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M.SC. (ENG) SUSTAINABLE ENERGY PLANNING AND MANAGEMENT

Extreme Smart Grid:
The Case of Single Danish Dwellings

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Abstract

Smart grids are part of the future Danish energy system. This project studies the extreme case of a micro-grid composed of a single dwelling isolated from the grid and its possibility to supply electricity in order to meet its demand. Different dwellings are considered in size and in level of electricity efficiency consumption, with taking into consideration user practices and technical parameters of the electrical devices and appliances.

Using a piece of software specially designed for this project, load profiles have been calculated for each of the cases. Thereafter, analyses have been conducted in order to evaluate the potential both technical and economic to supply the demand with different combination of energy system; it includes wind turbine, generator, PV panel and storage system.

It appears that a single dwelling can be isolated from the grid with different energy systems. The most efficient regarding the electricity price is the hybrid systems composed of a generator used as a backup system, a wind turbine and a storage system. However, the increase in the price of electricity is not negligible compared to the one from the grid thus being isolated from the grid remains a choice.

End date: 07/06/2012

PREFACE

This report is the result of my Master's Thesis for the conclusion of my Master program in Sustainable Energy Planning and Management (SEPM), Aalborg University. It was written during the period of February 2012 to June 2012.

I would like to thank my supervisor at Aalborg University, David Connolly assistant professor. He gave me a lot of trust and flexibility in this project and was always available for help. His great advices allow me reaching a better result and providing a more understanding report.

I also want to express my gratitude to Nils Daugaard from Energy Consulting Network (ECNet) for providing me a student job with lot of flexibility in order to conduct my thesis in the best conditions.

Alexandre Canet, June 2012

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1 INTRODUCTION

1.1 THE SMART GRID

The Danish energy system is trying to evolve from a fossil fuel based system to a 100 per cent renewable energy system. This transformation shall operate through the increase of the electricity share in the secondary energy mix. New services will have to come up to provide satisfaction to customers for the replacement of their old-fired burners with electric heat pumps or their conventional vehicles with electric ones for instance. Both of these reasons will lead to a significant change in electricity consumption and generation.

In the future energy system wind power is tend to become the principal source of electricity generation. Actually, not only wind will become predominant but renewable energy in general. And the main problem to resolve is their integration in an energy system used to adapt the energy generation to the demand and not the opposite.

This is the reason for the development of smart grids. Smart grids aim is to enable an effective interaction between fluctuating renewable energy, mostly wind in Danish case, heat pumps in private households, electric vehicles and future electrical devices such as washing machine or fridges. Commonly, a smart grid can be split into five sub parts as seen in Figure 1.

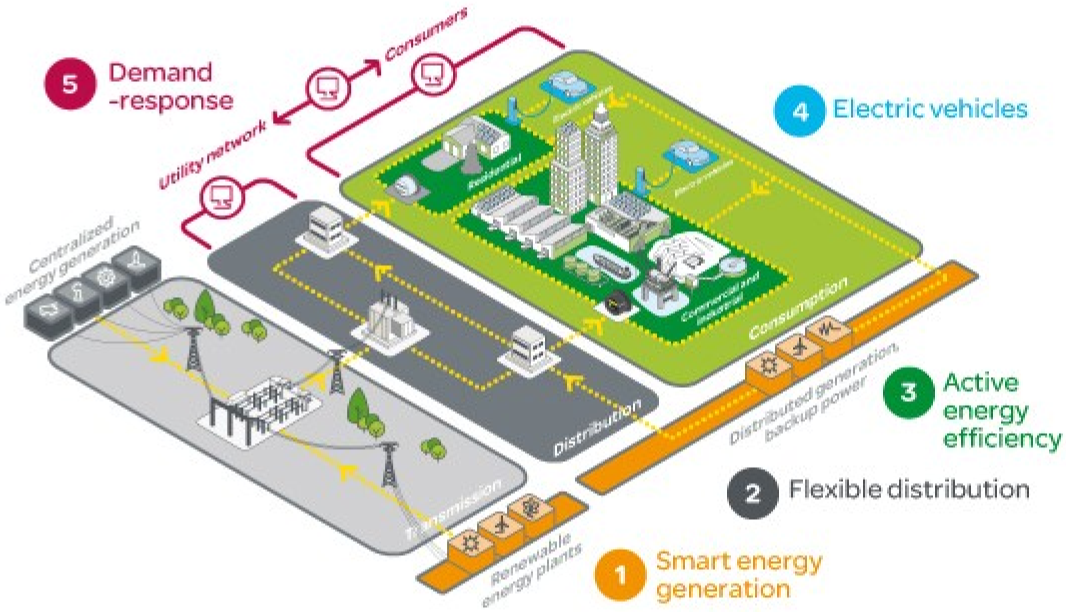


FIGURE 1: THE SMART GRID STRUCTURE FROM SCHNEIDER ELECTRIC (SCHNEIDER ELECTRIC S.D.)

These five parts are:

1. Smart energy generation; the energy mix is composed by individual and large means of production in order to achieve a “greener” mix.
2. Flexible distribution; it consists of a reliable electricity grid adapted to the new stakes created by the growing amount of fluctuating renewable energy.
3. Active Energy efficiency; it makes visible the electricity consumption and develop better energy management systems.
4. Electric vehicles; it implements electric vehicle into the energy mix as consumer and possibly supplier of electricity.
5. Demand response; the growing share of fluctuating renewable energy requires better communication between centres of consumption and centres of supply.

The way the smart grid is presented in this figure can easily be transposed to another scale. A national grid can be composed of several “micro grids” of the size of municipalities presenting the same organization. And even these micro-grids can be composed by “Nano grids” that will only consist of a simple building, a dwelling for instance. This building can have its own means of production (wind mill, micro CHP, photovoltaic panels, etc.) and the purpose will be to have a “just in time” demand response to the different means of production. It represents a complete energy system by itself. In the case, the production overcomes the required consumption the surplus of electricity will be send to the grid. In a more extreme way, we can imagine “Nano” or “micro” grids totally isolated from one another which can be the case for islands. In that case, there is a need for a correctly calibrated and designed system to face the unforeseen.

1.2 THE RESEARCH QUESTION

Regardless of the size of the smart-grid or its isolation, the main issue for the development of smart grids in general remains the technical feasibility of such projects. The first technical barriers identified are the storage of electricity and the management of the demand according to the production. For these reasons, it has been decided in this report to focus on a smart grid of the smallest scale: a dwelling, and analyse the possibility to be grid independent depending of the demand side management chosen. This leads to the following research question:

> Considering electrical devices, means of production and possible storage installed in a dwelling, is it possible to be completely isolated from the grid according to different customers behaviour in demand side management?

The answer to this research question will be informed through the analysis of different profiles of electricity consumption related to the Danish residential sector. They will differ from user practice and overall demand. These load profiles will be calculated through the use of a piece of software designed specifically for this project which provides flexibility in the parameters chosen and in the outputs. Thereafter, the capacity of these dwellings to be isolated from the grid will be analysed and discussed through technical and economic points of view.

The process used to answer the research question will be more largely discussed through the Report structure (page 8), the Theoretical framework (page 11) and the Methodology (page 13).

1.3 REPORT STRUCTURE

This report follows a classic structure composed by five parts, as illustrated by Figure 2. The introduction sets up the situation about smart grid and the reason for answering the research question. Then the theory part develops the theoretical approach about electricity consumption on which this project is based. The methodology part explains how the project in general and some specific section have been managed. Thereafter, the analysis presents the results obtained and then a cost comparison is conducted in order to identify which energy systems are the most relevant from a technical and economic point of view. Finally the last part concludes the project.

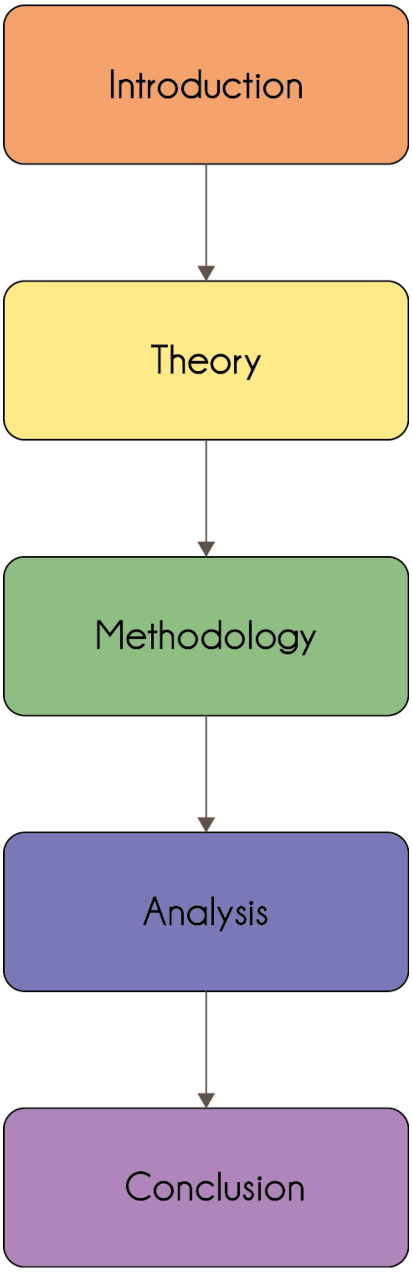


FIGURE 2: REPORT STRUCTURE

2 Theoretical framework

In the case of a residential unit such as a dwelling isolated from the grid, the electricity savings potential has an important role to play. Hence, the theory around the electricity consumption and the possible savings will be developed in this chapter.

The residential sector represents 30 per cent of the total electricity consumption in Denmark (Figure 3). It is the second centre of consumption just after the commercial sector. According to the report IDA 2050 (Brian Vad Mathiesen 2009) a potential of 25 per cent can be attained by 2020 and another 25 per cent toward 2030, which represents a total of 50 cent electricity saving potential in the residential sector.

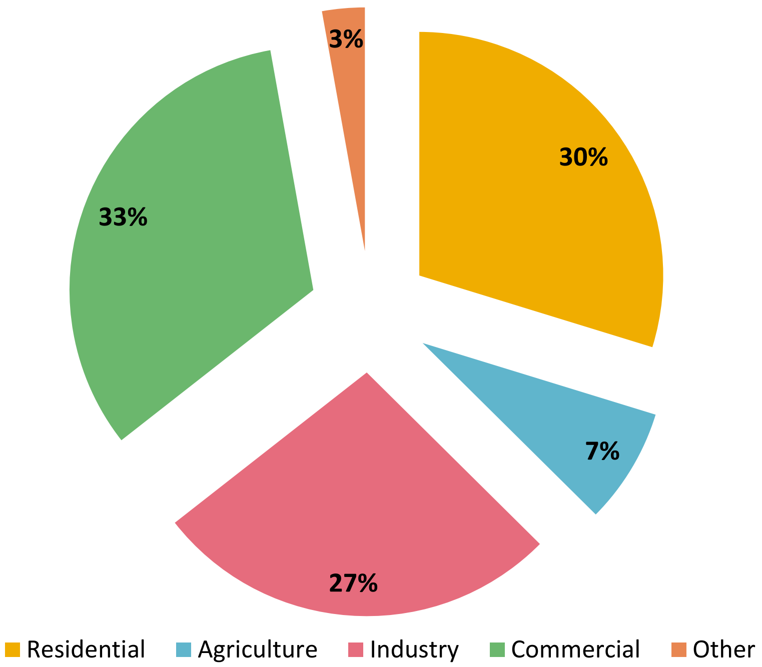


FIGURE 3: ELECTRICITY CONSUMPTION PER SECTOR IN DENMARK IN 2010 (DANISH ENERGY ASSOCIATION 2010)

There are different actions to develop in order to reach this potential. The two most important are assumed to be through campaigns (Brian Vad Mathiesen 2009) and replacement of appliances (Danish Energy Agency 2011). However, a common question to ask would be: is it more important to have efficient technologies or user practices regarding electricity consumption?

This question will be answered from a theoretical point of view through two parts; firstly a description of the practice theory approach and thereafter an analysis of the Danish electricity consumption.

It is considered that a part of these potential can be reached through information campaigns which will change people conducts regarding their electricity consumption. Hence, it is important to understand the mechanisms that affect the behaviour and social practices of the people regarding electricity consumption in order to develop efficient measures.

This chapter provides a theoretical framework for the development of smart grid and in the case of this project: demand side management.

2.1 Practice theory approach

A ‘practice’ (Praktik) is a routinized type of behaviour which consists of several elements, interconnected to one another: forms of bodily activities, forms of mental activities, ‘things’ and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge. A practice - a way of cooking, of consuming, of working, of investigating, of taking care of oneself or of others, etc. - forms (…) a “block” whose existence necessarily depends on the existence and specific interconnectedness of these elements, and which cannot be reduced to any one of these single elements » (Reckwitz 2002).

According to this definition, the resource consumption cannot be considered as a practice by itself. It results from a practice. Practices are usually associated to various material artefacts such as appliances, equipment and tools; therefore the consumption consciousness is not always present in the people mind during their daily activities. Hence, the material artefact is just the link between the practice and the environment. It can explain that people firstly think about meaningful practice rather than consumption.

The meaning of consumption for people is often associated to market exchange. For instance, people feel considered as consumers when they are going shopping. In a practice perspective, shopping is just a practice as many others in daily life. And thus, aspects of consumption can be analysed in a different way than from theories of consumption. In fact, theories of consumption are often based on the property and draw the attention to having whereas the theory of practices focuses on the action (Shove, et al. 2007). This statement can be supported by the following formulation: “things are acquired, discarded and redesigned with reference to culturally and temporally specific expectations of doing and having – not of having alone” from the same source page 37.

This part can be summarized by the following statement from (Røpke 1999) which presents also a new problem: “Consumption is woven into everyday life, the activities that are decisive for the quality of life and the images of the good life, so consumption is difficult to isolate as something that can be reduced without diminishing quality of life. “

This interrogation about the relation between quality of life and consumption is often related to the rebound effect. The rebound effect is the tendency of people using more a material due to its better efficiency which results in energy consumption savings lower than expected. For instance, it could be possible for a person using efficient light bulbs that the light stays on much longer than before because it is efficient. This tendency has been reviewed in the report from (S.Sorrel, Dimitropoulos et Sommerville 2009). The first reason that comes in mind to explain this rebound effect is economic. You spend less thus you can afford more. However, it should not be the only explanation and it is also important to consider psychological and social aspects to have a complete understanding (Gram-Hanssen 2011). According to this same report, it is shown that “heat consumption seems to be more dependent on energy efficiency whereas electricity consumption is more dependent on user practices including the number and size of the appliances.” However, it is assumed that energy consumption related to appliances such as refrigerators and freezers are more dependent on appliance efficiency than on user practice.

Therefore, it results in the fact that in this project, both theories are considered, depending on the type of electrical appliances or devices. They are included in this project through the possibility of defining different user practice and specify the technical parameters of each appliance within a software designed for this project as it is explained in The load profile section of the Methodology chapter (page 18).

3 METHODOLOGY

As illustrated by Figure 4, the methodology used for this project is decomposed into four points:

1. Planning and Analysis; it corresponds to the phase of research, defining requirements, research question and theories.
2. Design and Data Collection; this phase encompasses the development of the software and data collection
3. Implementation; development of scenarios and extraction of results from the software
4. Discussion; comparison of the results and interpretation

The starting point of this project, and thus the phase Planning and Analysis, is the study of the development of micro grids and their potential. And it has been decided to study the most extreme vision of the micro grid which corresponds to a single dwelling be entirely isolated from the grid. In order to study and analyse the possibility and viability of such system in Denmark the first idea was to use an energy modelling software. However, it quickly appears that most of the available software on the market did not provide the right features to answer the research question and did not meet the requirements concerning the desired outputs. In fact, one of the outputs of this project should be the possibility for common people with few experiences in energy field to be able to assess their own calculation. Then, software such as TRNSYS or TRACE which can be relevant, are not considered because of their high costs and their difficulty to handle without any specific background.

After some research, it appears that no software had the feature corresponding to the needs of this project. Hence, it has been decided to specifically design and develop a tool for this project. This section is focusing on the methodology used to develop the software which is represented, within the project development by the Design and Data collection step.

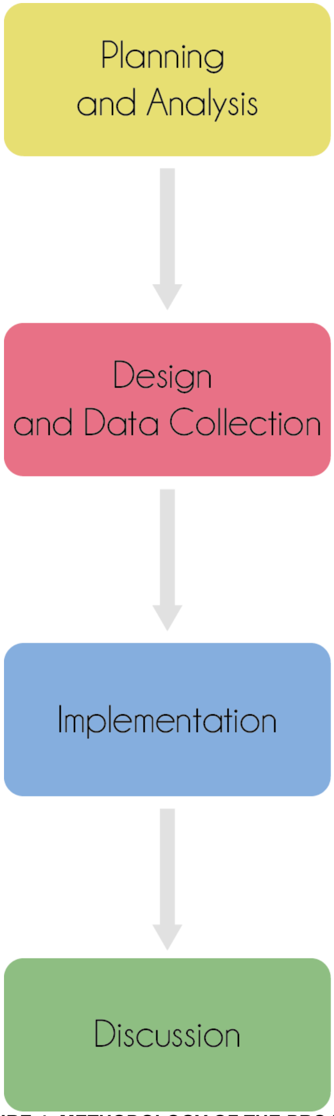


FIGURE 4: METHODOLOGY OF THE PROJECT

3.1 THE SOFTWARE DEVELOPMENT PROCESS

Software development can be viewed as a cycle process which never totally ends as illustrated in Figure 5. The starting point is always an analysis of the situation and requirements, thereafter takes place the design part which consists of developing algorithms and architecture to the software. The development part is the process of writing/updating the code and when it is done the software is ready to be implemented. This cycle process is done several times during the creation of the software and even after for updates or add of new features.

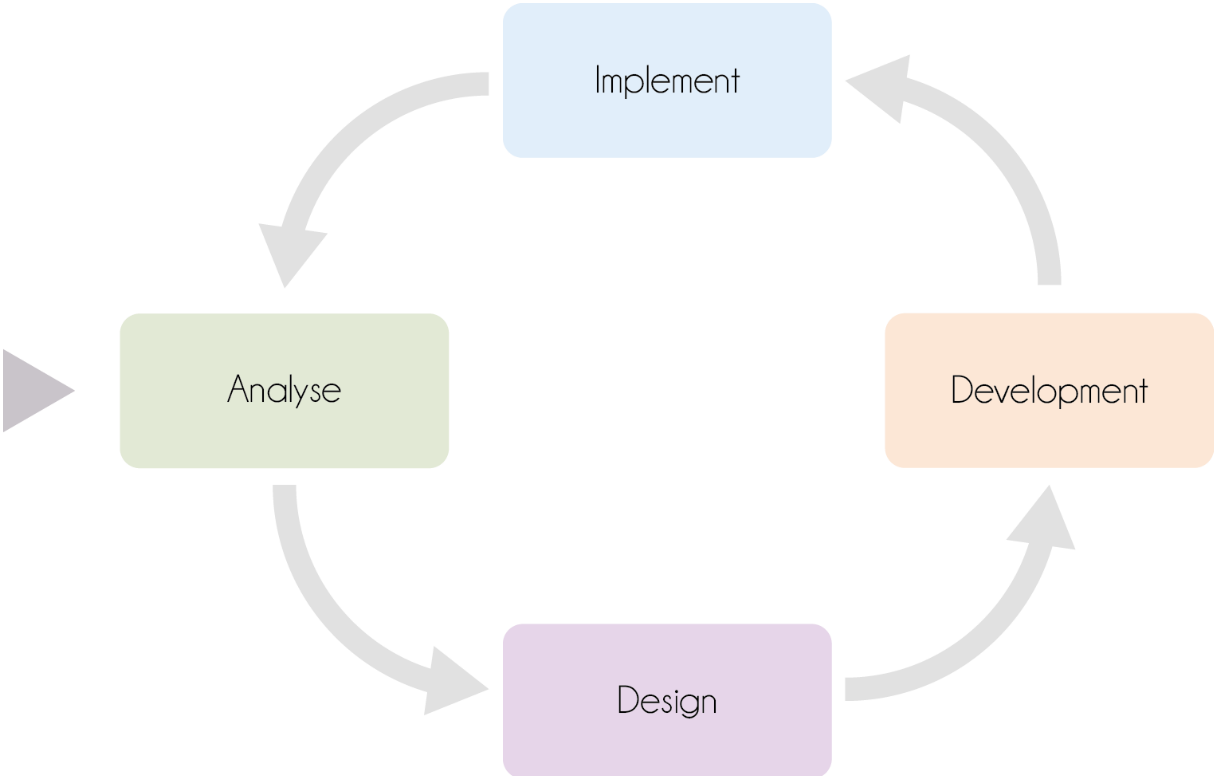


FIGURE 5: SOFTWARE DEVELOPMENT PROCESS

This report does not encompass all phases of this process in depth, and only focus on certain important points require for a better understanding of the project. Thereby, Development and Implement phases are just briefly evoked while Analyse and Design phases are more developed.

3.2 The specifications

The first objective of this project is to be able to identify different Danish consumption profile for the residential sector and conducts some calculation using the software developed. The need to choose different consumption profile is due to the fact of consumer practices. Each consumer has different practice thus the final electricity consumption is often clearly different from one to another. This statement can be illustrated by Figure 6 which shows the daily electricity load for two individual consumers in Ireland. Customer 1 has two peaks one in the late morning and one in the evening whereas customer 2 has a double peak in the late morning.

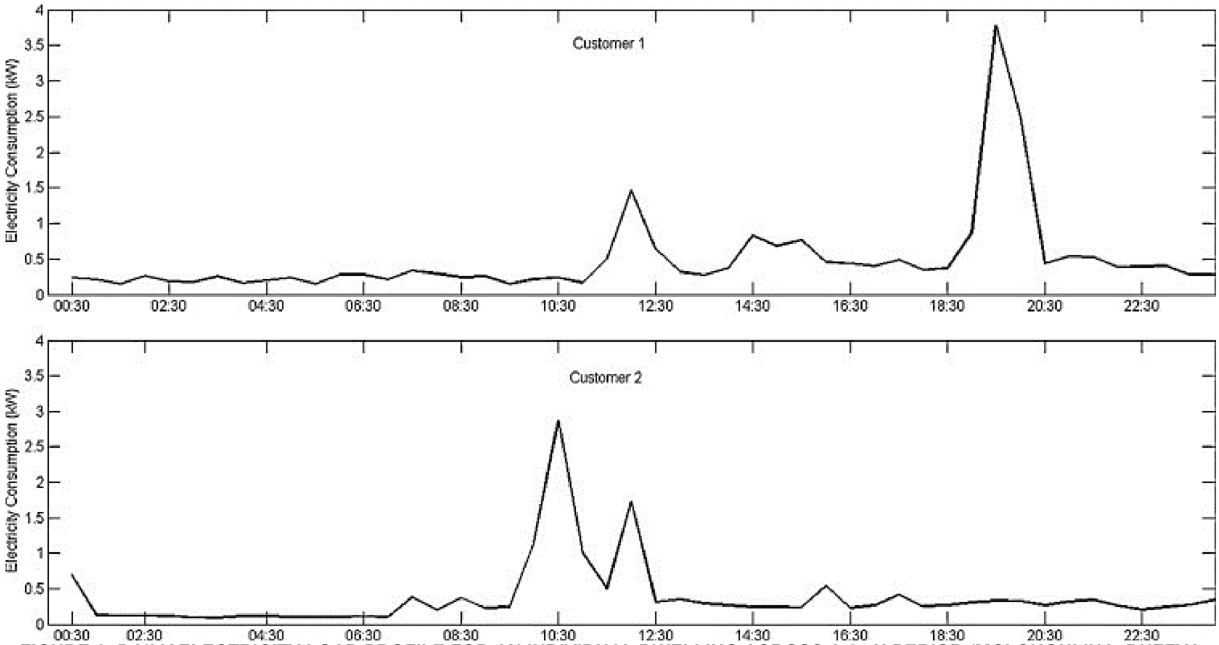


FIGURE 6: DAILY ELECTRICITY LOAD PROFILE FOR AN INDIVIDUAL DWELLING ACROSS A 24 H PERIOD (MCLOUGHLINA, DUFFYA ET CONLONB 2012)

For this project, the yearly load profile with an hour scale is assumed to be the best option in order to reflect the user practice and the influence of fluctuating energy systems such as wind turbines. However, the yearly electricity load profile is not available for every user because it requires the installation of metering devices. Hence, in order to give the possibility to most people to use this software it has been integrated the possibility to calculate an estimation of their yearly electricity load profile.

Therefore, the first feature of this software becomes the possibility to design a virtual house reflecting the electricity consumption. The user will be able to define the number of room and the electrical appliances or devices plugged in for each of them. The user can also indicate different parameters that will help the program to calculate a load profile. These parameters are related to the user practices and behaviour. This step is not compulsory for users who are already monitoring their electricity consumption. In that case, they can directly indicate to the software the relevant load curve and conduct calculation. The two main processes that can be processed are illustrated by Figure 7.

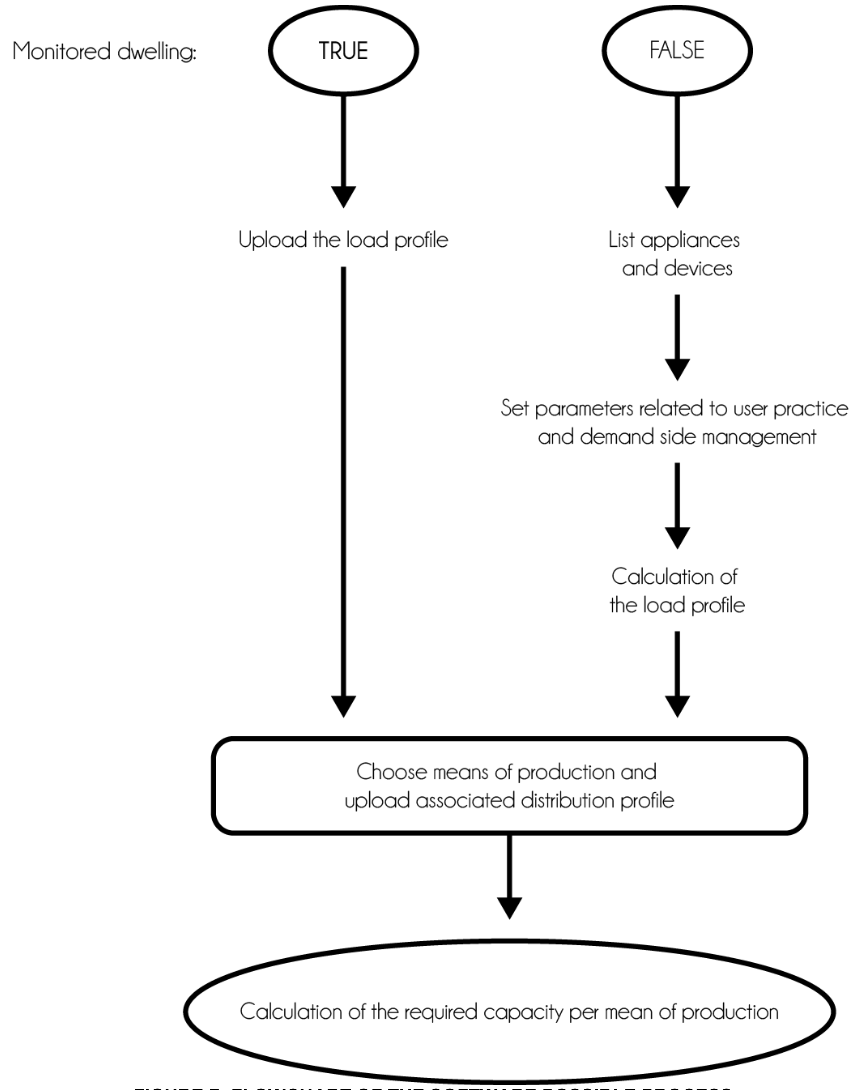


FIGURE 7: FLOWCHART OF THE SOFTWARE POSSIBLE PROCESS

First case, the user has intelligent electricity meters in his dwelling thus it is possible to extract the exact load profile for his dwelling and to upload it into the software. Second case, the user has no data related to his electricity consumption. Then, a listing of all the electric appliances and devices installed has to be done and for each of them different information has to be gathered such as: maximum consumption, standby consumption, frequency of use, etc. The more detailed at the information, the more relevant will be the result. Thereafter regardless the case, it is now possible to conduct calculation.

Listing the specifications of the software was the first step. Then, the choice of the programming language has an important role due to this influence on the designing process.

3.3 THE CHOICE OF THE PROGRAMMING LANGUAGE

The decision about the choice of the programming language is based on different factors such as type of programming, integration and portability. As illustrated by Table 1, there are a large number of potential programming languages that can be chosen.

TABLE 1: DIFFERENT PROGRAMMING LANGUAGES THAT CAN BE RELEVANT FOR THIS PROJECT

Logo	Name	Website
	Java	www.java.com
	Python	www.python.org/
	MATLAB	www.mathworks.com
	Ruby	www.ruby-lang.org
	PHP	www.php.net
C#	C#	msdn.microsoft.com/
C++	C++	www.cplusplus.com

Hence, it is important to define a list of requirements in order to lower the number of possibilities. The requirements for the choice of the programming language are the following:

- High level; the programming language is closer to the human language than to the machine language thus there is no need to take into consideration the specification of the machine that is used.
- Numerous libraries available; set of predefined function that avoid for the programmer to redefine them.
- Object oriented programming; it is a programming paradigm based on "objects" interactions, an object can define an idea, a concept or an entity from the physical world.
- Large community; it allows finding answers for common problems and tutorials that explain in details certain feature of the programming language.
- Portable on different architectures (e.g. Windows, Linux, Mac, etc.).

Due to the large number of existing programming languages, some of them are really close in terms of features and possibilities. Consequently, there is no programming language better than another just different way of thinking and different level of popularity. In this project, Java has been chosen because of the fact that it fits the requirements listed previously finally ends the research. However, it does not mean that Java is the best option; it is just an option between many others. The next section will provide an understanding of how the software has been designed including some algorithm descriptions.

3.4 Software Design

The object oriented programming is particularly relevant in this project for the simple reason there is a need for modelling home, room, appliances and devices which are nothing else than objects. Then, for each of the objects required to model a list of attributes is defined. The object home has access to the list of the room and in the same way; each room has access to the list of electric devices installed within. Only the object representing the electric devices possesses details attributes both technical and behavioural. The hierarchy between the different objects and their attributes is illustrated in Figure 8.

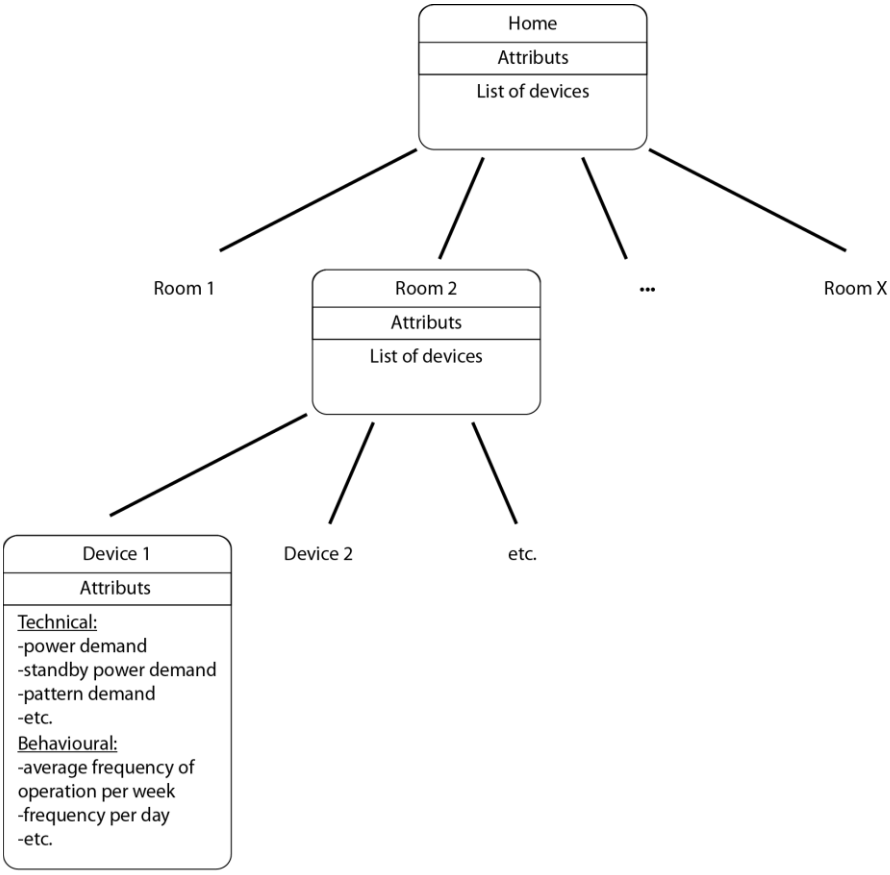
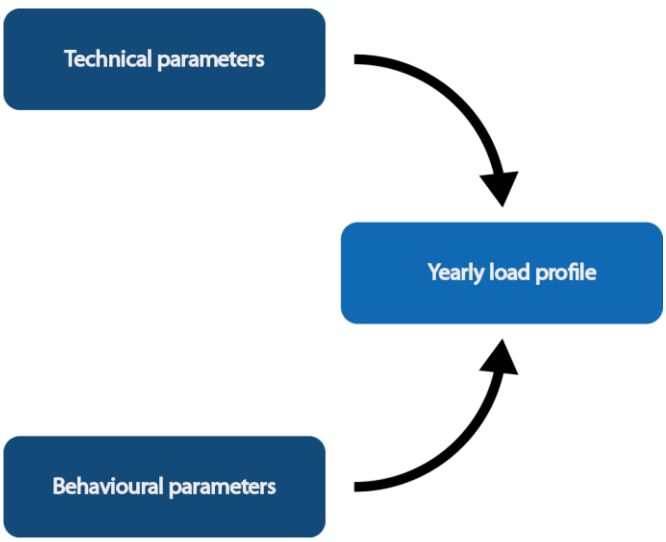


FIGURE 8: HIERARCHY OF THE OBJECT CLASSES INCLUDING THEIR RESPECTIVE ATTRIBUTES

This set of objects constitutes the basis of the software architecture. The other parts of the software are conducting calculation using data from the three types of objects: home, room and device. In the following is described the algorithms used to deduce a yearly load profile from device attributes both technical and behavioural, and after the algorithm to calculate the capacity required to be isolated from the grid.

3.5 THE LOAD PROFILE

The load profile is deduced from the list of electric appliances and devices installed in the dwelling. The methodology used for the load profile estimation is based on different parameters both technical and behavioural.



a) TECHNICAL PARAMETERS

The technical parameters consist of the consumption of the electric appliance or device. This consumption corresponds to the maximum power if the load profile of the material is not constant. This is the case for appliances such as washing machine and dish washer. For instance, a washing machine with a maximum power of 2000 Watt will commonly follow the distribution presented in Figure 9 according to the report Synergy Potential of Smart Appliances (Stamminger 2009). The time scale does not fit with the fact that the software is an hourly model thus an hourly profile is calculated as presented by Figure 10.

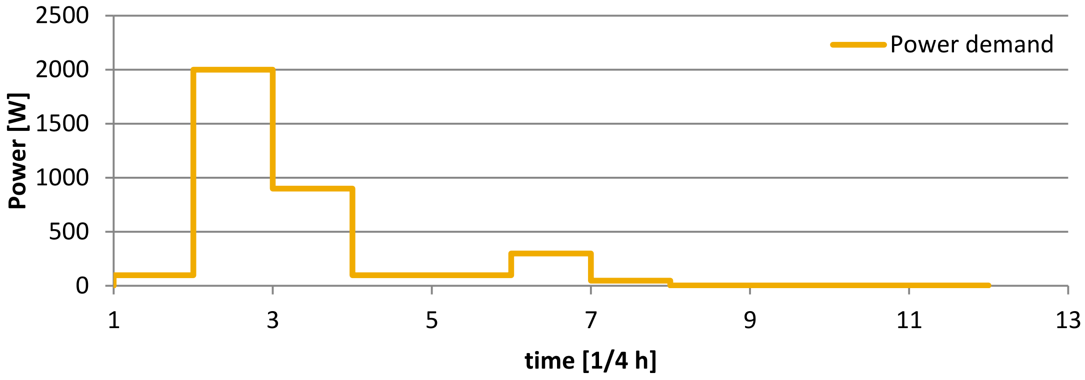


FIGURE 9: PATTERN DEMAND OF A WASHING MACHINE WITH ¼ HOURLY SCALE

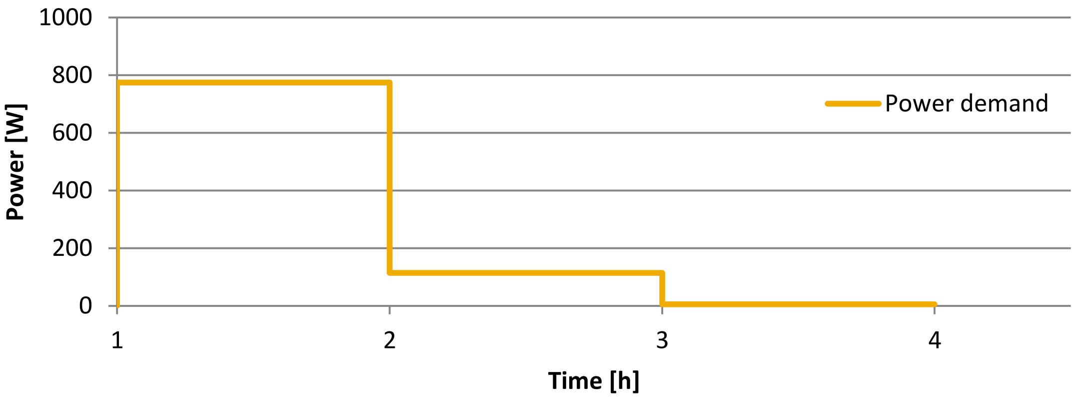


FIGURE 10: PATTERN DEMAND OF A WASHING MACHINE WITH HOURLY SCALE

In the case the electric appliances or devices follow a constant profile. The load profile is a flat curve with a constant value corresponding to its power. Knowing the technical parameters is not sufficient to deduce an hourly load profile on a year scale because as described in the Theoretical framework (page 11) an important part of the consumption is related to user practice. In the next part will be detailed the different parameters that are taking into account for the calculation of a relevant load profile.

- BEHAVIOURAL PARAMETERS

User practices can be defined by two parameters: time space and frequency. The time space is answering the question: When the practice is conducted? When the frequency is answering: How many times the practice is conducted?

The method used in order to define the user practice is based on probability theory and statistics. There are several distributions that could have been chosen but it has been decided to use the Normal distribution due to its characteristics. In fact, this distribution allows expressing “a continuous probability distribution” (Wikipedia, Normal distribution s.d.) with no requirements about the order of magnitude of the figures used.

The Normal distribution

If the average number of occurrences during the given interval is μ, then the probability that the count is exactly k is equal to:

$$P(x = k) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2}$$

Where:

- e is the base of the natural logarithm
- μ is the mean
- σ is the variance

It has been assumed that the variance will be defined as the root square of the mean $\sqrt{\mu}$ in order to get closer from the results that could have been obtained using the Poisson distribution. The Poisson distribution expresses “the probability of a given number of events occurring in a fixed interval of time and/or space if these events occur with a known average rate and independently of the time since the last event” (Wikipedia, Poisson distribution s.d.). However the fact that the Poisson distribution does not provide enough flexibility due to the lack of continuous probability distribution and relevance with numbers superior to 15 has conducted to the only use of the Normal distribution in this project.

Example

A washing-machine has a probability to be launched 4.5 times a week with a maximum of 10 operations per week. Then the probability that the washing machine is launched 0, 1, 2….10 times is defined in Table 2 and illustrated by Figure 11.

TABLE 2: NORMAL DISTRIBUTION REPRESENTING THE FREQUENCY OF OPERATION OF A WASHING MACHINE WITH $\lambda = 4.49$

Frequency of operation	Normal distribution
0	0.019943
1	0.048498
2	0.094392
3	0.147034
4	0.183305
5	0.182898
6	0.146055
7	0.093347
8	0.047748
9	0.019547
10	0.006405

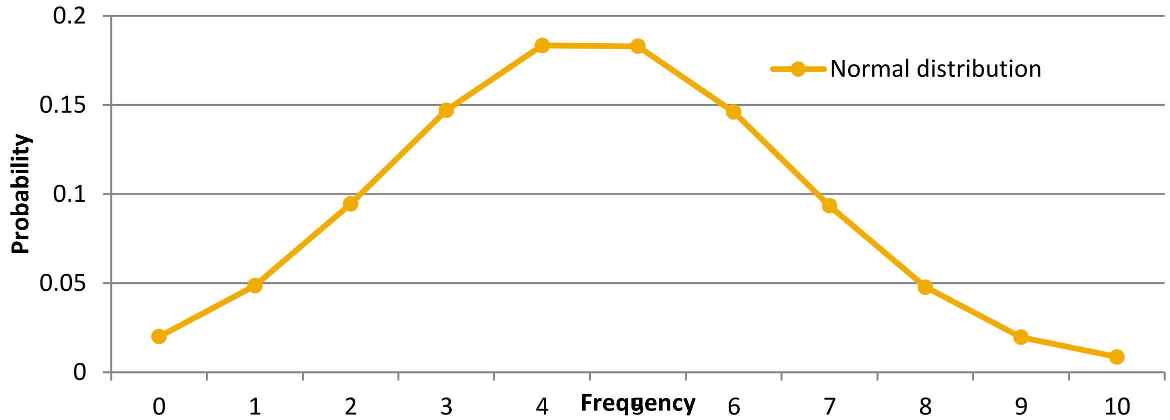


FIGURE 11: CURVE REPRESENTING THE POISSON DISTRIBUTION OF TABLE 2

Normal distributions, in addition to probability and statistics about user practices collected through Danish Energy saving trust (The Danish Energy Saving Trust s.d.) and ELMODEL-bolig (ELMODEL-bolig s.d.) other relevant sources previously cited, will allow calculating a relevant yearly load profile. The next part explains how these parameters are used in order to achieve a relevant load profile.

- THE LOAD PROFILE ALGORITHM

For this algorithm, a bottom up approach has been used. It means that first calculation have been conducted for devices then for room and finally for the entire home. In fact, as illustrated by Figure 12 when there is a need to get a yearly load profile for a dwelling from technical and behavioural parameters, the first step is to calculate the load profile for each device separately. Then for each room, the load profiles of each device are summed and the final result is the sum of the load profile of each room. Each calculation is conducted within the relevant object: home, room or device.

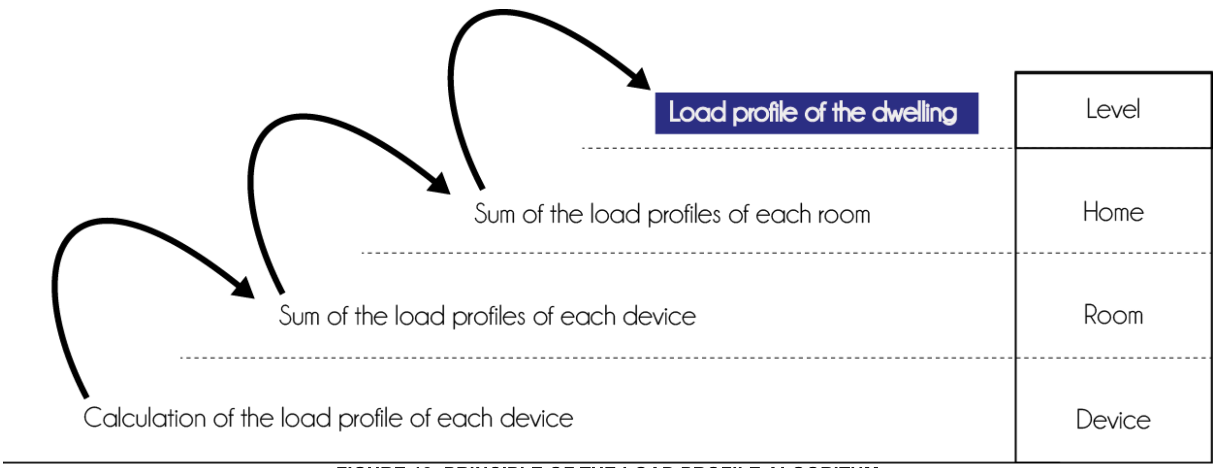


FIGURE 12: PRINCIPLE OF THE LOAD PROFILE ALGORITHM

Most of the process is done during the calculation of the load profile of each device thus only this part is detailed in this report. In order to conduct a clear and concrete explanation, the example of the calculation of a load profile from a washing machine is chosen. Table 3 gathers the main parameters used for the calculation and Figure 13 the pattern demand followed by the washing machine during its operation.

TABLE 3: MAIN PARAMETERS BOTH TECHNICAL AND BEHAVIOURAL FOR THIS WASHING MACHINE

Washing machine	
Technical parameters	
Max power [Watt]	1700
Standby power [Watt]	3
Behavioural parameters	
Average number of operation per week [times/week]	4.49
Maximum number of operation per week [times/week]	7
Maximum number of operation per day [times/day]	2
Probability to unplug the device after use [%]	0.3

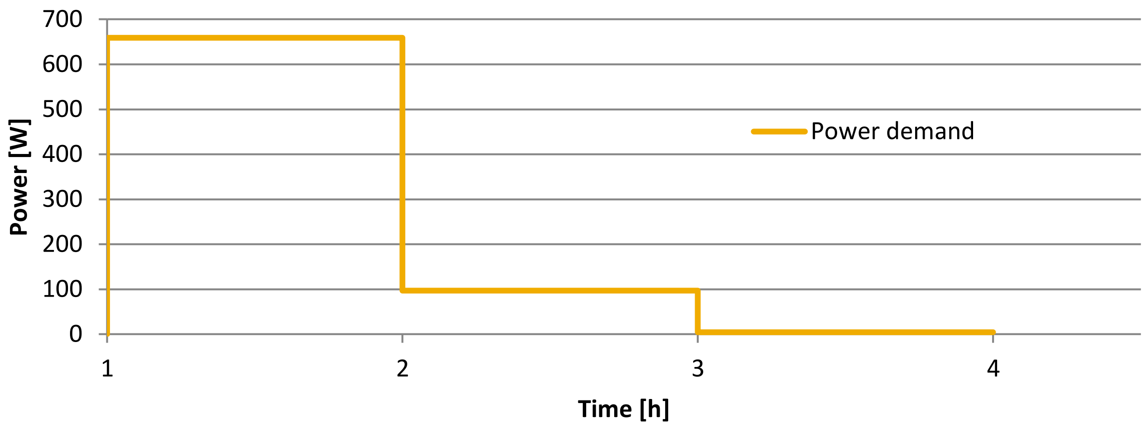


FIGURE 13: POWER DEMAND FOR A WASHING MACHINE OF 1700 W (STAMMINGER 2009)

In addition to these parameters and in order to conduct a calculation, there is also a need for probability and statistics distribution that reflect the user behaviour. The three distributions used for calculation represents the probability of operation per day (see Figure 14), the probability of operation per hour (see Figure 15) and the probability regarding the number of operation per week according to the fact that the average number of operation is 4.49 on a year (see Figure 16). This last figure is calculated by the software itself using the behavioural parameters from Table 3 and based on the Normal distribution developed in the section: Behavioural parameters.

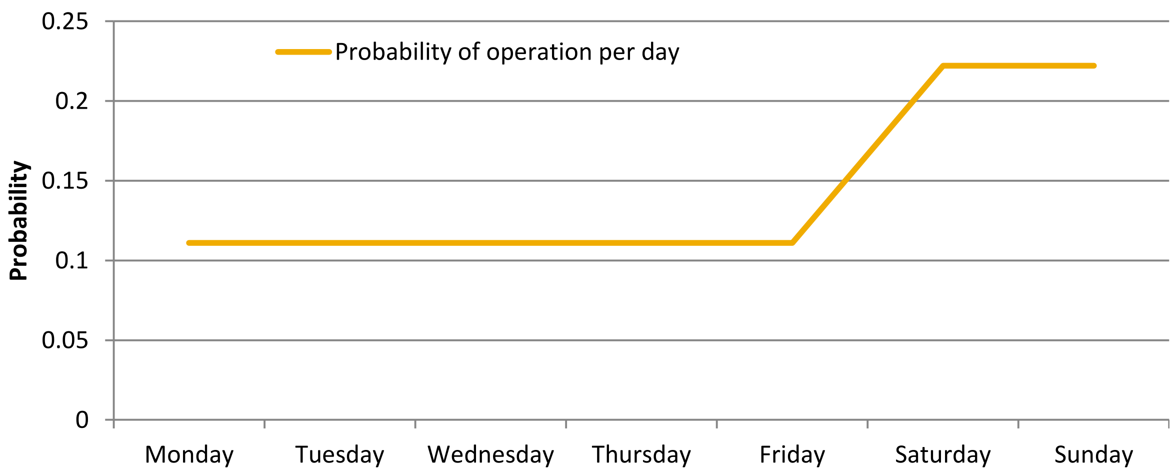


FIGURE 14: ASSUMED PROBABILITY OF OPERATION PER DAY FOR A WASHING MACHINE

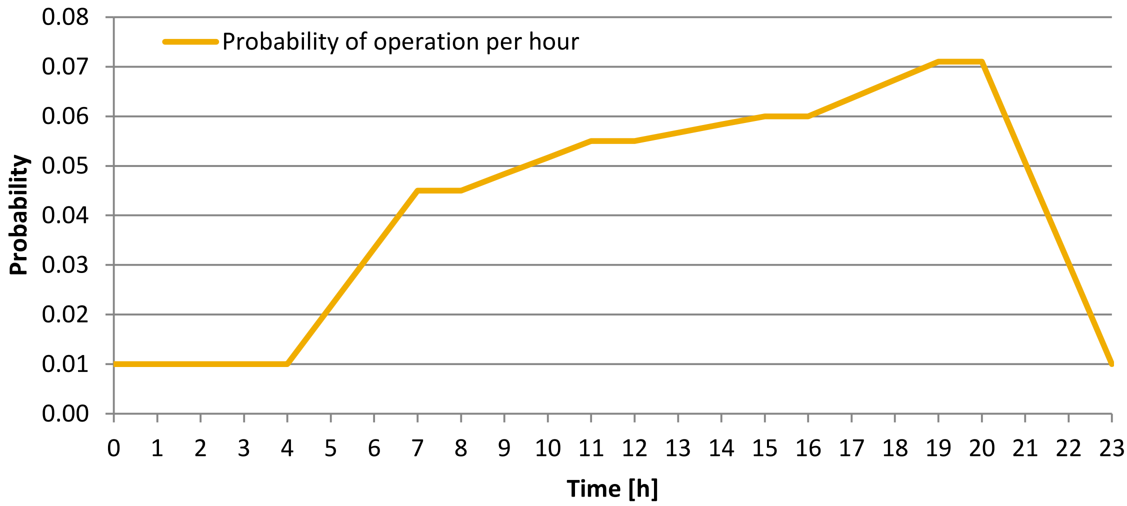


FIGURE 15: PROBABILITY OF OPERATION PER HOUR FOR A WASHING MACHINE IN SWEDEN (STAMMINGER 2009)

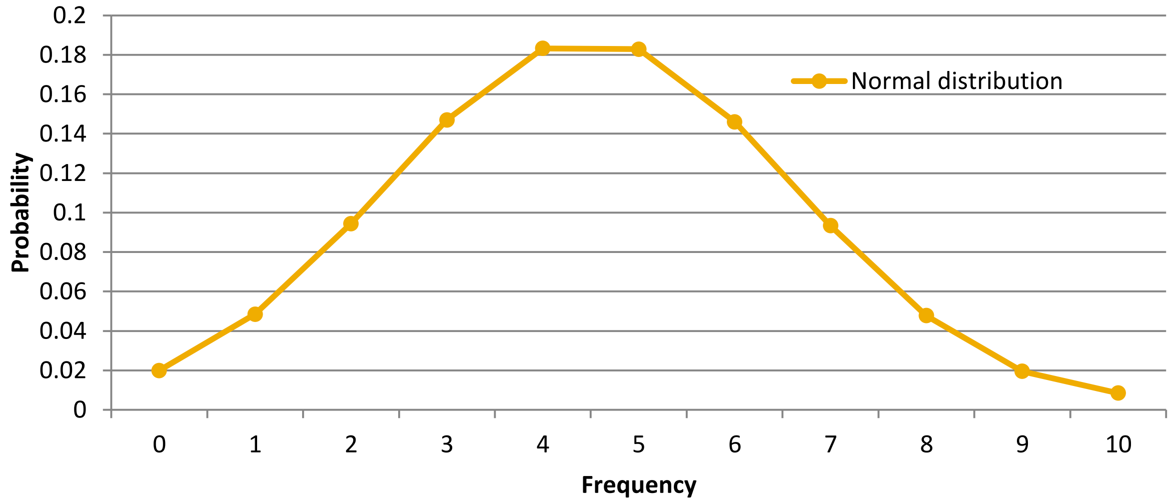


FIGURE 16: PROBABILITY OF THE NUMBER OF OPERATION PER WEEK FOR A WASHING MACHINE WITH $\lambda = 4.49$

By using these figures, it allows assessing a load profile for the washing machine used in our example. It is important to notice that parameters from Table 3, Figure 13, Figure 14 and Figure 15 are inputs provided by the user and thus can be modified to reflect at best the electricity consumption. Most of the curves used for this project are presented in the Annex.

The algorithm used to deduce the load profile is weekly based which means that the process is done week by week and the results for each week are aggregated afterwards to form a yearly profile. Hence, for a given week, the first step is to extract the number of operation that will be conducted during this week using Figure 16, then using Figure 14 the number of operation per day is deduced.

For instance on week 18, 4 washing machines are launched and the distribution along the week is as follows:

Days of the week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Number of operation	0	1	0	1	0	0	2

Thereafter using this example, on Tuesday there is one washing machine. The starting hour of this washing machine is decided using Figure 15. Then the pattern demand presented in Figure 13 is applied to the three hours following the starting hour. In this case, the washing machine is considered to consume electricity while on standby thus it has been added the possibility to specify how often the user thinks about unplug it when the operation is finished. This parameter is also taken into account in the final calculation of the load profile for a washing machine. Figure 17 illustrates a week extracted from the yearly load profile of the washing machine defined in this example. There are 4 washing machine launched during this week: one on Monday, one on Friday, one on Saturday morning and one on Sunday night. Moreover, the standby consumption is null on Monday morning but the washing machine stays plug the rest of the week. The fact that the last washing machine conducted on Sunday did not finish before the end of the week is managed by the software and thus reported on Monday of the next week.

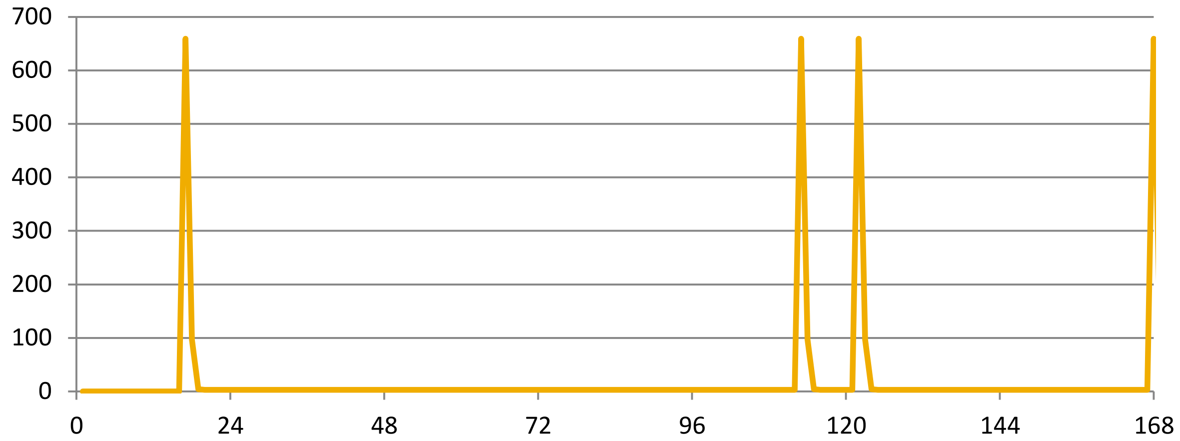


FIGURE 17: WEEKLY LOAD PROFILE OF THE WASHING MACHINE

In the same way than for the washing machine, the same process is used to calculate the load profile for other devices. As explained before, the last step is to sum all the load profiles together to achieve to get the overall load profile for the dwelling. When this is done, the next step is to conduct calculation in order to deduce the capacity, from a given source, required to fit the demand of the dwelling.

b) Energy and Storage system algorithms

- The energy system algorithm

At this stage, there is access to the load profile of the dwelling; this load profile defined the demand of the dwelling per hour during one year. The user can now decide which kind of power sources will be used to cover the demand of the dwelling. There is no limit concerning the type of sources and their number, there is just need for the normalized distribution for each sources chosen. For instance, if the user has chosen wind power as a source, the corresponding distribution of wind for the year given has to be uploaded.

The objective of this algorithm is to fit the demand using the minimum capacity for each of the source chosen. The order of the different sources has an importance because the first chosen source has the priority on the second, and the second on the third, etc. For instance, if the user decides to add two sources wind and solar in this precise order. When the algorithm face a case where it has the choice to increase wind or solar capacity, the wind capacity will be increase.

The principle of this algorithm is to base the calculation on the different distribution sources and for each hour of the year try to meet the demand using these distributions. Hence, the equation to resolve can be defined as follows:

$$demand\ (h) = \sum_{i=1}^{i=Y} capacity_i \times distribution_i(h)$$

Where:

- $demand\ (h)$ is the load of the dwelling at the hour h
- $capacity_i$ is the capacity of the source i when the overall capacity is minimal
- $distribution_i(h)$ is the distribution of the source i at the hour h

Once, this equation resolved for each hour of the year, the maximum capacity obtained for each sources is extracted. These capacities represent the minimum capacity required to fit the demand of the dwelling. Thereafter, extra calculation can be conducted to ripen the result, for instance with the addition of losses, or also for cost analysis.

- THE STORAGE SYSTEM ALGORITHM

About the storage system, the process is similar. However, the user needs to specify the different technical parameters of the storage system that want to be used such as capacity, distribution, discharging capacity or charging capacity. Several storage systems can be designed. Thereafter, the software will conduct the calculation and return the number of hours that the battery system allowed covering the demand by comparing the energy system with and without storage system.

The distribution related to the storage system indicates if the battery is connected and the efficiency of the system. For instance, if at the hour X the distribution is 0.9 it means that the battery is connected and the efficiency to charge and discharge is 90%. Thereafter, if the battery is connected it can be charged or discharged depending of the current demand and current production from energy system.

Here are explained the possible cases:

1. The storage system is connected and there is a need for energy from the dwelling

The source code presented in Figure 18 illustrates the process of calculation. It verifies that the storage system is not supplying more power than possible. After the power is supplied, it modifies the state of charge of the storage system.

```
if(currentCapacity>dischargeCapacity)
currentCapacity=dischargeCapacity;

if((currentCapacity*distrib)<need)
{
      need=need-currentCapacity*distrib;
      currentCapacity=0.;
}
else currentCapacity=currentCapacity-need/distrib;
```

FIGURE 18: SOURCE CODE 1

Where:

- `need` is equal to the quantity of power required by the dwelling
- `currentCapacity` is the current capacity of the storage system
- `dischargeCapacity` is equal to the maximum power that can be transfer from the storage system to the dwelling in one hour
- `distrib` is the value of the distribution and of the efficiency as explained previously.
-

2. The storage system is connected and there is a surplus of energy from the dwelling

The source code presented in Figure 19, illustrates the charge of the storage system. When there is a surplus of power from the dwelling the storage system is charged according to its technical parameters. It also verifies that the capacity of the storage system does not exceed the stated capacity.

```
if(need>chargeCapacity)
{
currentCapacity=currentCapacity+chargeCapacity*distrib;
need=need-chargeCapacity;
}
else currentCapacity=currentCapacity+need*distrib;

if(currentCapacity>capacity) currentCapacity=capacity;
```

FIGURE 19: SOURCE CODE 2

Where:

- `need` is equal to the quantity of power supplied by the dwelling
- `chargeCapacity` is equal to the maximum power that the storage system can accept as input
- `currentCapacity` is the current capacity of the storage system
- `capacity` is the maximum capacity of the storage system
-

3. The storage system is not connected; the next time the battery gets connected to the system, its state of charge will be considered null.

4 THE LOAD PROFILES

In order to conduct analysis about the capacity of dwellings to be isolated from the grid, the first step is to define different profile of consumption relevant with the Danish residential sector. According to the DONG energy, the main electricity supplier in Denmark, the relation between the number of people in Danish dwellings and the consumption is as illustrated Table 4. This project is only focusing on electricity consumption non-related to heating.

TABLE 4: ANNUAL ELECTRICITY CONSUMPTION IN DANISH DWELLINGS ACCORDING TO THE SIZE OF THE DWELLING AND THEIR CONSUMPTION EFFICIENCY. TRANSLATED FROM: (DONG ENERGY S.D.)

Annual electricity consumption [kWh]		Number of persons				
		1	2	3	4	>4
A	Very low power consumption	2,285	2,950	3,680	4,300	4,790
B	Low power consumption	2,381	3,065	3,800	4,426	4,919
C	Slightly below average power consumption	2,572	3,294	4,040	4,677	5,178
D	Average power consumption	2,954	3,752	4,520	5,181	5,695
E	Slightly above average power consumption	4,070	4,668	5,480	6,187	6,730
F	High power consumption	5,600	6,500	7,400	8,200	8,800
G	Very high power consumption	>5,600	>6,500	>7,400	>8,200	>8,800

By crossing data from Table 4 and Table 5, it shows that the centres of electricity consumption in the detached houses are represented by dwellings with 2 or 4 persons. Hence, it has been decided that the focus will be on these two categories due to larger potential of implementation and impacts.

TABLE 5: SIZE OF THE DETACHED HOUSES IN DENMARK IN 2010 (STAMMINGER 2009)

Number of persons	1	2	3	4	5	6	7	8 or more
Detached houses in2010	193,031	412,429	151,797	194,523	67,392	13,206	3,036	1,677

In the following, tables and figures are only related to a 4 persons dwelling. The most important tables and figures for a 2 persons dwelling are available in the Annex.

A sample of the consumption related to Danish dwelling is illustrated in Figure 20. A choice would have been to base the analysis of this project on this distribution and just make varied the overall consumption. However, the average load profile presented here is not representative of a single dwelling but of several hundred thus it results in a smoother and regular curve due to the fact that differences of user practices between dwellings are not visible anymore. In contrary, when the focus is done on a single dwelling the result is highly influenced by the user practices as it has been shown in Methodology chapter in Figure 6.

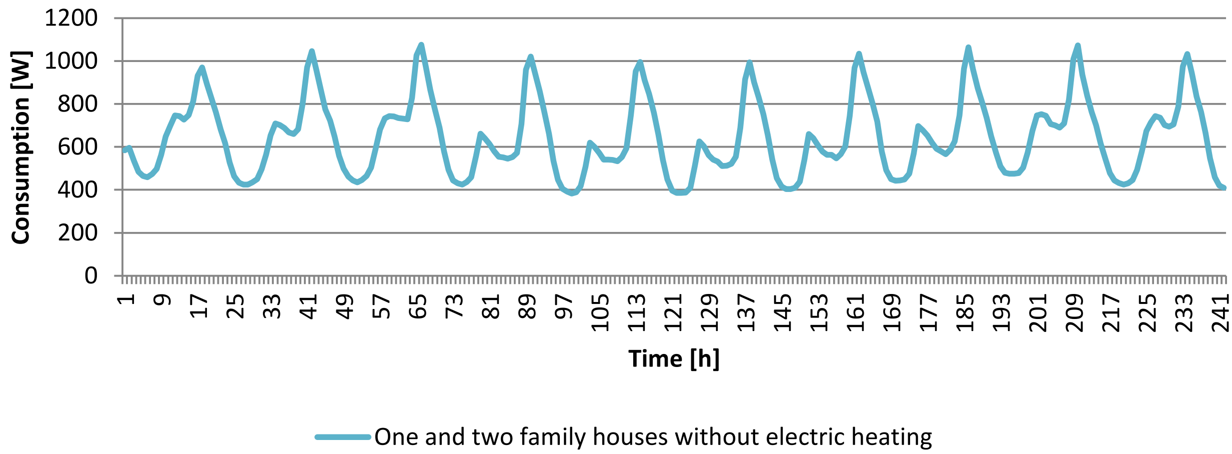


FIGURE 20: AVERAGE ELECTRICITY CONSUMPTION FOR TWO CONSUMER CATEGORIES DURING SOME DAYS IN JANUARY 2010 (DANISH ENERGY ASSOCIATION 2010)

The conclusion of this short analysis is the decision to base the analysis developed in the next sections on load profile from monitored dwellings or from the result of the load profile algorithm developed previously in the Methodology chapter.

Data from monitored dwellings are difficult to find especially when there is a need for hour distributions over a year. Hence, the different analysis will be based on load profile calculated from the software. In the next section is described the data used to reach profile fitting Danish profile of the residential sector.

4.1 THE PARAMETERS OF THE LOAD PROFILES

In order to achieve relevant load profiles calculation, it is important to define different kind of user practice and different end-use profile for electricity according to data related to Danish residential consumption and behaviour.

a) END USE OF ELECTRICITY

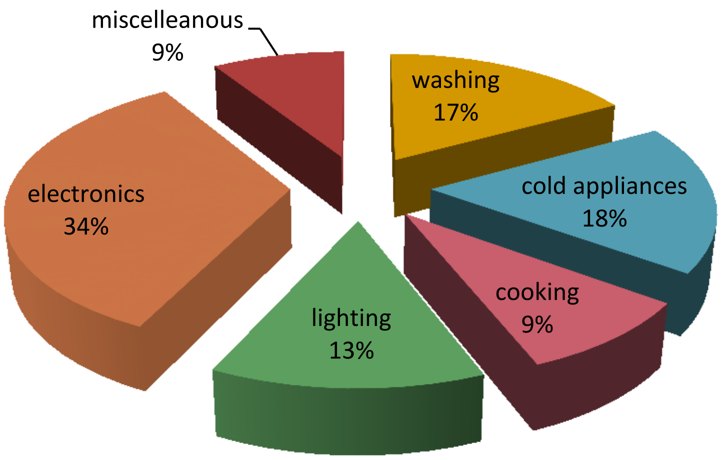


FIGURE 21: DANISH AVERAGE DWELLING ELECTRICITY CONSUMPTION DISTRIBUTED BY FINAL USE IN 2010 (EXCLUDING HEATING) (THE DANISH ENERGY SAVING TRUST S.D.)

Figure 21 illustrates the distribution of the electricity consumption per final use in Danish dwellings. It presents one major centre of consumption: electronics with 34 per cent, followed by an almost equal distribution with 18-17 per cent between respectively cold appliances and washing. Lighting and cooking are involved in 13 and 9 per cent of the overall electricity consumption. The last 9 per cent represents miscellaneous electricity consumption such as vacuum cleaner or alarm system. Each profile in this project will try to respect this distribution as much as it is possible according to the inputs parameters.

The input parameters are composed by the list of electrical devices installed in the dwelling and their respective parameters both technical and behavioural. Most of the data used for these two sections are extracted from (ELMODEL-bolig s.d.) and (Stamminger 2009). Elmodel-bolig Statistics is a platform that proposes data from questionnaires sent to Danish households. These questionnaires encompass both technical and behavioural aspects of the consumers. The report Synergy potential of smart appliances (Stamminger 2009) is a more technical report that proposes different pattern demand for common appliances.

- TECHNICAL PARAMETERS

The first differentiation that can occur between two dwellings is the quantity and the quality of the electrical devices installed. In this project, the focus is only done on the quality of the devices and thus on their power efficiency. Hence, two sets of electric devices are chosen. The two sets are gathering the same type of electrical devices and encompass the different end-use categories illustrated earlier by Figure 21. The first one is presenting devices with average power consumption and the second one with only efficient devices. By efficient devices are considered the devices meeting the requirements of the most efficient category that can apply to this device. These categories are set by the European Union and Figure 22 illustrates the label used to inform user when they make their choice. It presents the electricity consumption over a year under certain circumstances as well as some other parameters in relation with the type of devices such as water consumption for a washing machine or a dish washer.

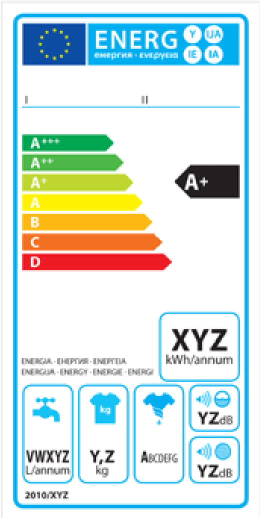


FIGURE 22: ENERGY LABELLING WITHIN THE EUROPEAN UNION

These two sets are assumed to represent the electrical devices installed in most Danish dwellings. Table 6 presents the technical parameters of these two sets including power consumption and standby consumption for a 4 persons dwelling. There are slight differences with a 2 persons such as the presence of a game console and a superior wattage concerning lighting.

TABLE 6: TECHNICAL PARAMETERS OF THE TWO SETS OF ELECTRICAL DEVICES FOR A 4 PERSONS FAMILY (ELMODEL-BOLIG S.D.) AND (STAMMINGER 2009)

Technical parameters	Number of unit (Average/Efficient)	4 persons family (average)		4 persons family (efficient)	
		Power [W]	Standby Power [W]	Power [W]	Standby Power [W]
Washing					
Washing machine (7kg)	1	2000	0.0	2000 or 900	0.0
Tumble dryer	1	2000	0.0	2000	0.0
Dish Washer	1	2000	0.0	1800	0.0
Cold appliances					
Combi fridges	1	35.00	0.0	30	0.0
box/chest freezer	1	30.00	0.0	25	0.0
Cooking					
hob+hood	1	2379	7.5	2379	7.5
Oven	1	1171	1.6	1171	1.6
Mixer/food processor	1	1029	0.7	1029	0.7
Coffee maker	1	1300	1.3	1300	1.3
Lighting					
CFL 8 watt	8/14	80	0.0	146	0.0
Halogen 50 W	6	300	0.0	300	0.0
incandescent 43 W	6/0	258	0.0	0	0.0
Electronics					
Television 82 cm + surround	1	412.71	4.7	303.34	3.2
Stereo	1	14.45	4.9	14.45	2.4
Desktop system	1	76.35	10.8	27.21	9.6
TV+game console only 4 persons dwelling	1	536.71	15.6	536.71	7.8
Miscellaneous electronics	1	500	0.0	500	0.0
Miscellaneous					
Miscellaneous	1	400.0	11.5	400.0	3

A Danish dwelling has more electrical devices installed than the ones presented in Table 6. Consequently, the sum of the consumption of each electrical device introduced in Table 6 will not fit the average Danish consumption chosen in Table 4 and the distribution presented in Figure 21. As a solution for this problem, it has been decided to add when it is required, a specific electrical device. This specific electrical device reflects the overall electricity consumption of the different electric devices encompassed. For instance, the specific device called "miscellaneous electronics" will merge the consumption of devices such as vacuum cleaner/hair dryer/etc. The power demand and the standby power of this device correspond to the weighted average according to their use.

Thereafter, for each of this electrical devices, specific behavioural parameters or pattern demand when applicable are applied in order to obtain a final load profile as relevant as possible.

- BEHAVIOURAL PARAMETERS

The behavioural parameters for a 4 persons dwelling are presented in Table 7 for the family with average power consumption and in Table 8 for the family with very low power consumption.

TABLE 7: BEHAVIOURAL PARAMETERS FOR A 4 PERSONS DWELLING WITH AVERAGE ENERGY CONSUMPTION IN DENMARK BASED ON ASSUMPTION AND DATA FROM (ELMODEL-BOLIG S.D.)

Average behaviour	Average op per week [times/week]	duration or average duration [hour]	Maximum duration [hour]	Max op per day [times/day]	Max op per week [times/week]	standby probability [%]
Washing						
Washing machine (7kg)	4.8 (40°-50°)	-	-	2	7	0
Tumble dryer	1.9	-	-	1	7	
Dish Washer	3.87	-	-	1	7	
Cold appliances						
Combi fridges	-	-	-	-	-	-
box/chest freezer	-	-	-	-	-	-
Cooking						
hob+hood	7.70	0.40	2.00	2.00	10.00	0.00
Oven	2.20	0.83	1.50	1.00	5.00	0.00
Mixer/food processor	2.00	0.25	0.50	1.00	4.00	0.00
Coffee maker	10.50	0.17	0.40	4.00	15.00	0.00
Lighting						
CFL 8 watt	7.00	3.60	6.00	1.00	7.00	0.00
Halogen 50 W	7.00	2.95	6.00	1.00	7.00	0.00
incandescent 43 W	7.00	2.75	6.00	1.00	7.00	0.00
Electronics						
Television 82 cm + surround	7.00	3.10	4.00	3.00	10.00	0.47
Stereo	7.00	0.67	2.00	2.00	10.00	0.38
Desktop system	7.00	6.59	10.00	2.00	10.00	0.49
TV+game console only 4 persons dwelling	7.00	2.00	4.00	2.00	10.00	0.18

TABLE 8: BEHAVIOURAL PARAMETERS FOR A 4 PERSONS DWELLING WITH LOW ENERGY CONSUMPTION IN DENMARK BASED ON ASSUMPTION AND DATA FROM (ELMODEL-BOLIG S.D.)

Efficient behaviour	Average op per week [times/week]	duration or average duration [hour]	Maximum duration [hour]	Max op per day [times/day]	Max op per week [times/week]	standby probability [%]
Washing						
Washing machine (7kg)	1.7 (20°C) and 3.1 (40°-50°)	-	-	2.00	7.00	0.00
Tumble dryer	0.95	0.00	0.00	0.00	0.00	0.00
Dish Washer	3.87	-	-	1.00	7.00	0.00
Cold appliances						
Combi fridges	-	-	-	-	-	-
box/chest freezer	-	-	-	-	-	-
Cooking						
hob+hood	7.70	0.34	1.70	2.00	10.00	0.00
Oven	2.20	0.71	1.28	1.00	5.00	0.00
Mixer/food processor	2.00	0.25	0.50	1.00	4.00	0.00
Coffee maker	10.50	0.17	0.40	4.00	15.00	0.00
Lighting						
CFL 8 watt	7.00	3.60	6.00	1.00	7.00	0.00
Halogen 50 W	7.00	2.95	6.00	1.00	7.00	0.00
incandescent 43 W	7.00	2.75	6.00	1.00	7.00	0.00
Electronics						
Television 82 cm + surround	7.00	3.10	4.00	3.00	10.00	1.00
Stereo	7.00	0.67	2.00	2.00	10.00	1.00
Desktop system	7.00	6.59	10.00	2.00	10.00	
TV+game console only 4 persons dwelling	7.00	2.00	4.00	2.00	10.00	1.00

The differentiations of behaviour between these two tables are based on data and behavioural advices provided by the Danish energy saving Trust (The Danish Energy Saving Trust s.d.). In the following is described some of the information related to some electrical devices on which are based the results presented in the two previous tables:

- Washing machine; it is proposed to use program with lower temperature. In family house in Denmark, most of the laundries are launched with a program temperature between 40 and 50°C. For lower energy consumption, it is assumed than 60 per cent of the laundry can be done with a temperature inferior to 40°C and thus saved around 45 per cent of energy. Consequently, in Table 8 a share of the 4.8 operation per week from Table 7 is now conducted using a low temperature program that consumed 0.4 kWh compared to the 0.89 kWh used with a normal program.
- Tumble dryer; it is assumed that the use of a tumble dryer is not always compulsory and thus the number of operation per week is divided by two.
- Dishwasher; in the same way than for the washing machine, the reduction of 10°C in the programme temperature can conduct to a saving around 10 per cent in energy consumption. Hence, one cycle only consumes 1.07 kWh in an efficient dwelling while it reaches 1.19 kWh in an average dwelling.
- Hob, hood and oven; with good practice and adapted equipment, the energy consumption can be decreased by 15 per cent. These improvements are assumed to be reflected by the duration of use.

As it is explained in the Methodology chapter, for the electrical devices which do not have a constant power demand while they are running such as washing machine, dishwasher or tumble dryer a specific normalized pattern demand has been used to reflect the reality. These patterns demand are adapted from the report Synergy potential of smart appliance (Stamminger 2009) and available in the Annex. In addition to these patterns and for all the electrical devices that do not follow an hourly distribution over a year, probability and statistics distributions have been used to simulate the reality of the user behaviour. These distributions encompass the user behaviour during the week and during the day.

The load profile of electrical device that is difficult to assess will follow a specifically designed hourly distribution over a year. For instance, this is the case for cold appliances because their consumptions are increasing with the number of time their doors are open. Figure 23 proposed an example of the type of load profile used for cold appliances based on data from the report Synergy potential of smart appliance (Stamminger 2009). The blue line presents the consumption of a cold appliance when the door stays close during the whole day whereas the red curve presents the demand of a cold appliance according to common practice.

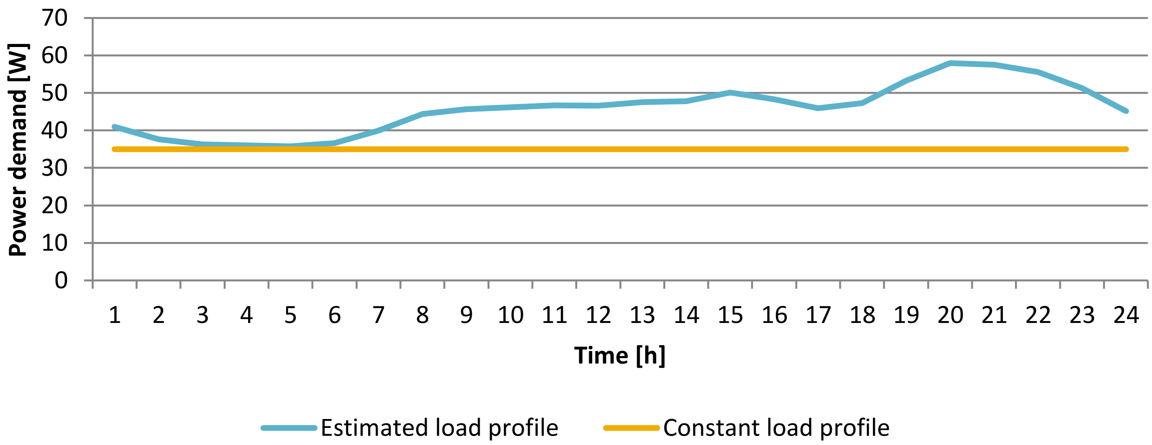


FIGURE 23: HOURLY LOAD PROFILE FOR COLD APPLIANCES OVER A DAY

In a similar way, an hourly distribution over a year has also been used for the lighting. This distribution is based on a solar distribution in Denmark which allows having a difference between winter and summer time in the electricity consumption.

For electrical devices without proper distribution, the normalized average load profile of a dwelling in Denmark is used, see Figure 20.

Most of the different parameters that have a direct impact on the overall energy consumption have been explained. However there exists another important source of energy consumption that has not been discussed yet: the standby consumption.

b) Standby consumption

Standby consumption is often not considered as a large energy consumer by most users. However, according to several studies it is a non-negligible source of energy consumption. A paper written by Erik Gudbjerg (Gudbjerg s.d.) gathers conclusion from a project conducted in Denmark focusing on standby consumption in households. It appears that the standby consumption within EU countries accounts for 8 per cent of the overall electricity consumption in average. In Denmark, similar figures are found; 9 per cent of the total electricity consumption is standby consumption with a spread from 2 per cent to 18 per cent.

In this project, 9 per cent of the annual electricity consumption will be considered standby consumption for average households while 2 per cent for efficient households. It represents respectively 470 and 160 kWh per year of electricity consumption. Same figures are used for 2 person's dwellings with respectively 240 and 80 kWh.

4.2 Results

The different Danish load profiles, using the different parameters explained previously, are presented in this section. A sample of a load profile is presented in Figure 24 in order to give an idea about the result that is obtained and as a comparison to Figure 20 (page 27).

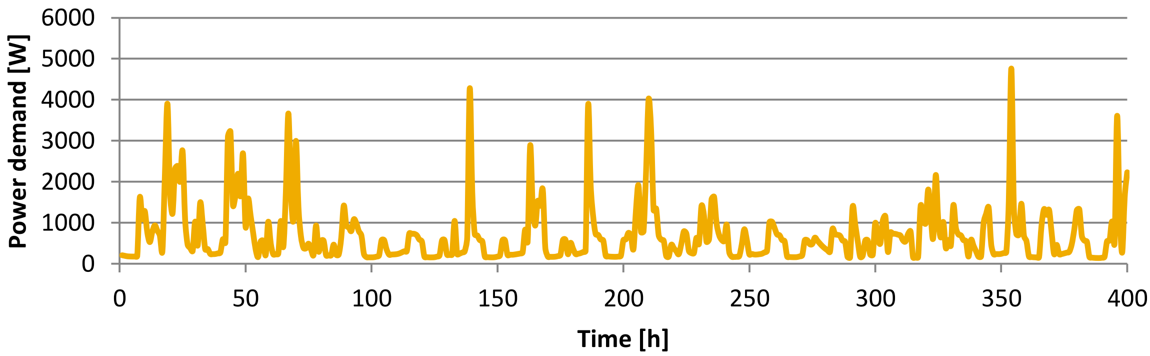


FIGURE 24: SAMPLE OF A LOAD PROFILE THROUGH SOFTWARE CALCULATION FOR AN AVERAGE 4 PERSONS DWELLING

The figures and numbers presented are calculation from 100 samples for each of the scenarios due to the fact that the load profile calculation is based on probability and statistics and thus can slightly change from one to another. They illustrate the share of electricity consumption per final use, the average overall electricity consumption are presented and the spread minimum and maximum electricity consumption.

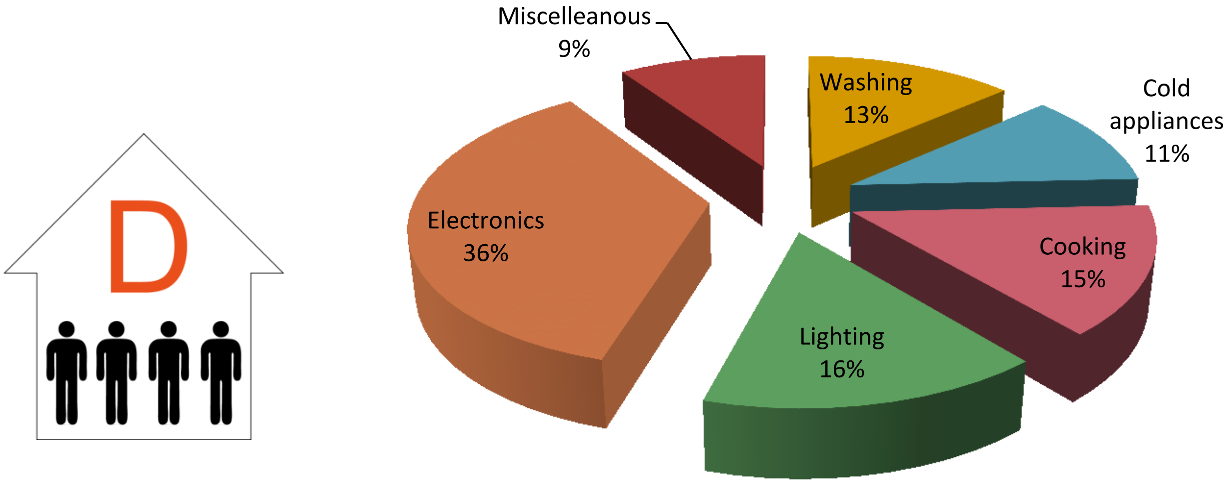


FIGURE 25: FINAL ELECTRICITY USE FOR AN AVERAGE FOUR PERSONS DWELLING

TABLE 9: THE AVERAGE FOUR PERSONS DWELLING

Average electricity consumption [kWh]	Minimum electricity consumption [kWh]	Maximum electricity consumption [kWh]
5288	4936	5436

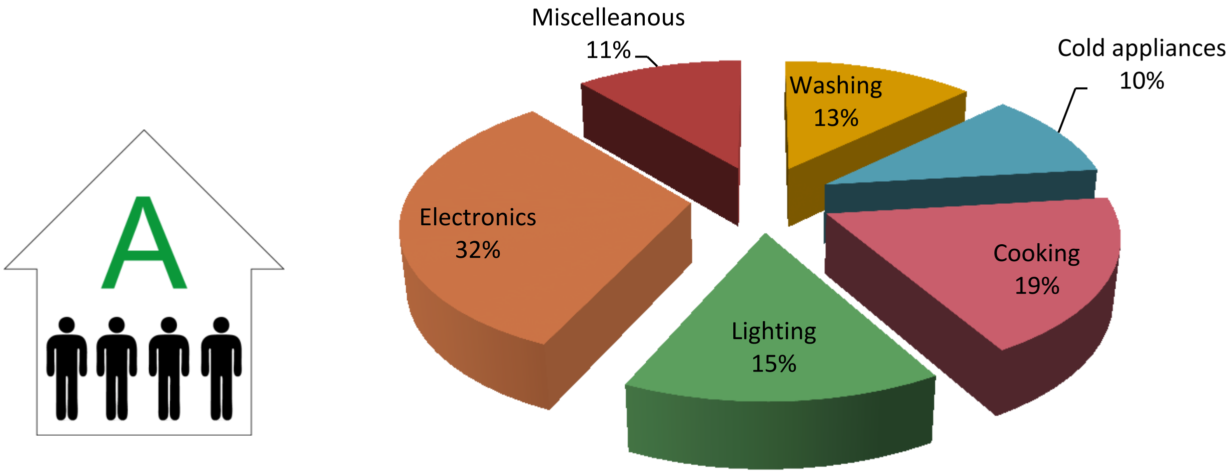


FIGURE 26: FINAL ELECTRICITY USE FOR AN EFFICIENT FOUR PERSONS DWELLING

TABLE 10: THE EFFICIENT FOUR PERSONS DWELLING

Average electricity consumption [kWh]	Minimum electricity consumption [kWh]	Maximum electricity consumption [kWh]
3957	3555	4108

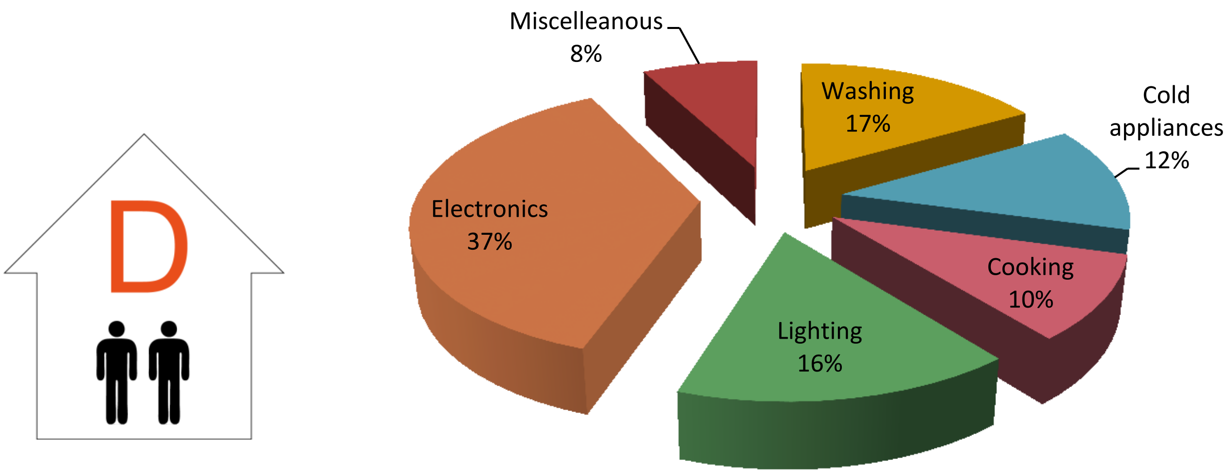


FIGURE 27: FINAL ELECTRICITY USE FOR AN AVERAGE TWO PERSONS DWELLING

TABLE 11: THE AVERAGE TWO PERSONS DWELLING

Average electricity consumption [kWh]	Minimum electricity consumption [kWh]	Maximum electricity consumption [kWh]
3840	3636	4013

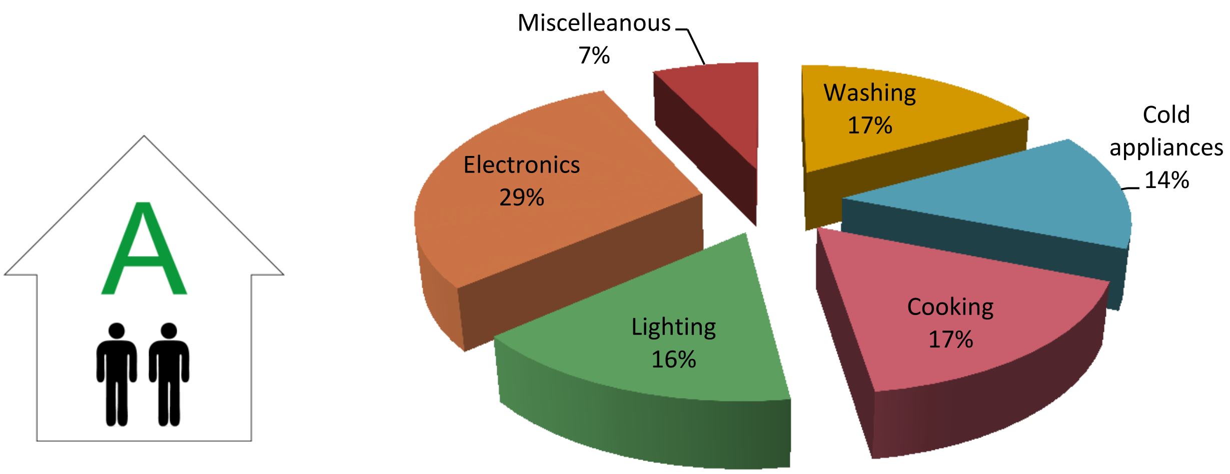


FIGURE 28: FINAL ELECTRICITY USE FOR AN EFFICIENT TWO PERSONS DWELLING

TABLE 12: THE EFFICIENT TWO PERSONS DWELLING

Average electricity consumption [kWh]	Minimum electricity consumption [kWh]	Maximum electricity consumption [kWh]
2812	2660	2896

4.3 CONCLUSION

By observing these figures (Figure 25, Figure 26, Figure 27 and Figure 28), it appears that the overall consumption for the two types and two sizes of dwellings fits the figures presented in Table 4. However, the share in the final use, illustrated by Figure 21, appears to be different for some categories. This is mostly the case for cold appliances, cooking and washing. For cold appliances, the original figure (18 per cent) seems overestimated compared with the ownership level of cold appliances in Danish dwelling and their respective power consumptions (ELMODEL-bolig s.d.). This fact can also be enlarged by underestimating the behaviour impacts on the overall consumption. The cooking and washing categories are highly influenced by the users' behaviours thus there could have a difference of behaviour between the set of users chosen for Figure 21 and the users that answered the questionnaire from Elmodel-bolig (ELMODEL-bolig s.d.). In general, the calculation method of the software can also have an impact on the final consumption of some categories.

Despite these slight differences, the figures are considered to be relevant for the next calculations in relation with electricity generation presented in the next section. Most of the figures in the analysis section will be related to the average 4 persons dwelling or to the efficient 2 persons dwelling because of the fact that they represent the most extreme cases.

5 ANALYSIS

In order to provide a complete answer to the research question, different scenarios have been decided. Different scenarios related to energy consumption as presented in the previous section with dwellings of 2 and 4 persons and also different scenarios related to energy production as it is going to be developed in this section.

Energy systems can be divided into three different types:

- Adaptable; it is an energy system which is able to provide the amount of energy required to fit the demand without any other constraints than fuel. This is the case of electricity generator.
- Fluctuating; an energy system that is dependent from external resources (wind, sun, water flow, etc.). This is the case of wind turbines and photovoltaic panel.
- Storage; a storage system is not a mean of production by itself and just serves to shift the surplus of production to another time. It can be represented by an electric vehicle or per a simple battery.

Using this, three different scenarios are extracted as illustrated by Figure 29. The first scenario assumes that only an adaptable energy system is used, the second one only fluctuating energy systems and the third one a combination of both. For each of the two last scenarios, the addition of a storage system will also be discussed. Each result presented is based on 100 samples for the reason explained previously (Results page 34).

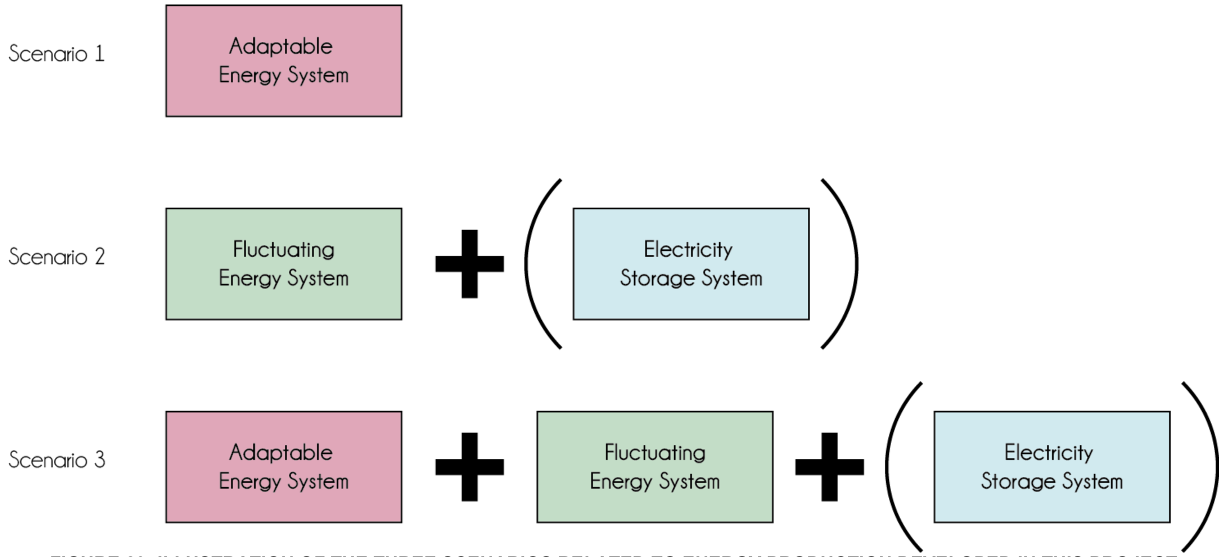


FIGURE 29: ILLUSTRATION OF THE THREE SCENARIOS RELATED TO ENERGY PRODUCTION DEVELOPED IN THIS PROJECT

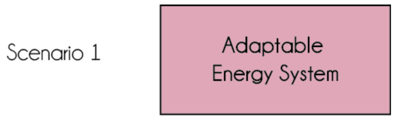
It is important to notice that an energy system should be considered as a virtual energy system that can gather several different means of production of the same type such as a wind turbine in addition to photovoltaic panel for a fluctuating energy system.

5.1 THE STORAGE SYSTEM

The storage system is considered to be represented by an electric vehicle. The common capacity for an electric vehicle is around 20 kWh. This project is based on data from the Nissan Leaf[1]. Hence, the capacity installed chosen is equal to 24 kWh and 8 hours are required to fully charge it, which corresponds to an average charging power of 3,000 W whereas the discharge is set to 8,000 W. It means that when there is a surplus of electricity production the electric vehicle can be charged at its maximum with 3,000 W per hour while when there is an electricity demand from the dwelling the electricity vehicle can supply at its maximum 8,000 W per hour. It is considered that when the vehicle is used, there is 25 per cent battery depletion. However, it is assumed an access to interim charging infrastructure in parking lots thus only 12.5 per cent charge is needed at home. The vehicle is assumed to be plugged to the dwelling from 18:00 to 7:00 the day after. An efficiency of 90 per cent is set in charge and discharge.

[1] http://www.nissan.dk/

5.2 Scenario 1



The focus is only done on an energy system composed by an adaptable energy system. In fact, this scenario does not include a storage system due to the low interest to add such a system when there is an energy system able to adapt to the demand. However, it can be considered as an asset to have a storage system in order to cover the peaks demand and thus, limiting the capacity required by the energy system but it is not discussed in this report. There are different types of adaptable energy system that can be suitable to supply electricity to a dwelling such as diesel generator and micro CHP. However, the type of technology is not considered relevant in this project due to the exact similarity of the electricity output between technologies, thus only the general term "adaptable energy system" will be used in this report.

According to these facts, the capacity required for an adaptable system in stand-alone is equal to the maximum power demand of the dwelling during the year. Figure 30 and Figure 31 illustrates the result for the two sizes of dwelling chosen in this report. The mean gap between average and efficient dwellings is for a 4 persons dwelling around 1,100 Watt, with an average value respectively for the two categories around 6,300 and 5,150 Watt. The similar results are extracted from the calculation on the 2 persons dwelling as illustrated by Figure 31.

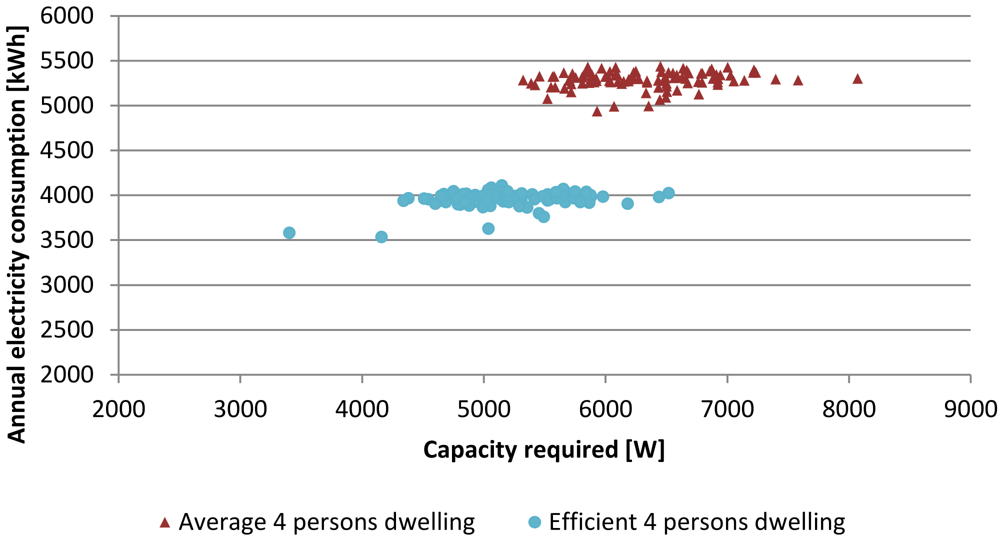


FIGURE 30: CAPACITY REQUIRED FOR AN ADAPTABLE ENERGY SYSTEM TO COVER THE ANNUAL ELECTRICITY CONSUMPTION FROM RESPECTIVELY AN AVERAGE AND AN EFFICIENT 4 PERSON'S DWELLING

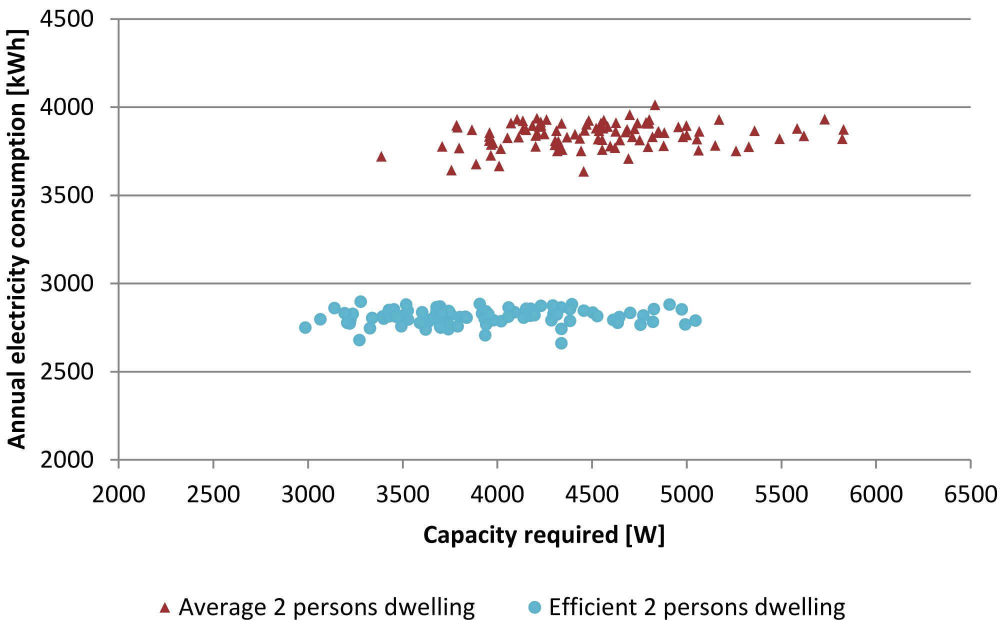
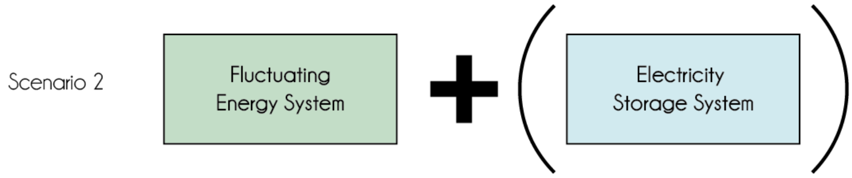


FIGURE 31: CAPACITY REQUIRED FOR AN ADAPTABLE ENERGY SYSTEM ACCORDING SYSTEM TO COVER THE ANNUAL ELECTRICITY CONSUMPTION FROM RESPECTIVELY AN AVERAGE AND AN EFFICIENT 2 PERSON'S DWELLING

- CONCLUSION SCENARIO 1

This scenario allows showing the advantages of an efficient dwelling compared to an average one. The reduction of the overall consumption allow decreasing the fuel consumption and the choice of efficient electrical devices allow reducing the value of the power demand peaks which results in a lower capacity required.

5.3 SCENARIO 2



Renewable energies have an important role in the energy mix in Denmark. In this project, the calculation will be based only on wind turbines and photovoltaic (PV) panels which are assumed to be the most available fluctuating renewable sources in Denmark. According to Technology Data for Energy plants from the Danish Energy Agency (Danish Energy Agency 2012), the wind turbines capacity installed in households is mostly between 5 and 25 kW and PV capacity is between 1 and 4 kW which corresponds to an area from 8 to 32 m². In this scenario, the capacity installed will not exceed respectively 25 and 4 kW. The distribution used for the wind turbines is adapted from the wind turbines production in west Denmark in 2010 (Energinet 2010). The solar radiation distribution is extracted from EnergyPLAN it is called: "DK-solar-02.txt". EnergyPLAN is an energy modelling software developed by Henrik Lund from Aalborg University (http://energy.plan.aau.dk/).

Figure 32 and Figure 33 presents the result obtained for three different systems for an average 4 persons dwelling and an efficient 2 persons dwelling. These figures provide the orders of magnitude of the efficiency of the three chosen systems for covering electricity demand. An energy system based on a 25 kW wind turbine can meet the electricity demand from an average 4 persons dwelling 92 per cent of the time, and 96 per cent of the time for an efficient 2 persons dwelling. With a 5 kW wind turbine, it meets the demand respectively 69 and 81 per cent of the time whereas it reaches only 25 and 32 per cent with a 4 kW PV panel.

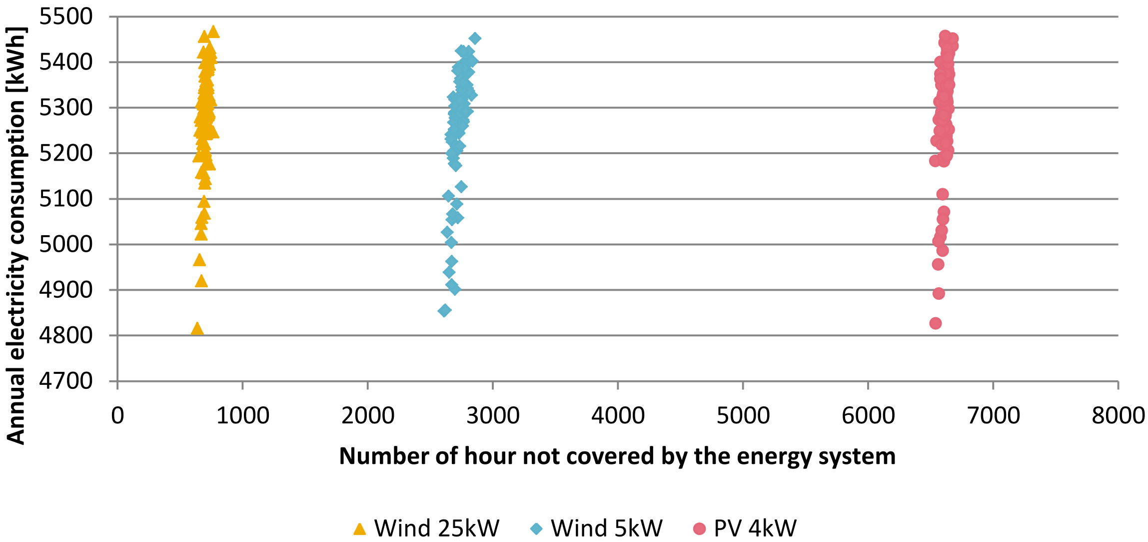


FIGURE 32: NUMBER OF HOUR NOT COVERED ACCORDING TO THE ANNUAL ELECTRICITY CONSUMPTION FOR THREE ENERGY SYSTEMS FOR AN AVERAGE 4 PERSONS DWELLING

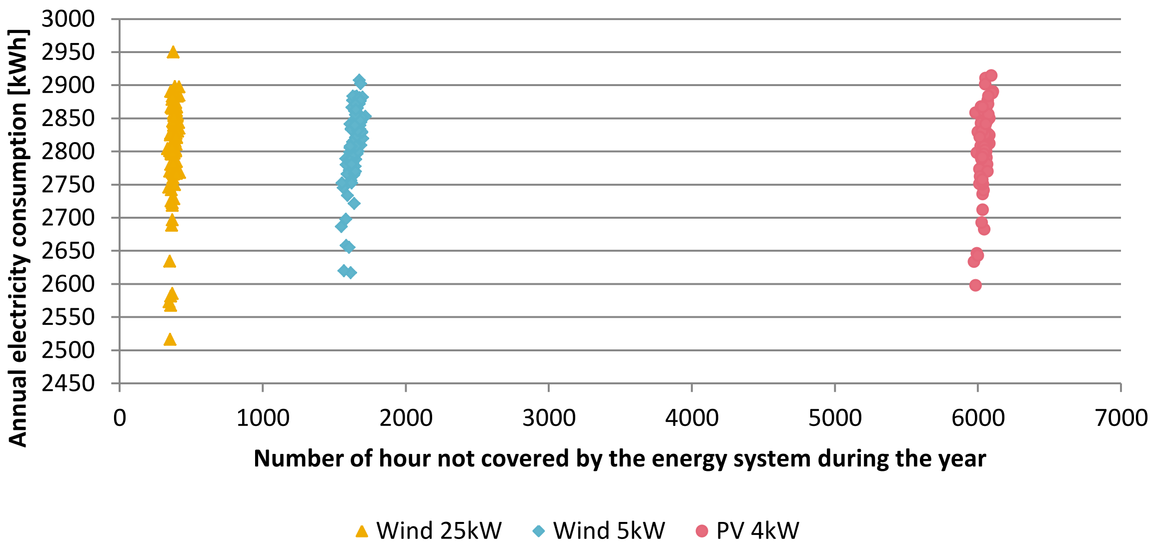


FIGURE 33: NUMBER OF HOUR NOT COVERED ACCORDING TO THE ANNUAL ELECTRICITY CONSUMPTION FOR THREE ENERGY SYSTEMS FOR AN EFFICIENT 2 PERSONS DWELLING

These results can be explained by an insufficient overall electricity production or too high fluctuations. According to Table 13, the overall electricity production from both wind turbines are more than sufficient to cover the annual demand of an average 4 persons dwelling thus the problem should be mostly based on the fluctuations of the production. Although, the PV panel is only able to cover the electricity demand from an efficient 2 persons dwelling which can explained the results obtained.

TABLE 13: ANNUAL ELECTRICITY PRODUCTION FOR THE THREE FLUCTUATING ENERGY SYSTEM USED IN FIGURE 32 AND FIGURE 33

Energy system	25 kW Wind turbine	5 kW Wind turbine	4 kW PV
Annual electricity production [kWh]	54750	10950	2950

a) Research of performance

The fact that there is a large surplus of electricity and thus that the capacity installed can be considered as oversized is discussed later in this section and in the cost comparison (page 48). However, based on a performance point of view, and thus to get closer to an energy system able to meet the demand over a year, three new energy systems are designed:

1. 25 kW wind turbine plus a 4 kW PV panel,
2. 25 kW wind turbine plus a storage system, and
3. 25 kW turbine plus a 4 kW PV panel plus a storage system.

After analysis of the result illustrated by Figure 34 and Figure 35, it appears that the addition of either a 4 kW PV panel either a storage system conduct to a sensible gain in meeting the demand. In fact, from a 92 per cent with a 25 kW wind turbine, it attains now respectively 94 per cent and 95.5 per cent electricity cover for an average 4 persons dwelling (Figure 34). While the energy system composed by a 25 kW wind turbine, a 4kW PV and storage, allows covering the electricity demand more than 97 per cent of the time. Similar results are extracted from the calculation on an efficient 2 persons dwelling as seen in Figure 35, with even a smaller difference between the two energy systems including either a 4 kW PV panel or a storage.

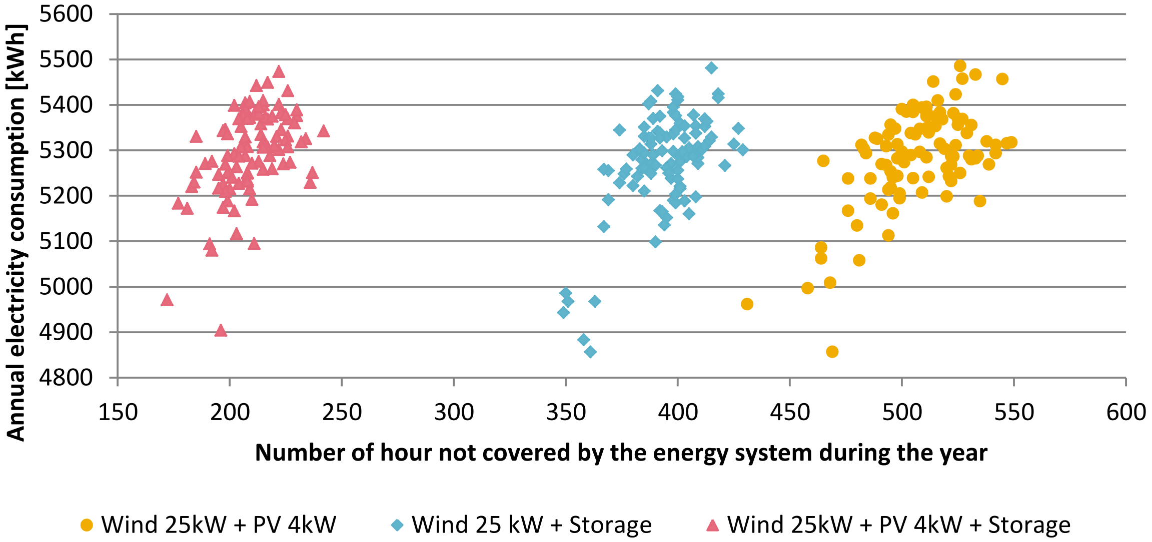


FIGURE 34: NUMBER OF HOUR NOT COVERED ACCORDING TO THE ANNUAL ELECTRICITY CONSUMPTION FOR THREE COMPOSED ENERGY SYSTEMS FOR AN AVERAGE 4 PERSONS DWELLING

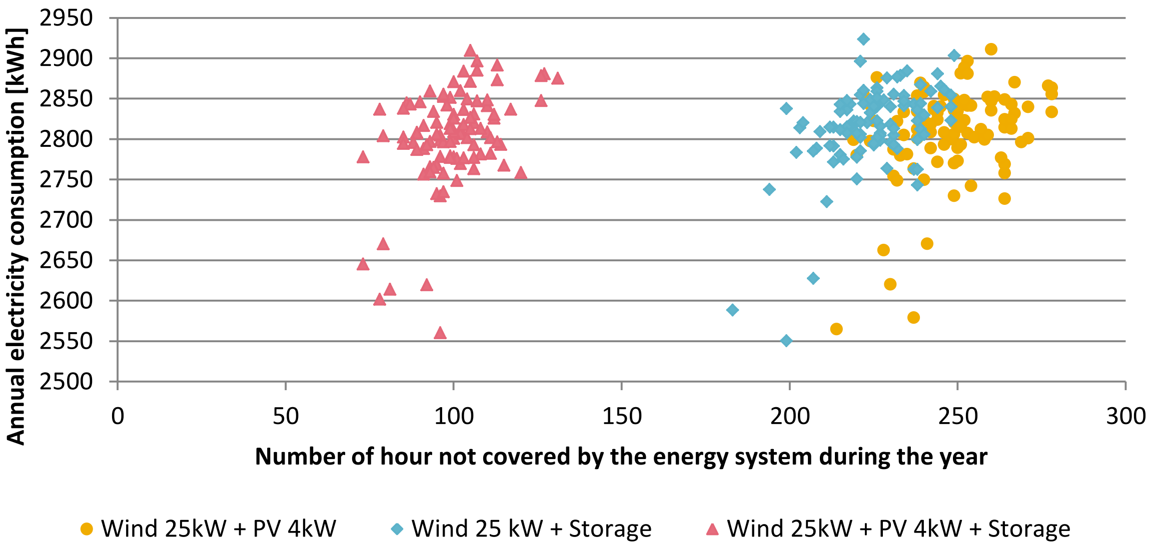


FIGURE 35: NUMBER OF HOUR NOT COVERED ACCORDING TO THE ANNUAL ELECTRICITY CONSUMPTION FOR THREE COMPOSED ENERGY SYSTEMS FOR AN EFFICIENT 2 PERSONS DWELLING

Other combinations, than the ones illustrated in the previous figures, have been designed but none of them has reaches better result. However, some interesting observations have been extracted. It appears that the combination of a 5 kW wind turbine in association with a storage system, compared to a 5 kW wind turbine alone, conducts to an improvement of more than 39 per cent in the number of hours covered for the different targets. It shows that this combination can be a good start in order to supply more than 80 per cent of the time the electricity demand and the need for an electric vehicle according to the parameters developed in the *The storage system* section. This observations is not regained with the 4 kW PV panel due to its incapacity to charge the storage system most of the time because of an electricity demand, most of the time, inferior to the demand.

b) THE SIZE OF THE OVERALL ENERGY SYSTEM

From a capacity installed point of view, the choice of wind turbines of 25 kW and PV panels of 4 kW can be largely discussed. Figure 36 presents the evolution of the amount of electricity consumed per an average 4 persons dwelling according to the capacity installed of two fluctuating energy systems: a wind turbine and PV panel. It appears that the capacity of a wind turbine is quickly oversized, and consequently a large amount of the electricity produced is not used. The same kind of curve is observed for the PV panel.

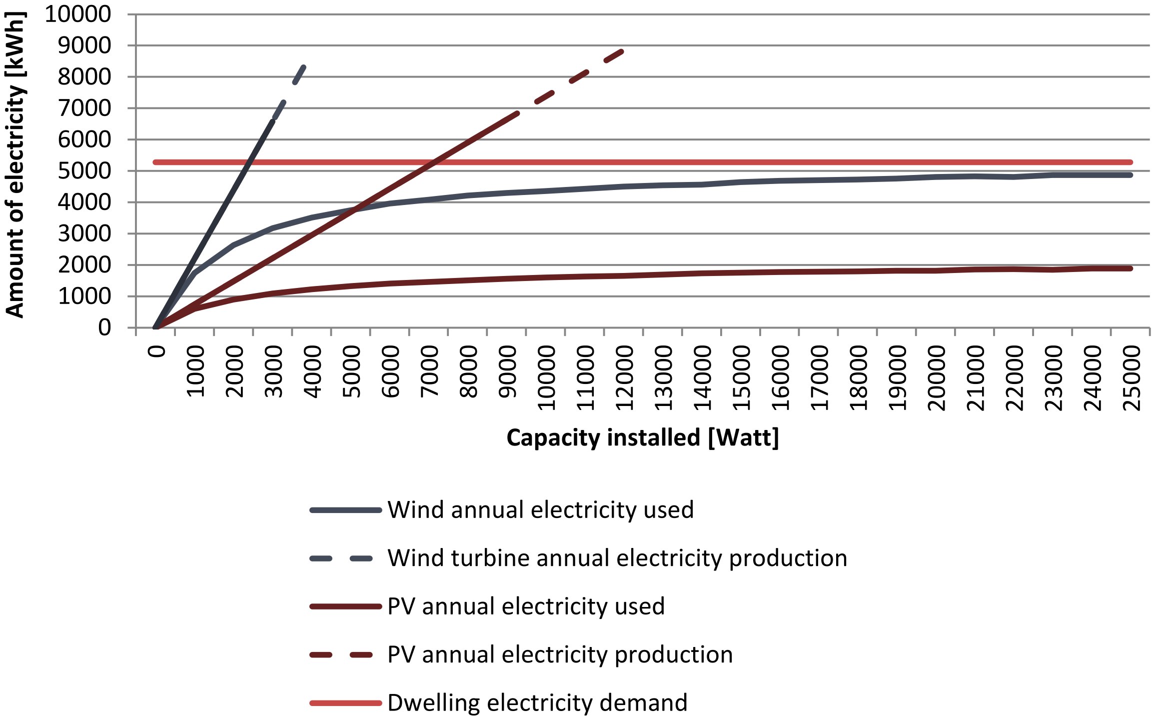


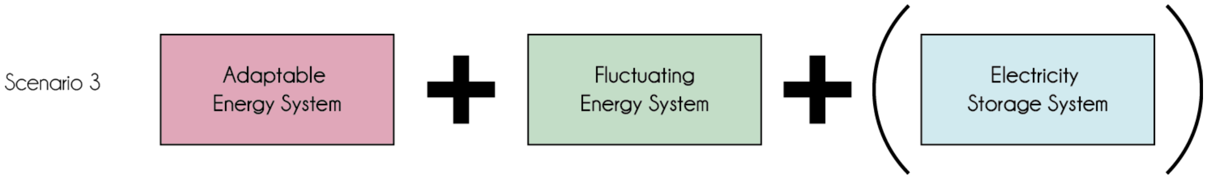
FIGURE 36: COMPARISON OF THE ELECTRICITY PRODUCTION AND THE ELECTRICITY ACTUALLY USED FOR WIND TURBINE AND PV PANEL FOR AN AVERAGE 4 PERSONS DWELLING

The technical consequences should be taken into consideration when such systems are designed. For a dwelling connected to grid, the problem can be resolved by sending the electricity surplus to the grid. However, in the case of this project, a dwelling off the grid, the surplus of electricity is just lost when the storage system is already charged at its maximum.

- CONCLUSION SCENARIO 2

From the study of the results of this scenario, it appears that the combination of different energy system provides the optimal result for meeting the electricity demand at every hour. However, there is still some hours where the electricity demand is not covered due to factors such as no storage system available, not enough wind or not enough sun. And these fluctuations of availability conduct to an uncertainty in the electricity production and thus in covering the demand. In a same way than for national energy systems, the energy system for a single dwelling should be as diverse as possible when based on fluctuating energy sources in order to overcome the uncertainty of the electricity production from one source or another. The second issue enlighten by this scenario is the annual electricity production that can quickly take large proportion compared to the demand in the case there is a purpose to meet the demand using only fluctuating energy system. In order to try to cover these issues scenario 3 has been developed as well as the Cost comparison between energy systems (page 48).

5.4 SCENARIO 3



The scenario 3 is a mix of scenario 1 and 2; it proposes a combination of adaptable and fluctuating energy systems. These new energy systems are based on the observations of the two first scenarios and the strengths and weaknesses of the energy systems previously designed. The electricity demand of the dwelling will be always entirely covered due to the presence of an adaptable energy system. Thereby, the ratio between electricity production and electricity demand and the utility to have a storage system are the points that will be essentially observed.

The first energy system presented in this section is trying to minimize the electricity production from the adaptable energy system. Hence, it is based on a 25 kW wind turbine and a 4 kW PV panel concerning the fluctuating energy systems and an adaptable energy system. In this case, the entire electricity demand can be covered at any time of the year if the capacity installed of the adaptable energy system is sufficient to cover the peak demand. According to Figure 37 Figure 38, it corresponds in average of a capacity over 4,600 W for an average 4 persons dwelling and 2,500 W for an efficient 2 persons dwelling. The electricity production of the adaptable energy system accounts for 6 per cent of the overall consumption or 300 kWh in the most demanding case. With the addition of a storage system, the capacity installed required is similar than without but the electricity production from the adaptable energy system is divided by two.

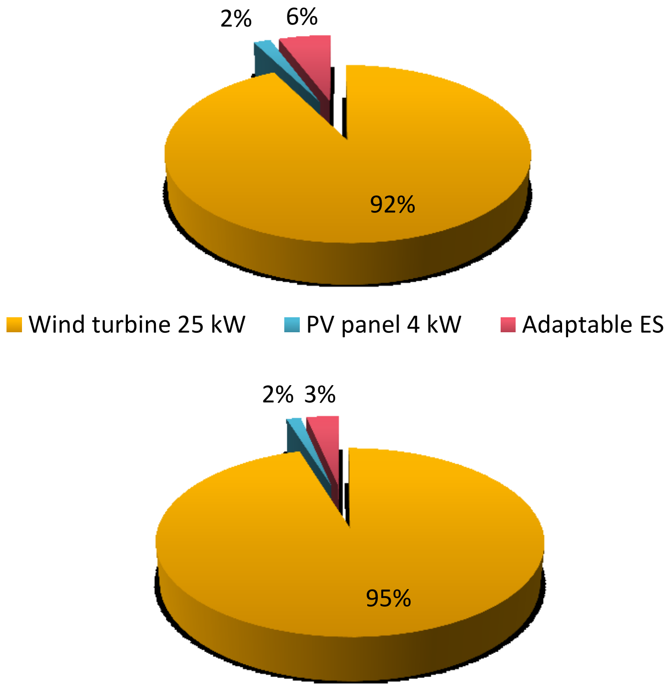


FIGURE 37: AVERAGE SHARE OF THE DIFFERENT ENERGY SYSTEM IN THE ELECTRICITY CONSUMPTION OF AN AVERAGE 4 PERSONS DWELLING AND AN EFFICIENT 2 PERSONS DWELLING

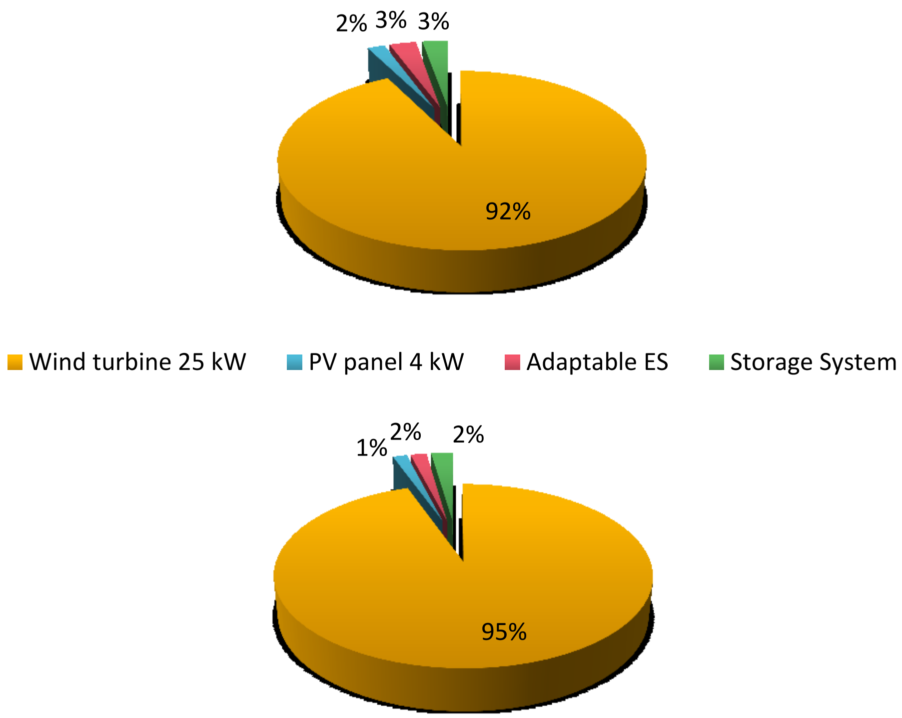


FIGURE 38: AVERAGE SHARE OF THE DIFFERENT ENERGY SYSTEM INCLUDING A STORAGE SYSTEM IN THE ELECTRICITY CONSUMPTION OF AN AVERAGE 4 PERSONS DWELLING AND AN EFFICIENT 2 PERSONS DWELLING

The capacity required for adaptable energy system remains respectively around 4,500 Watt for an average 4 persons dwelling and 2,500 Watt for an efficient 2 persons dwelling, and this regardless the increase of the capacity installed in the fluctuating energy systems. The reason for this is the need over a year to have a system able to cover the peak demand when there is no wind or no solar radiation. It explains the fact that the only visible impact is on the annual electricity production that is decreasing with the increase of the capacity installed from fluctuating energy system as seen in Figure 39. From the same figure, it is shown that the curves representing the consumed electricity production from wind turbines and from the optimal combination of fluctuating energy systems are following the same path. It is only going slightly above the wind turbine curve when the capacity installed is around 10 kW. It means that, for instance, better results will probably be achieved by installing a 3 kW wind turbine than a 2 kW wind turbine plus a 1 kW PV panel. This can be explained by the fact that, in the distribution used there is almost always a superior wind production than a PV panel pro

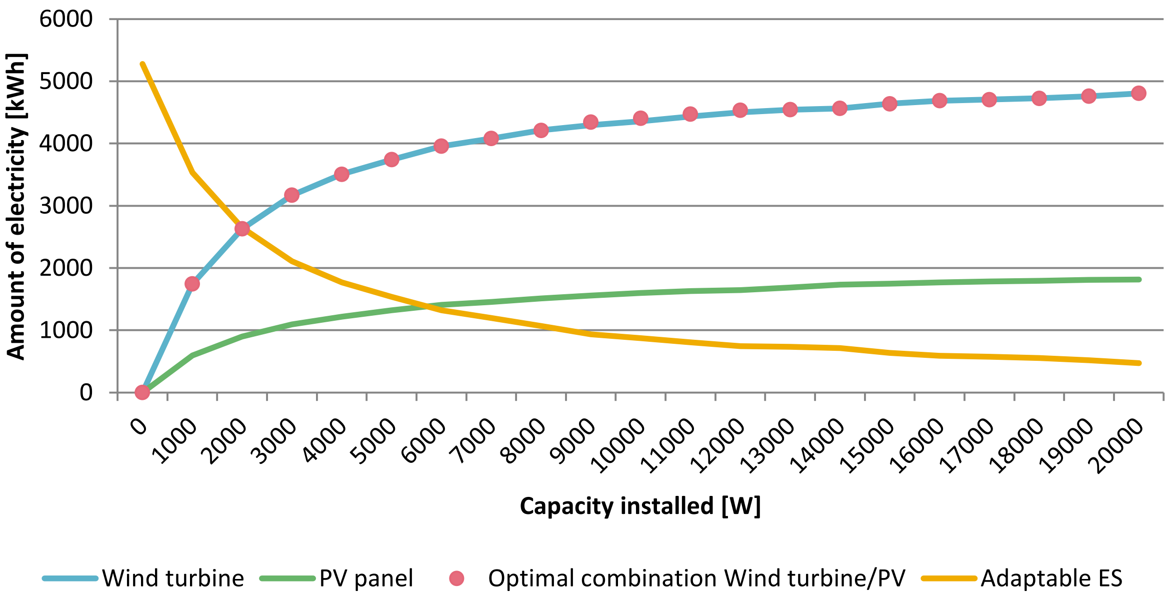


FIGURE 39: EVOLUTION OF THE USED ELECTRICITY PRODUCTION FOR DIFFERENT ENERGY SYSTEM ACCORDING TO THE CAPACITY OF FLUCTUATING ENERGY SYSTEM FOR AN AVERAGE 4 PERSONS DWELLING

- CONCLUSION SCENARIO 3

Through this section, it has been shown that being isolated from the grid is technically possible by being equipped of an energy system composed by adaptable and fluctuating energy systems. This type of mix allows decreasing the use of adaptable energy systems, thereby they can be quickly considered as security systems while the capacity of fluctuating energy systems increase as seen in Figure 39. As explained in the section: The size of the overall energy system (page 43), the ratio between annual electricity production used and annual electricity production can become really low with the increase of the capacity installed. Therefore, it is important to include economic considerations in the discussion in order to evaluate the viability of such project. The next section presents a cost comparison of the energy systems considered relevant after these three scenarios.

6 COST COMPARISON BETWEEN ENERGY SYSTEMS

In this section, only adaptable energy system and wind turbine are considered due to the fact that according to Figure 39, the PV panel should not be prioritized from a technical point of view. Moreover the storage system is not included in this cost comparison due to the fact it is considered to be an electric vehicle, and thus its first function is transportation and not electricity supply. Regarding the adaptable energy system, it is considered to be a diesel electricity generator. Its capacity is depending of the type of dwelling. Regarding wind turbine, due to high investment cost for turbine with capacity inferior to 5 kW, they are not considered in this report. The different technical and economic parameters related to each of the technology used are presented in Table 14. The regulation and conversion devices required are assumed to be included in the investment cost of the wind turbine and diesel generator.

TABLE 14: TECHNICAL AND ECONOMIC PARAMETERS FOR WIND TURBINE AND DIESEL GENERATOR (ALLIANCE FOR RURAL ELECTRIFICATION (ARE) S.D.) (DANISH ENERGY AGENCY 2012)

Technology	Wind turbine	Diesel generator
Capacity [kW]	5-25	N/A
Lifetime	20 yr.	25,000 h
Efficiency [%]	N/A	33
Investment cost [€/W]	2.15	0.28
O&M [€/kWh]	0	0.7
Fuel price [€/l]	N/A	1.579

The fact that the lifetime of each technology is not the same and in order to compare the different system according to the actual electricity production used, it has been decided to use the Levelized Cost of Electricity (LCOE) for each technology. "[LCOE] is in effect, the average cost of every unit of energy produced by a generator across its entire lifetime, brought back to the value of that unit of energy determined at the time of the analysis" (Nishikawa, Horne et Melia 2008).

It can be defined as:

$$\mathbf{LCOE} = \frac{Annual\ costs}{Annual\ production} = \frac{\mathrm{NPV1}}{\mathrm{NPV2}}$$

With:

$$\mathrm{NPV1} = [Investment\ cost] + [O\&M\ cost + Fuel\ cost + Environmental\ cost] \times \left[\frac{1-(1+DR)^{-n}}{DR}\right]$$

$$\mathrm{NPV2} = [Annual\ energy\ used] \times \left[\frac{1-(1+DR)^{-n}}{DR}\right]$$

Notes:

- LCOE formula considers a constant production of electricity from year to year
- NPV1 = Net Present Value of total cost [€]
- NPV2 = Net Present Value of total energy produced [kWh]
- DR = Discount Rate [%]; it is assumed a DR of 6 per cent in this project
- n = Lifetime of technology [years]
- Annual energy used corresponds to the amount of electricity used by the dwelling

6.1 LCOE RESULTS FOR SINGLE ENERGY SYSTEM

In this part, the results presented are based on the amount of electricity that can be covered by a single energy system. For the diesel generator, it corresponds to the overall electricity demand whereas for wind turbine, it follows the curves presented in Figure 39.

For the diesel generator, the capacity chosen is based on results from scenario 1 thus:

- For an average 4 persons dwelling; the capacity installed is 8 kW
- For an efficient 4 persons dwelling; the capacity installed is 7 kW
- For an average 2 persons dwelling; the capacity installed is 6 kW
- For an efficient 2 persons dwelling; the capacity installed is 6 kW

It results in Figure 40 that illustrates the LCOE for each of the four cases. The LCOE is higher for the two efficient dwellings, respectively 2 and 4.5 per cent. It can be explained by the fact that the capacity required is similar to the average cases, the duration of use stay the same for all the cases and thus the lifetime is not extended even if the dwelling is more efficient. In order to attain better result, the peaks demand should be even more reduced by the change from average to efficient dwelling and consequently the capacity required could be decreased even if the overall electricity consumption remains stable.

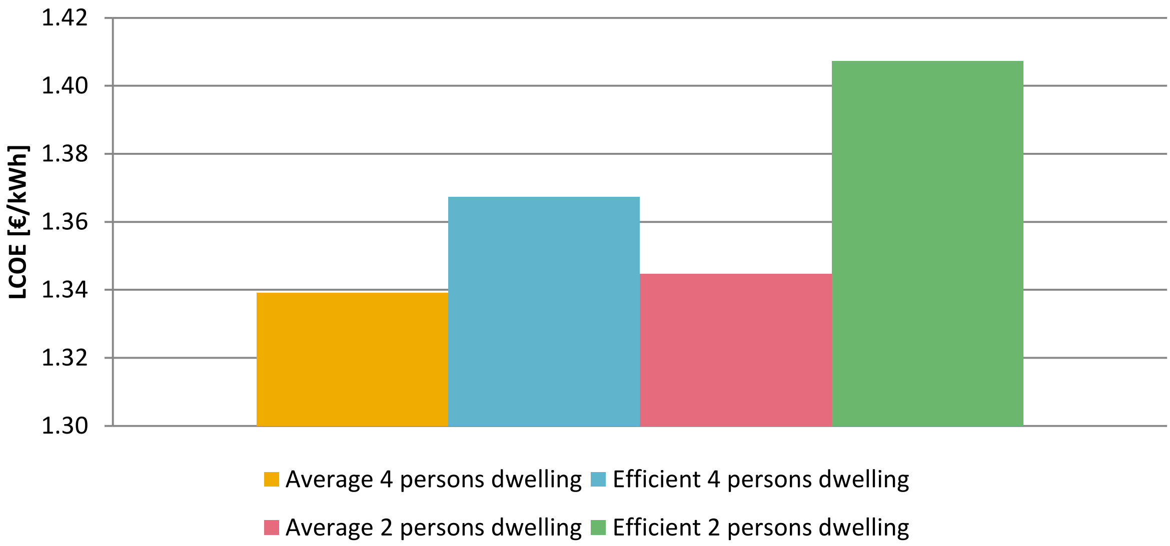


FIGURE 40: LCOE OF A DIESEL GENERATOR FOR THE FOUR TYPE OF DWELLING PRESENTED IN THIS REPORT

About the LCOE for wind turbine, it appears that more the capacity installed increased more the related LCOE increase, as presented in Figure 41. It is simply explained by the fact that the electricity consumption actually used does not increase at the same rate than the capacity installed. Hence, in the same way than for the diesel generator, less the dwelling consumes electricity more the LCOE increases as it can be seen by the gap between the blue and red histograms.

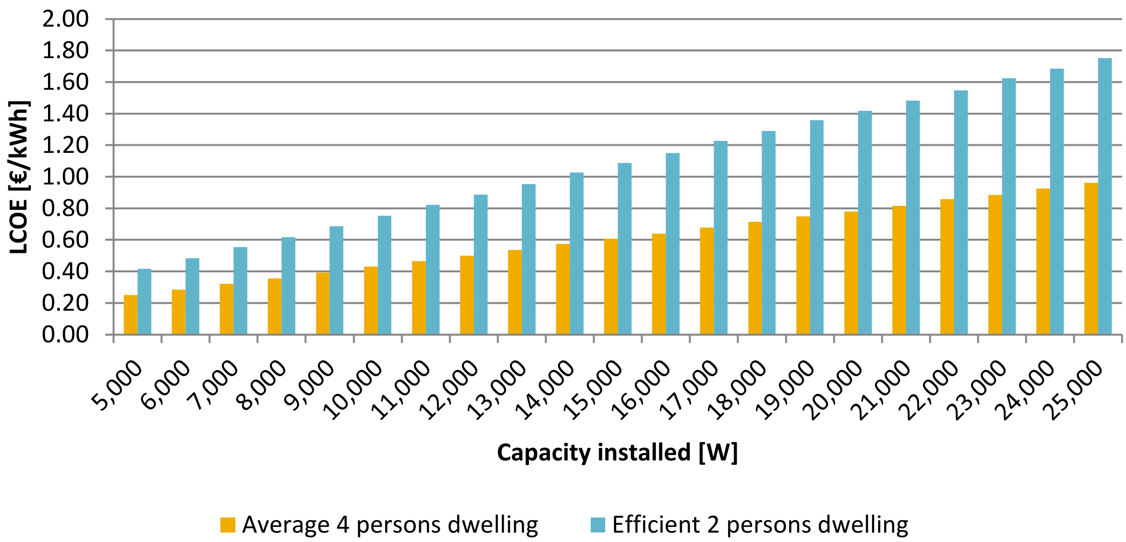


FIGURE 41: EVOLUTION OF THE LCOE FOR WIND TURBINE ACCORDING TO THE CAPACITY INSTALLED

As a conclusion to this part, it appears that only using a diesel generator as an electricity supplier requires an electricity price approximately equal to 1.35 €/kWh in the best case and 1.41 €/kWh in the worst case. For the wind turbine, the LCOE remains lower most of the time, between 0.25 to 1.75 €/kWh, but the overall electricity consumption of the dwelling is not covered and thus additional expenses should be conducted. In order to resolve this problem, a hybrid system combination of a diesel generator and a wind turbine is discussed in the following.

6.2 LCOE RESULTS FOR HYBRID SYSTEMS

The hybrid system is schematized in Figure 42. Notice that the electric vehicle is only included in the second part of this sub-section.

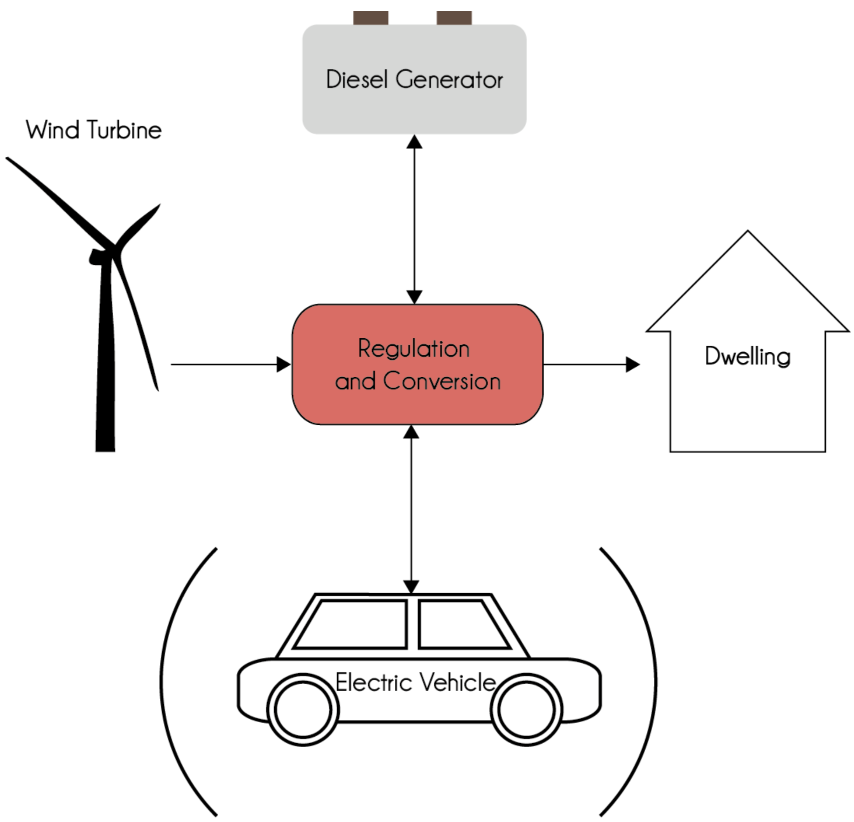


FIGURE 42: SCHEME OF A HYBRID SYSTEM COMPOSED OF WIND TURBINE, DIESEL GENERATOR AND ELECTRIC VEHICLE

The purpose of this system is to minimize the use of the diesel generator because it appears that the LCOE from the diesel generator is higher than the one from wind turbine. Hence, the diesel generator is launched only when it is necessary which allow increasing its lifetime and decrease the amount of fuel used. Figure 43 illustrates the evolution of the LCOE according to the capacity installed of wind power, while the diesel generator capacity remains the same, for an average 4 persons dwelling. It appears that the best results are attained when the wind capacity is the lowest. When the wind power capacity is 6 kW the LCOE is equal to 0.56 €/kWh while it attains 1.01 €/kWh when the capacity is 25 kW.

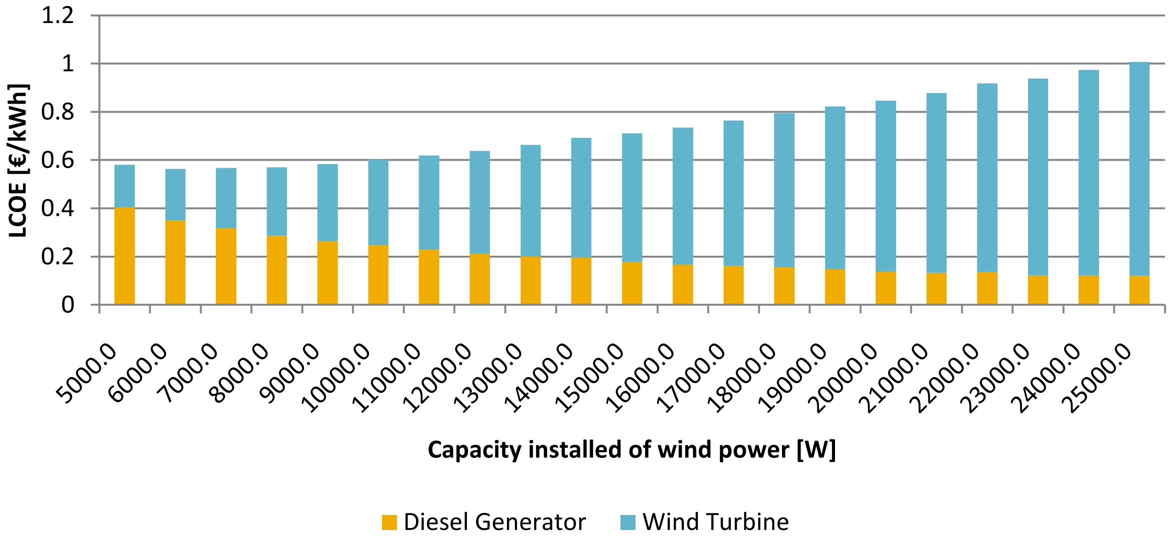


FIGURE 43: WEIGHTED LCOE FOR A HYBRID SYSTEM COMPOSED OF A WIND TURBINE AND A DIESEL GENERATOR FOR AN AVERAGE 4 PERSONS DWELLING

In the same way than with the previous figure, Figure 44 presents the results for an efficient 2 persons dwelling. They follow the same kind of curve but the LCOE starts at 0.63 €/kWh with a 5kW wind turbine and ends at 1.67 €/kWh with a 25 kW wind turbine.

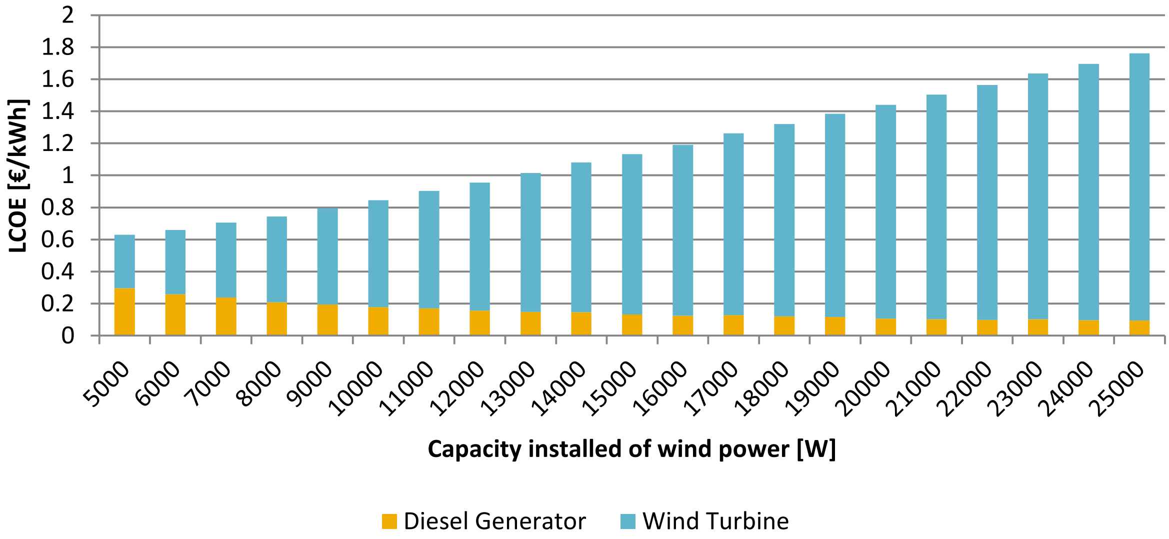


FIGURE 44: WEIGHTED LCOE FOR A HYBRID SYSTEM COMPOSED OF A WIND TURBINE AND A DIESEL GENERATOR FOR AN EFFICIENT 2 PERSONS DWELLING

The study of these two figures allows deducing that the best hybrid system is reached using a 5kW wind turbine in both cases. Moreover, the LCOE can even be lowered by using a larger share of wind electricity compared to diesel generator. Without changing the load profile, the solution to use more wind electricity is to include a storage system in the hybrid system which can shift the wind electricity production. The results obtained for the two cases discussed previously are illustrated by Figure 45 and Figure 46. On one hand for an average 4 persons dwelling, a hybrid system with a 6 kW wind turbine including a storage system allows decreasing the LCOE from 0.56 to 0.43 €/kWh and diesel generator production by 39 per cent. On the other hand, for an efficient 2 persons dwelling with a 5 kW wind turbine, the LCOE drops from 0.63 to 0.52 €/kWh.

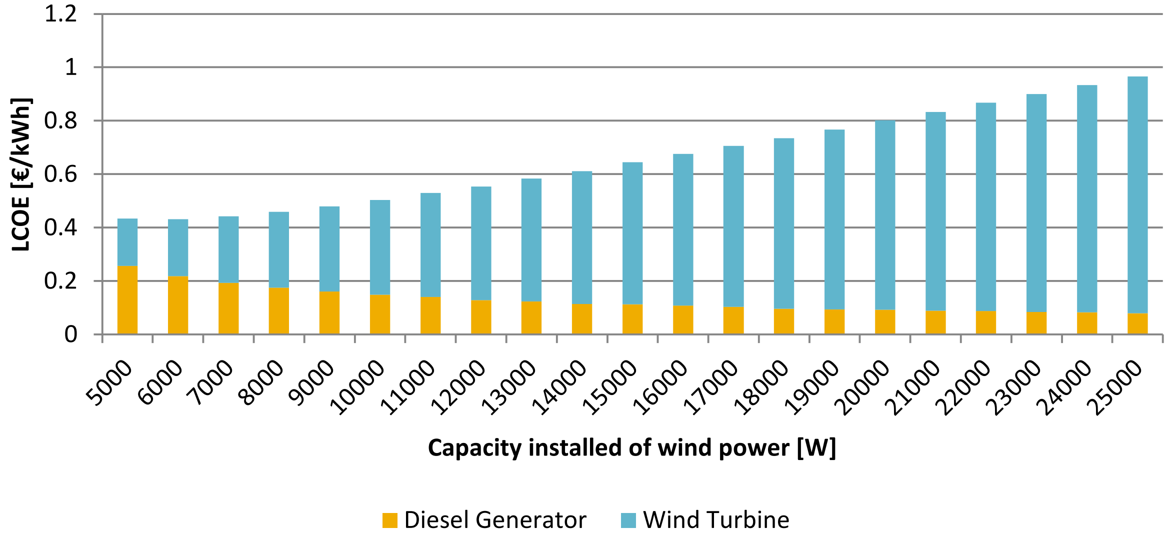


FIGURE 45: WEIGHTED LCOE FOR A HYBRID SYSTEM COMPOSED OF A WIND TURBINE, A DIESEL GENERATOR AND A STORAGE SYSTEM FOR AN AVERAGE 4 PERSONS DWELLING

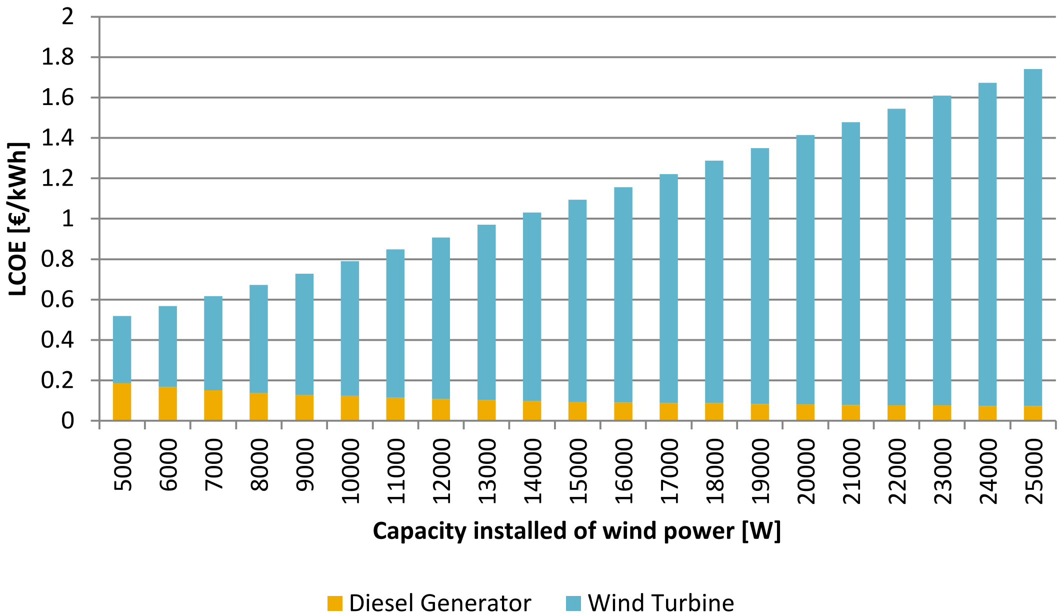


FIGURE 46: WEIGHTED LCOE FOR A HYBRID SYSTEM COMPOSED OF A WIND TURBINE, A DIESEL GENERATOR AND A STORAGE SYSTEM FOR AN EFFICIENT 2 PERSONS DWELLING

6.3 Conclusion of the cost comparison

In conclusion, it appears that the optimal energy system from an economic and technical point of view is for a 4 persons dwelling a diesel generator with a capacity of 8 or 7 kW depending of the peaks demand, a wind turbine of 6 kW and a storage system. The same kind of configuration is also chosen for a 2 persons dwelling but with a 6 kW diesel generator and a 5 kW wind turbine. According to the Europe's Energy Portal, the electricity price in Denmark is 0.3078 €/kWh. Hence with a minimum of

0.43 €/kWh or 0.52 €/kWh depending of the dwelling, from an economic point of view none of the energy system designed in this section can compete with a dwelling already connected to the grid. However, a single isolated dwelling can get closer to the grid electricity grid by using even more electricity produced by the wind turbine and by decreasing the maximum value of the peaks demand. It can be done by adapting the consumption of the dwelling to the production of the wind turbine.

7 Sensitivity analysis

As it could have been noticed, the analysis part is based on different parameters that could have high influences on the final result. In fact, from the design of the different categories of dwelling to the choice of distribution for the fluctuating energy system the data can vary from one dwelling to another and from one location to another. The user practice concerning the electric vehicle can also have strong impacts on the final results. Hence, it is important to discuss these different aspects and their respective impacts in order to have a relevant answer.

7.1 The dwelling load profile

The variation of parameters in the calculation of an annual load profile for dwellings can be observed by a change in the overall electricity demand and/or a change in the maximum power demand. In this report, an average 4 persons dwelling has an average annual electricity consumption of 5,288 kWh and the maximum power demand is spread between 5,326 and 8,073 W. Change in the annual electricity consumption will have impacts on fuel consumption as seen in Scenario 1 and Scenario 3. And change in the maximum power demand of a dwelling can have both impacts on the annual electricity consumption and the capacity required. In fact, if the maximum power demand gets higher two cases can occur. First, there are more risks to have shortage if no adaptable energy systems are installed to balance the electricity production (Scenario 2). Secondly, if an adaptable energy system is present it will probably be used more often to cover the peak demand in addition to the normal cases when there is no production from fluctuating energy system (Scenario 3).

7.2 The influence of distributions

Distributions for both fluctuating energy and storage systems can have large impacts on the outputs and thus on the results obtained. For wind turbines a distribution based on West Denmark data has been used. Although, a distribution based on East Denmark data there is almost a factor 2 concerning the results obtained on an average 4 persons dwelling with a 25 kW wind turbine, as seen in Figure 47. Moreover, these two distributions are based on the wind turbine production of thousands of wind turbine thus the curves are probably more flattened and smooth that it should have been expected.

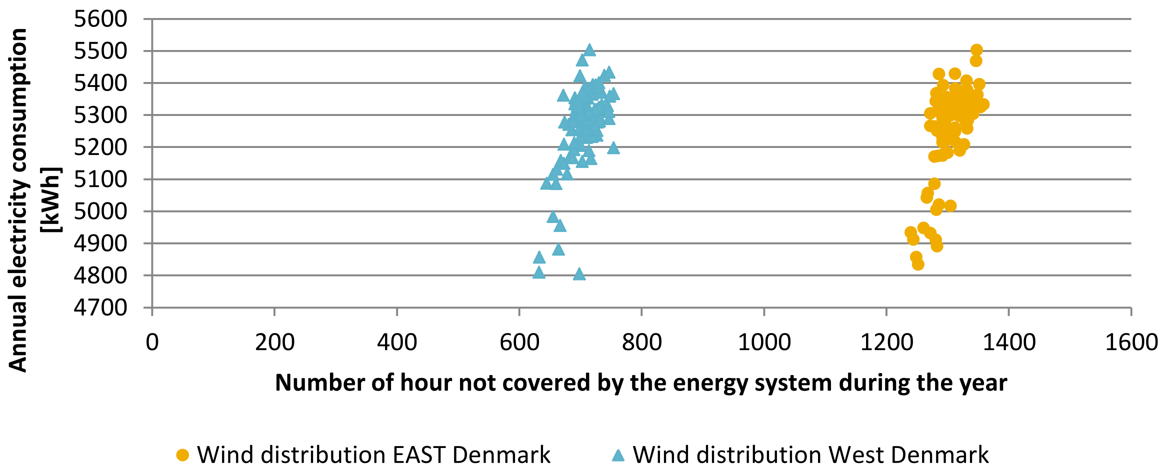


FIGURE 47: COMPARISON OF THE DISTRIBUTION IMPACTS ON A 25 KW WIND TURBINE FOR AN AVERAGE 4 PERSONS DWELLING

In the same way, the change of the distribution regarding the storage system can have similar impacts. Using a case from scenario 2 (25 kW wind turbine + storage system) and considering a storage system always available, it results in an energy system covering, in average, more than 99 per cent of the time the electricity demand from an average 4 persons dwelling and thus being almost independent from the grid, as seen in Figure 48.

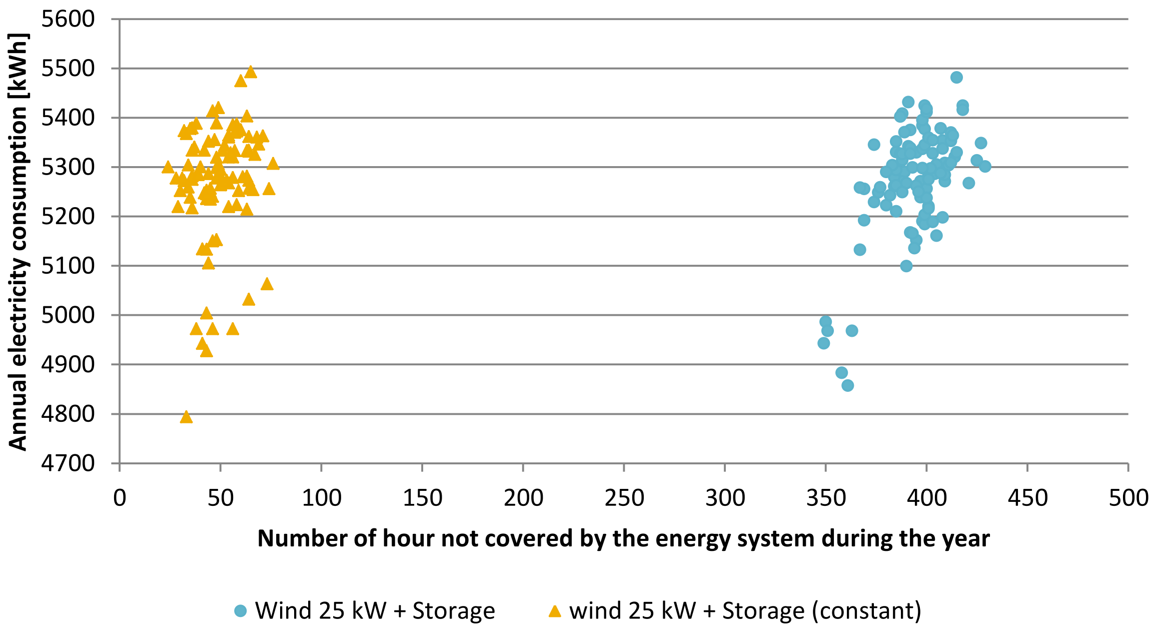


FIGURE 48: COMPARISON OF THE DISTRIBUTION IMPACTS ON A STORAGE SYSTEM FOR AN AVERAGE 4 PERSONS DWELLING

7.3 THE INFLUENCE OF THE DISCOUNT RATE

In this section is discussed the influence of the discount rate on the final results. For a diesel generator, the discount rate has a small influence on the final result as seen in Figure 49. A change of discount rate of 2 per cent results in a 1 per cent change in the LCOE.

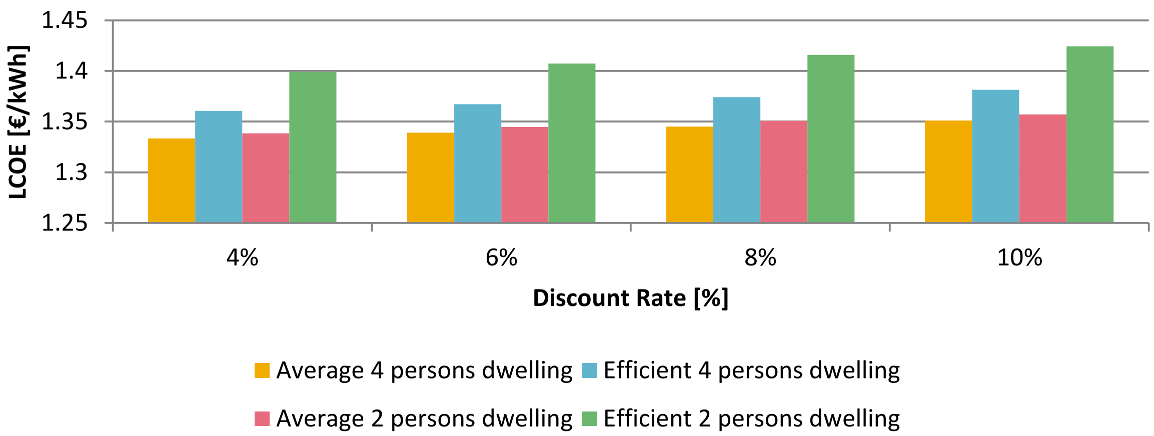


FIGURE 49: LCOE OF A DIESEL GENERATOR FOR THE FOUR TYPE OF DWELLING PRESENTED IN THIS REPORT FOR DIFFERENT DISCOUNT RATE

In the same way than with the diesel generator, the discount rate has a small influence on the LCOE of a hybrid system as illustrated by Figure 50. The final order between LCOE for hybrid systems with different wind power capacity remains unchanged and the figures have the same order of magnitude.

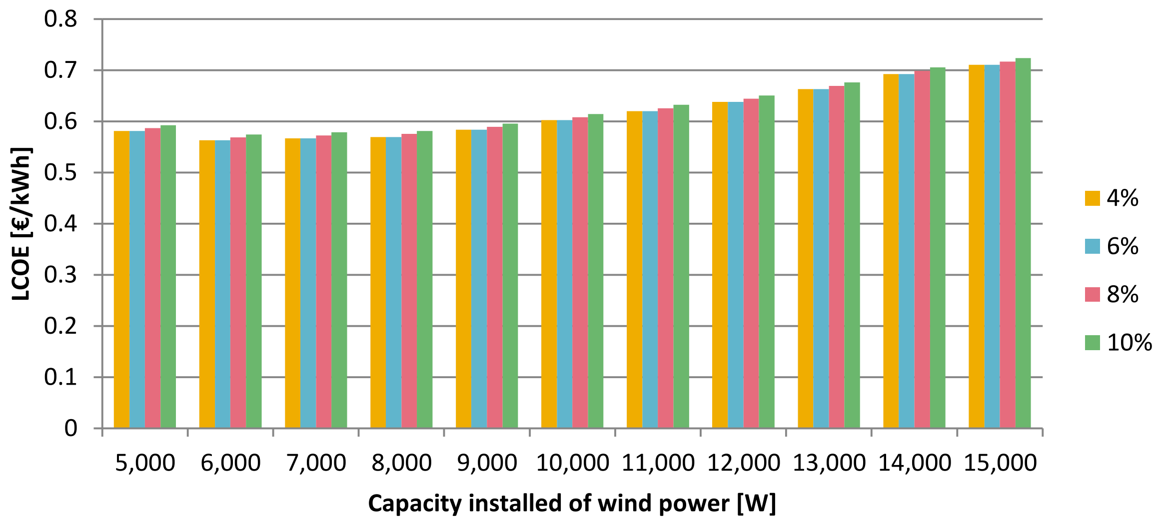


FIGURE 50: WEIGHTED LCOE FOR A HYBRID SYSTEM COMPOSED OF A WIND TURBINE AND A DIESEL GENERATOR FOR AN AVERAGE 4 PERSONS DWELLING FOR DIFFERENT DISCOUNT RATE

7.4 The choice of the adaptable system

In this project, the choice of a diesel generator has been made and the cost comparison shows that it results in a high LCOE compared to the grid electricity price. In the case an adaptable energy system would have supplied electricity at the same cost than the grid; the result would have been similar to Figure 51 . As it can be observed, in the best cases the electricity price (minimum of 0.27 €/kWh) is lowered compared to the grid electricity price (0.3078 €/kWh). Hence, the addition of a wind turbine can have a positive impact on the electricity price even if the dwelling is supplied by an adaptable energy system providing an electricity price equals to the grid.

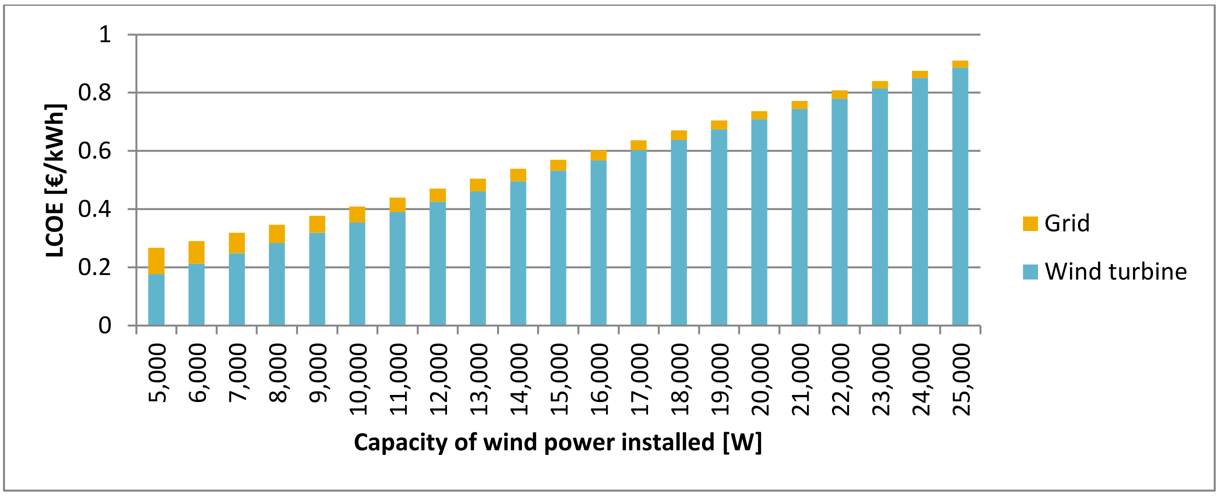


FIGURE 51: WEIGHTED LCOE FOR A HYBRID SYSTEM COMPOSED OF A WIND TURBINE AND AN ADAPTABLE ENERGY SYSTEM PROVIDING AN ELECTRICITY PRICE EQUALS TO THE ONE FROM THE GRID FOR AN AVERAGE 4 PERSONS DWELLING

7.5 Conclusion

In conclusion to this section, the results obtained in this report have to be balanced by the difference of climate condition and user's behaviour. However, as it have been shown in this section the order of magnitude remains the same thus no large changes should be expected in the final result. In a similar way, the cost comparison is slightly influenced by the discount rate chosen.

8 Conclusion

Considering electrical devices, means of production and possible storage installed in a dwelling, is it possible to be completely isolated from the grid according to customers behaviour in demand side management?

As defined in the research question above, this report aims to assess the possibility for a single dwelling to be isolated according to different parameters influencing the electricity demand and production sides.

The first part of the analysis part presents the load profiles calculated for dwellings of 2 and 4 persons with two types of user practice: average or efficient. These calculations show the influence of user practices on the overall electricity consumption; approximately 1,000 kWh can be saved by adopting efficient ones. Larger savings should be difficult to attain due to time commitment or lack of information. For instance delaying a washing machine to avoid a peak demand or to fit the demand with production can be difficult to realize. Hence, it should be done automatically by developing intelligent electronic systems that allow managing the electrical devices and limiting the standby consumption. Demand side management both from change of behaviour and development of intelligent systems can have large impacts of the overall consumption and should be prioritized in order to lower the electricity needs, and consequently decrease the size and costs of the energy system required.

According to the calculated load profiles, it appears that from the different combination of energy systems developed in this report, the technically viable solutions are the hybrid systems based on wind turbine and/or PV panel plus a generator. Depending of the systems chosen and the capacity installed of wind/PV, the role of the generator varies from the main electricity supplier to a simple backup. Without economic considerations it would have been difficult to establish the possibility for a dwelling to be isolated from the grid. Hence, the addition of the cost comparison part allows defining a more detailed answer to this project by providing the cost per unit of electricity consumed for different hybrid energy systems. The hybrid system composed of a diesel generator, a wind turbine and a storage system appeared to be the most appropriate in order to supply electricity to an isolated dwelling from a technical and economic point of view. Their respective capacity is chosen in order to minimize the LCOE and to respect the electricity demand from the dwelling. However, with a LCOE spread between 0.43 and 0.52 €/kWh in the best cases it is far from the 0.3078 €/kWh when the dwelling is connected to the grid. Hence, being isolated from the grid is mostly a choice if it is assumed that being connected to the grid is free of charge. Nevertheless, it is possible to decrease the LCOE calculated in this project and probably get closer to the grid price. The first solution would be to use even more electricity produced by the wind turbine and by decreasing the maximum value of the peaks demand in order to limit the use and the size of the diesel generator. It can be done by adapting the consumption of the dwelling to the production of the wind turbine using intelligent electronic system that can influence the functioning of electrical devices of the dwelling. The second solution would be to find a use of the surplus of electricity from wind power such as the addition of an electric boiler with a large tank than can supply heat water and heating to the dwelling. The surplus of electricity is used in order to produce heat that can be stored into the tank and used afterwards. These propositions of solution should be precisely analysed in order to identify the most relevant ones.

The future development of smart grid in Denmark is considered to be a large field of research due to the numerous and diverse issues that can occur at different level. This project focused on a very specific parts of the smart grid development and thus can easily be extend by providing the same kind of analysis for small village, city, municipality, etc.

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9 ANNEX

TABLE 15: TECHNICAL PARAMETERS OF THE TWO SETS OF ELECTRICAL DEVICES FOR A 4 PERSONS FAMILY (ELMODEL-BOLIG S.D.) AND (STAMMINGER 2009)

Technical parameters	Number of unit (Average/Efficient)	2 persons family (average)		2 persons family (efficient)	
		Power [W]	Standby Power [W]	Power [W]	Standby Power [W]
Washing					
Washing machine (7kg)	1	2000	0.0	2000 or 900	0.0
Tumble dryer	1	2000	0.0	1300	0.0
Dish Washer	1	2000	0.0	1800	0.0
Cold appliances					
Combi fridges	1	30.00	0.0	25	0.0
box/chest freezer	1	25.00	0.0	20	0.0
Cooking					
hob+hood	1	2379	7.5	2379	7.5
Oven	1	1171	1.6	1171	1.6
Mixer/food processor	1	1029	0.7	1029	0.7
Coffee maker	1	1300	1.3	1300	1.3
Lighting					
CFL 8 watt	7/11	63	0.0	107	0.0
Halogen 50 W	5	240	0.0	240	0.0
incandescent 43 W	4/0	172	0.0	0	0.0
Electronics					
Television 82 cm + surround	1	412.71	4.7	303.34	3.22
Stereo	1	14.45	4.9	14.45	4.9
Desktop system	1	76.35	10.8	27.21	9.59
Miscellaneous electronics	1	300		200	0
Miscellaneous					
Miscellaneous	1	200	11	200	0

TABLE 16: BEHAVIOURAL PARAMETERS FOR A 2 PERSONS DWELLING WITH AVERAGE ENERGY CONSUMPTION IN DENMARK BASED ON ASSUMPTION AND DATA FROM (ELMODEL-BOLIG S.D.)

Average behaviour	Average op per week	duration or average duration	Maximum duration	Max op per day	Max op per week	standby probability
Washing						
Washing machine (7kg)	3.8	-	-	2	7	
Tumble dryer	1.7	-	-	1	7	
Dish Washer	3.68	-	-	1	7	
Cold appliances						
Combi fridges	-	-	-	-	-	-
box/chest freezer	-	-	-	-	-	-
Cooking						
hob+hood	5.6	0.40	1.00	2.00	8.00	
Oven	2	0.83	1.20	1.00	4.00	
Mixer/food processor	1.00	0.25	0.50	1.00	4.00	
Coffee maker	9.10	0.17	0.20	4.00	15.00	
Lighting						
CFL 8 watt	7.00	3.15	6.00	1.00	7.00	0.00
Halogen 50 W	7.00	2.90	6.00	1.00	7.00	0.00
incandescent 43 W	7.00	2.85	6.00	1.00	7.00	0.00
Electronics						
Television 82 cm + surround	7.00	3.46	4.00	3.00	10.00	0.47
Stereo	7.00	0.67	2.00	2.00	10.00	0.38
Desktop system	7.00	7.06	10.00	2.00	10.00	0.49

TABLE 17: BEHAVIOURAL PARAMETERS FOR A 2 PERSONS DWELLING WITH LOW ENERGY CONSUMPTION IN DENMARK BASED ON ASSUMPTION AND DATA FROM (ELMODEL-BOLIG S.D.)

Efficient behaviour	Average op per week	duration or average duration	Maximum duration	Max op per day	Max op per week	standby probability
Washing						
Washing machine (7kg)	1.4 (20°C) and 2.4 (40°-50°)	-	-	2.00	7.00	0.00
Tumble dryer	0.85	0.00	0.00	0.00	0.00	0.00
Dish Washer	3.68	-	-	1.00	7.00	0.00
Cold appliances						
Combi fridges	-	-	-	-	-	-
box/chest freezer	-	-	-	-	-	-
Cooking						
hob+hood	5.60	0.34	0.85	2.00	10.00	0.00
Oven	2.00	0.71	1.02	1.00	4.00	0.00
Mixer/food processor	1.00	0.25	0.50	1.00	4.00	0.00
Coffee maker	9.10	0.17	0.20	4.00	15.00	0.00
Lighting						
CFL 8 watt	7.00	3.15	6.00	1.00	7.00	0.00
Halogen 50 W	7.00	2.90	6.00	1.00	7.00	0.00
incandescent 43 W	7.00	2.85	6.00	1.00	7.00	0.00
Electronics						
Television 82 cm + surround	7.00	3.46	4.00	3.00	10.00	1.00
Stereo	7.00	0.67	2.00	2.00	10.00	1.00
Desktop system	7.00	7.06	10.00	2.00	10.00	1.00

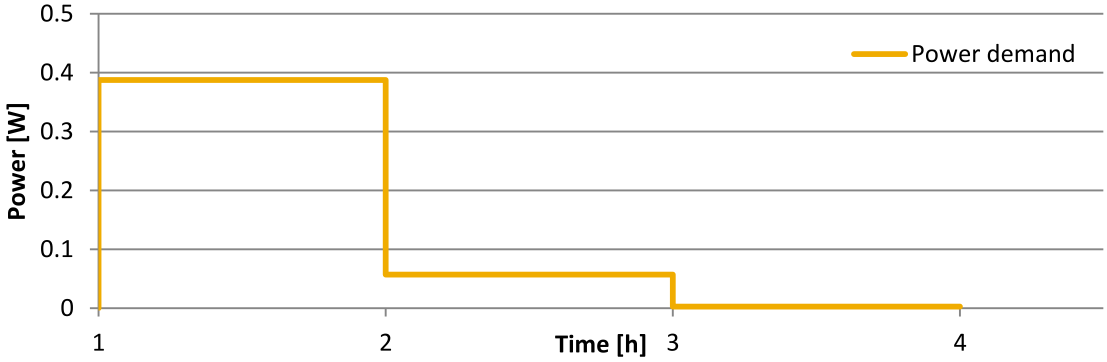

FIGURE 52: PATTERN DEMAND FOR A WASHING MACHINE

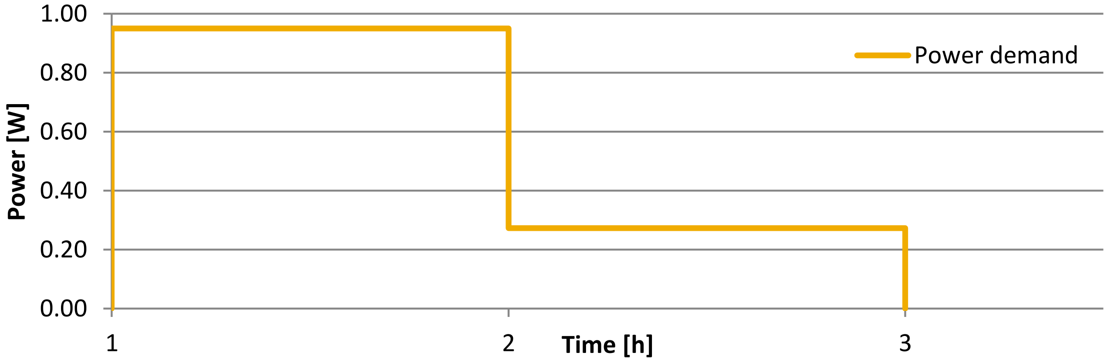

FIGURE 53: PATTERN DEMAND FOR A TUMBLE DRYER

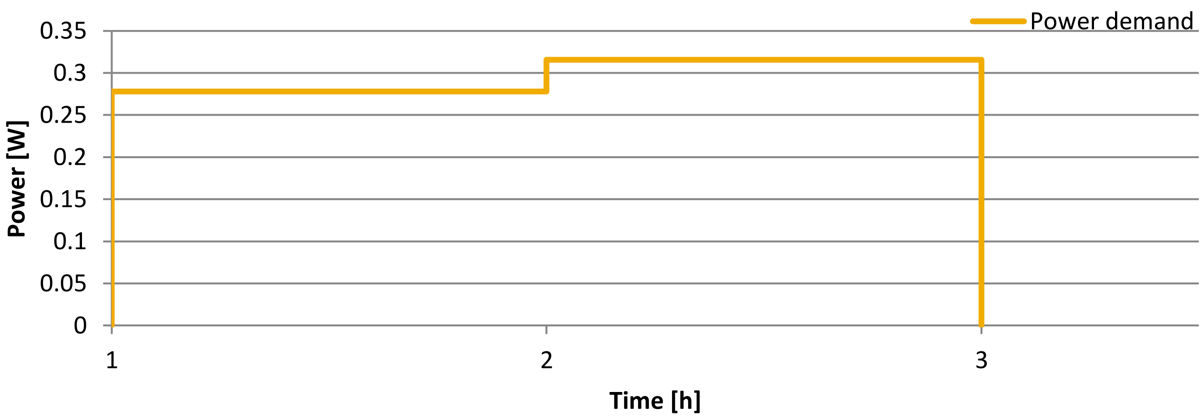

FIGURE 54: PATTERN DEMAND FOR A DISHWASHER