Smart Grid Ready House

A European definition of a Smart Grid Ready House, based on existing solutions

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Final report

European Project Semester

Vaasa, May 2015

Prologue

This report is the result of the European Project Semester in Vaasa during the spring of 2015 and contains the research that has been done by a team of international students. The team consisted of Merce Ros from Spain, Niels Symons from Belgium, Dariusz Szwarc from Poland, Mathias Thuysbaert from Belgium and Lukas Zenz from Austria and who worked part-time on the project.

A European Project Semester has as a goal to make you familiar with working on a project in an international group. A part of this goal is to deliver a decent report about the project the team worked on during the past months, but even more important is the experience to work in a team with people with different nationalities.

So we would like to thank Niklas Frände, the team supervisor, and Roger Nylund, the EPS coordinator, to give us the possibility to be a part of this semester and be able to gain this experiences. We would also like to thank Babette Masselink from the university of Den Haag, in the Netherlands, for she learned us a lot about working together in international teams.

Finally we would also like to thank Aalto university, ABB, Anvia, There corporation, Vaasa energy week 2015, Vaasa university and Wapice for the time they spent helping us and the information they provided us and which gave us the possibility to create a better view on the subject.

Merce Ros, Niels Symons, Dariusz Szwarc, Mathias Thuysbaert and Lukas Zenz,
Vaasa, 15th of May 2015

Abstract

Smart grid is a new topic, which is getting more important all over the world. It leads to new research and development fields and a lot of new invented systems. Companies in the energy sector are working on different fields within the smart grid technology, which causes a lot of different solutions and system. Sometimes these systems are not able to interact with each other, which in turn is the most important thing in a smart grid. Renewables, households, industry, electric vehicles and all other parties of the electrical grid have to interact in an efficient way. To prove how these new developed technologies are working and interacting with each other, a lot of pilot projects are set up all around the world. Results and experiences of these projects provide companies and governments with very important information on how the future track should look like.

In the following document the introduction of households in a smart grid will be discussed. First a general information about smart grids and smart homes will be given and also the explanation of why this project is important. The communication will be separated into general information, how it is working today, how it should work in the future and smart meters. Two pilot projects, one from Finland and one from Spain are shown with a focus on data communication. Then the home systems, which include the network structure and most important devices for home area networks and how this differs from energy management, will be explained. In this part there are also some pilot projects discussed. In the energy part the topics of renewable energy sources and energy storages are explained in more detail. An overview of the existing systems is given and the advantages are listed and compared. Out of this comparison a conclusion is done. As a final part of this document the benefits of a smart grid and conclusions of this project are given.

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List of Abbreviations

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
ASCII	American Standard Code for Information Interchange
BACS	Building Automation and Control System
DR	Demand Response
DSO	Distribution System Operator, electricity provider
ERDF	European Regional Development Fund
ERGEG	European Regulators for Electricity and Gas
GUI	Graphic User Interface
HAN	Home Automation Network
HVAC	Heating, Ventilation and Air Conditioning
IoT	Internet of Things
Irms	Intensity in root mean square (Irms = I / √ 2)
ICTs	information and communication technologies
IEC	La international electrotechnical commission
IP	Internet Protocol
Kbps	Kilo bytes per second (= 10^3 bytes)
LAN	Local Area Network
Mbps	Mega bytes per second (= 10^6 bytes)
NAN	Near-me Area Network
OSGP	Open Smart Grid Protocol
OPEN	Open Public Extended Network metering
P	Powe Average (P = Vrms Irms cosθ = $Irms^2$ R)
Pbps	Peta bytes per second (= 10^{15} bytes)
PLC	Power Line Communication
P2M	point to multipoint
Q	Reactive Power (Q = Vrms Irms sinθ = $Irms^2$ X)
RES	Renewable Energy Sources
RF	Radio Frequency
S	Complex Power (S = Vrms (Irms)* = Vrms Irms ∠θ
ToU	Time of Use
US	United States
Vrms	Voltage in in root mean square (Vrms = V / √ 2)
WAN	Wide Area Network
Wi-Fi	Wireless Fibernet
WiMAX	Worldwide interoperability for Microwave Access

1 Project organisation

The focus of this project is on the Smart Grid Ready houses. However since it is an academic project there are also secondary objectives. Those objectives focus on giving the participants possibility to improve their skills like soft skills and to learn more about different aspects that may help to deliver a successful project.

1.1 Who are we

The next subchapters will give more explanation about the team and what the setup of the European Project Semester is.

1.1.1 European Project Semester

European Project Semester, EPS, is a programme offered by 13 universities in 11 countries in Europe. It was created to prepare engineering students with the necessary skills to face today's world, focussing on the design requirements of engineers. The projects are interdisciplinary and in English. Therefore all students with different backgrounds should be able to contribute something to the project.

1.1.2 Meet the Team

The team consist of 5 international students each from different background. There is a variety of skills present ranging from critical thinking to sustainable engineering. Part of the EPS program is to work together and break through the intercultural barriers, to make sure that the project becomes a succes.

Table 1 : Team members

Team member	Origins
Ros Perache, Mercè	**Country:** Spain **Home University:** University of Lleida - Polytechnic **Degree Program:** Building Engineering (Bachelor)
Szwarc, Dariusz	**Country:** Poland **Home University:** Lodz University of Technology **Degree Program:** Mechanical Engineering (Bachelor)
Symons, Niels	**Country:** Belgium **Home University:** University of Antwerp **Degree Program:** Industrial Construction Engineering (Master) **Home University:** University of Leuven **Degree Program:** Civil Construction Engineering (Master)
Thuysbaert, Mathias	**Country:** Belgium **Home University:** Artesis Plantijn - University College **Degree Program:** Energy Management (Bachelor)
Zenz, Lukas	**Country:** Austria **Home University:** University of Applies Sciences - Technikum Vienna **Degree Program:** Urban Renewable Energy Technologies (Bachelor)

1.1.3 The foundation

The project was provided by Kristian Blomqvist and is supervised by Niklas Frände, both researchers at R&D department at Novia University of Applied Sciences. The project focuses generally on cooperation between households and smart grids. The project assumes working more closely on Smart Grid Ready houses. A 'Smart Grid Ready' (hereafter reffered to as SGR) means that an entity can be connected to a smart grid and work as an integral part of it, making use of all of its features. This includes the ability to communicate with the grid to improve its stability and reliability, being able to operate in a decentralized fashion and many more. Initially the goal was to create a standard that Finnish houses should follow in order to be SGR. However as it will be explained later in the report this appeared to be impossible and thus the goal had to be adapted.

1.2 Team identity

This part of the report is about the organization and structure of the team. More precisely, about the team identity and the project management, thus mission statement, vision, responsibility matrix, etc. The team identity is made up of different parts. The biggest one is the team contract, in which the rules and the expectations are fixed.

1.2.1 Team contract

The team contract contains the rules for the chairman, secretary for meetings and also for the Project manager and Project secretary. The templates for agendas and reports are also fixed in this contract. (Team contract attached in the annex A)

1.2.2 Logo, contact and web

During the first meetings it was agreed to create a logo (figure 1) as a part of the team identity. The logo should give a first thought about what this project deals with. There were some different suggestions and versions of the logo made. After comparing these versions the team agreed on the following logo.

Figure 1 : Team logo

To explain this logo a bit more: The colour of the text and the first bar is based on the blue in the Finland flag, because this project is situated in Finland. The bars should represent how the energy consumption can be decreased with a smart home and also the internet/Wi-Fi connection from the smart home to the grid. And the text should give a short overview of what this project is about. The shortcut is SG4F and it means: "Smart Grid for Future". The F includes the Finland flag and should also refer to where this project is situated in.

A title (figure 2) has also been created which is used in the WordPress webpage.

SMART GRID 4 F

Figure 2 : Smart grid title figure

To stay in contact with companies and other outstanding organizations, on a professional base, a group e-mail address has been created. This e-mail address – smartgrid4f@novia.fi - is available to use for every team member.

To work on a professional level and to show that to companies, the team agreed on creating a webpage, in which a short project specification, a "About us" site, a Blog with the ongoing process, and the contact details are included. This is the link to the WordPress webpage: smartgrid4f.wordpress.com.

Figure 3 shows one example of the Businesscards, each team member has.

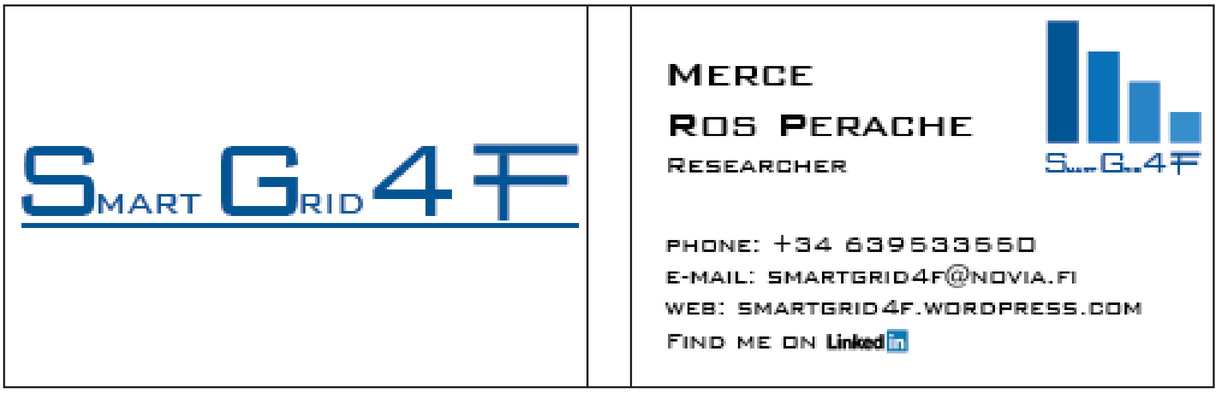


Figure 3 : Business card example

1.3 Project management

Project Management revolves around the entire project. It is a tool used to make sure that the project is both clear and that it is easy to keep track of all events. The purpose of this type of management is to define certain standards that allow making sure that the project comes out on top in regard to accuracy and clarity.

1.3.1 Mission and Vision

The mission and vision for this particular project were tools used to obtain a clear definition of the project. For this exercise out of the box thinking was essential, because one would assume that defining a project would be easy. But nothing is further away from the truth. When one is creating one's goals and path on how to get there, there are several things which need to be taken into account.

A. Mission

To define a smart house based on existig solutions.

B. Vision

Table 2 : Vision requirments

Must	Want	Nice to have
Lessons learned	Company input	Environmental impact study
Compact summary		Visit pilot projects
Research		
Conclusions		

Description of the chart

Through research and lessons learned, from the pilot projects all over Europe, derive a compact summary and conclusions about what is a Smart House and to make a document that handles about the work being done right now and what the team thinks will be the future of smart grid housing. Company input will be used as a backbone for this research and conclusions, so that a document can be prepared that can be used by all parties such as; companies, governments, study groups, etc. An environmental impact study should be done if there is enough time left. It is to make sure that the new technology has no or as small as possible impact on the environment.

Table 3 : Tools and techniques

Input	Tools & techniques	Output
Companies	Thinking process	Standard
Online documents	Calculations	Tool
People at Novia	Research	Report
Pilot projects	Networking	ECTS
Work	Company meetings	

1.3.2 Project specification

The project specification is a more detailed comprehension of the previously defined mission and vision. It goes deeper into how the team is going to establish the various items that will be researched and added to the project. It also provides a clearer outlook on the project's principle ideas and intakes.

A. Specification

The goal is to define a smart grid ready house based on existing solution. These solutions contain, pilot projects, existing systems and regulation. We will achieve this goal by researching and summarizing these existing solutions, pilot projects, regulations and existing systems. The industrial input will be used in a supporting manner, as it is not really mandatory for the project. So that in the end the group can present a compact summary of what is a SGR house and present the conclusion. If there is time left the project will include an environmental impact study about energy storage through various elements. If the timeline allows it, visit some pilot projects.

The project focuses on Europe and includes:

- A compact summary (about the existing solutions).
- Final conclusions about the definition.
- Lessons learned from the pilot projects.

The project does not include:

- Defining a standard.
- Specific descriptions of the production / distribution of energy on the network.
- A description of specific appliances.

B. Project structure

- Intro of SG
- Why Smart House
- Why this project
- Own Research
- Existing Regulations
- Real Systems
- Our vision on Smart Grids
- Summary of our project

1.3.3 Responsibility

With this tool it will be easier for the project group, to keep track of who does what and to see that the work will be distributed equally amongst the various team members. It also gives the insurance about various standards the team wants implemented in the project work.

Things we expect from a responsible team member;

- On time
- High quality of deliverable
- Status reports
- Overview of how the task is progressing
- Push the team forward
- Delegate subtasks

A. Matrix

Table 4 : Responsability matrix

TASK	Responsible	Main Author	Support	Finished
1 Introduction	Niels			24/3
1.1 Intro of SG	Niels	Mathias		23/3
1.2 Why Smart House	Niels	Merce		23/3
1.3 Why this project	Niels	Dariusz		23/3
2 Own Research	Lukas			13/4
2.1 Comm 2 Grid	Lukas	Merce	Niels	13/4
2.1.1 Privacy + Data protection	Lukas	Niels	Merce	13/4
2.2 Home System	Dariusz			13/4
2.2.1 HAN-System	Dariusz	Mathias		13/4
2.2.2 USER-Control	Dariusz	Mathias		13/4
2.3 Energy	Mathias			13/4

2.3.1 RES	Mathias			13/4
2.3.2 Energy Storage	Mathias	Lukas		13/4
2.3.3 Energy Consumption + Price	Mathias	Niels		13/4
2.4 Existing Regulations	Merce		Dariusz	13/4
3 Real Systems	Mathias			27/4
3.1 Comm 2 Grid	Lukas	Merce	Niels	27/4
3.1.1 Privacy + Data Protection	Lukas	Niels	Merce	27/4
3.2 Home System	Dariusz			27/4
3.2.1 HAN-System	Dariusz	Mathias		27/4
3.2.2 USER-Control	Dariusz	Mathias		27/4
3.3 Energy	Mathias			27/4
3.3.1 RES	Mathias			27/4
3.3.2 Energy Storage	Mathias	Lukas		27/4
3.3.3 Energy Consumption + Price	Mathias	Niels		27/4
3.4 Existing Regulations	Merce		Dariusz	27/4
4 Our Vision of SG	Lukas			11/5
4.1 Comm 2 Grid	Lukas	Merce	Niels	11/5
4.1.1 Privacy + Data Protection	Lukas	Niels	Merce	11/5
4.2 Home System	Dariusz			11/5
4.2.1 HAN-System	Dariusz	Mathias		11/5
4.2.2 USER-Control	Dariusz	Mathias		11/5
4.3 Energy	Mathias			11/5
4.3.1 RES	Mathias			11/5
4.3.2 Energy Storage	Mathias	Lukas		11/5
4.3.3 Energy Consumption + Price	Mathias	Niels		11/5
4.4 Existing Regulations	Merce		Dariusz	11/5
5 Summary	Dariusz			11/5
Lay-out	Niels		Mathias	22/5

The matrix is a clear and well defined structure, it points out the various team members working on specified tasks. It defines the following "responsibilities":

- Responsible: This person will make sure that the work is finished on time.
- Main author: If the responsible person is not the main author, it is mentioned, he/she is managed by the responsible person.
- Support: Responds directly to the main author, helps where she/he can.

These different tasks and responsibilities will make sure that the project will be finished on time and according to our standards of quality.

1.3.4 Work Breakdown Structure

A work breakdown structure (hereafter abbreviated as WBS), is a tool used in project management, where one tries to divide the global project into smaller deliverables. This is a means to divide one big task into a lot of smaller tasks to make sure that a project is not as complex as it seems to be.

A. WBS

The first WBS was more hands on and not really thought through, that is why it was tried the use an easier approach, and come up with a better solution. That is why the second WBS is more of a detailed project structure.

1. Introduction
   - 1.1. Introduction of Smart Grid
   - 1.2. Why Smart House
   - 1.3. Why this project
2. Own research
   - 2.1. Communication to the grid
     - 2.1.1. Privacy and data protection
   - 2.2. Home system
     - 2.2.1. HAN system
     - 2.2.2. User control
   - 2.3. Energy
     - 2.3.1. Renewable Energy Sources
     - 2.3.2. Energy storage
     - 2.3.3. Energy consumption and pricing
   - 2.4. Existing regulations
3. Real systems

   The detailed structure and responsibilities follow the point 2.
4. Teams vision on Smart Grid

   The whole point follows structure and responsibilities of point 2.
5. Summary of this project

1.3.5 Gantt chart

A Gantt chart is a timeline. A timeline that includes all the different task and milestones the team provides for the entire project. It spans from the first day, when the project began, untill the very end when the team has to hand in the project. As well as a project a Gantt chart is a tool that evolves over time, that can adapt to every litlle thing that changes during a project.

A. Draft

For the new direction of the project a totally different gantt chart was made and based upon the new WBS. This provided the team with an entire new timeline since almost everything changed regarding research and baseline of the project. Can be found in annex B.

1.3.6 Risk management

Risk management is all about minimizing or controlling the risk involved with a project. For this part of the project one identifies and mitigates most of the risks involved with the project. If one is not able to, one has to make sure that the consequences tied to the various risks are small enough so they can be handled until project ending.

A. Identification of risks

- Getting behind the schedule
  - Because someone is not doing the tasks he/she has to do
  - Slow start on subtasks
  - No internet
- Not enough input
  - From companies
  - From research
  - From team members
  - Because the companies are not reached
  - Bad research
- Unavailability of members
  - Sickness, injuries...
  - Essential persons are on trips
- Lose track of the scope
- Crash of OneNote and loss of data
- Bad communication
  - Double work
  - Wrong work
  - Getting behind the schedule
- Language problems
  - Bad communication with companies
  - Bad team communication

B. Probability table

The following table (Table 5) shows theprobabilitiy for every risk which was mentoined before.

Table 5 : Occurence chart

Risk	Chance (1 to 5)	Damage (time, 1 to 5)	Total
Getting behind because of a slow start	3	3	9
Getting behind because of bad communication	1	2	2
Getting behind because there is no internet	2	1	2
Lack of input from companies	4	4	16
Lack of research on standards	2	3	6
Lack of input of team members slacking	3	4	12
Losing track of the scope	1	4	4
Lack of input because the companies can not be reached	2	3	6
Lack of input because of bad research	3	4	12
Sickness and injuries	1	3	3
Essential persons on trips	3	4	12
Crash of OneNote and los of data	1	5	5
Double work because of bad communication	2	1	2
Wrong work because of bad communication	2	2	4
Getting behind on schedule by bad communication	1	3	3
Bad communication with companies (language)	1	2	2
Bad team communication (language)	2	3	6

C. Prevent or mitigate

Risks with a total of 8 or higher shall be prevented. Risks in between 4 and 6 shall be prevented or mitigated depending on the possibilities. Lower risks will be mitigated.

D. Solutions for 8 to 16 scaled risks

- Getting behind because of a slow start
  - Checking the progress during meetings (fixed agenda point)
  - Usage of the responsibility matrix
  - Weekly planning (Gantt chart 2-3 weeks in progress)

- Lack of input from companies
  - Contacting a lot of companies
  - In case of big companies, adressing more people
  - Ask people in the university if they have connections
  - Asking references for other companies if they do not have information
  - Mailing more than once in case of no answer
- Slacking team members
  - Checking the to-do's in the beginning of the meetings
  - Project secretary is micro managing the ToDo's
- Bad research
  - More then one person on research, try to have at least three people
  - Expert meetings for the people who are doing the research so they can validate and share data
- Essential persons on trip
  - See that they do not have essential to-do's on the time that they are away
  - Transfering responsibilities
  - Making some clear rules for communication during trips and holidays

E. Solutions for lower scaled risks

- Lack of research on standards
  - Putting more people on the research (at least three)
  - Do not wait to long before going to the supervisor
  - Looking to other countries (Scandinavian, Europe, world)
- Can not reach companies
  - Immediately look if the team can get there and contact the supervisor if needed
  - In case of emergency, rent something ourself and try to get the money back later
- Language problems in the team (lack of research, communication...)
  - Making reports and to-do's
  - Check each others' work
  - More people researching = more languages = bigger basses

F. If the big risks become reality

- Getting behind because of a slow start
  - See how it comes and prevent it in the future, more people on the task, more work on the task
- Lack of input from companies
  - Fall back on the research and do the best we can based on the information we found and what has been suggested by te supervisor
- Slacking team members
  - Tell team members in meetings
  - If it keeps happening, go to supervisor
- Bad research
  - Do more research with different people and get things straight
- Essential person on a trip
  - Use the emergency communication tool

G. Trigger points

- Getting behind because of a slow start
    - Missed milestone
    - When the ending date of a task is rescheduled
- Lack of input from companies
    - If there is almost no viewpoint (1 or 2) and the information is not detailed enough after we tried everything or when we are running out of time (3 weeks).
- Slacking team members
    - Missing too many ToDo deadlines
    - When the deadline is missed of a ToDo for 2 meetings
- Bad research
    - When things do not align anymore or an expert is telling a different story
- Essential person on a trip
    - When we need information from a person on a trip

Table 6 : Tools and techniques

INPUT	TOOLS & TECHNIQUES	OUTPUT
WBS	Team meeting	Risks for project
List of risks, Stakeholder analysis, Expert judgement	Team meeting	Risks' severity assessment
List of risk with ratings, Team contract, Gantt chart	Team meeting	Solutions for major risks, solutions for minor risks

1.3.7 Time management

As a group sets out on a project path, it is necessary to keep a record of the time the team members spent on various tasks and writing summaries. In the end it is usefull to see how much time the team needed to finish the project and to reflect upon itself. Also the evaluation after the project can be done easier with this time management.

During the project each team member was free to keep their record in any way they wanted to. But the goal was to make sure that every little detail was present in the record. That is why the team uses the excel sheet provided by team member Symons Niels to keep record of their time spent on the project.In these records one can find the time spent on;

- Various classes
- Research time
- Work at home
- Vacation

The excel sheets can be found in the annexes C-G.

2 Introduction

Due to the increasing amount of renewable energy sources and the increasing global energy demand, the temporary energy grid needs a makeover to be able to keep handeling this. The solution can be found in a smart grid. What a smart grid is and why this project has the focus on smart houses will be explained in the following subchapters.

2.1 What is a smart grid?

The smart grid has come to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy. (US Dep. of Energy, 2015) If we look at the electric grid today we see that there is only one-way communication, which leads to a volatile state of the electrical grid. The smart grid is a way to establish a two-way communication on the electrical grid. This will give the utilities the information directly from the consumers leading do the stabilization of the electrical grid.

The general understanding is that the Smart Grid is the concept of modernizing the electric grid. The Smart Grid comprises everything related to the electric system in between any point of generation and any point of consumption. Through the addition of Smart Grid technologies the grid becomes more flexible, interactive and is able to provide real time feedback. (IEC, 2015)

Efficiency is also one of the main concerns among the utilities for the introduction of smart grids to the consumers. These days the utilities experience a loss of efficiency on the grid because of the unstable and volatile nature of energy usage. By introducing the smart grid and the two-way communication the utilities can improve the stability of the grid and thereby enhancing the efficiency of the energy generation by the power plants.

2.1.1 Basics of smart grids

The backbone of the smart grid system is the two-way communication between the utilities (who provide the electricity) and the consumers (who need the electricity). The grid today uses one-way communication (from the utilities to the consumers) which creates a lot of problems for grid reliability and efficiency.

The utilities are enhancing the electrical grids and transforming them into digital networks that will deliver the two-way communication needed to provide the consumers with more reliable power distribution. These "smart" electrical grids will utilize telecommunications and information technology infrastructure to enhance the reliability and efficiency of the distribution network. Because of this two-way communication, this will result in the fact that the utilities will be able to meet and adapt to the ever growing power needs of our digital economy. (SGIC, 2013)

The two-way communication provided by the modern grid will not only make it easier for the utilities to detect and repair service disruptions but also to reduce the amount of disruptions on the electrical grid. The interconnectivity will also make it possible to minimize the effect of the disruptions when they do occur. Due to the higher efficiency on the grid, it will be easier for the utilities to respond to the demand of power needed at a certain time, because of the fact that have access to the real-time power loads provided by the customers. This will also help the customers understanding of their power usage and will result in a decrease of energy price.

To deliver this sustainable, efficient, reliable and secure power supply, the smart grid will employ innovative product and services together with intelligent monitoring, control, communication and self-healing technologies to:

- Enhance reliability and security of supply
- Improve efficiency on demand and response
- Allow consumers to be a part in optimizing smart grid operations
- Enhance the interconnectivity between producers, consumers and "prosumers"

A smart grid is an evolved grid system that manages electricity demand in a sustainable, reliable and economic manner, built on advanced infrastructure and tuned to facilitate the integration of all involved. (ABB, 2015)

2.1.2 Towards the future

There is no denying that smart grids are necessary in the years to come, not only for the customer itself in case of energy pricing but also for the ever increasing demand of energy in our modern economy. But it has to be kept in regard that the implementation of smart grids in the infrastructure of today's network, will demand some serious compromises and actions. These are stated in the following commentaries;

"In order for the Smart Grid to be successful, there needs to be a set of well-established standards in place that all industries and organizations involved can utilize." (Dr. W. Charlton Adams)

Electrical systems will undergo a major evolution, improving reliability and reducing electrical losses, capital expenditures and maintenance costs. A smarter grid will provide greater control over energy costs and a more reliable energy supply for consumers. (IEC, 2015)

The vision of a modernized electrical delivery system (the Smart Grid) promises to revolutionize the production, delivery and use of electricity worldwide. Enormous investments are underway to move nations toward energy independence and environmentally sustainable economic growth. (IEEE Smart Grid, 2015)

Looking towards the enormous benefits of "Smart Grids", there are a few that demand our attention. When we have the technology of the smart grids in place, it will be much easier for the consumer to implement RES, connect them to grid, and become a "prosumer'. This will provide the utilities with the means to lower their own production of energy, and they will be able to shutdown some of their own producing facilities, which leads to a decrease of CO_2 emissions and also a decrease in energy price.

2.2 Why a smart house?

Smart houses are a necessity in order to make the smart grid work in the most efficient way. Without smart houses, provided with smart meters, the real-time pricing will not be possible and a big advantage of the smart grid will be lost. For this reason, smart houses should be introduced and become more familiar for the population in order to achieve an efficient energy market.

Smart houses and smart grids can be seen as two different parts that need each other to function in the most efficient way. Without smart houses, a smart grid could be enrolled and used to monitor the energy grid more in detail and achieve a higher reliability and a smart house could be introduced without a smart grid to reach a more efficient use of energy and reduce the energy bill. But coupling these two different components creates the opportunity of having a lot more advantages. Real-time energy pricing could be introduced, decreasing the energy bills even more. Inefficient power plants could be closed and the peas in energy demand could disappear.

This are only a few advantages that could become reality if synergy takes place between the smart grid and the smart houses. So although most of the research today is done in the field of the actual smart grid, smart houses are as important in the road towards a smarter and more efficient energy grid.

2.3 Why this project?

The term smart house is widely used today. More and more people use the word in discussions or written texts where it seems to fit quite well. But what is the exact definition of a smart house? According to the UK department of trade and industry, a smart house is "a dwelling incorporating a communications network that connects the key electrical appliances and services, and allows them to be remotely controlled, monitored and accessed" (Smart home energy, 2015). This definition mentions a communication network for data exchange and the remote control of appliances.

According to the Oxford dictionary, a smart house is "a home equipped with lighting, heating and electronic devices that can be controlled remotely by a Smartphone or a computer" (Oxford dictionaries , 2015). In this definition, the focus is more on the automation of a house and the possibility to control appliances from one device.

When referring to a smart house in the context of a smart grid, the idea is that the building should be able to exchange information with the energy grid, by using smart appliances, use the energy in a most efficient way (Nikko, 2015).

It seems that the definition of a smart house changes depending on the context where it is used. Some definitions focus on the exchange of information and the efficient use of energy while others focus more on the automation of appliances and the remote control of a building while some even combine the two. In this project, the focus will be on the smart houses used in smart grids and will try to give a describe the different aspects of a smart house, and the ongoing developments, in order to create a clearer view on what the term smart house for a smart grid actually covers.

Since there are currently 450 smart grid projects ongoing in the 28 member states of the European Union (Joint research centre, 2014), another goal of the project is to look at the different pilot projects that are ongoing in Europe and create a general overview of the obstacles that are encountered and the good practices that can serve as a solution for these obstacles or developments.

A lot of research is done in the US on the smart grid topic and however the project focusses on Europe, referrences from the US are used for theoretical parts since they are more experienced and have more documents handeling the subject.

3 Data Communication

In order to achieve efficient usage of the electricity, buildings have to communicate with the electrical grid. The Home Area Network needs the real time electricity price to decide wetter an appliance should be turned off or on and the grid needs to know if a building is producing or demanding electricity in order to define the real time energy price. This is why a Smart Grid is a two way communication network, where the existing electricity network is based on one way communication.

To support this transition of the electrical grid, the European Union obligated his member states to provide 80% of the buildings with smart meters by 2020 (European Commission, 2015). This means that in 2020 at least 80% of the buildings in Europe must be able to collect real time data about their energy usage and be able to share it with the electrical grid.

Although this is a step in the right direction, a smart meter is not sufficient enough. To use it efficiently smart appliances, home area networks and data communication capacity of the grid are necessary. The data communication infrastructure that the grid needs to handle all this information and the smart meters who collect all the data from the smart house will be discussed in this chapter. How the home area network, that provides the information for the smart meter works will be explained in chapter 4.1 (Home Area / Automation Systems).

3.1 Data communication infrastructure in the grid

The optimisation of the efficiency of the energy grid goes hand in hand with data transferring. To have a maximal profit of a smart grid, information about the weather, energy storages, energy consuming appliances and the grid itself is needed. In order to achieve this, a lot of data transferring capacity and data storage has to be available. Since this infrastructure is not installed in the temporary grids, companies and researchers are using pilot projects to see what kind of data communication is needed and how it can be achieved in a cost efficient way. (Aiello & Pagani, 2014)

This subchapter will take a deeper look in how the future data communication in the grid will look like. It will give an insight in data communication possibilities and what infrastructure is needed to handle this data. This is outside the smart house level but is necessary to know what information a smart house should provide to the utility.

3.1.1 The grid today

Electricity produced today is transported from the power plants to different areas over high voltage power lines. Before the energy can be used in households it is transformed to a lower voltage level, called the medium voltage level, and thereafter to the lower voltage level which is also known as the utilization voltage level. This is the electricity that is used to power the appliances people use.

Figure 4 shows the shares in power line infrastructure of the different voltage levels today in Europe. The chart shows that the low voltage level represents 60% of the power lines used today while the

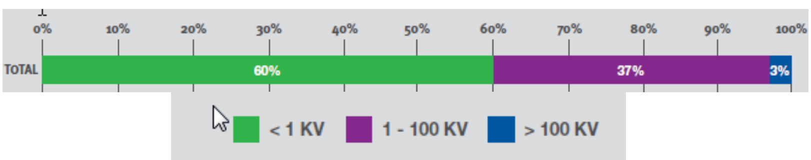


Figure 4 : Shares of power line infrastructure of different voltage levels in Europe.

medium and high voltage level represent the other 40%. The real division between the medium and high voltage level is not as shown in figure 4. Smaller countries do not need to transport their energy over long distances and keep the energy on a lower level than bigger countries. Because of this the real share of the high voltage level is more around 6% of the existing power lines (Eurelectric, 2014).

Today the electricity companies only collect data from the high voltage level in order to keep the frequency of the grid at 50 Hz and avoid disturbances of the grid. This means that just around 6% of the power lines are monitored today. When a disturbance occurs on the medium or low voltage level, whole areas can fall without electricity and the energy company has to figure out where the error took place before fixing it. This can take a long time, cost a lot of money and create unsatisfied costumers (Gobmaier, 2015).

To avoid this problems and because European governments tighten their laws about accepted grid outages, energy companies are willing to participate in smart grid pilot projects. Creating a smart grid creates multiple ways for the energy to reach houses, so areas do not fall without electricity in case of an error in the grid. A second reason is that they also measure the substations on the medium voltage level, what creates the opportunity to automatically locate the error (Vanhaenen, 2015).

A. Data Communication today

The measurements of energy use evolved from having personnel going from house to house to note the energy use, to an automatic meter reading system where the energy use is communicated to the DSO over the internet. This AMR system was introduced to reduce the personnel cost of the DSO's and to have slightly more detailed information of the client's energy consuming behaviour, but are still using the one-way communication idea. AMR has the potential to do more detailed measurements of the energy grid and deliver data from the lower voltage level and the substations but today most DSO's only use it to collect information of the clients energy usage once a week or month, depending on how the DSO works (Tampere University of Technology, 2014).

In order to develop a smart grid network, the communication system has to change to a so called advanced metering infrastructure. AMI is based on the two-way communication idea and makes it possible to exchange information between the DSO and the energy consumers. The architecture can be seen as a big router where all the clients have a specific IP address and the DSO is the router where the information is received and sent (Rouse, 2010).

AMI is an architecture of a two-way data communication system and can be created with different infrastructural solutions. Today PLC's are the most common solutions when AMI is implemented. Power line communication makes use of the existing power lines to transport data over it, so there is no extra need of building new data infrastructure to support the data communication, is cheap and easy to provide data access to rural areas but also has some disadvantages. When PLC cables go through a transformer the data, transported over the cable, should be "bridged" because the energy transformation would interrupt the data signal. This bridges can be created by using a Wi-Fi signal. The problem with this solution is that the weak points, the bridges, are located in the substations, what means that more personnel needs access to this substations while in a smart grid, security will become a big issue (Nikko, 2015).

Another problem can occur when the smart grid will be enrolled over a larger scale and more data will be transferred over the system. In this case more houses will be connected to the data communication network while PLC only provides a bandwidth of 47Mbps, which means it can connect a limited amount of houses . For this reason PLC's will not become the big data communication solution for the AMI but will be more a solution for specific cases, for example to reach desolated single houses (Department of energy, 2010).

Another thing encountered when transporting data over electricity cables is the fact that the electricity and data signal interfere. The data signal needs a part of the spectrum where no electricity signals are transferred. So the PLC becomes useless on the high voltage level since there the electricity is on a very high voltage here (155.000 - 765.000V) and becomes very "noisy". This means that the electricity signal will jump over the whole spectrum and data communication will be disrupted.

On the medium voltage level, where the electricity is on a more stable level of around 7.200V, the data signal can be transferred without interfering with the electricity signal. The problem here is that the signal will decrease according to the transferring length. To solve this problem repeaters are installed in the medium voltage level. Repeating a signal is a good solution for a certain distance but when the signal is repeated a lot, the quality of the signal will decrease (Valdes, 2014).

PLC is also a solution for the lower voltage level but then the signal needs to be bridged again in the substation from the medium voltage level to the lower voltage level. For desolated areas a Wi-Fi communication can be preferred because the cost of the repeaters and the bridge in the substation can become quite high. The PLC network information is shown in figure 5 (Valdes, 2014).

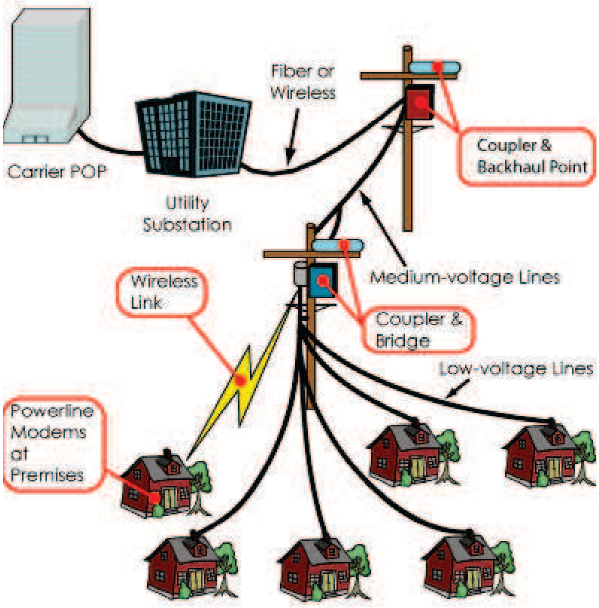


Figure 5 : Architecture of a PLC based AMI network with PLC on the medium and lower voltage levels.

Because PLC is limited in bandwidth but a cheap solution it can become a valuable part as data transferring infrastructure in smart grid but on the house level to exchange data between the appliances and the smart meter.

B. Data communication protocols

The companies that are developing some kind of and AMI system today all have their own data communication method and thereby develop their own data communication protocol. Today, more than 360 data protocols are already existing and the number is rising. The problem here is that the different protocols cannot communicate with each other which creates a lot of problems. This can create problems when people change from DSO (Cisco, 2009).

Another problem with DSO's creating their own protocols and data communication networks is that this will result in a lot of small data networks instead of one big data communication network, with the problem that all the companies have to gather their own information and can only regulate the part of the grid which they own. When all the companies would use the same protocol, there could be corporation in balancing the grid, the price and data transferring. This would result in higher efficiencies, lower costs and better results (Nikko, 2015).

3.1.2 Evolution of the data network in the grid

The European Union wants to replace 80% of the electricity meters with smart meters by 2020. This goal must help Europe in their development to a smarter and more efficient grid (European Commission, 2015). But apart from this, a lot more work has to be done. Installing smart meters is just a small part of upgrading the existing energy grid towards a smart grid. Expanding the existing electricity grid, creating a full data communication network, investing in energy storages... This are just some of the big challenges that are ahead.

The implementation of a full data communication network all along the grid is probably one of the biggest challenges on the roadmap towards a smart grid. Where the adaption of the electricity grid demands an expansion of the existing network, the data network almost has to start from scratch. Beside this there is a need of corporation of different sectors to make this successful. The government is needed to create guidelines and rules, the DSO's have to define what kind of data they want to receive from the grid and ICT companies need to develop a data infrastructure which can fulfil all the requests from the previous entities and provide it with a solid security system.

A. Real-Time Data measurement

When speaking about smart grids, real-time pricing always comes along. People expect that the grid is constantly monitored and the energy price is adjusted every second, depending on the amount of energy available and the amount of energy consumed during the moment. In this case the energy grid would be used in the most efficient way, looking to the energy part, but there would be a few zeta bytes (= 10^{21} bytes) produces each year. Knowing that there will be around one zeta byte of information produced worldwide in 2015, it becomes clear that a true real-time system is not manageable because there would be too much data to be handled and stored. The financial benefit of the smart grid would be neutralised by the cost of the data handling (Aiello & Pagani, The Smart grid's data generating potentials, 2014).

The communication needs be periodically to reduce the amount of exchanged data. To fit best on the existing energy system, data should be transferred each 15 minutes because the energy utilities decide evaluate the electricity market situation every 15 minutes and decide then if they need to start up or shut down extra power plants (Kronman, 2015).

According to a report from the Netherlands, the country would create 1.5 to 1.8 peta bytes (= 10^{15} bytes) each year when used a 15 minutes period. This is shown in figure 6 and based on case1, 2 and 3. Case 4 represents the situation where almost all the data available is gathered but which is not realistic. It includes the data of smart appliances and DSO's will have no interest in receiving this information since it is on a too small scale to be interesting (Aiello & Pagani, The Smart grid's data generating potentials, 2014).

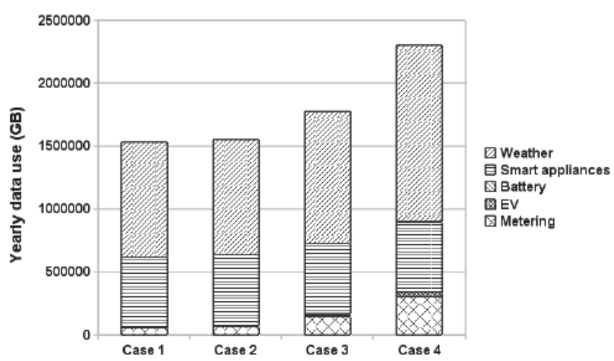


Figure 6 : Yearly data amount produced in the Netherlands when used a 15 minutes period

The amount of data was calculated based on the fact that there are 9 million private households in the Netherlands. So when there are 214 million private households in the European Union (Eurostat, 2014), 35.7 till 42.8 peta bytes would be produced in the European union when using a 15 minutes period for the data exchange. This amount is based on a simplified calculation. The data communication with the industry, which is most of the time more detailed, was not taken into account so the data amount will be higher, but in the same magnitude.

In the future, when the smart grid is installed and functioning, there would be the possibility to go to a period of 5 minutes. This allows an even more efficient use of the energy and can save more money. The amount of data produced in the Netherlands when using this period varies from 6 till 7 peta bytes (figure 7), which means that it would be in between 142.6 and 166.4 peta bytes for the European Union (Aiello & Pagani, The Smart grid's data generating potentials, 2014).

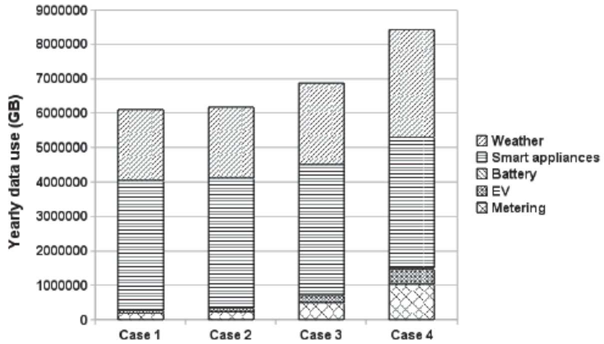


Figure 7 : Yearly data amount produced in the Netherlands when using a 5 minutes period

B. Architecture of the data network

The data communication network in a smart grid is divided in different layers. It consists of the HAN, the access point, the backhaul point and the backbone. The HAN manages the data in the smart house and will be explained in chapter 4.1 (Home Area / Automation Network). The data from the HAN that needs to be communicated to the grid is collected at the access point, which is represented by the smart meters. From here the information is sent to the backhaul point, which is a substation or a communication tower. Here all the information of the HAN's from a neighbourhood is collected and sent to the backbone, which collects all the data from the grid and sends it to the data centre (Department of energy, 2010).

The whole data communication architecture can be compared with a road network, where houses are connected by small streets (= access point to backhaul distribution point), neighbourhoods by normal streets (= backhaul point to the backbone) and cities by highways (= the backbone to the data centre). The comparison also applies for the capacity. the backbone needs to be able to handle a big amount of data (like a highway needs to handle a lot of cars) while the backhaul distribution point can be provided with a smaller capacity.

Figure 8 shows a possible solution for a data communication network. The yellow arrows represent the energy transport while the blue, green and purple clouds, circle and lines represent the data network. In this figure the information of the HAN is send to the NAN, from where the information of the whole neighbourhood is collected and send to the distribution point (substations in this case). From here, the information is send to the backbone,

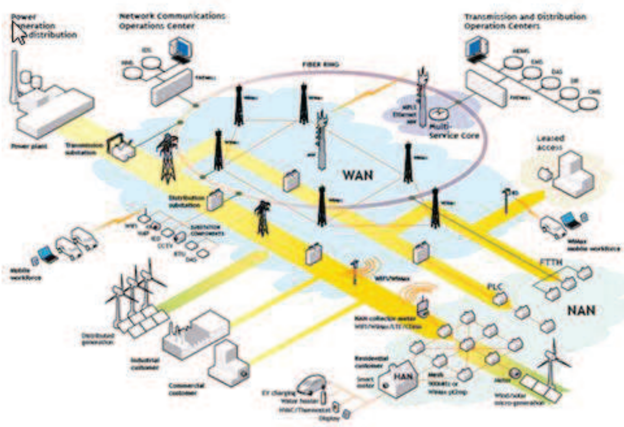


Figure 8 : Architecture of the data communication network in a smart grid

which is represented by the purple circle, before transferred to the data centre. Figure 8 shows that the different levels can be performed by using wireless or fixed line technologies, depending on the location and environment (Sogang University, 2012).

C. House clusters

It is not interesting for a DSO to know from each house which appliances they are using. The device specific information is useful to use on the house level in the HAN. Even measuring on a house level is not interesting enough. DSO's need clusters of at least 10MWh to be able to balance the grid. Cutting of one house from the grid is not effective so houses should be clustered. The clustering should happen randomly to prevent a whole neighbourhood falling without electricity. It is a lot better when single houses in different neighbourhoods are cut of so the social life is not interrupted. In America, companies cluster houses in groups of 20MWh to anticipate on the fact that not all the houses are participating in the smart grid (Kronman, 2015).

D. Technologies for the data transfer to the backhaul point

There are two factors defining the capacity that is necessary for the data transferring. The amount of data, which defines how much data the systems needs to be able to handle, and the latency. The latency factor is the lag on the signal and is an important factor in data transferring (Nikko, 2015).

For the data transfer between the houses and the backhaul point, a latency of 80ms and a bandwidth of 8Mbps is required. The high latency is necessary for the fault location in the grid and not for the energy consumption since this is allowed to have a latency of a minute. Technologies that are suitable for this part of the data communication are WiMAX, broadband PLC, 900MHz wireless mesh networks and fixed point-to-multipoint radio frequency networks (Department of energy, 2010).

1. WiMAX

WiMAX can be seen as the improved version of Wi-Fi. It covers a larger area, has a bigger bandwidth and serves more users. A WiMAX system consist of WiMAX towers who are communicating with each other and the houses surrounding them. A WiMAX tower communicating with houses is working on the lower frequency range (2 - 11GHz, which is the same as Wi-Fi) and has a maximal bandwidth of 70Mbps. The reason of using a lower frequency for the communication with the houses is that the signal is less sensitive for obstacles and can go in every direction without losing quality (Tutorialspoint, 2015).

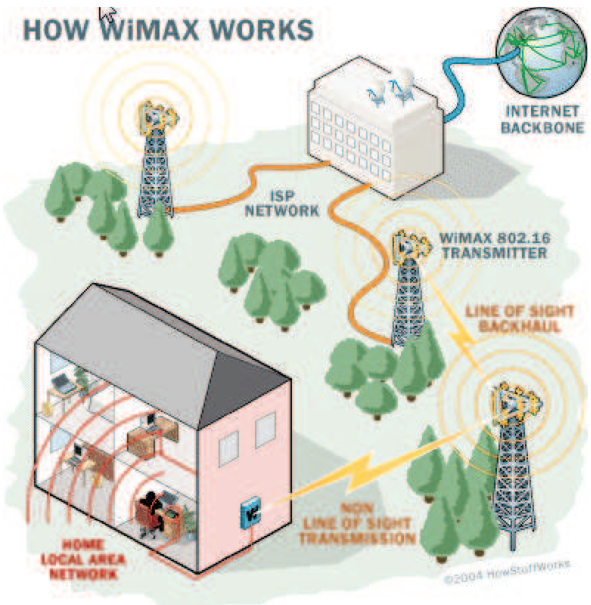


Figure 9 : Architecture of a WiMAX network.

When WiMAX towers communicate with each other, the signal can be directed which creates the opportunity of enlarging the distance in between two towers. In this case, the signal is transferred on a frequency of 66GHz, which makes the signal less sensitive for interference with other signals. The architecture of a WiMAX network is shown in figure 9 (Brain & Grabianowski, 2015).

A non-line of sight transmission tower can provide an internet connection, which is qualitatively equal to a cable connection, to houses within 9.6km. This means that one WiMAX non-line of sight tower can cover an area of 290km². A line of sight WiMAX tower can communicate with another tower which is situated till 48km away, what makes it able to cover an area of 7238km² (Brain & Grabianowski, 2015).

The fact that WiMAX can cover large areas with a small amount of infrastructure makes it an ideal solution to reach desolated and rural areas. It can also be a solution for urban areas, but in this case the amount of WiMAX towers needed is dependent of the amount of houses in the city. When too much houses are connected to the same tower, the amount of bandwidth per house will drop and the quality of the connection will be lost (Department of energy, 2010).

2. broadband PLC

Broadband PLC is already discussed on page 18 and is already used today as a communication infrastructure. As told before PLC is a good solution to reach desolated and rural areas, since it is cheap and can connect a small amount of houses. But problems are encountered when a transformer needs to be bridged or when combined with a high voltage level. It could be a good solution to reach desolated areas, but when the area is too desolated, and there is need to use a high voltage power line to reduce power loss, the PLC needs to be combined with other technologies. For this reason, the PLC will probably only be used on the house level to transfer data between the appliances and the HAN (Valdes, 2014).

3. 900MHz mesh network

A mesh network consists of a lot of nodes that communicate with each other on the 900MHz frequency. The idea is to cover a big urban area, like a city, by connecting different nodes, which function as routers. It can be seen as a big Wi-Fi network where all the small Wi-Fi networks are connected. In this network the different nodes communicate with each other when transferring a signal and they automatically choose the closest connected node (Roos, 2015).

The advantage of a mesh network is that is can adjust itself. Where Wi-Fi can be bothered by physical elements, the mesh network will automatically send the signal around it by using other nodes. This is called "Dynamic routing" and improves the reliability of the network. Also a damaged node will not disrupt the system but the signal will be send around by other nodes. Another advantage is that only one node needs to be connected to the internet with a cable where in a Wi-Fi system all the routers have to be connected to the internet by a cable (Roos, 2015).

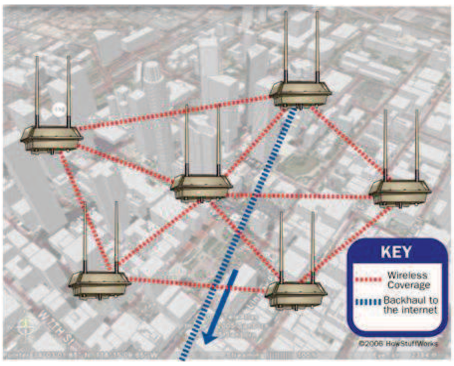


Figure 10 : Backhaul node in a mesh network.

When using the mesh network in a big city, some nodes need to be programmes as backhaul nodes where all the information needs to go and from where it is transferred to the backbone and after that to the data centre. This is shown in figure 10 (Roos, 2015).

The network uses the 900MHz frequency to broadcast the signal because it is used for the Wi-Fi networks. Where bigger frequencies, with more bandwidth, provide a bigger bandwidth, 900MHz provides a maximal bandwidth of 4Mbps, but the strength lies in the number of nodes used in the network (Justice, 2010)

4. Fixed point-to-multipoint radio frequency networks

This system has a similar architecture as the mesh network and is also based on one backhaul node that is connected to the grid. The difference with the mesh network is that the nodes in the P2M network are directed, which means that they only can communicate with the nodes for which they are programmed so the reliability of the network decreased compared to the mesh network (Department of energy, 2010).

The idea of P2M is that the signal is sent from the backhaul point and from there divided to multiple other, pre-programmed, nodes. The same idea is used for the other way around where the information from the different point is sent via prefixed ways to the backhaul point (Janssen, 2015).

The advantage of this system is that it can works on higher frequencies (1GHZ - 25 GHz) which offers a bigger bandwidth than a mesh network, but due to the impossibility of the nodes to adjust the communication road when a node fails, the reliability of the network is decreased (Janssen, 2015).

E. Technologies for the backbone network

The backbone network gathers all the data from the backhaul point and sends it to the data centre. To be able to handle all this data, a big data transfer capacity is needed (the exact size depends on the topology of the network). The maximum latency here is 50ms to balance the grid and fault location (Department of energy, 2010).

There are two possible backbone architectures that can be used. The first is the cloud architecture, which is used for wireless network solutions and where data can be transmitted in every way. The other one it a decentralised network, used for fixed line technologies, where the information is sent in between nodes. The principle of this system is shown in figure 11. Because the notes are connected with several other nodes, the reliability of the network increases. The only disadvantage is that more cables are needed for this system, what results in a higher network cost. Technologies that are suitable for the backbone are fibre cables and microwave networks (Skelsey, 2015).

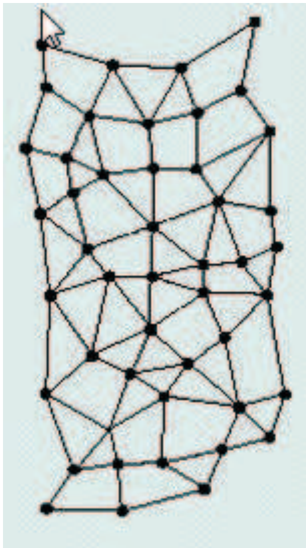


Figure 11 : Decentralised network

1. Fibre cables

Fibre cables are used in a decentralised topology and are available with different capacities which can be applied depending on the network topology. Almost every bandwidth necessary can be created using fibre cables by combining multiple cables in one line. The company NEC - Cornbit successfully installed a fibre cable which could process 1.05 Pbps (= 10^{15}bps) by combining 12 fibre cores. The only problem is the price, which will rise when using cables with a bigger bandwidth (Corning, 2015).

2. Microwave networks

The key to transfer a lot of data over microwave network is using a big frequency. For this reason, WiMAX with line of sight towers are the best solution. Because they are working on a frequency of 66GHz and can send to 48km away, then are able to transfer a lot of data over a big distance. To increase the reliability of the network, the towers are connected with more than one other tower. The WiMAX network is explained more in detail on page 21 (Brain & Grabianowski, 2015).

3.1.3 Obstacles encountered today

The introduction of a fully working smart grid system is not something that will in the next two years. It will take a lot of time since there are a lot of obstacles that need to be conquered before the industry has the possibility and the motivation to start the development of the necessary infrastructure. Which obstacles this are and how they can be bridged will be discussed in the next subchapters.

A. Lack of interest of the DSO's

When it comes to the development and introduction of a smart grid, everyone agrees on the fact that DSO's have to take the leading role. When they provide the necessary infrastructure, people can invest in smart houses and fully make use of the smart grid. But in reality the DSO's only develop and invest in the things that are obligated by law. For example today they are investing in more electricity cables to achieve a more reliable grid because a new law states that outages should be reduced to 36 hours in rural areas and 6 hours in urban areas (Vanhaenen, 2015).

This example shows that companies are not investing in the correct infrastructure. Instead of investing in copper, they should replace their old substations by new, smart, substations who can measure the grid and use fault location systems to improve the reliability. This would also give them the option to improve the grid later on towards a full working smart grid (Kronman, 2015).

Another obstacle are the smart meters. Because of the European directive stating that by 2020, 80% of the European households should be equipped with smart metering infrastructure, all houses in Finland have a smart meter installed. This offers companies the possibility to do more specific measurements of the production and demand on the grid. But today DSO's are not using this possibilities and only use the meters to register the energy consumption of the consumers. This will evolve when more people start to produce energy and DSO's would need more specific information about who is producing and who is consuming energy (Kauhaniemi, 2015).

Because the DSO's first have to make the step to measurements on the medium voltage level, it will take an extra 10 to 20 years before measurements of the low voltage level will make their introduction. This type of measurements is one of the last steps towards a smart grid because it would create the possibility for very efficient grid management. Companies would become able to balance the grid on a very detailed scale, which requires a fully functioning data communication system (Kauhaniemi, 2015).

B. Lack of regulation

As stated in the previous subchapter, DSO's need regulation to push them forward. For this reason there should come a European directive which defines the role of the DSO in the new energy market. In fact, the directive should contain more regulation about the new market roles in a smart grid. Today, a lot of investments and development are not taking place because of this missing regulation. The directive should come from the European level to create one European market system instead of having all the member states running their own system (Kronman, 2015).

Another problem, that is already discussed on page 17 (data communication protocols) is the lack of regulation concerning the protocols for the data communication networks. There is a need for regulation to make sure that the different protocols are suitable and able to communicate with other protocols. This to avoid a proliferation of communication systems and end up with an inefficient system. Today already, there are over 360 data protocols developed and used by different companies (Cisco, 2009).

Although it is necessary to have regulation for the protocols, the industry should be free to develop their own system in order to assure that the technology will be kept at the state of the art level. When a technology is imposed by the government, it will be used till another government updates the legislation. This traditionally takes a lot of time and by then the technology will be dramatically obsolete (Kronman, 2015).

The last, but most important, missing regulation handles about the data security. There should be a very clear and strict regulation about the protection of the data communication system to avoid electricity outages. This already happened in America, where hackers took control over the data communication network which resulted in outages. The data should also be protected because of privacy reasons since the data network contains information about energy consumption and production of households (Nikko, 2015).

This privacy issues are a hot topic in the smart grid development. People have the feeling that DSO's will become some kind of "Big Brother" who knows which appliances they are using when. But because it is not possible to do real time measurements and the data would be exchanges periodically, this problem will not occur. DSO's can only efficiently balance the grid when clustering houses in groups of at least 10MWh and the knowledge of houses producing or consuming energy. This means that it would only take a lot of unnecessary bandwidth on the data system to receive information from appliances. The security of the HAN, where this appliances information is useful, is another thing (Nikko, 2015).

C. Need for more knowledge

Before the infrastructure can be integrated, more know how about data collection and necessary infrastructure is needed. It is impossible to blindly collect all the data since it would be too much to process. More research is needed to see what data is necessary to collect and process. Based on this, the necessary data infrastructure can be defined.

Also for the electricity infrastructure more research is needed. How much cables need to be added to the grid to reach a reliable network without installing too much of them and invest unnecessary money (Bichler, 2012).

D. Lack of knowledge amongst consumers

People do not know enough about the smart grids and the possibilities is creates for them. Because of this, people are not investing in smart technologies when building new houses, which makes is less interesting for the DSO's to develop a smart grid because of the lack of smart houses. This catch 22 situation should be broken by stimulating the DSO's to invest and develop the grid by regulation. besides, consumers should be better informed about the possibilities of a smart grid and what it can mean to them (Nikko, 2015).

Depending on the residence of consumers, they need more real advantages before they become interested in a smart grid. Studies have shown that people living in an apartment building need more advantages than just the fact that they will save money on their energy bill because the energy bills of flats are rather low. Technologies improving their comfort should be embedded to convince people to invest in smart technologies. For people living in a detached and attached house, the savings in the energy bills alone is convincing enough to invest in smart technologies because they have a bigger energy bill and their profit from investing is bigger (Kronman, 2015).

Finally the perception of the decision makers and the people talking about the transition to a more sustainable energy system is wrong. The focus is too much on investing in green energy technologies and not so much on upgrading the grid. Figure 12 (APEC energy working group, 2011) is a good example of this. It shows the percentage of countries in the Asian - Pacific region with policies handling about the integration of renewables and smart grids. It clearly states where the focus was during the last decades. When it comes to smart grids, people still have the wrong perception and relate it with giving the DSO the opportunity of playing "Big Brother" and see it as an invasion of their privacy (Bichler, 2012).

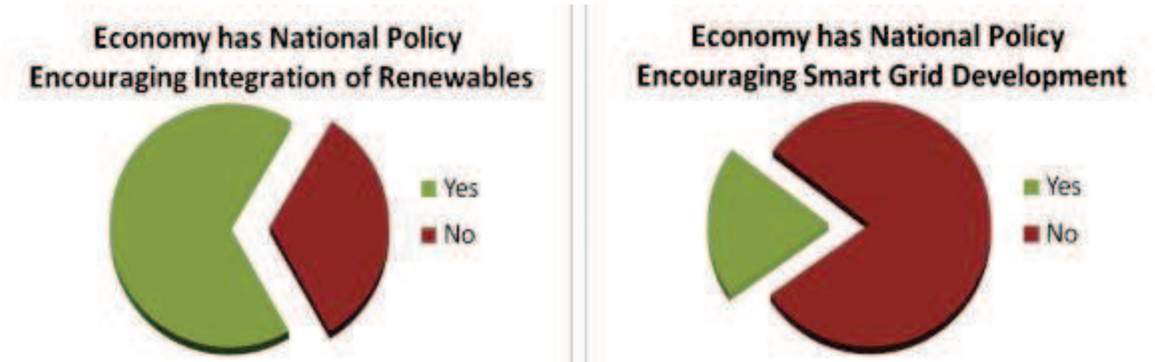


Figure 12 : Share of countries in the Asian / Pacific region with policies on the integration of renewables and smart grids.

This perceptions have led to unstable energy grid situations in Germany and even negative electricity prices in Denmark because of too much wind energy being available. Because of these events, people slowly start to realise that developing the energy grid is a necessity although too much people still tend to have a wrong impression when it comes to smart grids.

3.2 Smart Meters

Smart meters are electronic devices that record consumption in real time and send the information to a central system. These devices are aware of real time energy price and are a strategy to save energy and a tool to succeed in the plan of the EU to equip 80% of the households with smart meters by 2020. Smart meters make it possible to lower your energy bills by allowing households to manage their own electricity use and transfer data to the DSO without the need for personnel.

Constructing new fossil based power plants becomes more and more expensive by the day. Another problem is that the peak in energy demand keeps rising, which forces to ramp up expensive an polluting power plants and which affects the energy bills of the households in a direct way (Smart Grids y la Evolución de la Red, 2011).

3.2.1 New way to provide information

To provide real time information or time restrictions on energy use, there is a need for measuring equipment other than the electromechanical meter. There is a need to define a new way of measuring, called Smart Metering, which refers to the process of measuring the quantity of energy used and instantly transmitting the information of the amount of energy consumed or produced to the DSO in order to manage the grid (Universitat Politècnica de Catalunya (UPC), 2015).

A Smart Meter includes at least the following components; programmable power management by establishing the consumption limit, a HAN port, the possibility to give information about the real-time energy price and communication about the energy use. The general idea of the meter is to exchange the three principal elements, such as the measurement system, memory and energy pricing information, with the grid.

To expand its operational capabilities, the following additional elements are added:

- Power Systems
- Calculation processor
- Communication processor
- Control device

The measurement equipment can be classified according to their characteristics:

- Technological: electromechanical or electronics
- Functional: single-phase or three phase
- Energy: meters active and / or reactive counters
- Operative: Programmable type that allow remote management

Registration equipment can be of the following typs;

- Electro mechanics: it can only measure one type of energy unit, being kWh or kVAh. They use one energy price for a longer time so it does not matter when you consume energy.
- Automatic Meter Reading (AMR): It can only collect information about the monthly energy use. They can however communicate with the data network of the grid and thereby create the opportunity for companies to use a Time of Use (ToU), where they can see on each

moment how much energy the grid is exactly consuming. However, this is only a one way communication tool.

With the change from electro mechanics to automatics meters the information exchange between the Smart Meters and the DSO would be digitalised. It creates the possibility for the DSO to see at any time how much energy a household used during a certain period.

The implementation of AMR systems and eliminating traditional reading were and are made to reduce the personnel costs to gain access to the energy meter information . Nowadays, the industry has realized that the AMR systems enable companies to produce greater benefits and services such as an immediate detection of faults in the system and more accurate consumption data of the user.

- AMR systems are replaced by AMI (Advanced Metering Infrastructure). AMI measuring systems can be run using technologies from satellites to radio equipment. Today RF and PLC are the most used systems. AMI can be considered as an extension of AMR. This equipment allows DSO's to see the real-time energy consumption or production of households.

(Smart Grids y la Evolución de la Red, 2011)

Electronic mechanism companies for Smart Meters offer different basic designs to facilitate the production of energy meters. Here are some of the most widely used integrated circuits shown.

- ADE5169 (Analog Devices)
  It is a device that can measure the following parameters: Irms, Vrms, P, Q and S; in single shots.

- AVR465 (Atmel)
  It is a device prepared for measuring parameters: Irms, Vrms and P; in single shots.

- AS8268 (Austriamicro-sys)
  It is a device prepared for measuring parameters: Irms, Vrms, P and Q; in single shots
- CS5463 (Cirrus Logic)
  It is a device prepared for measuring the basic parameters of voltage, current and power, is able to calculate frequencies and harmonics.

- MAXQ3183 (MAXIM)
  Like the CS5463 Cirrus, this system is able to collect and calculate more parameters than other devices such as phase, harmonics, frequencies, etc.

- MCP3905 (Microchip)
  This system is designed to measure voltage and current in phase systems, providing an output proportional to the actual power that is being consumed in the line pulses. The operation of this system is simple because no controller, additional inputs / outputs, or communication ports.

- 71M6531F (Teridian)
  The Teridian system is one of the best in the market. This device can measure Irms, Vrms, and power.

(Smart Grids y la Evolución de la Red, 2011)

3.2.2 Various protocols

The relationship between consumers and companies was based only on companies supplying power when needed, and customers were satisfied if this was fulfilled. The rates were regulated and customer had little control.

Recently this relationship has evolved. Concern about climate change, rising energy costs, increasing demand for reliability and technological advances lead to increased consumer participation. To enable this new relationship an interface for making decisions based on real-time information is needed.

A. Smart meter protocol and principal agents

One of the biggest problems that appear when talking about Smart grids is the absence of laws and regulations. For this reason protocols are important in the smart grid system. A communication protocol is a set of rules to regulate the exchange of data between computers or within these. The protocols for the exchange of messages must be well defined as each message has a specific meaning for which you receive a response to this situation. They also have to be agreed by all parties, being able to become a technical standard. (Encyclopædia Britannica , 2014).

The principal agent that directs the regulation of smart grids in the EU is the European Commission. It has also established a list of objectives of standardization in the field of smart grids in the form of mandates. European standardization organizations (European Standardization Organizations, which are part CEN, CENELEC and ETSI) are responsible for complying with the mandates of the European Commission to establish standards that facilitate regulatory harmonization on a European level.

A clear example of the importance of these directives for the implementation of smart grids is the regulation related to smart meters. The successful deployment of smart meters in Europe is mainly due to the regulatory push introduced by Directive 2009/72 / EC, which requires the implementation of smart meters in 80% of households in 2020 (Fundación para la sostenibilidad energética y ambiental (FUNSEAM) - Universitat Politècnica de Catalunya (UPC)), 2013),

IEC is a non-profit nongovernmental organization, founded in 1906, that elaborates International Standards and Conformity Assessment for all electrical and electronic related technologies.

IEC 61107 is a communication protocol for smart meters that is used for utility meters in the European Union. It sends ASCII data using a serial port. The Open Smart Grid Protocol (OSGP) is a family of specifications published by the European Telecommunications Standards Institute (ETSI) and is used together with the ISO / IEC 14908 standard control networks for smart metering and smart grid applications (ETSI world class standards, 2012), (IEC-International Electrotechnical Comission, 2013).

Smart meters must be designed and equipped according to the standardization and Recommendation 2012/148 from the European Commission in order to ensure technical interoperability.

B. Important protocol parameters

A performance improvement of market requirements means innovate and integrate technology into business processes. The technologies for information and communication will be the cornerstone of the companies in the future. Telecommunications to interact with customers, and sales become more and more important.

In recent years, meters have become an important part of a comprehensive system of measurement and billing, through their communication skills, integration system and interoperability. The OPEN meter project came in 2009 to overcome barriers that existed in the large-scale adoption of smart metering and building the infrastructure for a measurement system made in Europe.

The main objective of OPEN meter is to specify a set of public standards for AMI systems that support electricity meters, water and gas, according to all interested parties, taking into account the actual conditions of the utility network. These standards include IEC 61334 series PLC, the IEC 62056 DLMS / COSEM standards for the measurement of electricity.

The OPEN meter project looked to all the advantages and disadvantages of available technologies and applications. Among these technologies, the most appropriate one was chosen according to the communication requirements. These technologies include such protocols DLMS / COSEM and Meters and more.

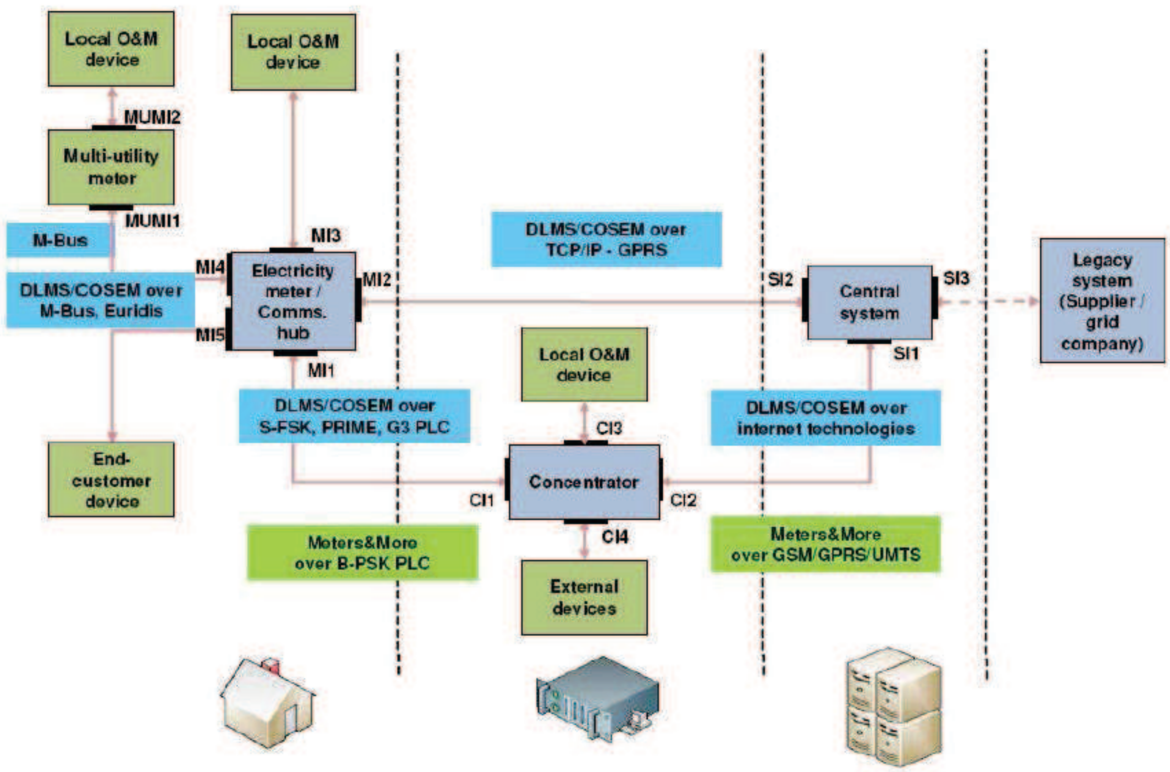


Figure 13 : Most appropriate technologies for each communication port DLMS / COSEM

- DLMS/COSEM: IEC 62056, EN 13757-1: is an open international standard for the exchange of data from a Smart Meter and more generally from intelligent devices. It is the most accepted international standard to exchange data from utility meters. It was developed with the aim to provide a way to exchanging data between accountants according to an independent energy type and manufacturer and on different media interoperable standard (DLMS-Device Lenguage Message Specification, 2015), (Open Meter, 2009) .

- Meters and More: In 2001 the company ENEL is proposed to replace traditional electro mechanical meters in 5 years with other modern electronics that could be locally or remotely managed by the AMR solution.

Figure 13 gives a overview about the areas where these protocols are applicable.

Enel and Endesa, an Italian and a Spanish electrical company, contributed to global smart metering solutions with the M & M non-profit association. This is an association that promotes communication and is open to third parties. This protocol allows bidirectional transmission of data, and the association certifies compliance teams and promotes the implementation of the protocol in Europe. This technology presents a solution for smart metering, which comprises the following elements, in order to ensure exchange of short messages and optimisation:

  - Adopt, maintain and develop an open communication protocol for smart metering solutions.
  - Provide a certificate process to ensure compliance with the MM specifications of the products tested.
  - Support for standardizing smart metering.
  - Driving evolutions M&M protocol by creating a place where members of the association to propose and evaluate improvements within an open, well-defined rules.

Telegestore communicates to the central system via the public telecommunications network and a low voltage concentrator installed in each medium-voltage substation, being capable of handling communication in both directions, to the central system and to electronic meters.

The Telegestore system was designed to reduce the cost by avoiding manual meter reading and create in this way a profit for both the companies and the consumers. Its main objective is to improve the quality of services offered while reducing operating costs. This system is capable of:

  - reading data out of the Smart Meter.
  - Make remote changes in the contractual parameters.
  - Remote shutdown and authorization for the connection of the Smart Meters.
  - Alarm management.
  - Detection and prevention of fraud.
  - Monitoring the quality of supply.

The reality nowadays is there are too much protocols and it is a problem because they are not working together, which creates conflicts in the data communication network. It is true that there are existing solutions, like explained above, but there is still a lot of work to do and most of the companies keep creating their own protocols (Smart Grids y la Evolución de la Red, 2011), (Meter On, 2015), (Meters and More, 2015).

3.2.3 Consumer benefits

With the introduction of new applications it will be possible for costumers to participate in the electrical system. Consumers will stop being passive actors in the system and will have an important role in the energy grid management.

The first step to this situation is the substitution of the electro mechanical meters for electronics, as mentioned before. The meters will make it possible to do real-time pricing and avoid the need for manual work to reduce the cost for households and DSO's

In order to reach this change there is need for more infrastructure that is not installed yet today. First it is necessary to create a network that handle a two way communication between Smart Meters and the DSO. It is also necessary to provide houses with a load controller to manage the energy consumption of a house. This controller is part of an automation system of households, in which the appliances, plugs or thermostat are provided with intelligence to achieve an energy and an economically efficient operation of the building. This concept of home automation is known as BACS. Although smart meters are a reality, home automation is still under development (Fundación para la sostenibilidad energética y ambiental (FUNSEAM) - Universitat Politècnica de Catalunya (UPC)), 2013).

3.2.4 Present state and future look-out

To start implementing systems and technologies that make smart grids, it is necessary that the investments made have ensured a certain return. If this is not the case, companies will not be eager to invest in smart grid technologies unless they receive incentives from governments.

The European Commission estimates that smart grids allow a reduction of 15% of emissions and a reduction of 9% of primary energy consumption, which would save about €7,500 million per year (Manuel Sánchez, PhD Programme Manager for Smart Grids European Commission, DG ENER, 2012).

Smart meters are being deployed as part of a European mandate, which notes that by 2020 80% of the households in Europe should be equipped with Smart Meters. Figure 14 shows how different European countries are doing on the way towards this goal. GTM Research analyses the deployment of AMI in millions in today's market (blue bars), confirmed plans (yellow bars), and the forecast for 2020 of AMI to be installed, depending on the population of each country (Geert-Jan van der Zanden , 2011).

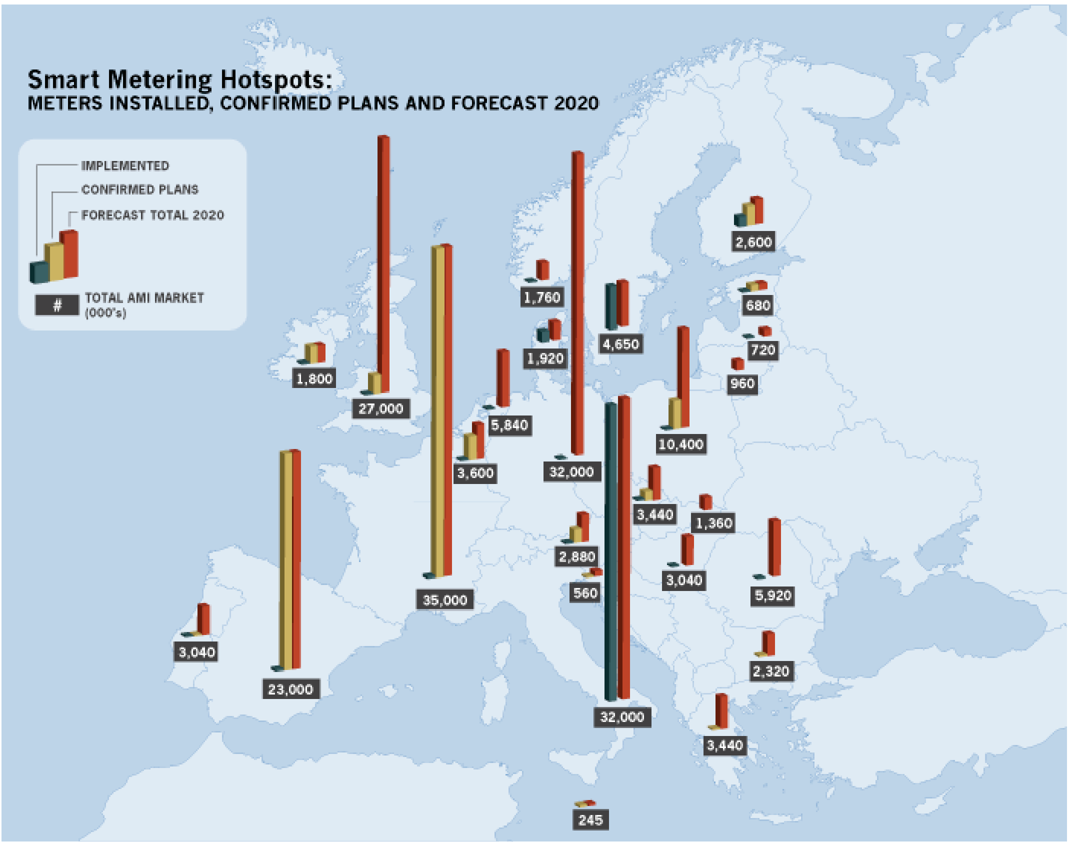


Figure 14 : European smart grid metering hotspots

In December 2014, the deployment of accountants say that there are already more than 45 million smart meters installed in only three Member States (Finland, Italy and Sweden), which represent 23% of the goal by 2020 (European Commission, 2014).

According to the Report of the Commission: comparison of the implementation of smart meters evaluation, assessment of costs and benefits December 2014 is as follows.

“Smart meters for electricity:

- Sixteen Member States (Austria, Denmark, Estonia, Finland, France, Greece, Holland, Italy, Luxembourg, Malta, Netherlands, Poland, Romania, Spain, Sweden and the UK) will conduct a large-scale deployment of smart meters 2020 or before, or have already done. In two of them, namely Poland and Romania, the cost-benefit analysis have yielded positive results, but we still have not taken official decisions about implementation.
- In seven Member States (Belgium, Czech Republic, Germany, Latvia, Lithuania, Portugal and Slovakia), the cost-benefit analysis for large-scale implementation of 2020 were negative or

economically justified for certain groups of users.

inconclusive, but in Germany, Latvia and Slovakia considered that smart meters were economically justified for certain groups of users.

- In the case of four Member States (Bulgaria, Cyprus, Hungary and Slovenia), the cost-benefit analysis or implementation plans were not available at the time of preparation of this document.

The legislation for smart electricity meters applies in most Member States, providing a legal framework for the deployment and / or regulating certain issues as the timing of the implementation deadlines or setting technical specifications for accountants, etc. only five Member States (Belgium, Bulgaria, Hungary, Latvia and Lithuania) have no such legislation in force.

Smart meters for gas:

- Five Member States (Ireland, Italy, Luxembourg, the Netherlands and the United Kingdom) have decided to make the deployment of smart meters by 2020 or earlier.
- Two Member States (France and Austria) are planning to conduct a large-scale implementation, but have yet to take formal decisions.
- In twelve Member States (Belgium, Czech Republic, Denmark, Finland, Germany, Greece, Latvia, Portugal, Romania, Slovakia, Spain and Sweden) the results of cost-benefit analysis have been negative.
- The other Member States have not yet completed its analysis (note that there is no gas network in Cyprus and in Malta)." (European Commission, 2014)

3.3 Pilot projects

The next subchapters will discuss pilot projects in Malaga, Spain, and Sundom, Finland and take a deeper look on how the data communication technologies are embedded, what the interests of the companies in thi pilot projects are and what the plans for the future are.

3.3.1 Smart City

Malaga Smart City is a project promoted by a group of eleven companies: Enel, Acciona, IBN, Sadiel, Ormazabal, Neo Metrics, Isotrol, Telvent, Ingeteam and Greenpowe; led by ENDESA. Except for companies, a lot of universities and research organisations are involved.

This project was developed in Malaga (Spain), near the beach of Misericordia, as shown in figure 15, to satisfy 300 industrial customers, 900 service and 11.000 household and had a budget of 31 million of euros from ERDF, funded with support from the Government of Andalusia and the Centre for the Development of Industrial Technology, Ministry of Science and Innovation. The first post for recharging electric automobiles were inaugurated in November 2010 and the control centre was ready in March 2011.

Figuur 15 : General view of Malga SmartCity area

A. Network structure

The network structure in Malaga Smart City has two HV substations. One is connected to a cogeneration plant in wastewater treatment, where most electricity in the area occurs. And the other is made up of more than ten MV lines used to distribute electricity in most of the project area. In each region there is a distribution network that interconnects each of the regional control centres with high voltage substations.

The telecommunications infrastructure has 40 km of MV PLC reported by broadband, it is a network that connects 72 distribution centres and services linked to these in LV. This technology complements 3G and WiMAX, which are connected to the existing network ENDESA, Spanish company.

B. Remote management and Smart Meters

Remote management is a remote system that is automatically managed with the information from electricity usage out of new information technologies and requires an IT infrastructure, communication infrastructure and information concentrators which are installed in transformers substations. Smart Meters are a part of an integrated system that requires a communication infrastructure. Smart meters and information concentrators communicate with each other through the grid by the PLC.

All clients participating in the project have the new smart meters to facilitate more sustainable consumption. This allows them to use energy management systems and reduce their electricity bills.

The smart meters distribution in Spain is motivate by the European and Spanish Regulation, which regulates the minimum functions of these and forces the progressive change of smart meters in Spain in the end of 2018, with distribution companies responsible for the refund.

The basis for Smartcity Malaga is Endesa's remote management system. This remote management system is a new generation technique stemming from Enel, which developed this technology solution and which is used for over 34 million times already.

In this SmartCity, concentrators and smart meters communicate with the grid through PLC where the base is an open protocol of Meters and More according to the European standards. Communication between concentrators and IT systems is based on insurance and confinable protocols, which ensure privacy and security exchange information.

Using this system provides remote management improvements between companies and users. This remote management also provide timely accurate reading with the price of time, making a flexible invoicing. In addition this network also provides information on the status of the system to improve operations on it. In this way consumers are an active part of the system.

Remote management is the most important part of the SmartCity as it facilitates the integration of distributed generation, the introduction to the system of renewable energy, to recharge electric vehicles, the optimal lighting public management, and automated control. Because it offers a multitude of application.

It gives creates the opportunity for the system to create the most efficint situation concerning the energy use and energy management during peak demand periods. Allowing a wide range of possibilities with different prices for each time of day, so that the client can choose the lowest rate advisable according to their needs and plan their consumption. The goal is a better energy efficiency, incorporated renewable energy and reduced CO_2 emissions.

The remote management deployment started in 2010, when the smart meters were integrated into Endesa's technical syste. Endesa installed 17,751 single phase meters, 181 three phase meters and also 103 concentrators in transformer substations. After a successfully test Endesa was able to get data from the grid and households and make a study of the electricity consumption and users habits with the aim to find a method to increase energy and grid efficiency.

The application of this system remote management is taking place throughout the parts in Spain where Endesa is responsible for the distribution of electricity. This plan involves the implantation of 13 million meters and 140,000 concentrators in distribution substations.

C. Renewable energy

Renewable energy sources are integrated through the installation of photovoltaic panels on public buildings, the use of electrical micro generation in some hotels or installing micro wind systems in the street lamps, as shown in figure 16. Energy is also stored in batteries, so that part of the energy will be consumed after the air conditioning of buildings, street lighting and electrical transport. The use of electric cars, with the installation of charging posts and sending a small fleet of vehicles is also enhanced. But above all, it seeks to involve the whole process to the end user.

Figure 16 : Micro generation in street lamps

The next step is to collect consumption data and efficiency to draw conclusions and exporting experience to new urban areas, so that it can change the current energy model towards a more sustainable model. The goal is to achieve energy savings of 20% and reducing emissions by more than 6,000 tonnes of CO_2 per year in the project area.

Smart City will become a world leader in the development of energy technologies together with other programs already in operation in Stockholm, Dubai, Malta, Ohio and Colorado. The project is part of the 20-20-20 Plan, designed by the EU, which sets targets to achieve the goals of the "Smart Grids and evolution of the System 67/82" program by 2020.

The project includes development of new solutions, but the main objective is to demonstrate existing systems and solutions. So, the difference is that Malaga Smart City is a project scale demonstration. Among other things, automation control system power, charging systems for electric vehicles, systems optimization of consumption of public lighting and management systems via the distribution network will be tested (Directorate General Distribution Endesa, 2011).

3.3.2 Sundom project - Finland

The Sundom project is part of the INKA project which is created by the Finnish national funding agency for innovation, Tekes. The goal of the INKA project is to create electricity innovation clusters in Finland in cooperation with companies and other organisations. This must enable companies to create new technologies and deliver high quality international services (Tekes, 2015).

The Sundom project aims to create a smart grid in the entire Sundom village, near Vaasa (figure 17) (Sundom, 2015). With the creation of a smart grid for around 2600 people, the goal of the participants is to upgrade the reliability of the energy grid and to research the efficiency of data collection and the integration of wind and solar energy in the grid.

Figure 17 : The Sundom village next to Vaasa, Finland

The Sundom project is a result of the cooperation of different entities specialised in certain fields. The participants are:

- ABB: Energy technology and innovation company.
- Anvia: Data communication company with a data network all over Vaasa.
- Vaasan Sähkö: DSO in the Vaasa region.
- University of Vaasa: Research on the efficiency of the data collection.

The involvement of all this companies creates the unique opportunity to develop a well integrated smart grid. Since Anvia already had a data communication network, in the form of a fibreglass network, in place, the DSO willing to invest in the grid, the university with the necessary knowledge to study the data collection and ABB with the technological solutions to enrol the smart grid.

Another advantage of Sundom is the presence of a windmill and several houses equipped with solar panels. This creates the opportunity to study the effect of the integration of renewables in the grid and to use them as an energy source for households (Tekes, 2014).

A. The organisation of the Sundom project

Vaasan Sähkö became interested in the development of smart grids after the Finnish government introduced a law that obligates DSO's to reduce outages of the energy grid to 36 hours in rural areas and 6 hours in urban areas by 2028 (Tekes, 2015). This could be achieved with the construction of more power lines through the whole country but this is an expensive and inefficient solution. One of the advantages of a smart grid is the increased reliability of the grid (see chapter 5.3) while the development costs are relatively low, especially when the data communication network is already in place.

to create a smart grid, a data communication network is necessary. The development cost of a smart grid can be seriously reduced when this is already in place and only needs a slightly adaption. This was the case in the Sundom project, where Anvia had a network of fibreglass cables in place to provide the households with internet and television.

To enable the measurement of the energy grid on a lower level, the necessary technologies need to be installed. ABB is the global market leader when it comes to energy grid solutions so with their involvement and technologies, the connection between the energy grid and the data communication network could be made.

Finally there is the data research department of the university of Vaasa. The data communication network can be studied and made more efficient with their knowhow. By doing this, the costs of the data communication network and the data storage infrastructure can be reduced when enrolling the grid on a national and commercial level (Vanhaenen, 2015).

B. Data communication

The data communication network in the Sundom project consists of the already existing fibreglasss network. In order to use the existing network as a data communication network for the grid, some adaptions and expansions were made. This resulted in a cost of €120.000 for the optimisation of the data communication network. 20% was used for the construction costs, 20% of the cost went to the fibreglass cables and 60% of the costs are due to research purposes.

This research purposes consist of extra infrastructure or over dimensioned infrastructure which makes it possible to measure all the data of the grid and do research without being limited by the infrastructure. For example the fibreglass that is used has a capacity of 1Gbps while only 8Mbps is used for the moment (Nikko, 2015).

The data infrastructure in this project is fibreglass, as mentioned before. The reason that this material is used is because this network was already available and only small adoptions, and small costs, were necessary to achieve the requested data communication network. To increase the reliability of the data network, some extra lines were constructed to create circles. In case an error would occur in one of the lines, there is another way to send and receive data so the system would not be interrupted.

Each day the system collects 660Gb of data, that is compressed to 66Gb, and stored in the office of Anvia. Each participant in the project has access to this data. In this project, all the data from the medium voltage level is gathered. Because it is a research project where the university will have a deeper look in the data, all the data is gathered. So a lot of the 660Gb of data is useless, however it is necessary to define which parts specifically need to be measured in the future (Kauhaniemi, 2015).

C. Smart metering and smart houses

The development of a smart grid in the Sundom area gives the inhabitants the possibility to start with energy management in their buildings. Another option is to integrate renewables in their buildings and produce electricity to provide to the grid. To see how the grid handles this implementations is also one of the goals of the project.

The problem however is that most of the households are not aware of this possibilities and do not make use of these advantages. Houses that are provided with renewable energy sources, for example solar panels, heat pumps..., only produce as much as they can consume since it is not economically feasible to deliver energy to the grid today (chapter renewable energy sources) (Nikko, 2015).

This lack of knowledge amongst the inhabitants of Sundom means that a big part of the potential research gets lost. The development of a new residential area is ongoing and the new inhabitants could design their houses, knowing that there is a smart grid installed. But because no one is really informing the people, they do not integrate smart technologies in their houses and miss a big opportunity.

D. Evaluation of the Sundom project

However the Sundom project received an INKA award for "the best implementation of objectives of the innovative cities programme" (ABB, 2014), it cannot be considered as a real smart grid since it only measures the data from the medium voltage level and is not monitoring on the lower voltage level at all.

In order to reach a real functioning smart grid, households should be involved and use smart meters to participate in the energy management. In this case, the energy consumption pattern of that area would change and it would be possible to study the effect this has on the grid. The Sundom project is not making this transition and is basically just measuring the medium voltage level, without really stimulating households to use the opportunities.

The same is true for the renewable energy sources. If the planned houses would be equipped with this technologies the project would create the opportunity to study the effect of renewables in a smart grid more in detail.

Out of this can be concluded that the intention of the DSO is not yet what it should be. Instead of creating a pilot project where all the aspects of a smart grid can be studied, the DSO created a grid where the medium voltage level is measured to create a higher level of grid reliability. The motivation behind this is the new law that forces them to reduce outages (1.1.1 organisation of the Sundom project). This creates the perception that DSO's only take the necessary steps instead of trying to develop the energy grid to a more efficient and sustainable one.

A positive thing about the Sundom project is the data study. The data amounts and storage capacities of a smart grid is a field that needs more research and it could be a very useful result to define the useful data and by doing this, specifying exactly the capacity a data network would need. There would be no need to install over dimensioned power lines and data storage capacities. This could save a lot of money when the grid would be enrolled over a bigger scale.

The data network used in the Sundom project was already available in the form of fibreglass and the measurements of the grid are only done on the medium voltage level. This means that most of the things learned out of this projects can only be used as an indicator for a real smart grid, where the lower voltage level is taken into account.

4 Home Systems

Home systems are an intricate part of smart "intelligent" houses, for home users to be able to communicate with the smart grids of the future. The home systems provide the technological means for the gathering of information from the home users to benefit the energy providing utilities. During the following subtopics the two major topics of home systems, home area / automation network and energy management systems are explained.

4.1 Home Automation / Area Network

Home automation / area networks also referred to as HAN systems, have the ability to interface with the systems and appliances installed at your home. Residences that have this technology installed are also called "Smart Homes". By using their own microprocessors or computers these systems can perform actions and interact with the electricity grid based on given scenarios'. (PC MechTV, 2015)

4.1.1 Purpose of HAN systems

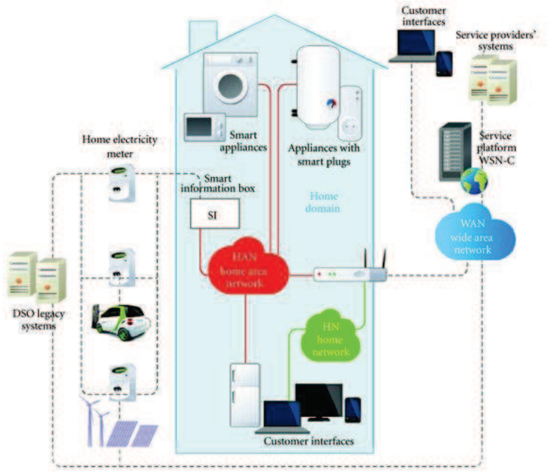
As mentioned before HAN systems can control your home systems and appliances depending on various scenarios'. These scenarios' can vary from turning on the lights at a preferred moment in time to more complex as detecting a water leakage, controlling the thermostat or controlling each light separately in every room. Home automation will also save on the electricity usage, for example by tuning heating and cooling schedules throughout the year to increase maximum efficiency. Furthermore does home automation provide the centralization of control for various systems in the home. Home systems these days combine the following systems;

- Lighting
- HVAC
- Security systems (Alarm's, cameras, etc)
- Home entertainment systems
- Appliances

By combining these systems the home user will achieve a more convenient, comfortable, energy efficient and secure home. Devices that are connected through a computer network may be accessed by a PC or smart phone and may also provide remote access over the internet. (Corry, 2012)

4.1.2 Network structure

Viewing a smart grid is the same as viewing a cooperation of networks, where the HAN is the network of communicating loads, sensors, and appliances within the customer’s premises. This HAN is then connected to the smart grid through the LAN. (Saponara & Bacchillone, 2012)



When viewing a HAN 4 main elements can be described;

- A gateway connecting the HAN to the outside information services, in the LAN or WAN network.

Figure 18 : Smart Energy HAN general architecture

- Access Points or network nodes composing the HAN network.
- A network operating system and a network management software.
- Smart endpoints (smart meters, displays, thermostats, appliances, etc.)

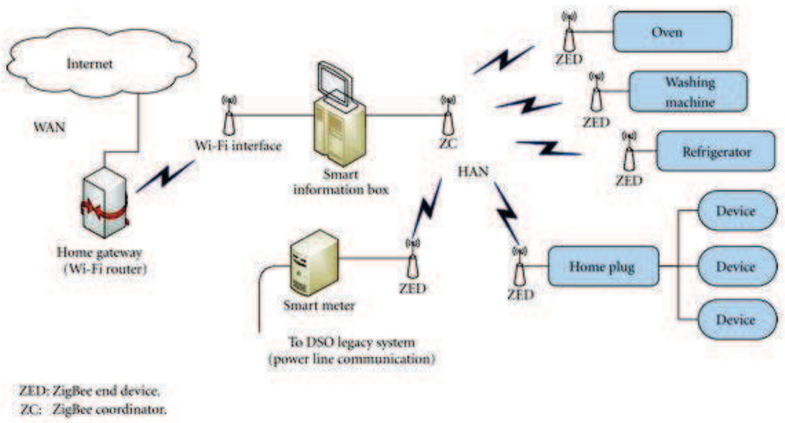


Figure 19 : Smart energy HAN architecture example

Figure 19 shows a possible implementation of a HAN network, using a ZIGBEE network (see 1.4.1.A), within this network the 4 main parts of a HAN can be identified. The smart information box (see 1.3.1) connected through a transceiver and equipped with a Wi-Fi interface for contacting the home gateway. This home gateway is a simple Wi-Fi router, this ensures the connecting between the HAN and the WAN. Through various receivers and home plugs the smart information box can gather the information from the connected appliances.

4.1.3 Most important devices

As mentioned in chapter 4.1.2 there are 4 main elements that compose a HAN network; connecting gateway, access points or network nodes, an operating system and management software and smart endpoints. During this chapter these 4 points will be explained further.

A. Smart information box

The smart information box consist of an electronical control unit with on-board memory, computing capabilities and digital networking interfaces. The smart information box implements 5 core functions concerning the home energy management (Saponara & Bacchillone, 2012);

- Collecting data from power meters and from the smart endpoints in the HAN, monitoring the energy sources (from the provider or RES), the energy loads and the energy buffers (See chapter 6).
- Collecting data through the HAN from environmental sensors (temperature, light, humidity).
- Forecasting of the home users' needs, based on data provided by sensors and profiling methods.
- Sending commands to smart appliances according to pre-programmed strategies to implement power saving strategies.

- Providing information to the home users' about their energy behaviour through their PC's, tablets or smart phones.

The smart information box is connected to the WAN network through an internet gateway, which can be an simple Wi-Fi router, this way the users' can obtain information from the smart information box through their home gateway via their GUI on their smart phones, laptops or PC's.

B. Smart endpoints

In this subtopic the smart endpoints will be explained. The smart endpoints are like the name itself says the final points of the entire home are network systems. These devices are controlled by the main control box found in the HAN.

1. Smart products

Smart appliances or smart connected products are products, assets and other items embedded with processors, sensors, software and connectivity that allow data to be exchanged between the product and the controller. The controller can take various forms, operator/user, other products and control systems such as the smart information box. The connectivity of these appliances enables some capabilities of the product to exist outside of the physical presence of the product. The data collected from the products can be used by smart integrated systems for decision making, enable operational efficiencies and continuously improve the performance of the product.

The smart products are made up of three primary, key components; physical, smart, connectivity. Each of these components expands the capabilities of one another resulting in a virtuous cycle of value improvement. (Porter & Heppelman, 2014)

2. Home plugs

These devices, also called smart plugs, are able to add intelligence to old generation appliances. Simply stated they are socket points, devices that plug in to a socket, that have a wireless connection providing consumption monitoring of the connected devices. As well as providing this monitoring they can also control the devices' status (powering them on or off).

C. Smart meter

The smart meter is connected to the smart information box via the HAN network, and provides information about the current state of the energy sources and energy loads. For further information about this topic see (Chapter 3.2)

4.1.4 Device communication

Previous chapters explained, the various parts needed for the HAN and why a HAN can be useful for a homeowner. In this part of the chapter, there will be more information about the communication of the HAN and how we can accomplish the "master-slave" performance of the HAN. This is by far the most important characteristic of a HAN, the fact that one element from the HAN structure is in control of all its peripherals.

Just like other electronic systems, smart devices all run on a variety of different protocols, a set of rules and standards for communication between electronic devices. This is the most important factor of the HAN, to make sure that all devices and peripherals have the same protocol for communication.

Home networks can either rely on wired or wireless technologies, to make sure that the communication between the various network elements is ensured. Devices can be accessed, monitored and controlled using these built in wired or wireless communication protocols such as Zigbee, Wi-Fi, RFID, Bluetooth, GPRS, Home-Plug, PLC. (Hafeez, Kandil, Al-Omar, Landolsi, & Al-Ali, 2014)

D. HAN wireless network technologies

Wireless protocols in HAN are used to provide remote access to the homeowners, utilities and third party service providers. Zigbee, Wi-Fi, RFID, Bluetooth and Z-wave are the most widely used wireless communication protocols in home area networking.

1. Zigbee Technology

Zigbee technology is a bidirectional RF wireless network standard which conforms to the IEEE 802.15.4. (Prindle, 2014) It has a low data rate, long battery life and operates in the license free frequency for short range. Zigbee is the most suitable and most implemented protocol in the HAN's, it is used in most home appliances such as lighting, air-conditioning and security systems. As explained earlier on the Zigbee protocol utilizes the master-slave model to control the connected appliances. Figure 20 shows a mesh network setup, in this mesh network nodes are interconnected with other nodes in the network. This allows for at least two different pathways to connect each different node. This mesh network creates a decentralisation of the control, this means that each node is capable of self-routing and is able to connect to other nodes as needed. These characteristic create greater stability in changing conditions or failure from single nodes. (Huq & Islam, 2014) This is why THERE corporation used the Zigbee protocol as the base for their operating system. (Sailo, 2015)

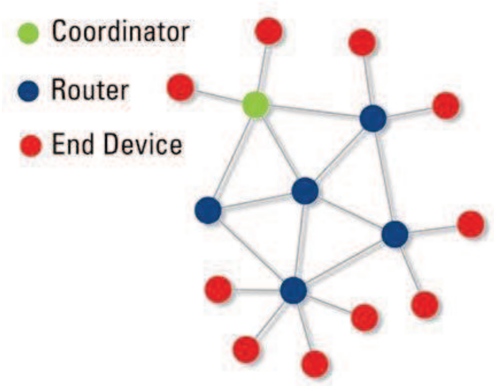


Figure 20 : Mesh network

Table 7 : Zigbee benefits and disadvantages

Zigbee benefits	Zigbee disadvantages
Highly secured connection	Installation requires additional devices
Long battery lifetime	Incompatible with other network protocols
Very reliable	Low data transmission
High control capacity, large network	
Self organizing networking capabilities	

2. Wi-Fi Technology

Wi-Fi is like Zigbee a bidirectional RF wireless network standard but conforms to the IEEE 802.11. The main element of Wi-Fi usage in HAN's is the fact that Wi-Fi can coexist with the other communication protocols. Wi-Fi is utilized in HAN's for high-rate information related devices (TV's, smart terminals, personal computers) and for data download.

Table 8 : Wi-Fi Benefits and Disadvantages

Wi-Fi benefits	Wi-Fi disadvantages
Highly secured connection	Significant power usage
Networking over wired network	Affected by electromagnetic radiation
Supports IP capability	Prone to interference with other protocols

3. Radio Frequency Identification Technology

RFID is also a bidirectional RF identification systems which consists of tags and readers that can be interfaced to handheld computing devices or personal computers. It follows the electronic product code or EPC protocol. It can also coexist with technologies such as Zigbee and Wi-Fi. This is possible because RFID operates under a wide range of frequencies, which range from 120 kHz - 10 GHz and the detection distance can vary from 10 cm - 200 m. (Saponara & Bacchillone, 2012)

An example for RFID use can be found in the area of the home energy management systems. A home user can carry a RFID tag that can be recognized by the lighting controls. This same system can support multiple users and can vary in priority for each tag.

Table 9 : RFID Benefits and Disadvatages

RFID benefits	RFID disadvantages
High transmission speed	Expensive
Low Latency	Low bandwidth compared to Wi-Fi
Allows bidirectional communication	Collision between TAG's
	Accuracy depends on line of sight

E. HAN wired network technologies

Although there are a wide variety of wireless networks available, wired protocols are still as prevalent in home area networking since they are more secure and are capable of transmitting data at higher rates. The most common wired technologies that are utilized in HAN's are; I²C, SPI, PLC.

1. Inter integrated circuit I²C

This protocol is used for slow communication of a microcontroller with onboard peripherals. The I²C bus follows master-salve serial bus architecture as shown in figure 21. (Hafeez, Kandil, Al-Omar, Landolsi, & Al-Ali, 2014) The bus uses two bidirectional wires; The serial data line or SDA and the

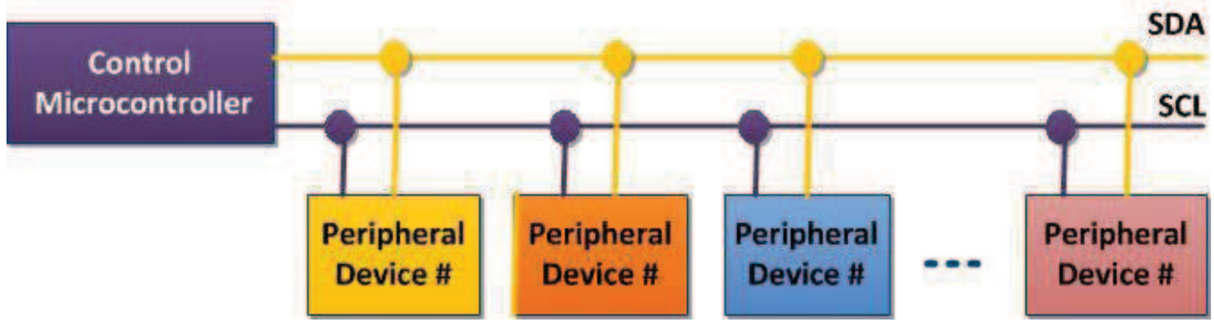


Figure 21 : I²C master/slave serial bus architecture

single serial clock or SCL. The SDA allows data transmission to and from the various slave devices. The SLC signal, which is generated by the master, the microcontroller, is used to clock in or clock out data of the various slave devices. Furthermore does this protocol allow for multiple master devices to communicate with various slave devices.

Table 10 : I²C benefits and disadvantages

I²C benefits	I²C disadvantages
Widely supported	Data rates limited
Simple interface	Nodes limited to address space
Low power consumption	No long distance communication

2. Serial Peripheral Interface SPI

SPI consist of a four wire synchronous interface serial bus which allows processors to communicate with peripheral devices. The SPI hardware is implemented in the various devices as a simple shift register which controls the data flow from those devices by either shifting the data in or shifting the data out. Similar to I²C, SPI also follows a master-slave mechanism; however the protocol involves a single master controlling a whole network of slaves. The interface is wired as a 3+N wired interfaces, where N is the number of devices connected to the master on a single bus. (Hafeez, Kandil, Al-Omar, Landolsi, & Al-Ali, 2014) The SPI interface is used in smart homes to interface external microcontrollers with various sensors. SPI protocol is also used in smart meter communication and in personal health monitoring systems

Table 11 : SPI benefits and disadvantages

SPI benefits	SPI disadvantages
Variety of data transfer rates	Manual configuration
Low power consumption	Hard to integrate new devices
Cost-effective	

3. Power line communication: Home Plug PLC

PLC is used for sending and receiving data on cables which are also used to simultaneously transmit power to the home user. The use of power line cables is made possible with the aid of certain modulation techniques in order to allow high speed communication with minimal interference. Each socket acts as an access point to which appliances connect to. The appliances then communicate with each other through the power line, this makes it suitable for real-time streaming applications. (Hafeez, Kandil, Al-Omar, Landolsi, & Al-Ali, 2014) In order for the home user to create this network, two adapters are to be connected to various power outlets throughout the smart home. The user is then able to connect the devices to the created network via the adapters. Alternatively devices may already be fitted with home plug adapters and therefore need only to be plugged in with the power cable tot be connected to the home network. (Huq & Islam, 2014)

Table 12 : PLC benefits and disadvantages

PLC benefits	PLC disadvantages
Low setup cost	Data signals can be attenuated
No additional hardware required	Electromagnetic interference
Controller can be integrated	Skill required to install

4.2 Energy management system

A building needs an Energy Management System (hereafter abbreviated as EMS) in order to be able to actively make use of features of a Smart Grid as well as to manage its energy usage in a 'smart way'. In case of relatively simple buildings like households it is often called House Energy Management System and in other cases it is referred to as Building Energy Management System (abbreviated as HEMS and BEMS respectively).

The EMS is defined by ISO standards as "set of interrelated or interacting elements to establish an energy policy and energy objectives, and processes and procedures to achieve those objectives" (International Organization for Standardization, 2011). This essentially means that proper management and technology need to be applied in order to improve the overall energy performance of an organisation.

This definition focuses on the process, however in this chapter the focus will be on solutions since the process will not be clearly visible to the end-users. Instead it will be developed by providers of those solutions in such a way that the users are guided through the process and at the same time encouraged in various ways to pursue the presented goals.

4.2.1 History of EMS

The first place to introduce EMS were commercial buildings and factories. In case of the former mostly Building Automation Systems (abbreviated as BAS) were used which allowed to integrate into single system all HVAC elements and sometimes also lighting systems. In case of the latter mostly Supervisory Control and Data Acquisition units were used as the systems were much more complex and required more advanced solutions.

In a study for US government it was estimated that 56% of generated energy goes towards HVAC and lighting systems (Roth, Westphalen, Dieckmann, Hamilton i Goetzler, 2002). Studies like this coupled with data obtained from BAS made many companies notice that the cost of electricity is not fixed and may be lowered by employing proper management techniques. This has become even more important with increasing energy prices and incentives from utilities to participate in load management or demand side management where the customer actively helps to balance the power grid by adjusting their own load.

Increasing awareness of effect of greenhouse gases on the environment which are introduced during energy generation processes and aging power grid that needs to be updated has led to creation of legislation that requires or incentivizes organisations to introduce EMS (EU Energy Efficiency Directive, 2012). At the same time stakeholders and customers have expected the companies to be an example when it comes to being environmentally friendly.

All that together has forced the companies to pursue implementation of EMS if possible and worthwhile. Since then EMS has been studied and described thoroughly in many different national and international standards like ANSI/MSE 2000:2000 or ISO 50001:2011. Those standards provide both an overview and guidelines on how to introduce EMS into companies. However, it can be noticed that all the time the focus is on commercial customers. At the same time it has become clear that in order to reach the energy goals set by for instance European Union, it will be necessary to introduce the EMS in the residential branch of the electricity network.

4.2.2 Structure

First it is very important to make it clear that BEMS and HEMS are not the same as BAS and HAN. The BAS and HAN systems focus on connectivity and control of elements present in the building like HVAC, lighting systems and others. On the other hand EMS focuses strictly on collecting data on energy consumption, its optimization and preparation of feedback for users'. (Hertzog, 2009)

While HEMS and HAN are completly different ideas, it is impossible to discuss the first without mentioning the second. This is because introduction of a simplest HEMS solution requires a certain level of connectivity at a household level which by definition is HAN.

The hardware mostly depends on what solutions have already been introduced by service and device providers as well as user preferences. In general the EMS can be introduced in the following ways:

- As a stand-alone device with HEMS software
- As a separate device with HEMS software being introduced into an existing HAN
- As HEMS software working as a part of a HAN control unit

In the first case the HAN has a very simplified form. The device with EMS software may be greatly simplified and provide the user with just information on the current state of energy consumption – e.g. if it is high or low, or may control Smart Appliances and simple Smart on-off switches without additional HAN elements. In second case a device running EMS software is introduced as an element of existing HAN. An example of such device could be a Smart Meter. In this case the Smart Meter and the control unit for HAN have to closely cooperate in order to control the devices and provide feedback data to the user. A schematic of such setup is presented in figure 22 (Oh, Moholkar, Douglas i Klinkachorn, 2006). In the last case the EMS software is provided as a part of the HAN device.

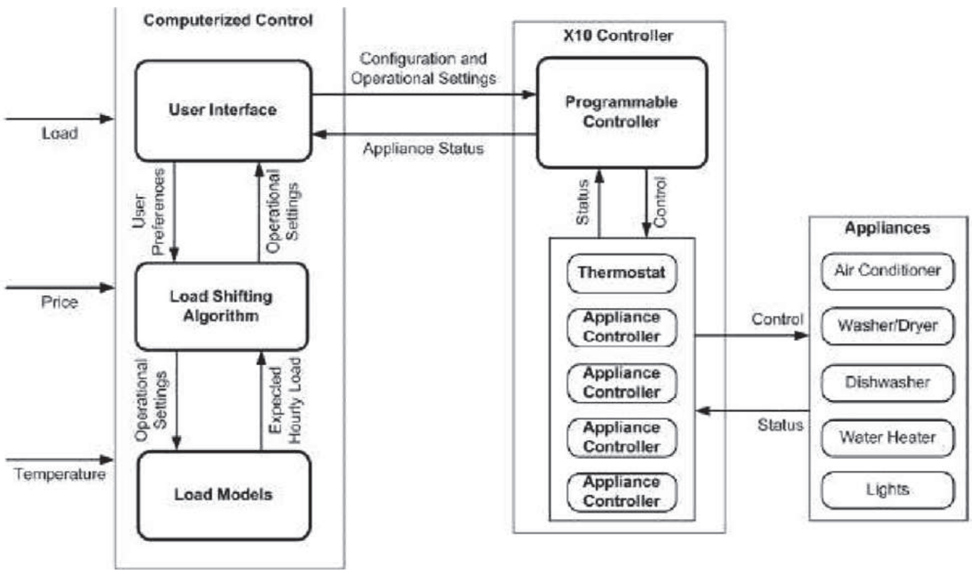


Figure 22 : Example of a separate EMS device cooperating with a HAN controller

The detailed structure of the physical network used by EMS or the technology on basis of which it is built, like communication protocols, are described in detail in chapter 4.1 (Home Automation / Area Network).

The other essential part of HEMS, the software makes sure that the household becomes more eco-friendly. In its simplest form the HEMS provides user with real time information on their energy consumption to make them aware of how much energy they are using. More advanced systems include other modules and algorithms that allow it to actively optimize the energy consumption. In order to make full use of Smart Grids the software would need an ability to communicate two-way with the utility or service provider (described in chapter 3 Communication to the grid), to control the appliances and to plan ahead their work times. However the precise way of operation will be presented later in the chapter.

4.2.3 Operation

In this section many different topics on the way of operation of HEMS will be covered. This includes Demand Response (abbreviated as DR) different algorithms used by HEMS for optimization and scheduling as well as user interaction with the software and challenges presented by it. In addition to that necessary elements for the software's operation like electricity tariffs or issues connected to interaction with users will also be discussed.

The main task of the HEMS is to make sure that users are aware of their power consumption patterns and how they can be controlled. However, teaching is only the first step. The next one is about automation of a house in such a way that it may coordinate with the power grid in such a way that the stability of the power grid is reinforced, the users' costs are lowest while their comfort does not become noticeably worse.

A. Operation algorithms

The algorithms for HEM can be divided into many groups based on different criteria. They can be divided with respect to how much the user can influence them, what is their main goal or what appliances they focuses on.

While the goal of simplest HEMS is to simply educate the user, the more advanced systems focus on very detailed forecasting and precise planning in order to achieve for example lowest possible cost of operation while retaining a minimum level of comfort for the user.

Below will be presented some of scheduling algorithms and operation strategies suggested for HEMS.

1. Least Slack Time (LST)

This algorithm is very simple and is commonly used to schedule tasks. The priority of the task is decided based on the remaining slack of the tasks, which is the remaining time until the latest time the task should start. (Myunggwon, Dongjin i Pankoo, 2010)

2. Earliest Deadline First (EDF)

This is another very simple yet commonly used algorithm for scheduling tasks. The queue is decided based on deadlines of items in it. The earlier the deadline is the higher is the priority of the task. (Myunggwon, Dongjin i Pankoo, 2010)

3. eDIANA project

During the eDIANA project two different algorithms were created. The first one is fully automatic and operates on basis of current energy price, price limits and preferences of use set by user. The function calculates the cost of finishing work of appliances which are already running and cost of tasks that are not started. Then the algorithm will chose as many solutions as possible within the given limits decreased by restraints due to working appliances.

The second algorithm assumes encouraging the user to act on their own. This is achieved by providing clear information to them which allows them to see what kind of devices are consuming power, when they are doing it and how much power they use both over time and at any given instant.
(Ugalde i inni, eDIANA: D3.2-B In-Home energy management strategies development, 2010)

4. OREM

This simple algorithm aims to shift the load from peak times to off-peak times. It assigns all appliances into time slots during low price hours. This algorithm does not have any space for user settings or preferences – it will delay the appliances until a predefined time passes or the condition of low cost is met. (Erol-Kantarci i Mouftah, 2010)

5. In-Home Energy Management (iHEM)

Similarly to OREM, iHEM focuses on shifting the energy usage to less busy times. This algorithm was created mainly for TOU tariff with two or three daily prices. When a device is scheduled for use by the user, HEMS checks the expected price and then suggests a suitable time for the operation of appliance. The user may then accept the suggestion or start the device right away, regardless of the tariff. The delay is defined here as the time between when the user wanted to run the device and when it was scheduled to run by the software. This scheme is capable of reducing peak loads in residence by up to 5%. (Khan i inni, 2013)

6. Decision Support Tool (DsT)

Decision Support Tool or Decision Support System is a program that aims to help the user by gathering data and presenting it in such a way that it is easy for user to make a business decision. This algorithm is focused on inclusion of distributed energy resources, which are things that may help balance the power grid. Those include for example distributed generation, energy storage and controllable user loads. A simple schematic of the system is presented in figure 20. (Pedrasa, Spooner i MacGill, 2010) In simulations this model has resulted in bill reduction of 16-25%. (Pedrasa, Spooner i MacGill, 2010)

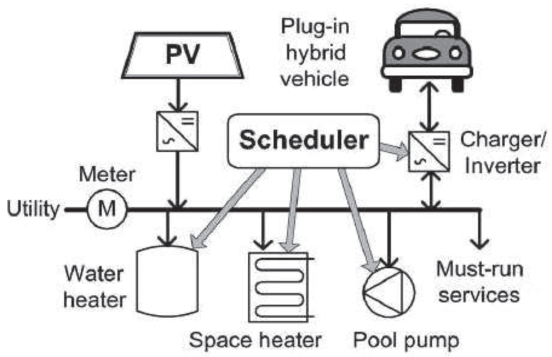


Figure 23 : Schematic of DsT

7. Optimum Load Management (OLM) Strategy

This rather complex algorithm requires a lot of setup by user. It requires information for forecasting on things like local power production, load prediction and prices for the next day. Based on this information it devises a schedule for operation of appliances. Simulations of this algorithm have shown a possibility of reaching 7-22% lower energy bills. (Lujano-Rojas, Monteiro, Dufo-Lopez i Bernal-Agustin, 2012)

8. **Residential Load Control (RLC)**

This algorithm, sometimes also called Optimal and Autonomous Residential Load Control, was created for a real-time pricing tariffs. It does however require some form of price predicting. Its main aim is to decrease the ratio between the peak consumption to average consumption by rescheduling appliances' work times. A schematic of such system is show in figure 24. It presents a smart meter with implemented HEMS software that creates energy price forecasts and based on that schedules the work times of appliances. The algorithm has reduced the energy bill by 10-25% according to simulations. (Mohsenian-Rad i Leon-Garcia, 2010)

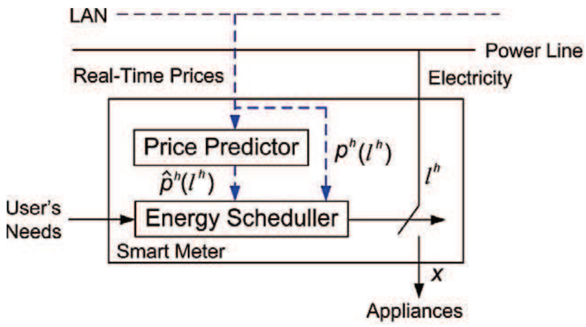


Figure 24 : Schematic of RLC system

9. **Autonomous Demand Side Load Management**

This algorithm depends on three different modules: Admission Controller, Load Balancer, and Demand Response Manager together with Load Forecaster. The first module is collecting data from appliances and controlling them. The Demand Response Manager is responsible for communication with the power grid while the remaining systems are responsible for scheduling the appliances and planning the load in such a way that it is balanced. (Costanzo, Zhu, Anjos i Savard, 2012)

10. **Backtracking-based technique**

This algorithm divides the tasks into preemptive and non-preemtive. The preemptive tasks must be started at time between their activation time and the latest start time at which the device will complete its task before reaching the deadline. In case of non-preemptive tasks they are alocated into slots starting from the deadlines and towards the activation time. The method then creates a tree of all possible solutions including worthless ones. It is then searched for the best posible result which is executed. (Lee, Kim, Park i Kang, 2011)

11. **Game-Theoretic Based DSM**

This method is different from previous ones in that it focuses on managing a whole neighborhood at the same time instead of a single household. The houses are assumed to be players, their strategies are their daily scheduled loads while the utility is serving them. The solution is found based on Nash equilibrium. In order to find it a distributed algorithm is used and an energy consumption scheduling is carried out by smart meters. Figure 25 presents a simple model of such system. (Mohsenian-Rad, Wong, Jatskevich, Schober i Leon-Garcia, 2010)

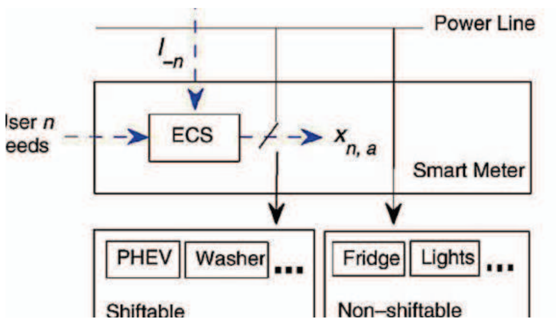


Figure 25 : Theoretical based model

12. **Energy Consumption Scheduler Device based scheduling**

This is another method that focuses on a neighbourhood instead of a single household. It assumes that multiple houses use a single power source. A distributed algorithm is used to schedule optimal energy usage of each user. According to balance of this small cell the individual scheduling devices plan the energy consumption plan for each of the houses. (Mohsenian-Rad, Wong, Jatskevich i Schober, Innovative Smart Grid Technologies (ISGT), 2010)

13. Vickrey-Clarke-Groves Mechanism based DSM

This algorithm approaches the DSM in a bit different way as it focuses on maximizing of users' comfort and lowering the total energy cost taken by the utility. In a neighbourhood the houses' Energy Consumption Controllers create schedules for appliances for each house. Next necessary energy is computed and presented to the utility. Based on this information a price is set for each individual user. This allows to lower the cost of energy for some of the users. (Samadi, Mohsenian-Rad, Schober i Wong, 2012)

14. A Scheme for Tackling Load Uncertainty

This algorithm focuses on reducing energy cost in real-time based on lowering the load irregularity. This method assigns each task a time slot when it can be run based on whether the task must be run or not and expected loads. The slots are assigned in an optimal way by an Energy Consumption Controller. This method also incorporates the IBR prices strategies when planning the schedule. (Samadi, Mohsenian-Rad, Wong i Schober, 2013)

B. Input and outputs

In order to operate the HEMS requires input which will feed it data and outputs upon which it may act. The inputs may be different ranging from energy price provided by utility, through weather forecast that will allow to estimate the amount of energy obtained from renewable energy sources to temperature inside a house. On the other hand the types of outputs are rather limited as most of appliances could make use only of simple on/off control.

In order to better define them a number of inputs and outputs were marked that may affect HEMS and thus improve the power management. Below in table 13 are presented possible inputs and outputs based on (Ugalde i inni, eDIANA: D3.2-B In-Home energy management strategies development, 2010).

Table 13: Table of EMS inputs and outputs

Inputs	Outputs
User's settings • Occupancy • Device programs • Automatic energy saving profile set up	Devices statuses • On/Off control • Stand-by control • Pause control
Device's status • On • Off • Stand-by	Devices feature control • Lighting dimming • Screen brilliance • Temperature control
Devices consumption	
Device's priorities	
Sensor's data • Occupancy • Humidity • Lighting • Temperature	
Energy price	

The data presented in the project assumes that the device is programmable which might not always be the case. In such case the device is usually controlled by the service operator based on the status of the grid.

A. User interaction

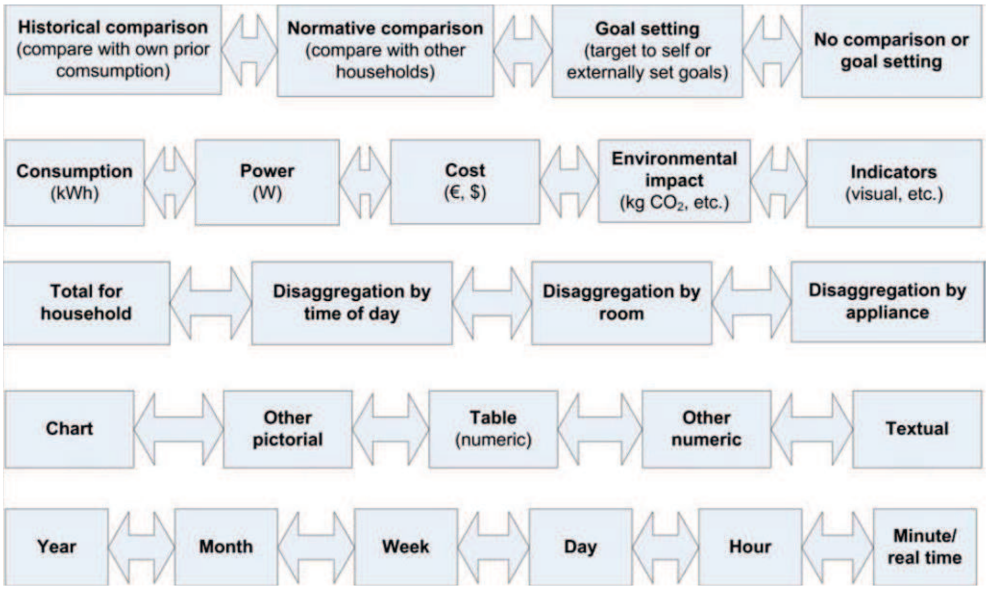
A very challenging topic for HEMS is the interaction with the user. Unlike in case of BEMS it should be assumed that the software will be used by regular people with varying levels of technical knowledge. While keeping that in mind it is still necessary to provide the users with feedback on their energy usage and possibly with information that could encourage them to optimize their energy usage even further. In addition to that if the system is not fully autonomous the usage of it should not pose big problems for the users either.

In many studies it has been noticed that even though the users use electricity daily and are faced with electricity bills regularly they have little idea about their actual energy consumption. In order to improve this awareness the possible feedback that can be provided has been divided into three different groups: direct, indirect and inadvertent feedback.

In direct feedback the user learns about the energy consumption first hand by using devices and widgets which allow them to learn of power usage and review the energy used at any time. It may also be achieved by using feedback via devices like PCs or mobile devices. In case of indirect feedback a more detailed energy bill is suggested that could be combined with different forms of feedback like historical data on their energy usage or comparison with similar households in the area. It is also mentioned that while bills should be more detailed they should be provided more often so the user is updated with the issue. Finally, inadvertent feedback is learning by association. That means that when a person invests into for instance renewable energy sources they become involved and their awareness of energy generation and consumption grows. (Karjalainen, 2011)

A detailed study by Darby on over 40 different pilots indicates that among projects where a single type of improvement was used, the best methods were direct ones. Various types of displays presenting the users with real time information on their energy usage and cost of it have proved to have the best effect. The second best results were provided by indirect ones. The most commonly used techniques here were shorter times between consecutive energy bills, introduction of historical feedback and tips on how the energy usage can be lowered. In case of multiple types of improved feedback the most effective proved to be combination of direct feedback like ability to know the consumption real-time with improved energy bills with historical feedback and tips on energy consumption. What is more in cases where the participants were asked about the participation in the projects the majority was satisfied with the information they were being provided. (Darby, 2006)

In his study Karjalainen suggest the following possibilities when it comes to types of feedback (figure 26). He discusses reasonability of different kinds of feedback. For instance he explains that while kWh is an easy to understand and to calculate unit to measure energy used, for some people it might be unclear. In such situation he suggests to use unit that will be much more familiar for users and will give them a better idea of their energy expenses – their local currency.



During the eDIANA project a feedback system was developed and its effectiveness was checked. The participants were given a number of tasks to be performed with an interface developed for in-home displays and smartphones. The results of the tests were that the users in general were quite interested in the presented data, but some of them said they would not wish to interact with the system on a daily basis. Instead they explained they saw the activity as a means of understanding their energy bill by seeing what has contributed mostly to it. What is more some users found it hard to understand the values of energy consumption presented in watts and some did not understand the values presented in euros. In addition to that the users have expressed their opinions on general functionality of the software which were in general positive. (Ugalde i inni, eDIANA: D7.2-C Final Test Results, 2010)

4.2.4 Impact of HEMS

Different sources study influence of introduction of EMS into households. There are documents available presenting results of theoretical simulations, small-scale pilot projects and demonstration

Figure 26 : Possible feedback options from HEMS

projects.

A report by Ullah et al. presents an analysis and results of simulations for different models for scheduling of appliances that may be used for introduction of demand side management. Their results are presented in table 14. The methods are described earlier in the chapter. The load minimization refers to peak load reduction while cost minimization refers to reduction of total power usage. It can be noticed that effectiveness greatly varies between the algorithms.

Table 14 : Results of simulations of HEMS scheduling algorithms

Scheme name	Method	Load minimization	Cost minimization
A Model for Autonomous DSM	Load control scheduling model	66.7%	NA
Backtracking Based Technique	Back-tracking based scheduling	23.1%	NA
Game Theoretic Model	Game theoretic pricing and scheduling	17.0%	18.0%
ECS Device Based Scheme	Energy consumption scheduling	38.0%	37.0%
Optimal Residential Load Control Scheme	LP-Based optimization	22.0%	10-25%
Vickrey-Clarke Groves Mechanism	Scheduling and Optimization	38.0%	37.8%
Scheme for Tackling the Load Uncertainty	Optimization based algorithm and scheduling	25.5%	NA

A pilot project carried out in Turkey on a smart house presents interesting results of energy usage of a household before and after installation of HEMS. In figure 27 daily monthly consumption is presented. It can be noticed that both during summer and winter the house with HEMS has generally lower energy consumption. What is more it can be observed that with HEMS when appliances seem not to be used at homes, the energy consumption is reduced to 0 unlike before introduction of EMS.

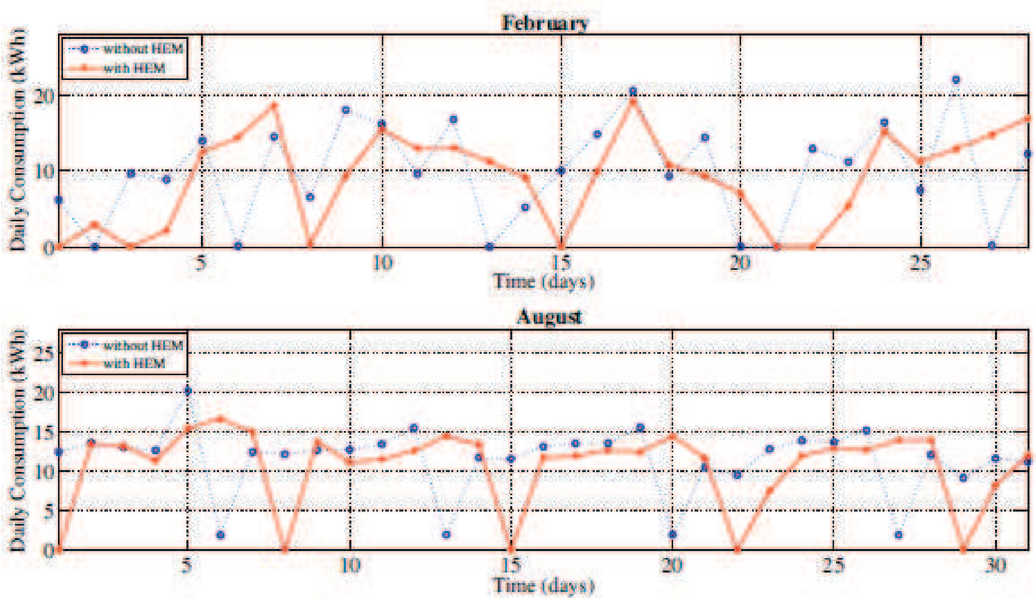


Figure 27: Domestic energy consumption

In the report prepared by Darby the direct methods of feedback resulted in up to 10% average reduction and up to 27% of peak reduction of energy consumption. In case where the indirect methods were used alone a reduction of average consumption of up to 10% was achieved. Finally, in cases where at least two different types of improved feedback was used up to 13% reduction of energy consumption was observed. (Darby, 2006)

When comparing the data from simulations and real test it can be noticed that only some of the simulations were able to provide similar results. But even for those types the simulations provide results that are similar to the best possible ones. This means that the actual impact of HEMS might not be as good as expected.

However there are also problems that appear due to HEMS. Germany has a very high number of photovoltaic's installed contributing a lot of power generation to its power grid during the year. However, sometimes the power generated exceeds the power load what can be observed by increasing frequency of electricity. In order to protect the grid from outages due to overload the photovoltaic's were fitted with inverters which were to shut down or reduce their output if the frequency increased by 0.2 Hz. It was later noticed that in case of high level of penetration of power grid with photovoltaic's it could cause a sudden disappearance of a lot of power causing a blackout due to insufficient power on the grid. Because of that the inverters had to be upgraded in such a way that the renewables are turned off randomly at varying frequencies while even some continue to work in case the measured increase or drop in frequency is very short. The difference in input of photovoltaic's to the grid and the load curves is presented on figure 28 (Coggins, 2014). As it can be noticed the stability of power grid with standard inverters is much worse than that of improved ones. The randomization introduced for inverters in Germany proves to be a very effective measure to solve this kind of problem. (Morris, 2011)

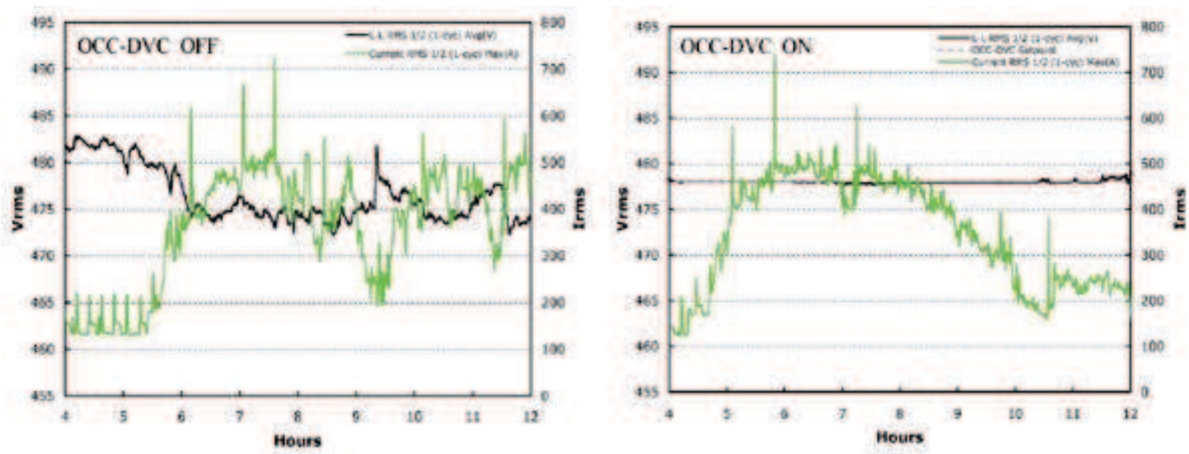


Figure 28 : Power on grid; Left: with simple inverters; Right: with randomized inverters

In case of HEMS achieving a very high grid penetration might result in similar problems. The software would need to be even more sophisticated as the Smart Grid assumes both better market penetration by renewable energy sources and introduction of demand side management. This means that if a solution is not created for this early enough a situation similar to that in Germany with its photovoltaic's could arise where all existing systems would need to be retrofitted which might be a costly process.

5 Renewable energy sources for smart housing

Energy is the convertible currency of technology. Without energy the whole fabric of society as we know it would crumble; the effect of a 24-h cut in electricity supplies to a city would show how totally dependent we are of that particularly useful form of energy. As the world's population will grow, much faster than the average 2 %, the need for more and more energy is exacerbated. (Dincer, 199)

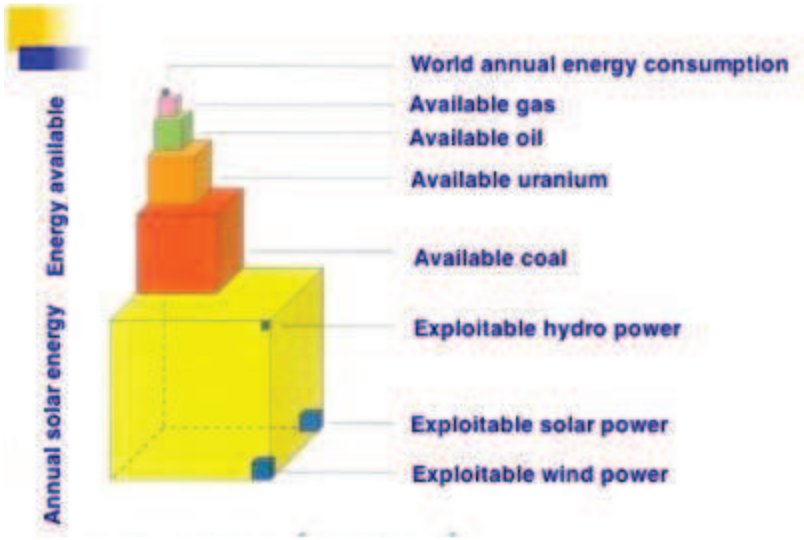


Figure 29: Available renewable sources

Figure 29 (Olino) depicts the size of the annual energy consumption around the world, and how it relates to the worlds reserves of fossil fuels on one hand and to renewable sources in the other hand. As shown in the image, the fossil fuels are a finite resource while the renewable as the word itself describes are not. That is why it is of the utmost importance that the grid today is adapted to implement a variety of renewable energy sources.

With the liberalization of electricity production, promotion of non-conventional generation as a strategy for security of supply in the long term, coupled with technological advances have led to the consolidation of generators with renewable energy sources, mainly wind and solar, as electricity producers (FUMESA, 2013).

5.1 Introduction

One of the reasons why renewable energy sources are so important for the grid today is the availability of the traditional fossil fuels. The reserves of coal, oil and natural gas are finite on earth, but they are also expensive to extract and complex to transform. The reliability, stability and security is another reason in favour of renewable energies, since the former depend on the political stability of the regions where these fossil resources are found, or the structural stability of the platforms or mines. For the price and supply depends on many factors. In contrast, renewable energies are infinite products that do not need complex transformation. They can be produced locally and therefore are not affected by political or economic instability in other countries.

Pollution is another important aspect. Coal mines and exploitation and oil refinement produce a lot of solid toxic waste and emissions of highly polluting gases. Which cause serious long-term illness for the population, and acid rain caused major damage to buildings and ecosystems. Consequently, this carbon dioxide and greenhouse gases these are the cause of climate change and global warming. Not the case of renewable energy, as these are cleaner.

In conclusion renewable energy sources are important for their environmental benefits, as they are clean sources with less environmental impact than conventional energy technologies. They are a source of infinite energy, or rather finite very long term. Being more respectful of the environment and contributing to the 20 EU plan. The economic effects are not dependent on oil imports from abroad so they are cheaper and safer. And with the variety of options each country could choose the most convenient (Eric Moll, Demand Media, 2015), (Renewable Energy World, 2015).

As stated before, renewable energy is reliable, plentiful and an infinite source of energy. The reliability of RES is important because they are not influenced by volatility or availability. Other upsides are the fact that they can be produced locally and in large quantities. (Moll BSc) The production of renewable energy is increasing every year and is no longer restricted to large quantity operations. The amount of small, consumer operated renewable energy plants is increasing year after year. For example in 2011 Belgium's residential installations (<10kW) represented 55 % of the total installed power. (ODE, 2011) This is why it is of the utmost importance that consumers evolve to "pro-sumers", where they play a significant part in the production of energy.

The benefit of renewable sources can be found on many levels, but the most important level will be sustainability. The fact that energy can be produced in large scale without any of the downsides found when using fossil fuels.

5.2 Various RES

There are a vast number of renewable resources available to mankind today, but not all of these resources are also applicable to housing infrastructure. This has everything to do with the limits of the house environment and availability of resources. Therefore there are only a few renewable resources that can be applied on house level into the smart grid.

A second important point about the various renewable energy sources that are available to be implemented in smart homes, is that their primary objective is not solely to produce power but also to decrease the amount of power needed from the grid. This means that the more of renewable sources are installed in the homes, the less energy is required by the home owners from the grid.

Most renewable energy comes directly or indirectly from the sun. Sunlight can be used directly for heating homes, lighting, power generation, generating hot water, among other uses. But it is also responsible for the wind and air currents. Which spinning mills to produce energy, but also make the water which later was stored in reservoir evaporate and will be used to produce hydroelectric power. The sun and water are responsible for growing plants, organic matter which is called biomass, which can be used later to produce electricity, transportation fuel or chemicals. Not all energy resources come from the sun. For example geothermal energy, which comes from inside the earth, is also a type of renewable energy used to generate electricity, heating and cooling. Or the energy of ocean tides comes from the gravitational pull of the Moon and Sun on the Earth (Roberto villafáfilla, 2015).

5.2.1 Solar power

Solar power is the most important form of renewable energy, this for the reason that it not only delivers the energy form the sun, but it also powers other renewable energies such as wind power and geothermal power. Solar power can be harnessed in 2 different ways; first in its active way by using solar panels and solar collectors and secondly in a passive way by orientation of buildings.

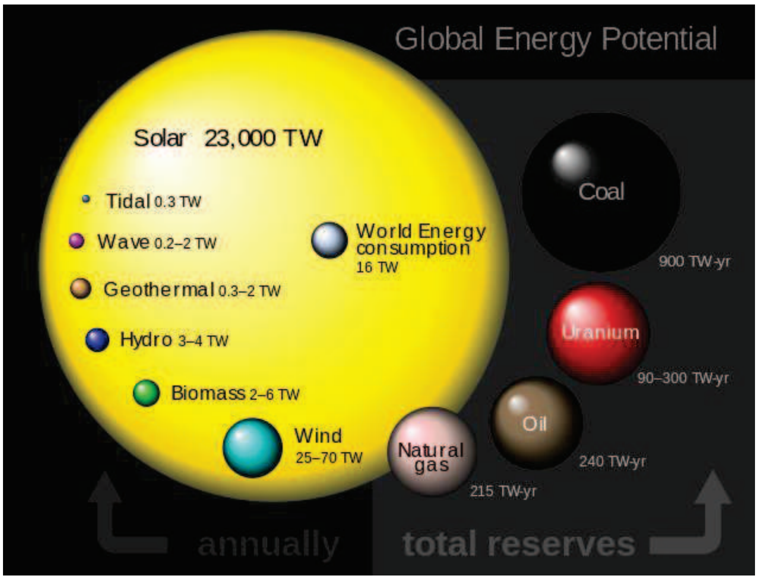


Figure 30 : Global energy potential

Figure 30 shows that the energy received from the sun is massive, so massive in fact that the sun's energy during 1 day can fuel the energy need for the entire world's population for the next 27 years. In fact the amount of energy that the suns radiates annually contains more energy than all energy stored in the remaining fossils available on earth. (Marc & Richard, 2009)

A. Active collecting

The active collecting of solar energy is most common by usage of photovoltaic panels or solar collectors. These panels and collectors harness the sun energy by either turning it into electric energy or thermal energy.

When looking to the active collecting, the most used type of collecting are the photovoltaic panels. These panels turn the sun's light energy into electric energy. The panels consist of semiconductor material, that generate electricity when being struck by sunlight. Figure 31 shows this process and how the produced electricity is then converted and made applicable for the homes.

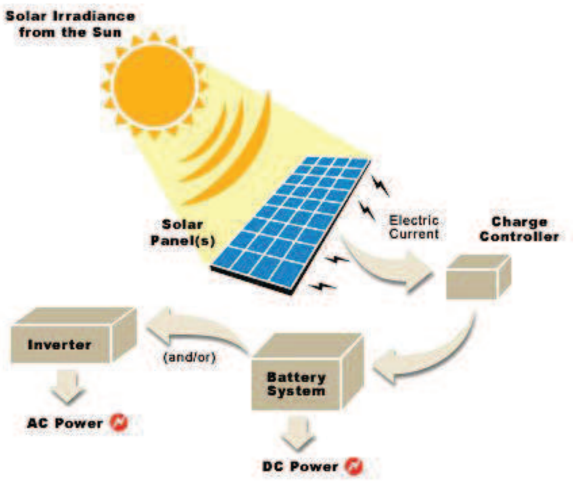


Figure 31 : Photovoltaic energy

For a domestic setup, an array of panels is mostly installed on the rooftop, where the array can harness the optimal solar energy for the largest amount of time. The solar panels than create a current which can be directly linked to the amount of panels installed in the array.

A second way of active collecting is the thermal collecting, where the systems collects heat by absorbing sunlight where it captures the electromagnetic radiation, from the infrared and ultraviolet spectrum, emitted by the sun. The main usage for the housing market are the solar hot water panels or the solar boilers, here it is then referred to as "heat collectors". The distinction can be made that they are either concentrating or non-concentrating, for the latter this means that the collector area (i.e., the area that intercepts the solar radiation) is the same size as the absorber area (i.e., the area absorbing the radiation). When looking at the concentrating type, it functions the same ways as the non-concentrating, only the fact that the collector area is bigger than the absorber, giving the fact that it then can receive more radiation ergo more heat per square surface.

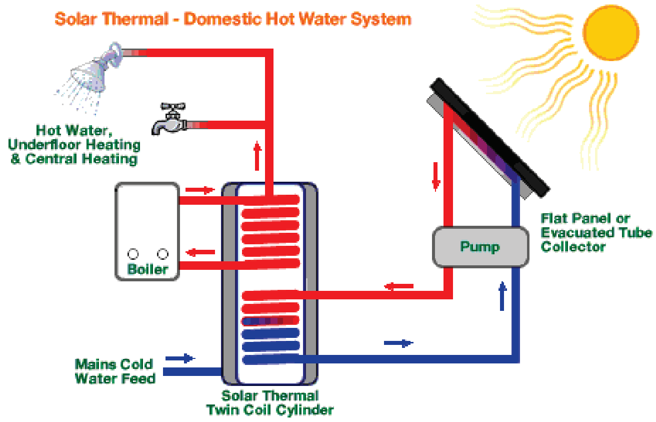


Figure 32 : Domestic thermal solar system

Figure 32 show a typical setup for a solar water heating process. As shown in the figure the solar collector is placed on the roof at the optimal angle so it can capture as much energy as possible. The fluid that runs through the collector than stores the captured energy and heats up the domestic hot water supply which can be used for the various systems throughout the house. The figure also show that there is a backup installed in the systems by the means of an independent boiler.

Figure 33 (Sundrom Solar) depicts a hybrid solar panel performs two functions in one module. Generation of electricity by photovoltaic effect, and heating sanitary water by solar radiation. Water also performs the function of cooling, increasing the efficiency of the photovoltaic panel.

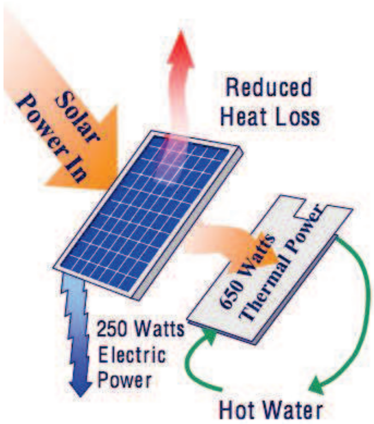


Figure 33 : Hybrid solar panel

B. Passive collecting

Passive collecting or harnessing of the sun's available power, is the least known but yet the most implemented means used by mankind. Passive collecting or passive solar design refers to the use of the sun's energy to cool or to heat living spaces. By using this approach, the building or other elements will take advantage from its natural energy characteristics in the materials or in the air due to the exposure to the sun. The systems implemented in houses are simple and require little to no maintenance.

5.2.2 Geothermal power

The use of geothermal energy is based upon the fact, that once these systems are installed in the home, it decreases the amount of power required by the housing unit. The traditional uses for geothermal power are to heat and / or cool housing units according to their requirements during a period of time.

Geothermal power is as the name itself explains, is a power created by using the heat from the earth mass. It is a clean, renewable source of energy with a variety of applications and resources. The heat of the earth is available everywhere and is limitless since the heat is coming from the earth's interior. The total heat that is available at any given moment is equivalent to 42 million MW of power and is expected to remain so for the remainder of earths existence, ensuring an inexhaustible supply of energy.

A. Geothermal heat pump

A geothermal heat pump or GSHP is a central heating and / or cooling unit that transfers heat to or from the ground, this according to the requirements of the housing unit over a period of time. It uses the earth as a heat source or a heat sink depending on the time of year.

Figure 34 shows a depiction of a crude schematic about the workings of a GSHP. A heat pump functions the same way as a households refrigerator, but can also work in the opposite way. This causes the effect that a heat pump can either heat your home or cool it as well.

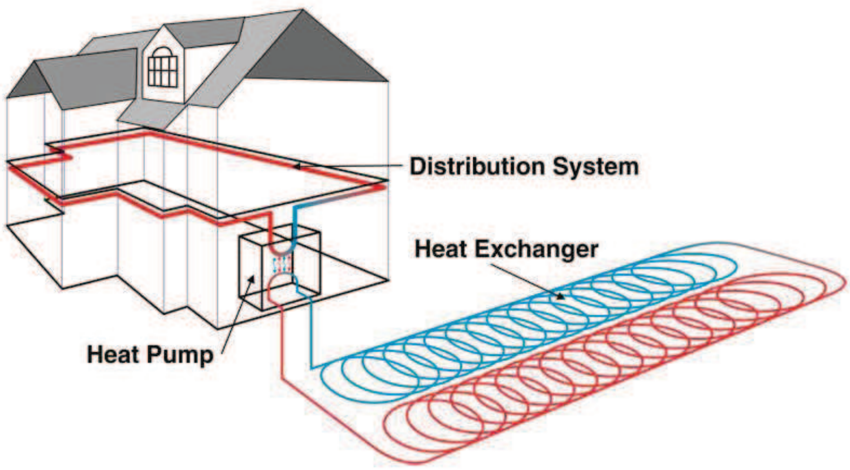


Figure 34 : GSHP Schematic

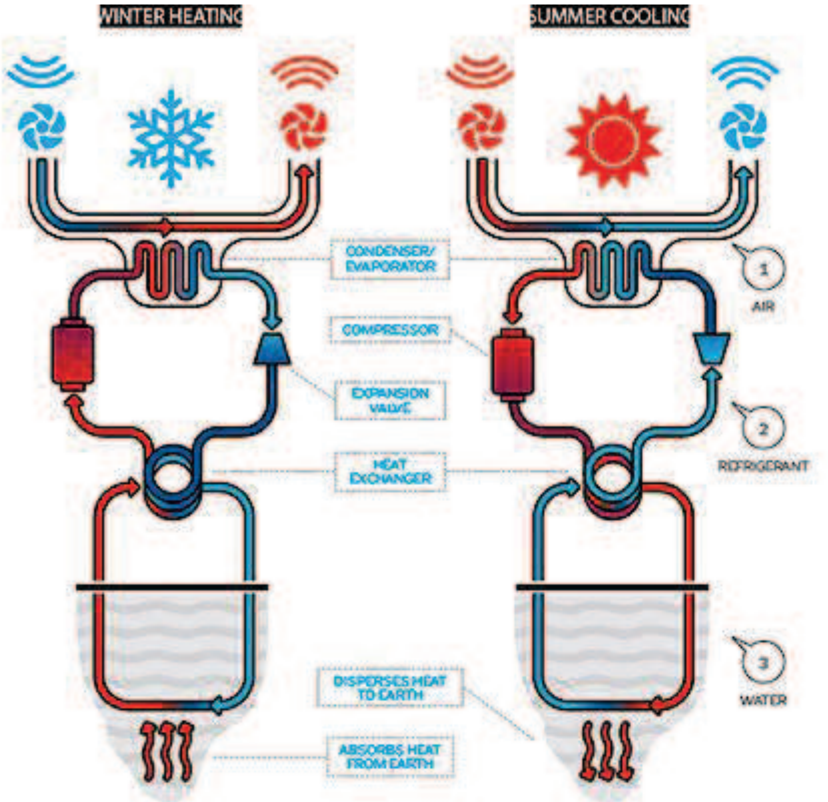


Figure 35 : Alternating performance GSHP

Figure 35 explains the alternate function that the GSHP can perform during the alternating seasons. During the colder periods throughout the year the GSHP will perform a heating process, carrying the heat from the ground into the home. Whereas during the hotter periods it will perform a cooling process, carrying the heat from the home to the ground.

5.2.3 Other renewable energy sources

As mentioned in the introduction text there are still a lot of possible renewable energy sources for smart housing available, for example wind energy or fuel cells. These two are examples of renewable sources that are not really focused on the home owner's market but still can provide a significant advantage to the smart grid when installed by a group of smart homes. In the following chapters these two renewable energy sources will be further explained.

A. Wind power

Wind power is a renewable energy that generates electricity from wind power through wind turbines. Some mechanical devices that simulate the old windmills, which transform the kinetic energy of wind into mechanical energy with their blades (ENDESA, 2015).

1. Present

Wind energy is a technology that has experienced an increasing demand to the foreseeable depletion of traditional energy resources. According gamesacorp "it is estimated that the energy contained in the wind accounts for approximately 2% of the total solar energy reaching the Earth, which represents almost two billion tonnes of oil equivalent (TOE) per year (200 times the consuming all countries of the world) " (GAMESA, 2015).

Nowaday the countries that generate more wind power are: China (62,700 megawatts), United States (46,900 MW), Germany (29,000 MW), Spain (21,600 MW), India (16,000 MW), France (6800 MW), Italy (6700 MW), UK (6500 MW), Canada (5200 MW) and Portugal (4000 MW). (Energía Eólica.org, 2015)

This way of obtaining energy has grown significantly in recent years due to its numerous advantages over other forms of energy.

Benefits:

- Avoid CO2 emissions and other greenhouse gases.
- No large ground movements or change in the bed of the water.
- There is no residues or pollution, nor changes in the surrounding environment.
- It is an inexhaustible resource.
- Is present in all countries so reducing energy vulnerability.
- It has an industrial character.
- Generates competitive prices in the market due to its technological development.

"These strengths suggest that the energy cost of an average farm will be competitive with coal, gas and nuclear energy by 2016," according to Bloomberg Energy Finance.

Disadvantages:

- Big visual impact due to the magnitude of mills.
- Negative effects caused by disturbances that cause the wind with relief.

(GAMESA, 2015)

2. Power generation

The solar radiation absorbed by the atmosphere generates air masses of different temperatures, and consequently different densities and pressures. The convection currents of these masses to move from high to low pressure results in the wind. In the map below (figure 36) you can see the distribution of wind resources in Europe (GAMESA, 2015).

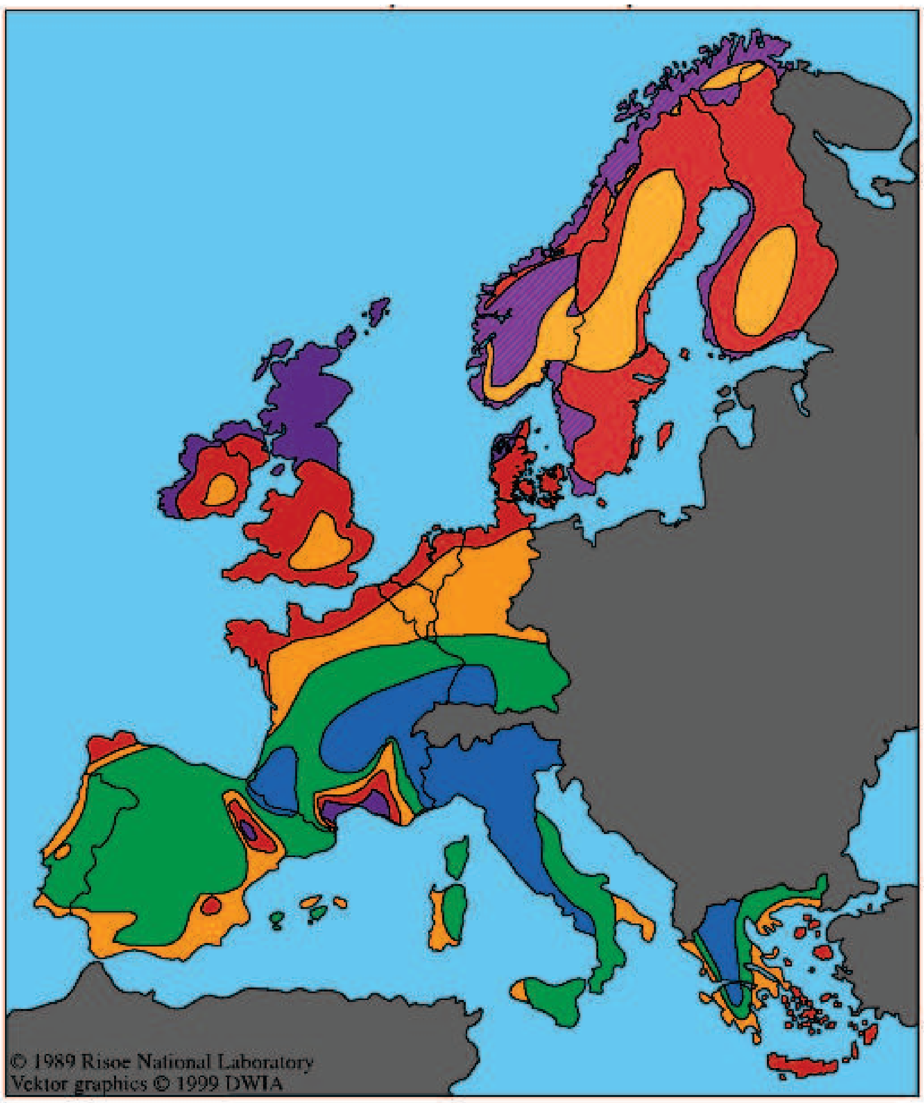


Figure 36 : Wind map of Western Europe. Danish Wind Industry Association

Wind energy can to capture it with wind turbines. Who transform the kinetic energy to electrical energy, which will be distributed through utilities. Wind turbines produce electricity using natural wind power to run a generator. Wind turbines, which attempt to simulate the appearance of old windmills, consisting of a rotor with fibreglass blades rotating around a horizontal or vertical axis, which is connected to a set of mechanical transmissions. And finally to an electric generator, which are located on top of the tower. These towers are made of steel. In other consist of automatic power control with mechanical safety stop at very high speeds.

Wind Resources at 50 (45) m Above Ground Level

Colour	Sheltered terrain		Open plain		At a sea coast		Open sea		Hills and ridges	
	m/s	W/m²	m/s	W/m²	m/s	W/m²	m/s	W/m²	m/s	W/m²
	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400
			>7.5							
			5.5-7.5							
			<5.5							

Figure 37 : Wind resources from wind map

The diameter of the turbine is important for energy production, since the higher blade length greater swept area, and therefore greater energy produced. But also important is the place where they are located. Wind farms are often installed in very windy areas where there are lower wind disturbances due to geographical reasons, but also taking into account the visual impact they create. These gadgets usually consist of an odd number of blades, as an even number can cause stability problems in a machine with a rigid structure due to flexibility calculation purposes. The three-bladed Danish or classical concept is most often used. This is a tower with three blades, a rotor in the face by which gives the wind and an electric motor. (GAMESA, 2015), (Aerogenderadores, 2015)

B. Fuel cells

Fuel cells are energy conversion devices that generate electricity and heat by an electrochemical process. This process consist of the combining a fuel and an oxidant gas through a series of electrodes and across an ion conducting electrolyte, when the fuel is being oxidised only water is formed as a by-product. The fuel cell does not run down or require any recharging, and that is the great upside to a fuel cell, as long as you have fuel to provide to the fuel cell it will keep on going. The principle characteristic of a fuel cell is its ability to convert chemical energy directly into electrical energy giving it much higher conversion efficiencies than other conventional thermo-mechanical systems thus extracting more electricity from the same amount of fuel as shown in table 15 (Segura & Andujar, 2009)

Table 15 : Efficiency comparison

Means	Gas-Electric	Microturbine	Diesel-electric	Fuel cell
Efficiency	20 %	24 %	32 %	90 % (with heat recovery)

Figure 38 (Dervisoglu, 2012) shows the basic inner working of a fuel cell. The fuel cell is mainly composed of two electrodes, the anode and the cathode, the catalyst, and an electrolyte. The fuel is also important as the principal parameter but independent of the other as it is most of the time converted into hydrogen. The main function of the electrode is to bring about reaction between the reactant (fuel or oxygen) and the electrolyte without itself being consumed or corroded. It must also bring into contact the three phases i.e. the gaseous fuel, the liquid or solid electrolyte and the electrode itself. The anode, used as the

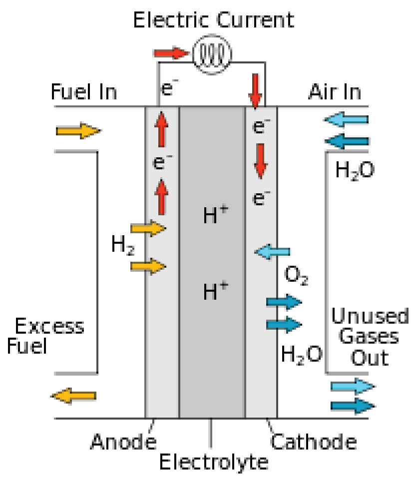


Figure 38 : Fuel cell schematic

negative post of the fuel cell, disperses the hydrogen gas equally over the whole surface of the catalyst and conducts the electrons, that are freed from hydrogen molecule, to be used as a useful power in an external circuit. The cathode, the positive post of the fuel cell, distributes the oxygen fed to it onto the surface of the catalyst and conducts the electrons back from the external circuit where they can recombine with hydrogen ions, passed across the electrolyte, and oxygen to form water. The catalyst is a special material used to facilitate the reaction between the fuel and the oxygen. Operating temperatures are determined by the nature of the electrolyte used in the fuel cell.

Table 16 : Technical characteristics of different fuel cells

Type of FC	Electrolyte	Operating T (°C)	Fuel
Alkaline (AFC)	Potassium hydroxide	50 - 200	H_2, Hydrazine
Direct methanol (DMFC)	Polymer	60 - 200	Liquid methanol
Phosphoric acid (PAFC)	Phosphoric acid	160 - 210	Alcohol, H_2
Sulphuric acid (SAFC)	Sulphuric acid	80 - 90	Alcohol, impure H_2
Proton exchange (PEMFC)	Polymer, proton exchange membrane	50 - 80	Methanol, impure H_2
Solid oxide (SOFC)	Stabilized zirconia and doped perovskite	600 - 1000	Natural gas, propane
Solid polymer (SPFC)	Solid sulphonated polystyrene	90	H_2
Molten carbonate (MCFC)	Molten salt	630 - 650	H_2, CO, Natural gas, propane, Marine diesel

The electrolyte is used to prevent electronic contact between the two electrodes. It also allows the flow of charged ions from one electrode to the other. It can either be an oxygen ion conductor or a hydrogen ion (proton) conductor, the major difference between the two types is the side in the fuel cell in which the water is produced: the oxidant side in proton conductor fuel cells and the fuel side in oxygen-ion-conductor ones. (Boudghene Stambouli & Traversa, 2001)

Table 17 : Benefits of fuel cells

Benefits	
Energy security	○ Reduce oil consumption ○ Cut oil import ○ Increase amount of available electricity supply
Reliability	○ Operating times > 90% ○ Available power 99,99% of time ○ Minimal degradation (< 0,1% / 1000 h)
Low operating cost	○ Efficiency reduces energy bill ○ Minimal installation ○ Low maintenance
Constant power production	○ Continuous generation ○ Optional cogeneration

Choice of fuel	○ Flexibility
Clean emission	○ As shown in table 4 ○ 100 - 1000 cleaner than 1998 American standards
Quiet operations	○ Unattended operations ○ Low noise, indoors implementation possible ○ Normal conversation possible next tot device
High Efficiency	○ Converts 50 - 70 % of fuel to electricity ○ 90 % with heat recovery

5.3 Benefits from RES

A mentioned before there are a lot of benefits to renewable energy sources, when we can implement them in smart homes. Not do they only provide benefits to the smart home owners they also provide a lot of benefits to the smart grids distributors. Each source of renewable energy has its unique benefits and costs.

When looking to the various benefits that renewable energy resources can provide, there are four main topics that can be described. The environmental, the future of energy, economical and energy security. These four topics are considered to be fundamental to the instalment and use of renewable energy sources. (Nextera energy resources LLC, 2009)

5.3.1 Environmental

When looking into the environmental benefits of renewable energy sources it is hard to ignore the main reason why it is so important to start using renewable energy on a massive scale. The human activity is overloading the earth's atmosphere with CO_2 and other global warming emission gasses which create significant and harmful impacts on the health, environment and climate. (Union of Concerned Scientists, 2014)

Renewable energy has a significant role to play in mitigating climate change. Increasing the share of renewable energy will result in a significantly lower greenhouse gas emissions. When looking to wind, solar, hydropower, ocean and geothermal energy it is stated that these do not contain any fossil carbon atoms to form CO_2 during combustion. Hence renewable energy is not only resource compatible, but also climate compatible. (EREC, 2012)

Table 18 : Comparing air emissions

Air emissions	SO_x	NO_x	CO	Particles	Organic compounds	CO_2
Fossil fuelled plant	28.000	41.427	28.125	500	468	4.044.000
Fuel cell	0	0	72	0	0	1.860.000

Table 18 (Boudghene Stambouli & Traversa, 2001) shows that in comparison to a traditional fossil fuelled plant, pounds of emission per 1650 MWh during a period of one year of continuous operation, a fuel cell emits almost no greenhouse gasses.

For example; Germany has been investing heavily in the use and implementation of renewable energy sources over the last few years. In 2014 the use of renewable sources has gone from 25 % to 28 % compared to 2013. At the same time Germany was able to decrease the energy demand with 3,8 % despite having an booming economy (+ 1,4 %), which is normally followed by an increase of energy demand. Combining these two factors Germany was able to decrease their output of CO_2 with almost 5 % compared to 2014.(figure 39) (Agora Energiewende, 2014)

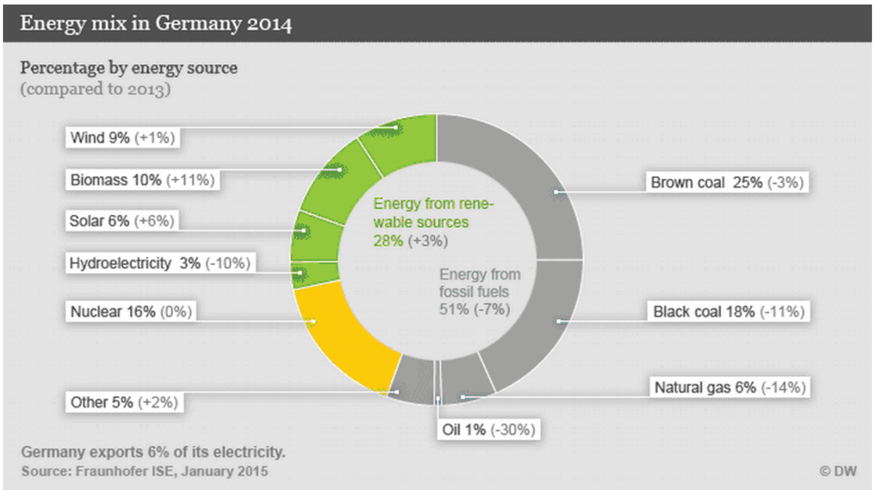


Figure 39 : Energy mix Germany 2014

5.3.2 Future of Energy / Energy security

As mentioned in the introduction of this theme in the report, is that the main theme for the future is the decentralization of the production of electricity and power. This is where the smart grids come in, smart grids are a network of interconnected energy producers and consumers. This is where energy security comes in, energy security is nothing more than to provide an uninterrupted supply of energy to the consumer via the grid.

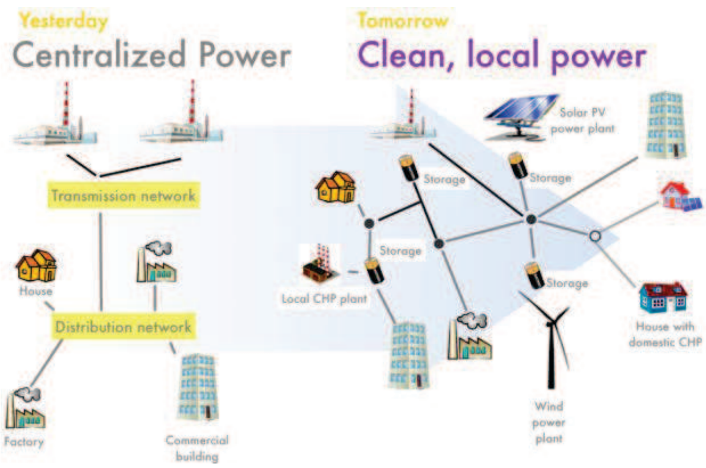


Figure 40 : Decentralization of power generation

Figure 40 (Farrell) depicts the future way of a decentralized power generation. This type of decentralization can only be created when renewable sources are largely integrated and implemented in the power grids we know today.

Renewable energy sources such as; solar power, wind, geo-thermal are less prone to large-scale failure because they are distributed and modular. Distributed systems are spread out over a large geographical area, so a severe event in one location will not cut off power to an entire region. Modular systems are composed of numerous individual production facilities such as wind turbines or solar arrays. Even if some of the equipment in the system is damaged, the rest can typically continue to operate. (Union of Concerned Scientists, 2014)

5.3.3 Economical benefits

The economical benefits of renewable energy resources, are not only confined to the smart home. The benefits far exceed the smart home, if implemented on a large scale, they can even have an impact on a nations economy.

Compared with fossil fuel technologies, which are typically mechanized and capital intensive, the renewable energy sector is far more labour intensive. This creates on the long term more jobs for each unit of electricity generated from renewable energy sources than from fossil fuels. In addition to the creation of new jobs in the RES industry, the growth of the RES industry creates a positive economic ripple effect. Not only the main industry will create an economic positive, but also the supply chain industry will see a increase in demand and output.

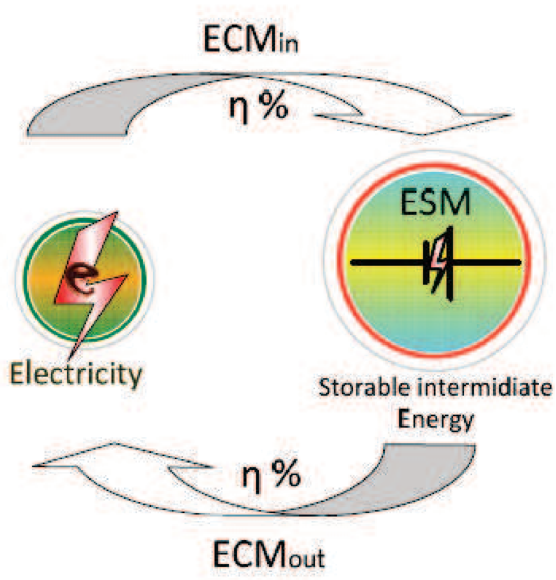
Another major economical aspect of the renewable integration over the power grids is the stabilization of the energy market. The cost of renewable technologies has seen a steady decline and are projected to decrease even more over the next few years. While the renewable facilities demand and require and upfront investment, once they are installed they operate at a low cost and, for most technologies, the fuel is free. In contrast, fossil fuel can vary dramatically and are prone to substantial price swings.

6 Energy storage

The topic energy storage is nothing completely new; storages have been created and used since the introduction of the electrical grid. Storages are very important for a stable and steady power supply, which would cause reliability, security and an economical benefit.

With the introduction of RES to the grid, energy storages are becoming more important than ever before. These RES are providing a lot of energy, if there is for example a lot of wind or sun then there is also a lot of power available. This power is not always needed at the same time and therefore it needs energy storages to store this surplus of energy for a later time and to release this stored power to the grid, if there is a lack of power in the system. (ABB Ltd, 2012)

One fact that seems logical, but it is good to mention it, is that storing energy means that there are always losses depending on how good these storage systems are. **Fout! Verwijzingsbron niet gevonden.**3 (P.Medina, A.W.Bizuayehu, Catalao, Rodrigues, & J.Contreras, 2014) shows the cycle of charging and discharging (loading and unloading) of an Energy Storage System (ESS) and it includes



the efficiency factor η.

The efficiency factor is just one of the characteristics of an ESS. The other characteristics are the capacity, the lifetime, the location/environment and the charge and discharge behaviour. These characteristics are especially focused on electrical ESS, but they also apply to other ESS like air Compressed Air Energy Storages (CAES) which are discussed later on in chapter 6.2.2 (P.Medina, A.W.Bizuayehu, Catalao, Rodrigues, & J.Contreras, 2014)

6.1 Storage systems

If somebody is talking about energy storing it has to be clear that there are different possibilities to store energy. The conventional storages are mostly big scale storages like pumped hydro power

Figuur 41 : Charge / Discharge schematic of an ESS plants or big centralized capacitors. The following list shows the most common and commercial used technologies for energy storages.

- Compressed Air Storage
- Batteries
    - Electric vehicles
- Flywheels
- Superconducting magnetic energy storage
- Hydroelectricity (pumped hydropower)
- Thermal energy storage (will be not discussed in this paper)
- Capacitors

These technologies can be separated into large-scale storages and small-scale storages. In this paper, the large-scale storages will be shortly discussed and explained why they are just for larger scales. The main focus will lie on small-scale technologies and the usage of ESS in households and pilot projects.

6.2 Large scale storages

The most common storages for the grid regulation nowadays are large scale storages. The reasons for that are again the old centralized grid system and the economical point of view. This sub chapter will handle with large scale storage system and explain shortly why they are just "efficient" (economical and technical) for bigger scales. Some storage systems are not mentioned in this chapter e.g. hydrogen, synthetic methane. (Renews Spezial – Strom speichern_pdf)

6.2.1 Pumped Hydro-Power Plants (PHPP)

Pumped Hydro-power plants are the most important and reliable storages worldwide. The long term experience in development and the high efficiency are main reasons for being that important for the nowadays grid regulation. (Association, 2015) The principal of this system is quite easy; there are two reservoirs on different altitudes, if there is too much energy available on the grid, the water from the lower pond gets pumped up to the higher pond and if there is not enough energy available (peak of consumption), instead of turning on an inefficient conventional power plant, the water from the higher reservoir gets released through a turbine to the lower one. This turbine generates the electrical energy which is needed at that moment. (Mahnke, 2014)

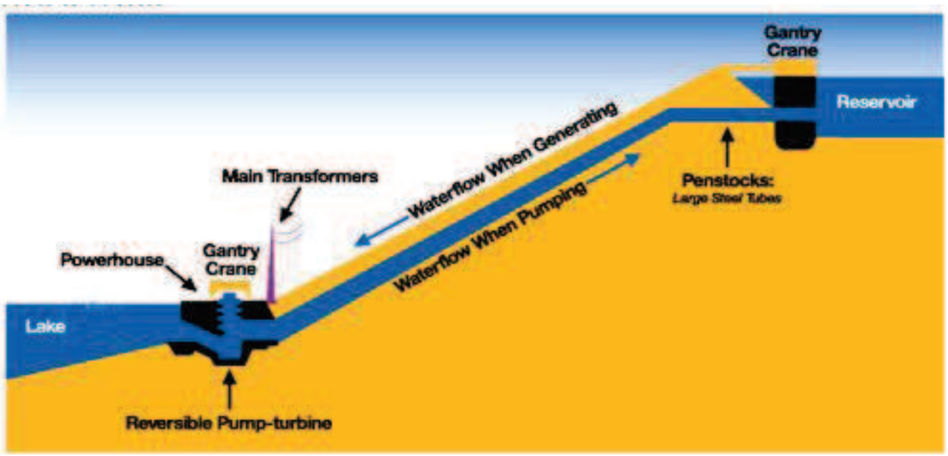


Figure 42 : Principal of a PHPP

Figure 42 (Kraemer, 2011) shows the principal of PHPPs in a very simplified way. The power, which can be provided by such power plants, depends on the size of the reservoirs, the generators and the height difference between these reservoirs. The basic equation for this system;

$$E = m * g * h.$$

E : Energy (J)
m : Mass (kg)
g : Gravity (m/s^2)
h : Height (m)

Nowadays PHPPs have efficiency about 70-80%, old ones are about 56-77%. Compared to other storage systems this system is a long term solution. Another big benefit is the wide area of application. This system can be used for load balancing, black start, secondary reserve and minute reserve. (Mahnke, 2014)

6.2.2 Compressed Air Energy Storages (CAES)

CAESs are as flexible as PHPPs and also about the same size. The principal of this system is to compress air into underground reservoirs, when there is a surplus and to release this compressed air through a turbine, when there is a minus of energy. During this process the temperature of the air varies a lot. When a gas gets compressed it causes a rise of temperature, that's why operators have to cool down the compressed air at this stage of the process. The reservoir injection air temperature is then about 43-49°C. (Association, 2015) When it comes to the release of this compressed and cooled down air, the gas has to be heated up again, otherwise the system might freeze and damage would result. After heating up the air it drives the turbine, which generates the electrical power.

All over the world there are just two commercial CAESs, one of them is in Huntorf, Germany, and one is in McIntosh, Alabama, USA. Both of them are working with the diabatic method. In this method the cooling is done with inter-cooling over several compression stages and then stored in large underground caverns (salt caverns). When the grid needs to be provided with electrical energy, the air is released and mixed with natural gas to be then combusted in a gas turbine. In the following Figure 43 (Barbour, 2015) the schematic of a diabatic CAES is shown.

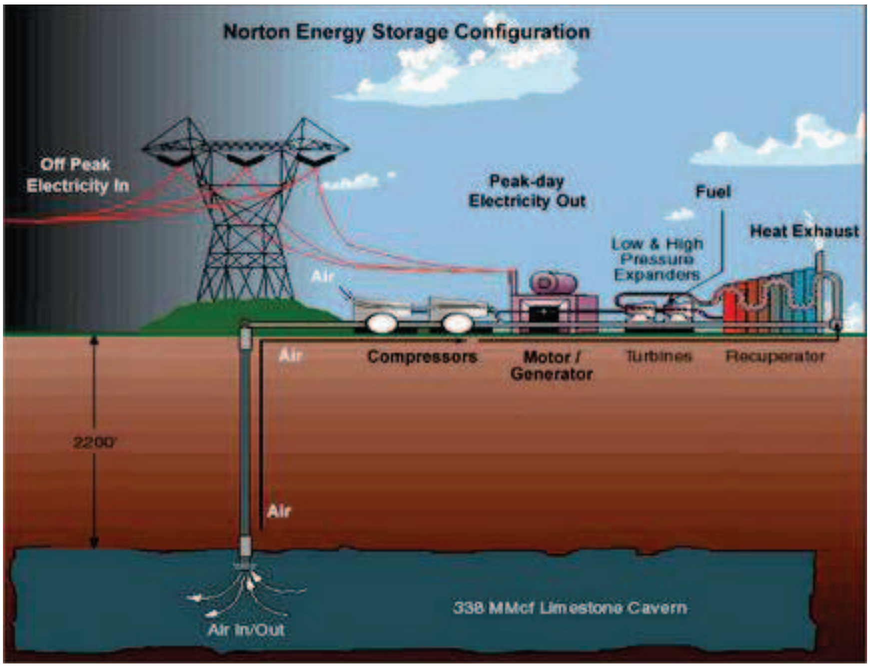


Figure 43 : Schematic of diabatic CAES

The efficiency of these CAES is 42% in Huntorf and 54% in McIntosh. For the future there are so called Advanced Adiabatic Compressed Air Energy Storages (AA-CAES) planned. In this method the released heat should be stored in big heat storages and then used to heat up the stored and cooled down air, so to say a re-injection of the heat. This causes higher efficiency, which is estimated to 70%. (Mahnke, 2014)

6.2.3 Flywheel Energy Storage (FES)

Flywheels are used in many different situation and sizes. It is a mechanical storage technology, in which a mass is spinning at very high speed, which means the energy is stored in rotational kinetic form. This storage system is used in different fields starting from primary reserve and stabilizing the power on the grid to short term storing and electro mobility. FES can provide the whole power within milliseconds to ensure an uninterruptible power supply. They are mostly used in systems where a frequently charge- and discharge process is going on. How much energy a FES can provide depends on the mass and the rotation speed. Nowadays research and development is going into reducing the weight and increasing the rotation speed. These FES systems are then called High-Speed-Flywheels. Wheels with a bigger mass (the material is here is most of the time steal) and therefore a lower rotation speed are called Low-Speed-Flywheels. Their rotation rate is up to 10,000 rpm, while the rotation at High-Speed-Flywheels rates up to 100,000 rpm. (Association, 2015)

Compared to other storage systems the FES has a very short discharge time, which limits the action area on minute/second-reserve and mobility. Although it is limited is some case FES are very efficient, up to 95%. The reaction time is > 10 milliseconds and during the lifetime of FES, about 15-

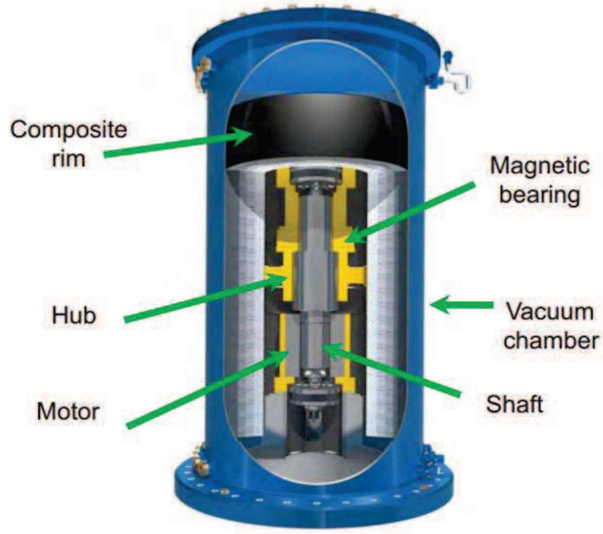


Figure 44 : FES schematic

20 years, it can stand some million cycles. (Mahnke, 2014) Figure 44 (PennEnergy, 2013) shows the basic schematic of a FES.

6.2.4 Supercapacitor (SCAP)

This storage system is an electrical storage system and not a mechanical as the systems before. It is a type of high power high energy density capacitors it consist of two, with high activated carbon, coated metal electrodes, which are separated by a thin porous insulator. These components are all in an electrolyte, which depends on different applications, e.g. the power requirement and operating voltage. (Barbour, 2015) SCAPs are like the FESs, they can provide the grid with high power for a short time and with a fast reaction time. The reaction time is even shorter than with FESs (< 10 milliseconds). Another big benefit of these SCAPs is the high efficiency grad up to 98%. Compared to battery storages SCAPs have higher cycle stability but their life time is expected to be about 15 years. And that is short, compared to CAESs and PHPPs. The application area of SCAPs is wide because of their cycle stability and the high energy density. They are applied in electrical vehicles and as safety unit for the grid power. The most important application area is in the field of RES like wind power plants. As FES, SCAPs are there for the minute/second reserve. The costs for one kilowatt hour are about 10,000 to 20,000 €, which makes SCAPs not economical sustainable.

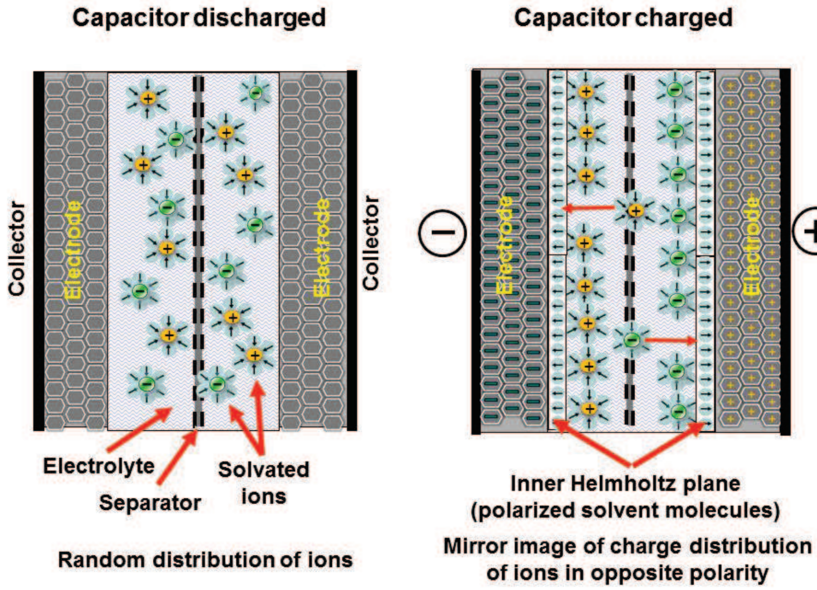


Figure 45 : Structure and function of an ideal double-layer capacitor

6.2.5 Redox Flow Battery (RFB)

Redox Flow Batteries are systems in which the storage is physically separated from the electrochemical inverter module. That means that the amount of stored energy can be varied. In chapter 6.4.1 Battery Storage it will be discussed a bit more about different battery systems and technologies.

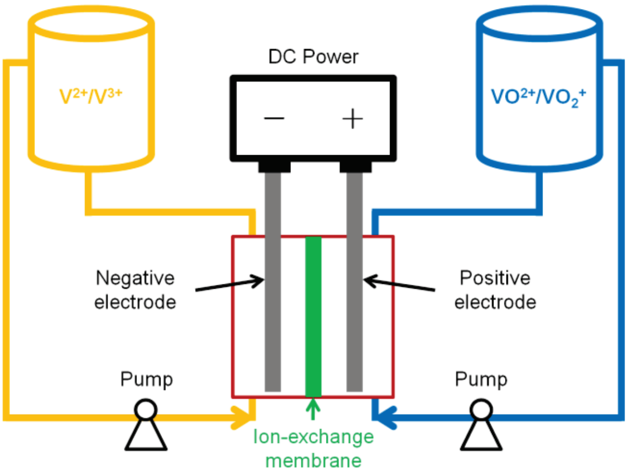


Figure 46 : Schematic of a RFB

The principal schematic of RFBs is shown in figure 46 (Xie, 2011). In this kind of system the cathode and anode consists of liquid electrolytes which contain metal salts. These electrolytes flow through the electrochemical cell, which includes a membrane for separating the electrolytes. Through this membrane only ions can be exchanged, which causes the electrochemical reaction and further the storing.

Many Redox-Flow-Systems are in different stadiums of development, the most developed and mature systems are zinc-bromine- and vanadium-redox-batteries. This storage system is, because of its size and its ornate technique, more efficient for large scales. It is a long-term storage with almost no discharge losses. The efficiency is about 75-85% and the energy density about 20-70 Wh/l.

6.3 Superconducting Magnetic Energy Storage (SMES)

These SMESs are electrical storages as the SCAPs. In this system there are 3 important components: the coil, the inverter and the cooling system. To get a little bit more into detail; the order of events in a SMES is explained like followed. The inverter inverts the AC into DC, where the AC side is connected to the grid and the DC side is connected to the coil. The coil consists of superconductive material, most of the time Niobium-Titan (NbTi) or Niobium-Zinn (NbSn). (Mahnke, 2014) This material has a special feature, if it is below its critical temperature it gets negligible resistance. That means the current will still flow, even if the voltage source got disconnected. The only problem with this system is that the critical temperature is about -200°C to -273.15°C. Therefore it needs liquid helium or nitrogen, which needs a lot of energy. (Barbour, 2015) The maximum capacity of this system is about 5-6 kWh and therefor it is not a large scale storage system.

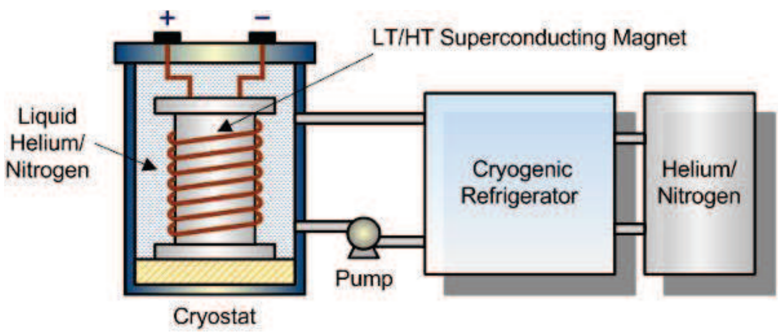


Figure 47 : Schematic of a SMES

6.4 Small scale storages

Small scale energy storages are getting more important with the increasing energy demand and the decentralized energy producers, e.g. PV-plants on house roofs and small scale wind power turbines. Most common storages in small scale solutions are battery systems and thermal storages. This subchapter will focus on battery storages, which are nowadays in use and in research and development.

6.4.1 Battery Storages

Battery storages are the most used storages in everyday life. You can find them in very small devices, e.g. mobile phones, cameras, as well as in cars and also as balancing feature in electrical grids. As all the other storages, which were discussed before, battery systems are very important features for a reliable and cost efficient grid in the future. Battery storages are together with thermal storages the most common ones for small scale solutions and they are still under research and development to increase the efficiency, the life time and to decrease the costs for it. Of course every battery system can be also used for bigger scales; it is just a question of cost. This chapter will focus on the general information of nowadays battery technologies and system which are used in smaller-scales like Households and Electric vehicles. Batteries are working with an electrochemical process in which the systems can be separated in two categories, those with internal storage and those with external storage. Systems with internal storage are storing the energy at the same place where the electrochemical reaction takes place. In systems with external storage the electrochemical reaction and the storage are physically separated.

A. Common types

The following list shows the most common used battery types.

- Lead-acid
- Nickel-cadmium
- Nickel-metal-hydride
- Lithium-ion
- Lithium-ion polymer
- Redox Flow (have been discussed before)

1. Lead-acid

Lead-acid batteries are the oldest known batteries. Over 150 years ago this battery was invented by Gaston Planté and it is still under research and development to get the best out of these batteries. The goal is to maximize the energy density in a cost efficient way.

The energy density of nowadays lead-acid batteries is about 50-100Wh/l and the life time is estimated to be 5-15 years, which correspond to 500-2.000 cycles. The efficiency of this system is about 80-95% the same as the efficiency of lithium-ion. Lead-acid batteries are often used together with small scale PV-plants, especially to higher the own consumption and for stand-alone systems. The biggest competitor is the Lithium-ion technology, which is discussed in the next point. One of the big benefits is that there are a lot of lead-acid batteries in use and for producing new lead-acid batteries 74% ot the lead comes from recycling. (Battery Council International, 2012). The fact that there is such a wide use of this technology, makes it cheaper than other systems. There is no cost-effective alternative compared to lead-acid batteries. (Battery University, 2015) On the other hand the energy density is very low compared to other battery technologies, which causes that the size of these storage systems is bigger. Another issue is the long charging time about 14-16 hours and the low depth of discharge. (Mahnke, 2014)

2. Nickel-cadmium (NiCd)

Nickel cadmium batteries are the most mature ones of the many different nickel based battery technologies. The charging-time of these batteries is lower than from lead-acid batteries and the number of charge/discharge cycles is over 1,000. These kinds of batteries can be stored in a discharged state; if lead-acid batteries are fully discharged it would cause damage of the cells. The worst parts of these batteries are the memory effect and the fact that cadmium is a toxic substance. The batteries remember the previous delivered energy and if this delivery gets routine the battery won't give more energy than before. To prevent this effect the battery needs periodic full discharges. It is hard to do this with storages for small scale PV-plants because of the ever changing energy demand and production. That might be the reason for using lead-acid or lithium-ion batteries in such cases. (Battery University, 2015)

3. Nickel-metal-hydride (NiMH)

NiMH-batteries have 40% higher specific energy than normal NiCd-batteries. As the NiCd-batteries also NiMH-batteries have a high self-discharge, about 20% of the capacity within the first 24 hours. Less prone to the memory effect than NiCd-technologies is one of the advantages of this battery system. Another positive thing is that there are just mild toxins included and Nickel content makes the recycling of these products profitable. The biggest application area is in the rechargeable portable battery field. (Battery University, 2015)

4. Lithium-ion

"Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest specific energy per weight." Quote: (Battery University, 2015)

Lithium-ion batteries are similar in there architecture to lead- and nickel-based technologies. The cathode (positive electrode) is a lithium metal oxide and the anode (negative electrode) consists of carbon. These two components are stored in an electrolyte. Figure 48 (Battery University, 2015) illustrates the process of the charging/discharging ion flow.

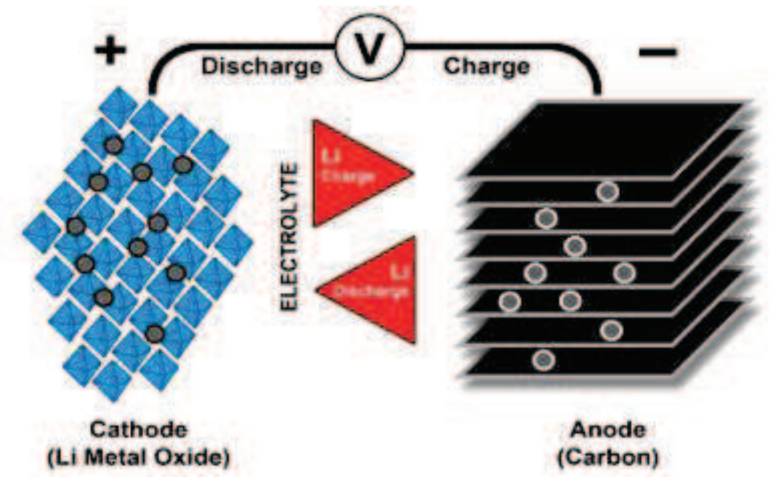


Figure 48 : Ion flow in lithium-ion battery

Lithium-ion batteries are fully integrated in the commercial consumer electronics, e.g. laptops, mobile phones, tools, etc. A second market, which is actually increasing the last few years, is the e-bike/pedelec-market. Li-ion batteries are there used as energy provider for electric motors, which drive the bike and support the driver.

These two fields are not the only application areas. Lithium-ion batteries are also used in the field of RES, to provide the grid/consumer with a constant power, ensure that power failures are not affecting any safety issues, etc.

The big advantages of this technology are the high energy density, about 200-350Wh/l, the low self-discharge, a rapid charge and a long cycle life, about 1.000-5.000 cycles (equals to 5-20 years). (Mahnke, 2014)

One of the biggest problems with this technology is the "thermal runaway". The higher the energy density is the higher is the possibility for a "thermal runaway". To explain the thermal runaway process in a very simplified way; the chemical reaction in a battery produces heat, if this heat is not transported away from the battery, e.g. by a cooling system, the battery gets warmer, which causes a higher reaction rate, this higher reaction rate causes a faster chemical reaction and again more heat in the battery. This is called a "thermal runaway". In the worst case it leads to an explosion.

That means to ensure a safe operation of lithium-ion batteries with a high energy density; these systems need a cooling system or an electronic monitoring system.

As mentioned before this technology is also well integrated in the RES field to higher the self-consumption of the produced energy of home integrated PV- or wind power plants. The biggest disadvantages are the high cost of this system, the battery management, the availability of resources and the hazardous substances.

The market of lithium-ion batteries is nowadays in a very strong movement, because of the ongoing development in the electro mobility industry. The series production of Electric Vehicles (EVs) caused a decrease in the price to 200€/kWh capacitance, in 2014. Germany is planning to integrate one million EVs till 2020 to use these EV batteries as an energy balancing system for the grid. This integration of this amount of EVs would also cause a reduction in the price for these batteries. But to reach this goal some other issues have to be solved e.g. the grid infrastructure, economical benefits for private persons to buy EVs and finally the price regulation for surpluses and minuses of energy on the grid. (Mahnke, 2014)

5. Lithium-ion-polymer

Lithium-ion-polymer systems differ from other systems in the electrolyte type. Some years back the polymer systems hat a solid electrolyte, which was just conductive at a temperature around 60°C. Nowadays polymer batteries have a gel electrolyte, which makes them conductive at room temperature. The differences between normal lithium-ion batteries are that polymers use micro porous electrolytes instead of the traditional porous separator and the specific energy is slightly higher and the construction a bit thinner, but the costs for manufacturing are 10-30% higher than with normal lithium-ion batteries. (Battery University, 2015)

B. Comparison of battery systems

After the theoretical research of battery systems it was clear that there are two technologies most common in the field of small scale storage system for households and battery systems for EVs. These two technologies and their advantages and properties were put into table 19 (Mahnke, 2014) to get a better overview.

Table 19 : Comparison: Lead-acid - Lithium-ion

	Lead-acid	Lithhium-ion
Application area	Load balancing, uninterruptible power supply, Balancing energy, stand-alone solutions	Load balancing, uninterruptible power supply, Balancing energy, electromobility
Efficiency	80 - 95 %	80 - 95 %
Power	1 kW - 100 MW	1 kW - 100 MW
Storage capacity	1 kWh - 40 MWh	20 - 50 kWh (electromobility) up to 5000 kWh (stationary)
Energy density	50 - 100 Wh/l (per cell); expected in 2030: up to 130 Wh/l	200 - 350 Wh/l (per cell); expected in 2030: 250 - 550 Wh/l
Reaction time	3 - 5 msec	3 - 5 msec
Self-discharge rate	0.1 - 0.4 %/d ; expected in 2030: 0.05 - 0.2 %/d	5 %/month ; expected in 2030: 1 %/month
Number of cycles	500 - 2000, 5 - 15 years; expected in 2030: 1500 - 5000, 10 - 20 years	1000 - 5000, 5 - 20 years; expected in 2030: 3000 - 10.000, 10 - 30 years
Specific investment costs	100 - 250 €/kWh storage capacity; expected in 2030: 50 - 80 €/kwh storage capacity	<300 - 800 €/kWh storage capacity; expected in 2030: 150 - 300 €/kwh storage capacity
Market stadium	ready	largely ready
Potential of development	Extend the service life; increase efficiency	Increasing the number of cycles; Cost reduction; increasing Energy density; Improving the rapid charging capability

Finally to get also an overview about all the different battery technologies. Figure 49 (Wikipedia, 2015) shows the energy densities of the different systems.

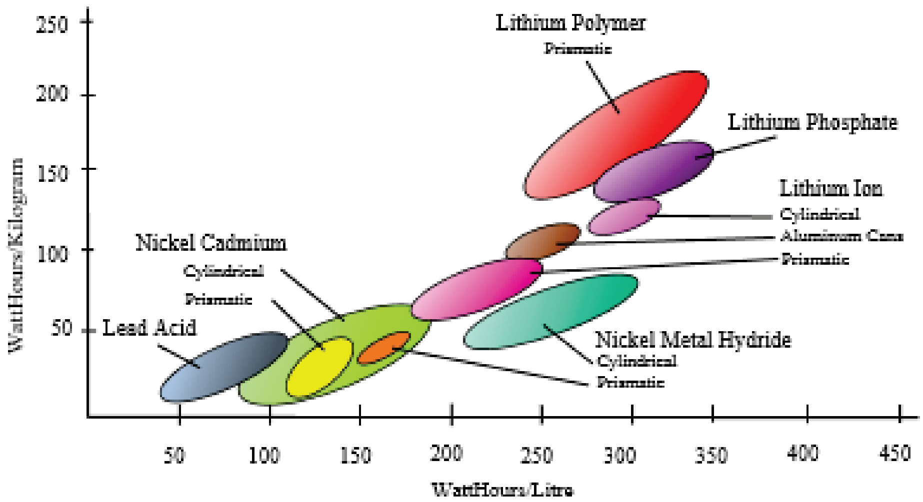


Figure 49 : Mass and volume energy density

6.5 Company solutions and pilot projects

Many different companies, especially companies in the PV sector, are nowadays working on small scale battery storages to increase the value of small scale PV power plants. The fact that most of the energy produced with these power plants is given to the grid for a low price is not very attracting to invest in this technology. If this technology would be combined with battery storage, to increase the self-consumption of the produced energy, it would be more attracting to consumers and it would also help the grid, by reducing the fluctuations. The following subchapters are showing just two company solutions about battery technologies combined with PV, one microgrid pilot project in Greece and another microgrid pilot project which focused on PV combined with battery storages.

6.5.1 Helion Solar

Helion Solar is a Swiss PV company working on battery systems to increase the self-consumption of their customers. In 2013 they installed a 5 kWh battery storage combined with a 6.1 kWp PV plant on a singly family house. (Toggweiler, 2013)The goal was to cover 60-80% of the produced energy for self-consumption. These values are usual for these kinds of projects. In this project lithium-metal-phosphate batteries are used, which are safe against thermal runaway, have an average energy density, about 90-110 Wh/kg. To ensure that the self-consumption is at its highest value the system includes a controlling unit, which regulates the perfect balance between the consumption from the PV plant, the battery and the grid. In figure 50 (Solarbatterie für EFH, 2013) a simplified schematic of this system is shown.

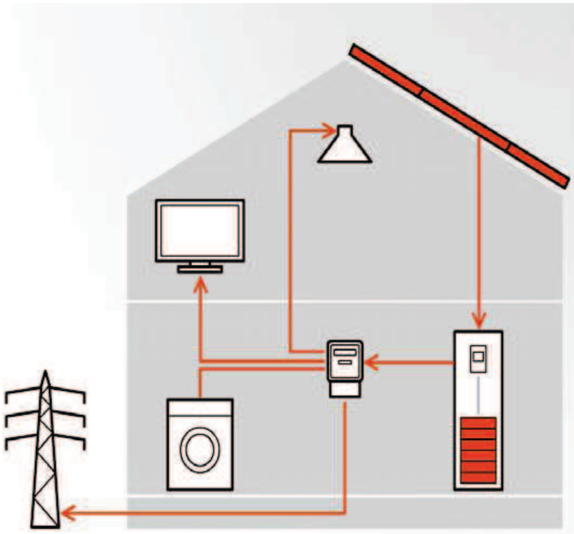


Figure 50 : Schematic of a combined PV plant and battery system

6.5.2 IBC Solar

As it was explained in the previous subchapter companies are working on battery storages to increase the self-consumption of the own produced energy with PV cells. IBC Solar is working with two different battery types; lithium-based battery technologies and lead-gel batteries. The technical differences were shown in chapter 6.4.1 Battery storages under the subtopic "Comparison of battery systems".

IBC Solar is providing three sizes of battery storages: 5 kWh, 8 kWh and 16.2 kWh. The smallest battery system is based on lithium polymer and has efficiency 10% higher than the lead-gel batteries. (IBC Solar AG, 2014)

6.5.3 Microgrid - Kythnos

The microgrid in Kythnos, Greece, contains 12 houses, 10 kW of PV, 53 kWh battery bank and a 5 kW diesel generator. On the roof of the control system building there is a second PV plant with 2 kW mounted and a 32 kWh battery bank to provide energy for the communication and monitoring. This project was started in the beginning of 2013 and will end in December 2015. They are using lead-acid batteries, but an interview with the responsible person showed that they would use newer technologies, if they would start now from the beginning. Figure 51 (Hatziargyriou, 2007) shows the setup of the microgrid system.

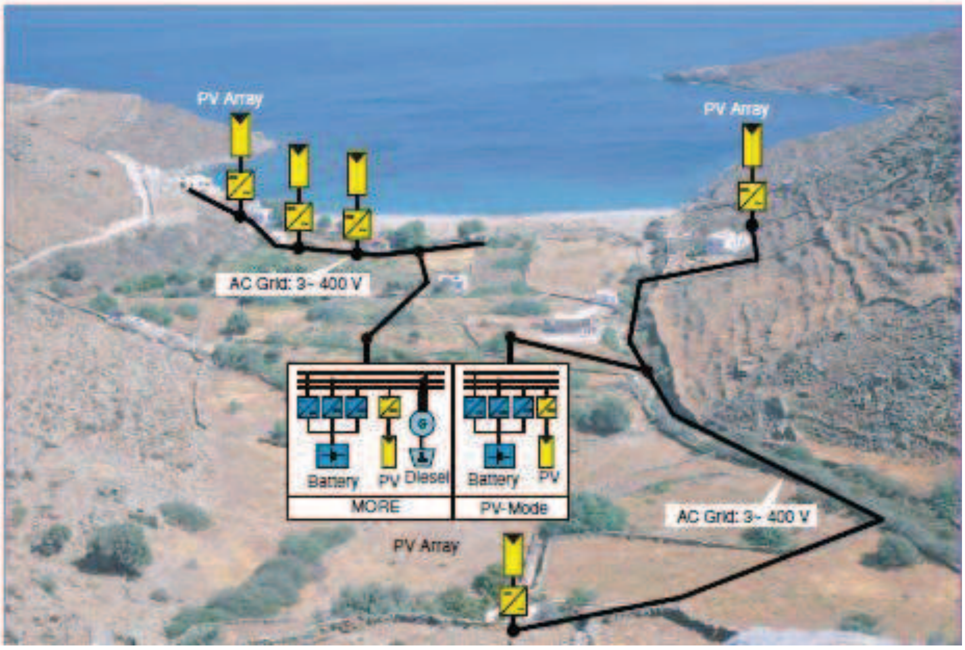


Figure 51 : Microgrid Kythnos

6.5.4 Swiss to Grid (S2G)

This pilot project is was lasting three years, from 2010 to 2013 and the main objective was to demonstrate the Smart Grid concept for small scales, where consumption, production, storage and management of electrical energy were combined in a decentralised place. They tried to merge new technologies with existing ones. It was about analysing the utilisation and improving the management of small scale energy production in 20 private households. Some of them were provided with batteries in the house some of them with EVs. But there were also some theoretical studies and a modelling project included in this big project.

A. Pilot project with 20 households

Load management on the local grid by an algorithm with limited information about single appliances was the basic idea, to understand to impact on the grid performance of decentralized systems. Out of 134 candidates 20 were chosen to participate in this project. The total installed generating power of PV was 88.13 kWp instead of the planned 30 kWp. Further four B2G systems, ten heat pumps and electric heaters and 3 electric cars were involved. After the installation of the PV systems the houses were equipped with so called household appliance controller (HAC). This device was developed by the Swiss2Grid project to measure grid relevant data like voltage, current, frequency, active and reactive power. It can be installed in households without major modifications of the cabling.

The results after this project show that there is space to improve load management by introducing electric vehicles and B2G systems. To visualize the effects of B2G systems the following modelling project has been started.

B. Modelling - Neighbourhood with PV system coupled to ESS

One subproject was to simulate scenarios for households with PV systems and ESS. A model of a neighbourhood with 39 single-family houses was built with "Dynola", a modelling and simulation environment based on Modelica (modelling language). With this programme all the devices, such as PV and ESS, and weather data could be collected. The weather got clustered into different groups: very-clear, cloudy and overcast. The PV unit was selected to be between 3 kWp and 5 kWp with a power loss of 10%.

For the battery system they chose lithium-ion battery storages, which are the most common ones in such a project and this technology was also used in the pilot, which was shortly described in the previous subchapter. For the battery was just the cyclic the self-discharge and the aging considered.

For the battery control system a simple solution got implemented; if the generated power of the PV plant is above 20% of its maximum power the battery got charged and if it is below it got discharged. 7 simulation scenarios were defined, in which the first was without any PV or ESS to have a reference for the other scenarios. The following table 20 (Baggi, 2014) shows the scenarios with the different penetration rates of PV and Battery to Grid (B2G).

Table 20 : Scenario description

Scenario	Active Houses	PV	B2G	Pen. Rate
1	0/39	-	-	0%
2	10/39	x	-	~25%
3	10/39	x	x	~25%
4	20/39	x	-	~50%
5	20/39	x	x	~50%
6	39/39	x	-	100%
7	39/39	x	x	100%

In these scenarios they looked at the relative instability of transformer power, the relative median instability of local voltage and the self-consumption in the neighbourhood.

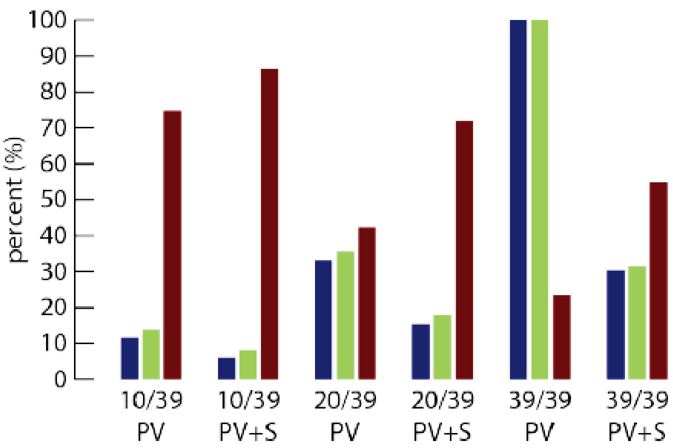


Figure 52: Simulation results

Figure 52 (Baggi, 2014) shows the results of the simulations, where the blue bar is the instability of transformer power, green is the one of the instability of local voltage and the red one shows the self-consumption. The reference is, as mentioned before, the zero PV and ESS scenario.

One can directly see that the instability without storage and a lot of PV systems is very high which means that the grid high loaded. Storages are taking away that load from the grid and higher the self-consumption.

C. Vehicle 2 Grid

Another subproject in the Swiss2Grid programme was the measurement of EVs connected to the grid to get more information about the power-quality. In total there were 47 EVs involve in this project, from which most of them were “Think City” cars with a 3 kW one-phase-charging module. Two measurements were done, the first one with 12 EVs, which were connected to the low voltage (LV) grid in a typical residential area in Switzerland. The connection points were chosen to be as far away from the next transforming station as possible. The second measurement was done with 35 EVs close to an industrial area. The results of these measurements showed that the connection of these EVs had a positive effect on the current harmonics. The strongest measurable effect was recognised at the voltage level, where the voltage decreased by 6% of the line voltage, when the 12 EVs where connected to it. The maximal line asymmetry of 2% was not reached. The highest asymmetry was 1.5%, also with the 12 EVs. Based on these results it can be estimated that every fifth household in Switzerland can load its EV at the same time, without pushing the lines to the limit. (Höckel, 2012)

6.5.5 Hållbarheten – Western Harbour Malmö

Hållbarheten is a custom designed apartment house in the Western Harbour of Malmö. This project was supposed to be a pilot on sustainable and smart living it includes many different technologies, e.g. small scale PV power plant, an urban wind turbine, a home energy management system (HEMS), EVs and battery energy storage system (BESS). There are eight apartments and two battery storages, from which each is responsible for four apartments.

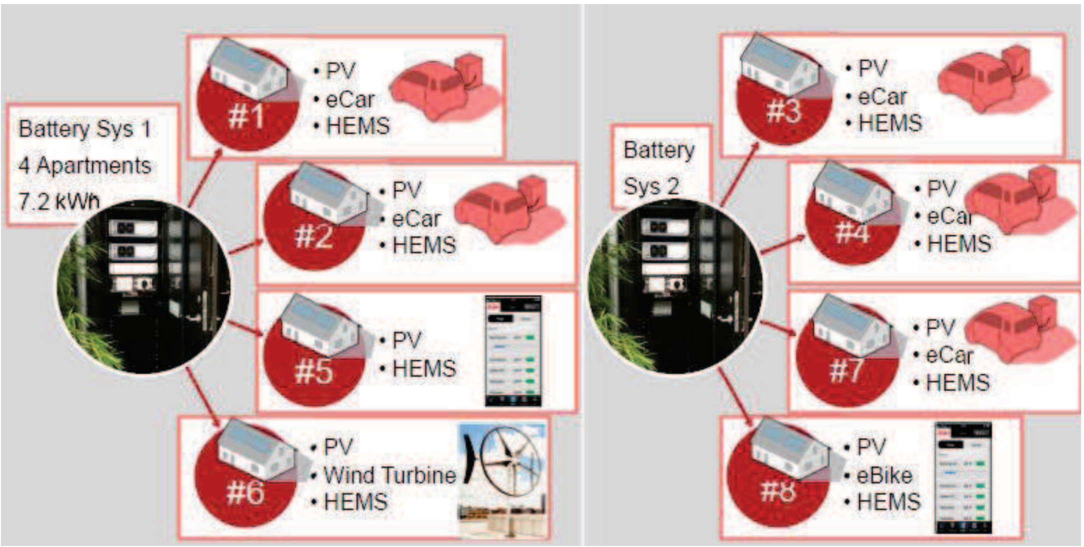


Figure 52 : Overview of the apartments and their technologies used

Figure 53 (Magnus, 2015) gives an overview about the technologies used in every single apartment. Each of the BESS have a capacity of 7.2kWh, which is reached with six 1.2 kWh Li-ion batteries from Sony, manufactured in Japan. Each of these BESS has a local controller, from the EPC (Enterprise Power Conversion) Corporation. It is connected to the Internet through a secure VPN connection. Through this connection the EPC module receives information from the HEMS server, which makes the EPC responsible for charging and discharging the batteries. The control logic for now is that the HEMS supplies data to the BESS, which is used to regulate the charging and discharging of the batteries. In the future the HEMS should also receive commands for turning on and off loads in the building, e.g. EVs charge/discharge or heat pumps. That's totally in the sense of a future smart home. ngham is cooperating with this project. (Magnus, 2015) (Lindström, 2015)

7 Benefits of a smart grid

The previous chapters made clear that the introduction of a smart grid will require big investments and that it will take at least a decade before it will be enrolled on a commercial scale. Although high investments are required, more benefits will be made once the smart grid is fully functioning, or as Reuters states for the American energy market "Smart grid to cost billions, save trillions" (DiSavino, 2011).

This chapter will take a closer look on the benefits of a smart grid, with a focus on the financial savings and the energy load shift. As mentioned in the introduction, most of the examples and references used in this part will be related to the American energy market for the simple reason that more research has been done there. The American situation can be reflected on the European market since there are no big differences when it comes to the benefits and theoretical study of smart grids.

7.1 Different benefits

Figure 54 shows the different areas where benefits can be found and expresses them in billion dollar where the low and the high columns are the range of the benefit and depend of the development level of the smart grid. The table reflects the situation in America.

Attribute	Net Present Worth (2010) $B	
	Low	High
Productivity	1	1
Safety	13	13
Environment	102	390
Capacity	299	393
Cost	330	475
Quality	42	86
Quality of Life	74	74
Security	152	152
Reliability	281	444
Total	**1294**	**2028**

Figure 53 : Estimated benefits of smart grids in billion $

The biggest benefits can be found in environmental issues, more efficient use of the capacity, reduction of the energy price and producing cost, higher security and higher reliability. this will be discussed more in detail further on. The smaller advantages, such as quality, quality of life and safety are extra and are not the main reasons to introduce a smart grid. They can also be simply declared due to the fact that a more stable, reliable and developed grid reduces the amount of outages and thereby makes the quality, the quality of life and the safety higher. However these benefits are also related to other processes, which will become clear during the next subchapters (EPRI, 2011).

The benefits that are discussed further one are most of the time the direct benefits. The extra benefits created with the money that is gained from the direct benefits are not taken into account.

7.2 Reliability and security

A smart grid means that components in the grid are connected in more than one way and that the grid is measured on a more detailed level. This creates a so called "self-healing energy grid" where the grid can reorganise itself in case of damage, without a human intervention. Because of the real time measurement, the grid is constantly measured and is able to detect errors. In case an error is detected, the grid will isolate this part and send the energy through another way. By using this system a minimum of entities will encounter problems due to an error and the grid can keep functioning while a technician can repair the specific part (Amin, 2013).

Due to the higher reliability of the grid the number of outages will undergo a serious reduction. This will reduce the economical damage that comes along with grid outages and gives companies the opportunity to invest less money in power backups and more in processes that contribute to the economy (Executive office of the president of the USA, 2013).

Another benefit is that DSO's will meet the law when it comes to outages. Almost all European countries have laws stating the number of hours an outage can take place in certain areas. For Finland, the law is recently tightened and states that energy outages in rural areas can only last for 36 hours and for 6 hours in urban areas. Governments will only make the laws more and more tight so DSO's would benefit to avoid outages at all by investing in a smart grid (Vanhaenen, 2015).

7.3 Environment

Renewable energy took a share of 12% in the European Union in 2011 and is expected to reach 30% by 2030. Although this is a positive evolution according to the global warming it also has a negative side effect. Because wind and solar, the biggest sources for renewable energy, are not constant and not similar with the energy demand, other energy sources are needed to fill the gap between the energy production out of renewable sources and the energy demand. When a peak in the energy demand occurs, energy providers ramp up flexible power plants to produce the extra energy but unfortunately, this flexible power plants use fossil fuels as their energy source. This system is visualised in figure 55 (Pickard & Meinecke, 2011).

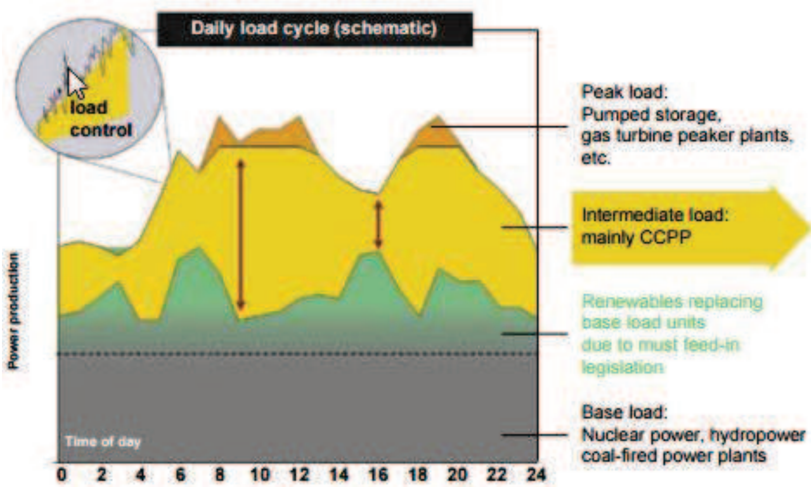


Figure 54 : Different power sourceds applies to fulfill the energy demand

This peak demand, and the use of fossil based power plants that comes along, can be avoided by the development of a smart grid. The smart grid will create a more constant energy demand during the day and avoid energy demand peaks by using the real-time pricing system. In this system, the price will be set every 15 minutes, or in the future every 5 minutes (chapter 3 data communication), based on the actual energy demand and energy production. When the ratio energy available/energy demand is high, the price will drop and households will start to use more energy, while the price will go up when the ratio is lower and households will reduce their energy usage.

To realise this increase or decrease in energy consumption according to the energy price, which is on its turn depends on the ratio energy production/energy demand, households will have to install smart appliances. This appliances can be programmed to start working once the energy price drops under a certain level. For example a washing machine can be started but instead of immediately washing the clothes, it will wait until the energy price goes under €0.10/kWh. In case people need the application to work immediately, the system can be overruled and the application will run with higher energy prices.

The real-time energy pricing will create a load shift from the day to the night and create a more steady energy demand and flatten out the difference in energy demand that exists between the day and the night today. When a situation where a lot of households overrule the system at the same time would occur, a higher energy price would be paid and the energy producer will not have a financial disadvantage by ramping up an extra power plant, which is the situation today (Siemens, 2010).

The real-time pricing concept, also known as demand response or DR, is shown in figure 56, where a peak reduction and a load shift take place (Siemens, 2010).

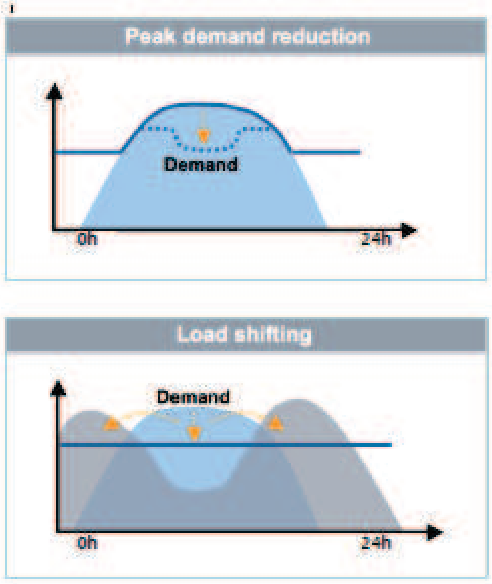


Figure 55: Load shift and reduction in energy demand peak due to real-time pricing

7.4 Cost reduction

Due to the reduction of peaks in the energy demand, energy producing companies do not need to start up inefficient power plants anymore and avoid creating financial disadvantageous situations by starting up fossil based power plants.

Another cost reduction is found in the energy bills of households. By introducing the smart grid and using the real-time pricing system, households will be able to move some big energy consuming household processes to a moment in the day where the energy price is lower and get an annual reduction of their energy bill up to $600 (What is smart grid, 2015).

Figure 57 shows the amount of energy household appliances use and the annual energy cost. The three biggest energy consuming appliances are appliances that can be implemented in the real-time pricing system and start working on a moment where energy prices are low. Some applications will not get an advantage of the real-time pricing system because they cannot be tuned off or are used on a specific point in time. For example a refrigerator cannot be turned off when the energy price is rising because and people will not wait for a lower energy price to use their hair dryer but will use it when their hair is wet (IBM, 2015).

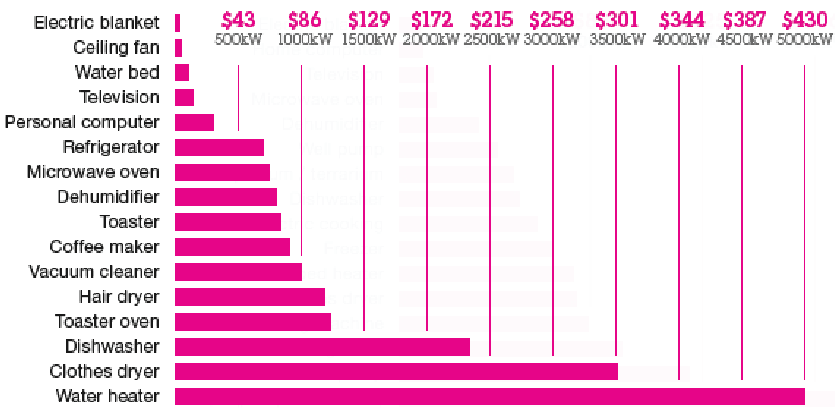


Figure 56 : Energy used per appliance / year.

The energy consumption of a normal household during a day will change as shown in figure 58. The big peak moves from the evening to the night and a more constant energy consumption pattern appears. The different colours represent different energy consumption themes where the dark blue represents the HVAC system, light blue the water heating, red the dish washer, and yellow the entertainment. In this particular study, houses could save up to 20% of their energy bill (Liukku, 2014).

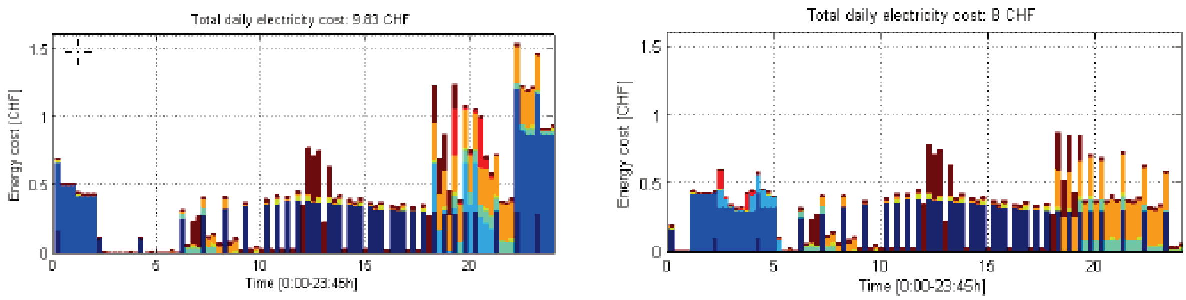


Figure 57 : Energy load shift in a household with the energy cost expressed in Swiss Franks (CHF).

7.5 Capacity

In a smart grid, the energy is used in the most efficient way. Where the DSO's always need a buffer of extra energy, to keep the energy grid in balance and prevent it from going down at a small incident, they could provide the whole grid with less energy when a smart grid is enrolled. Figure 59 shows the potential reduction on the energy that had to be provided to the US grid in order to provide enough energy during a peak moment.

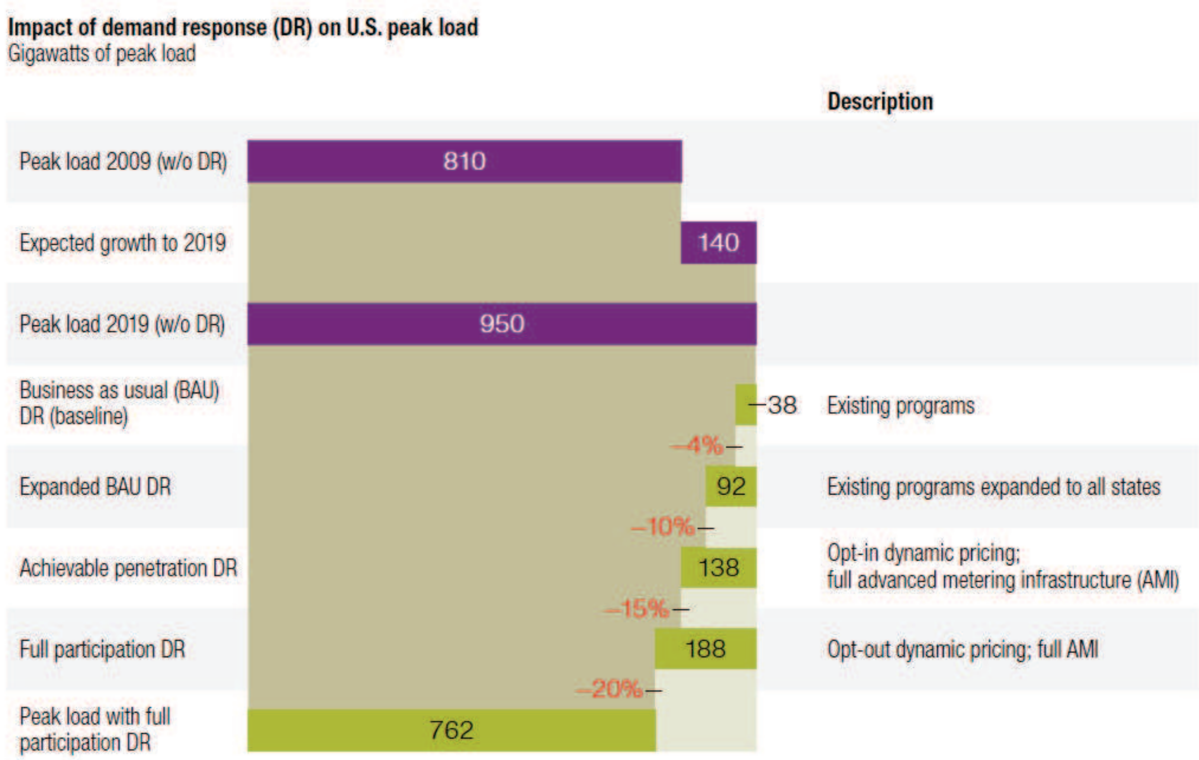


Figure 58 : Potential reduction of the energy that had to be provided during a peak in energy demand in the US.

According to figure 59, it is expected that by 2019 an amount of 950GW will be needed to provide enough energy during a peak load in the US. This could already be reduced with 4%, or 38GW, when a minimum of demand response would be introduced. This could be to work together with big industries and companies and store energy in their cooling systems when there is too much energy and reuse it when there is a lack of energy (Nikko, 2015).

When a demand response, or real-time pricing, mechanism would be introduced for the whole industry and big companies, the peak demand could be reduced with 10% or 138GW. When it would finally reach the house level, respectively 15% and 20% could be reduced if it would be enrolled for houses and when it would be enrolled for everyone. This means that the energy demand during a peak could be lower in 2019 than it is today (Davito, Tai, & Uhlaner, 2010).

8 Conclusion

This chapter will give an overview of the conclusions that can be formed out of the previous chapters. It is however not as detailed and minor items are left out, but in general it gives a decent overview of the situation amongst smart grid development.

8.1 Data communication

The data communication network for the electricity grid is almost nonexistent today. Everybody is looking to the DSO's when it comes to the enrolment of this network but they are only participating in pilot projects to increase the reliability of the energy network because this creates a direct financial benefit. To reach a reliable network, it is only necessary to create a data communication network on the medium voltage level and the low voltage level is left out.

In order to create a full performing smart grid, a bigger communication network is necessary. To have the DSO's installing data communication network infrastructure on the lower voltage level, governments should obligate them or a situation should be created so they would gain a financial profit by installing it. The best solution would be to come to a European solution for this since it will allow a cross border data network.

When companies are installing data communication technologies today, they tend to use PLC. However this communication infrastructure will not suffice in the future when more bandwidth will be required due to the fact that there will be more data to transfer. The best options for the data infrastructure seem to be a mesh grid network for urban areas and WiMAX networks for the rural areas. PLC can be used for the last part, from the substation to the house.

When it comes to the data transferring it seems that real-time communication is not possible since it would require too much data capacity and the DSO's have no advantage in gathering this detailed information. In reality the information will be exchanged periodically (every 15 minutes and in a later stage every 5 minutes).

When it comes to the security of the data network, it will be necessary to protect the data communication network with decent technologies. This to prevent hackers taking over the energy network and shutting it down, what happened already in America. However information of the appliances households use will not be visible on the grid's data network since this information will only be used locally, in the HAN. This means that DSO's will not see which appliances households are using and will never become a Big Brother.

But the biggest change is to be made with the households. Almost no households know what a smart grid can mean for them and what the opportunities are. They need to be informed about this before they will implement HAN and EMS when building a new house. The problem today is that no one really has the responsibility to do this so no one is informing households about it.

8.2 Smart meters

To provide information in real time according to the different prices during de day, it is necessary to have a smart meter, which quantifies and instantly transmits information on the quantities of energy consumed or produced for management in the grid.

In recent years, meters have become an important part of a comprehensive system of measurement and billing, through their communication skills, integration system and interoperability. Smart meters are electronic devices that record consumption in real time and send the information to a central system. AMI (Advanced Metering Infrastructure) can to see the real-time energy consumption or production of households. This electronics meters will make it possible to do real-time pricing and avoid the need for manual work to reduce the cost for households, which send data to the central system for a good communication between consumers and companies. So also consumers become an active part in this new system.

In addition environmental issues are present in the reasons why you need the Smart grids. Many of today's fossil fuel power plants with corresponding implications for emissions and fumes that cause the greenhouse effect. For this, the EU has based its policy change in the energy model in the 20-20-20 Plan which aims for 2020 decreased by 20% the emission of greenhouse gases since 1990 levels, contribute 20% of renewable energy generation and improve energy efficiency by 20% as well.

These meters are a strategy of saving energy and make possible the plan 20 from EU, since it is possible estimated at the time billing, ability to manage your own consumption, but also the transmission of data remotely without the need for workers. The result is an economic and energy savings.

8.3 Home area / automation networks

Home area / automation networks are an integral part of smart grid technology in developing demand response management at the distribution and substation transformers levels. HAN plays a critical role to control the home appliances, proper use of electricity and lowering the gas emissions. The success of smart grid largely depends on the bundling of different network and consumer participation. Proper HAN technology selection is a critical part to involve the consumer in this process. (Huq & Islam, 2010)

The use of HAN technology will only increase during the years to come, and this is change that can only be applauded. The HAN technology offers immense benefits for not only the consumer but also for the electricity providing utilities. When looking at the HAN using consumer, it can be stated that there is an reduced energy spending and increased environmental benefits and also increased empowerment by gaining control, flexibility and choice over their energy usage. This can be achieved because the HAN system provides the consumers with the tools to reduce their net energy use and shift demand from the peak periods, reducing the cost and improving their environmental footprint.

For the energy providing utilities this means even greater positive outlooks namely, an improved match between energy consumption and its generation by improving the energy efficiency and reducing peak demands this will reduce energy supply constraints and also reduce the need for investment in growing energy generation. It will also increase operational efficiency by enabling the two-way communication between the consumer and the utilities.

But there is still a long way to be travelled by the consumers and by the utilities, to make sure that these benefits, that are connected to the use of HAN systems, are reached.

8.4 Energy management systems

In Europe that is striving to be more and more eco-friendly Energy Management Systems are nothing new. However, so far only the commercial and industrial users were in scope of the program. Nowadays it has been recognised that other users of the power grid may contribute as much or even more once Home Energy Management Systems are created, introduced and used.

The currently existing solutions for EMS have been designed with a commercial and industrial users in mind. This means that in case of regular, residential use those solutions are often too complex, too costly and in general not fit to be used in households. In addition to that many assumptions that are made when creating those systems are completely different. All of this calls for a completely new set of instructions and guidelines for HEMS.

Because the possible input of the residential grid users was recognised relatively recently there are not many existing solutions. Among those that have been created specifically for households many are still just ideas and considerations. Other are either prototypes or pilots that are meant to explore the possibilities and borders for future HEMS.

All those ideas have already brought up many issues which need to be tackled before a proper standard can be established for energy management in households. The two most important issues are the division of control between the user and the system administrator and ways in which a user can be encouraged to willingly participate in demand side management schemes.

The first issue is strictly connected to privacy and user comfort. The solution to this problem will decide how comfortably and safe the user will feel in his own house. On the other hand this will affect the final result the HEMS will have on the power grid as the user comfort and the grid stability does not always go together.

The second problem is in fact connected to two smaller issues, namely ability to communicate technical data to a user that may possess no technical knowledge and passing on this information in such a way that the user finds it interesting and is willing to change his behaviour based on it. Unlike in case of the commercial users there is no management staff in households that could perform complex business analysis or staff tasked with taking care of EMS. This means that in general the system needs to be dumbed down and made appealing to the users. In addition to that measures need to be introduced to keep the user involved in the HEMS schemes.

However once these issues are overcome and HEMS is correctly introduced the future seems very bright for EU’s plan for smart grids. Several schemes of operation and pilots that have been carried out have shown to have a significant impact. When the HEMS is operating properly and the users are actively taking care of it the loads and power on the grid are put under control and thus the overall stability is improved.

8.5 Renewable energy sources

A smart grid is a combination of different activities to produce electricity, when linked together, form a complex grid. With the liberalization of electricity production, promotion of non-conventional generation as a strategy for security of supply in the long term, coupled with technological advances have led to the consolidation of power generation with renewable energy sources, as electricity producers.

Energy as we know it, is an intricate part of today's society without a constant supply of energy society will stop to exist in the way we know it. The fossil fuels used today for our ever growing energy consumption are finite and are decreasing at an ever increasing rate. That is why it is so important to implement renewable energy sources into the smart homes of today and in the future.

There are a lot of renewable energy sources, solar, wind, bio fuel, fuel cells, geothermal,..., that can be used in the domestic market today. Solar and wind are the most abundant and the most used to generate electricity. Since traditional fossil reserves are scarce and generate a lot of pollution to the environment. Wind and solar energy are two clean and inexhaustible resources, they also ensure stability and security in this complex electrical system.

In conclusion renewables are important for their environmental benefits, as they are clean sources with less environmental impact than conventional energy technologies. They are a source of infinite energy, or rather finite very long term. Being more respectful of the environment and contributing to the 20 EU plan. The economic effects are not dependent on oil imports from abroad so they are cheaper and safer. And with the variety of options each country could choose the most convenient, since the wind and sunlight are not equal in all countries.

8.6 Energy storages

Energy storages are important in every scale for the future grid. But there are many things to be aware of. These storages have to be integrated with an intelligent energy management and the possibility to communicate with the whole system has to be ensured. For now, small scale storages are not economical sustainable that means that the industry still has to work on these storage systems and governments have to think about incentives for customers to buy such technologies. A lot more practical research in pilot projects will be needed to get a better overview of how efficient small scale energy storages are and in which regions they are most valuable. The following quote is an outtake from an e-mail interview with Dr. Stathis Tselepis, he is the responsible person at the micro-grid project on the island “Kythnos” in Greece and he works at Photovoltaic Systems and Distributed Generation Department at the Center for Renewable Energy Resources and Saving, CRES and he describes the problem about the topic small scale energy storages quite well.

“Small scale storage and RES generation is a reasonable way to develop as you produce at the point of consumption with the minimum losses. When it will be integrated in the DSO business model and becomes economically attractive then we will see a gradual increase in the installation. The distribution grid would have to be smart to integrate optimally and safely regarding the grid operation the “prosumers”. Maybe in the future we may choose to disconnect ourselves from the grid and provide our own power and energy. At the moment we are in a transition period and we do not have all the economic data to decide if it is attractive. The technical capacity is there but the cost is not completely known. But at the end it will be strategic and regulatory decisions that would set the rules based of course on social, environmental, technical and economic terms how the new smart grids will operate and what will be the involvement and contribution of consumers and prosumers.”
(Quote: Dr. Stathis Tselepis)

9 Project summary

The European Project Semester during the Spring of 2015 in Vaasa will be an experience that we will all remember for the rest of our lives. It was a very valuable personal asset to work and live in Finland for 4 months but it was also an asset for our studies. We had the opportunity to work together with companies of the energy cluster, who are global leaders in their field, and learned a lot about state of the art electrical technology. A valuable asset for every engineering student and a very good opportunity to broaden our field of interest.

During this 4 months, it was not always as easy and the team had some struggles with lagging team members and goal shifts. This created a lot of frustrations and unpleasant situations, but now that we can look back on it we realise that this were the most interesting moments when it comes to improving our soft-skills. We learned how to handle this crisis situations and this experience will be very useful in our later careers where we realise that this situations will occur as well.

The European project semester created a simulation of a work environment where we could fill in our own schedule and decide in which direction we want to go with the project. This is probably one of the most valuable experiences that we will take home since it seemed not as easy for everyone to find a good working pace from day one, after being used to professors telling you what to do during the last years. But the further in the semester, the better most of us knew to manage this. With the eye on a first job in the nearby future, this is a very useful experience.

A lot of time was spent on the structure of the project so it took some time before the project work really started. This probably has to do with the fact that the project goal was very unclear in the beginning and that putting work in the setup of a structure is a task with a very clear goal. Because of this, we ended up with a very extensive project organisation without having real results after a few weeks. In case we had to redo this the focus would be more on the project work and the organisation would be more limited. However we also think that a lot of the problems could have been solved if we had a clear and reachable goal from day 1.

So however we learned a lot about smart grids and the future energy technologies, we believe that the soft-skills which we achieved here are the things from which we will gain the most profit during our further lives and careers. After living abroad, the experience of working and living together with students from all over the world and experience to live in another culture, we will all go home with different visions on and thoughts about things. We don't think that we changed as persons but we see it as an extra part that we added to our personality and that will help us in a lot of situations we are about to encounter in our further lives.

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