PROJECT FINAL REPORT

“Smart Control of Demand for Consumption and Supply to enable balanced, energy-positive buildings and neighbourhoods”

(SmartCoDe)

Grant Agreement number: 247473

Funding Scheme: STREP (ICT-2009-6.3.b)

Period covered: from 2010-01-01 to 2012-12-31

Project website address: https://www.fp7-smartcode.eu/

Contents

1. Final publishable summary report

1.1 Executive Summary

Overview of Results

Demand Side Management and *Demand Integration Management* (DSM / DIM) approaches are currently only feasible in large industrial companies. A roll-out of DSM measures to the sector of consumer buildings, which are responsible for approximately one third of the overall energy consumption in industrialized countries, as well as DSM-enabling measures for Small and Medium Enterprises (SME) would be preferable, however, the setup is complex and costs are high.

The SmartCoDe project proofed, that a low-cost, low-power microelectronic component developed in the project could enable *Energy using and producing Products* (EupP) to become part of a locally managed energy resource cluster. In such a local cluster EupPs can constantly be monitored. With the help of the aforesaid component they can further react on the basis of energy grid requirements as well as on forecasts of local energy generation and consumption.

A roll-out analysis example of the SmartCoDe concept to only 10% of the 40,3 million households in Germany indicated an energy saving potential of 5,2 TWh per year and an additional potential of 1,6 TWh of regulating energy per year, i.e. energy that can either be used to balance the local energy consumption / production curve or that can be provided as a service to the grid operator for the purpose of grid stability. The latter, however, implies that a communication infrastructure will be established on lower grid levels.

Which one leads to the first of two identified major show-stopper: the current low level grid does not possess the required communication measures to connect the end customer to the grid infrastructure. Low-level grid scheduling in the past has been executed mainly on the basis of experienced consumption data pattern. The setup of a communication infrastructure for the lower grid level, however, would require a significant investment by the grid operators, Return on Invest (RoI) therefore is a key issue. Since there is no indication today how such a potential investment could be regained, the authors of this report suggest regulating measures by national and EU bodies.

The second show-stopper is the absence of standardisation when it comes to the integration of household equipment into DSM approaches. White goods provider all over the world are currently busy working on DSM-enabled household equipment, however, approaches are proprietary and there is almost no cooperation between manufacturers. A promising step in the right direction is the EC initiative *eeSemantics*, which focuses on the communication of smart appliances at information level in smart homes. The SmartCoDe project contributed to the initiative with its EupP classification.

Outlook

The required change from fossil to renewable energy generation is mainly approached with medium- to large-scale set-ups on the MW and GW level. Large scale approaches, however, require large investments, they are complex from a technical point of view (mainly the grid integration) and they often lack in public acceptance.

Small-scale concepts on the other hand do not need a large financial investment. Also the technical challenges could be reduced significantly. Small smart energy clusters could be rolled out one-by-one, they could even be financed by cooperatives of citizen, keeping the creation of value local. When more and more of these clusters become available, the effect on the overall grid will continuously grow. The coordination of several clusters will even enhance the benefit and could be considered as the next step in the direction of Virtual Power Plants (VPP).

1.2 Project Context and Objectives

Although SmartCoDe is in principal a demand-side management project, it includes considerable technical and infrastructural aspects. Technically, SmartCoDe focuses on three main parts:

- **Hardware development** of the wireless sensor/actor nodes, to be implemented either as System on Chip (SoC) or System in Package (SiP) and to be integrated into Energy using Products to become *SmartCoDe-Enabled Devices*.
- **Wireless infrastructure** of the local consumers / producers
- **Energy management** using the wireless infrastructure

Regarding the hardware part, the goal for the wireless sensor/actor nodes is to be cheap (<3€), low-power, secure, and small in size (e.g. 1cm•2cm•2cm) in order to make the application attractive both economically and technically. The long term target for high volume is to integrate all the functionality into a single chip, namely a System in Package (SiP). A special challenge here is the integration of high voltage 230V mains power and low voltage analogue and digital electronics into a small package so that overall component count and cost can be reduced significantly.

For wireless networking, SmartCoDe builds on the ZigBee wireless standard and implements highest-grade information security to ensure robustness against malicious attacks and intrusion, starting with the commissioning process. Where necessary the ZigBee protocol is extended to support the required functionality, for example new energy management and security concepts. This functionality is summarized for the different classes of devices in the *SmartCoDe Profile*. It allows Energy using Products to participate in the local energy management of buildings.

Regarding energy management, the general concept of SmartCoDe considers a “local energy resource cluster” with:

- Local **renewable energy resources** like small-scale wind turbines and building-integrated PV. Via weather forecasts and other statistical means predictions of the renewable energy output can be forecasted and the information can be integrated into the energy management process.
- Local **energy storage** such as car batteries (plug-in hybrids, electric vehicles) which might also provide energy to the cluster if needed.
- **Energy using Products** (EuP) such as Heating, Ventilation and Air Conditioning (HVAC), electric lighting, consumer electronics, white goods, etc.

With the help of the hardware developed in the project the EuP’s power consumption can be monitored periodically. These SmartCode-Enabled Devices are further able to provide power consumption forecasts which are analysed together with the energy output from the local renewable sources. On the basis of energy available, consumption forecasts, and (optional) directives from the grid operator a local energy management unit derives directives for the EuPs which then can adapt their consumption to the requested requirements. Figure 1.2.1 shows an overview of the suggested wireless consumer / producer network (*SmartCoDe cluster*).

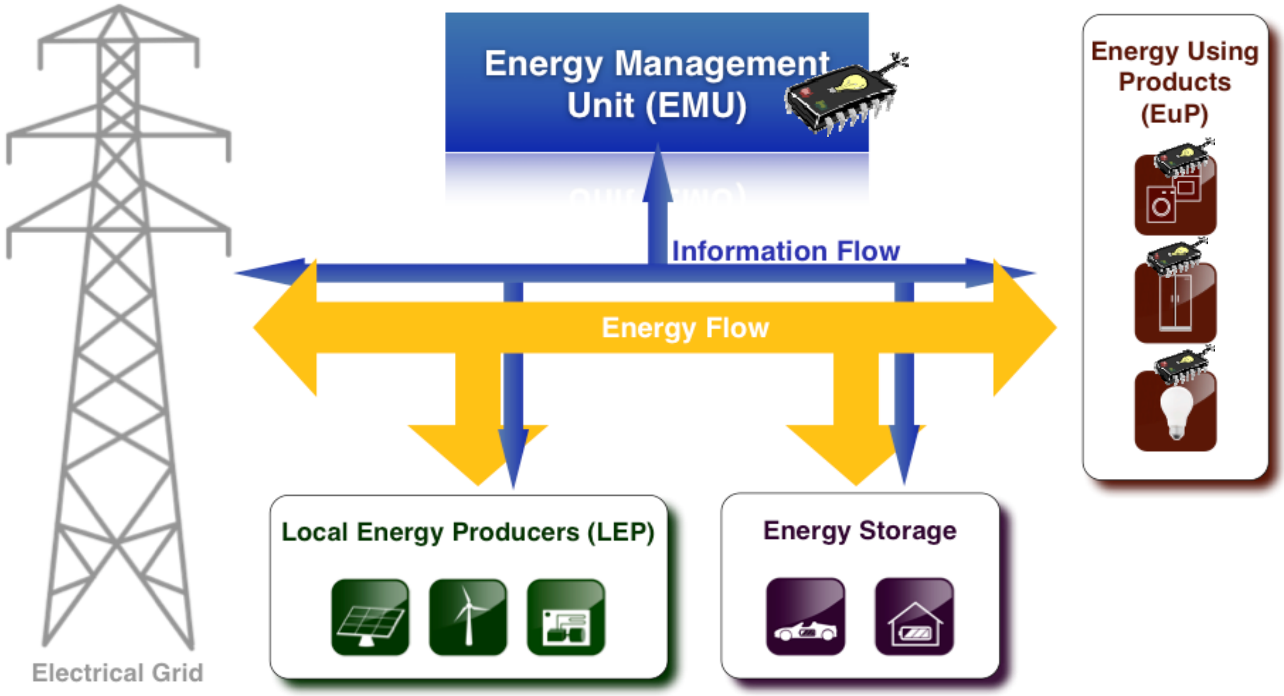

Figure: 1.2.1: SmartCoDe cluster overview

Some of the EuPs, namely those in the area of heating (heater, boiler) and cooling (fridge, air-conditioning) do also possess implicit storage capacities. These EuPs are so-called *virtual storages* since the energy is stored in a different energy form (e.g. thermal energy). It is used later as-is – it is not transferred back to electrical energy again.

Virtual storages play an important role in the SmartCoDe concept because they facilitate to optimise the time of energy usage (or storage). In times when there is a surplus of energy within the overall grid (i.e. "cheap energy") or when local energy generation supplies more power than required for immediate local use the virtual storages can be "filled". The effect is that the actual run-time of a virtual storage device can be shifted so that a device execution at non-optimal times in terms of energy availability is delayed.

As indicated in figure 1.2.1 the SmartCoDe cluster is controlled by a local Energy Management Unit. It gathers the available data and controls the components of the cluster via the wireless nodes which are integrated into the EuPs and local energy provider (LEP). Since the cluster can also sell energy to the grid, it is necessary to have a predictable consumption / production behaviour. A common business model today for large industrial consumers is that planned or expected load profiles are communicated to the grid operator. The consumers are then charged according to the precision with which the profiles can be met.

The SmartCoDe results now for the first time enable also smaller consumers to participate in the energy market, either by load profile data communication between grid operator and customer – provided that a bi-directional communication interface exists – or implicitly initiated via time-dependent energy tariffs that are passed unidirectional from the grid operator to the customer.

1.3 Scientific and Technological Results and Foreground

The following section is an introduction to the main SmartCoDe project achievements:

- **EuP Classification:** The project has initiated and provided a basic fundament for a common approach for EuP classification in the future.
- **Semi-Decentralized Energy Management:** Allowing fine-grained and low communication bandwidth energy management approaches.
- **SiP Integration:** Showing approaches and results to some key critical issues in future SiP integration such as the combination of high and low voltage, an integrated energy meter and ultra-low power main power supply concepts.
- **SmartCode ZigBee Profile:** Extending ZigBee functionality to support high grade security and commissioning methods as well as cost and load profiles combined with innovative energy management approaches.

The results provided in this document demonstrate the feasibility of an inexpensive and integrated microelectronic solution for EuP manufacturers to add energy management functionality to their products. They further show that energy management strategies work for small scale scenarios, i.e. relatively low individual device power consumption combined with short time frames.

1.3.1 SmartCoDe Energy Management

1.3.1.1 EuP Classification

An important development for the SmartCoDe energy management approach is the classification of EuPs in the household and office area. The idea here is to group appliances according to the nature of their service, their interfaces, and the leverage they offer regarding energy management. Figure 1.3.1 shows the classification overview.

Figure 1.3.1: Classification of EuPs

The class VSTSVC for example contains all appliances which can act as so called virtual storages; typical representatives of this class are freezers or heating. An important foundation for the SmartCoDe energy management approach is the **classification of EuPs** in the household / office area. The idea here is to group the appliances according to the nature of their service, their interfaces, and the leverage they offer regarding energy management. 1.3.1 shows an overview of the classification. For example, the class VSTSVC contains all appliances which can act as so called *virtual storages*; typical representatives of this class are freezers or heating. If energy is cheap or abundant, these appliances can cool down, resp. heat up more a bit more than necessary such that they can stay off longer during more “costly” times, while still maintaining an acceptable service.

Other important classes are SKDSVC, e.g. washing machines, whose service can be scheduled such that it runs during “cheap” times, or VARSVC, which is like VSTSVC without the virtual storage property, and for the purpose of SmartCoDe mostly covers the lighting applications. The more exotic class COMCON covers autonomous robotic services like robot hoovers, and CUSCON encompasses all services where the user interaction is so high that no automatic energy management would be tolerated (e.g. TV, HiFi).
Appliances can cool down or heat up more than required by the function of the respective appliance such that they can be switched-off longer during times when energy is expensive. The extension of the temperature ranges however have to follow strict rules because an acceptable customer service has to be maintained at all times.

Other important classes are SKDSVC, which includes for example washing machines whose service can be scheduled such that it runs during times when energy is cheap, or VARSVC which is comparable to VSTSVC although without the virtual storage property (for the purpose of SmartCoDe it mainly covers lighting applications).

The more exotic class COMCON covers autonomous robotic services like robot-hoovers. This class will probably only have mainstream influences in the years to come. The CUSCON class encompasses all services where the user interaction is so high that no automatic energy management would be tolerated (e.g. TV, HiFi).

The CHACON class provides functionality for local energy storages and becomes highly important when larger storages such as car batteries are included in the local grid. These shall be charged mainly at times where the grid stability is not compromised.

1.3.1.2 Semi-decentralised energy management of local appliances

For the communication between the EMU and the EuPs simple control signals (on/off) are not sufficient since the EMU needs a lot of information about the specifics of the EuPs and their current state of service to control the appliance properly. The required bandwidth for a centralized control of all available EuPs in a household or office can be significant since especially in offices the number of lighting appliances alone can be in the several thousands.

For this reason, a **semi-decentralised approach** has been developed in the SmartCoDe projects where the EMU issues abstract cost profiles for defined future time periods to the sensor/actor nodes integrated into the EuPs. These load profiles are basically functions over time which indicate the specific times when it will be favourable (or not favourable) to consume energy. Each node controls an EuP such that the target energy consumption is low during peak times of the cost function and high when costs are low,– while still maintaining a satisfactory customer service.

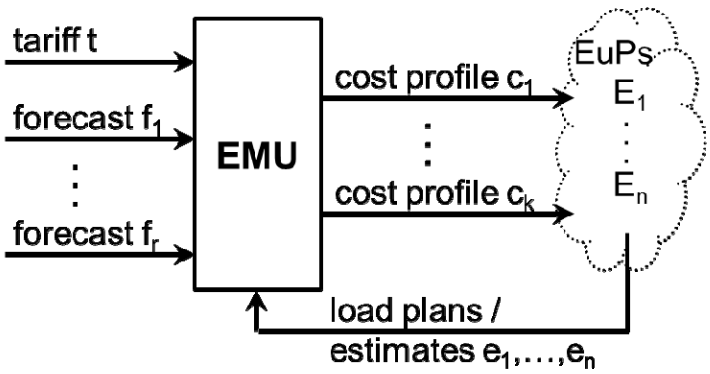

Figure 1.3.2: Semi-decentralised EM **approach**

The sensor / actor nodes in turn compute forecasts (or ideally even committed plans) of the future energy consumption of the appliances connected and send the information back as *load profiles* to the EMU to be processed and integrated into the overall energy consumption plan. This approach leads to a simple protocol for all EuPs in the network where only one cost profile which is constantly updated on the basis of the information received is broadcasted by the EMU:

- The EMU broadcasts a cost-profile to all EuPs in a group. The base of this initial cost profile could be a volatile tariff (e.g. hourly-changing) and / or a forecast of the local wind turbine power output. If the only management target is load-balancing, the initial cost-profile could be set to zero.
- At some point an EuP issues a load-plan to the EMU, for example when a freezer switches off for the first time after finishing its learning phase.
- The EMU incorporates the load-plan into the current cost-profile and broadcasts the update. Since the EuP which is responsible for the cost-profile update is committed to its load plan it just sent, it ignores all subsequent cost-profile updates until its load plan is finished.
- Eventually, other EuPs will compute and send load-plans, giving rise to subsequent cost-profile updates.

The basic idea is that the cost profile inherently represents a power budget over time, and by incorporating a load plan into the next cost-profile update, a certain part of this budget is reserved for the appliance which issued the plan.

1.3.1.3 Local cost-dependant control of appliances

For certain EuPs, the idea of planning the power consumption according to a cost profile is straightforward. For washing machines and other appliances in the SKDSVC class, this works as follows:

- If a user loads a machine and selects a program, a deadline for the completion of the program is selected in addition.
- The cost profile provided by the grid operator and the principal load profile of the selected program are used by the sensor / actor node to compute a start time such that the selected deadline is met and the load profile produces minimal cost. The time-accurate load profile (generated by the node) is then sent to the EMU as described in the section above.

In the case described above the principal load profile will in general depend also on the (incoming) water temperature, on the weight of the load, and on manufacturer-dependent parameters (degree of dirt, etc). Nevertheless, cost-profile dependent load planning comes very natural to the SKDSVC class with sufficient results even when just using worst-case profiles.

For other EuPs, cost-profile dependent load planning is not so obvious. Fridges and similar EuPs in the VSTSVC class usually have some kind of simple bang-bang controller which switches the fridges' compressor on or off depending on the upper and lower temperature thresholds. Therefore the power consumption for the average cooling process (i.e. without user interference) is basically periodic. Usual demand side management techniques use adaption of the threshold temperatures to manipulate the power consumption.

Within the SmartCoDe project a cost-profile dependent load planning algorithm has been developed which directly manipulates the length of the VSTSVC class power-cycles. The core idea is to replace the usual bang-bang controller with a PI-controller which computes a load-plan for the next Off-On cycle of the compressor. This load plan is then tweaked according to the provided cost profile, which in general will cause the maximal / minimal temperatures observed during this cycle to exceed or fall short of the temperature thresholds set. The PI-controller will then counteract these violations in the following cycle.

In an initial learning phase, the usual bang-bang control is used to "learn" the normal duty cycle. This duty cycle is then used to parameterise the PI controller in the sense that the error values observed will manipulate this normal duty cycle. After the learning phase, the node goes into planning mode:

- During the on-going Off-On cycle, the temperature maximum and minimum is determined.
- After switching off, the PI controller determines an initial schedule by looking at the difference between the observed extremal temperatures to the usual ones when using bang-bang control. For example, when the minimum temperature tends to be too low, the On-phase is shortened, and when the maximum temperature is too low, the Off-phase is prolonged.
- The schedule is now stretched or squeezed by a factor such that the result is maximally cost-effective with respect to the cost-profile.
- The SmartCoDe node then sends back this load-plan and is committed to it until the next switch-off. If the temperature bounds are breached by an unacceptable amount due to drastic events like putting hot food in the fridge, a fail save bang-bang controller still can switch the appliance earlier if a bound is exceeded by more than 2°C.

Figure 1.3.3 shows an overview of this algorithm. Note that the use of the PI controller here is quiet unusual. While PI controllers are normally used to get a certain target value stable, this PI controller inherently organizes deposits and withdrawals into and from the thermal capacitance of the appliance. The idea is that the deviations from the ideal temperature caused by the cost-tweak are successively counteracted by the PI-controller. That is, the cost-tweaks act as disturbances in this setting.

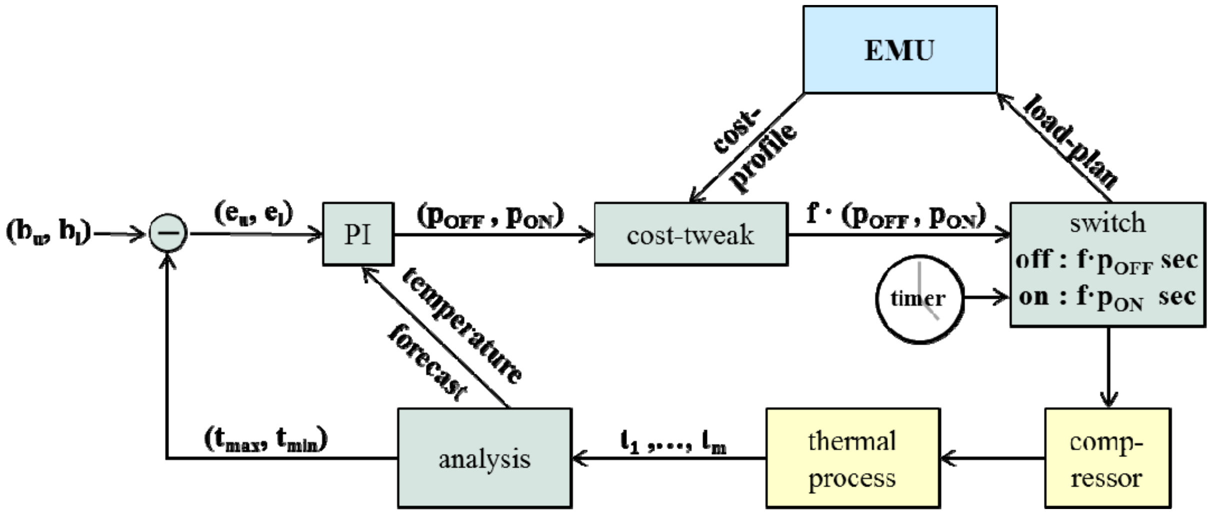

Figure 1.3.3: Cost-function dependent PI-based control loop for a VSTSVC appliance

The control loop in Figure 1.3.3 has a big delay of about 1 hour for typical fridges and freezers. That is, after the decision is made when to switch the compressor on again, the system essentially runs “blind” for an hour, except for the fail-save procedure. To ensure that the fail-save procedure is used a little as possible (since that would constitute a breach of the load plan), a new temperature forecast method is used to ensure that the temperature at the end of the off-cycle is still within acceptable bounds. The temperature forecast algorithm employs least-square-error curve fitting on the sensor-actor node itself, learns the thermal process of the EuP over time and constantly updates it.

Figure 1.3.4 shows how the forecasting of the temperature curve of the off-cycles gets accurate after 4-5 cycles of learning, and also reacts relatively robust to a sudden change in conditions.

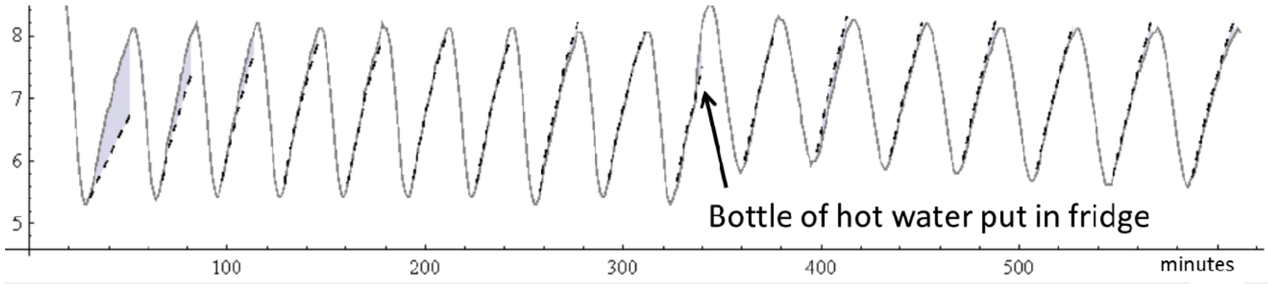

Figure 1.3.4: Temperature forecast (dashed) and actual temperature (solid)

1.3.1.4 Forecasting of wind- and solar energy

The power output from a wind turbine varies dramatically with time. This is especially true for small-scale wind turbines since wind is a lot more unstable in low height.

The wind speed- and direction-variation however is not random: the power output is a deterministic function of the weather conditions and the orology, i.e. the description of the surrounding surface of the earth.

If the wind speed, air density and other parameters are known, then the power output of a wind turbine can be predicted quite accurately (see figure 1.3.5).

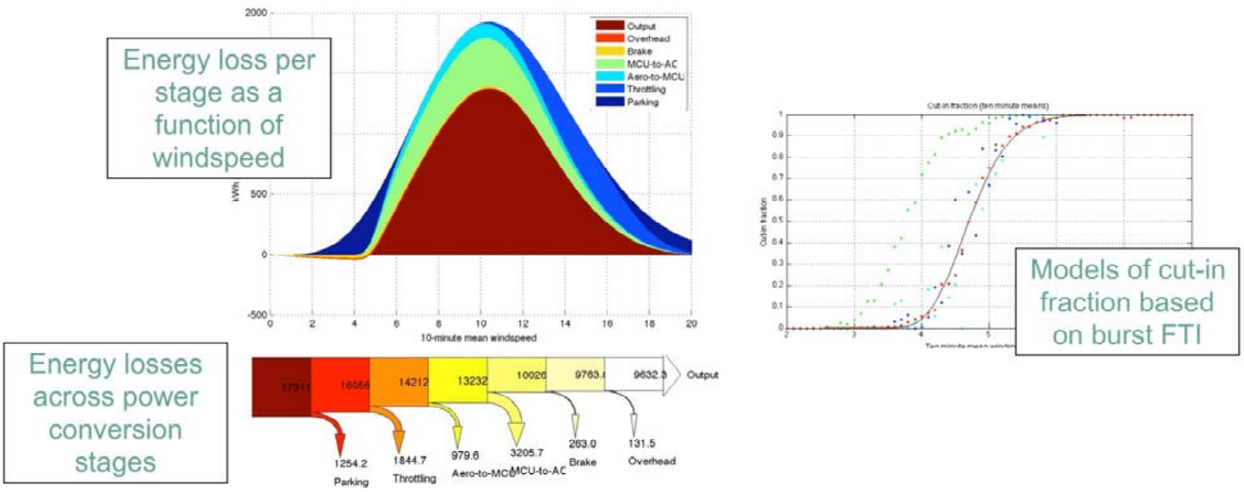

Figure 1.3.5: Advanced Energy Yield Model

To get an input for this energy yield model, a forecast for the local wind resource is needed. For this a model which provides correction factors for published wide-area forecasts to specific site conditions was developed (see figure 1.3.6).

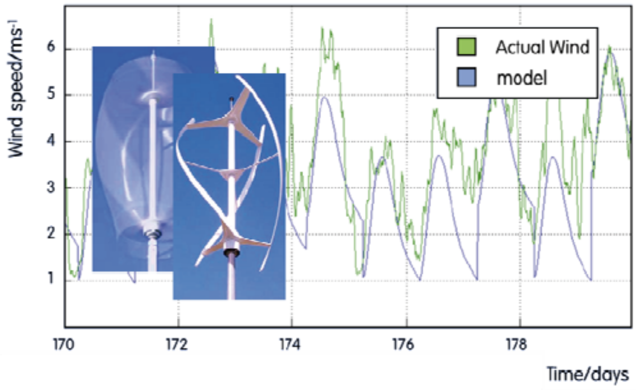

Figure 1.3.6: Wind speed prediction for Energy

The combined model is able to use the turbine's performance information to convert the forecast wind speeds into predictions of the power generated.

The Solar Forecast Calculator takes different parameters like the maximum output, the position and orientation and calculates the maximum sun beam power of the specific PV-System. First the ratio is multiplied with the maximum device output power. This power is then compared against the real power meter at the very moment. Together with the weather forecast from SmartCoDe Associated Partner *q.met* (which includes also cloud coverage), an average production forecast can be generated. The total ratio calculation within the EMU is done within approximate 200 ms (0.2 seconds) for all 96 forecast values (timestep: 15 minutes).

The developed algorithm allows the forecast of the PV production based on trigonometric calculations which fit easily into the computing capacity of the embedded device (EMU). Although the practical problem of regional (local) cloud cover forecasting still remains and an although wide-area forecasts are only available free of costs as daily average values, the PV energy calculations have been sufficient for the SmartCoDe demonstrator purposes.

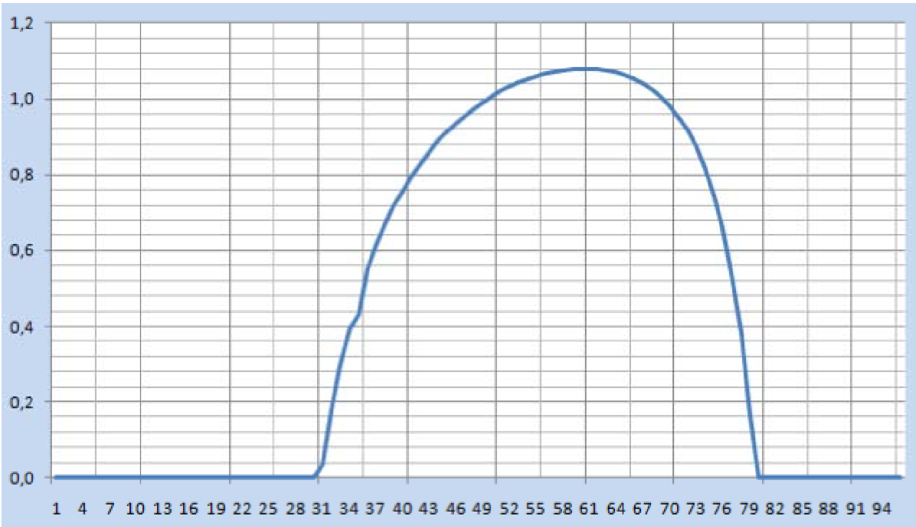

Figure 1.3.7: Solar forecast example

1.3.2 Wireless networking

1.3.2.1 The SmartCoDe ZigBee profile

For the SmartCoDe energy management approach a dedicated SmartCoDe profile was implemented on top of the existing standard ZigBee technology. It includes clusters for cost profiles and load profiles with scalable granularity.

Figure 1.3.8 shows the message format of the cost profile. It can be considered as a derivative of the *ZigBee Smart Energy 1.0 load control event*, which describes an event with a start time, duration and several values to control different kind of appliances, e.g. temperature set points. One of these values is the Criticality Level that is also used in the SmartCoDe cost profile and indicates with an abstract value how costly the use of energy is during a specific time-span.

The idea of the SmartCoDe cost profile is to bundle a series of such (successive) load control events, specialised only to the Criticality Level which indicates an abstract cost. It contains a vector of duration - Criticality Level pairs describing the varied abstract cost of energy use for a certain time span beginning at the start time. For maximum flexibility, the time granularity can be chosen from 0.1 seconds to about 1.5 hours in the time resolution field.

Data Type	Unsigned 8-bit int	Unsigned 8-bit int	Unsigned 16-Bit integer	UTC Time	Unsigned 8-bit int	Unsigned 8-bit int	Unsigned 8-bit int	(repeat) …	Unsigned 8-bit int	Unsigned 8-bit int
Field Name	appliance class	utility enrolement group	Time Resolution	Start Time	cost profile length n	Criticality Level 1	Duration 1 (in time resolution units)	…	Criticality Level n	Duration n (in time resolution units)

Figure 1.3.8: SmartCoDe cost profile

The load profile message used for the load plans is shown in figure 1.3.9. It is very similar to the cost profile, the main difference is that the unit of the values is not abstract any more, but now specifies the power to be used in Watts. The resolution of the power fields can be set from 0.1 watts to about 6.5 kW.

Data Type	Unsigned 8-bit int	Unsigned 8-bit int	Unsigned 16-Bit integer	Unsigned 16-Bit integer	UTC Time	Unsigned 8-bit int	Unsigned 8-bit int	Unsigned 8-bit int	(repeat) …	Unsigned 8-bit int	Unsigned 8-bit int
Field Name	appliance class	utility enrolement group	Power Resolution	Time Resolution	Start Time	load profile length n	Load Level 1 (in power resolution units)	Duration 1 (in time resolution units)	…	Load Level n (in power resolution units)	Duration n (in time resolution units)

Figure 1.3.9: SmartCoDe load profile

1.3.2.2 Security

The SmartCoDe project builds on mature algorithms suitable for embedded systems and offers integration of highest grade security components as a distinguishing feature between SmartCoDe and other projects. Special attention is paid to the commissioning process, where an innovative approach for public key distribution using 2D codes has been developed.

SmartCoDe security builds on and extends ZigBee on the following network layers:

- Sensitive information, especially information potentially compromising user privacy, is encrypted at the Application layer (APL). It uses a model known from draft of ZigBee SE 2.0 based on elliptic curve cryptography (ECC). Devices are pre-programmed with device certificates which persist for the lifetime of device or at least pre-programmed with a key pair.
- Network layer (NWK) provides security primary for network command frames (like route request and route reply). This layer is not customized and it fully follows ZigBee specification.

Cryptographic Suite

Algorithms and protocol suites based on elliptic curve cryptography (ECC) are more adequate for small wireless devices and guarantee higher security level at higher speed and lower energy consumption than RSA based mechanisms that are state of the art in computer networks. The savings in communication costs are caused mainly by significantly shorter key sizes[1].

The security layer is designed to maximize compatibility with existing and proposed standards:

- ZigBee (ZigBee SE and draft of ZigBee SE 2.0)
- Draft of Cryptographic Suite for Embedded Systems (SuiteE)[2]

Both standards address integrity, confidentiality and authentication of communication. SmartCoDe relies on the same algorithms as ZigBee SE 2.0 (ECDSA, ECDH, AES). Suite E is a more general standard and it aims to optimally meet the wide variety of cryptographic requirements, by providing a compact and complete collection of cryptographic algorithms having minimal code space, computational requirements and bandwidth usage. Additionally, the selection of these algorithms are tuned to minimize overall system costs in mass production by selecting easily embeddable algorithms which will further reduce code space, energy usage and increase computational performance.

Smart Card Integration

A smart card is an optional and potentially replaceable[3] component of a SmartCoDe node. The integration of well tested and certified components reduces the risk of security attacks due to implementation flaws and increases physical security and overall efficiency of the system because of hardware acceleration. Smart card features are currently used only at the application layer. It is however possible to reuse them also on other layers although it is assumed that lower layers like MAC are often implemented on independent protocol processor.

The execution platform used for demonstration supports chip cards from Infineon Security Dual Interface Controller family SLE70 which meets the highest requirements in terms of performance and security. The SLE70 family provides a common architecture upon which specific products can be tailored for markets ranging from low security applications (SLE76) up to high security applications (SLE78). This allows efficient tradeoffs between cost and security.

The smart card contains two cryptographic co-processors. The symmetric coprocessor (SCP) combines both AES and Triple-DES with dual-key or triple-key hardware acceleration. The asymmetric crypto coprocessor (ACP) can be used for RSA and elliptic curve cryptography (ECC).

---

[1] For comparison of the energy consumption and speed of handshake protocol based on RSA and ECC see: Sun Microsystems Laboratories, "Analysis of Public-Key Cryptography on Small Wireless Devices", http://users.soe.ucsc.edu/~awander/stuff/EnergyPaper.pdf.

[2] http://tools.ietf.org/html/draft-campagna-suitee-04. Final version is not available yet to date of publication of this document.

[3] It is assumed that replacement of already deployed smart cards will be considered only in sectors with specific requirements, procedures and regulations related to IT security (e.g. banking)..

The implementation of the security protocol uses the following security features provided by smart card:

- ECDSA key generation
- ECDSA signature calculation
- ECDSA signature verification
- ECDH (Elliptic Curve Diffie Hellman), key exchange over an unsecured communication channel
- AES encryption

Random numbers used for key generation are delivered by true random generator (TRNG, SLE 78) or by pseudorandom number generator (PRNG, SLE 76).

1.3.2.3 Advanced Commissioning for Large-Scale Installations

Overall network security is closely related to the commissioning process, because even the most sophisticated algorithms fail if security policies are misapplied or chains of trust are broken. Design and implementation of the protocol software focuses on advanced commissioning scenarios. Simple scenarios like push-button configuration are supported but they are not the primary goal of the project.

For large-scale installations, commissioning process includes setup of network parameters including communication frequency and channel, security parameters, device pairing, scene configuration, etc. Physical installation, configuration and maintenance happen at different times by separate roles like electricians, commissioners and maintenance crews. It is important that only one of those roles needs to physically access the SmartCoDe nodes, everything else can be done system-wide. Each role can have different requirements for qualification and technical skills. Testability and auditability are crucial. It is important to be able to document that work has been done correctly for each role and to identify faults / errors / defects after each step. It further must be possible to allow partial testing of the network, for example before expensive devices like trust centres are installed. Tests can include simple scenarios like turning on / off lights at some granularity (room, floor, etc.).

A prototype commissioning tool for the SmartCoDe network has been developed (see figure 1.3.10). The tool allows collecting information about installed devices together with the respective security certificates, managing list of trusted devices, identification of devices and network configuration (channels, network id, security level, etc). Collected data can be imported and exported and potentially used by other software products like building planning or building management tools. Integration and compatibility with professional tools for commissioning and network analysis is considered for further research.[4]

---

[4] http://tools.ietf.org/html/draft-campagna-suitee-04. Final version is not available yet to date of publication of this document.

Figure 1.3.10: The SmartCoDe commissioning tool

Vendors can publish information about each device in machine-readable form, such as a QR code attached to each device. This information contains the public ECC certificate used for device authentication. This speeds up deployment and prevents human error.

Figure 1.3.11: Example of QR Code

The whole commissioning process can be broken into several independent steps. Devices can be physically installed by less qualified staff and network configuration and binding can be done by another group onsite or offsite.

1.3.3 SmartCoDe Energy Management Node Development

Within the SmartCoDe project a printed-circuit-board (PCB) based prototype node has been developed that uses ZigBee as underlying wireless technology. It has been used at the demonstration site to provide a prove-of-concept of the overall project goals by means of hardware and software components developed within the project. For this purpose it has been built from off-the-shelf components (see figure 1.3.12).

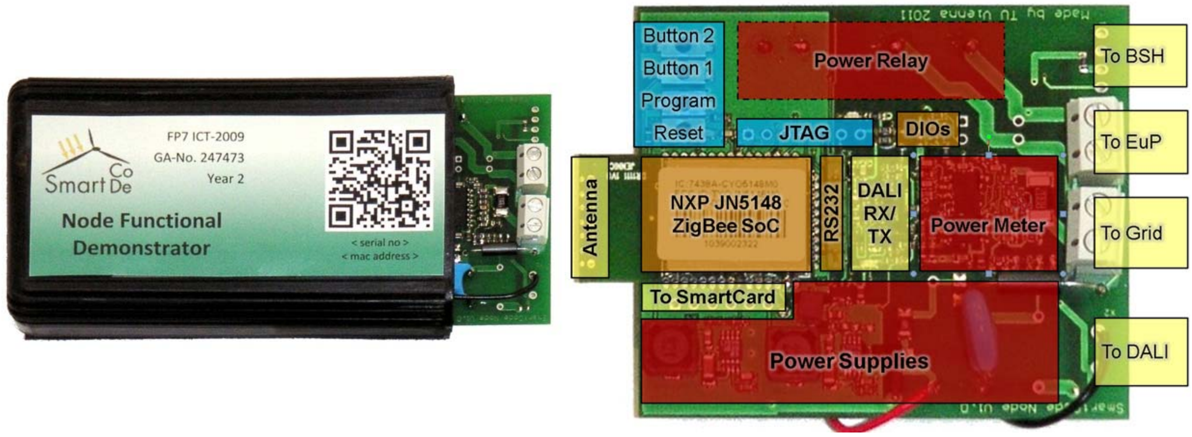

Figure 1.3.12: Example of the SmartCoDe PCB node prototype used at the demonstration site

For commercial use, the PCB solution is of course to large (the right part of figure 1.3.12 is approximately 10x7 cm) and too costly, therefore a scalable fully integrated hardware architecture has been developed. This architecture will be implemented as a highly-integrated microelectronic component in high volume markets in the future; it will enable the low cost target of less than 3 Euro production cost per SmartCoDe node.

In order to fulfil the requirements of low cost, small size, flexible communication infra-structure, and high security, the following approach has been taken:

- Integration of the distributed energy-management functionality of the SmartCoDe Node hardware (as defined in the semi-decentralized overall energy management concept) into a specific highly-integrated circuit, a so-called “System in Package” (SiP). The integration allows reaching even ambitions targets considering size, cost, and low-power. A SiP implementation however only makes sense for high volume markets since the non-recurring engineering cost (NRE) for such an implementation is very high and the number of pieces sold per year have be in the millions. In addition some external components will be unavoidable to manage 230V / 110V inputs and outputs.
- Communication between all members of the local energy resource cluster unit via RF interfaces over a single- or multi-hop ISM Band communication interface. This allows for dependable networks using multiple routes.
- Integration of highest-grade security features from existing “SmartCard” designs (a.k.a. crypto-cards) to guarantee information authenticity and privacy, either embedded or in form of a separate replaceable smart card.

1.3.3.1 Hardware concept

A single SmartCoDe Node consists of high voltage, medium voltage, mixed signal and low voltage digital subsystems. The difficulty lies in the integration of all voltage domains into a System-in-Package that minimizes the number of external components. Dedicated SmartCoDe developments to be highlighted are a power metering chip and a supply design which will advance the integration level for future SiP nodes.

The SmartCoDe high level node architecture is shown in Figure 1.3.13. The orange components (power supply and power metering) were at the focus of the project in order to allow for a future SmartCoDe SiP solution.

A further focus of the project was to develop a scalable node architecture, i.e. different variants of the node hardware are available to enable optimal integration in different use scenarios. If, for example, a dedicated power supply and power metering is not required in cases where this functionality is already provided by the EuP that integrates the node, a *core-single chip* SmartCoDe node can be used instead.

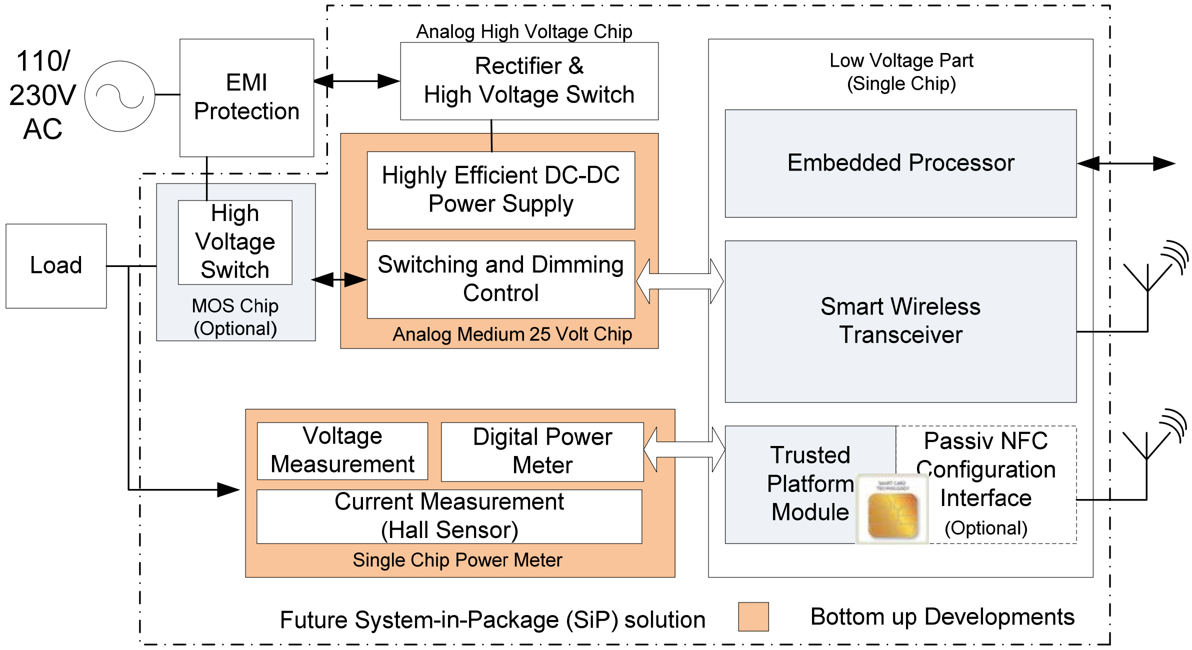

Figure 1.3.13: SmartCoDe node design – system partitioning

As already mentioned the SmartCoDe node architecture allows varying hardware functionality, i.e. different variants are available to optimize a node for different device classes and use cases in terms of cost and functionality. The benefit of the approach is that it tackles security issues and installation issues as a central point in the overall system architecture, while still focusing on the highest level of integration including high voltage subsystems typically not found in SiP based solutions.

The idea of a scalable architecture is that many of the different subsystems may or may not be part of a node, based on the requirements for different products. There are three basic variants of the SmartCoDe Node in order to optimize for cost within the given class of application. The full featured variant that is shown in figure 1.3.13 and in figure 1.3.14 (left block) can be used together with any type of EuP; it also can be integrated within an intelligent power plug or power adapter.

For more cost-sensitive devices or smart appliances which already provide basic functionality like energy consumption information or a low voltage supply, certain functional blocks can be omitted.

In smart (“Energy Management enabled”) EuPs certain functional blocks of the node architecture which are already built-in into the EuP can be shared. Examples are power supply and a possible control interface where information on power consumption or state of the device can be exchanged with the node. In this case no separate voltage and current measurement circuit is required and therefore cost per node can be reduced.

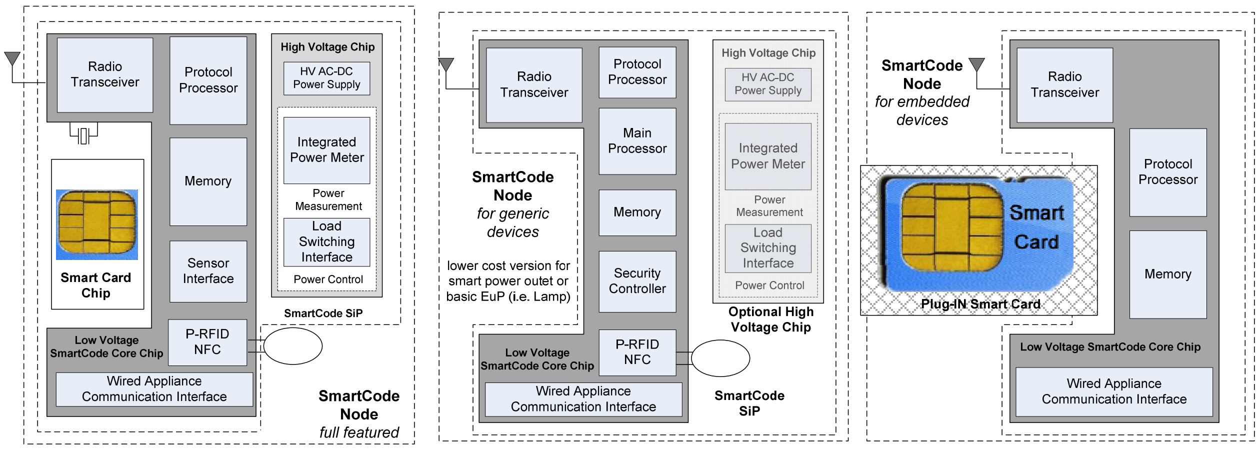

Figure 1.3.14:

LEFT: Fully extended system architecture of a node with plug-in Smart Card and wireless passive configuration interface.

MIDDLE: System architecture without Smart Card but with encryption hardware within the core chip eliminating a third die in the SiP package.

RIGHT: Plug-in Smart Card version for smart devices to be integrated directly into smart EuP which provide a basic communication interface for exchanging power states power consumption and controlling the device.

On the other hand, low cost devices such as lamps or generic power plugs need a high voltage power measurement and supply unit. For cost reasons, we propose a variant as shown in figure 1.3.14 MIDDLE, i.e. a variant without a smart card where specific smart card functionality is integrated directly in the core chip. This variant saves the cost of the smart card.

For both variants an optional Near-Field-Communication (NFC) Interface allows to configure at close proximity the network configuration and security settings. The SmartCoDe node comes without any network parameters and private network keys stored when delivered. For the establishment of a trusted relationship the extremely short range wireless NFC interface is used to establish the relevant network information within the node automatically using a programming device or even a standard NFC enabled cell phone with the respective application program.

Another way of establishing a trusted relationship is shown in the RIGHT variant of the proposed architecture in figure 1.3.14: A smart card is delivered separately to the device, similar to cell phones where the user establishes a trusted relationship between the phone and the network by simply plugging-in the SIM card to enable the phone to join the network.

In the same or similar way it can work for any EuP as well. The specific energy management architecture for embedded devices (figure 1.3.14 RIGHT) has the advantage that the additional cost for the device manufacturer is minimal as only the core chip has to be integrated on the motherboard as well as a low cost Smart Card connector and antenna to prepare the EuP for an energy management enabled network. Only if the user wants the additional SmartCoDe functionality a Smart Card for the given device class has to be purchased and plugged into the device which then automatically joins the network.

Another very interesting use case of NFC in private homes is that any user with a trusted NFC enabled phone could approach any energy management enabled device and query its energy usage or statistics or even control the device. This could be very interesting for consumer electronics or white goods where connection is established only at close proximity giving intruders from outside little chance to access a device.

The SmartCoDe concept of three basic variants of the given node architecture gives enough flexibility to accommodate most application use cases. A show case of a minimal energy management node as depicted in figure 1.3.14 is a wireless controlled LED-lamp without separate main processor. It has been used as test-bed for gathering indicative results of electro-magnetic susceptibility for the SmartCoDe SiP-demonstrator. The prototype of such a LED-lamp which has been developed during the project is outlined in the next section.

1.3.3.2 Minimised SmartCoDe node prototype

A very compact, fully-functional SmartCoDe prototype, hardly larger than a 1€ coin, is another result of the SmartCoDe project. The prototype makes use of only two tiny sub-packaged System-on-Chip (SoC) / System-in-Package (SiP) key-components (power acquisition sensor and the RF smart transceiver), while it is still able to offer wireless power monitoring and control for LED lighting devices. It reuses the main power supply which is part of an LED driver module.

The **fully integrated power acquisition sensor** makes use of the dual-Hall differential sensor principle, which proved to provide sufficient suppression of external magnetic fields during the initial analysis phase of the project. For the current prototype, a lead frame approach has been used (figure 1.3.15, left, lead frame and bonding concept). The overall package size is 7mm x 7mm (figure 1.3.15, right: sketch of the package).

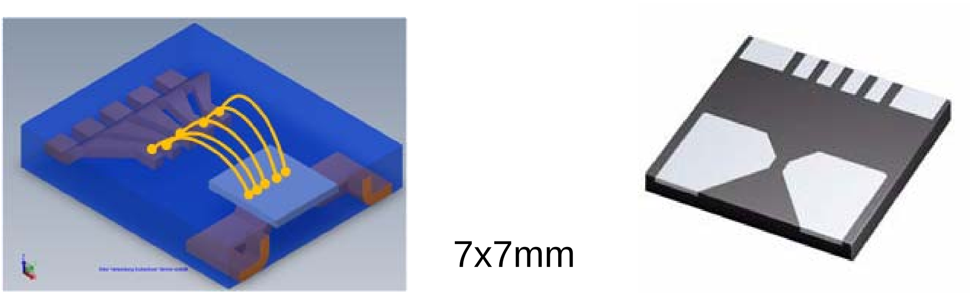

Figure 1.3.15: Integrated power acquisition sensor prototype

The fully integrated RF Smart Transceiver (a prototype IC from the EU FP7 funded project "*CHOSeN*") comprises full functionality for a single chip wireless solution in the sub-GHz frequency range. Only some external discrete components are required (crystal, RF-matching network and antenna). The Smart Transceiver also comprises a programmable protocol processing unit with a small amount of internal memory (some kBytes) for "simple" protocol and application implementations. For the "minimal" SmartCoDe node prototype a highly compact firmware has been developed and implemented upon this protocol processor. The firmware fulfils following tasks with a very small memory footprint:

- **Power measurement** using the power acquisition sensor
- Executing a simple, effective **wireless protocol**
- **LED control** (diming, switching)

The developed prototype also features an on-board antenna. Due to size restrictions the antenna performance is reduced, but still reasonable for the SmartCoDe scenario. Tests have shown that an in-door transmission range of ~50m can still be reached.

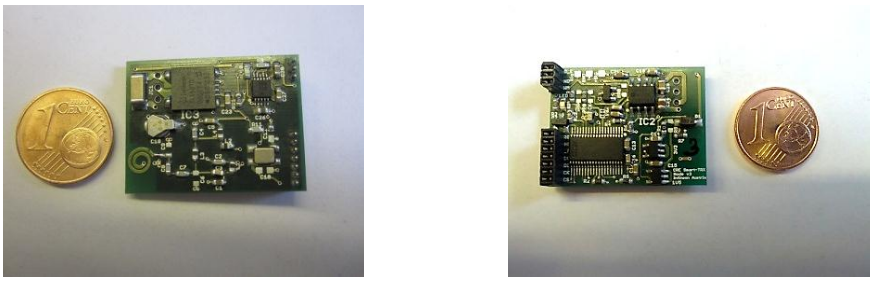

Figure 1.3.16: Highly miniaturized “minimal” SmartCoDe node

Figure 1.3.16, left picture: bottom view with power acquisition sensor and RF-matching/ antenna; right picture: top view with RF transceiver, power supply and connectors. For demonstration purposes the prototype node has been integrated into commercially available 25W LED-spots (see figure 1.3.17).

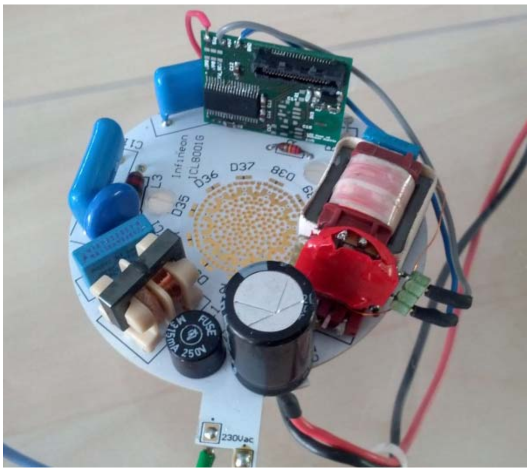

Figure 1.3.17: Highly miniaturized SmartCoDe node integrated into a commercial 25W LED spot

1.3.3.3 Highly integrated version: cost estimation

To estimate the costs of implementing the SmartCoDe hardware in a household two scenarios have been analysed:

- The first one considers an early, low volume roll out of SmartCoDe technology (100.000 nodes). For this scenario it is assumed that all required node hardware will be built by means of standard PCBs and discrete components.
  For white good appliances (washing machines, refrigerators, etc.) it is not assumed that a digital smart remote control interfaces is provided, so the wireless appliance control nodes itself need to provide full 220V power switching ability and power supply.
  For LED- lighting devices a simple architecture for the wireless node is assumed (no 220V to DC power supply, no 220V power switching ability).
- The second scenario considers a mature market which can be supplied with highly-integrated SmartCoDe technology in large volumes (10.000.000 nodes). White good appliances are assumed to provide digital communication interfaces and DC power supply, therefore the complexity of the wireless control-nodes can be significantly reduced, resulting in simple node architecture, similar to the LED-lighting control scenario above. There is only a small amount of complex nodes assumed for the use in Smart Plugs.

For both scenarios a general distinction is made between wireless control-nodes (those nodes which are connected to end-devices like appliances, LED-lighting modules, sensors etc.) and infrastructure components like message forwarding / routing nodes, WSN2LAN gateway including Energy Management Unit (EMU) and software-applications for visualisation and remote control (APP for Smart-Phones or Tablets). Infrastructure hardware is assumed to be built by standard PCBs and discrete components.

Cost Estimation for low volume

Initial markets will start with retrofitting existing EuPs so that they become SmartCoDe enabled, hence a larger number of the typical fully featured and more expensive power plug adapter will be needed compared to embedded solutions directly built into the EuPs. For the cost estimation of the given nodes it is assumed that these will be ZigBee enabled.

For an initial market deployment (volume < 100.000), a home use-case for an average household is considered which consists of:

- infrastructure nodes for
  - one Energy Management Unit - EMU,
  - two routers,
  - one gateway and
- several SmartCoDe enabled sensor nodes for
  - four simple nodes embedded into electrically connected devices,
  - eight complex sensor nodes or smart plugs and
  - three simple sensors i.e. for temperature measurements

The cost figures for one average household are summarized in figure 1.3.18. It shows that an **overall cost of 548 Euro per household and with an average cost per node of 24 Euro** this scenario is only attractive for a small (not price sensitive) market segment.

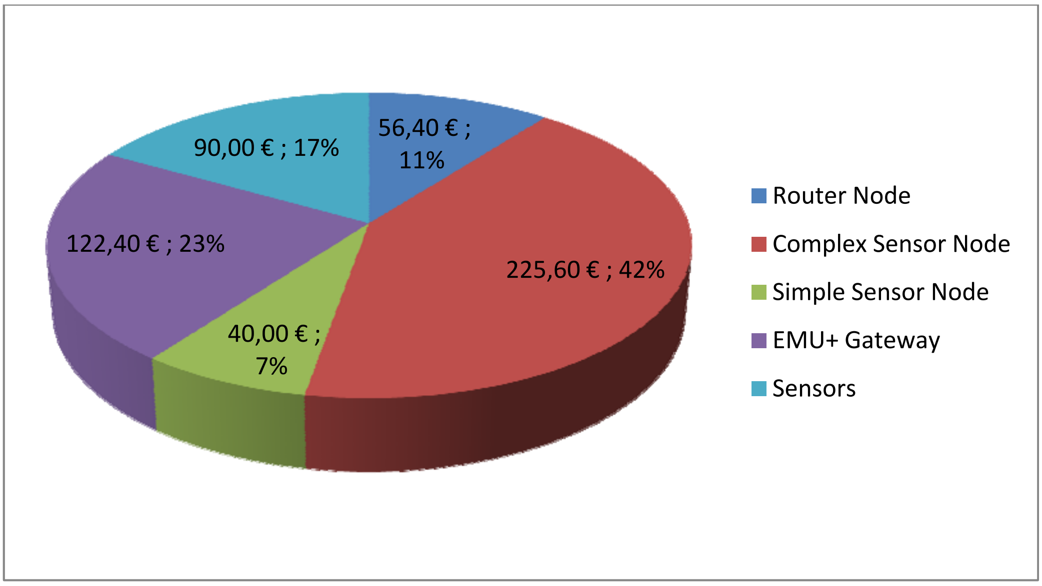

Figure 1.3.18 Low-volume (100.000 units) scenario, overall cost distribution

<u>Cost Estimation for mass deployment:</u>

For a mature market deployment (volume > 10.000.000), a home use-case for an average household is considered which consists of

- infrastructure nodes for
    - one Energy Management Unit - EMU,
    - two routers,
    - one gateway and
- several SmartCoDe enabled sensor nodes
    - eight simple nodes embedded into electrically connected devices
    - four complex sensor nodes or smart plugs and
    - three simple sensors i.e. for temperature measurements.

The cost figures for one average household are summarized in figure 1.3.19. With an overall cost of 215 Euro per household and an average cost per node of 6,8 Euro this scenario reduced the costs by approx. 60% compared to the low-volume scenario.

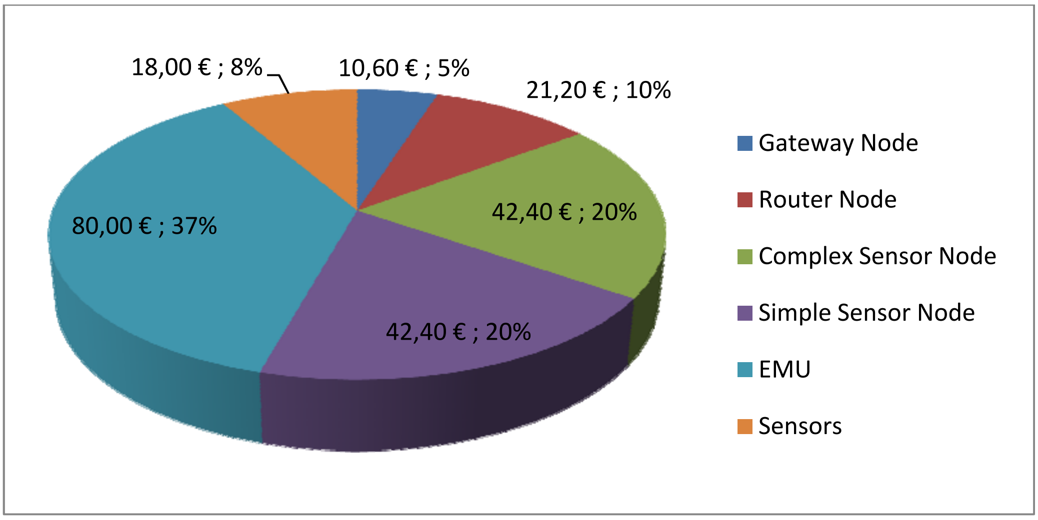

Figure 1.1.19 High-volume (10.000.000 units) scenario, overall cost distribution

While the share of infrastructure costs is still a dominant cost factor, the total cost of a package including 15 wireless nodes has become affordable. This is due to the cost-benefit of the integrated sensor nodes and the assumed reduced complexity of white good controlling wireless nodes, resulting in **average costs of 6,8 Euro per node in contrast to the 24€ per node** for the low volume scenario. The high-volume scenario also shows much more potential for system upgrades (in terms of energy-managed appliances, but also in terms of applications / sensors in the context of Ambient Assisted Living) due to the cheap node costs.

1.3.4 Results

1.3.4.1 Load balancing

Load balancing is one of the most important sub-task in the SmartCoDe demand side management approach. It can release the grid from stochastic stress when communication measures exists that initiate load shifting at a local cluster in times of grid under- or overload.

It can further be argued that increasing the EuPs combined power consumption at favourable times, e.g. when energy from local renewable sources like wind turbines or PV is available, is in fact a variant of CO_2 reduction, since the additional-utilized amount of energy is not consumed from the global energy providers who are still relying to a large amount on fossil energy generation. Setting the priority on the consumption of "own" energy instead of feeding it into the grid also releases the grid from load in general since the energy is used at the place where it is generated, it is neither consumed from the grid nor fed into the grid. The result of this approach is an optimized use of the grids distribution capacity.

It has to be ensured however that an increased local consumption still stays within certain bounds. If all of the local EuPs switch on in times of locally available energy, the overall power consumption might surpass the power provided locally by far.

The conclusion is that local power consumption as well as local power generation has to be periodically forecasted, it has to be constantly monitored, and the "local distribution" of energy has to be scheduled in advance and communicated to the connected (energy-management enabled) appliances. And that is where the SmartCoDe approach comes in.

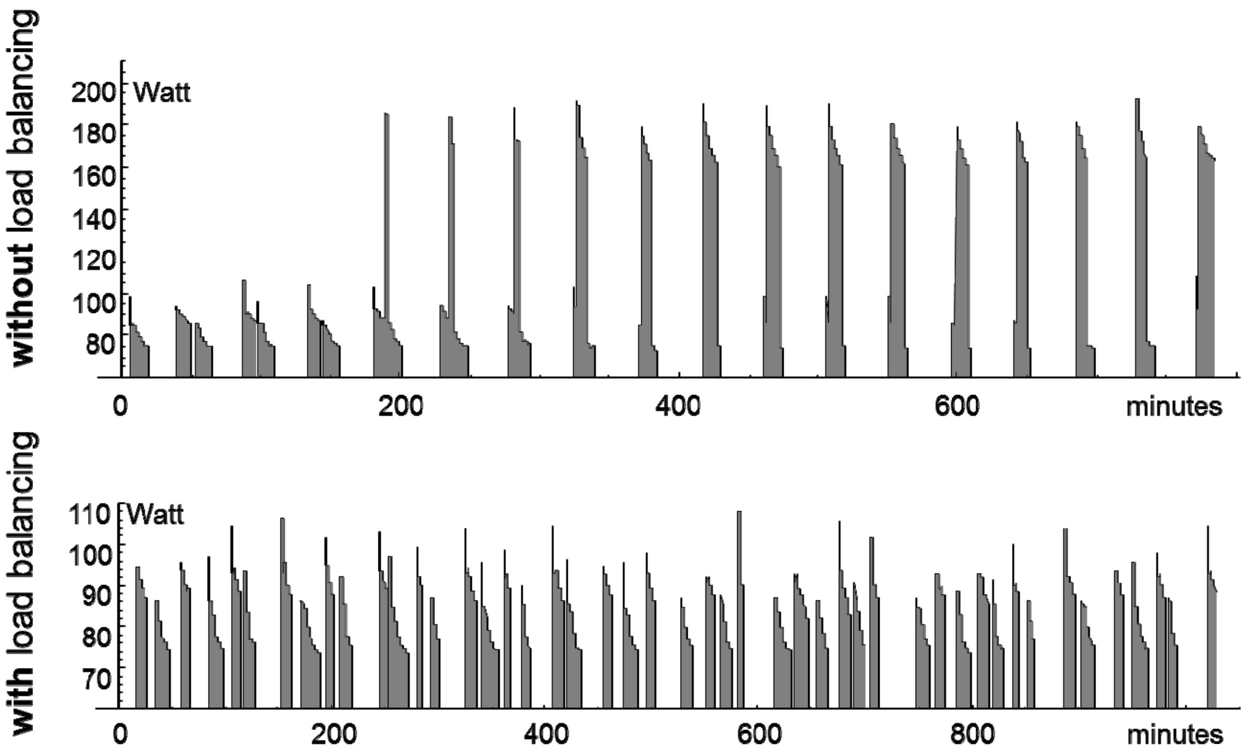

Figure 1.3.4.1: Combined power consumption of two fridges: no balancing (top) vs. SmartCoDe load balancing (bottom)

Figure 1.3.4.1 shows a real life example of load balancing using the SmartCoDe nodes: Two fridges which run independently with no further energy management as show in the upper part of figure

1.3.4.1. The fridges switch on randomly, which can easily be at the same time such that the combined power consumption equals the maximum peak load. In the case shown above the fridges even began to essentially run in lockstep.

The lower part of the picture shows the behaviour with SmartCoDe-enabled devices and with local energy management. With the SmartCoDe load balancing approach in place, the fridges are never running at the same time, which results in a significant reduced combined maximum (peak) power consumption.

To illustrate the influence of the SmartCoDe concept on peak-power behaviour figure 1.3.4.2 shows the sample variance (basically an indicator for up- and downswings as well peak and valley occurrences in the power consumption) of four freezers from different manufacturers installed at the SmartCoDe demonstrator location at the Buchberg restaurant. The freezers are all running under SmartCoDe management except for the time frame indicated by the pink rectangle where external control has been switched of. It can be deduced from the graph that the fridges return to an unpredictable behaviour similar to the one displayed in the upper half of figure 1.3.4.1.

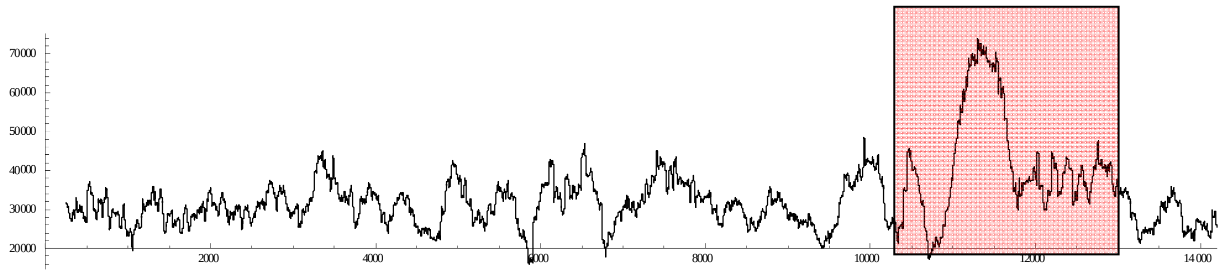

Figure 1.3.4.2: Sample variance of four freezers at the SmartCoDe demonstrator location

To enable the management of fridges and freezers however implies that the strict temperature driven control of the appliances (basically a bang-bang strategy that ensures that the fridges temperature is always between a defined upper and lower temperature bound) is replaced with a mechanism that allows the appliance controller to exploit a wider temperature band. By cooling a fridge down to 4° Celsius instead of 7° Celsius in times of locally available energy for example, a virtual storage capacity equivalent to the electrical energy required to cool down from 7° Celsius to 4° Celsius can be exploited in times when local energy is not available or when it is required by other local appliances. Due to this behaviour, fridges and freezers have been classified to be of class "*Virtual Storage Service*" (VSTSVC) (see also chapter 1.3.1.1).

Another important class of appliances in the SmartCoDe nomenclature is the schedulable service device class (SKDSVC). These are devices whose operation (and therefore power consumption) may be shifted in time but do not have any implicit option to store energy. A common example of this class is a washing machine. With the requirement of "having the washing done until tomorrow morning" an energy management system that has information of future locally available energy, future energy costs if consumed from the grid, and future local energy consumption can choose the best time within the specified time frame to run the machine.

Figure 1.3.4.3 shows the effect of using the "finish washing within 12 hours" button in combination with a three-step cost profile (6:00 to 20:00: 25 ct/kWh, 20:00 to 24:00: 20 ct/kWh, 0:00 to 6:00: 15 ct/kWh). In this case the user pressed the button at 18:20, i.e. the washing has to be finished by 6:20. From the graph can be see that the washing machine was started by the SmartCoDe management on Nov. 11 at 0:00 ("0 Uhr") during the time of the lowest energy cost, it finished about 1:40.

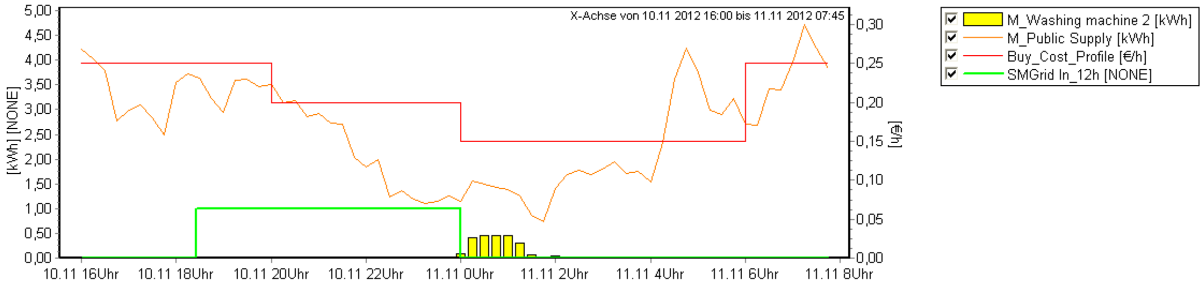

Figure 1.3.4.3: Load shifting within a 12 hour time frame

In figure 1.3.4.4 the effect of using the “ready within 4 hours” button in combination with the same three-step cost profile is shown. The user pressed the blue button at 19:00, i.e. the washing has to be finished by 23:00. In this case the washing machine started at 20:00 during the medium cost time and finished about 21:40 because the time of lowest cost was beyond the defined washing time frame.

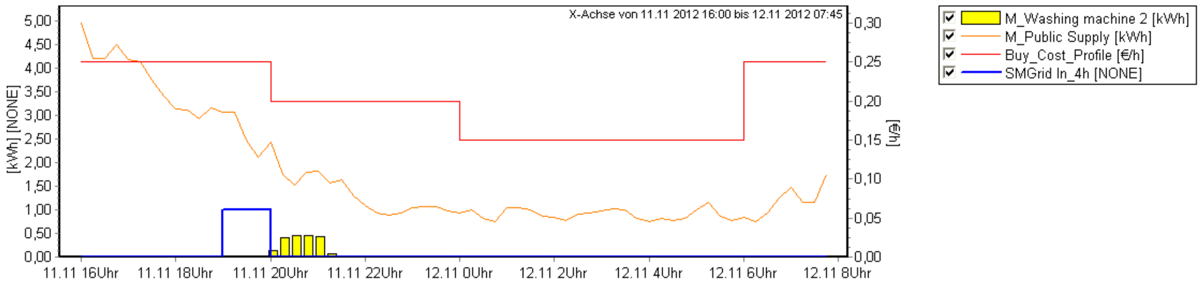

Figure 1.3.4.4: Load shifting within a 4 hour time frame

1.3.4.2 Hot water as common virtual energy storage

Another example of virtual energy storage capacity if integrated into the energy management process is the usage of pre-heated water which has the potential to reduce the electric power needed for a washing circle by up to 80%. The more effective solar pre-heating is used, the less additional electrical energy is required for those EuPs which would otherwise heat up water themselves for their operation (e.g. dishwashers and washing machines).

The consequence: If solar pre-heating is available, not only the price of electric power is a criteria but also the availability of a storage capacity for pre-heated water. Or, in more simple words: the introduction of energy management into households enables the use of energy storage capacities like (already available) hot water tanks to store available surplus electrical energy.

Figure 1.3.4.4 shows the respective analysis results from the SmartCoDe demonstrator sit at Almersberg that has been equipped with photovoltaic and solar-thermal energy. The example of a washing cycle of a washing machine shows that a small shift of about 4 hours can lower the consumption per cycle from 0,35 kWh to 0,12 kWh (65%) because the washing machine run has been shifted to a time when the pre-heating of the water boiler by the locally available renewable energy sources became effective.

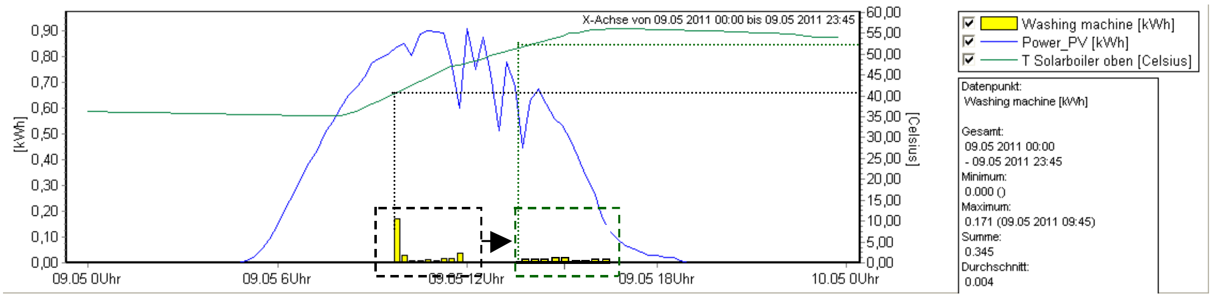

Figure 1.3.4.4: Consumption of a washing machine as a function of the solar boiler temperature

1.3.4.3 Analysis of potential energy savings

To estimate the potential of the overall energy savings based on the SmartCoDe approach a detailed analysis has been executed that considered the effects of *user awareness* in combination with state-of-the-art energy monitoring measures, enhanced by SmartCoDe enabled control devices and consumption / generation appliances.

The merged effects of these approaches were analysed for the example of a households in Germany. Germany has been chosen because detailed statistical data on average energy consumption, appliance saturation etc. for the approx. 40 million households has been available from the Federal Statistical Office (https://www.destatis.de) of Germany.

The overall energy savings were calculated for an average household and for different roll-out scenarios of 1%, 10%, and 20% saturation. For the example calculations, we assumed 40.3 million households in Germany with an average electrical power consumption of 3.600 kWh and an electricity price of 0,25 €/kWh (see table 1.3.4.1).

Nr	*Description*	*German Standard Household*			*Rollout to Germany*		
		Percentage	*Consumtion*	*Cost*	*Percentage of covered households*		
					1%	10%	20%
5.1.1.	Awareness						
	- deliberate usage	5,0%	180 kWh	45,00 €			
	- replacement in general	15,0%	540 kWh	135,00 €			
	- pre-heated water	2,6%	94 kWh	23,40 €			
	Total	**22,6%**	**814 kWh**	**203,40 €**	**329 GWh**	**3.287 GWh**	**6.574 GWh**
5.1.2.	Monitoring and Visualisation						
	- pre-heated water (additional)	1,8%	65 kWh	16,20 €			
	- optimization of heating system	8,0%	288 kWh	72,00 €			
	- optimize deepfreezer	3,7%	133 kWh	33,30 €			
	Total	**13,5%**	**486 kWh**	**121,50 €**	**196 GWh**	**1.963 GWh**	**3.927 GWh**
5.1.3.	Load Balancing						
	- manual load balancing						
	+ SKDSVC	2,4%	86 kWh				
	+ CUSCON	2,2%	79 kWh				
	- automatic load balancing						
	+ SKDSVC	2,0%	72 kWh				
	+ VSTSVC	4,7%	169 kWh				
	- reduction of the variance						
	Total	**11,3%**	**407 kWh**		**164 GWh**	**1.643 GWh**	**3.287 GWh**

Table 1.3.4.1: From household to the roll-out – overview on total effects

The possible effects of awareness are at least about 23% of the total power consumption. Together with the effects from monitoring and visualisation and the analysis of the monitoring data a total reduction potential of 36% and a reduction of the energy costs of about 325,- € per year can be deduced.

For load-balancing things are a little bit more complex. For the above analysis with a stable energy price of 0,25 €/kWh and an assumed balanced grid there is only very little overall benefit. In practise, however, the grid will have varying situations in the future in terms of over- and underload. This volatility of the grid's power (and frequency) due to the enlarged portion of renewable energy sources on a large scale will lead to severe grid instability scenarios in the future. This situation demands for a service that reduces or enlarges the consumption of energy on demand (i.e. consumption based on the status of the grid). The commonly accepted result will be energy tariffs that vary on the basis of the above scenario. Therefore the interesting outcome of the calculation, which has been made on a very conservative basis in terms of the amount of energy that actually can be shifted or virtually stored, is not the financial benefit but the amount of energy that is available as a **regulating energy (1,6TWh for a 10% roll-out scenario),** which can be **provided as a service**.

1.4 Project Impact, Dissemination and Exploitation

1.4.1 Societal Impact

We are living in a world of change. The immediate requirement to reduce CO_2 emission requests for a radical change in how we generate and use energy. In principle we have to generate energy from renewable sources, we need options to store it, and we have to change the paradigm of "generation following demand" to "demand following availability (of the renewable resources)".

But what are the implications? In terms of electrical energy generation, simply exchanging large fossil power plant with large renewable ones (e.g. off-shore wind power plants) won't do the trick.

In Germany, a pioneer in the "Energiewende", the overall transition to renewable energy sources, it has been realised lately that especially with large (volatile) renewable power plant the issues of:

- finance and secured Return on Invest (RoI) and
- energy transport

have been underestimated. Large renewable power plants require huge investments. To attract large investors to engage in future energy concepts the respective regulations have to ensure the return *of* the investment and a return *on* the investment, otherwise no-one will raise the huge amount of required money.

On the other hand, huge amounts of wind energy are not consumed off-shore where they are generated but are required to be transported to far away industrial centres in the south of the country. The grid however has not been constructed to transport huge amounts of energy from the north of the country to the south. The outcome is that since the transport of energy can not be guaranteed unless the electric grid has been enhanced in capacity the financial investors will not invest in the off-shore plants. In Germany the governmental plan for the energy transition already is experiencing delay.

But what has this to do with the SmartCoDe project?

SmartCoDe addresses buildings and neighbourhoods,- it is a small-scale concept instead of a large-scale one and therefore requires only little investment. Once the microelectronic devices (the *SmartCoDe Nodes*) become available, the concept can be implemented in a step-by-step fashion, starting with energy management in buildings, connecting devices one-by-one.

The SmartCoDe concept not only addresses energy savings, it also - and this might be the even more important functionality in the future – executes local energy balancing. It releases the connected grid from peak loads, or, in other words, **the capacity of the existing grid is enhanced in total since local peak loads are balanced**. Since a SmartCoDe neighbourhood (we call it a "*SmartCode Cluster*", see figure 1.4.1.1) also includes local renewable energy generation, such **a SmartCoDe neighbourhood can even provide energy balancing services to the overall grid**, i.e. it becomes a stabilising overall factor. And, in the final stage, a cluster of SmartCoDe Clusters, connected and intelligently managed via information and communication technology (ICT), is basically what can be considered a so-called **Distributed Energy Resource** (DER) or a Virtual Power Plant (VPP).

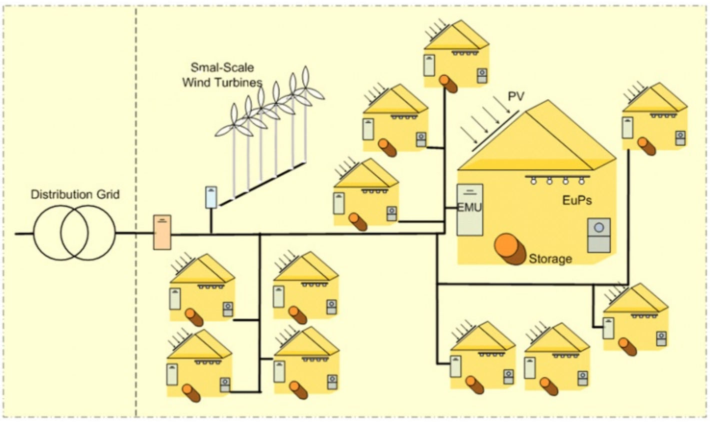

Figure 1.4.1.1: Concept of a SmartCoDe Cluster

Although the technical implications of the SmartCoDe concept are already very promising, the societal implications might be even more far-reaching. In most of the countries we have the situation that energy is provided from a few very large power plants (i.e. centralized power generation) that are owned by few large companies. This is due to the fact that large power plants require huge investments, partially coming from investors from all over the world. Further, having only few market players means only little competition, which again often results in high market prices for the end user.

Decentralised energy generation and management concepts (as in SmartCoDe) on the other hand are scalable, i.e. they can be rolled-out step by step, requiring only little to medium investment. These investments, however, can be raised by collectives of citizen, public participation, municipal utilities etc. This now is important for two reasons:

First, the **added value, or value creation, is kept within the local region** – the money comes from local (small-scale) investors, it is invested (i.e. spent) locally, and also the added value is kept local instead going abroad. This is not only true for the initial investment, it is also relevant for the financial benefit gained from local energy generation and local energy services.

Second, **local citizen get involved**. A number of projects in Germany have shown that if local citizen have the chance to participate in future projects, to become part of them, to invest in them - even with very small amounts of money - the result is a very high percentage of acceptance of new technologies. In times where almost every large-scale building project is questioned from the public and where the subsequent legal disputes result in significant project delays, sometimes even in the complete stop of a project, the importance of public awareness and public acceptance can not be over-estimated at all.

Having outlined the conceptual implications of SmartCoDe, the question arises, what the project precisely did to enable the above vision. In the following, we will therefore report on awareness-generation, the involvement of actors, dissemination activities, future research, and exploitation plans.

1.4.2 Spread Awareness / Involved Actors / Opportunities

SmartCoDe partners and associated partners published a book on the energy topic “Embedded Systems for Energy Management and Smart Appliances”. Differently from the traditional approach to research publications, the SmartCoDe book not only focuses on the technical aspects but also addresses the “big picture”,- it puts the technological aspect into the societal context.

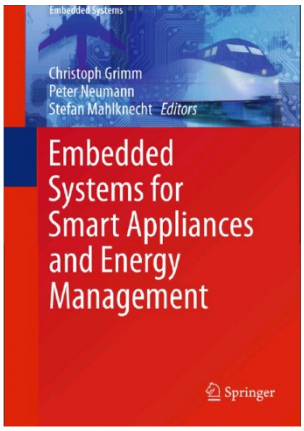

Figure 1.4.2.2: The SmartCoDe book index

The book addresses the consequences a shift from fossil energy generation to renewable energy generation has for the transport and distribution of electrical energy and analyses the implications thereof on the stability of the global grid. It further considers the chances and opportunities that arise with the shift from centralized energy generation structures to decentralized energy generation that accompany the above mentioned shift to renewable energy generation. It then bridges the gap to energy management in buildings and neighbourhoods (“SmartCoDe Clusters”), i.e. the active management (shifting and switching) of **Energy using and producing Products** (EupP, i.e. household appliances and local energy generation like PV or small-scale wind energy generation), before it finally addresses the “core” of the project, the microelectronic component that can be considerer the key enabling technology. A novelty is also that the book is not only available as a “complete” book in print and as eBook but also on a chapter basis for download. This allows a view only on certain aspects of the topic without the requirement to be an expert in microelectronics.

Further info on the book is available from Springer Publishers, US:

http://dx.doi.org/10.1007/978-1-4419-8795-2

To further promote the project’s concept SmartCoDe has released an animation outlining the project goals to the public (March 2011), a small video clip showing the wind turbine ramped up at the SmartCoDe demonstrator location at Buchberg, Austria (August 2011), and a video clip explaining project goals and intentions in more detail (March 2012). Animation and videos have been made available on the SmartCoDe homepage as well as on YouTube. On YouTube they have been downloaded more than 1600 times (status Nov. 2012). For the turbine ramp-up there is also a photo gallery available at https://www.edacentrum.de/gallery3/index.php/Projects/smartcode.

Figures 1.4.2.3 shows the YouTube reference. All three items are also available at the SmartCoDe website: https://www.fp7-smartcode.eu

Figure 1.4.2.3: SmartCoDe on YouTube

On a regional basis the SmartCoDe project became quiet famous: the demonstrator location where the turbine has been set-up is located on a small hill with an approximate height of 450 meters above see level. The result is that it is that the wind turbine visible in the surrounding area. The demonstrator location itself is a tenant’s house and a restaurant, and the restaurant’s owner reported that he experienced more visitors since the turbine ramp-up,- a lot of guests also were interested in the whys and wherefores of this setup.

So it was not very surprising that during early 2012 the Austrian television ORF became aware of the SmartCoDe demonstrator setup at the Buchberg location near Vienna. ORF indicated interest to broadcast a short report on the project in its regular television program "konkret". In late February 2012 they taped the SmartCoDe set and it was broadcasted on ORF2 on March 10, 2012.

SmartCoDe has further released several research publications, it appeared in magazines and has presented the project's goals and objectives on numerous conferences and workshops.

In March 2012 it further had the opportunity to present the project results to the European Commissioner for the Digital Agenda and Vice-President of the European Commission, Mrs. Neelie Kroes, at CeBIT 2012, probably the largest event for the ICT community with more than 300.000 attendants each year (figure 1.4.2.4).

The full list of publications is available as deliverable D-5.5 as public download at the SmartCoDe website at https://www.fp7-smartcode.eu.

Figure 1.4.2.4: SmartCoDe coordinator Peter Neumann presenting an example of a so-called System-in-Package (SiP) microelectronic component to EC VP Mrs. Neelie Kroes at CeBIT 2012

Also from an educational point of view the SmartCoDe project has been quite successful. At University of Novi Sad (UNS) a new course on *Embedded Systems for Power Efficient Buildings* was introduced into the study program *Energy Efficient Engineering* at the Faculty of Technical Sciences in 2011. The SmartCoDe team at UNS took part in the shaping of the study program and defined the theoretical and laboratory parts of the course. The study program is currently evaluated to become accredited by the National Agency for Quality Assurance and Accreditation (of Higher Education). In addition two PhD-thesis are currently running at UNS in the context of the SmartCoDe topic, namely:

- "Localized energy-efficient and energy-balanced dispatch of robots to events in wireless sensor networks"
  Author: Milan Lukic (UNS), on-going
- "Auction Agregation Algorithms for Task Assignment in Wireless Multihop Electronic Sensor and Actuator Networks"
  Author: Ivan Mezei (UNS), defended in 2012

In addition to several Batchelor and Master theses three PhD-theses have been started in the context of the SmartCoDe project at Technical University of Vienna:

- "Power Supply Concepts for Wireless Sensor Nodes in Smart Appliances"

Author: Franz Lukasch (TUV), on-going

- “Crossing Modelling Paradigms in System Models“
  Author: Markus Damm (TUV), on-going
- “Topology Analysis of Indoor Wireless Networks using Deterministic Channel Simulation”
  Author: Edgar Holleis (TUV / Tridonic), on-going

It is important to note here that SmartCoDe partner Tridonic is in the business of deploying large-scale lighting automation networks and is currently at the verge of going wireless. These wireless networks share many characteristics with SmartCoDe's wireless energy management approach and therefore the SmartCoDe project results will provide valid input the future Tridonic product roadmap.

Right from the start of the project the SmartCoDe team was pushing the integration of research institutions and industry as so-called *Associated Partners* of the project. In this context the cooperation of the project with Associated Partner Technical University of Kaiserslautern has been very productive. The Technical University of Kaiserslautern has set up a two new lectures on “Energy Aware Embedded Systems” in the context of the SmartCoDe topic and is planning to start four PhD thesis in 2013 in the area of the “Smart Grid”.

<u>Exploitation Opportunities:</u>

The project’s concept of Associated Partnerships has been mentioned earlier. As of today (Dec. 2012) twenty-two companies and research institutions have signed an Associated Partnership with the SmartCoDe project, among them global industry player like Siemens, SMA Solar Technology, Telefunken Semiconductors, Bosch-Siemens Hausgeräte (BSH) and others. Worth mentioning is especially the engagement of BSH which not only provided the project with white goods appliances for the research demonstrator at the Maria-Anzbach location in Austria but also served the project with valuable input on the topic of energy management of household appliances.

One of the major targets of the project is to develop a microelectronic component (the “*SmartCoDe Node*”) that can be integrated into as many household appliances as possible. To achieve this goal, the component must be available at a low-cost of approx. 3-5 Euro per device. This goal clearly can only be achieved when the component is manufactured in mass-production of several million units per year. Since this can not be achieved at once there has to be a path to mass-production.

SmartCoDe partner Infineon therefore has taken further action to address potentially interested customers for its SmartCoDe development results. Basically two exploitation scenarios have been identified:

- The short- to mid-term target is to market subsystems and components.
- The long-term anticipated goal is the marketing of a miniaturized System in Package (SiP) integrated platform.

In order to tackle business opportunities with the IP developed in SmartCoDe, negotiations with several companies have been set in place. This includes both product/system manufacturers as well as service provider from different application markets (home automation, smart grid, solar systems, industrial).

Apart from the negotiations with SmartCoDe Associated Partner and white-goods supplier Bosch-Siemens Hausgeräte (BSH) also the home-appliance provider Philips showed strong interest for both the current/power meter and the whole platform concept. Philips SmartCoDe-relevant portfolio reaches from “simple” household products/appliances up to lighting products and lifestyle/system solutions. For Infineon this is the chance for an initial design-in of available SmartCoDe IP. For the power metering approach it has already been agreed that samples of available prototypes will be transferred to Philips for detailed evaluation.

Another new exploitation opportunity that recently arose is the exploitation of the SmartCoDe microelectronic platform for remote monitoring and maintenance of photo voltaic generators and plants. A detailed investigation of the relevant market is scheduled for 2013.

While project partner Infineon is addressing the mid- to long-term goal of a highly-integrated, ultra-low-power, low-cost microelectronic device to enable the active management of mass-appliances, project partner ennovatis is planning to address **energy management of industrial appliances in small and medium enterprises** (SME). Since the number of required nodes is smaller than in private homes and the amount off energy that can be saved per node is much larger, from a financial point of view it is acceptable to produce the microelectronic components in a non-integrated, discrete fashion at a price of 20-30 Euro per node. The results from a roll-out of the SmartCoDe concept in SMEs, which can be considered as a field-test, will have a significant (verification-) impact on the highly-integrated version to be mass-rolled-out for household appliances.

The involvement of household appliance manufacturers and energy management in SMEs however is only one part of the SmartCoDe concept. Energy management in buildings is achieving its greatest value only when a communication interface to the global energy provider is established. Energy provider in general however have been very conservative in the past when it comes to the (expensive) set up of communication links to the energy end user. One of the biggest problems here is the absence of standardisation and the unclear situation concerning the legal regulations, i.e. who will provide which kind of service and how will the significant required investment be regained.

As mentioned earlier the structure of energy generation in general is changing due to the shift to renewable sources. A lot of energy generation facilities are small- and medium-class facilities and are connected to the distribution grid on a regional basis. This however leads to a shift from having only few but large energy provider companies to an increased importance of regional, often municipal energy provider. There have been very promising discussion with these municipal stakeholders lately and especially the mid-term target of including SME energy management on the basis of discrete SmartCoDe nodes seems to be a hot topic. The reason is not only the opportunity to reduce energy consumption and to balance the local energy load: the installation of a fine-grained local network of communicating SmartCoDe Nodes within the SME appliances can also **exploit previously unused locally available storage capacities**. Examples are *air pressure systems* or *warehouse freezers*. If intelligently managed and communication-connected to the global grid these energy capacities can be utilized to **store and release energy on demand** (of the grid or the local utility) and therefore provide the desperately needed energy balancing capacities to the grid operator. From our point of view an exploitation of such capacities offers great opportunities for the *near future*, since the **actual storage capacities are already at hand and only have to be enabled with limited financial investment**.

Standardisation: The eeSmantics Project:

On the 24 Sept. 2012 a **Workshop on a Roadmap for the Standardisation of Smart Appliances – "Plug-and-Play" interoperability of Energy using and producing Products (EupP)** took place in Brussels. The workshop, initiated by EC Project Officer Rogelio Segovia, included different stakeholders of manufacturers of white goods, Heating, Ventilation and Air Conditioning (HVAC), plumbing, security and electrical systems, lightings, sensors and actuators (windows, doors, stores), micro renewable home solutions (solar panels, solar heaters, wind, etc.), and other indirect stakeholders like the construction industry, facility management and building control industry, Energy Services Providers (ESCO), utilities and operators of the power grid, together with several standardisation bodies, to discuss a roadmap for a standardization action in the field.

From the executive summary:

"*An increasing amount of products and appliances is networked and controlled remotely. The rapid market adoption of smartphones and tablet computers is not only a prime example of this trend, but has also initiated a change in the way people control devices. At present, consumers and industries are confused by the diversity of non-interchangeable wired and wireless communication standards that prevents smart appliances from appearing in larger numbers in the European markets, some of them proposing conventions at layers above communications, at vertical markets (like, for instance energy) with de facto silo approaches. To increase adoption of these technologies, the workshop brings together stakeholder with the objective of creating a roadmap towards agreed solutions for interoperability. Focus is communication with smart appliances at information level in smart homes. Use case is energy management, but closely related use cases like lighting, eHealth, surveillance, multimedia, 3play are considered as well.*"

A driving force in the standardisation of EupPs is former SmartCoDe Partner and now SmartCoDe Associated Partner Prof. Dr. Christoph Grimm from the Technical University of Kaiserslautern. The EupP categorization derived from the SmartCoDe project has been chosen as a starting point for the discussions at the workshop. The project therefore has initiated and provided a basic fundament for a common approach for EupP classification in the future. Figure 1.4.2.5 shows the proposed energy label including the SmartCoDe DSM compliance.

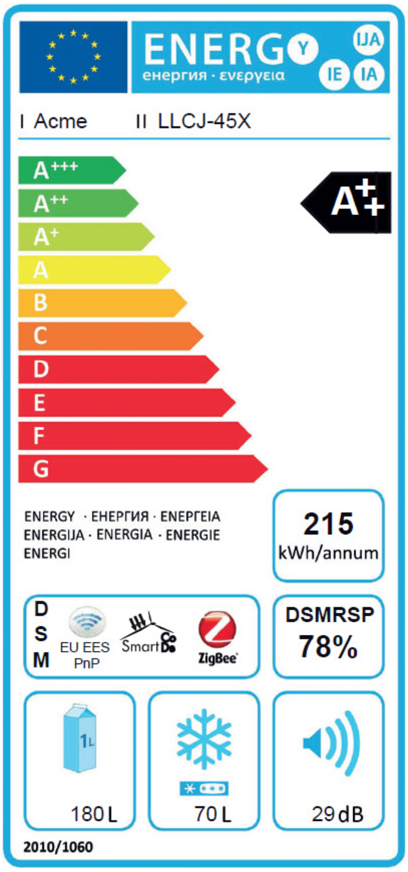

Figure 1.4.2.5: Proposed SmartCoDe DSM Compliance

1.5 General Information

SmartCoDe Web-Portal:
www.fp7-smartcode.eu

Public available project reports at www.fp7-smartcode.eu

(1) D-1.1.1 Model of local energy resource cluster, initial report
(2) D-1.1.2 Model of local energy resource cluster, final report
(3) D-1.2 Methods for advanced power management in local grids
(4) D-1.3 Energy generation forecasting report
(5) D-1.5 Evaluation report
(6) D-1.6 Energy generation forecasting evaluation
(7) D-2.2 Executable specification of a SmartCoDe node (functional model)
(8) D-3.1.1 Overall SiP cost estimation
(9) D-4.1 SmartCoDe Demonstrator Test Plan
(10) D-5.1.1 Web Portal
(11) D-5.1.2 Energy-Positive Local Cluster Dissemination Platform
(12) D-5.2 Research and Development Map
(13) D-5.3.1 Expert Cooperation Workshop
(14) D-5.3.2 Expert Cooperation Workshop
(15) D-5.3.3 Expert Cooperation Workshop
(16) D-5.3.4 Press Releases and Video
(17) D-5.5 Scientific Publications

SmartCoDe Demonstrator Location at Buchberg, Maria-Anzbach, Austria

The SmartCoDe demonstrator is located in Austria, 40 kilometers outside of Vienna. The location is on 469 meter height above see level.

The demonstrator building is inhabited by a family that also runs the connected restaurant ("Schutzhaus Buchberg").

The picture on the left shows the respective building together with the SmartCoDe small-scale wind turbine installation from project partner Quiet Revolution, as seen from the close-by 23-meter look-out tower ("Buchbergwarte").

SmartCoDe Project Partner

Project Partner		Role in the Project	Partner Contact
edacentrum GmbH (Coordinator), Germany		Project management; Project dissemination; Web-based project platform;	Peter Neumann Neumann@edacentrum.de
Infineon Technologies Austria AG, Austria		SoC / SiP partitioning; Packaging of SiP; Chip manufacturing;	Thomas Herndl Thomas.Herndl@infineon.com
Vienna University of Technology, Austria		System level design of the SmartCoDe node; Modelling & simulation;	Stefan Mahlknecht Mahlknecht@ict.tuwien.ac.at
ennovatis GmbH, Germany		Energy management concept; Software development;	Roland Kopetzky R.Kopetzky@ennovatis.de
Tridonic GmbH & Co Kg, Austria		Lighting Application scenario; Building automation concepts; Commissioning concepts;	Walter Werner Walter.Werner@zumtobel.com
Ardaco a.s., Slovakia		Security; Protocol layer SW;	Daniela Pavlanska Daniela.Pavlanska@ardaco.com
Quiet Revolution Ltd., United Kingdom		Local small-scale energy Generation, Energy forecasting;	Wayne Hurley WayneH@quietrevolution.co.uk
University of Novi Sad, Serbia		Energy management HW & SW development; Demonstrator set-up	Veljko Malbasa Malbasa@uns.ac.rs