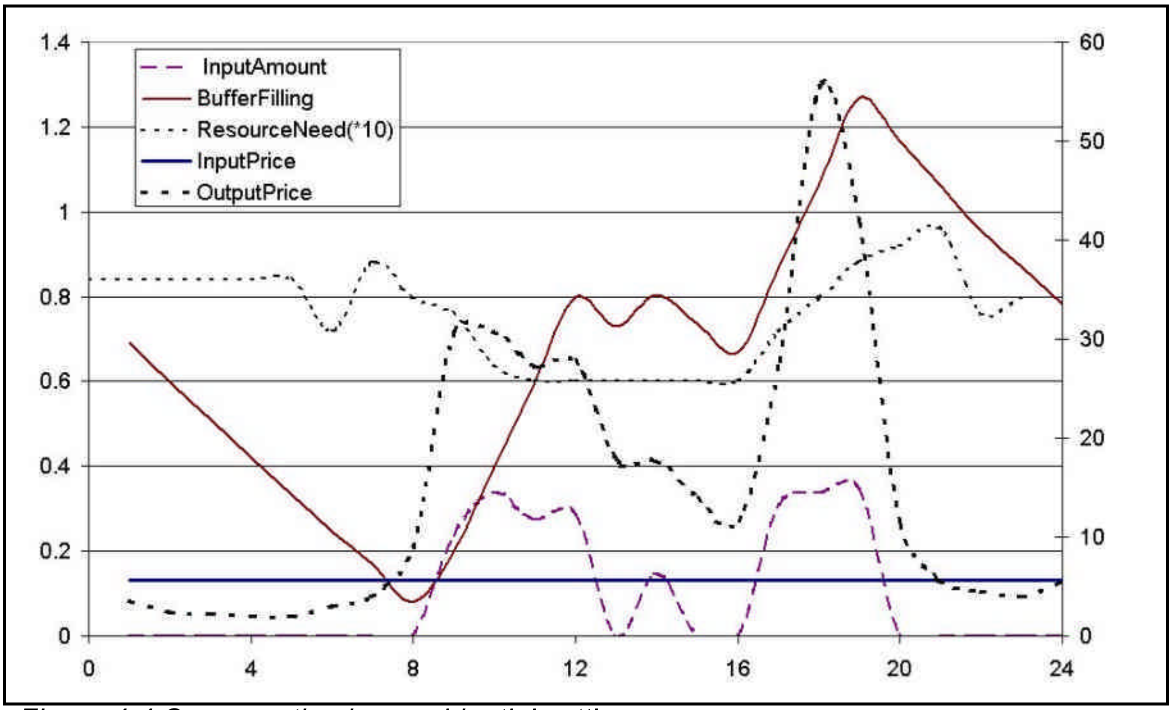


*Figure 4-4 Cogeneration in a residential setting*

### 4.5.2 Residential electrical heat production and heat storage.

Using the same data as in the previous section, the control strategy of a heat pump is shown in Figure 4-5. Electricity now is the input resource. Input and OutputPrices are the same in this case. Electricity is used during night time to fill the heat buffer. During the day the buffer is emptied. A similar strategy can be used to control hot tap water generation in a boiler.

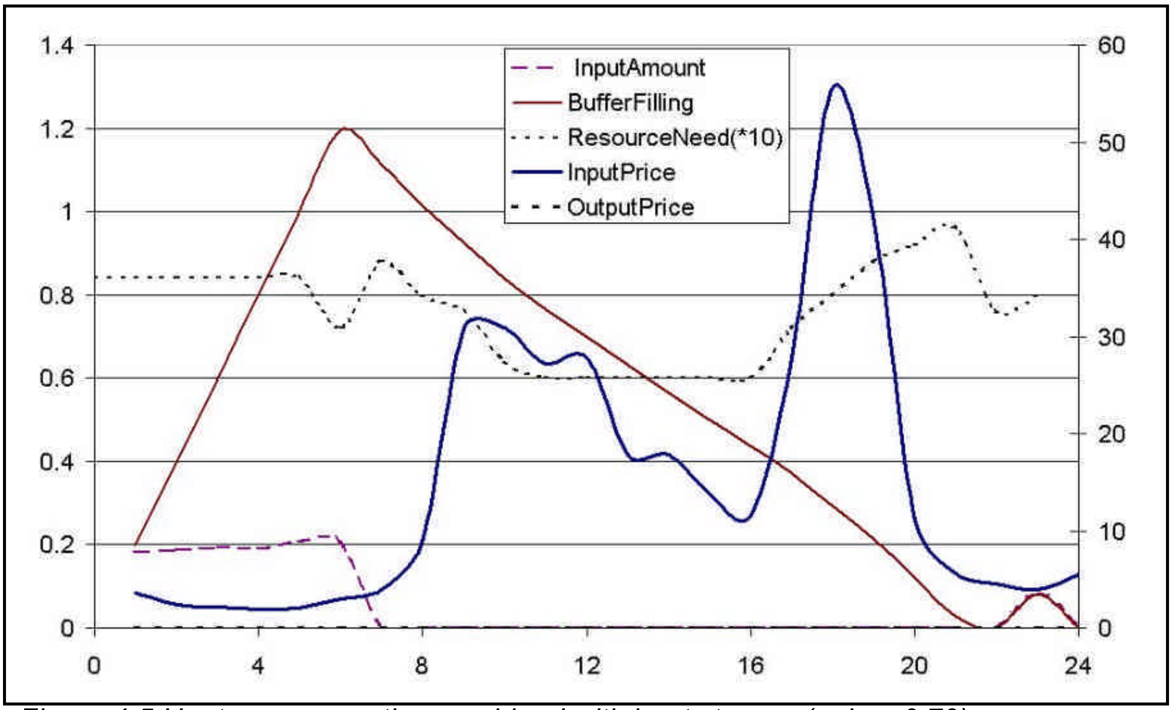


*Figure 4-5 Heatpump operation combined with heat storage (gain = 0.79)*

### 4.5.3 Residential electricity storage for heating or cooling

If not the heat is stored but the electricity in a buffer strategy the pattern is as shown in Figure 4-6. The prices indicated are for a typical heat demand in a residential building. Pre-emptive buffer filling, using day-ahead price information allows cost reduction. A similar plot, now for cooling in summer is shown in Figure 4-7.

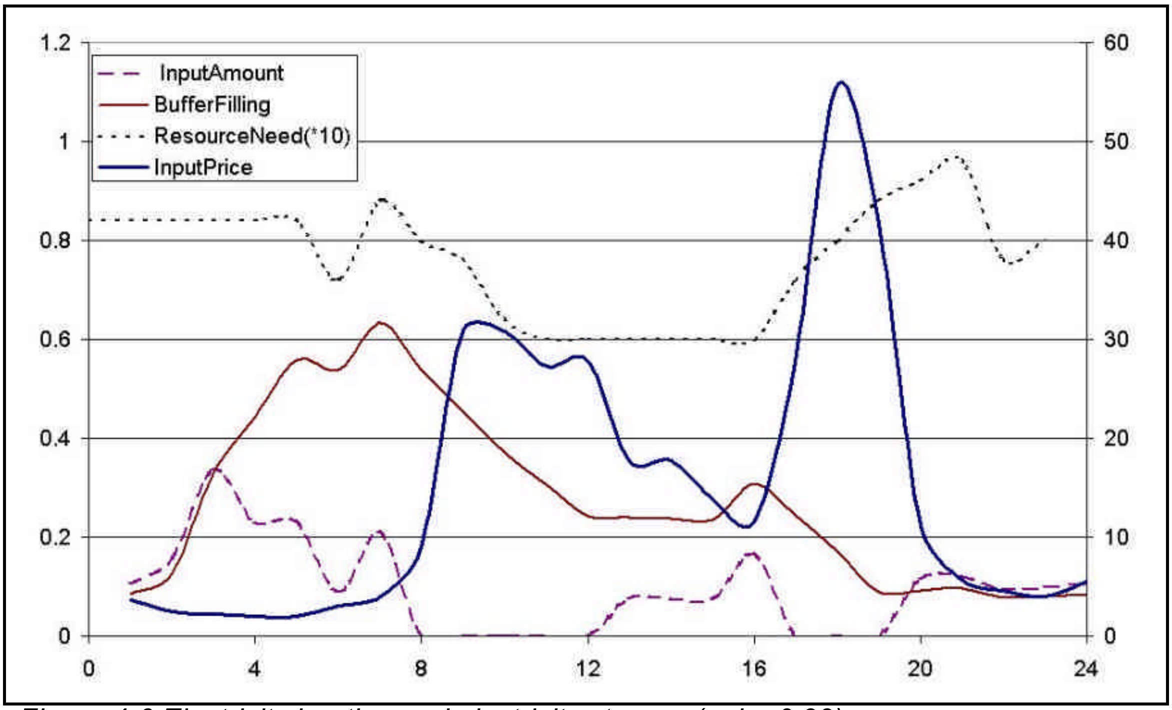


*Figure 4-6 Electricity heating and electricity storage (gain=0.99).*

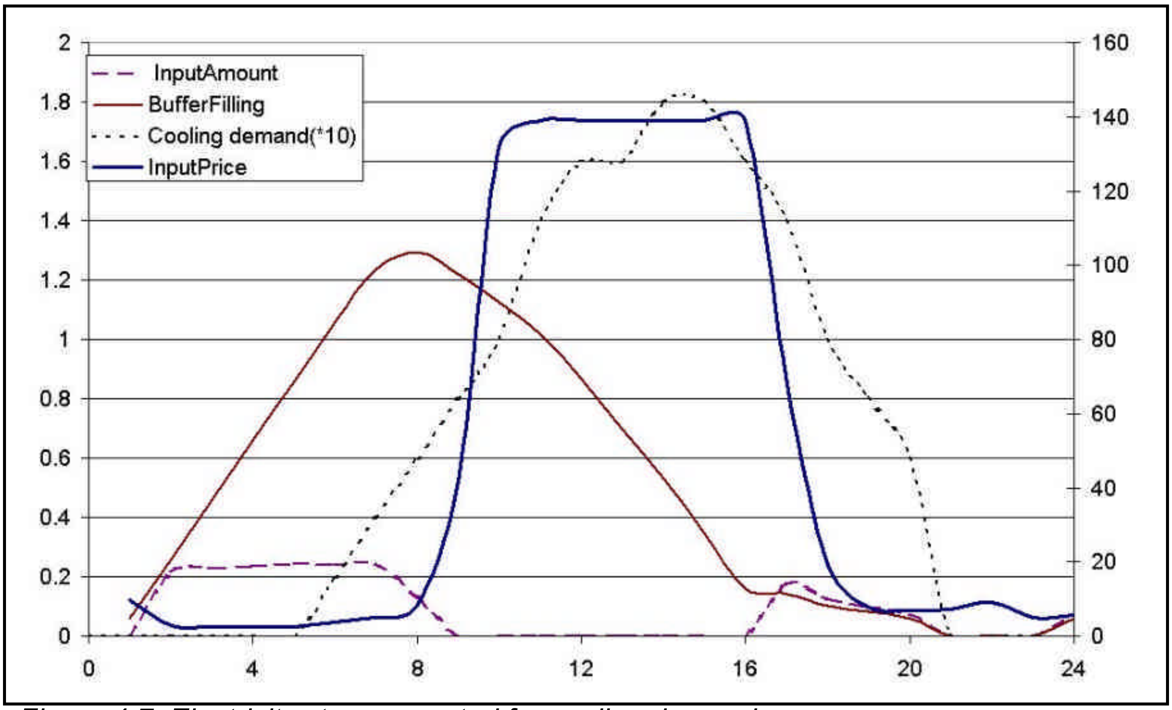


*Figure 4-7 Electricity storage control for cooling demand*

### 4.5.4 CHP in the Horticultural sector

In the horticultural sector CHP has been used throughout during the 90's. In Figure 4-8 the situation is sketched for the winter period with accompanying electricity prices and heat demands. In spring and autumn cost effective buffer management in this sector is more difficult in view of current fuel and electricity prices and power requirements.

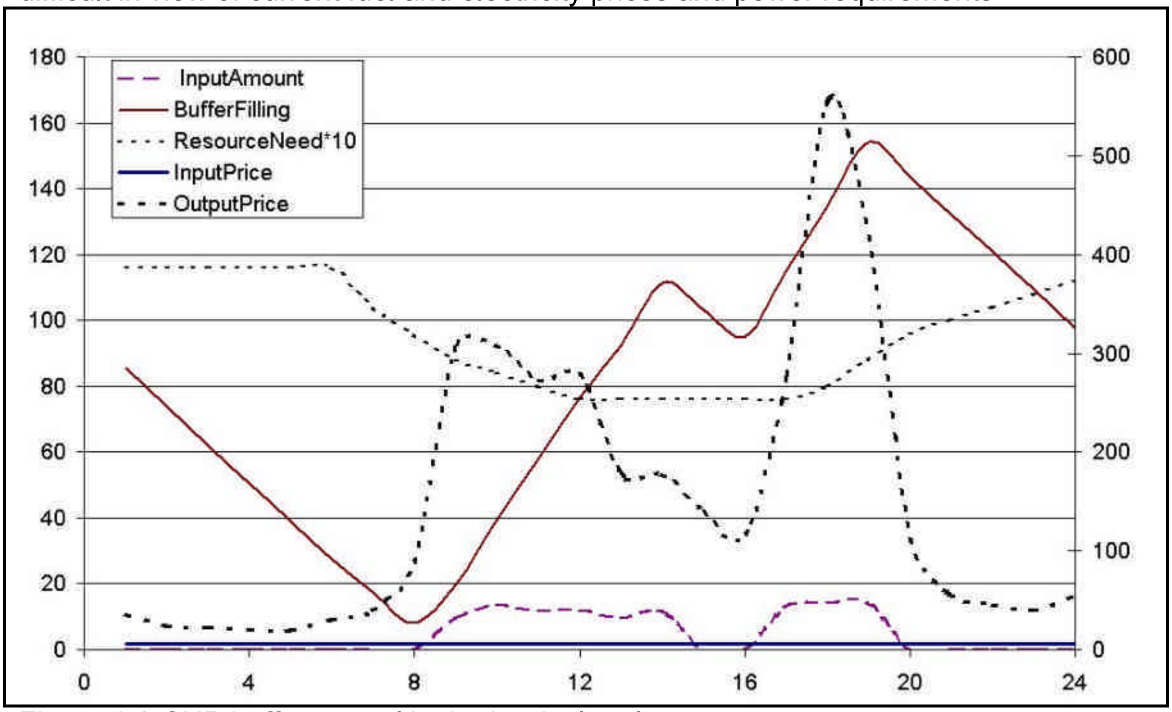


Figure 4-8 CHP buffer control in the horticultural sector

Thus, electricity price driven operation of cogeneration can be combined with effective heat delivery when using appropriate buffers. In all cases, possible cost reductions are when articulated time-dependent tariff schemes are utilized [this has been further detailed in one of the sample cases Table 7-2].

# 5. Distributed Intelligence: ICT Trends and Advances for the Future Utility Industry

Distributed intelligence is a summary term for a bundle of advanced ICTs that tackle the issue of how to develop Information Systems in open and distributed environments (such as, but certainly not only, the Web) and enable to exploit various intelligent systems techniques to improve functionality and performance in such environments. It would be misleading to view distributed intelligence as a single technology, despite the single term used for it: distributed intelligence is a collection of different ICTs that have their background and origin in different areas of computer science, but that do interact with each other in ways that make the whole bigger than the sum of its parts. It is not exaggerated to say that currently a new wave of distributed intelligent information processing is occurring, which is for example supported by the European Commission in its Information Society Technologies (EU-IST) program for Research and Technology Development. The long term vision of where distributed intelligence will go (as a coherent bundle of advanced ICTs) over the next ten to twenty years is depicted in
Figure *5-1.*

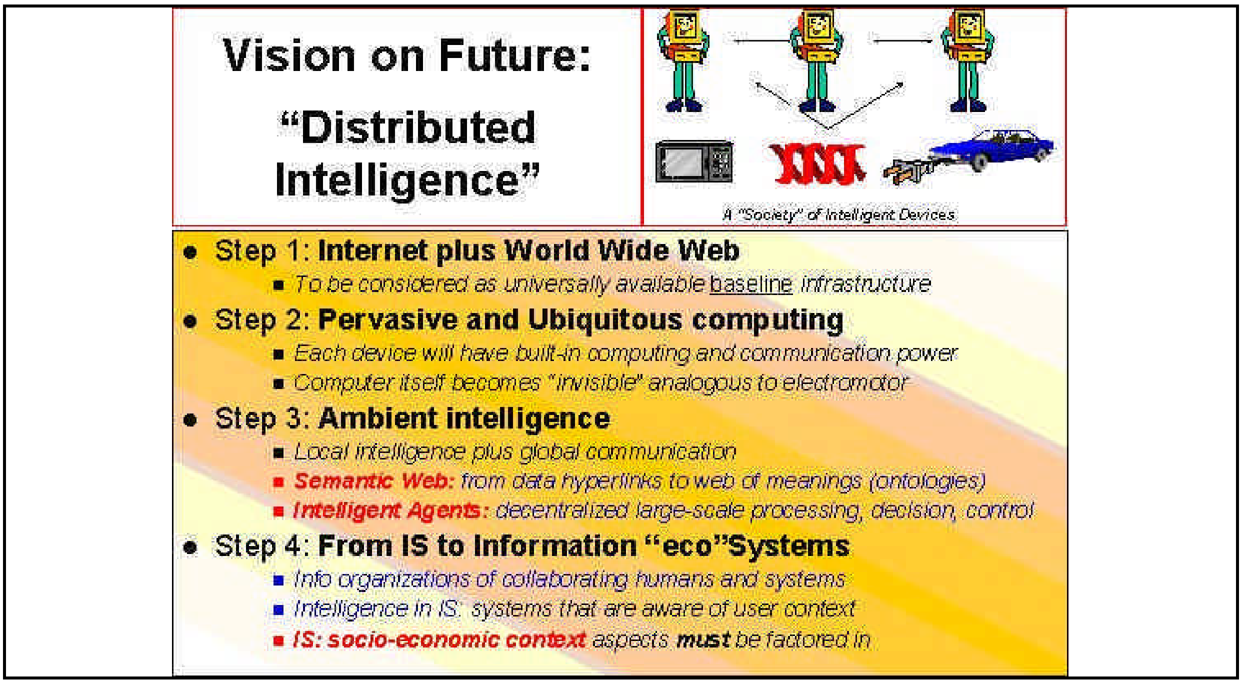


*Figure 5-1: Trends in distributed intelligence technologies.*

In this chapter we will particularly discuss intelligent agent systems and the development towards the Semantic Web. Agents represent a new type of Information Systems (IS) architecture particularly suited for distributed software applications as you have them in networked environments such as Intranets, Extranets and Internet/World Wide Web. Agents also offer several ways to embed intelligent systems techniques in large Information Systems. A definition and overview of the characteristics of agents is given in Figure 5-2. Subsequently we discuss the future trends of the Web, after which we survey some important application issues pertinent to the industrial use of emerging distributed intelligence technologies.

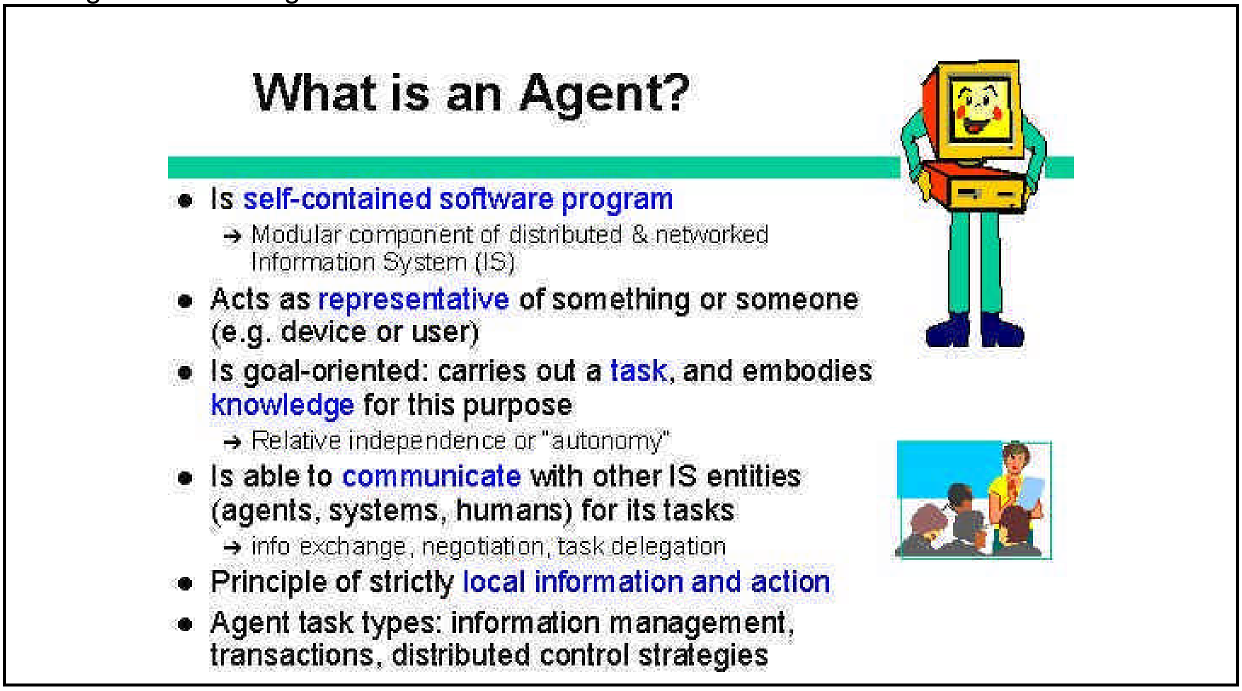


*Figure 5-2: Definition and characteristics of software agents.*

## 5.1 WWW's Next Generation: The Semantic Web

An exciting development in current intelligent information processing is the Semantic Web (cf. [Berners-Lee et al., 2001] [Davies et al., 2003]) and the innovative applications it promises to enable. The Semantic Web will provide the next generation of the World Wide Web. The current Web is a very interesting and successful, but also passive and rather unstructured storage place of information resources. This makes it increasingly difficult to quickly find the right information you need, a problem that becomes even more pressing with the scaling up of the Web. The vision of the Semantic Web is to make the Web from a passive information store into a proactive service facility for its users. This is done by equipping it with information management services, based on semantic and knowledge-based methods, that let the Web act - in the eyes of its users - as understanding the contents and meaning (rather than just the syntax) of the many information resources it contains and, moreover, as capable of knowledge processing these resources. In the words of Tim Berners-Lee, credited as the inventor of the Web, and now director of W3C: *"The Semantic Web will globalise knowledge representation, just as the WWW globalised hypertext".* This globalised semantic approach offers concrete research lines how to solve the problem of interoperability between systems and humans in a highly distributed but connected world.
Designing the infrastructure of the Semantic Web poses major technical and scientific challenges. This is already evident if we look at the envisaged technical architecture of the Semantic Web that somewhat resembles a delicately layered cake made from a variety of cyberspace ingredients.

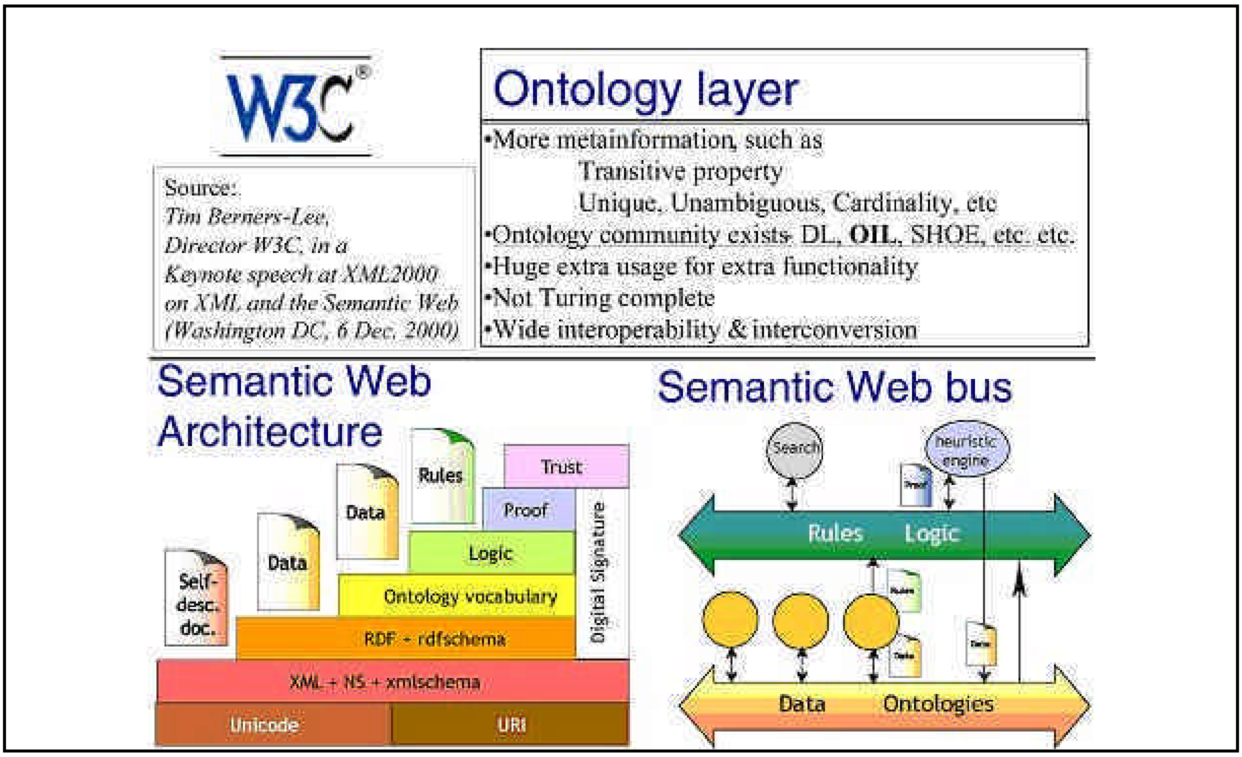


Figure 5-3. *Ingredients and envisaged technical architecture of the Semantic Web.*

Some of these ingredients are based on combining existing results and experiences that stem from research areas such as intelligent systems, knowledge representation and reasoning, knowledge engineering and management, or ontology and agent technology. Others are still in the process of invention. Recent progress is reported in e.g. [Davies et al., 2003], [Iosif et al., 2003].

Challenging and interesting as this is, it is a necessary but not yet sufficient condition to realize the full potential of the Web. For a comprehensive R&D strategy it is necessary to look at the broader picture (depicted in *Figure 5-4*) of the Semantic Web: how it is going to be useful in practical real-world applications, and how it will interact with and be beneficial to its users.

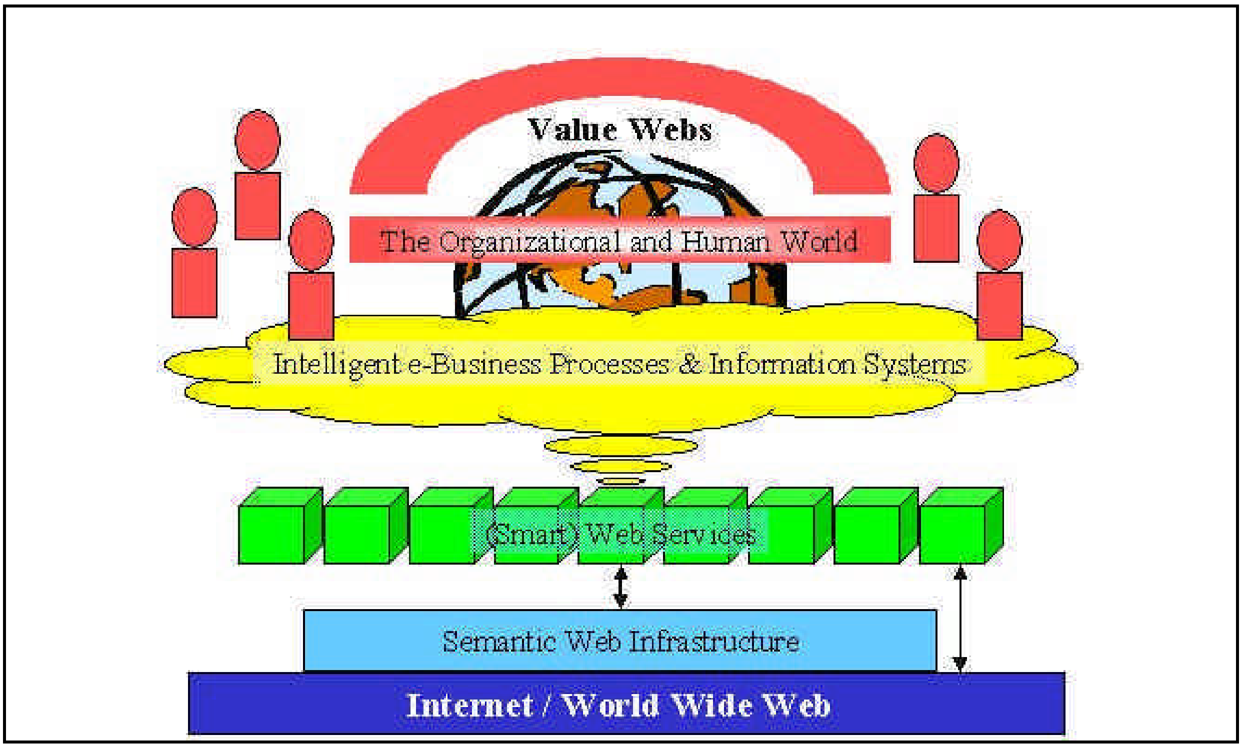


Figure 5-4. *The broader picture: Semantic Web infrastructure, smart services, e-applications and their human-world socio-economic context .*

The ongoing worldwide research effort related to the Semantic Web currently shows an emphasis on those technological issues that are indicated in *Figure 5-4* as web infrastructure and, to a lesser extent, smart web services. This is highly important research because generic semantic infrastructure (such as web ontology languages and content libraries) and associated generic smart web services (such as semantic search, semantic browsing, reasoning, knowledge processing and ontology management services) are a *conditio sine qua non* for the Semantic Web.
Nevertheless, it is also important to look already from the start from an *outside-in* perspective. What are the new business, domain, or user/customer applications that are not yet possible today but will be tomorrow as a result of the Semantic Web? Why would businesses, markets or individuals be willing to adopt such innovations? One of these innovations certainly will have to do with a closer mapping of technology onto everyday life processes.

After all, many great innovations fail or have very long lead times because of significant upfront investments. These are in many cases not just of a financial nature: in addition they require behavioural or -even more problematic- cultural changes from their adopters (whether individuals or organizations). We must recognize that the Semantic Web is such a great innovation. Consequently, there is no reason to assume that the new wave of intelligent information processing is immune to the age-old established social laws that govern innovation adoption [Rogers, 1995].

## 5.2 Intelligent Agents and Electronic Services in Energy

To illustrate some of the pertinent issues we will consider a few specific examples of advanced intelligent information processing that aim the creation and introduction of innovative e-applications for end users (the third level in Figure 2). In addition to the Web becoming smarter (which is denoted by the Semantic Web effort), it will also become more universal in the sense that it will not just connect computers, but essentially any device. This is variously referred to as “ambient intelligence”, “universal connectivity” or “pervasive computing”. Distributed Web applications are one step in this direction, but basically all equipment, including home appliances such as personal audio and video, telecom and home control systems, and even heaters, coolers or ventilation systems, will become part of the Web. This enables a broad spectrum of e-applications and e-services for end consumers in many different industry areas: home security, e-health, e-entertainment, e-shopping, distance learning, digital media services, and smart buildings that are able to manage themselves. All of these new imagined e-services are technically challenging, but will also require and induce different behaviours and attitudes from the end consumers as well as from the businesses delivering these e-services.

Figure 5-5. *Smart building field experiment site at ECN, Petten, The Netherlands.*

As a specific example, we take smart buildings. With several colleagues from different countries, we are researching how smart buildings can serve those who live or work in it [Ygge & Akkermans, 1999], [Gustavsson, 1999], [Kamphuis et al., 2001]. This work has progressed to the point that actual field experiments are carried out (*Figure 5-5*), whereby the social aspects are investigated as an integrated part of the research. One of the issues studied is comfort management: how buildings can automatically provide an optimally comfortable climate with at the same time energy use and costs that are as low as possible.

Technically, smart comfort management is based on intelligent agents (so-called *HomeBot* agents, see e.g. [Ygge and Akkermans, 1999], [Gustavson, 1999]) that act as software representatives of individual building users as well as of various types of equipment that play a role in the energy functionality, usage and production in a building (e.g. heaters, sun-blinds, ventilators, photovoltaic cells). These *HomeBot* agents communicate with each other over Internet and various communication media, and negotiate in order to optimise the overall energy efficiency in the building. This optimisation is based on multi-criteria agent negotiations taking place on an electronic marketplace. These take place in the form of a multi-commodity auction, where energy is being bought and sold in different time slots. They are based on the current energy needs, local sensor data, model forecasts (e.g. weather, building physics), and the going real-time power prices. The e-market outcome then determines the needed building control actions in a fully distributed and decentralised way.

The calculation model optimises the total utility, which is a trade-off between cost and comfort, over the coming 24 hours, taking into account both the customer preferences and the actual energy prices. This optimisation is redone every hour, because expected energy prices, outside temperatures, etc. may change, which results in different optimal device settings. Needed forecasts of comfort aspects in a building are based on simple thermodynamic climate models. Energy prices are in general known a certain period (typically 24 hours) in advance. The system reacts on electricity prices, trying to use as little energy as possible when prices are high. In simulations we have concentrated on two dimensions: the economic aspect and the indoor climate.
The economic aspect is illustrated by a scenario featuring two archetypes: Erika, a yuppie who wants to make no concessions to her comfort level whatsoever irrespective of cost; and Erik, a poor student who wants to keep comfort levels acceptable when at home, but also needs to economise as much as possible. Some typical results are presented in Figure 5-6. They do show that significant savings without loss of comfort are possible in smart self-managing buildings.

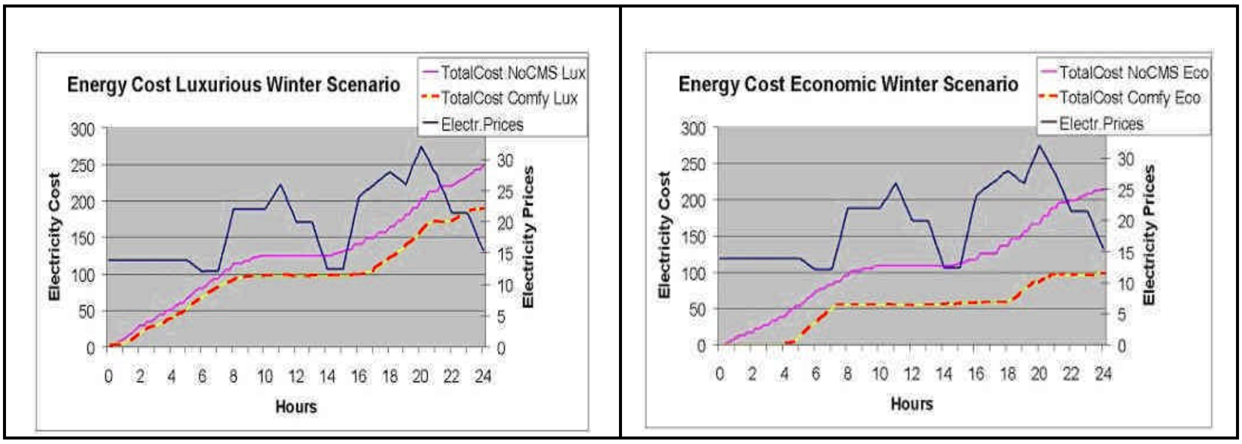


*Figure 5-6. Cumulative costs for a smart home*

In the scenario on a Winter day in Holland savings vary from 20% in the luxurious setting (yuppie Erika, left graph) to 45% in the economic setting (student Erik; right graph).
There are several general points beyond the specific e-application that are worth noting here in the context of intelligent information processing. First, most current multi-agent applications carry out information and transaction services. This application does that as well but it goes a significant step further: it is an example where agents carry out control tasks through an electronic marketplace that is a fully decentralized and large-scale alternative to common industrial central controllers [Ygge & Akkermans, 1999].
Secondly, technical and social considerations come together in the notion of comfort. In this application, comfort is the specialization of what counts as "*customer satisfaction*", an inherently qualitative and perceptual notion for most customers:

- People will typically be able to say whether or not they "like" the climate in a building, but they will find it extremely hard to make this explicit beyond qualitative statements.
- Comfort is a personal concept: users will generally differ in to what extent a given building climate is perceived as comfortable, and what climate they personally prefer.
- Comfort is a sophisticated multi-dimensional concept, as it causally depends on many interacting factors such as air temperature, radiant temperature, humidity, air velocity, clothing, and a person's metabolism (a measure of the person's activity).

- Delivering comfort in buildings is an economic issue: from marketing studies it is known that the financial costs of energy and equipment needed for heating, cooling, air quality, and climate control are key issues for customers and building managers.

Generally speaking, distributed intelligence techniques will require not only technological research: social and economic studies need to be integrated in a holistic fashion.

## 5.3 Socio-Economic Challenges: Business and Market Logics

Intelligent information processing will become a societal success only if it is able to deal with three very different logics of value, that are stated in terms of not necessarily compatible considerations of technology, business models, and market adoption (Figure 5). To start with the market considerations, the recent rise and fall of many e-commerce initiatives is testimony to the importance of correctly understanding the market logics. Extensive customer surveys were done related to the applications discussed in the previous section, with interesting conclusions ([Sweet et al., 2000], [Olsson and Kamphuis, 2001], [Jelsma, 2001]) such as:

- There actually *is* a strong customer interest in a broad variety of new-e-services, with a variability of this interest across different market segments.
- However, price and cost considerations are primary in this sector, with typically a window for incurring extra costs to the customer for new e-services of no more than 5-10%.
- Design logics of modern buildings (cf. the one of Figure 3) can be such that they run counter to the use(r) logics, so that sometimes they prevent their users from doing the right thing, even if both share the same goal of energy efficiency or comfort optimisation.

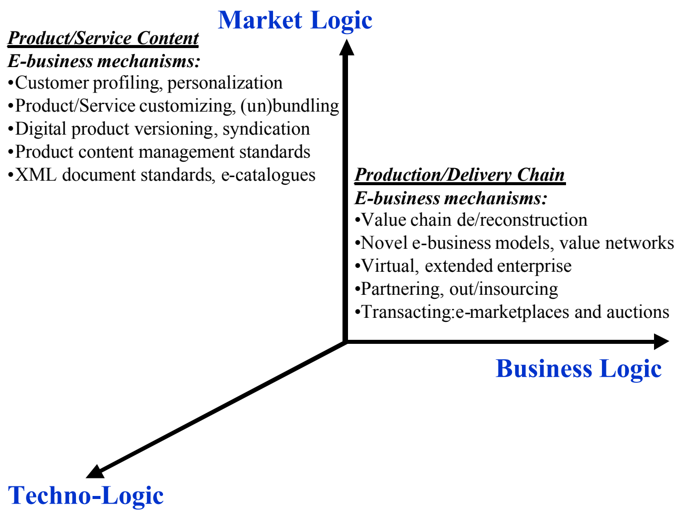


Figure 5-7. *Three different value logics at play in e-applications [Akkermans, 2001].*

Market logics refer to the demand side. Business logics refer to the supply side. Due to the developments of the World WideWeb, the same (digital) product or service can be created by wholly different value constellations. The degrees of freedom in designing business models have therefore significantly increased. An example of this is depicted in *Figure 5-8*. as developed for TrønderEnergi AS, Norway. The model is based on the *$e^3$-value* business modelling methodology of the Free University Amsterdam, and developed for this case by SINTEF Energy Research, Trondheim, Norway, in the EU-IST project OBELIX. It shows a highly networked business model [Gordijn and Akkermans, 2001; Gordijn, 2002, Gordijn and Akkermans, 2003] relating to the offering of a whole bundle of utility-offered services (as considered in the OBELIX EU project; the BUSMOD project is investigating similar networked business models for distributed power generation and DER). Clearly, many actors play a role, last but not least the customer, and establishing the business case for all actors is thus an important but non-trivial exercise. For example, it requires a thorough sensitivity analysis with respect to changes in important financial parameters in the business model. Such considerations similarly apply in the discussed smart building services, because many actors come into play also there and there is quite some freedom in designing the value constellation.

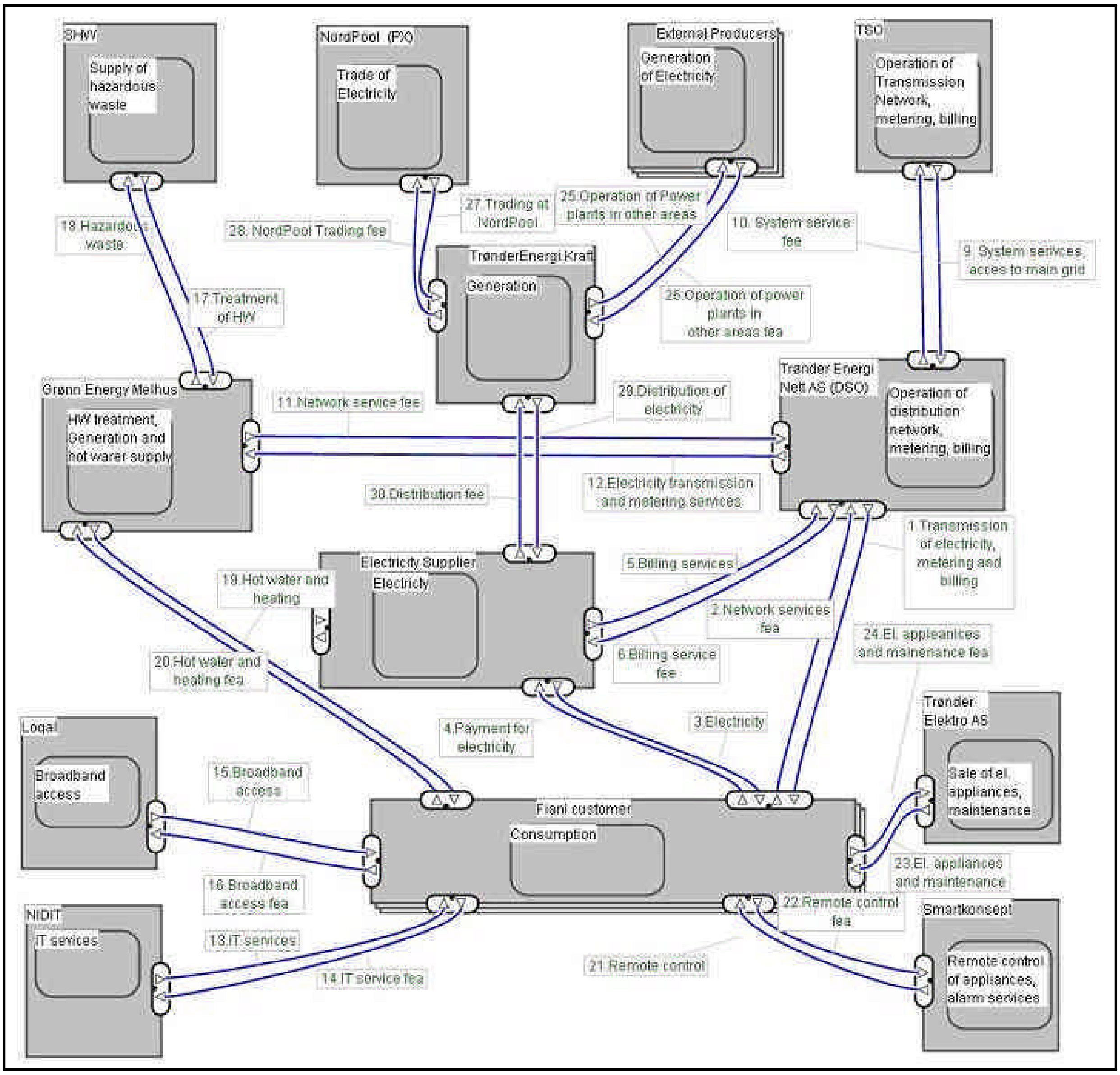


Figure 5-8. *Networked business model for new service bundles in energy.*

Generally, distributed intelligence must ultimately enable the creation of *value webs*. Hence, there is a clear need to develop scientifically grounded business analysis tools that help in understanding and designing the intertwined business-technology aspects of the next wave of intelligent information processing applications.

## 5.4 Concluding

We are on the eve of a new era of intelligent information processing as a truly promising development centred on the Internet, the (Semantic) Web, and corresponding distributed Information System applications. In order to realize its full potential, however, we have to take it for what it is: a great innovation. This implies, not confined to the CRISP-project, that we simultaneously have to address the technological, social, and business considerations that play a role in innovations and their adoption by the society at large.

# 6. Novel ICTs

## 6.1 The always-on broadband revolution

Through the cable Internet and ADSL a broadband, always-on infrastructure is on the eve of massive rollout in the European countries. Narrow-band control gateways, as they are needed to exert energy management functionality, may benefit from this development. Internet coupling aids in making these network connections transparent. This means, that computational processes, data and resources may be installed anywhere in a IP-based network. Local computing power may be defined as a low-cost thin-client, with a small footprint and server. Software models supporting this architecture are currently ubiquitous. Apart from transmitting information using secondary infrastructures, possibilities exist to use the power distribution network for narrow-band and broadband access. Narrow-band access using PLC (Power Line Communication) have been used for decades now to transmit limited amounts of data to parts of the power grid. Broadband access schemes through PLC are coming up at the moment [Olsson, 2001, Pavlidou, 2003].

In OSGi (the Open Services Gateway Initiative (www.osgi.org ) a complete service and application model is defined that can be implemented via a gateway with small computational resources. OSGi is completely targeted at providing a framework for connecting home network connected devices to application service providers. OSGi consists of an abstract specification of a number of Java-classes, which enable large scale deployment of bundles of service applications. It is possible to implement OSGi on a relatively small embedded operating systeem with a Java virtual machine. OSGi facilitates hot-pluggable devices and dynamic device configuration. New versions of applications are installable, without restarting the gateway.

In order to achieve maximum flexibility the OSGi model is defined completely in Java. By using the Java dynamic class loading mechanism service applications are easily downloadable and upgradeable. Data-transport from and to Internet-browsers is programmed in OSGi via Java-servlets. The mechanism of handling of tasks within OSGi resembles that of a classical real-time, embedded operating system. OSGi stresses robustness and security, large-scale deployment in service applications and no-break/always-on availability.

OSGi currently is attracting interest for remote monitoring of cars using mobile communication (GPRS) and multimedia applications in homes.

Recently, with the specification of IEEE standaard 802.15.4 [IEEE, 2002] the first step has been set to achieve low-cost connectivity of appliances at the level of end-user environments (homes, cars etc.) for control purposes. Compared to previous standards (e.g. Bluetooth) additional attention is paid to reduce the cost of communication nodes in the network and of maintenance cost (batteries). In a number of EU-research projects [Eyes, 2002] self-associating and configuring sensor networks are being developed. Energy-supply of these pico-processors during their product-cycle is covered by one battery [Eyes, 2002]. An important research item currently is defining protocols for dynamic configuration of a network of these pico-processors. On might think of dynamic reconfiguration if appliances are added or removed from the network context. Mobility is a major discriminating factor in these pico-processor networks within these static or dynamic device-configuration environments.

In consumer electronics small (wireless) communication interfaces in appliances are attracting a large interest at the moment. Important standards for these interfaces are Bluetooth, IEEE 802.11.15 [IEEE, 2002], when looking at wireless communication and for instance HomePlug for wired communication. The HomePlug alliance (http://www.homeplug.org/) explicitly uses in-building powerline communication for interconnectivity. The LONWorks-standard from Echelon uses a proprietary protocol and processorarchitecture to interconnect appliances. For a breakthrough of these techniques, industry currently is searching for small modules with a price tag of less then 3 $.

## 6.2 Architectural infrastructure schemes

### 6.2.1 Key problems in ICT-enabled near-energy services

There is a general agreement that an infrastructure serving the deployment of a control and management service for power would benefit from combination with other energy-near control services like surveillance and burglary alarm systems [Kamphuis, 2001]. The problem in most of these services, however, is, that existing service applications use their own infrastructures and that intelligence in the control networks is on the client-side. A rough architectural view of possible infrastructure schemes is shown in Figure 6-1. In the architectural scheme, the third dimension is used to indicate the required computing resources and complexity of the components is shown. Energy metering applications have very limited requirements for local intelligence non-volatile memory for a measurement history being the most important issue; ensuring the collection of correct data is the most important factor. For energy management applications, the local home network with the intelligent appliances has to be involved in controlling the variable demand. A key role now is for the intelligent gateway. In the case of fat clients, with a large memory footprint and demand for processor resources, to allow for identification and detection of persons and their movements, a fat-client/thin-server architecture is most appropriate. An example of this last category is the Unattended Autonomous Surveillance system, that has recently been developed by the Dutch organisation TNO.

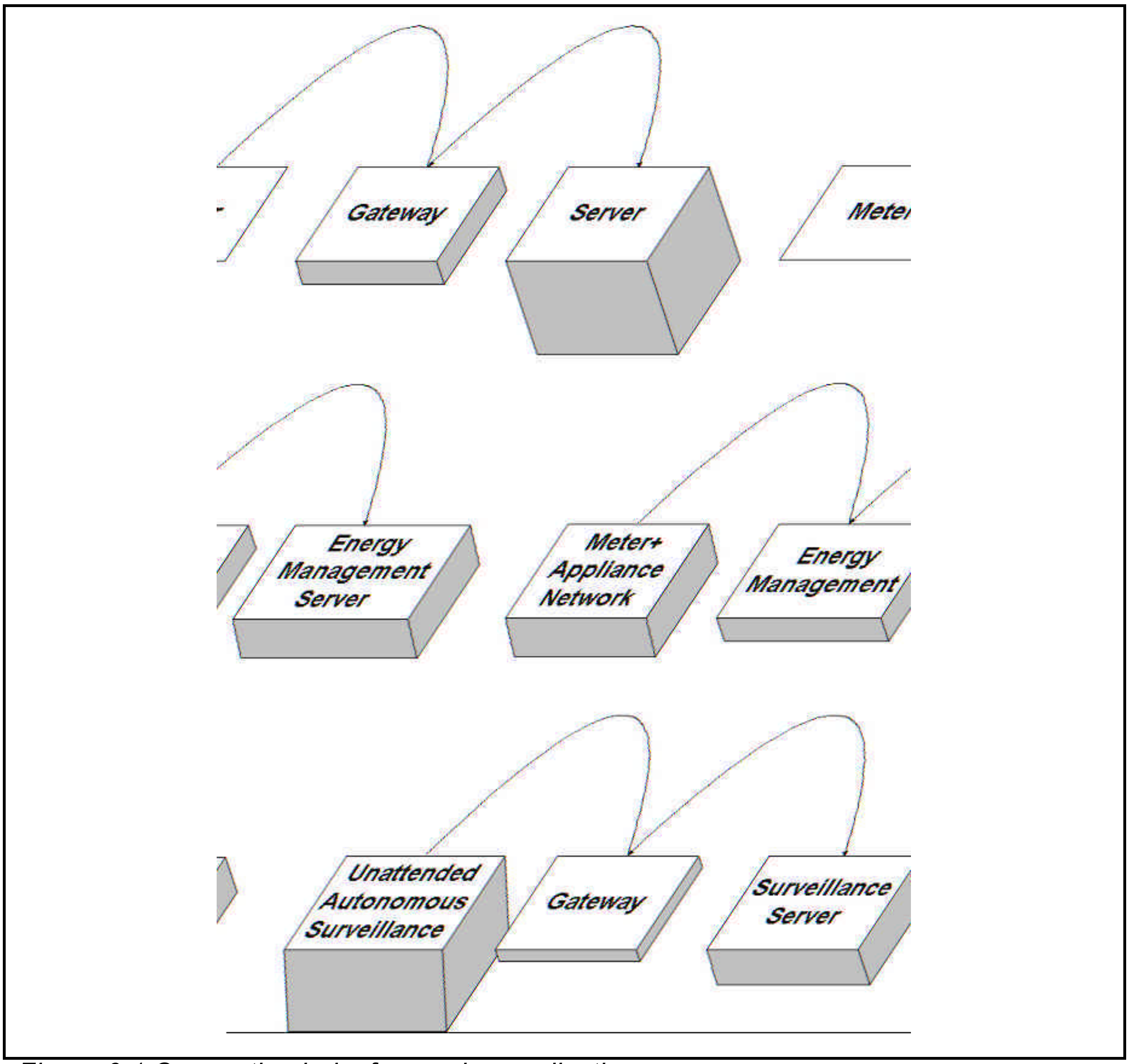


*Figure 6-1 Connection hubs for service applications*

### 6.2.2 ICT-transparency

Due to the fact, that communication technologies (wireless, cable, PLC, phone) permit the exchange of information from any place at any time; mapping these information flows onto the way markets act in an innovative setting, opens new possibilities for control and monitoring. In hierarchical grids, the operational end-nodes of the network typically are the MV-cells (Middle Voltage-distribution units; sub-stations). The possibilities of ICT currently are not used extensively at the moment. Utilizing the interconnectivity and optimal usage of processing power in the power network currently is not common because of a number of problems.

The first problem is the intrusion aspect. The problem has been enhanced since 9/11. At the moment, national authorities are increasingly worried about interconnecting parts of the power infrastructure referring to Cyber network terrorism. The hassle with these "problems" closely mimics the "Year2000"-hype concerning a large number of power companies.

The electrical safety is another aspect, which needs attention. The ICT-infrastructure itself consumes power; so after a power break itself in one of the nodes of the network, it should keep the rest of the network intact.
The third aspect has to do with maintaining the software controlling the power network; as the network complexity increases, repair of software and hardware errors will have less predictable consequences in different situations.
A fourth problem with digital, intelligent replacements of analogous counterparts (e.g. switches) has to do with increasing maintenance complexity for service technicians. Configuration possibilities for these new elements in the power control system are greatly enlarged, but how to configure and what parameters to set from one implementation to another might be difficult.
Therefore using ICT strongly urges a (physical) split of networks and functionalities between those parts controlling the primary process (delivering uninterrupted, high-quality power) and those that support other functions [Warmer,2003].

Once this split has been made, the transparency offered with modern software technology and models can be used and computational tasks and message exchanges between nodes in the network can be performed reliably and with enough fallback possibilities in case of failures.

## 6.3 Views on a communication infrastructure

An ICT-infrastructure is characterised by transparency for processes and data. A modern common software engineering design objective is to hide implementation details in solving a problem. On the other hand a power delivery infrastructure is an always-on, hard-wired critical infrastructure. A market information infrastructure should be **loosely** coupled to the PS(Power System)-node network. This means, that the second infrastructure may not depend on the first one. A services infrastructure, again, is **loosely** coupled to the market information infrastructure.
A synergy between the infrastructures can be developed if we look at the role of both infrastructures in a number of views. The power control and delivery view is completely mapped to the grid and operates with a virtually zero time-horizon. ICT, in this view, should be applied with simple but very reliable hardware and software. SDM operates using simple binary (on/off) or smooth (analogous) control of devices being part of the network. The market view should be imagined as being part of the Internet as transparent ICT-infrastructure. The market operates on basis from several days ahead to a quarter of an hour ahead. The user view corresponds to the power consumer or owner of a power production unit. The user view has a week/month ahead time range.

This leads to the following requirements for the software and hardware of the information and communication infrastructure.

1. An always-on communication connection has to be present, that enables simultaneous data collection from every node to every other node in the network (peer-to-peer). Polling and interrupt latencies must not exceed the timeframe of seconds. NOTE: This requirement is less strict than the requirement for the protection-fault or load-shedding ICT-networks.
2. A standard operating platform containing primitives for distributed interprocess-communication should be present on each node.
3. Each individual node should have enough processing capacity to execute (a part of) the distributed control algorithm.

4. The software on each node should be implemented using common interprocess communication standards and portable programming languages.
5. The network must be hot-pluggable. This means, that components should be able to be inserted in the network without shutting down the remaining parts.
6. The nodes should be hot-configurable. Configuration of the nodes should be possible without interference to current operational tasks. Configuration data for instance may include changing underlying databases.
7. The network topology should be hot-reconfigurable. This means, that network connectivity schemes should be dynamically changeable over time. According to changes in contracts it should be possible to invoke changes in the cluster configuration and size of producers or consumers.
8. Flexible, layered fall-back sequences should be defined in case of hardware failure of components in the network. Remaining parts of the network should not be functionally impaired. Nodes should re-enter the network without interference to other nodes.
9. Individual nodes should be able to run apart from the rest of the network without interference to the higher priority protection-fault and load-shedding networks. Other parts of the network should find a "healing" strategy to let the remainder of the network function with maximum intact functionality.

Further requirements regarding transparency can be found in 6.2.2.

## 6.4 Power markets and agents

The agent paradigm is used in the power industry in two different ways. Firstly, they are used as entities, which operate bottom up in conjunction with similar software entities to handle the control complexity of operating the powergrid especially in critical situations. The modelling framework of autonomous agents with "knowledge" as defined in a limited number of operation rules, can be shown to be superior to hierarchical top-down models. The first reason for this is the maintenance aspect. Large top-down hierarchical networks can be shown to be difficult to maintain. Imagine in this respect, that configuration and data-tables of a network of several thousands of generators have to be maintained in a top-down manner. The second advantage has to do with easier hot-pluggability and authentication of agent-like actors in power networks. A flexible set of discovery protocols has been developed to adress this issue. Secondly, they are used as a modelling framework for distributed computation. In this respect, the design of the algorithm is such, that parallel execution of "agent-algorithms" on a large number of small embedded computer nodes in a computation network is possible.

The price formation mechanism as depicted in section 2.5 triggered a discussion as to how elements of new theories in the operation of (micro-)economies and the paradigm of autonomously operating software entities, agents, with their own responsibilities would be suitable to be used in scheduling power generation and consumption devices [Ygge, 1998]. In these models, the market has to be seen differently as compared to the traditional power market. By a negotiation scheme, micro-economic theory using the agent paradigm leads to a market price having a limited scope in time and number systems covered. Using an adaptation of the model, scheduling of loads can be also be optimised given a certain pricing scheme. Handling both, price formation in distributed markets and time-scheduling of loads and generated power, poses a problem unsolved as yet. In Annex 1 of deliverable d1.5 [Carlsson,2003] an extensive overview is given of these price-reactive electronic power markets.

In the USA at EPRI [EPRI-Agents,1999] preliminary tests were performed with a different emphasis as compared to the Ygge-work. In this work real software processes with agents were modelled and their buying-selling behaviour was studied in a dedicated AgentBuilder simulation environment. This work has been followed up in recent years, but has not led to practical applications yet.

# 7. Novel approaches for high-DG RES grids

In the previous chapters an overview was given of current liberalised markets, demand side management, supply side management and of the role new hardware and software developments. In this chapter we establish a framework using previous derived concepts to make a categorisation of concurrent supply and demand matching systems using novel ICTs. First the SDM-cluster is defined, then, four variants of supply demand matching systems are discussed. A mapping of these variants on the three test cases, conducted in the CRISP-project, is described. As noted before, current legislation, market structures and actors to be used in business models do not really favour massive introduction of small scale dispersed DG in a RES-context. To assess the four scenarios it has to be taken into consideration, that new market design concepts, new legislation and innovative business models are essential pre-requisites for successful implementation of these sample cases. These prerequisites are subject of a number of other EU DG-RES cluster projects.

## 7.1 SDM cluster concept

A high DG-RES power infrastructure has to be discriminated from current power infrastructures by an increased granularity on the supply-side. Units for generating power in a distributed setting typically are small to medium sized and have a less predictable power production pattern. This fact has to be compensated for by certain elasticity ("articulation") in the demand pattern. The basic question of **SDM**, Supply and Demand Matching, is illustrated in Figure 7-1. The optimisation is focused on finding an optimal solution for the optimisation problem below:

$$\boldsymbol{\Sigma \mid S(t_a, t_n, t_m, p(t)) - D(t_a, t_p, t_q, \Delta t(t)) \mid} \text{ for } \boldsymbol{t_a} \text{ a range of times ahead}$$

**S** here represents the supply; $\mathbf{t_a}$ defines the time ahead, $\mathbf{t_n}$ and $\mathbf{t_m}$ define the time-span for supply of electricity of and **p(t)** the probability of delivery between the two limits. The probability accounts for the fact, that especially DG-RES resources may have a time-dependent probability of delivery; it is not taken into account for price manipulation purposes. **D** defines the demand at a given time ahead, $\mathbf{t_p}$ and $\mathbf{t_q}$ determine the time limits between which the electricity may be consumed and **Δt(t)** the shifting potential of the demand at that time **t** between the limits**.** The time ahead over which $\mathbf{t_a}$ is calculated typically is in the order of 24 hours up to 15 minutes. The optimisation is over the cost minus the utility for a certain (primary) operational purpose.

Basically a traditional grid can be depicted by a single SDM-actor with no demand articulation and with an uncertainty for delivery approaching zero for t=0. SDM in a distributed setting has a time dimension, a "market" dimension and a physical, "real world connectivity" dimension. The optimisation context, what the SDM-agents see in their context, may vary with time. In a power distribution grid the SDM-agents optimise which demand can best be satisfied by which supply and at what time. Additionally, SDM-agents are involved in aggregating supply and demand to construct optimal market prices. Using the SDM-agent concept a more direct bottom-up mapping of the real world power generation and attributes of generators and consumers is possible.

The objective of SDM is to be an intermediary software system to manage time-varying uncertainty for delivery of power with possible shiftable demands. Import/export of residual supply and demand may be defined by connecting one SDM-node into another. The distinction with DSM, already well known in the power industry, is the inclusion of an **active** supply side, the larger **granularity** (smaller units involved) and the different **timescale**s, in which SDM operates. To stress the importance of including the supply-side and to discriminate with "traditional" DSM, the term SDM is coined in this document. When performing SDM, as much information from all 'S'- and 'D-'-nodes as possible has to be available to the SDM-agent population. Due to the hyperfine granularity, traditional SCADA (Supervisory Control And Data Acquisition) is difficult to use and expensive to apply SDM. SDM, thus, requires an inexpensive, ubiquitous ICT-infrastructure with some intelligence on each node. On each node an electronic power market actor [Ygge, 1998] may be thought. Nodes are built-up in bottom-up clusters.

SDM-clusters have to be imagined as being constrained physically and regionally. One of the physical constraints is, that in current hierarchical distribution networks transferring power to higher voltage levels requires extensive redesign of protective equipment. Optimal clusters will be those, which have a sufficient spread in planning ahead periods for production and consumption, and with the possibility of achieving a small difference between demand and supply, when actual delivery has to be done.

Due to its transparency, the SDM-cluster concept is shown to map onto existing grids as well. On the scale of large customers, the concept will be proved in one of the experiments of the CRISP project. Apart from real-time supply and demand matching, the cluster concept may also be usable on the ancillary and balancing market.

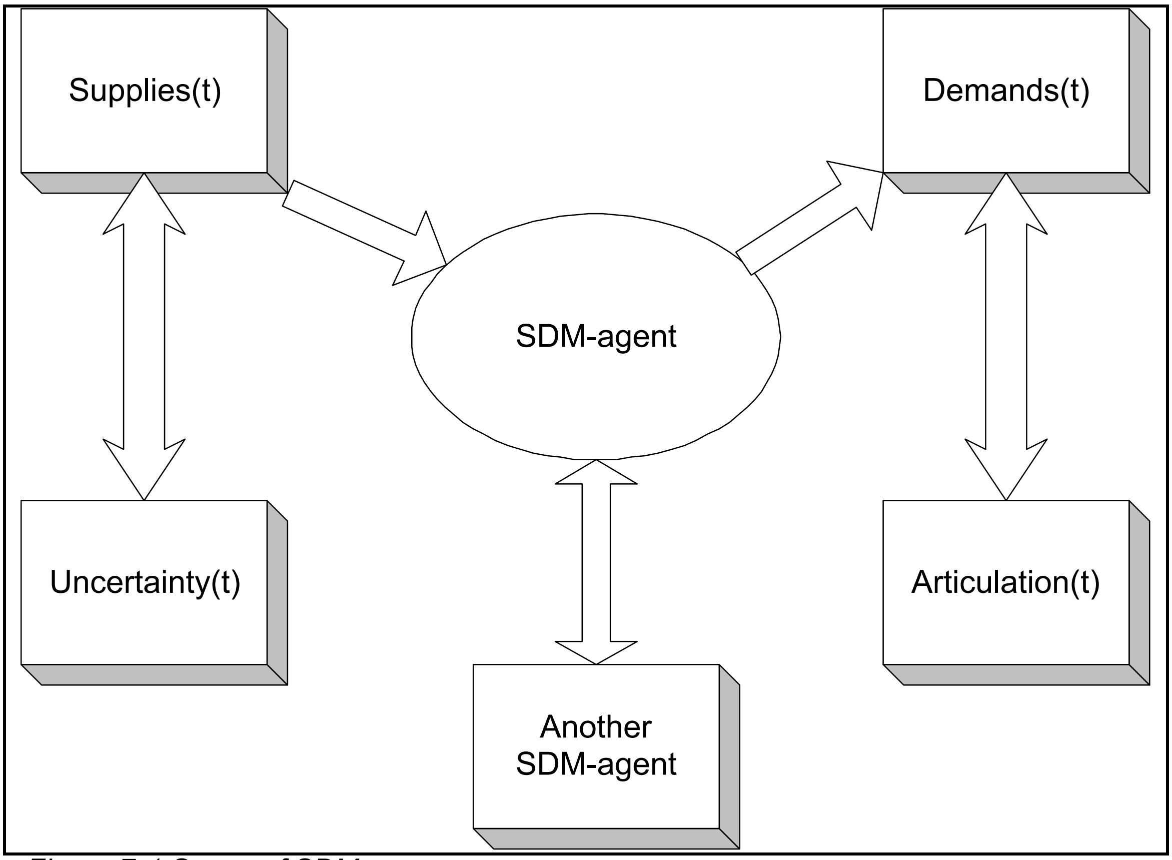


*Figure 7-1 Scope of SDM*

It is possible to envision the SDM-cluster concept at four different levels in the distribution and delivery of power [Figure 7-1]. In the figure demands are shown by circles, supplies by rectangles and the various types of SDM-clusters by rounded rectangles. The arrows indicate information flows. If dashed they probably will use a public data communication infrastructure to exchange information. In current grid situations, the central control is the major actor controlling which supply is used to serve a real-time demand.

In operating a network of SDM-clusters, the level of hierarchy and the level of transparency of the power network and the ICT-network are the important dimensions. In the simulation case four situations are defined, which represent each quadrant of the two-dimensional plane as shown in figure Figure 7-3.

The most elementary SDM-cluster is a multi-"**E-Box**", which operates within a limited scope environment. Internally, an E-box is concerned with managing local supply and demand in terms of a time-dependent tariff. An multi-E-box receives limited price-signals; price signals may be envisioned as multi-tariff signals to intelligent meters as compared to current low and high tariff signals.

A **net-coupled** control SDM-cluster is the DG-variant of a large central control cluster, used on a nation or region-wide basis at the moment. In a topology sense, the operation of the SDM-cluster is coupled to the physical distribution grid. Operation of this type of SDM-cluster, due to its size has an effect on market prices. This means, that the control strategy is driven by the behaviour of other similar SDM-clusters. Power grid requirements, of course, constrain this mechanism and optimal use of the infrastructure can be made by using the power lines for PLC-communication.

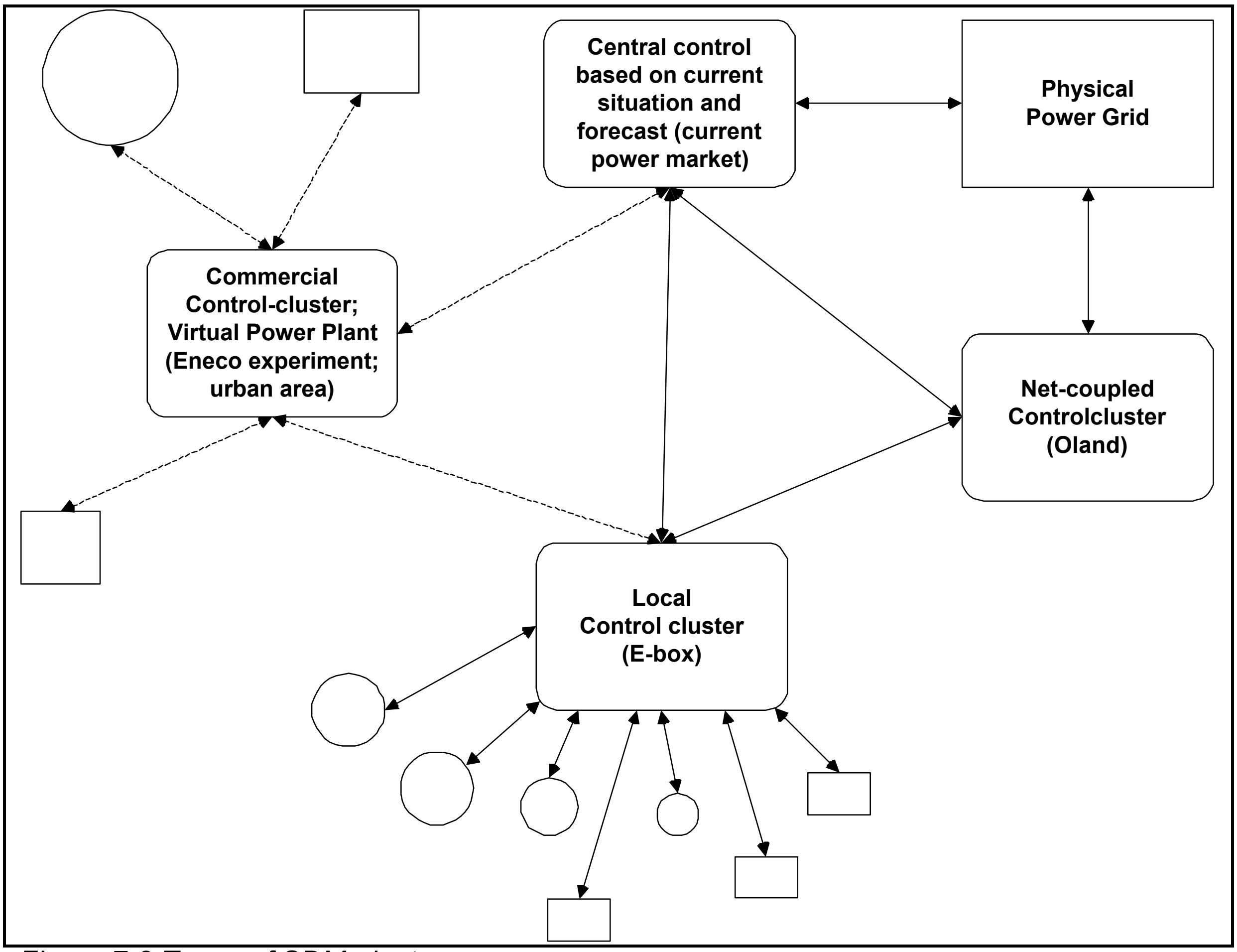


*Figure 7-2 Types of SDM-clusters*

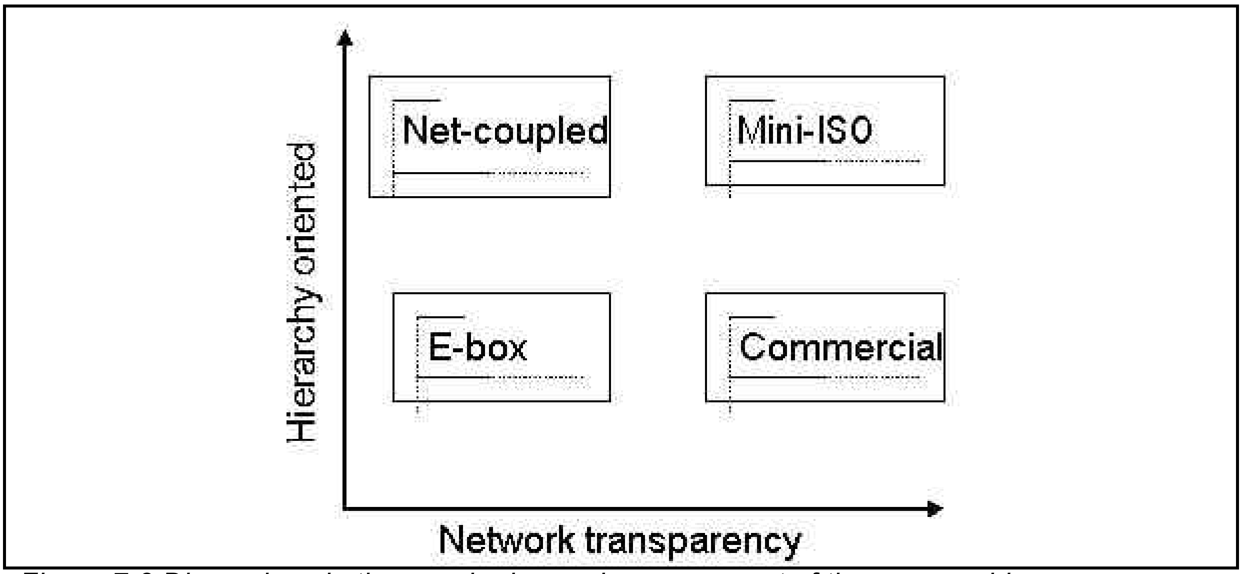


*Figure 7-3 Dimensions in the supply-demand management of the power grid*

A "**commercial**" control cluster can be compared to an extension of a virtual power plant [P1547,2003]. A commercial control cluster may react on price variations on the market, but also may be involved in price formation itself. Currently, in the USA, spare diesel power aggregates in buildings are combined to fulfil such functionality in periods of sparse electricity. The Eneco-experiment-A set-up most closely mimics this configuration.

A **"traditional-TSO"** cluster is a collection of mini-TSO operated smaller grid operating units. This variant closely resembles the current grid hierarchical approach; now however, the scope of demand and supply matching is variable. In this simulation scenario, it will be looked at, what the optimal operational strategy of a "mini-TSO" in a distributed setting will be.

In the next version of this document, the four above-mentioned types will be discussed in more detail. In this chapter only one of these four types of SDM-clusters is discussed. The E-Box, is discussed in greater detail to further illustrate the SDM-concept. The other concepts are discussed in subsequent chapters.

## 7.2 The E-Box concept

Being a part of the multi-EBox SDM-cluster, a more detailed view on an E-box for domestic applications is given in Figure 7-4. An E-box may be envisioned as an extension to an existing (intelligent) meter.

Arrows in the figure represent information flows. An E-box collects operational data of connected devices. These devices may have a *fixed* or a *shiftable* operation scheme (see Chapter 3.2). An example of the first, in a residential context, may be lighting, of the latter a fridge. An E-box also may have control on energy buffers and non-power using energy consumers like heating systems possibly connected to electricity production. An E-box further has an interface to users via a common Internet enabled technology [EBox, 2003]. As a reference to modelling the other variants of SDM-clusters an object model of an E-Box is shown in Figure 7-5.

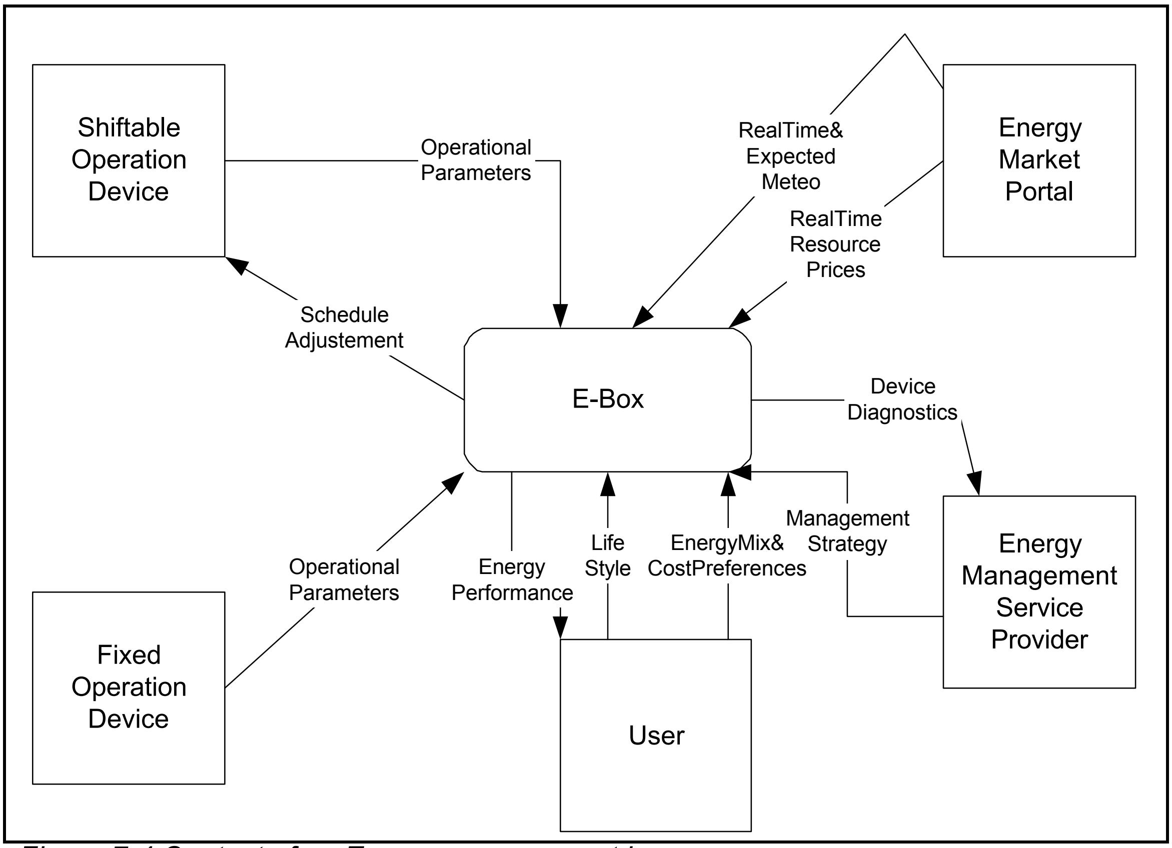


*Figure 7-4 Context of an Energy management box*

As an energy manager the E-box determines the optimal switching times of controllable devices with switchable demand or supply by calculation of all variants.

Preliminary results of an E-Box simulation study [EBox, 2003] using APX-pricing schemes as shown in section 2.1 indicate, that the largest profit can be gained from operating an electric boiler. As Table 7-1 with APX-prices of 21-08-2002 shows, the difference between the lowest and highest price scheme is several orders of magnitude.

An E-box is not only able to play a role in minimizing cost for a given demand, local small-scale production like micro-CHP and PV can be matched with local demand as well to minimize distribution cost. Concerted operation of cooling and PV and of co-generation and washing offer interesting possibilities in this respect. On a residential area level, there is an E-Box potential for combining heating in co-generating homes with operation of a heat pump in others. Buffering of electricity gives prime advantages in all time-differentiated tariff scenarios. In Table 7-2 the results of a number of simulations for concerted operation of appliances under price-scenarios as mentioned in 2.2.1 are given. Local generation can be seen to advantageous especially at peak price periods, when optimal usage is made of the elasticity of the demand.
As an illustration, the relative spread for an APX-January price path in all operation scenarios is given in Figure 7-6.

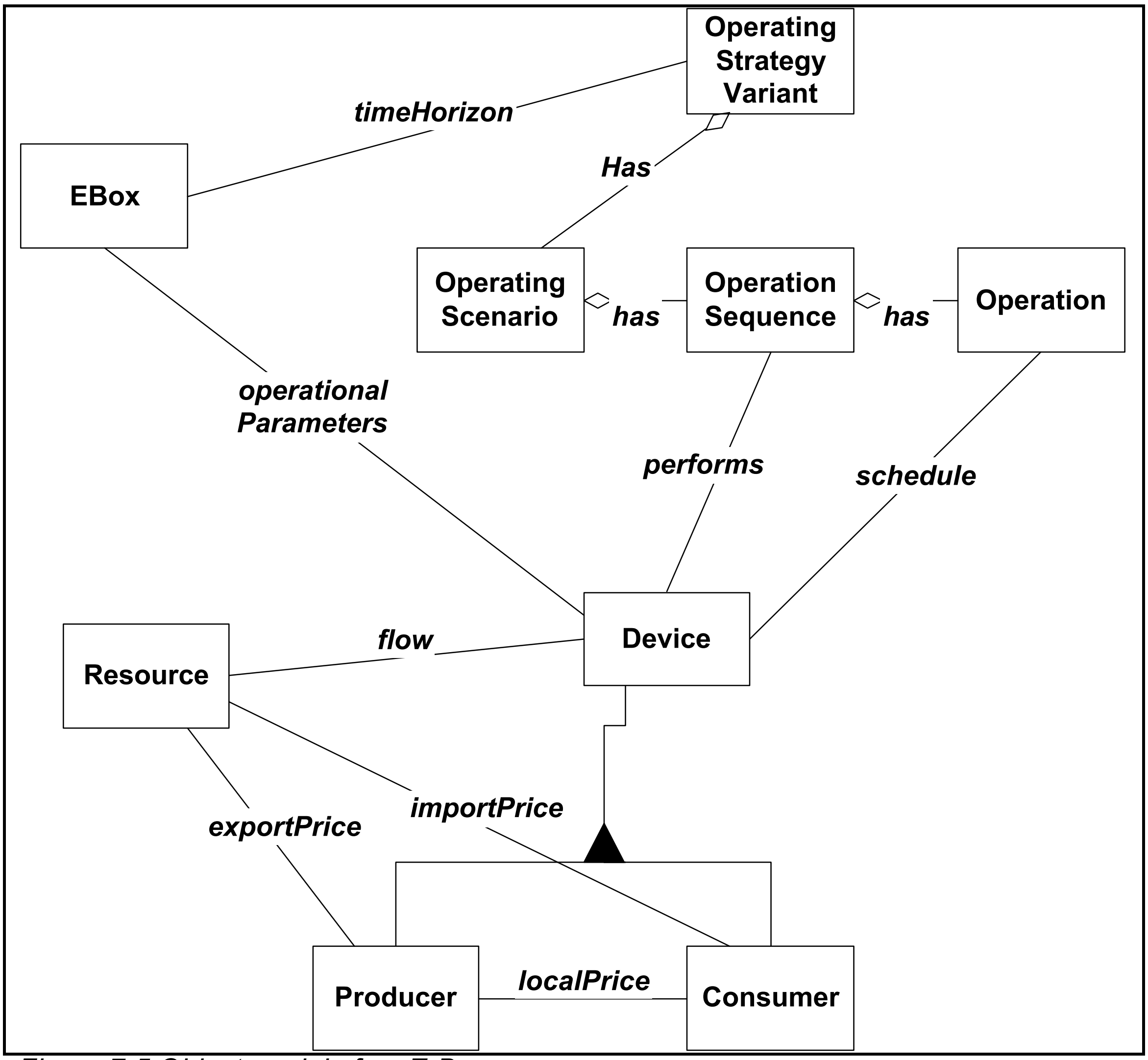


*Figure 7-5 Object model of an E-Box*

| Pricepath | Minimal | Average | Maximal | Sigma |
|---|---|---|---|---|
| APX January | 16.01 | 37.90 | 84.97 | 16.81 |
| APX0901 | 19.35 | 54.74 | 186.12 | 35.66 |
| APX2108 | 11.32 | 196.99 | 589.41 | 218.92 |
| APX August | 11.55 | 38.23 | 90.39 | 26.77 |
| Double Meter | 18.95 | 38.31 | 46.78 | 12.59 |
| One Meter | 37.50 | 37.50 | 37.50 | 0.00 |

*Table 7-1 Total price (€ct) of heating 100 litre water from 15 to 60 degr. C in different price scenarios*

| Devices | PricePath | Minimal | Average | Maximal | Sigma |
|---|---|---|---|---|---|
| CentralHeating (Gas) | Gas | 190.73 | 190.73 | 190.73 | 0.00 |
| Elec. Heatpump | Two-zone meter | 207.65 | 207.65 | 207.65 | 0.00 |
| Elec. Heatpump | One-zone meter | 188.17 | 188.17 | 188.17 | 0.00 |
| Elec. Heatpump | APX-January | 210.49 | 231.52 | 252.67 | 11.15 |
| Elec. Heatpump | APX-0901 | 290.39 | 373.05 | 461.20 | 54.97 |
| Refrig.+PV-Solar | Two-zone meter | -14.44 | -13.78 | -13.41 | 0.30 |
| Refrig.+PV-Solar | One-zone meter | -11.36 | -11.20 | -11.03 | 0.12 |
| Refrig.+PV-Solar | APX-August | -19.70 | -19.01 | -18.15 | 0.31 |
| Refrig.+PV-Solar | APX-2108 | -125.45 | -117.98 | -110.75 | 3.46 |
| µ-CHP | Two-zone meter | 158.10 | 158.10 | 158.10 | 0.00 |
| µ-CHP | One-zone meter | 160.94 | 160.94 | 160.94 | 0.00 |
| µ-CHP | APX_January | 150.73 | 154.08 | 157.41 | 1.76 |
| µ-CHP | APX-0901 | 119.35 | 133.30 | 146.39 | 8.70 |
| µ-WHP + Washing | Two-zone meter | 172.82 | 195.74 | 206.75 | 8.55 |
| µ-WHP + Washing | One-zone meter | 184.44 | 195.79 | 199.95 | 2.79 |
| µ-WHP + Washing | APX-January | 164.64 | 191.32 | 219.40 | 10.90 |
| µ-WHP + Washing | APX-0901 | 135.31 | 187.89 | 265.75 | 23.39 |
| Elec. Spaceheating | Two-zone meter | 519.13 | 519.13 | 519.13 | 0.00 |
| Elec. Spaceheating | One-zone meter | 470.43 | 470.43 | 470.43 | 0.00 |
| Elec. Spaceheating | APX-January | 526.24 | 581.16 | 638.25 | 32.62 |
| Elec. Spaceheating | APX-0901 | 725.98 | 938.95 | 1,173.46 | 166.58 |
| Elec. Spacecooling+PV | Two-zone meter | 38.06 | 38.40 | 38.68 | 0.20 |
| Elec. Spacecooling+PV | One-zone meter | 29.66 | 29.92 | 30.10 | 0.15 |
| Elec. Spacecooling+PV | APX-August | 54.90 | 55.55 | 56.34 | 0.41 |
| Elec. Spacecooling+PV | APX-2108 | 340.49 | 341.98 | 344.58 | 1.59 |

*Table 7-2 Simulation results of concerted operation of appliances in a home [EBox, 2003];prices in €-ct per day.*

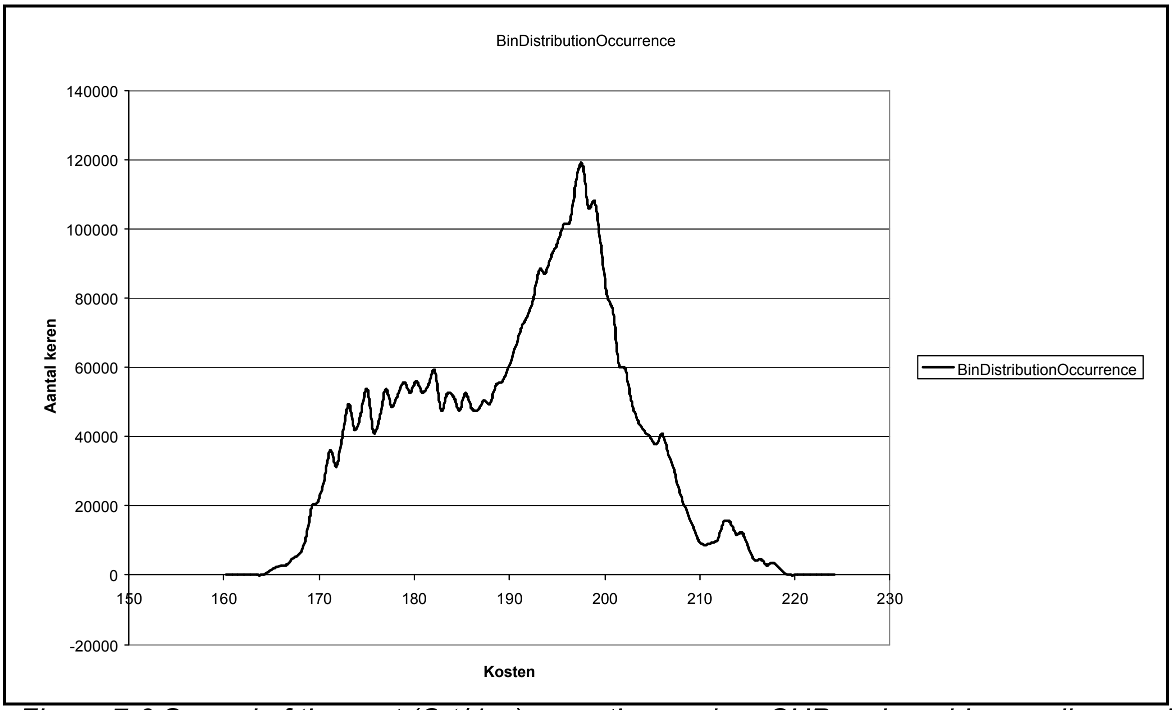


*Figure 7-6 Spread of the cost (€ct/day) operating a micro-CHP and washing appliance with APX-price control*

# 8. Mapping an SDM-cluster onto a LV-cell control cluster

This sample case has as its context a number of intelligent gateways at end-users premises on the scale of house. The optimisation target in this sample simulation case is cost and utility. The means of optimisation is shifting of supply and demand and optimising exploiting the potential of SDM and of buffer storage. As a Behind-The-Meter box an E-Box is defined. A multi-EBox configuration is connected to an LV-cell or a may constitute part of a Virtual Power Plant. Additional ICT drive comes from higher resolution metering, behind-the-meter WEB-service platforms and the expected further penetration of intelligent appliances. The utility-drive will be extension of the service portfolio. For customers the drive will be a cost-decrease and a drive to implement small scale renewables for electricity generation. The DG-RES-aspect is to embed a larger degree of RES in a cost-efficient way. With respect to rational use of energy adding intelligence for energy management will open possibilities for saving by giving increased feedback. The optimisation time will be from a day ahead up to 15 minutes before delivery. The control strategy scope will consist of 30 residential houses with several types of (co-)generation, buffering and PV. The mix of equipment is chosen in such a way, that mutual exchange of demand and supply of electricity is favoured during all seasons and that connection capacity in this context is well dimensioned; the capacity to export or import power is one of the constraining factors.

This SDM-cluster is lowest in the grid hierarchy. The concept is illustrated in Figure 8-1. On the lowest distribution level a number of E-Boxes operate in a concerted way in SDM.
A multi-E-Box configuration typically will be part of a higher power throughput low-voltage grid with more local power suppliers and a heavier demand on the local level. Shiftable demand and supply in time will be able to balance dynamically, while minimizing the import and export of power to higher voltage levels. The main rationale then is in investing more in the low voltage grid and less in the high voltage grid. Difference between these two variants is the difference in investment horizon.

Looking at national grid demand and supply curves it can be seen, that rather limited amounts of energy on the market may lead to very high price spiking. Furthermore the increase of the load factor of current grids currently leads to requirements for strengthening the grid. At the moment, retribution fees of renewable energy resources differ per type of RES and are different per country. The same holds for the transmission and distribution cost, which presently are determined very roughly per tariff zone, and for energy taxes and green labels and certificates. With an increasing level of DG and DG-RES, generation and consumption are expected to be measured at a much more fine-grained level; not only to settle power delivery and consumption but also to enable more flexible assignment of transmission and distribution charges and of type-specific and performance-based taxing for RES-resources. The last advantage of shortening distances between demand and supply is an increased stability of the total power grid, as control has a more limited scope than in large scale hierarchic networks; this aids in preventing large scale blackouts as occurred recently in a number of countries. The above factors stress the main objectives of the multi-EBox simulation case study.

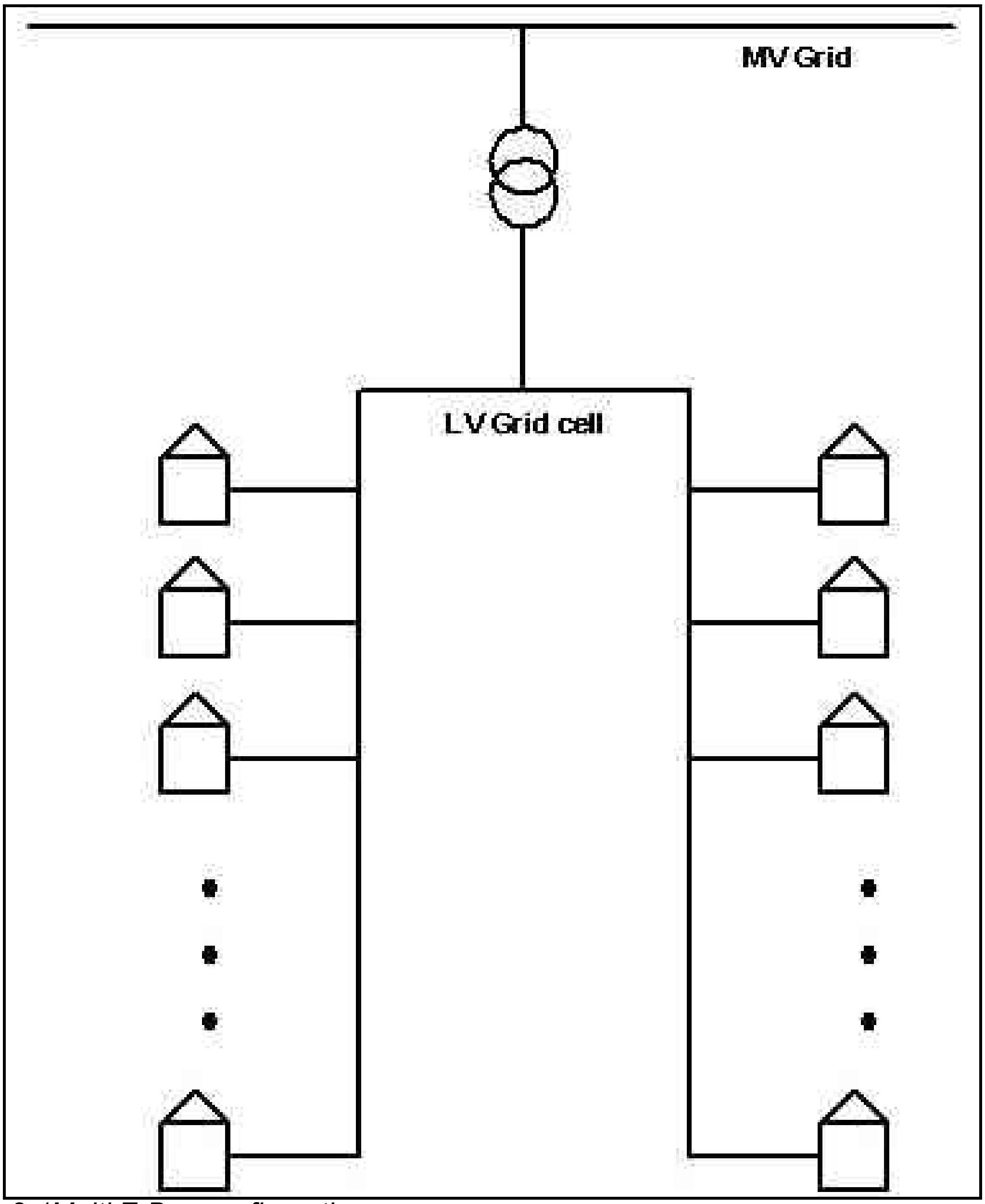


*Figure 8-1Multi E-Box configuration*

In the multi E-Box scenario the following objectives are to be met:

- Reduce imports and exports from higher transmission and distribution levels. The matching tool should optimally schedule operation of shiftable devices to allow for intermittent under- or overproduction of some RES-resources.
- Generate optimal benefit (cost and utility) for users at the local level and also on the community level by allowing flexible taxing and pricing of electricity.
- Enabling and empower large scale distributed intermittent RES by showing the added value of SDM.
- The time ahead range the distributed intelligence uses for optimal matching stretches from a few days ahead up to a quarter ahead.

Preconditions for the sample case are that existing power markets yield the time dependent retribution and buying power prices. Furthermore, on the planning level, the mix of the residential RES is chosen in such a way, that possibilities for year-round coverage of energy supply and demand is considerable.

Supply and Demand matching is performed in a local market setting. Exogenous to the multi EBox are time-dependent buy and sell prices. So, the tool may be used to represent a framework to acquire optimal components and dimensions for the small-scale RES-resources but may also be used for the design and operation of the real-time (up to 15 min ahead) control strategy during day-to-day operation of the grid. The results of the calculations lead to feasible import and export prices of power in next higher grid levels.

Typical control strategies, in which optimisation plays a role, are electrical tap-water storage, recharge of batteries of electric vehicles, residential laundry washing and drying processes, domestic heating and cooling combined with cogeneration or heat pumping and/or storage. An improved strategy for optimal embedding of intermittent DG-RES devices as Photo-Voltaic cells, PVT and small biomass turbines will be the result of the simulations, because the intermittent character of the supply by renewables is better compensated for by the shift on the demand side.

As compared to traditional multi-agent applications, for the tool to be developed for this sample case trading in multi-commodity markets, each commodity representing a bid in a certain time frame, will provide the major challenge. The cost and utility optimisation have to be done not only over one timeframe, but over a number of time-steps, typically a day.

# 9. Mapping an SDM-cluster onto an MV-Cell

The optimisation target here is the mitigation of capacity bottle necks and the reduction of investment cost. The means of optimisation is by supply planning and demand response. The ICT-drive comes from a refurbishment of distribution grids, metering at smaller time-intervals to optimise the grid and to account for smaller delivery volumes. The utility-drive thus has to do with postponement of infrastructure investments. The customer-drive will be obtaining a retribution fee and a fee for having the equipment available. Aspects favouring DG-RES include the implementation of badly predictable DG-RES more cost-effectively and with less transmission and distribution losses. Implementation involves an increase in the amount of energy usage information and in the frequency feedback rate. The time scope extends from a few days ahead to 15 minutes before delivery.

The control strategy scope is in the order the island based grid as on the isle of Öland, with large DG-RES production facilities on the North part and a larger consumer base on the mid part of the island. This scenario closely mimics the experimental set-up. The supply-demand matching process here enables shifting of load to avoid congestion in the MV-network.

The current situation on Öland is that the grid of the island is sufficiently strong to handle current demand, both from consumption side and local production. At least this holds as long as the connection to the mainland does not have to rely on the spare cable only, see deliverable D1.5. For a description of the Öland grid we refer to D1.5 too.

A new situation arises if and when planned offshore wind-power plants are connected to the 50 kV distribution grid of Northern Öland. Studies performed by Sydkraft within the project show that an increase of the installed capacity in the order of 20 – 30 MW could be handled without large investments, but a larger increase than this is plausible and hence there is a need for to investigate how to handle this.

From the viewpoint of the Öland situation, an interesting simulation scenario and optimisation objective is to look at possibilities to handle a large increase of installed capacity with the development of a local electronic power market. That is, to utilise interaction with consumer side dynamics to handle parts of the increase of installed production capacity. An objective of such a market partly mimics the objective of the optimisation within an LV-cell, i.e. to reduce the interaction with higher transmission and distribution levels in the grid. When we have *(i)* a local production with the characteristics of e.g. wind-based production, *(ii)* constraints on the capacity of the grid connections to higher levels, and *(iii)* a shiftable local consumer side demand that could interact with the local production, the matching constitutes an interesting problem. It might well be that a local electronic market could open for a higher increase of installed wind-based production than what would be acceptable without it, as the alternative is heavy investments in the grid.

From a precise demand and supply specification for a spring/summer day with a need to import power from the mainland, and an autumn/winter day with a possible surplus to export an optimal positioning of an SDM-aggregation level will be developed. Regarding supply – demand matching studies based on the Öland material, the suggestion is to focus on a comparison between methods based on today's technology for peak load reduction and a full electronic market setting.

The consumption pattern of Öland differs significantly from the main consumption pattern of Sweden due to its relative low industrial power consumption, low around the year population and high seasonal consumption due to the island being so popular as a recreational resort (spring and summer).

The plan is to perform a study based on

- a spring day scenario with high local consumption and low local production, and
- an autumn day scenario with low local consumption and high local production,

as this is the extremes in consumption patterns and local production patterns on Öland. The study will be based on yearly energy consumption as it is presented in the material underlying deliverable D 1.5 together with available material on load curves of different customer categories. When figures are not available and have to be estimated this will be clearly expressed in the reports.

# 10. Mapping an SDM-cluster in a commercial setting using a producer and consumer cluster

The optimisation target in this context is reduction of capital expenditures and cost. The cost saved pertain to obtaining extra generation capacity by having shiftable demand in day-ahead market peak-price periods and in the real-time reduction of imbalance. The imbalance in this respect is the deviation of the planned production and consumption at a certain time as compared to the realisations.
The means of optimisation is by medium scale supply and demand matching. The market embedding is power-system context free; i.e. operation is virtual with respect to the grid infrastructure and resembles a consumer alliance as sometimes found in Internet communities. The ICT-drive comes from concomitant higher resolution metering (TOU/Volume) schemes and the development of behind-the-meter service platforms. The Utility-drive (as a trading company) comes from an extension of services, reduction of APX-spike cost and of imbalance.
The customer-drive is having better compensation for the shift in time of delivery or uncertainty for production in the case of intermittent DG-RES and cost-decreases due to better contracts. In terms of DG-RES-aspects the mechanism should enable better embedding of medium-scale intermittent RES due to the fact, that the demand and supply side can be better mapped in terms of design of the market.
Rational use of energy is promoted by linking the commodity to the primary business process in an optimised, efficient way. In order to react pro-actively, the time scope stretches from 36 hours to 15 minutes ahead. Long time-ahead runs are done to include prediction data for intermittent data in the construction of the contracted programme for the next day. Later runs aim at tuning shiftable producers and consumers with the RES-realisation.
The Control strategy scope consists of a wind-turbine, cold stores, heating and cooling in co-generating office buildings and horticultural and residential co-generation.

This sample case closely mimics a virtual power plant setting, except for the fact, that we do not presume exactly the same market structure as it is defined at present in a number of EU countries and explicitly include the demand side. An SDM-cluster in a commercial setting optimally utilizes the transparency of the Internet. By combining the interests of a number of medium-scale power suppliers and power consumers concerted shifts in time-of-supply and time-of-demand allow increasing the benefits from the top-level, nation-wide power market. Distribution and tax-issues play a different role in this sample case. Parties participating in a VPP-SDM maximally utilize the uncertainty in their power prediction pattern on one hand with the shifting possibilities in their primary production processes on the other hand. Increased competitive advantages stem from the increasing volumes that can be brought to or withdrawn from the market.

In the Experiment-A, the Eneco case, an agent operating environment architecture will be the framework for the simulation case. In the experiment, one of the main purposes is to demonstrate the added value of information and communication technology, paralleling the power distribution grid, for information exchange and for processing of data in operating an electricity distribution network. The data needed may be roughly classified as market prices, meteorological information, period-ahead prices, expected loads and generation capacities as a function of time. These data may be the expected, real-time or historical values. Another primary aspect of the experiment is to show the advances of a bottom-up architecture of the distribution network as opposed to the current top-down control architecture of the distribution grid.

An interoperability interface will be defined to establish communication between the ENECO EBS-E system and the CRISP-experiment trial monitoring software. In the test the CRISP-infrastructure is in read-only, shadowing mode with respect to the EBS-E-system. Control signals are only emitted by the former system. Physically EBS-E and the CRISP-monitoringl software may share the same infrastructure; logically the infrastructures may be entirely different.

To analyse mutual data from the Eneco-experiment on one hand and the sample case om the other hand the following requirements have to be met:

1. A data-collection strategy has to be defined to monitor the behaviour of the network and the individual components during the test period. Variables to monitor are status reports, yields of generators and loads of consumers over time. Furthermore the dynamic responses of the system on external events have to be monitored.
2. A configuration management scheme for distributing and installing basic software components should be implemented. Basic software components include drivers, primary tools and software utilities.
3. Scenario's, specifying test sets in several normal and abnormal events should be specified.
4. A controlled testing environment should be established in which several versions of the algorithms are executed under well-defined circumstances before actually using them in operational circumstances. The involved scopes are module, integration, one-node and multi-node respectively.
5. One of the distributed nodes should function as a data collection, control and management node. Hierarchically however, this node should use the same primitives as those available to all other peer-nodes to query the network.
6. A "portal" software structure should be defined to get access to real-time external information. This portal should be available to the network from every node in the network.
7. To give access to external operational information a similar "portal" has to be defined to the distribution, protection and load shedding network infrastructure.

# 11. Mapping an SDM-cluster onto a number of mini-TSO's

The sample case for a mini-TSO is one level below a national TSO-level.

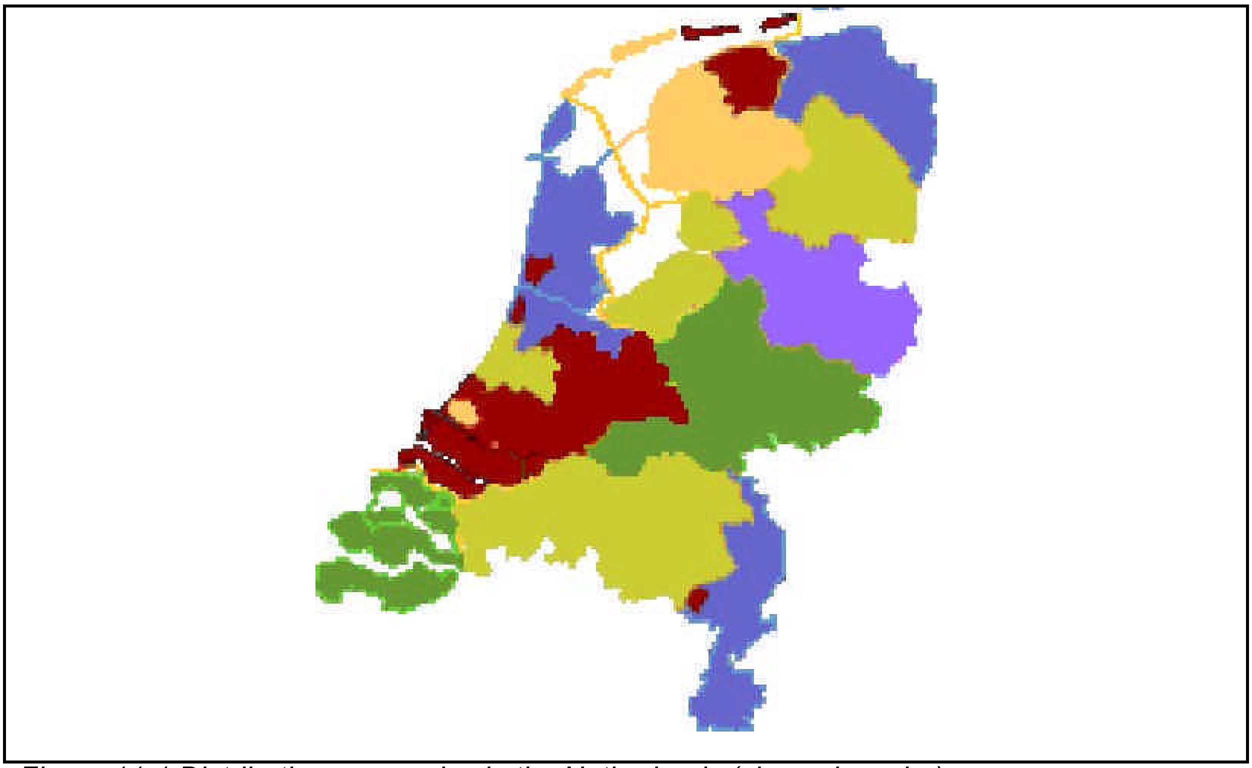

*Figure 11-1 Distribution companies in the Netherlands (shown by color)*

The optimisation target is improvement of net-stability/flexibility and the avoidance of bottlenecks at the level of a distribution company in a confined geographical area; furthermore large scale transmission capacity investment are less. The means of optimisation is reducing imbalance in this scope by providing distributed balancing services. In the BUSMOD-project [Elswijk, 2003, Kartseva,2003], a methodology has been developed, in which business models can be developed in a structured way, specifically looking at value interchanges at the micro-level, as now is already becoming a major trend in telecommunications. One of the deliverables specifically has as a test case a scenario paralleling the case simulated in this chapter from a operational Supply-Demand matching point-of-view [Elswijk, 2004].
Market embedding is within the national TSO operated grid. The ICT-drive is the renovation and automation of distribution grids and adding flexibility in supply and demand. The distribution company drive lies in avoiding APX- and balancing spikes. The deferral of investments for T&D capacity and delivering distributed balancing services to customers.
The customer-drive is extra income by payment per invocation and tariff compensation.
The DG-RES-aspects include better embedding of RES-supply following intermittent producers. Under-expected yield of medium scale intermittent resources can be compensated for as well. The control strategy scope is a distribution grid.

This SDM-cluster simulation has a strong resemblance to the existing hierarchical power net, but lays down the balancing level one hierarchical level lower than usual; the operating level of traditional distribution companies. Decreasing the balancing level in this way may defer investments in grid infrastructure and transmission and distribution facilities. Currently, investments in large power distribution infrastructures and transmission capacity are becoming more and more difficult for utility companies due to the NIMBY (Not In My BackYard), NOP (NotOnPlanetearth) and environmentalists movements. Investment payback periods for these facilities however pose problems in today's very volatile capital markets with short lead times. Having balancing power on a lower hierarchical level in the grid lingers these problems. Main target actor, that could operate a grid are distribution companies. In liberalised settings power distribution is not subject to market forces, but current tendencies to benchmarking these companies in order to rank their performance could include figures as investment level and local balancing power. In other EU-projects, like DISPOWER and SUSTELNET [Scheepers,2003], empowerment of distribution companies in this respect is a major issue. These types of companies, at this moment have no drive to balance locally and increase the use of renewable resources. Accommodation of larger amounts of DG-RES in current liberalised settings even in some case is hindered by deep connection charges; the complete transmission and distribution infrastructure are accounted for in the build-up of prices. Mechanisms empowering distributions companies in this respect include more fine-grained accounting procedures and giving the distribution companies proper stimuli for increased adoption of DG-RES. Mapping the advantages DG-RES not only from their green label point of view, but also from the inherent distribution advantages then would favour embedding yielding a better level playing field for these technologies.

On the DG-RES level, medium scale biomass installations in the form of gasturbines would be a possible resource.

Objective will be to determine the optimal cluster size to exert the same functionality as current TSO's have, that take-up the generation and demand profiles using an ICT-network and satisfy the needs of small-scale generators and consumers as well. A scope of an automated mini-TSO may resemble a residential area.

# 12. Conclusions

In this document market-oriented online supply-demand matching has been treated from a number of views. The impact introduction of more DG-RES into the electricity grid has been dealt especially looking at the different characteristics of electricity and energy suppliers and demanders. The role of ICT in these kinds of grids has been treated and the software and hardware architectural issues have been discussed and the role of modern agent technology has been discussed. Four sample cases are defined, which may yield results to judge the impact of these new tools and tune their application.
The liberalisation of the sector and the upcoming opportunities for stakeholders in the electricity commodity market, due to the introduction of new metering and energy management applications to add value for their customers, may be a critical success factor for successful embedding and control of DG-RES as well.
Modern ICT may allow more real-time pricing schemes and on-line settlement of contracts. In this way ICT may make the operation of energy suppliers and consumers aware of a wider operational context. On the other hand, the communication and computing make the actors in the energy scene more aware of energy use and also make strategies favouring renewables more cost-attractive. Four sample cases are defined, which may yield results to judge the impact of these new tools and tune their application.

Tailoring software agents operating in a limited context, 'market'-environment (to be discriminated from current nation-wide markets) using market-algorithms from micro-economic theory are the next step to further implementing the technique. This will be the purpose of work package 2.2.