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Abstract:

The purpose of this document is to evaluate for “screening the landscape” before deployment and contribute to the business planning.

Keywords:

Use cases, Indicators, SECs, Test site.

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1 Introduction

1.1 Purpose and Scope of the Document

The goal of this report is to analyse the actors involved in the goal in the SmartKYE platform and quantify the potential benefits obtained by applying the SmartKYE platform.

The ex-ante evaluation will focus on "screening the landscape" before deployment and contribute to the business planning. It will describe the point of reference in order to assess, within the framework of ex post evaluations, the impact of public support for the proposed system. This will reveal future-oriented fields of innovation and the main actors within these fields.

The work includes the analysis of the impact of the various EMSs (Buildings, PLS, EVs, RES) in the municipal energy efficiency. The work will include both a literature survey as well simulations for various levels of the system (single building to large aggregation of buildings)

More specific the document starts with the analysis of the key actors and the role in the platform. A literature survey is included about the potential impact in the municipal infrastructure. Various sources have been included such as the NOBEL project.

Next the simulations are presented covering cases from one building to large area (such the island of Crete). The simulations focus on the costs in case of flexible tariffs, changes in the production of RES and the behavior of EVs. This way the theoretical benefits of SmartKYE platform can be identified.

Finally the report analyses the business models and identify the thresholds for the System Evaluation Criteria (SECs) , introduced in D7.1.

1.2 Project Summary

SmartKYE Energy Management Systems (EMS) can share data and services among themselves and to external third party applications. Higher level applications will be developed in SmartKYE Cockpits, that are able to process real-time data and generate valuable analytics to affect the business and Monitoring and Control (M&C) strategies that operate a district. The project validates this approach in two high profile pilot sites:

- The 22@ district in Barcelona, Spain.

- The area of Lasithi in Crete, Greece.

1.2.1 Barcelona Test site - 22@ District

Short Description

The facilities and subsystems included in the pilot in Barcelona are part of the 22@Barcelona project, which transforms two hundred hectares of industrial land of Poble Nou into an innovative district offering modern spaces for the strategic concentration of intensive knowledge-based activities. In some cases, subsystems from surrounding districts will be included the project. Following sections present a short description of the systems that will be considered during SmartKYE project.

Barcelona LED public lighting platform: (monitoring)

In several streets of the Barcelona city, LED lamps have replaced old incandescent lamps. Information regarding these new lamps as well as old lighting systems is gathered in 3000 "control cabinets" (CM) spread across the city from which approximately 1100 CM can be remotely monitored and controlled. Control of these CMs is performed by the owner, the Barcelona City council (through the department "Gestió d'enllumenat de Barcelona"). Initially, during SmartKYE project, the following streets will be monitored:

- Hercegovina,
- JoaquimValls
- Marc Aureli

Depending on the type of control cabinet the number of lamps might be different. For example, the control cabinet for the Marc Aureli Street can control up to 81 lamps. Additional streets within or outside the 22@ district might be added later on based on the proper agreement reached with the municipality.

Mediatic Building BMS integration (monitoring)

BDigital facilities are located in the 22@ district in Barcelona in the MediaTIC building, located in Roc Boronat Street 117. All systems within this building are constantly monitored and controlled by a building management system (BMS) provided by Controlli. In addition, Bdigital has developed and deployed a system to monitor and control the energy consumption of its own facilities on the 5th floor of the MediaTIC building.

1.2.2 Crete test site

Short Description

The test area for the SmartKYE project will focus in the area of Lasithi, which is the eastern part of the island. The population of Lasithi area is about 75000 citizens and includes one major power station (200MW).Furthermore Lasithi has a great share of the installed W/Fs (70 MW) and installed PVs (~20MW). SmartKYE will focus in a subset of this population, matching a number of inhabitants in an extended urban and rural area similar to the number of inhabitants in the Barcelona pilot site –i.e. 5.000 users. The assets representative of that consumption are displayed in Table 6. Due to the high potential for wind generation in Crete (maximum wind production is approximately 130 MW, which is 82% of the installed wind capacity of 160.5MW). The monitored assets representative of power generation are wind farms.

1.3 Key Actors and Roles

As mentioned in D2.1 SmartKYE platform will eliminate barriers for many stakeholders that would be able to access the platform, specifically for public authorities, either to offer valuable energy-related data, or use it in new and innovative ways that assure an efficient use of energy resources and a reduction in CO2 emissions in a neighbourhood or a city.

The key stakeholders of SmartKYE system are:

- **Municipalities**: This stakeholder is the main target user of SmartKYE platform. It comprises the administrative persons responsible for the various technical and business aspects of the municipality. This includes also planning, monitoring and management activities including the operation of all the different systems within a municipality (e.g., public buildings, public lighting, EV infrastructure, etc.)
- **Electric Vehicle users:** For those scenarios where the integration of EV (hybrid or full electric vehicle) will be possible, an EV user will be considered as an actor that can interact with SmartKYE system. For example, EV user might interact with SmartKYE system in order to provide particular requirements regarding his EV charging process management (by SmartKYE). The users will be required to interface mobility needs with quality and security of supply needs of the electricity system.
- **Energy Retailers:** Selling energy and other (related) services and products to consumers. Retailers will develop consumer oriented programs and offerings.
- **Energy Service Companies (ESCOs):** Provision of a broad range of comprehensive energy solutions, including designs and implementation of energy savings projects, energy conservation, energy infrastructure outsourcing, power

generation and energy supply and risk management.

- **Storage Providers**: Delivery of storage products and services, including their maintenance and operation thereby shifting electricity and energy consumption in time either for third parties or own purposes.
- **Ancillary Service Providers**: Provision of services such as Power Balancing, Voltage Profile Support and Black start.
- **Distribution System Operators (DSOs):** Provision of services for secure, efficient and sustainable operation of electricity distribution systems. Legal obligation of a high quality, secure planning, operation and maintenance of the distribution grid.
- **Weather information/forecast providers:** This actor represents another external system interacting with SmartKYE system in order to provide updated weather information and/or weather forecast that can be used internally by SmartKYE to perform energy management.
- **Energy Producer:** This is the entity that manages large power station or RES stations. The goal of this actor is to minimise the cost and have more efficient operation in order to maximise its profits.

1.4 Goals of the Municipalities

Within the scope of SmartKYE project the goals of the municipality are:

- Increase the energy efficiency, thus to use minimum amount of energy without affecting the comfort and security level or the operation of the services and the facilities
- Increase the installed RES power and limiting the use of energy that comes from fossil fuels. Thus reduction in CO2 emissions may be achieved.
- Reduce the cost for electricity bills

In order to achieve these objectives, a platform such as the Smart KYE is mandatory. We should note that the CO2 reduction because of just an installation of a new PV or a Small Wind turbine is not the result of SmartKYE platform. However a new PV that wouldn't be installed, due to technical or commercial restrictions, but finally is installed because of the smart management, this is a benefit of SmartKYE. The CO2 reduction coming from this extra RES counts as benefit from the SmartKYE platform.

1.4.1Technical and non-technical barriers for the deployment of Smart KYE platform

However, the existence of Flexible Tariffs is one of the main barriers for the deployment of SmartKYE since they do not exist yet. Flexible tariff have two main components:

- They reflect the hourly (or quarterly) system production cost. Thus the consumer knows that during peak hours the production cost usually is much higher than in valley. Providing to the consumer tariffs reflecting the System Marginal Price (SMP), instead of flat tariffs is a motivation to shift the consumption to cheap hours.
- However the electricity market is quite complicated and the Energy Retailers /ESCO buy electricity from different sources: wholesale market, spot market ancillary services market, derivatives, long term contracts etc. The ability to control some load or RES provides them the option to gain profit from different sources. In order to do that they could provide flexible tariffs that do not reflect only the System Marginal Price but also include incentives coming from the other parts of the electricity market.

Another big issue is about the RES. So far the dominant policy in the EU is to pay the RES with Feed-In Tariff (FIT) which is defined by the local government. However the regulatory authorities across Europe face nowadays similar problems:

- Increased Cost for the consumer since typically the FIT is much higher than the SMP
- Technical Problem associated with the increased RES penetration such as voltage problems or system instability
- Lack of participation in the ancillary services market. So far only traditional power station where obliged to provide ancillary, however the claim that this cost is increasing and the RES should participate too.

The regulatory authorities propose several schemas in order to cope with these problems, such as net metering. An interesting schema is the one proposed in Germany in the new German Act. According to that only 70% of the installed capacity can be injected in the grid. The rest should be consumed locally or rejected. For large systems, such as the System in Crete other rules apply: the DSO may curtail wind energy according to some rules. This results a curtailment of 10-15% of the wind production, yearly.

1.5 Benefits for the Municipalities

The future smart city will be composed by all stakeholders at the demand and supply side which will have their own Energy Management Systems for local decisions and energy management. Typically these stakeholders will operate wind turbines and PV parks, public lighting systems, do facility management on buildings, heating management, electric vehicle management etc.

On the user side the public authority is the main user e.g. the municipality or some governmental organisation. SmartKYE is addressing this specific user providing a a Business Cockpit and a Monitoring &Control for real time analysis and decision support. They aim at gluing the different EMS together via the Open Energy Service Platform. Data will be acquired from all stakeholders, processed in the platform based on business related rules and communicated to the cockpits. There, real-time analytics will be done and results will be considered by a Decision Support System for business related aspects. Additionally a cockpit will provide visualization of key indicators for the neighbourhood assisting further in understanding the key aspects of the city as well as easing the decisions.

1.5.1 Buildings

Buildings are one of the fastest growing energy consuming sectors. According to the results of North Sea - Sustainable Energy Planning it is estimated that the amount of the energy consumed in the European Union's (EU) buildings reaches 40–45% of total energy consumption. In the current decade, energy demand of the tertiary sectors (offices, schools, hospitals, utilities buildings etc) are increasing 1.2%- 1.0%/annual, As a result, energy usage in the above sector of EU is responsible for approximately 50% of the greenhouse gas (GHG) emissions.

The municipal energy management can be the answer. The term municipal energy management (M.E.M.) covers all strategies and actions to achieve a sustainable and efficient use of energy in all municipal fields of activity – that includes organizational issues as well as technical measures in one's own property, or the energy efficient procurement and mobility. M.E.M. is based on the continuous acquisition and analysis of the consumption of heat, electricity and water in the municipal buildings. The objective of the municipal energy management is to reduce energy consumption as possible without extra burdening on the public budget and without sacrificing comfort.

There are many reasons for the introduction of a systematic and sustainable municipal energy management. First of all, the percentage of municipal load compared to the total load is not negligible.

For example the national average of a German community has building energy costs from 35 to 40 Euros per user person per year corresponding to 10,000 inhabitants, this equates an annual cost of about 350,000 to 400,000 Euros – with an increasing trend. According to the North Sea - Sustainable Energy Planning project, 10 to 20% of energy costs can be saved with low- and non-investment measures without sacrificing comfort. According to the calculation example above this equates from 35,000 to 70,000 Euros a year.

In a large scale, the energy supply in municipal buildings in Germany causes costs of over two billion Euros every year. (Information for municipal energy management; German Association of Cities 2012, www.staedtetag.de/fachinformationen/wirtschaft/057992/index.html). With energy prices rising, these costs are growing continuously and burden the municipal budgets every year a little more while municipal takings are declining. The precise knowledge of the actual costs and savings in the individual properties is essential for proper investment decisions. An appropriate basis is set by the inventory of the municipal energy management. The exact knowledge of the energy consumption also simplifies the tender for energy supply.

In addition, the requirements for the assurance of the necessary thermal comfort, visual comfort and indoor air quality are increased, especially in the prevailing situation of price fluctuations, the rapid population and the technology's evolution. In this chapter, efforts are currently focused on the satisfaction of the energy needs for the energy efficient of public buildings, by assuring the operational needs with the minimum possible energy cost and environmental protection.

Achieving Energy Efficiency in Municipal Buildings through Real-Time Feedback

In municipal buildings there are many different users' types, as there are various types of buildings – hospitals, schools etc, each with different needs, values and abilities. Influencing each of these users, requires an understanding of how these needs and values drive behaviour. Designing for influence requires analysis, identification of target behaviours and how these behaviours map to existing activity. Through the careful implementation of simple behaviour change measures, opportunities exist to achieve strategic gains, including greater operational efficiencies, energy cost savings, greater tenant health and ensuing productivity and an improved brand value through sustainability messaging and achievement.

Evaluating energy performance requires good information on how, when, and where energy is being used. Especially in Public buildings collecting and tracking this information is necessary for establishing baselines and managing energy use. All or part of data collection and management can also be outsourced. Regardless of what method you use to gather and track data, consider the steps below.

So, it is essential for Municipals to collect energy information for Public buildings. Energy efficient building occupancy gains can be made through a supported behaviour change strategy, incorporating deliberate placement of real-time energy use feedback for building users.

Providing information measured directly from the building itself, typically through a Building Interface Control System. Common building smart meters include electricity, water and gas meters, room occupancy sensors, CO2 sensors and cameras. The location and number of these sensors will determine how focused the building feedback can be (one per floor vs one per building). Since the smart meter is aimed at providing more real time information about building use activity, it is important that they be connected to a network and can log data in real time. There are capital costs involved in installing bespoke sensors (such as cameras or additional energy meters), however some existing building sensors will already provide adequate data for building feedback.

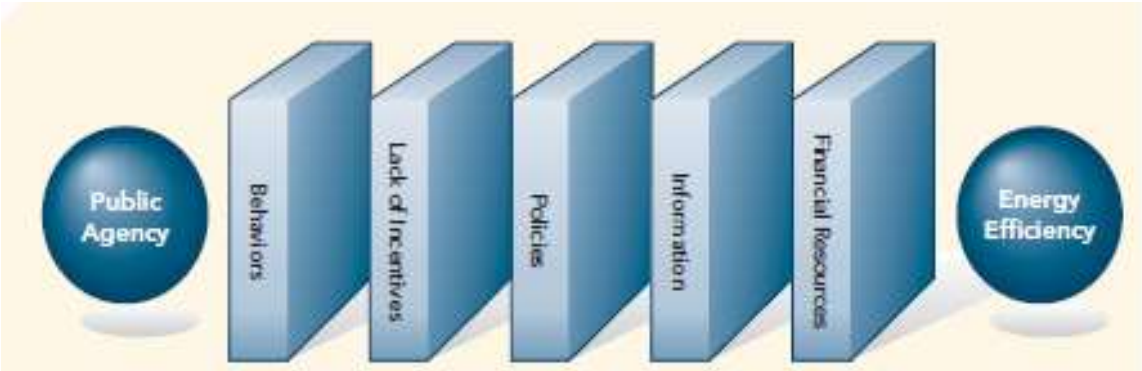


Figure 1 Roadmap to Energy efficiency

1.5.2 Public lighting system

Public lighting performs an essential public-good service, ensuring adequate illumination for traffic and public safety on roads and streets, and helps to deter crime and anti-social behavior. It also promotes the use of sustainable transport such as walking and cycling, and facilitates social inclusion.

Most public lighting assets are owned by local Authorities, who are responsible for paying the electricity and maintenance charges for their own lighting. Most local Authorities contract the maintenance to third parties. The national roads Authority (nrA) reimburses local Authorities for the energy and maintenance costs of public lighting on national routes.

There is a research of Public Lighting Special Working Group in the republic of Ireland. There are approximately 420,000 public lights in the republic of Ireland. The vast majority are owned by local Authorities. It is estimated by the Working Group that public lighting accounts for about 2% to 3% of total public sector energy consumption. Energy consumption data made available to the working group shows that approximately 205 GWh of electricity is consumed annually by public lighting across the entire country of Ireland. It is estimated that this represents between 15% and 35% of each local Authority's total energy use. This estimate is derived from the experience of the working group participants and from SeAi's (Sustainable energy authority of Ireland) wider experience in working collaboratively on energy management initiatives with 26 local Authorities. This consumption represents an annual energy cost of about €29 million and results in the generation of 110,000 tons of CO_2 per annum. When maintenance and replacement costs are included, the annual operational cost for the 420,000 public lights in Ireland amounts to about €50 million. Altogether, public lighting accounts for ~50 MW of electrical demand.

Figure 2 Public Lighting in Barcelona

Smart Lighting - Public lighting control and maintenance

With intelligent management, municipalities can drive down the energy consumption of their public lighting systems and realize significant savings, all while taking a big step towards becoming the green city of the future.

Smart Lighting is the comprehensive suite for the control and maintenance of a lighting system. It leverages cutting-edge innovations to make the existing lighting system more efficient and effective than before. It helps you achieve your service level agreements with real time warnings whenever a problem occurs and even provides predictions on possible outages. Smart Lighting may connect every street light to the internet via power line communications and it provides intelligent automatic scheduling features to control their performance through a web-based command centre. As a result, it reduces energy costs and prolongs the life of individual lamps. Because it also remotely detects and predicts lamp outages, it is allowed to optimize the logistic effort to keep all lights functioning while reducing outage rates –so the streets and high avenue will be a lot safer. Smart Lighting reduces the energy consumption of public lighting system by 30% without changing the technology of existing lights. This does not only benefit of municipal financial budget, it also reduces CO_2 emissions and transform the city into a leader in sustainability.

An energy-effective public lighting solution should balance several lighting criteria against the requirements of the area to be illuminated.

- efficiency of the light source or lumen efficiency, which is the ratio of light emitted by the light source to the power consumed by it, including power consumed by any auxiliary control gear
- colour appearance, which defines the lamp's 'whiteness'
- colour rendering, which is the ability of the light
- source to reproduce the colour relative to the same colour, or colours, illuminated by a reference source (daylight)
- lamp life
- luminaire efficiency, which is expressed as the light Output ratio – the ratio of the light output of a luminaire to the total light output of the bare lamp
- light distribution
- luminaire position and maintenance
- controls

The savings are about 30% in electricity consumption through intelligent management of lighting. Also there is a 50% decrease of the maintenance costs and 30% decrease of CO2 emissions. It is estimated that the Payback period is around 5-6 years.

The management efficient could also be combined with the implementation of dimming technologies to the LED fixtures. Dimmers allow the lights to be on at full capacity during peak traffic hours and dimmed at times when there is little traffic.

It is generally accepted that proven technological solutions are available to improve energy performance in the public lighting sector. The rate of technological development is rapid, especially the area of LED technologies. There are many suppliers of energy-efficient lighting, and new products are being continually released.

Figure 3 Public Lighting with LED technology

NOBEL Project-simulations regarding PLS

According to the results of the NOBEL project (Annex 1) it was managed to achieve an overall energy consumption reduction of 40% for the senior prosumers participant (Public lighting system).Results are focused mainly on energy performance and savings, translated also in monetary values.

Pilot tests in Alginet took place in order to evaluate the basic end-user application NOPL developed within the project:

- NOPL (Neighbourhood Oriented Public Lighting Monitoring and Control System) is a service used by operators of the Public Lighting system, and enables the monitoring of electricity needs for Public Lighting and finally a more efficient energy management. Within NOBEL sensor are also installed in order to adjust public lighting according to external conditions (traffic, weather, natural light).

The NOPL application is respectively addressed to SEnior Prosumer.

- SEnior Prosumer (SEP). A SEP is a STP that in addition requires internal energy management processes, as a public lighting system, a heavy industry, a sports centre, etc. (Industrial, Commercial and Public Infrastructure). Within NOBEL, the senior prosumer was the public lighting operator, testing NOPL application through segments of public lights.

The NOBEL Pilots were conducted in Alginet of Spain. A comparative study based on the simulation of the whole town of Alginet, has been performed. This simulation provides feasible values related to energy, power and luminosity levels.

Second round of pilots

In the second phase of tests in Alginet two types of lights were used in order to assess NOPL. The same avenue was used as in the first phase (Annex 1) as well as two led lights triggered by magnetic loops. A description of the testing infrastructure is provided in the following sections, as well as overall energy usage results for these two cases.

Points of light triggered by magnetic loops

One of the energy saving strategies tested in Alginet has consisted in making the luminosity level of certain parts of the town that hold an important traffic flow dependent on the actual presence of vehicles on the road. The objective of this strategy is to achieve energy savings by reducing the luminosity level of the lamps to a level adequate to the pedestrians when the traffic flow on the road is lower, while increasing the luminosity level in the presence of vehicles, in order to ensure the security of both pedestrians and drivers.

The idea of this strategy is to save as much energy as possible without reducing the security and comfort of the pedestrians and the drivers.

The Segment Controller is able to communicate with a magnetic loop (usually employed to retrieve traffic measurements) in order to check when a vehicle is driving through the controlled road. This information is used in the lighting control loop to perform changes on the luminosity of the lamps.

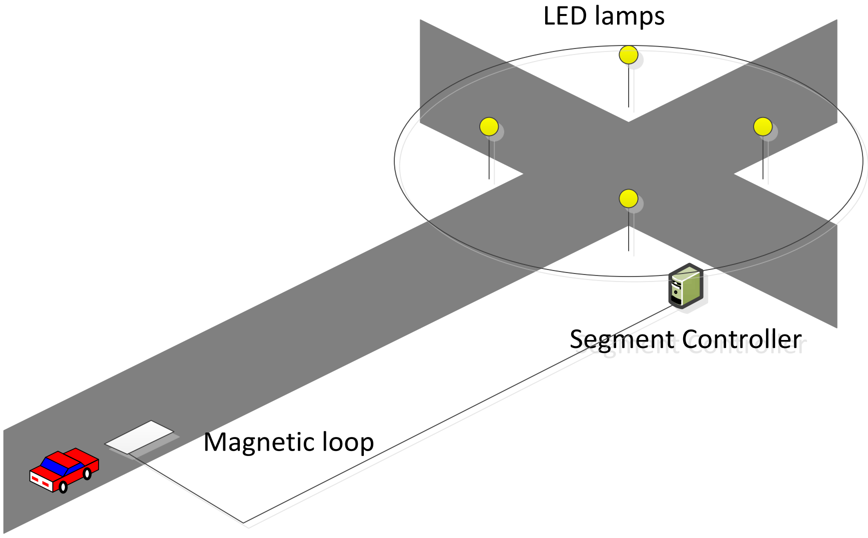


Figure 4Segment controller - Magnetic loop integration

This kind of strategy is only feasible with the use of LED lamps, due to their ability to modify instantaneously their luminosity level without degrading the lamps.

In order to test this strategy, two LED lamps controlled by one Segment Controller have been installed in one of the main streets in Alginet (Calle Mayor / Plaza Constitución). The Segment Controller was configured to manage the LED Lamps with the following behaviour:

- LED lamps are switched on during sunset
- LED lamps are switched off during sunrise
- Nominal luminosity level of LED Lamps is set to 20% (which provides good visibility for pedestrians)
- LED lamps are set to a luminosity of 100% when a vehicle is detected in the magnetic loop. This level is maintained for 1 minute
- The detection of new vehicles reset this timer (LED lamps keep a luminosity of 100% after 1 minute since the last vehicle has been detected)

Energy Impact in the Second phase of the project

Senior prosumer consumption (lighting system) – NOPL application

NOPL evaluation was performed for the second phase by controlling two smart meters, on segment of lights in the AV. REYES CATOLICOS avenue, where sensors where installed and two led lamps in PLAZA CONSTITUCION with inductor loops. The impacts of NOPL for these two cases are presented in the following Tables, in comparison with the baseline case.

Indicator	Second Pilot phase	Baseline case	Difference (%)
Total consumption (kWh)	8522	14928	-42,91
Total September consumption (kWh)	2650	4472	-40,74
Total October consumption (kWh)	2669	4727	-43,54
Total November consumption (kWh)	3203	5729	-44,09

Table 1 Second phase energy impact on AV. REYES CATOLICOS lamps consumption

Indicator	Second Pilot phase	Baseline case	Difference (%)
Total consumption (kWh)	12496	14897	-16,12
Total September consumption (kWh)	3999	4583	-12,74

Indicator	Second Pilot phase	Baseline case	Difference (%)
Total October consumption (kWh)	4093	4784	-14,44
Total November consumption (kWh)	4404	5530	-20,36

Table 2 Second phase energy impact on PLAZA CONSTITUTION lamps consumption

As expected the AV. REYES CATOLICOS lamps saved 43% energy, while the led lamps 16%. Sensors achieve more dynamic energy management as they take into account any change in the traffic in the area.

In order to evaluate future implementation of NOPL, it is convenient to know the saving per point of light, considering also the hardware equipment. Thus, the following table provides the saving per point of light.

Type of equipment	**Total energy saved in the pilots (kWh)**	**Interval (months)**	**Units of light**	**Saving per point of light per month (kWh/point of light/ per month)**
Sensors	6402	3	106	20,13
Led Lamps	12,28	3	2	2,05

Table 3 Saving per point of light/per month for different types of equipment

Considering a road with lights of the same type as in Alginet and assuming that an average road had lights with sensors installed every 20 m, the saving per km (thus 100 lights, 50 on each side) are 100 lights*20,13 kWh/point of light/ per month =2012 kWh/month/km.

Economic Impact

The public lighting segments participating in the pilots did not participated in the market. Thus, the economic benefit is only due to the consumption reduction. The lighting system has a contract with standard tariff and thus the economic impact is presented in the following table. The average contact tariff for the sensors segment is 0,124 €/kWh and for the led lamps segment is 0,117 €/kWh.

Indicator	Segment of lights	Total Energy Saving (kWh)	Contract tariff (€)	Impact (€)
Costs for consumption (€), Consumption* contract price	**AV. REYES CATOLICOS**	6406	0,124	**794,4 Savings** **42,7% Reduction**
	PLAZA	2401	0,117	**280,92**

	CONSTITUTION			**Savings** **16,12% Reduction**

Table 4 Economic impact for senior prosumers (lighting system)

1.5.3 Generation Management

According to the results of the More Microgrids project, a general overview of the main control functionalities in a microgrid (e.g. a system with controllable loads and DGs) is presented. Microgrids can be centrally managed by extending and properly adapting the functionalities of existing energy management system (EMS) functions.

The optimization problem is formulated differently, according to the market policies assumed. Since there are no mature reactive power markets at the distribution level, such a market is not considered within a microgrid. The Market Policy 1 aims to minimize the microgrid operational cost while Market Policy 2 maximizes revenues from the power exchange with the grid. End-users are assumed to be charged with flexible tariffs.

The network comprises three feeders, one serving a primarily residential area, one industrial feeder serving a small workshop and one commercial feeder. Load curves for each feeder and the whole microgrid for a typical day are shown in **Figure 5**. [10]
The total energy demand for this day is 3188 kWh. The power factor of all loads is assumed to be 0.85 lagging.

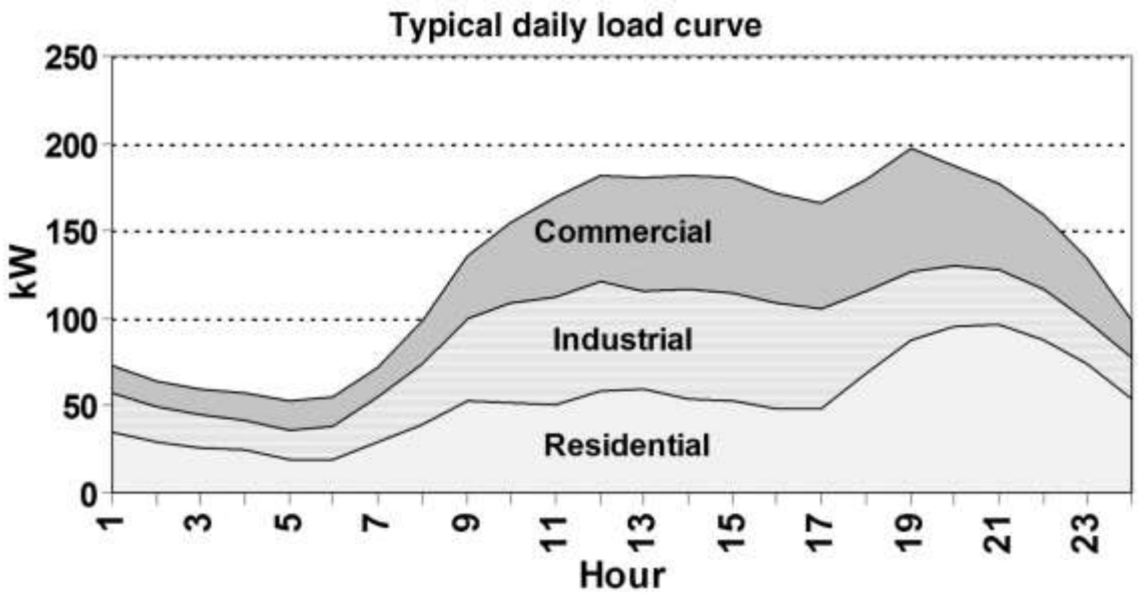


Figure 5 Typical load curve for each feeder of the study case network

For both market policies, the priority list method and the SQP method have been used. The perating cost for the day considered is 471.83€, and the price is 14.8 €ct/kWh, if no DGs are installed. Tables 5 and 6 provide results for the same day, if the two policies are simulated. The economic scheduling of the units is shown in **Figure 6**.

Reduced costs for the consumers by 21.56% are noticed in market policy 1. In market policy 2, the operation of DG does not affect the average price for the consumers of the microgrid; instead the aggregator receives profits of 102€.

The effect of demand side bidding is calculated by assuming that the consumers have two types of loads, "high" and "low" priority, and they bid for their supply, shift option or shedding, curtailment option. It is assumed that all consumers have 2kWof low priority loads(e.g. an air conditioning) and the price at which they bid is 6.8 €ct/kWh. The rest of their demand is considered as "high" priority load, and the price for the bid is assumed to be 8–10 times higher than the "low" priority price.

Cost euro	Difference with actual operation	Average price(€ct/kWh)
370.09	21.56%	11.61

Table 5 Results of market policy 1

Revenues euro	Percentage of revenues	Average price(€ct/kWh)
101.73	21.56%	14.8

Table 6 Results of market policy 2

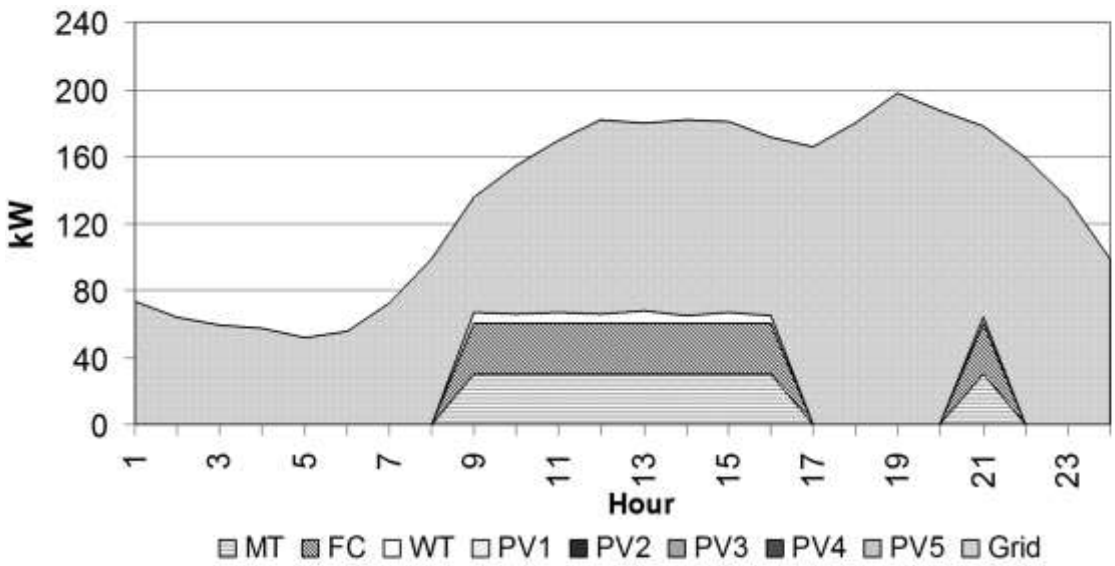


Figure 6 Typical results of the daily operation

1.5.4 EV Management- Expected impact.

Large scale adoption of an electric mobility paradigm raises the interest of many stakeholders. According to the results of the Merge Project (http://www.ev-merge.eu/), automotive industry is focused on EV manufacture while governments and policy makers underline the potential of environmental benefits and job opportunities creation. In the meantime, the electricity sector is evaluating foreseen impacts on their infrastructures to serve an additional electrical load, in this case with special characteristics compared to the common ones. The analysis focuses on the electricity sector‘s view aiming to identify the key issues that the large EV integration will provoke on grid operation (voltage profiles, line congestion, system losses, transformer loading, power quality and dynamic operation).

The results of this analysis will assist system operators to better understand the special characteristics of this new demand and how it affects the planning of the grid system. These outcomes can namely be explored by energy companies to better understand the impacts from the adoption of different EV charging strategies.

It is obtained from the simulations that it was possible to verify that the magnitude of the EV impacts are influenced by several factors, like the EV integration level, the EV owners‘ behaviour, mobility patterns, the networks‘ load profiles and technical characteristics, the number and location of fast charging stations in the grid and the EV charging modes, among others. These factors have been carefully analysed, being possible to reach the following major conclusions:

□**Maximum allowable EV integration levels (without considering network reinforcements**): The analysed systems can handle, up to a certain level, the penetration of EV without concerns to the networks’ infrastructures. However, it was verified that the maximum number of EV that can be safely integrated in the networks depends on the charging schemes adopted by the EV owners. From the three strategies analysed (dumb charging, dual tariff charging and smart charging), smart charging yielded better results in all the case studies addressed, since it was possible to reach higher EV integration levels without violating the networks´ technical restrictions.

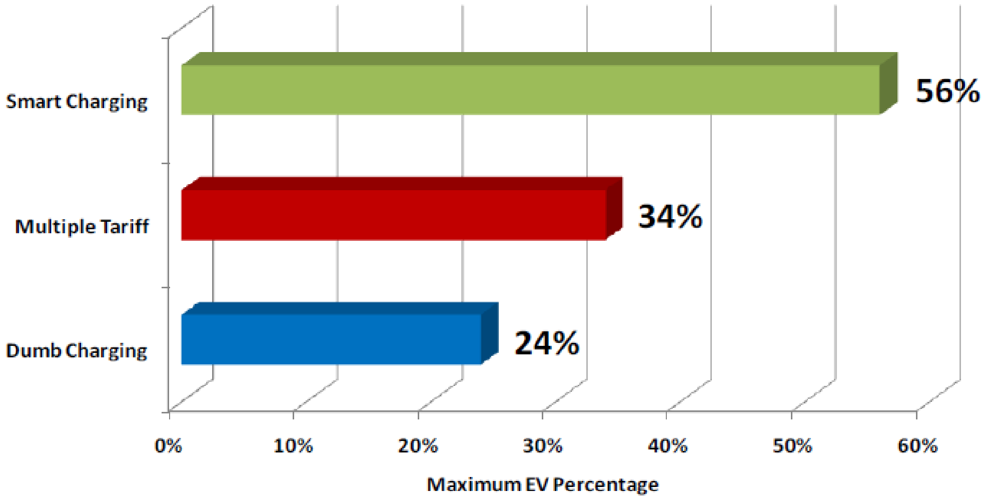


Figure 7 Maximum EV integration percentage in the MV Network 1

Figure 7 shows the results obtained for one of the MV(Medium Voltage) networks analysed

□**Dumb charging:** The dumb charging revealed to be the most problematic charging mode, as it provokes a considerable increase in the networks peak load, with negative consequences in what regards voltage profiles, branches overloading and energy losses.

□**Dual tariff:** The dual tariff strategy can be an effective charging strategy for some networks, provided that pronounced valley periods exist in the daily load diagrams and that they occur more or less during the same daily periods. Nevertheless, it should be stressed that the instantaneous increase of the EV load verified in the beginning of the lower energy price period, due to a large number of multiple tariff adherents starting their charging almost simultaneously, might provoke several technical problems in some networks, namely in those operating in more strained conditions.

□**Smart charging:** The smart charging is the charging mode that allows obtaining better results, as the envisaged mechanisms to manage the EV charging enable a better exploitation of the resources available at each moment, preventing the occurrence of voltage problems and branches' overloading.

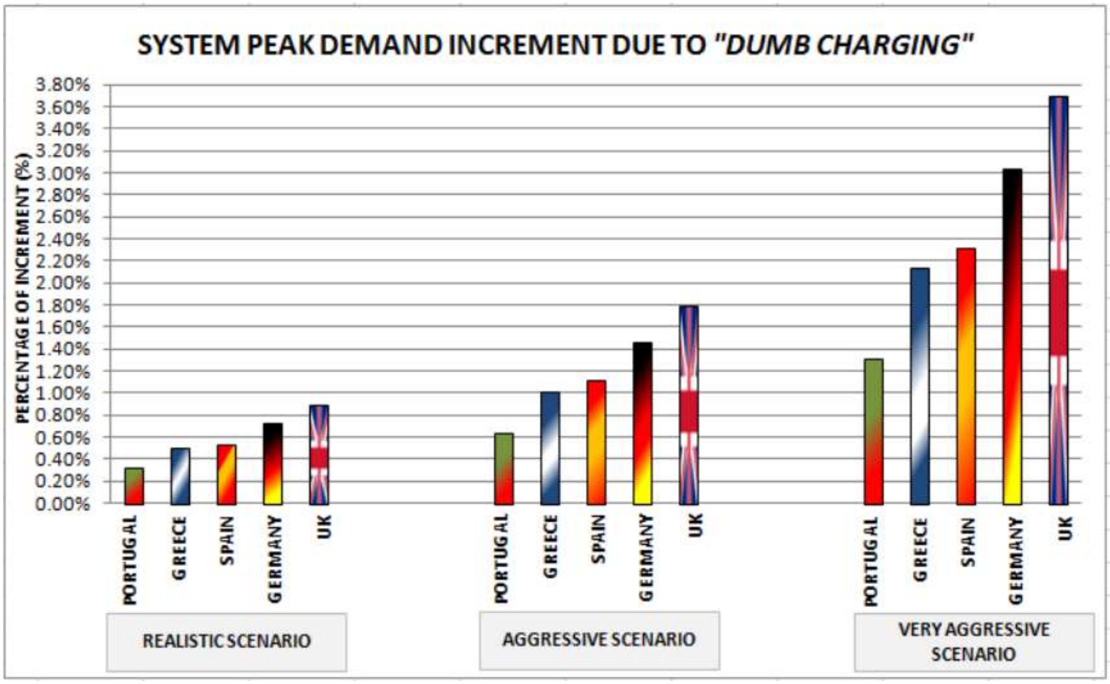


Figure 8 The increase in system peak demand in different European countries due to "dumb charging" for the three penetration scenarios (Home charging- worst case study: winter)

Figure 8 presents the impact of the ―dumb charging‖ in the system daily demand diagram examining different European countries and EV penetration scenarios.[4], [5]

The worst-case scenario, a typical winter day, is presented. In this ―dumb‖ charging analysis, only home charging has been considered, which means that EV owners plug-in their EV when they return home from their last daily travel. The grid impacts of home charging can be limited by developing charging infrastructures at workplaces. Part of the daily EV charging needs, the battery consumption for driving from home to work, can be fulfilled during morning hours at workplace when the system demand is still relatively low. As the number of EVs charging at workplaces increases, the additional system peak demand due to EV ―dumb charging‖ reduces. Dual-tariff charging is more effective than the dumb charging since it enables the shifting of the EV demand from high loading hours to off-peak ones namely valley hours. However, it should be mentioned that it results in a sharp increase of EV demand at the beginning of the low energy price period which might affect the network operation.

Smart charging prevents the occurrence of high peak loads by allocating the EV demand during off-peak hours.

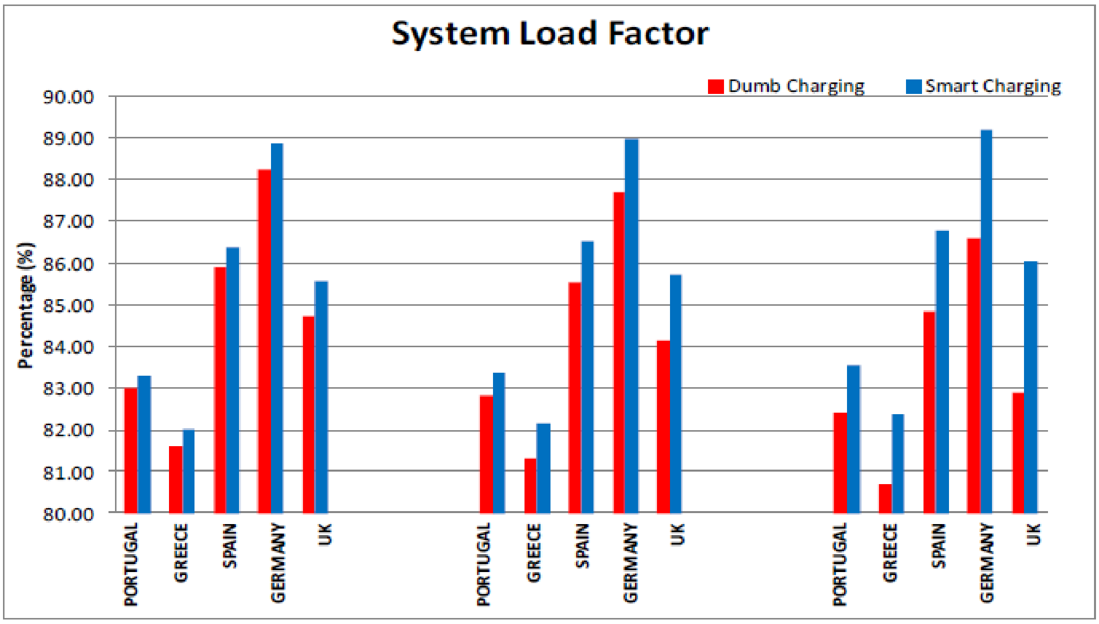


Figure 9 The increase of system load factor comparing "dumb charging" with "smart charging" (Home charging- winter)

Figure 9 illustrates the effect of this load allocation to the system load factor. In smart charging, EV demand is managed in a way that reduces the system load variation between off-peak hours and peak load hours. Smart charging is the most effective charging strategy compared with the aforementioned ones; however its implementation will require advanced management models.

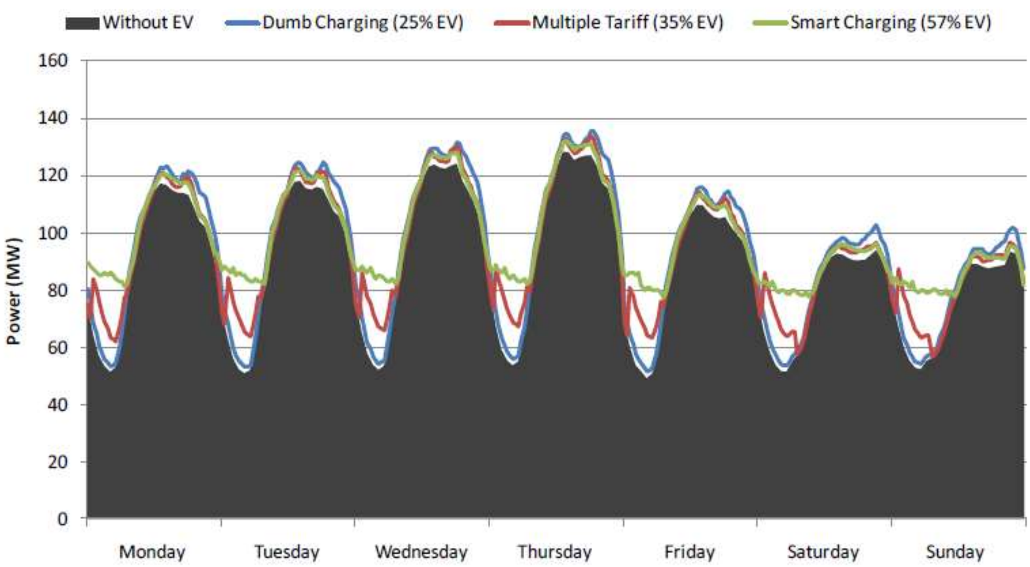


Figure 10 Load profiles without and with EV (MV Network 1)

Changes in the load diagrams: The extra power demanded by EV provokes several changes in the networks' load diagrams, which are more pronounced as the EV integration level rises. As an example, it is shown in Figure 8 the results obtained for one of the MV networks analysed.

The integration of EVs into power system results in the increase of the system load, no matter what charging strategy is adopted. Thus, additional generation is required to fulfil EV charging needs. The different charging profiles are based on different charging hours. The smart charging strategy implies charging during valley hours, the dumb strategy would mean charging during peak hours, and for the multi-tariff strategy the charging is performed during both peak and valley hours. The time allocation of the EV demand provokes significant changes in the generation mix which are mainly absorbed by coal and CCGT units. However, the generation units committed at each day time depends highly on the generation and grid capacity of each studied network. Indicative results are presented in Figure 11.

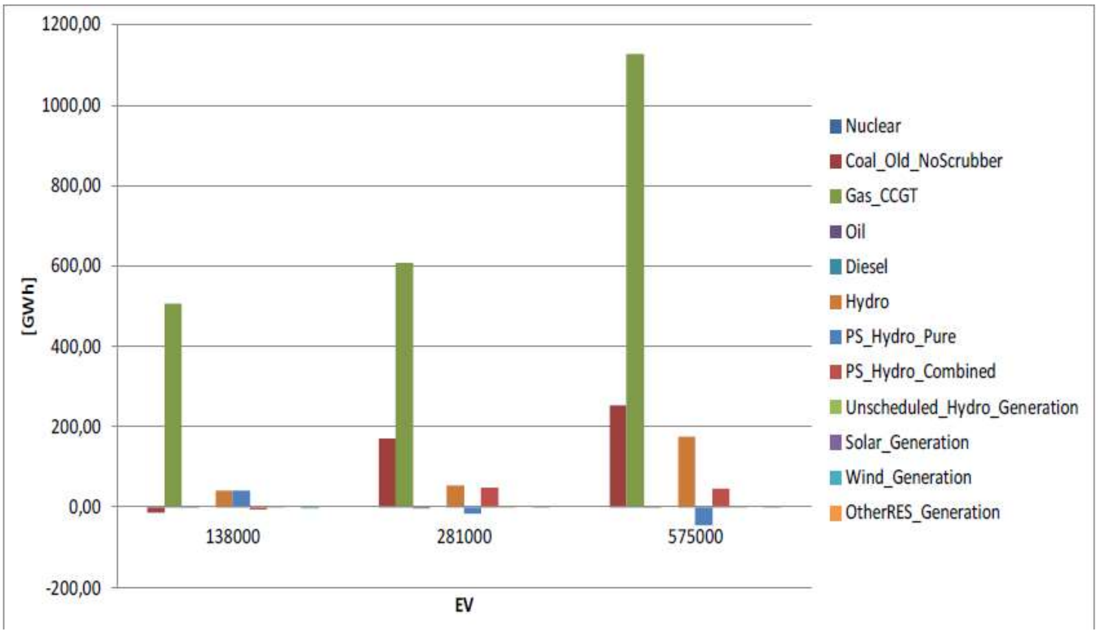


Figure 11 Generation mix change due to EV demand (Mainland Spain 2020- smart charging)

In general, it is expected that the deployment of a higher amount of EVs into the system would slightly increase the CO2 emissions of the power system. Nevertheless, the CO2 increase changes depending on the charging strategy adopted. Since the generation mix for EV supply is case dependent, the CO2 footprint is case dependent as well. For example in case of smart charging, CO2 emissions are reduced for low EV penetration level in Spanish case while they are maximized in Greek case as shown in Figure 6. This happens because in Greece, the additional EV demand during valley hours is supplied by coal units which are not at their maximum (Figure 11).

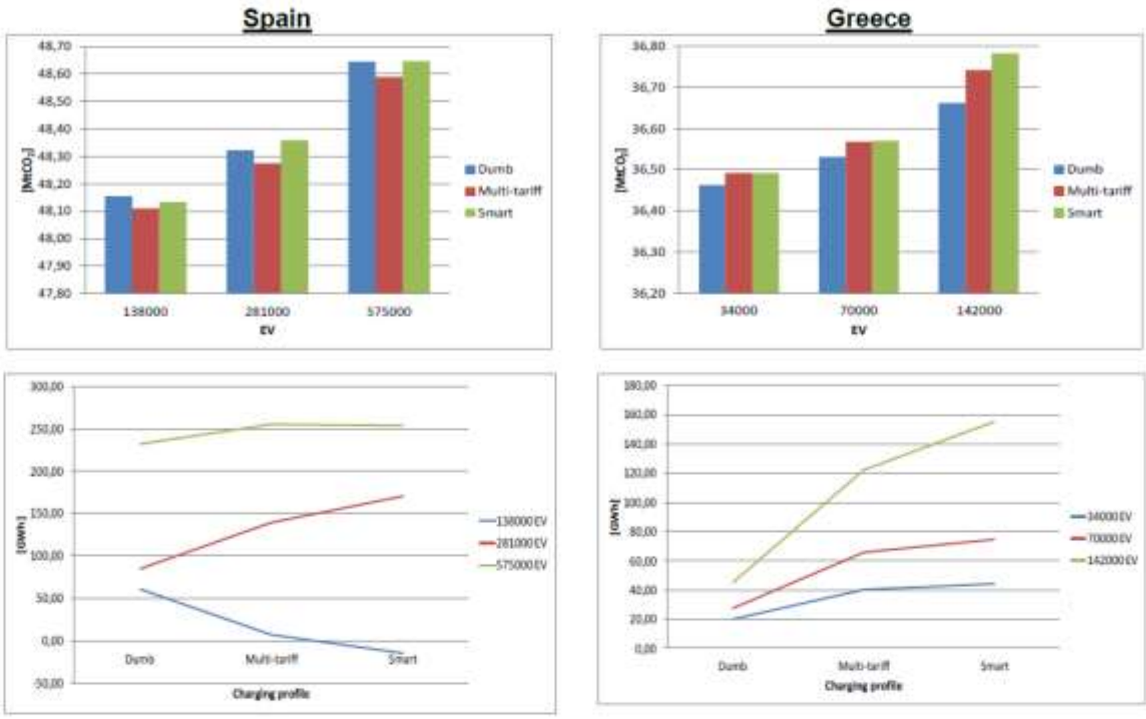


Figure 12 CO2 emissions and evolution of coal production for different EV penetration levels and charging strategies (comparative results for Greek and Spanish case)

The increase of EVs produces an increment in the specific cost of the system. The annual specific cost is also case dependent as it can be seen for Figure 11.

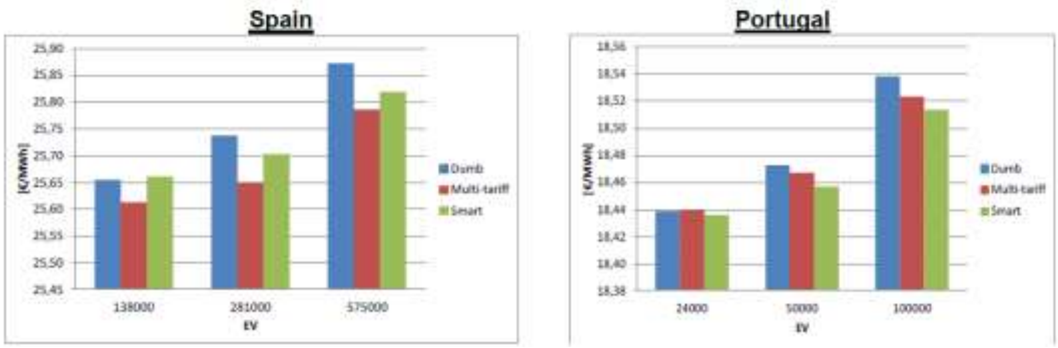


Figure 13 Annual specific cost for different charging scenarios (Spain Portugal)

At the light of the results obtained, it would be recommendable to adopt an intelligent charging profile to avoid negative impacts of the EV deployment. This charging profile has to be adapted to each particular power system and to the number of EVs deployed in it.

2 Ex-Ante Analysis Outline

This document is a technical description of the software simulations and results as carried out within SmartKEY. For arranging this task in the project's context, this section gives a short overview of connected tasks.

Four different case studies were defined which would consider the application of SmartKYE technology to roughly a small systems going next to large systems. At the beginning, BAU scenarios have been defined advanced that aim at reaching the EU EE/GHG and RES targets. Then by adding the individual SmartKYE technologies and infrastructure, scenarios are defined for each of the four cases.

The objective is to provide software-based simulations which study and proof the validity and feasibility of the SmartKYE concepts concerning different technical aspects. This task is technically oriented, but shall complement any economic analysis of the SmartKYE system.

Subsequently, the basic concepts and methodology that followed will be analysed.

2.1Energy curtailment

The energy curtailment is the renewable power that is rejected by the system due to technical reasons. The most important of these reasons is the penetration constraints imposed on the system. However, another reason may be the mismatch between the production profile of RES and demand profile. One of the basic goals of an EMS is to reduce the energy curtailment.

Each installation has a certain limit in the installed capacity set by technical and non-technical criteria. The technical criteria could be the size of the transformer in the upstream network or the capacity of the MV lines. The non-technical criteria could include regulatory limits in the installed capacity in the system since it can provide info about the potential energy savings in the future (e.g. 10kW for rooftop PV or 70% of the installed capacity according to the German Act).

Regulatory limits in the installed capacity might vary from country to country. In Spain, the generation of electricity from renewable sources is mainly promoted through a price regulation system. Plant operators may choose between two options: a guaranteed feed-in tariff and a guaranteed bonus (premium) paid on top of the electricity price achieved on the wholesale market. The price regulation system is currently phased out through Real

Decreto-ley 9/2013[1].

German is different. It is for this reason that in this report, the German act will be taken as limitation from the grid. According to the German Act only 70% of the produced PV energy can be exported to the grid. The other 30% must be consumed by the building or, if this is not possible, dumped. The meaning of this is that if 0.3*Ppv>Pload, a part of the PV production that equals to abs (0.3*Ppv-Pload) must be curtailed.

The **PV production** energy curtailment is calculated as follows:

Formula:

$$E_{CURTAILMENT} = E_{DEMAND} - E_{0,3PV\ PRODUCTION}$$

$E_{CURTAILMENT}$: energy curtailment of the RES

E_{DEMAND} : energy demand

$E_{0,3PV\ PRODUCTION}$: the 30% percentage of PV production (German Act)

The **wind** production energy curtailment is calculated as follows:

Formula:

$$E_{CURTAILMENT} = 30\% E_{DEMAND} - E_{wind\ PRODUCTION}$$

$E_{CURTAILMENT}$: energy curtailment of the RES

E_{DEMAND} : energy demand

$E_{WIND\ PRODUCTION}$: wind production

2.2 Payback Period

Another goal of an EMS system would be to increase the installed capacity. This increase cannot be unlimited. It should be related to the sustainability of investments of the Municipal.

The investor should gain a return profit in order to have an incentive to invest his money in the project. The return of the investment derives from the energy given in the grid and the feed-in tariff. For a profitable investment, the investor's return must exceed the total installation cost during a reasonable time period.

A minimum capacity factor will be set so the investment will be worthwhile and the limitations of the system will be respected.

Calculation of payback period for PV investment

[1] http://www.res-legal.eu/search-by-country/spain/summary/c/spain/s/res-e/sum/196/lpid/195/

A. The case when no rule like German Act is applied

$$\text{Income} = E_{pv} \cdot \text{Feed}_{in} \quad (1)$$

For a worthwhile investment to take place equation (2) must be valid:

$$\text{Income} \geq \frac{\text{Cost}}{T_{pb}} \quad (2)$$

Combining (1) and (2) the payback time can be calculated:

$$E_{pv} \cdot \text{Feed\_in} \geq \frac{\text{Cost}}{T_{pb}} \rightarrow T_{pb} = \frac{\text{Cost}}{E_{pv} \cdot \text{Feed\_in}} \rightarrow T_{pb} = \frac{\text{cost\_perKw} \cdot P_{pv}^{inst}}{E_{pv} \cdot \text{Feed\_in}} \quad (3)$$

The Capacity Factor is the ratio of annual production of renewable energy to the maximum installed capacity that can provide the PV plant.
The Capacity Factor CF is defined in (4):

$$CF = \frac{E_{pv}}{P_{pv}^{inst} \cdot 8760} \quad (4)$$

Combing (3) and (4) one can calculate the payback time as a function of the capacity factor:

$$T_{pb} = \frac{\text{cost\_perkW}}{CF \cdot 8760 \cdot \text{Feed\_in}} \quad (5)$$

B. The German Act case:

The Renewable Energy Sources Act (EEG) as amended mid-2011 and in force since the beginning of 2012 also includes new requirements regarding the grid integration of PV plants. It stipulates that PV plants with more than 100 kW peak power must participate in feed-in management and, at the same time, extends this requirement to smaller PV plants – albeit in somewhat less stringent form: for instance, there is no longer any obligation to let the distribution network operator retrieve the current actual power of the plant. For PV plants with less than 30 kWp, plant operators may moreover skip installing a device for remote power limitation, providing that they accept a general limitation of feed-in capacity to 70% of the installed generator power. PV plants between 30 kWp and 100 kWp must be retrofitted by the end of 2013 if they were commissioned after 31 December 2008. For plants with less than 30 kWp, no mandatory retrofitting applies. The rest 30% must be selfconsumed by the building where the PVs are installed. If 30% of the PV production is larger than the load, the remaining 0.3Ppv-Pload must be curtailed. In this case the income can be calculated by eq (6) where price denotes the price for energy consumption and curt the PV energy curtailment.

$$\mathrm{Income} = 0.7 \cdot \mathrm{E_{pv}} \cdot \mathrm{Feed\_in} + (0{,}3 \cdot \mathrm{E_{pv}} - \mathrm{curt}) \cdot \mathrm{price} \quad (6)$$

The total income is the sum of the profit made by selling 70% of the produced PV energy to the grid and the profit made by self-consuming the rest $0{,}3 \cdot \mathrm{E_{pv}}$ minus the curtailment.

Combining (2) and (6):

$$\mathrm{T_{pb}} = \frac{\mathrm{cost\_perkW} \cdot \mathrm{P_{pv}^{inst}}}{\mathrm{E_{pv}} \cdot (0{,}7 \cdot \mathrm{Feed_{in}} + 0{,}3 \cdot \mathrm{price}) - \mathrm{curt} \cdot \mathrm{price}} \quad (7)$$

It is obvious from (7) that by reducing the curtailed energy curt it is possible to reduce the payback time $\mathrm{T_{pb}}$. This means that by controlling devices like washing machines and HVAC PV investments can be made more attractive.

This scenario includes a sensitivity analysis in feed-in tariff and payback period.

2.3 Data summary

Data from SmartKYE partners are available for the calculations. A typical load curve of a small building (house) of Crete is used for the load curve for the small scale scenario.

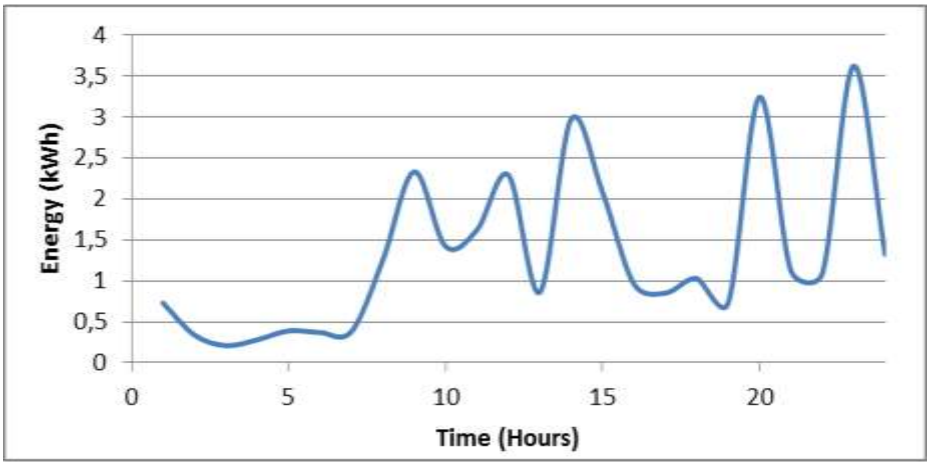


Figure 14 load curve of a small building

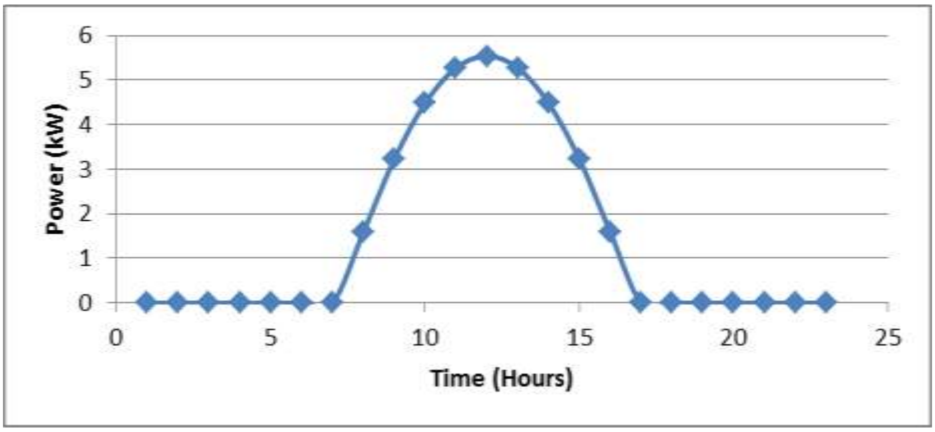


Figure 15 PV production

The load curve of 13 buildings taken from the web site http://en.openei.org/datasets is used for the load curve of the group of building. In the 13 buildings a hospital, hotels and offices are included.

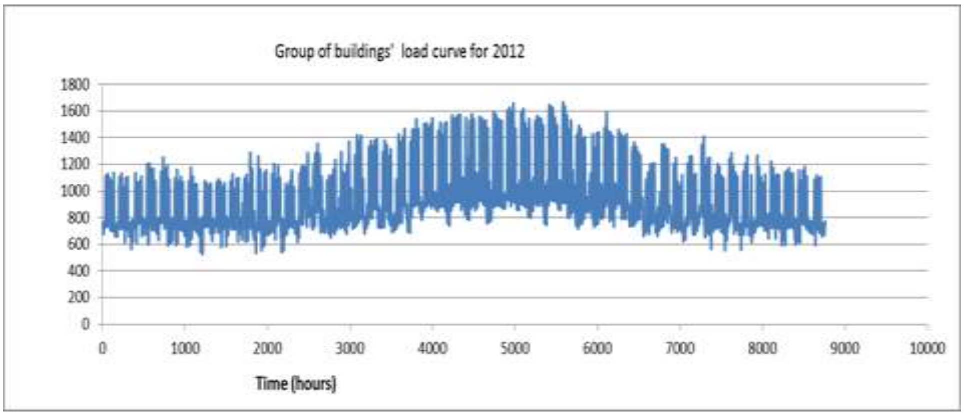


Figure 16 load curve of group of buildings

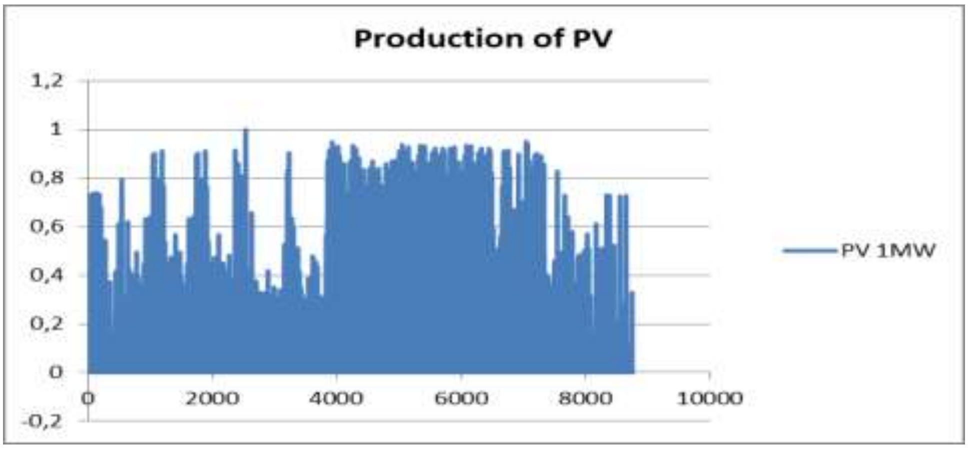


Figure 17 PV production

The load curve of Lasithi of 2012 is used for the load curve of medium communities.

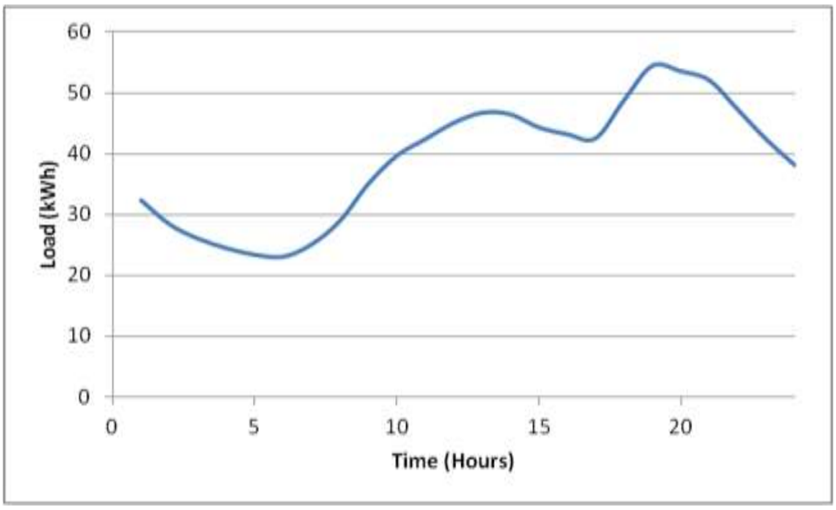


Figure 18 load curve of Lasithi

The wind power production of Crete of 2007 is used for the wind power production.

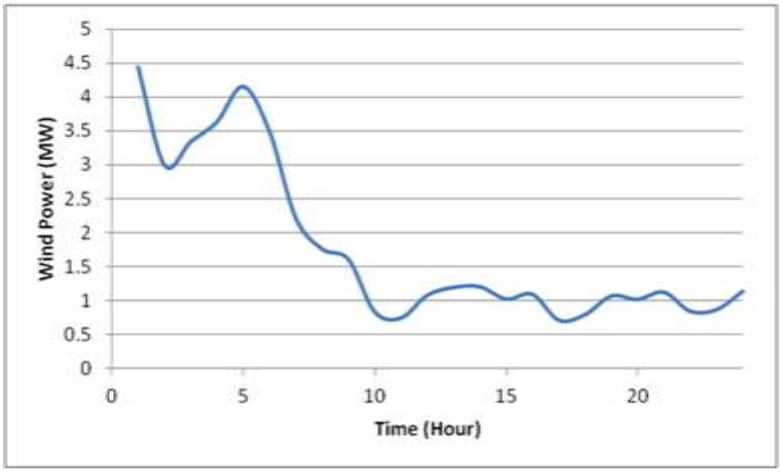


Figure 19 Figure of wind: The wind power production for a random day

The load curve of Crete of 2012 is used for the load curve of large communities.

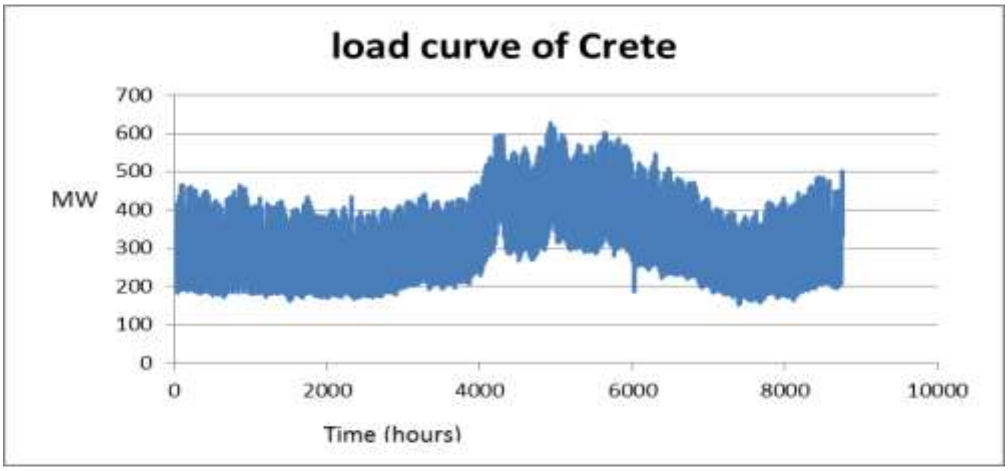


Figure 20 load curve of Crete

The curve of temperature of 2012 is used for the controllable HVAC loads.

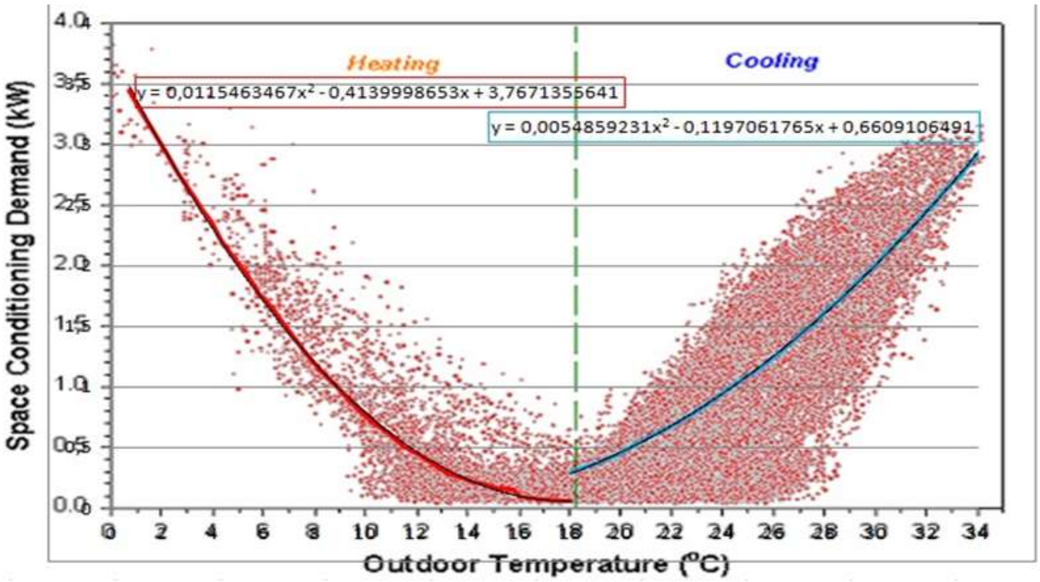


Figure 21 Temperature curve

The probability of a washing machine to be used for each hour loads are taken from "Stamminger, Prof. Dr. Rainer/ D2.3 of WP 2 from the Smart-A project "Synergy Potential of Smart Appliances 2008".

Time	Probability
0:00	0,016
1:00	0,016
2:00	0,016
3:00	0,023
4:00	0,037
5:00	0,051
6:00	0,058
7:00	0,05586
8:00	0,05153
9:00	0,0472
10:00	0,045
11:00	0,04626
12:00	0,04956
13:00	0,05286
14:00	0,055
15:00	0,05561
16:00	0,05694
17:00	0,05827
18:00	0,059

Table 7 The probability of a washing machine to be used for each hour

For the cost analysis two different tariff curves will be used:

1. The tariffs of Spain

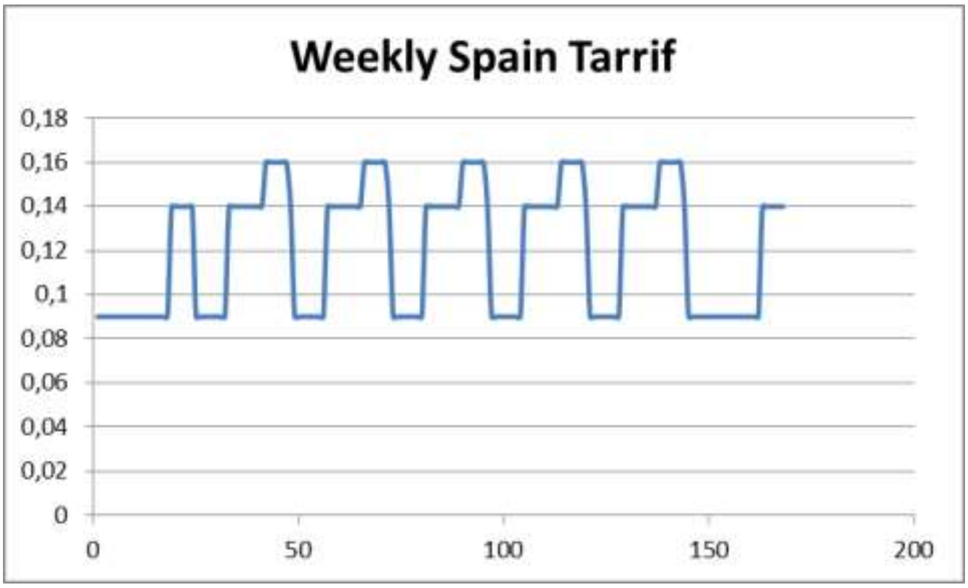


Figure 22 Curve A

2. Variable pricing of electricity with a day average of 0,15

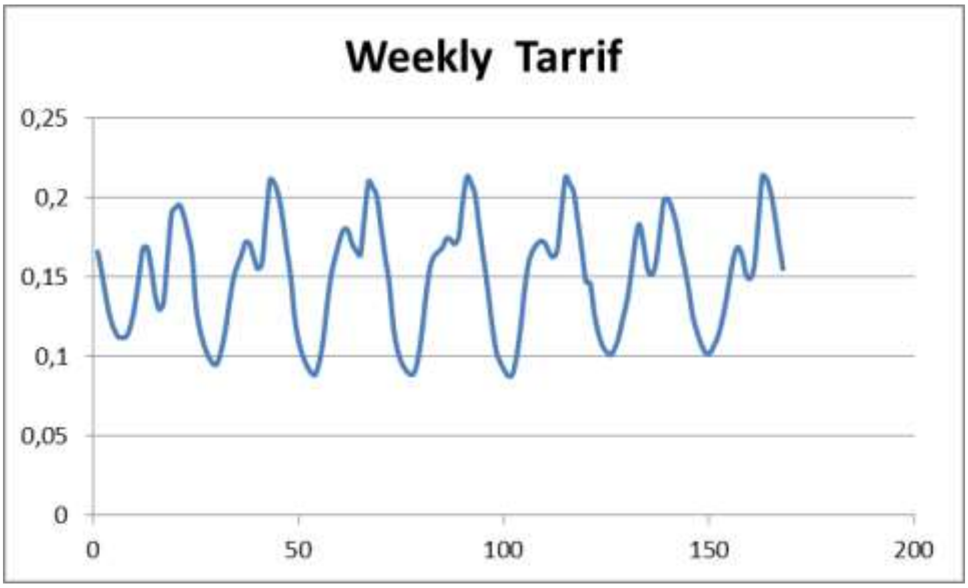
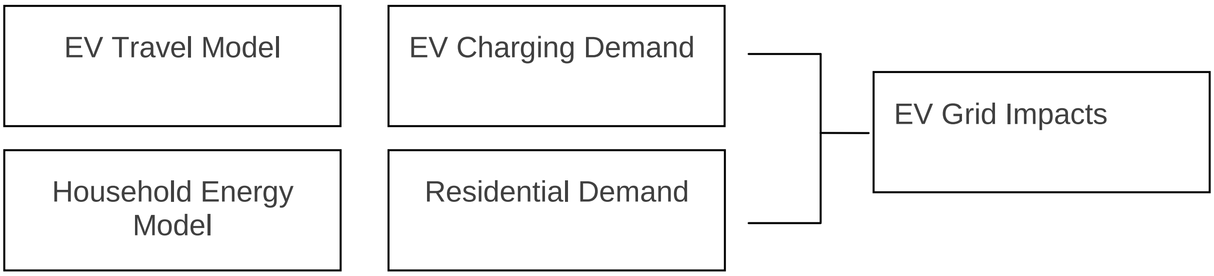


Figure 23 Curve B

2.4 EV Penetration Scenarios

An outline of several EV penetration scenarios and the potential impact on peak electric load will be presented. Models of EV travel by household, household electricity demand and charge/discharge of electric vehicles will be examined.

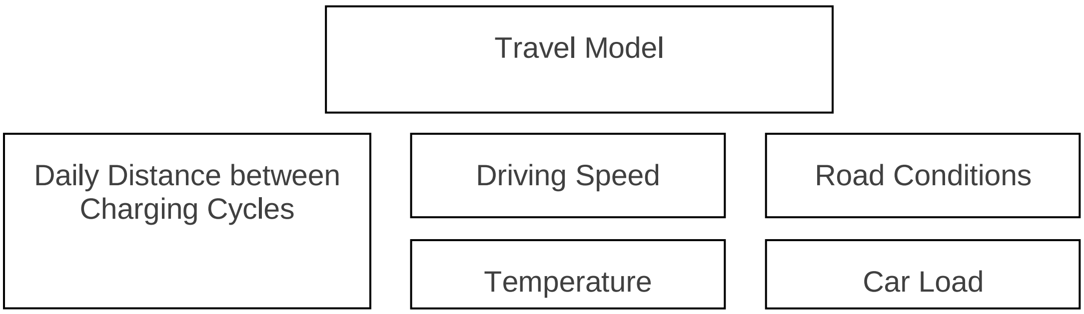


Model Description

A modelling approach is necessary for quantifying, understanding and planning for the impacts of EV charging loads on the electrical distribution network as well as the per household energy demand. Further, it could facilitate the quantification of exploitation scenarios of peak-shaving during high load times.

EV Travel Model

The travel model developed for this study projects likely patterns of vehicle usage and travel duration at hourly and daily timescales. Spatial patterns of vehicle usage have a significant impact on both the timing and duration of home charging of EVs and the shapes of aggregated charging profiles in different regions. For the implementation of the travel model the daily distance covered by an EV between two successive charging cycles is required. By defining the total travelled distance, the corresponding amount of charging energy can be calculated. The ratio between energy consumption and travelled distance (kWh/km) depends on the driving speed, road condition, temperature etc. These parameters are highly changeable and thus an average value kWh/km can be implemented for the purpose of EV analysis.



The travel model outputs can be summarized as probability surfaces for the whole of the city, and for each geographical region considered (e.g. Crete, Barcelona). The probability surfaces produced quantify the travel behaviour that is relevant for estimating EV charging demand at home, and illustrate the proportion of trips for a given home, arrival time and distance travelled.

EV Charging Pattern

The EV Charging and Discharging model is used for projecting hourly EV charging requirements by day of year at spatial scales down to appropriate spatial mesh blocks of relevant neighbourhoods. The EV charging and discharging model uses the outputs from the travel model, to determine the magnitude and timing of daily EV charging energy and power requirements at the base household, as well as the magnitude and timing of potential discharging events where relevant. Three charging modes are considered for the purposes of this study:

- Charging after last trip (home charging): Since the electrification of transportation remains at an initial stage, the number of charging points will be limited. Thus, most of the EV owner will not have the ability to charge their EV anywhere but mainly in their home private charging post.
- Charging when a (public or private) charging point is available: In the previous scenario, EV owner is allowed to charge his EV only when returning at home. In this scenario, an EV owner has also the ability to charge his EV away from home, for example in a workplace. This requires a mass installation of charging points in various private or public areas.
- Charging when the battery state of charge is lower than a desired level: The average travelling distance of an EV is more than 100km according to the current technologies. When the daily travelling distance is limited, for example in urban areas which may be less than 30km, then there is a possibility that the owner will not plug in his EV daily but only when he estimates that it is necessary. In this scenario, it is assumed that an EV owner will charge his EV only when the battery state of charge is lower than a threshold, which is 40%.

3 Typical Small Building

3.1 Introduction

In this chapter the use of the SmartKYE EMS platform for a small building (house, small office etc) will be evaluated. The system is assumed to work for the benefit of the owner, i.e. the municipal. The system in this case will be able to change the working hour of HVAC devices and washing machines, thus performing load shedding. One HVAC device and one washing machine (in case of a public Hospital, Nursery etc) are assumed to be installed. The main two objectives of the SmartKYE platform will be to minimize the total energy cost of the consumer and owner of the system and also minimize the rooftop PV curtailment. The evaluation of the system, as well as the way the system works (how HVAC devices and washing machines are moved in time) is described in this chapter.

3.2 Business as Usual

In this section the small scale scenario will be examined. Specifically, the case of a building with controllable HVAC loads and washing machines will be studied. The washing machine is presumed to work every other day. In addition, PVs are installed on the rooftop of the building.

An EMS is assumed to be installed in the building. The EMS can control one HVAC device and one washing machine. The objective of the EMS is to minimize PV curtailment and consumer cost.

Figure 24 presents a sample load curve of a small building while **Figure 25** presents a typical 24h production for the PVs.

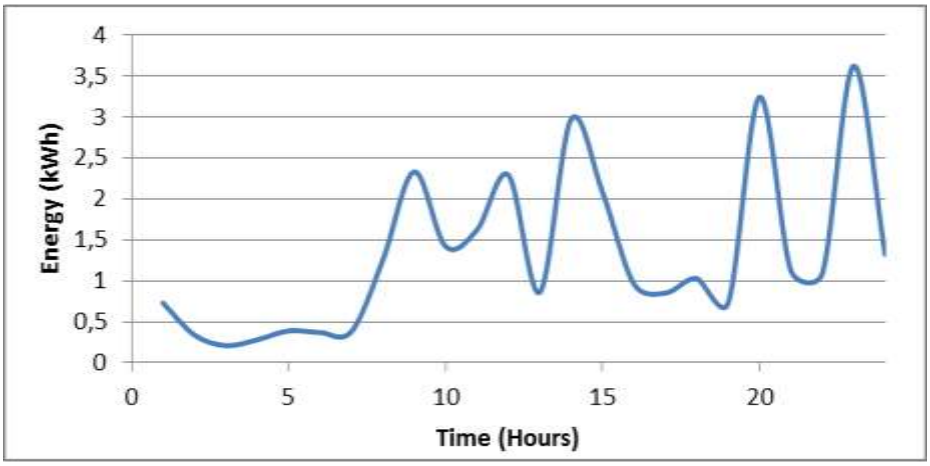


Figure 24 Typical consumption of a small building (e.g. office, hospital etc) (for a day)

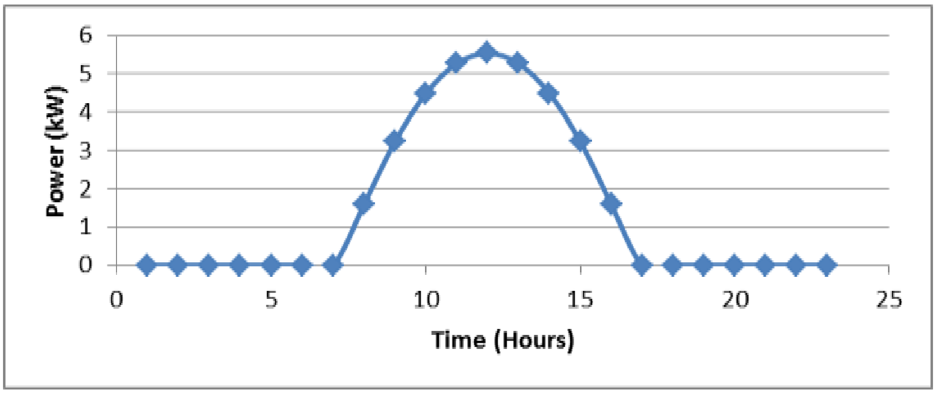


Figure 25 Typical PV production for a 10kW photovoltaic generator

The building is supposed to include an HVAC system and a washing machine. The HVAC consumption varies according to the temperature value while the typical energy consumed by a washing machine is assumed to be 1kWh. Fig. 26 shows the equations used to calculate HVAC consumption as a function of outdoor temperature. Temperature will be considered as a parameter of the analysis throughout this report. The temperature parameter (often seen in the x-axis of diagrams) is the mean temperature of the place the EMS is installed, and it is considered in order to evaluate the system output for various geographical locations.

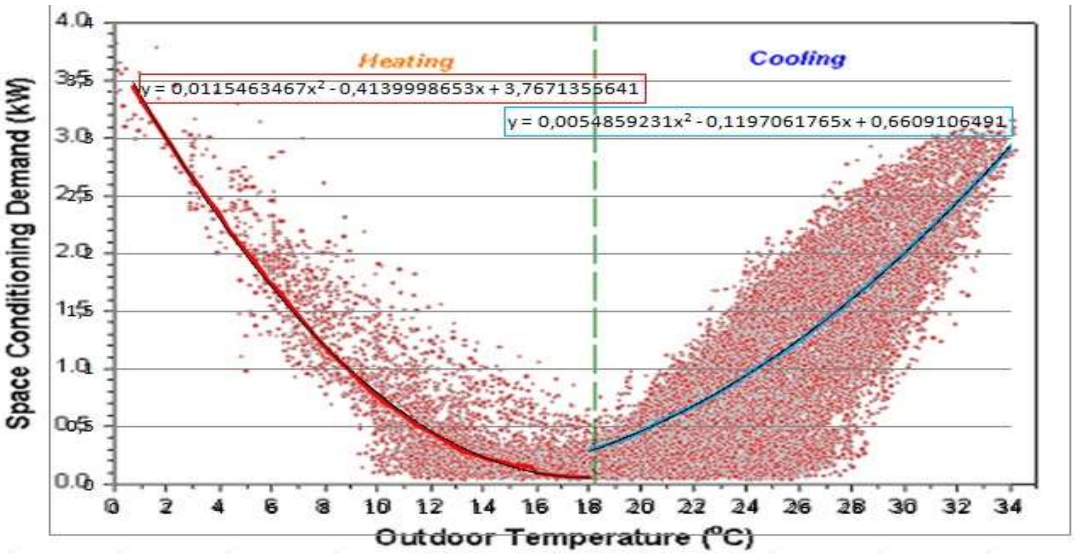


Figure 26 HVAC consumption curves

Figure 26 is provided as an example of how PV curtailment is calculated in the case of a rooftop PV when the German Act (explained in Chapter 1) is in use.

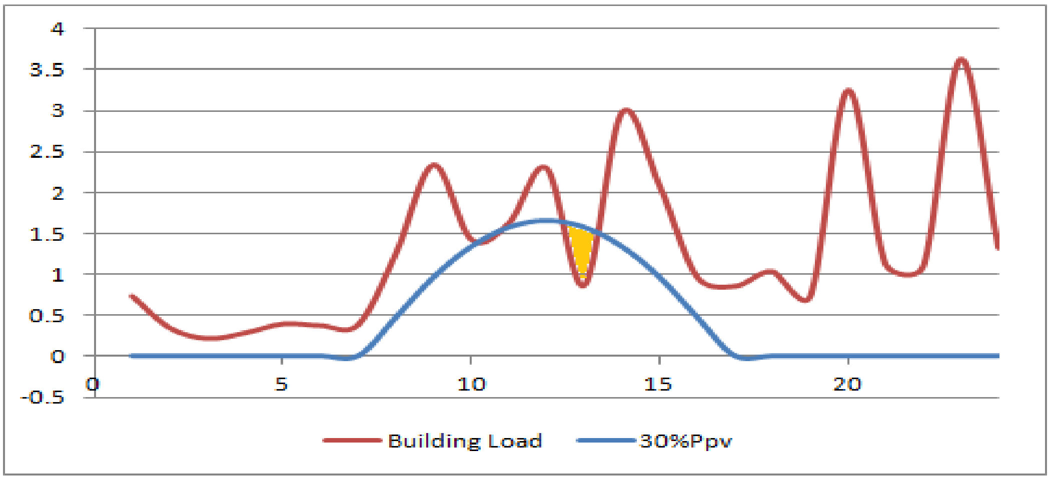


Figure 27 Energy curtailment for a building with PV installed capacity of 10kW.

Table 8 Business as Usual (small building)

Scenario Business as Usual (BAU)	
Total Cost	
Price Curve A:	2700 Euros
Price Curve B:	3350 Euros
Wind Power Curtailment	
5 kW installed PV capacity	10 kWh
10 kW installed PV capacity	150 kWh
15 kW installed PV capacity	550 h

3.3 HVAC Control Scenario

In the case of controllable HVAC the EMS can move the use of the device one hour back in time. The way the EMS minimizes PV curtailment in this case is described next: If there is no curtailment in the next hour and if there is some curtailment in the current hour, then HVAC can be moved from the next hour to the current one.

In order to minimize the cost, the EMS moves the HVAC devices one hour back in time strictly when the price of the previous hour is lower than the one of the current hour.

In addition, the case of a cold year/place and a second case, for a hotter one are studied in order to include temperature in the analysis.

3.3.1 Minimize PV Curtailment

Figure 27 and **Figure 28** show the reduction in PV curtailment for a cold and a hot year/place as a function of the installed PV capacity. For a typical 10 kW rooftop PV the reduction in curtailment is close to 15% assuming low temperatures and 20% assuming high.

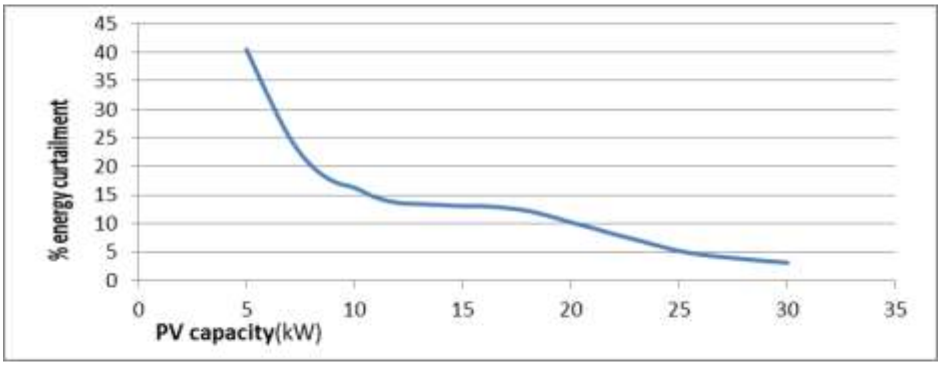


Figure 28 Reduction in Curtailment for low temperatures.

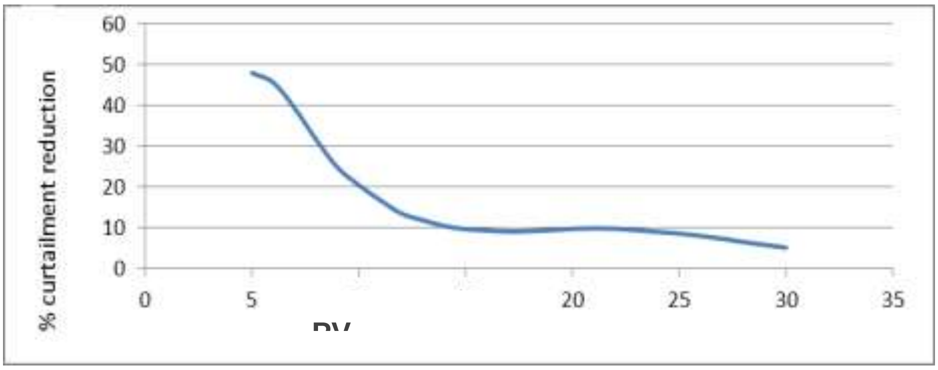


Figure 29 Reduction in Curtailment for high temperatures.

The reduction that would be caused to the payback time of the rooftop PV investment is also calculated and presented as a function of the installed PV capacity in **Figure 29**, assuming a very positive scenario of a feed-in tariff of 0.25euros/kWh and an energy cost of 0.1euros/kWh. The reduction in payback time due to curtailment reduction is negligible.

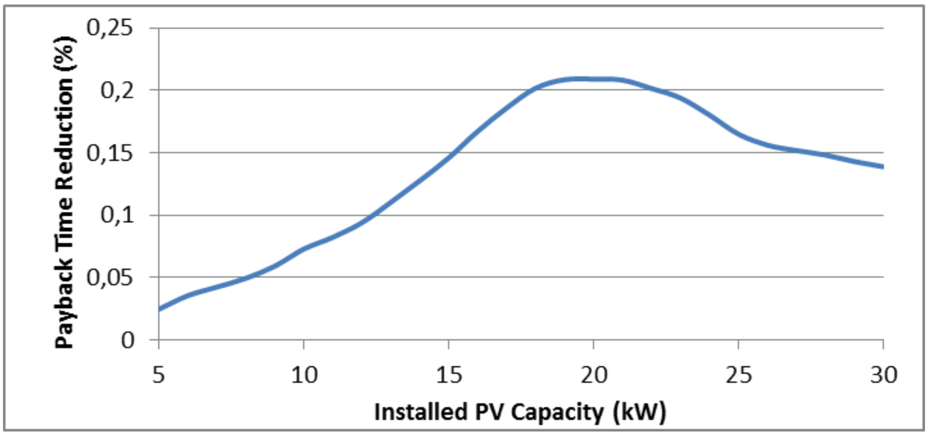


Figure 30 Reduction in payback time for rooftop PV investment

3.3.2 Minimize Consumer Cost

The second goal of a building EMS system would be to minimize the cost of electricity for the municipal. This scenario includes of course variable pricing of electricity. In that case, the user would like to minimize his cost by moving loads from high price time zones to lower price time zones as described previously.

Cost reduction as a function of the year temperature level is presented in Figures 31 and 32, for the two different price curves (Chapter 1). A maximum reduction of 1.8% (or 2.2% for price curve A) of reduction in the consumer cost is calculated for the scenario of a very hot year/place. This reduction is quite small since we are referring to a single consumer.

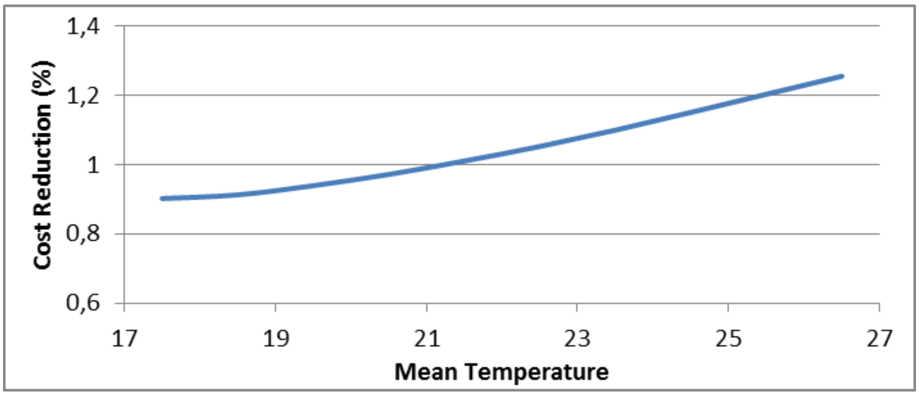


Figure 31 Cost reduction as a function of mean temperature for Cost Curve A

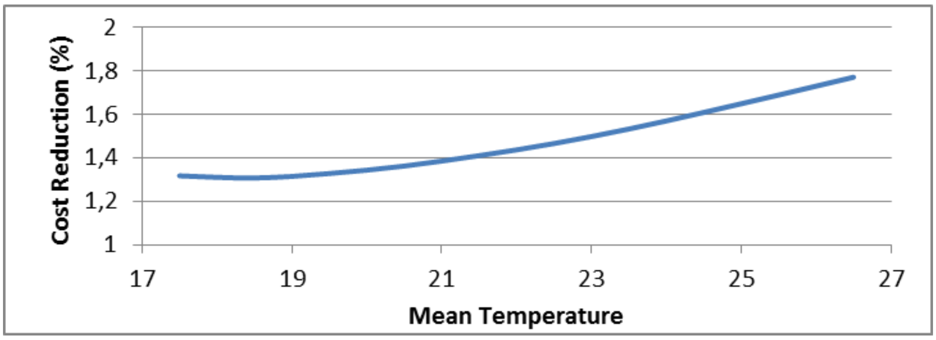


Figure 32 Cost reduction as a function of mean temperature for Cost Curve B

3.4 Washing Machine Control Scenario

The EMS is assumed to have the ability to control washing machines. In the washing machine scenario one should keep in mind that the time a consumer typically uses his washing machine varies a lot. In that manner two cases (one for 23:00 and one for 20:00) will be examined. A case where the user uses his washing machine at a time where PV production takes place is not of interest at least for the PV curtailment reduction objective. In addition, two more cases for the washing machine energy (a wash is assumed to last one hour and is not interruptible) are studied: in the first case a 1kWh wash energy is assumed and in the second one 0.5 kWh wash energy is assumed.

3.4.1 Minimize PV Curtailment

Figures 33-36 show the PV curtailment reduction as a function of the installed rooftop PV capacity. Wherever negative values are spotted (for example Fig.33) there is no actual PV curtailment. These cases should not be taken into account. The maximum reduction in curtailment reaches 1.6 % in any case.

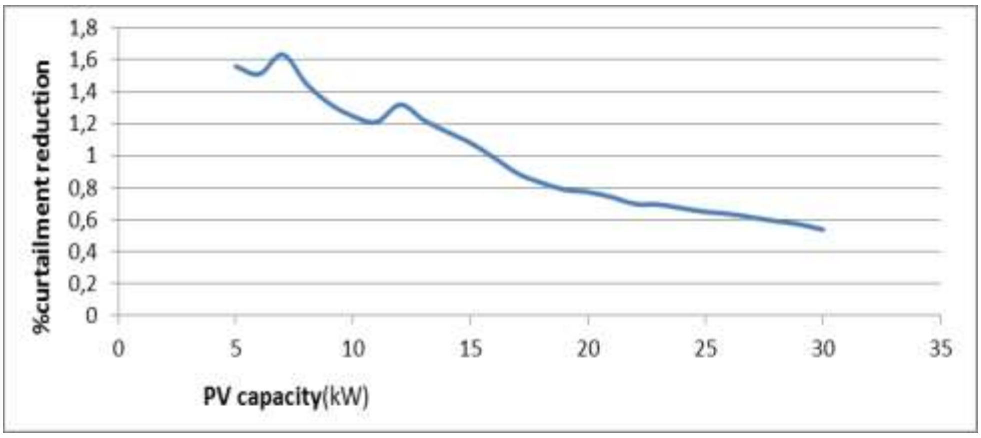


Figure 33 Reduction in Curtailment if initial washing hour is 23.00 and wash energy 1kWh

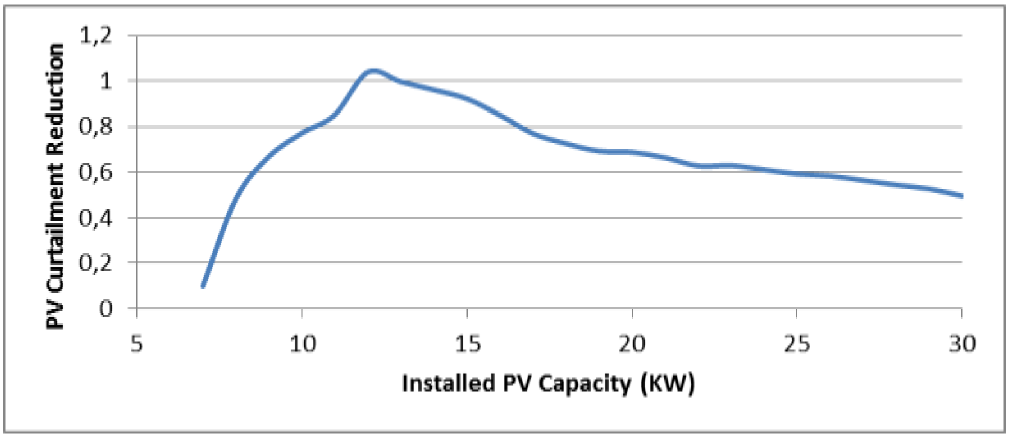


Figure 34 Reduction in Curtailment if initial washing hour is 20.00 and wash energy 1kWh

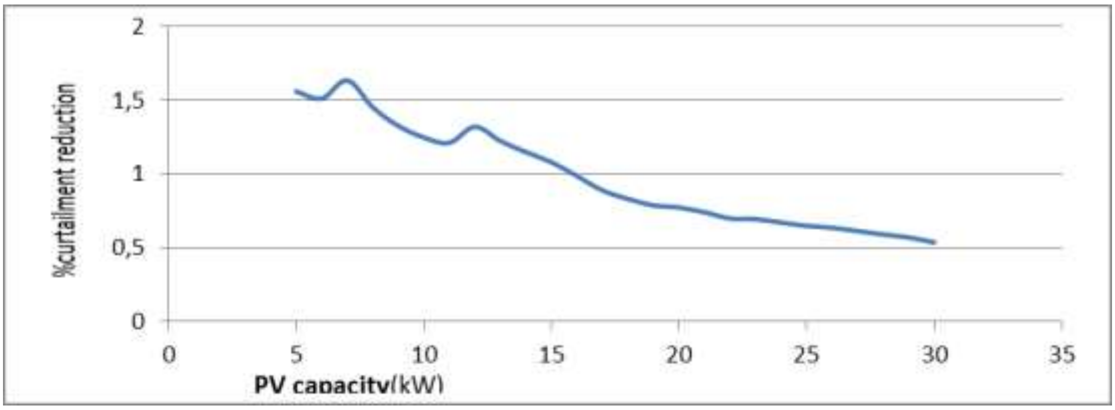


Figure 35 Reduction in Curtailment if initial washing hour is 23.00 and wash energy 0.5kWh

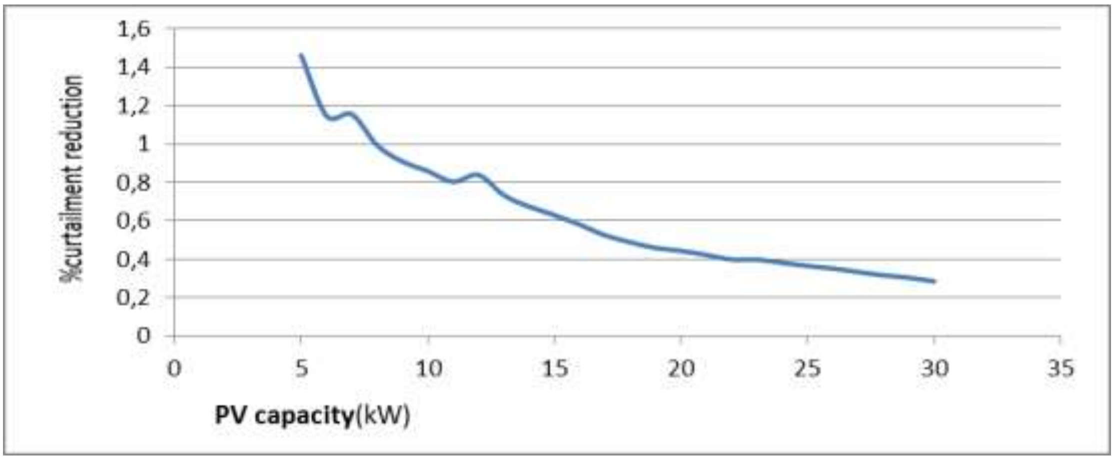


Figure 36 Reduction in Curtailment if initial washing hour is 20.00 and wash energy 0.5kWh

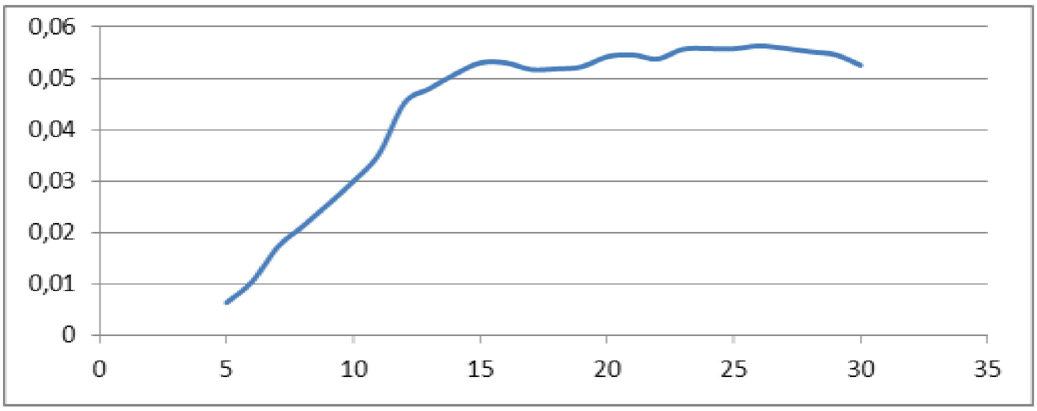


Figure 37 Reduction in PV investment payback time for feed-in tariff=0.25e/kWh and cost=0.1euros/kWh

In addition, the reduction of the payback time of the rooftop PV installation investment is calculated as a function of the installed PV capacity, and assuming a feed-in tariff of 0,25euros/kWh, cost of energy for the consumer 0,10euros/kWh and cost of PV installation

3000 Euros/kW. A maximum reduction of about 0.06% in the payback time is achieved which can be assumed to be negligible.

3.4.2 Minimize Consumer Cost

In this chapter the effects of moving washing machines to minimize consumer energy cost are presented. Figures 38- 41 show the cost reduction (%) as a function of the hour of the day the consumer typically uses his washing machine. A maximum reduction of 2% in the consumer yearly energy cost is calculated (Figure 40) for a consumer that uses his washing machine in times when the energy price has its maximum value.

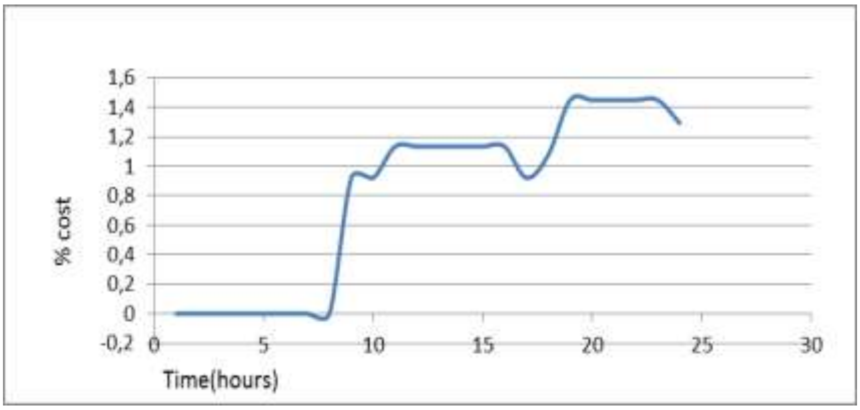


Figure 38 Cost reduction as a function of the time of wash for cost curve A and wash energy of 1kWh

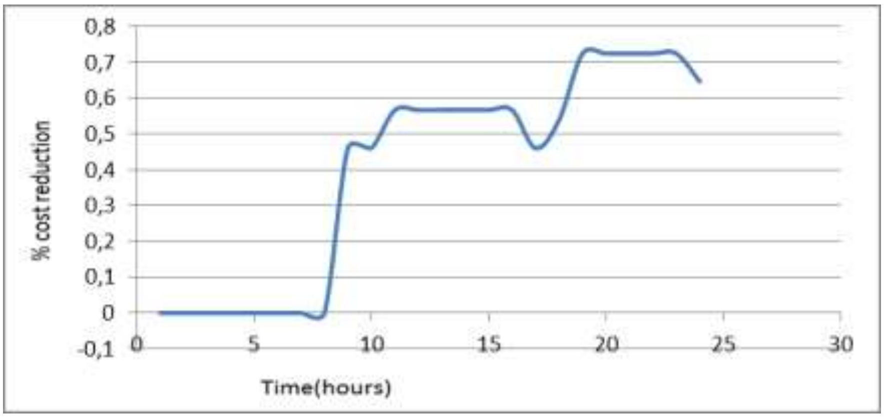


Figure 39 Cost reduction as a function of the time of wash for cost curve A and wash energy of 0.5kWh

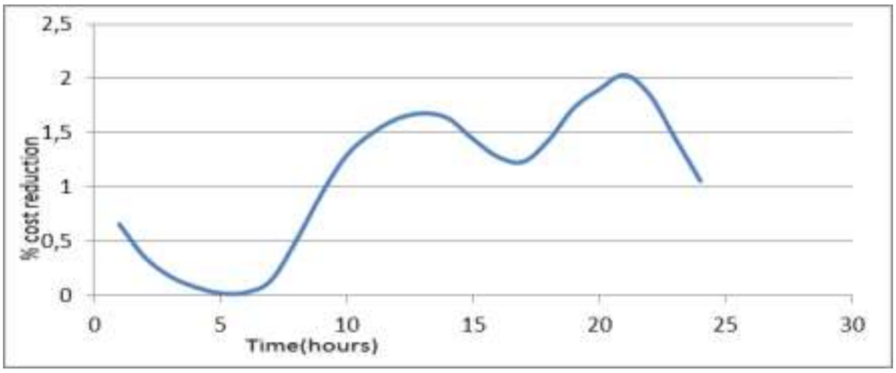


Figure 40 Cost reduction as a function of the time of wash for cost curve B and wash energy of 1kWh

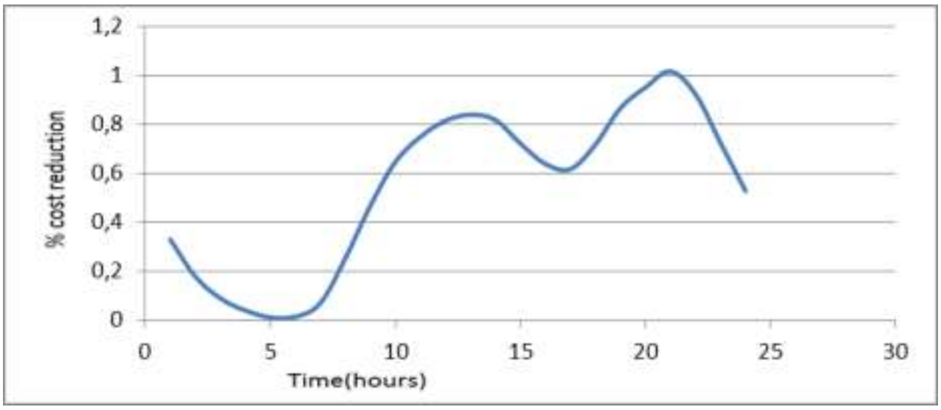


Figure 41 Cost reduction as a function of the time of wash for cost curve B and wash energy of 0.5kWh

4 Hospitals/Offices

4.1 Introduction

In this chapter the use of the SmartKYE EMS platform for a large building or group of buildings (hospitals, hotels, nursery homes, and large offices) will be evaluated. The system is assumed to work for the benefit of the building owner, i.e. the energy consumer. The system in this case will be able to change the working hour of HVAC devices and washing machines, thus performing load shedding. A variable number of HVAC device and washing machines are assumed to be installed. The main two objectives of the SmartKYE platform will be to minimize the total energy cost of the consumer and owner of the system and also minimize the rooftop PV curtailment. The evaluation of the system, as well as the way the system works (how HVAC devices and washing machines are moved in time) is described in this chapter.

4.2 Business as Usual

In this chapter the case of large buildings or groups of buildings will be studied. Hospitals, nursery homes, hotels and large office buildings belong to this category. The EMS is assumed to control washing machines and HVAC devices.

In order to provide an analysis for this scenario data for a total of 13 buildings are used. The peak of the load curve reaches 1.6MW. A typical day load curve (hourly values) for all 13 buildings is presented in **Figure 42**, while the annual load curve is presented in fig. 43.

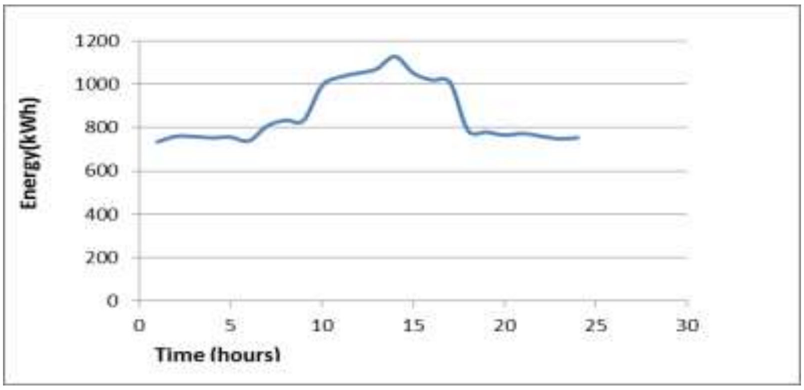


Figure 42 Typical Consumption for one day

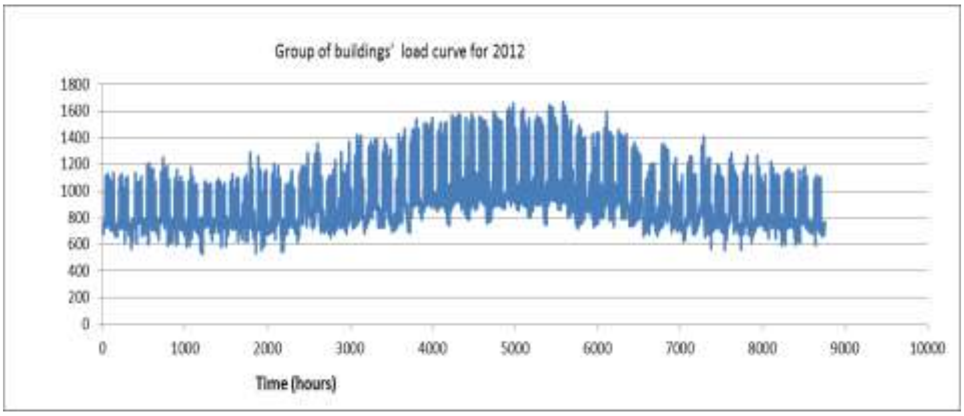


Figure 43 Annual load curve for the group of 13 buildings

Washing machines are of course only considered for the case of hospitals, nursery homes and hotels and not for offices. The number of washing machines (all of which are considered to be controllable be the EMS) is used as a parameter of the analysis and ranges from 50-120, as well as the energy used by a washing machines (ranging from 2kWh-4kWh).

HVAC energy use is calculated as in Chapter 2 only for a larger number of HVAC devices ranging from 50-150.

Finally, the building installations include PVs ranging from 2MW-10MW of installed capacity. Figure 43 shows typical PV production for the chosen range of installed PV capacity.

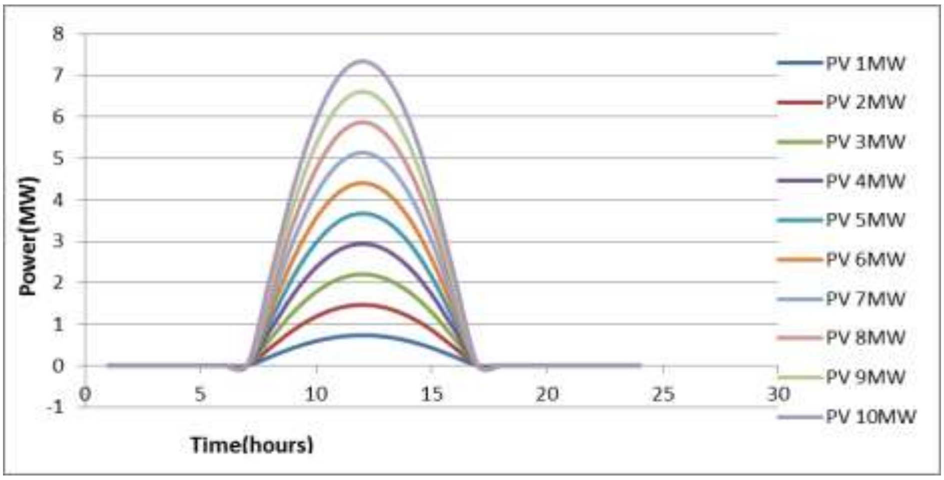


Figure 44 Typical PV production for 1-10MW photovoltaic generators.

Figures 46-51 show the PV energy curtailment for 5MW-10MW of installed PV capacity. Energy curtailment is once again calculated assuming the German Act is in use.

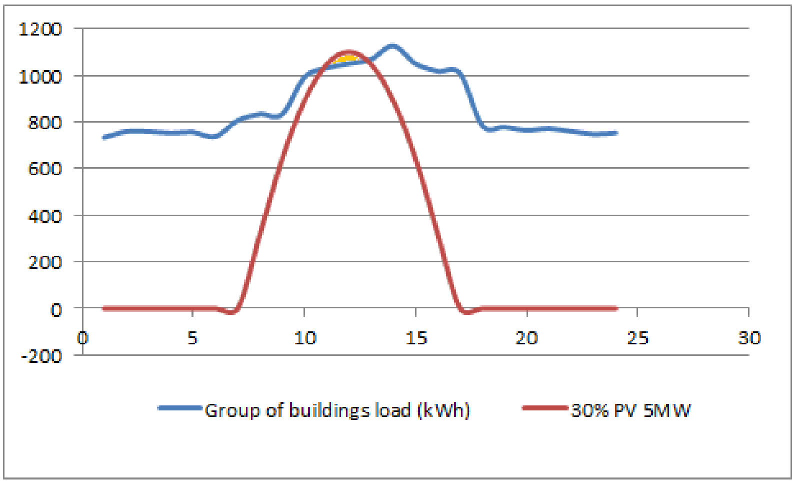


Figure 45 Energy curtailment for a group of buildings with PV installed capacity of 5MW.

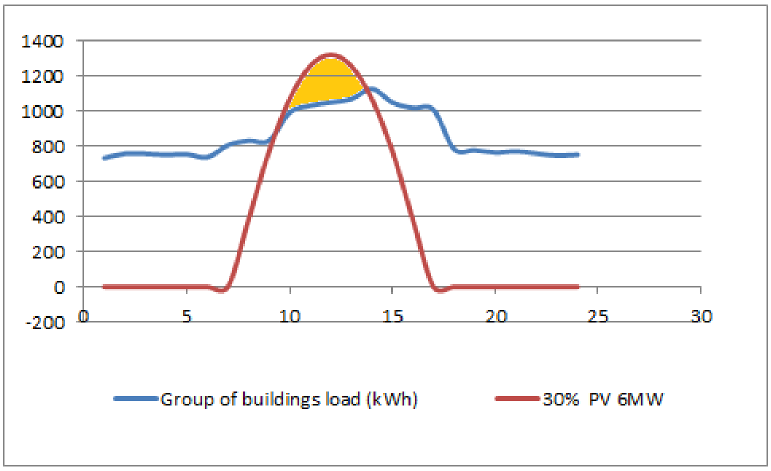


Figure 46 Energy curtailment for a group of buildings with PV installed capacity of 6MW

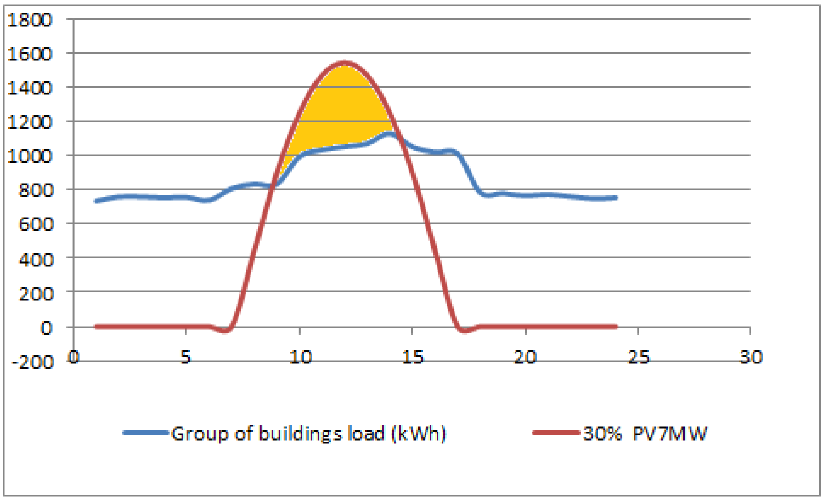


Figure 47 Energy curtailment for a group of buildings with PV installed capacity of 7MW.

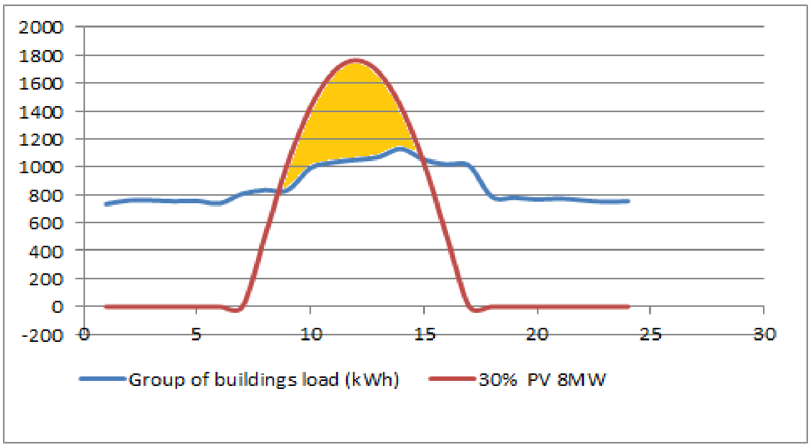


Figure 48 Energy curtailment for a group of buildings with PV installed capacity of 8MW.

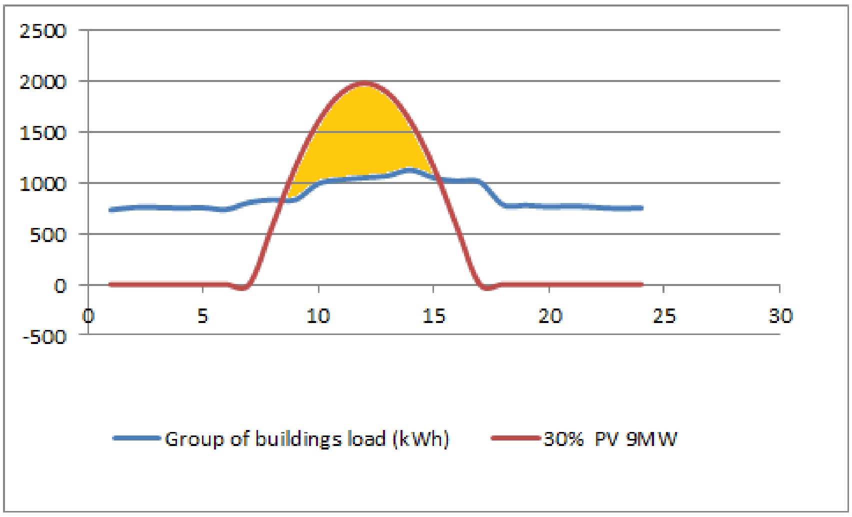


Figure 49 Energy curtailment for a group of buildings with PV installed capacity of 9MW

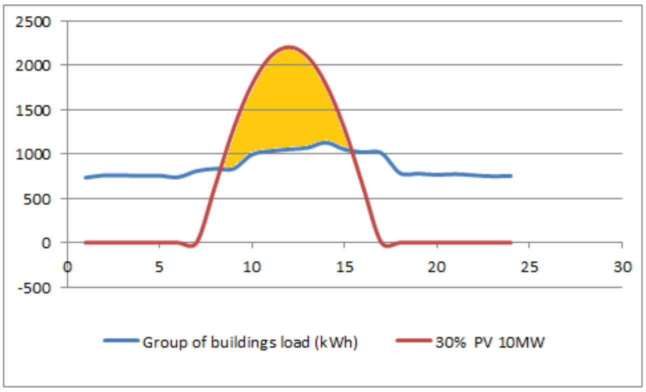


Figure 50 Energy curtailment for a group of buildings with PV installed capacity of 10MW.

Figure 51shows the case of no PV curtailment for a specific day (PV capacities 1-4MW)

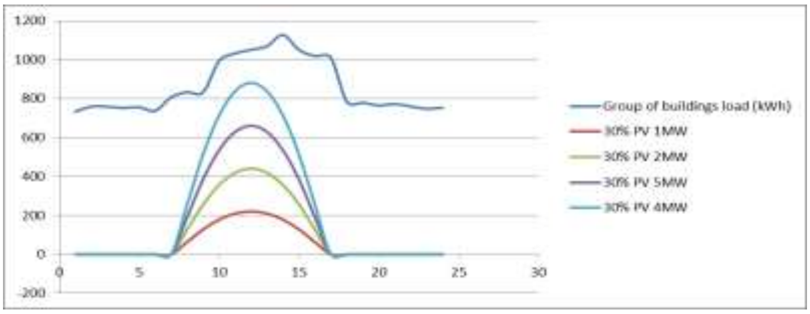


Figure 51 there is no energy curtailment for a group of buildings with PV installed capacity of 1-4MW.

Figure 51 and **Figure 52** show the daily and monthly cost of the group of buildings according to electricity tariffs of Spain (cost curve A). For the year 2012 the total cost was **984.696€.**

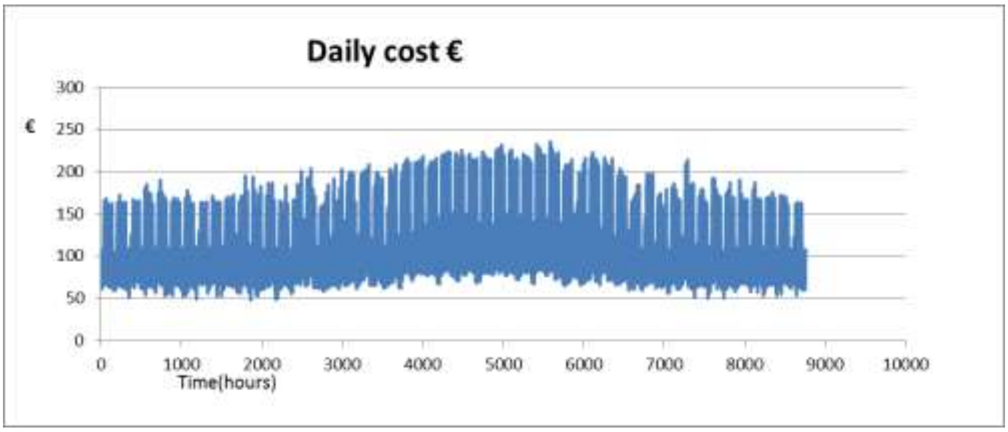


Figure 52 Daily cost (€) for the group of 13 buildings assuming price curve A

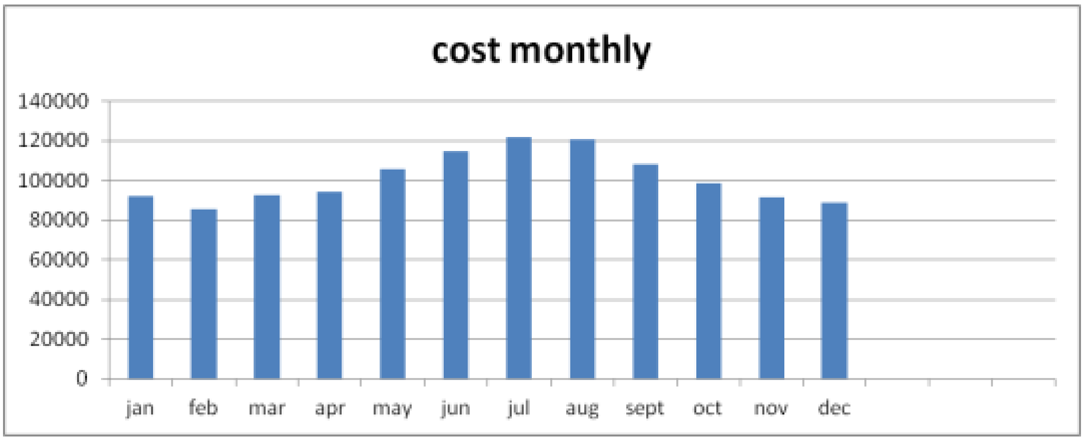


Figure 53 Monthly cost (€) for the group of 13 buildings assuming price curve A

Figure 53 and **Figure 54** show the daily and monthly cost of the group of buildings assuming cost curve B. For the year 2012 the total cost was **1.214.253€**

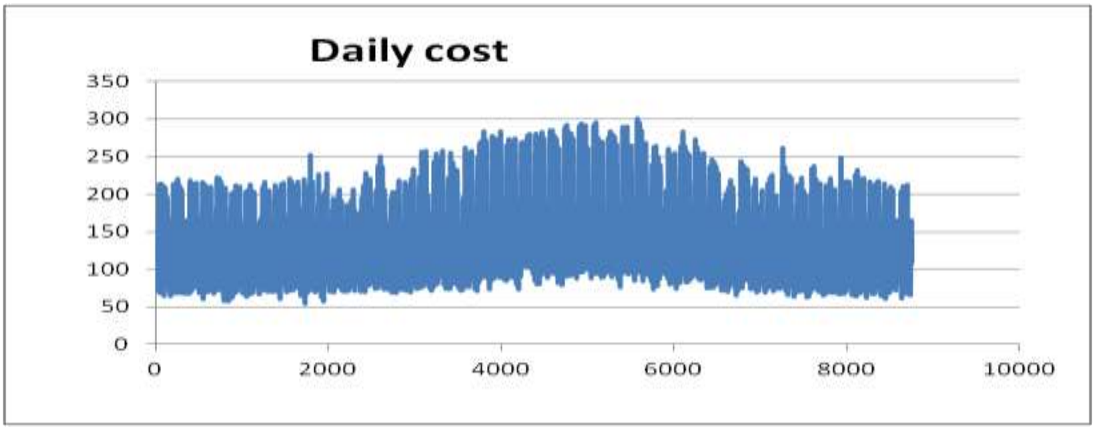


Figure 54 Daily cost (€) for the group of 13 buildings assuming price curve B

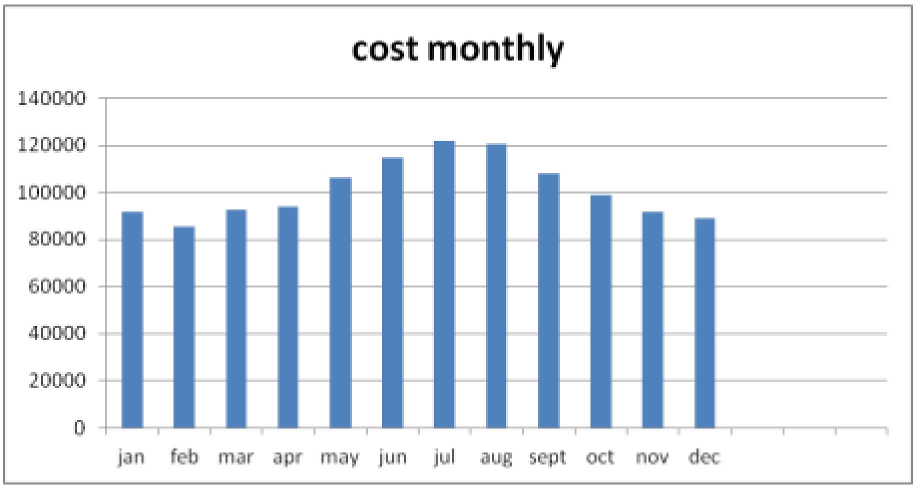


Figure 55 Monthly cost (€) for the group of 13 buildings assuming price curve B

4.3 HVAC Control Scenario

HVAC control is executed in this case in the same way as of the single building/house. HVAC devices are controlled by the EMS is order to minimize PV curtailment and consumer energy cost.

4.3.1 : Minimize PV Curtailment

Figure 55 shows the reduction in PV curtailment for installed PV capacity of 10 MW as a function of the installed controllable HVAC devices. For 150 devices the reduction in PV curtailment reaches 1.7%.

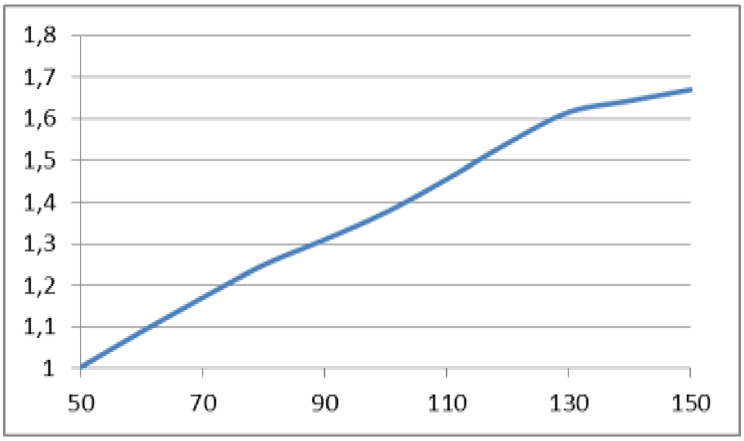


Figure 56 PV curtailment reduction as a function of the number of HVAC devices for installed PV capacity of 10 MW

Figure 56 shows the PV curtailment reduction as a function of the installed PV capacity (MW) assuming 100 HVAC devices. It can be observed in that case that for installed PV capacities greater than 2.5MW the reduction in curtailment is less than 10% and mostly close to 3-4%. PV capacities close to 2MW are too small for curtailment to even exist (or curtailment is too small). Fig 58 shows the same results (only a little better) for a hot year/place, while figures 59 and 60 present the same results for 50 HVAC devices. In that case curtailment is reduced in a worse manner.

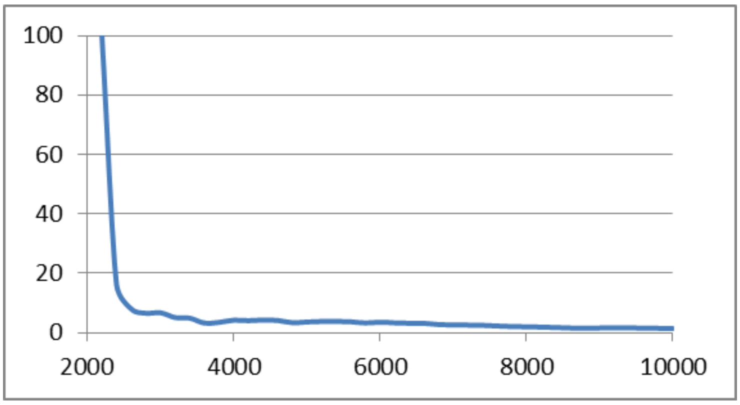


Figure 57 PV curtailment reduction as a function of the installed PV capacity 100 HVAC devices and cold year

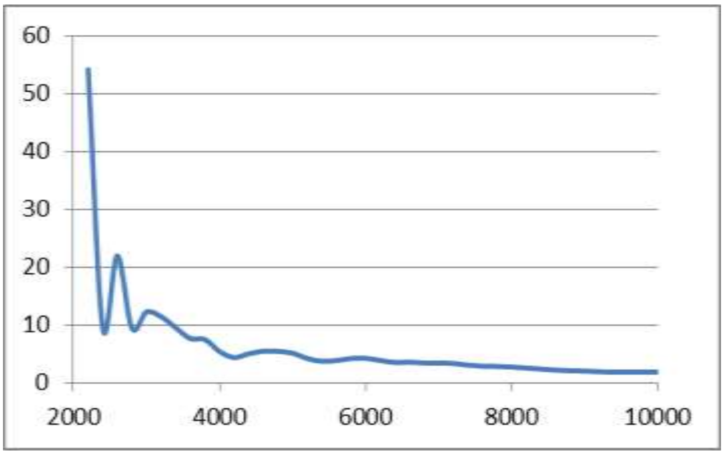


Figure 58 PV curtailment reduction as a function of the installed PV capacity 100 HVAC devices and hot year/place

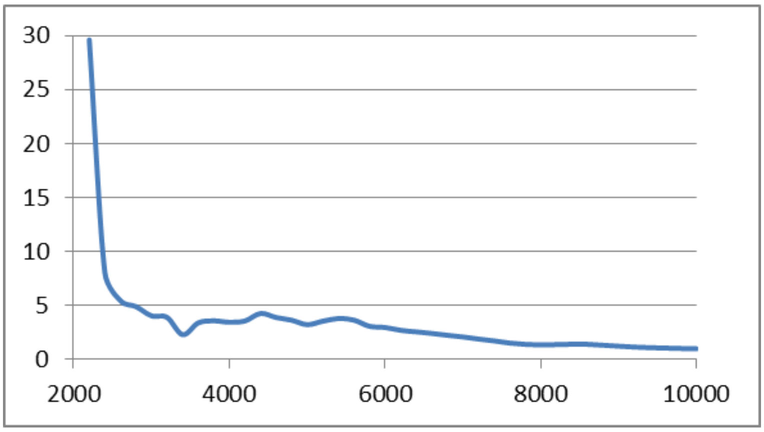


Figure 59 PV curtailment reduction as a function of the installed PV capacity 50 HVAC devices and cold year

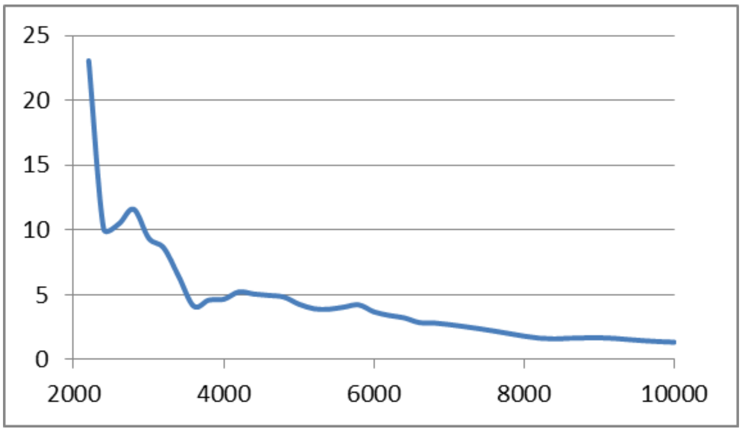


Figure 60 PV curtailment reduction as a function of the installed PV capacity 50 HVAC devices and hot year/place

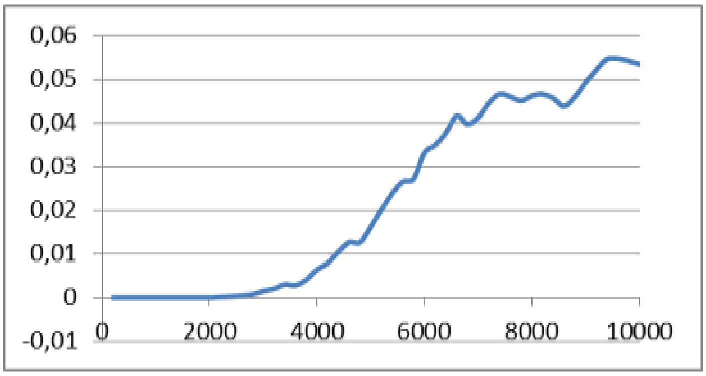


Figure 61 Reduction in PV investment payback time for feed-in tariff=0.25e/kWh and cost=0.1euros/kWh

Finally, in **Figure 60** the reduction in the investment payback time is calculated with minimal results.

4.3.2 Minimize Consumer Cost

Consumer cost reduction is presented in this chapter. Figures 62 and 63 show the cost reduction as a function of the number of HVAC devices for the two price curves presented in Chapter 1. A maximum reduction (with price curve B) of 2.94% is achieved for 150 HVAC devices.

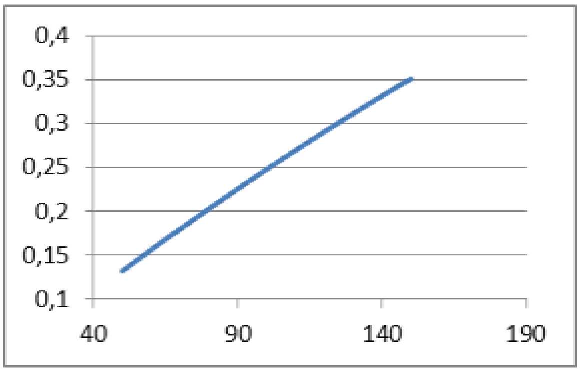


Figure 62 Cost reduction as a function of the number of HVAC devices for cost curve A

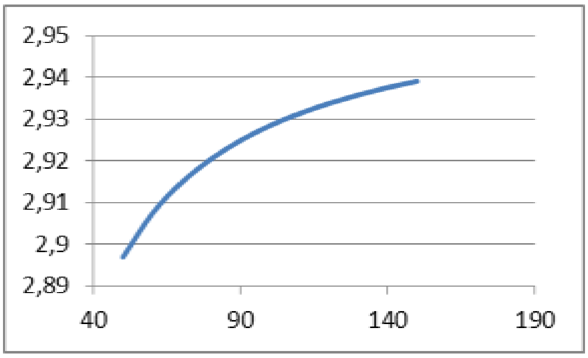


Figure 63 Cost reduction as a function of the number of HVAC devices for cost curve B

4.4 Washing Machine Control Scenario (not for offices)

This chapter presents the results for washing machine control in the case of a group of buildings. Washing machines are typically used at a standard time in the case of hospitals, hotels etc and are not distributed in the day. All the energy used by the washing machines will be distributed to the hours where PV curtailment takes place.

4.4.1 Minimize PV Curtailment

Figures 65 to 70 present various combinations of washing machines numbers (80 or 120) and washing machine energy (2, 3 and 4kWh). Results seem to be relatively good especially for installed PV capacities between 4-8MW while reduction in PV curtailment for a PV capacity of 10MW varies between 2-8% with the best case being 8.22% (120 washing machines of 4kWh energy).

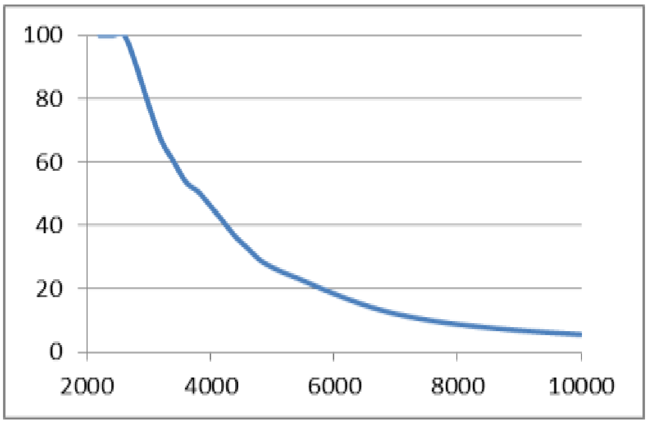


Figure 64 Curtailment reduction as a function of installed PV capacity for wash energy of 4kWh and 80 washing machines

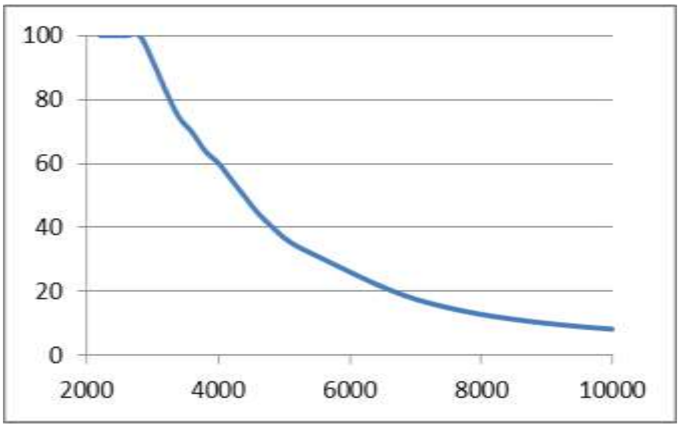


Figure 65 Curtailment reduction as a function of installed PV capacity for wash energy of 4kWh and 120 washing machines

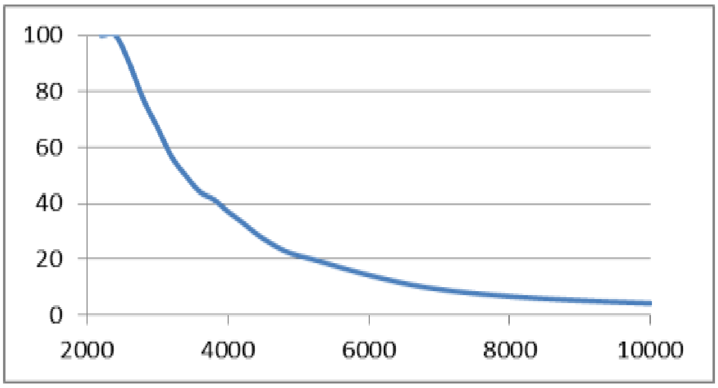


Figure 66 Curtailment reduction as a function of installed PV capacity for wash energy of 3kWh and 80 washing machines

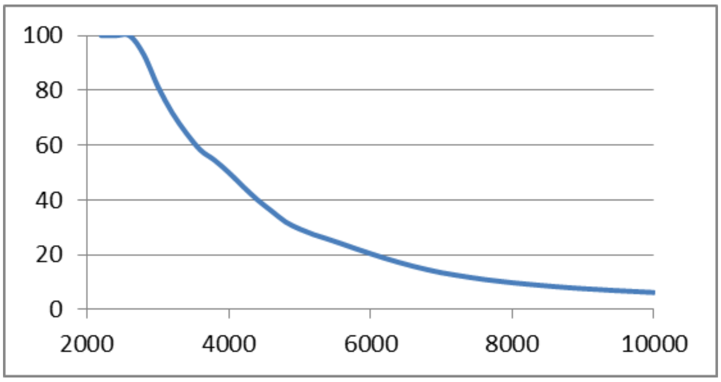


Figure 67 Curtailment reduction as a function of installed PV capacity for wash energy of 3kWh and 120 washing machines

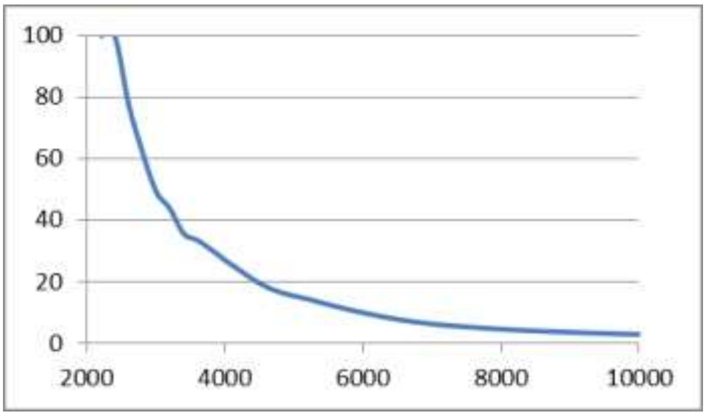


Figure 68 Curtailment reduction as a function of installed PV capacity for wash energy of 2kWh and 80 washing machines

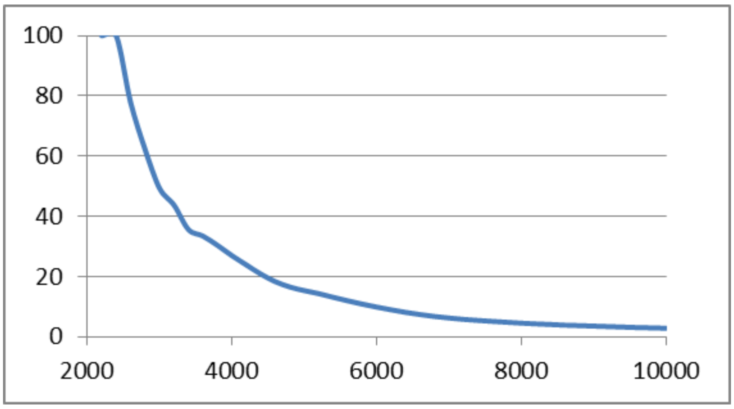


Figure 69 Curtailment reduction as a function of installed PV capacity for wash energy of 2kWh and 120 washing machines

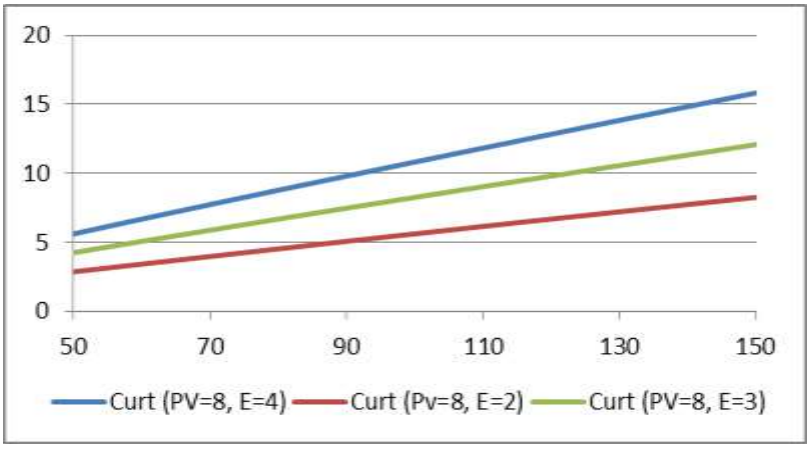


Figure 70 Curtailment reduction as a function of the number of washing machines for wash energy of 2-4kWh and installed PV capacity 8MW.

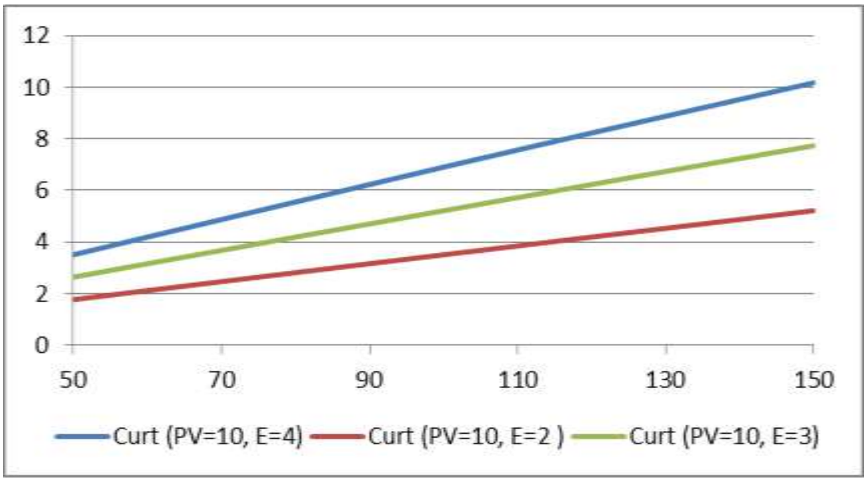


Figure 71 Curtailment reduction as a function of the number of washing machines for wash energy of 2-4kWh and installed PV capacity 10 MW.

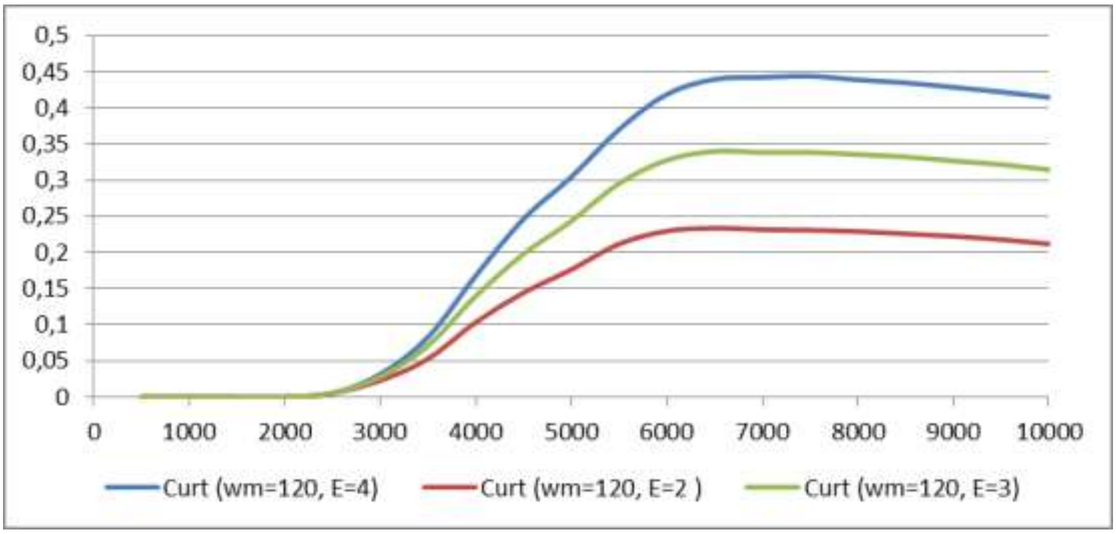


Figure 72 Reduction in PV investment payback time for feed-in tariff=0.25e/kWh and cost=0.1euros/kWh (120 washing machines)

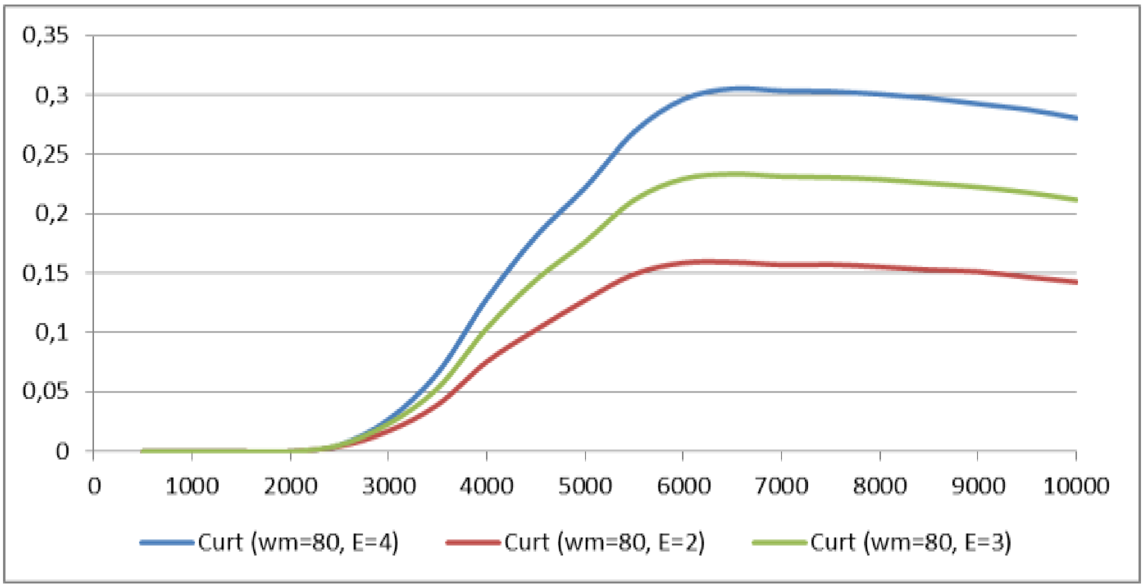


Figure 73 Reduction in PV investment payback time for feed-in tariff=0.25e/kWh and cost=0.1euros/kWh (120 washing machines)

Payback time is again calculated for various scenarios as a function of the installed PV capacity again producing minimal results (Figures 73 and 74)

4.4.2 Minimize Consumer Cost

Consumer cost minimization is calculated as a function of the total washing machine energy (i.e. combinations of number of washing machines and wash energy, for example 200kWh would be either 100 washing machines of 2kWh or 50 washing machines of 4kWh etc). The cost reduction is calculated for the two cost curves (A and B) in figures 75 and 76. Assuming that initially all the washing machines are operated at a standard hour (for example at 23.00 hours), the only action an EMS system should take is move the washing machines to the minimum price hour. The maximum reduction is close to 1% for both curves.

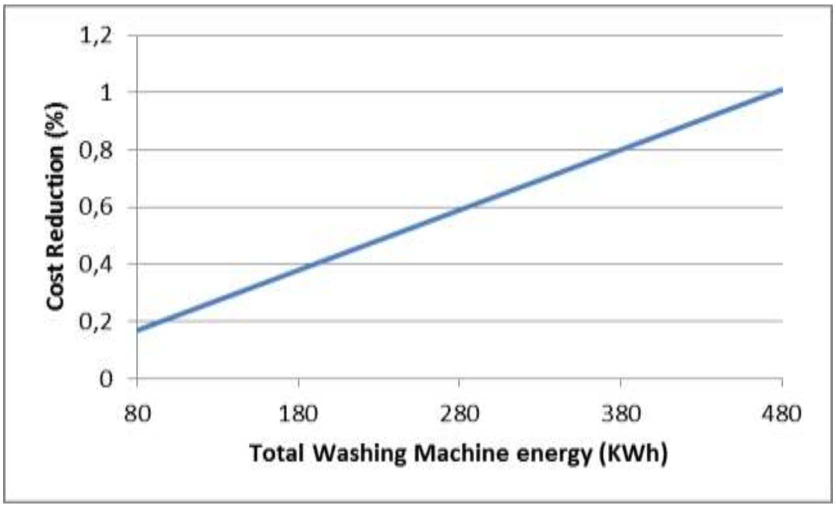


Figure 74 Cost reduction (%) as a function of total washing machine energy for cost curve A.

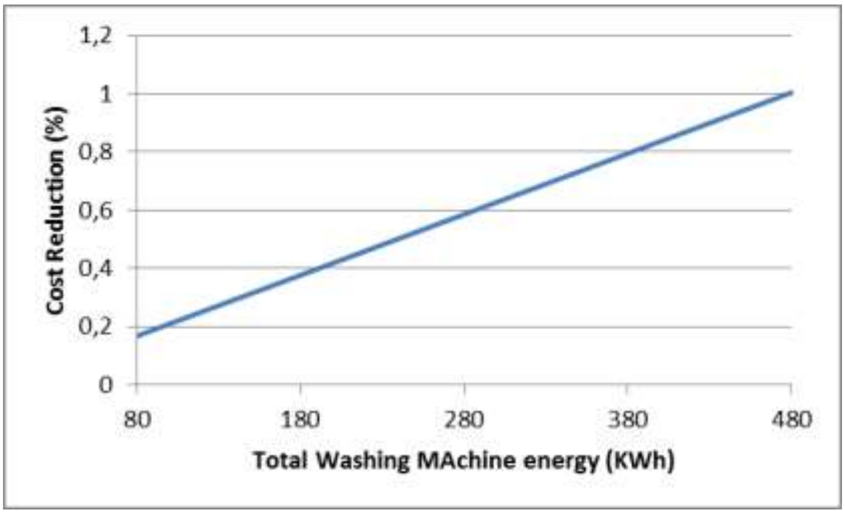


Figure 75 Cost reduction (%) as a function of total washing machine energy for cost curve B.

5 Medium Communities

5.1 Introduction

In this chapter the use of the SmartKYE EMS platform for a medium scale community (up to 75000 people) will be evaluated. The system is assumed to work for the benefit of the community manager. The system in this case will be able to change the working hour of HVAC devices and washing machines, thus performing load shedding. A variable number of HVAC devices and washing machines are assumed to be installed according to the number of buildings. The main two objectives of the SmartKYE platform will be to minimize the total energy cost of the community and also minimize the wind energy curtailment assuming some installed wind capacity. The evaluation of the system, as well as the way the system works (how HVAC devices and washing machines are moved in time) is described in this chapter.

5.2 Business as Usual

This scenario describes the use of an Energy management System in the case of small communities. A community of about 75000 people (Lasithi, Crete) is used as an example.

The load curve of Crete (population of 600.000 people) is scaled down to fit the population of Lasithi (75.000). This scaled down load curve is used as a representative example for medium sized communities. The total load for one year is equal to 366.938,8 MWh.

In this chapter various scenarios will be presented with the main two objectives of the Energy Management System being consumer cost reduction and wind power curtailment reduction. The EMS can control in this case HVAC devices and washing machines. For other EMS please check next chapters. HVAC consumption is calculated by using the equations of Fig 8 (Chapter 1) and temperature measurements for the island of Crete. Washing Machine available energy is dependent on consumer behavior. The probability distribution of table 1 that shows the probability of a washing machine to be used for each hour if the day is used to calculate the available washing machine power each hour of the year.

The level of control for both HVAC devices and washing machines is considered to be a parameter of the analysis that follows.

Table 8 Medium Community BAU scenario

Scenario Business as Usual (BAU)	
Total Cost	
Price Curve A:	45.997.467,13 Euros
Price Curve B:	57.630.496 Euros
Wind Power Curtailment	
20 MW installed wind	2.126,258 MWh
30 MW installed wind	14.180,523 MWh
40 MW installed wind	33.647,104 MWh

5.3 HVAC Control Scenario

In this scenario only HVAC devices can be controlled in order to minimize wind power curtailment or consumer cost. The way HVAC devices are moved is described next:

For the case of wind power curtailment, curtailment is calculated (Chapter 1) first for every hour of the year. If in the next hour wind power is not curtailed, then it is possible to move some load to the previous hour (in case the previous hour experiences curtailment).In addition, due to the thermal behavior of the buildings, it is assumed that HVAC can only be moved one hour back in time.

As far as cost is concerned, again HVAC can only be moved 1 hour back in time. The general rule for cost reduction in this case is to move load one hour back in time as long as the price of energy is on the increasing side.

Main parameters in the HVAC control scenario are the penetration of controllable HVAC (percent of total number of HVAC devices) and the installed wind capacity (MW).

5.3.1: Minimize Wind Curtailment

Figure 77 shows the reduction of wind curtailment for various levels of controllable HVAC devices (10%, 20%, 30% and 40%) as a function of the installed wind capacity. It can be seen that for installed capacities over 30MW the reduction is less than 0.5%, while in the case of 20 MW the reduction in curtailment reaches 1.5% for a 40% level of controllable HVAC.

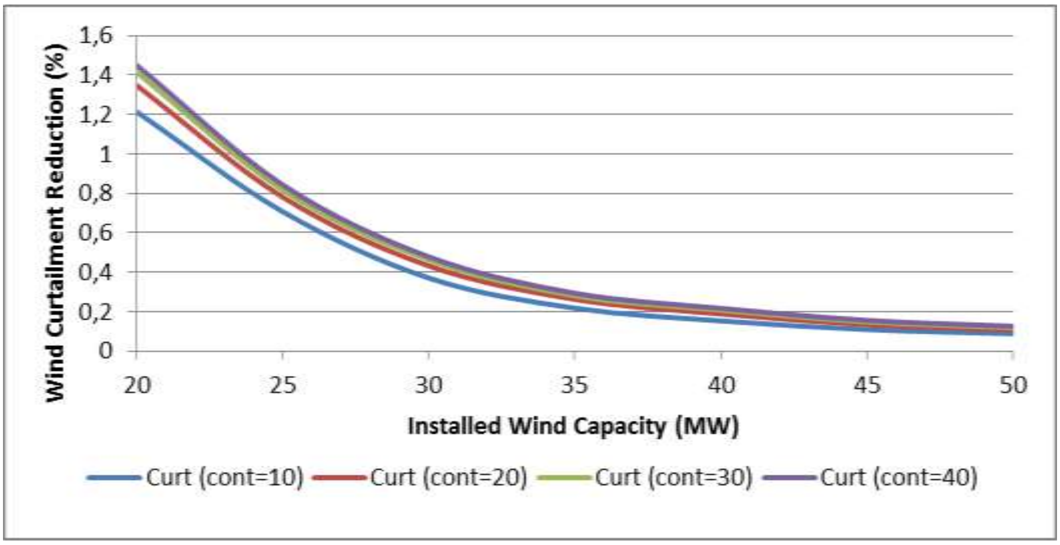


Figure 76 Wind curtailment reduction as a function of the installed Wind capacity (MW) for various levels of controllable HVAC

Fig.78 is the reverse of figure 77. This figure presents the reduction in wind curtailment for various levels of installed wind capacity (20MW, 30MW and 40MW) as a function of the penetration of controllable HVAC. It can be observed that after a certain point (i.e. 40%) the change in curtailment reduction is too small.

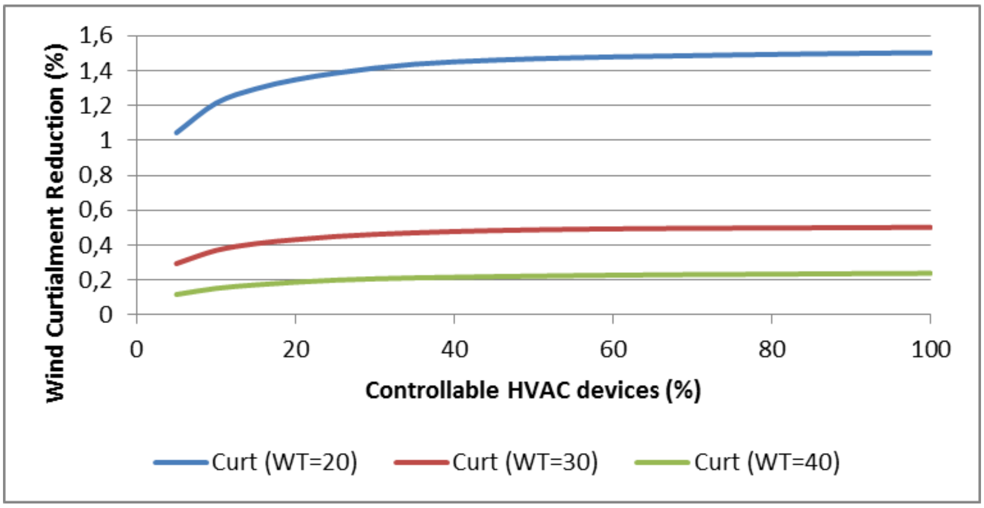


Figure 77 Wind curtailment reduction as a function of controllable HVAC for various levels of installed Wind capacity (MW)

5.3.2 Minimize Consumer Cost

This chapter discusses consumer cost minimization. The two cost curves presented in Chapter 1 are used in this case. Results are presented in figures 67 and 68. The main parameter of the analysis in the case of cost reduction is again the percentage of controllable HVAC devices. An easy assumption from both figures would be that the cost reduction remains low even when 100% of HVAC devices are considered to be controllable.

In the case of Price Curve A, (fig.78) the maximum cost reduction equals about 1.5%, while assuming Price Curve B, the maximum cost reduction would reach 4% a result that is not negligible.

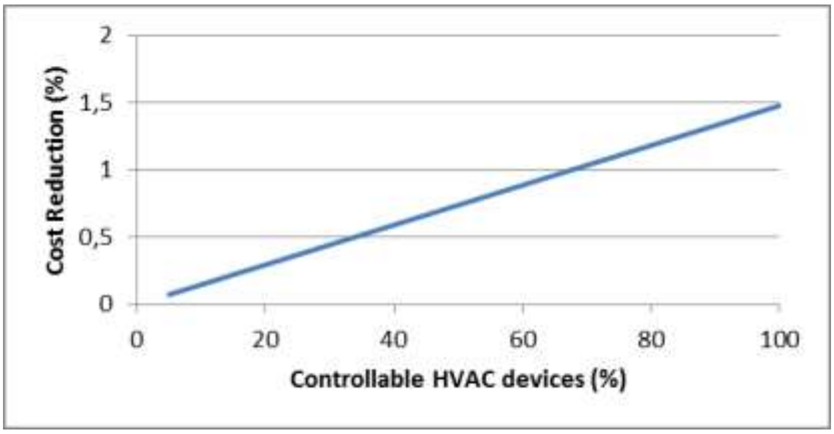


Figure 78 Consumer cost reduction as a function of controllable HVAC for price curve A

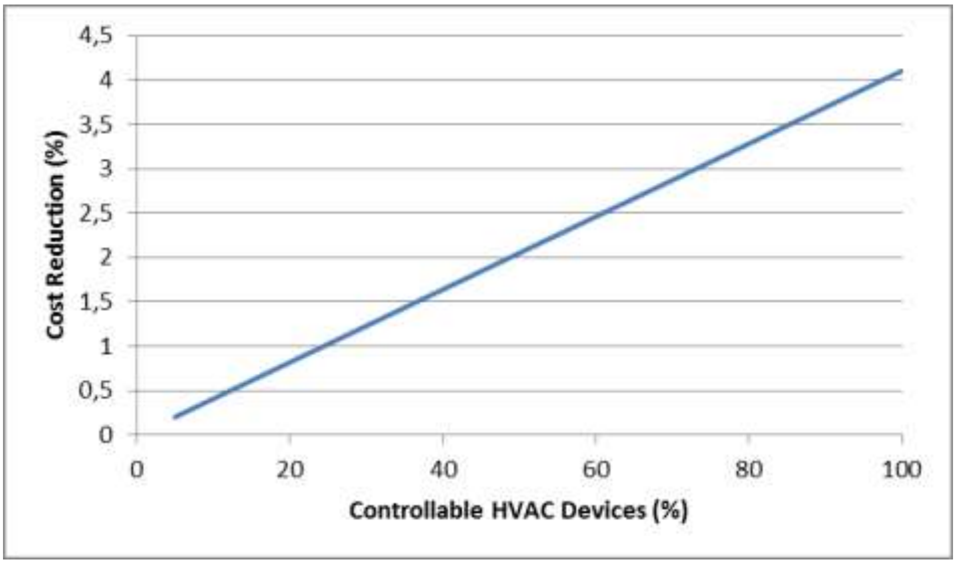


Figure 79 Consumer cost reduction as a function of controllable HVAC for price curve B

5.4 Washing Machine Control Scenario

This chapter will describe how washing machines are used to reduce wind curtailment and consumer cost. Washing machines are assumed to have no restriction on how far back or forth in time they can be moved. In the case of wind power curtailment reduction the available washing machine power for every hour is calculated as well as the wind curtailment for each hour. As a next step, washing machines are moved to hours with lots of curtailment and the new load curve is calculated.

Cost reduction is achieved by distributing washing machine power from high price zones to low price zones. In this way, the appearance of peaks on the load curve is avoided. Those picks would appear if the consumer EMS was free to just move all the washing machines to the minimum price hour. The result would be on the one hand to minimize consumer cost and on the other hand to increase system cost.

5.4.1 Minimize Wind Curtailment

Figure 81 shows the reduction of wind curtailment as a function of the installed wind capacity for various levels of controllable washing machines (10%, 20%, 30%, 40% and 50%). For installed wind capacities larger than 27MW cost reduction is less than 2%, while it reaches a maximum of close to 9.5% for the lowest capacity of 20MW and 50% of the washing machines being controllable.

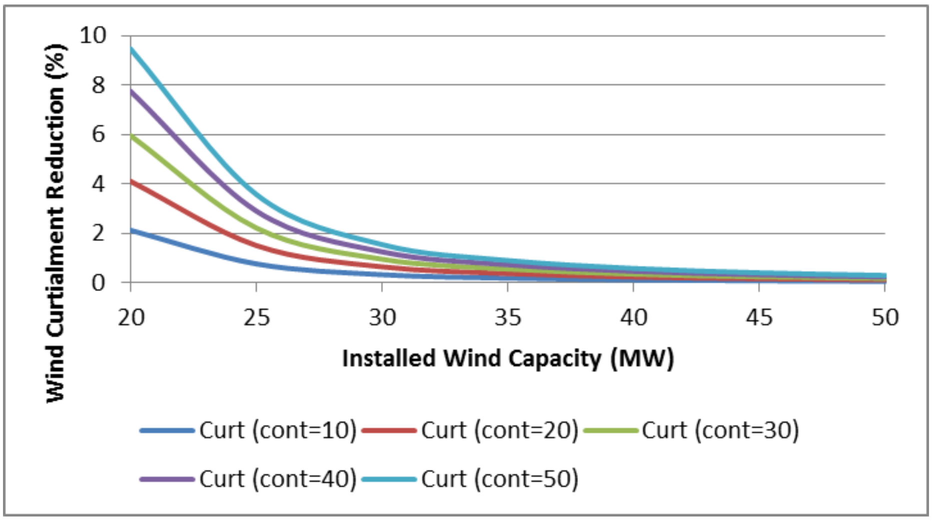


Figure 80 Wind curtailment reduction as a function of the installed Wind capacity (MW) for various levels of controllable Washing Machines

Figure 82 presents the reduction of wind curtailment as a function of the penetration of controllable washing machines for various levels of installed wind capacity. Results seem to be impressive, especially for a wind capacity of 20MW, but it must be noted that 20MW is an extreme scenario of low wind capacity. If the maximum of about 16% percent of curtailment were to be turned to actual energy, or even actual income the results would not be that impressive.

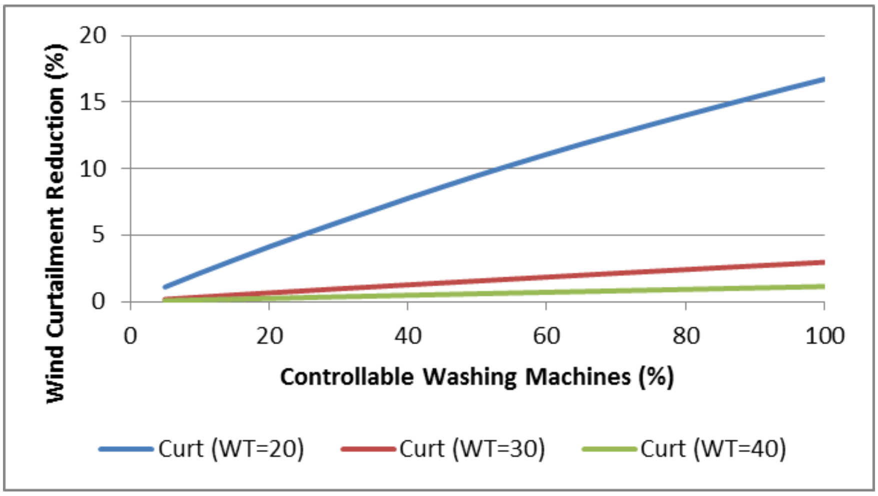


Figure 81 Wind curtailment reduction as a function of controllable washing Machines for various levels of installed Wind capacity (MW)

5.4.2 Minimize Consumer Cost

Finally, consumer cost is reduced by moving controllable washing machines. The two curves used in the previous chapter are used again here to calculate costs and cost reduction. Cost reduction is practically negligible in this case since in the best case scenario of Fig.83 and assuming 100% of controllable washing machines, the cost reduction only reaches 0.6%.

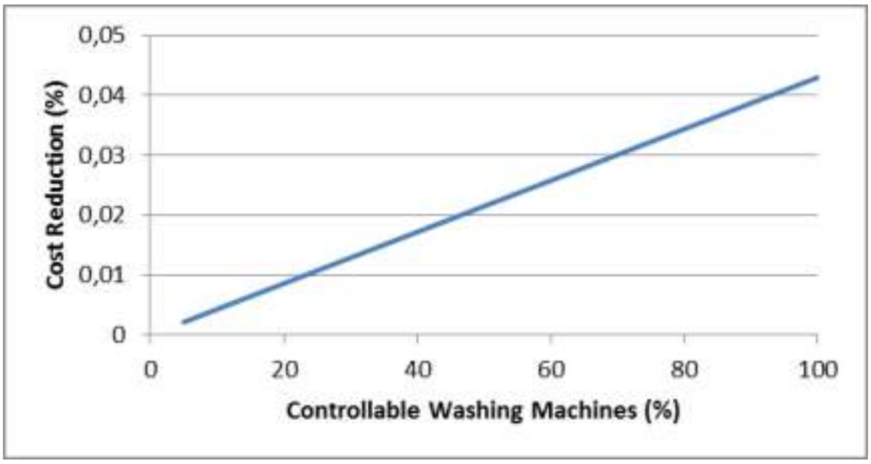


Figure 82 Consumer cost reduction as a function of controllable Washing Machines for price curve A

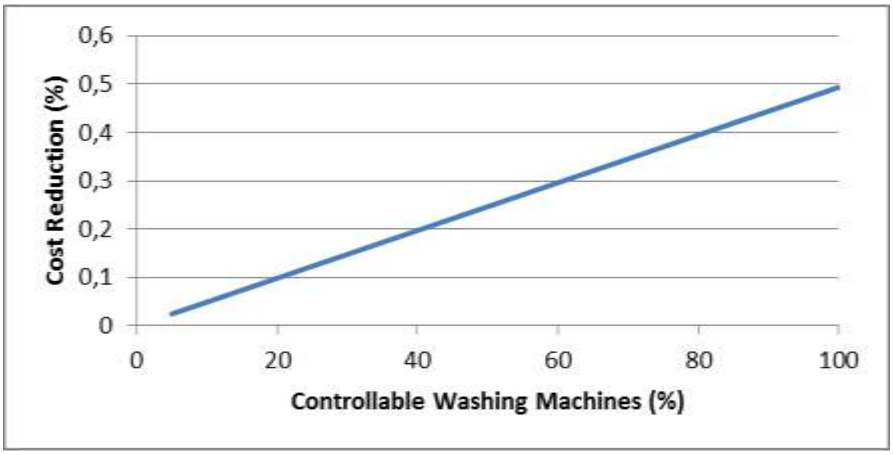


Figure 83 Consumer cost reduction as a function of controllable Washing Machines for price curve B

6 Large Communities

6.1 Introduction

In this chapter the use of an Energy Management System for a large community will be evaluated. The community of choice in this case is the whole island of Crete which is the area of responsibility of HEDNO, with a population of 600.000 people.

The total energy consumption in Crete equals to 2.935.508 MWh, while the installed wind capacity for 2012 equals to 174 MW.

Figure 84 illustrates the flowchart of the hour-by-hour simulation of the power system for the steady-state analysis. For each hour of the year, data regarding electricity consumption and wind production are combined with a recursive procedure that takes into account the technical minima of the committed units. Thus, the maximum allowed power from RES that ensures secure operation of the autonomous system is calculated. Furthermore, unit commitment and economic dispatch is performed taking into account the unit maintenance program and the necessary spinning reserve. With all the parameters of the system configured, load flow analysis is performed.

Maximum allowed power from Renewable Energy Sources (RES)

In autonomous power systems a maximum penetration level of intermittent power sources (such as wind power in the range of 30%-35% of total load) is usually considered.

The wind power is also limited by the technical minimum of the units. The aggregated technical minimum of committed units is determined by the following recursive procedure:

- At first it is assumed that all available wind power can be injected to the system.

$$P_W = P_{W\_av} \qquad (1)$$

- where PW is the wind power injected to the system and PW_av is the available wind power.
- The conventional units are committed according to their merit order, so that their total maximum power is adequate (eq. (2)).

$$\sum_{i \in A} P_{\max}^{i} \geq P_L + P_{SR} - P_W - P_{PV} \qquad (2)$$

- where $P_{\max}^{i}$ is the maximum power injected to the system by unit i, PL is the load of the system, PSR is the spinning reserve, PW and PPV are the wind and solar power injected to the system.
- In that case the maximum wind power that can be absorbed is equal to:

- $$P_{W\max} = P_L - P_{PV} - \sum_{i \in A} P_{\min}^{i} \quad (3)$$

In case PW_max is less than the available wind power PW_av, then it is assumed that PW=PW_max and the procedure is repeated from step 2. Otherwise it is considered that PW=PW_av and the procedure is terminated.

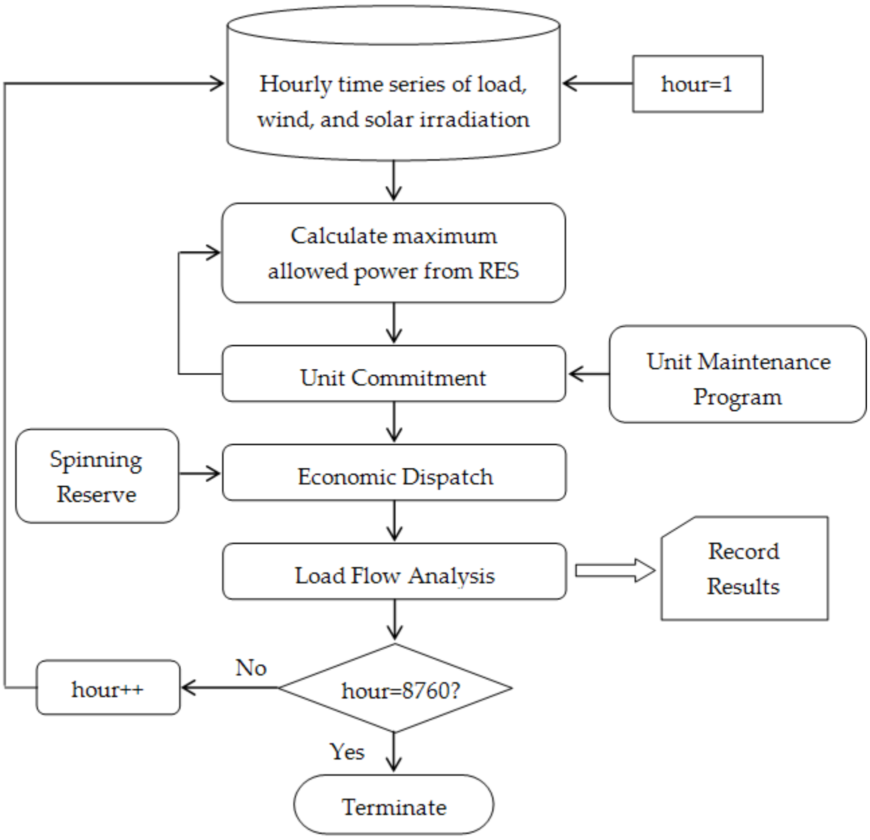


Figure 84 Hourly simulation flowchart for the steady-state analysis

Unit maintenance program

A maintenance schedule as well the availability for units is based on the current maintenance practice and is modified to include future installations.

Unit commitment

The criteria of unit commitment are related to fuel consumption, previous status of the unit and load prediction. More specifically, the following rules are taken into consideration for unit commitment in the system under study:

- Renewable energy sources are committed in first priority as long as their contribution does not exceed the limit of PW_max or 35% of total load.
- Conventional units are committed according to a priority list (merit order).
- Steam units are always committed in the system, unless they are on maintenance.

- There is no constraint in switching off and on gas turbines, so they are used during peak loads during the day.

Spinning reserve

The spinning reserve required is determined so that the following constraints are valid (not all together):

1. It is greater than the 15% of total load
2. It is greater than the wind power production
3. It is greater than the maximum generation of compatible units.

Economic dispatch

The economic dispatch problem can be formulated as follows:

The objective function to be minimized is as follows:

$$\min C_{TC}^{t} = \sum_{m=1}^{M} C_{G,m}^{t}\left(P_{G,m}^{t}\right) \quad (4)$$

where t is the time interval, M is the number of generation units biding in the energy market, $C_{G,m}^{t}$ is the cost of active power provided by unit m, and $P_{G,m}^{t}$ is the active power generation of the unit.

The load of the system is dispatched to the generators subject to the following constraints:

1. Real power balance constraint

$$\sum_{n=1}^{N} P_{G,n} - P_D - P_{losses} = 0$$ $\sum_{n=1}^{N} P_{G,n} - P_D - P_{losses} = 0$ (5)

where $P_{G,n}$ is the active power generation of unit n, N is the total number of units, PD is the demand for electricity, and Plosses are the losses of the transmission system.

2. Real power operating limits

$$P_{G,n}^{\min} \le P_{G,n} \le P_{G,n}^{\max}$$ $P_{G,n}^{min} \le P_{G,n} \le P_{G,n}^{max}$ (6)

where PG,n is the active power generation of unit n, and $P_{G,n}^{\min}$ and $P_{G,n}^{\max}$ $P_{G,n}^{max}$ are the minimum and maximum power that unit n can inject to the system.

3. Spinning reserve limits

$$P_{G,n}^{\min} \le P_{G,n} + P_{SR,n} \le P_{G,n}^{\max}$$ $P_{G,n}^{min} \le P_{G,n} + P_{SR,n} \le P_{G,n}^{max}$ (7)

$$P_{SR,n}^{\min} \le P_{SR,n}$$ $P_{SR,n}^{min} \le P_{SR,n}$ (8)

where PG,n is the active power generation of unit n, and $P_{G,n}^{\min}$ and $P_{G,n}^{\max}$ are the minimum and maximum power that unit n can inject to the system, PSR,n is the spinning reserve offered by unit n, $P_{SR,n}^{\min}$ is minimum the spinning reserve offered by unit n.

In the scenario where no EMS is applied to the system of Crete (BAU scenario) the two main system characteristics are shown in Table 9:

Table 9 Business as Usual Scenario

Business As Usual Scenario	
System Cost (euros)	645.189.743,3
CO2 Emissions (Tn)	819.630.633,6

6.2 Load Control Scenarios (HVAC + Washing Machines + EVs)

This part of the analysis will assume that HVAC, Washing Machines and Electrical Vehicles are moved with the main of objectives of system cost and CO2 emissions reduction.

For the case of Crete, which is examined as an example in this chapter the following combination of controllable load can be assumed to calculate a legitimate percentage of total controllable energy:

A) Washing Machines:

The number of buildings/households in Crete is about 200.000. Assuming every house has one washing machine, this gives a total of 200.000 washing machines in the whole island. Two basic assumptions must be made at this point: Firstly, not all washing machines are controllable, and secondly not every user will allow the control of his washing machine every time the EMS system wishes to do so. That gives a total of 30% of controllable energy from washing machines. Assuming that every wash requires 1kWh and that every wash takes place twice a week a total of:

0.3*200000 buildings*1appliance/.Building*1kWh/wash*2washes/week*52weeks/year=

6240MWh/year from washing machines

B) HVAC:

Just like in the case of washing machines a total of 60.000 controllable HVAC devices can be assumed to be installed on the island of Crete. HVAC consumption for each building can be assumed to be equal to 5MWh/year. That gives about 300.000MWh/year of controllable HVAC load. Though, HVAC is not freely controllable because the EMS system needs at the same time to retain the level of comfort of the individuals. Thus, we assume a 10% of control on the total of controllable HVAC energy. By following, the aforementioned procedure a total of 30.000MWH/year for HVAC.

C) Electric Vehicles (EVs):

Crete has a population of about 600.000. According to previous research for Crete, there is one car per 2 people, giving a total of 300.000 cars on the island. Assuming the scenario where 30% of the cars are EV's we get 90.000 EVs. Each EV can be considered to consume in average 7kWh/day summing up to a total load of 630MWh/dsy, that is close to

300.000 MWh/year. Next, we must assume that only a percentage of the EVs owners will allow for optimal control from the EMS. if this percentage equals to 50%, that means optimal control of 45.000 EVs we get a total of about 115.000 MWh/year of controllable EV energy.

The total energy consumption of Crete without considering EVs equals to 3.000.000MWh/year. Adding up the 90.000 EVs, the total energy consumption will be equal to 3.300.000MWh/year. The total controllable energy is the sum of washing machines, HVAC and EVs calculated previously and is equal to 115.000MWh/year from EVs, plus 30.000MWh/year from HVAC, plus 6240MWh/year from washing machines. That equals to a total of 151.240MWh/year that is about 4.58% of the total energy consumption of Crete for a year.

Taking into account the previous analysis scenarios from 1-10% of total controllable energy will be examined to have best and worst case scenarios.

The following diagrams show how the load curves change for a day of the year (Fig. 73). Most importantly, figures are given that present the reduction of system cost and CO2 emissions as a function of the total energy moved (figures 84 and 85).

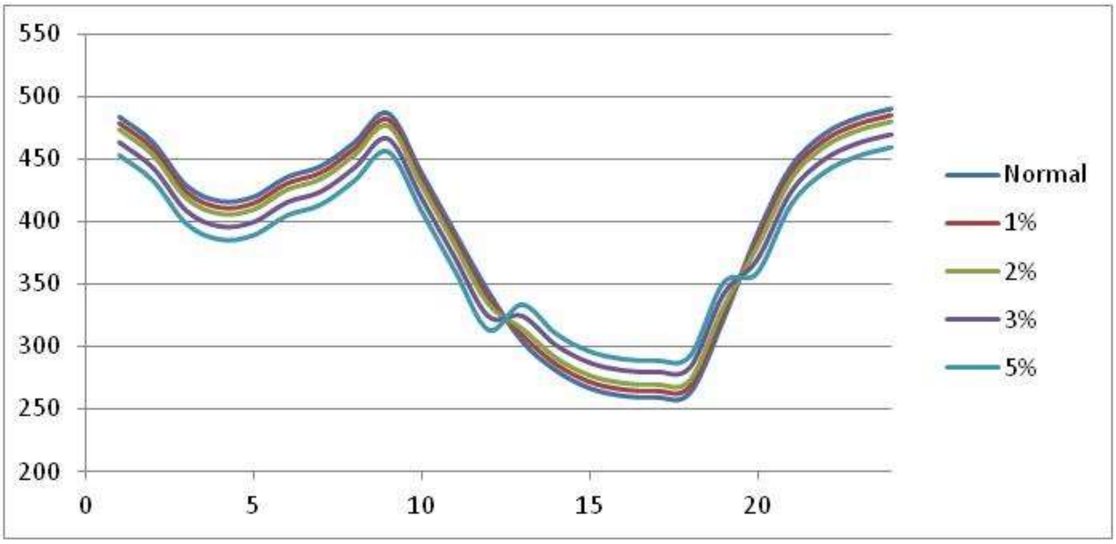


Figure 85 Load curves for the Island of Crete at 2012 for various levels of controllable load.

The controllable load for each day ranges from 1-10% of the total load. A big percentage (10%) is chosen in the analysis to examine if there is an optimum level of controllable load, over which the EMS produces less results (i.e. less reduction of system cost and CO2 emissions).

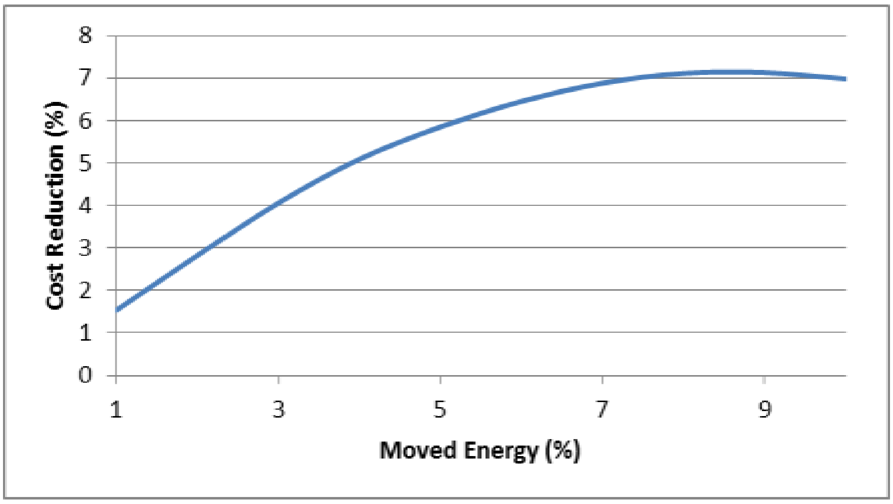


Figure 86 Cost reduction (%) as a function of the total energy moved (%) for 174 MW of installed wind power

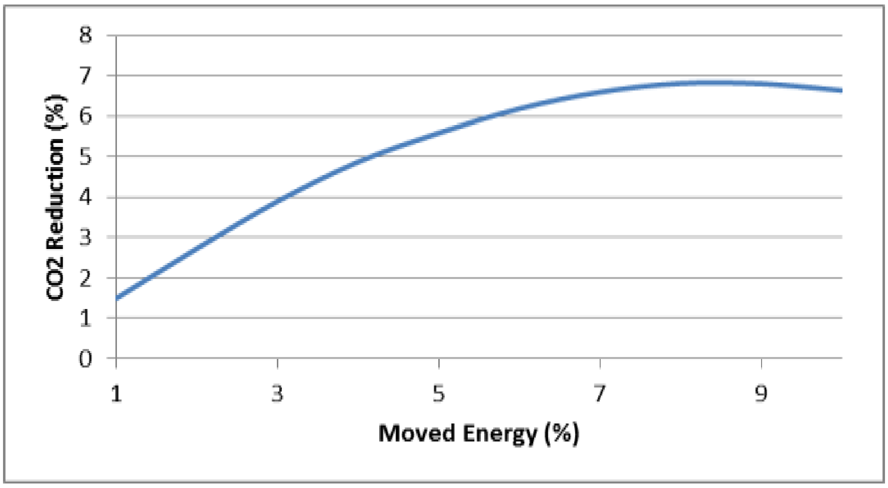


Figure 87 CO_2 emissions reduction (%) as a function of the total energy moved (%) for 174 MW of installed wind power

Fig. 88 shows the system cost reduction as a function of the controllable load. The cost is calculated by applying unit commitment for each load curve. It can be observed that cost reduction reaches its maximum value for a control percentage close to 9%, achieving a reduction of approximately 7.13%, that equals close to 43.000.000 Euros. CO_2 reduction is also minimized at a control level close to 8%, with a 6.81% of maximum reduction, which equals to 52.021.564,79 Tns.

Table 10 shows the aforementioned results:

Table 10 Cost and CO_2 reduction for various levels of controllable load

Energy shifted (%)	Cost reduction (%)	Cost reduction (euros)	CO2 Reduction (%)	CO2 reduction (TNs)

1	1.53	9728155.976	1.49	12078530.98
2	2.82	17684282.42	2.73	21765095.48
3	4.06	25143434.72	3.89	30714183.32
4	5.09	31175932.57	4.87	38019880.66
5	5.84	35534444.9	5.59	43263349.67
6	6.45	38933886.89	6.18	47571112.54
7	6.87	41324691.01	6.59	50488609.03
8	7.11	42624255.68	6.81	52021564.79
9	7.12	42719744.05	6.80	51967230.04
10	6.98	41892731.32	6.63	50790186.5

Next tables present the effect of the Load Management in the RES(WF) curtailed energy. As mentioned before the HEDNO curtails WF energy when one of the following rules:

- RES penetration (% Current Production/Current Load) should not exceed 35%
- There should be no violation of the technical minimum's of the running machines

It is obvious that during low load it is most possible to have violation of these rules. And this is illustrated in the following tables. When the installed WF power is increasing the curtailed energy is reduced. On the contrary when load shifting is taking place the curtailed energy is reduced.

		% Shifted Energy										
		0	1	2	3	4	5	6	7	8	9	10
WF Installed power	174	39,3	37,4	35,8	34,5	33,4	32,6	31,9	31,4	31,1	31,0	31,0
	184	53,2	51,2	49,5	48,0	46,8	45,9	45,2	44,6	44,3	44,1	44,1
	190	62,3	60,2	58,3	56,8	55,6	54,6	53,9	53,3	52,9	52,7	52,7
	195	70,2	68,0	66,1	64,5	63,3	62,3	61,5	60,9	60,5	60,3	60,3
	200	78,4	76,1	74,1	72,5	71,2	70,2	69,4	68,8	68,4	68,2	68,2
	205	86,8	84,5	82,5	80,8	79,5	78,5	77,7	77,1	76,6	76,4	76,4

Table 11 Curtailed Energy in various levels of RES penetration and % of Shifted Energy

		% Shifted Energy										
		0	1	2	3	4	5	6	7	8	9	10
WF Installed power	174	8,2%	7,8%	7,5%	7,2%	7,0%	6,8%	6,6%	6,5%	6,5%	6,4%	6,5%
	184	10,5%	10,1%	9,7%	9,5%	9,2%	9,0%	8,9%	8,8%	8,7%	8,7%	8,7%
	190	11,9%	11,5%	11,1%	10,8%	10,6%	10,4%	10,3%	10,2%	10,1%	10,0%	10,0%
	195	13,0%	12,6%	12,3%	12,0%	11,7%	11,6%	11,4%	11,3%	11,2%	11,2%	11,2%
	200	14,2%	13,8%	13,4%	13,1%	12,9%	12,7%	12,6%	12,5%	12,4%	12,4%	12,3%
	205	15,3%	14,9%	14,6%	14,3%	14,0%	13,9%	13,7%	13,6%	13,5%	13,5%	13,5%

Table 12 % Curtailed Energy in various levels of RES penetration and % of Shifted Energy

		% Shifted Energy										
		0	1	2	3	4	5	6	7	8	9	10
WF Installed power	174	28,9%	29,1%	29,2%	29,3%	29,3%	29,4%	29,4%	29,5%	29,5%	29,5%	29,5%
	184	28,2%	28,3%	28,5%	28,5%	28,6%	28,7%	28,7%	28,8%	28,8%	28,8%	28,8%
	190	27,8%	27,9%	28,0%	28,1%	28,2%	28,2%	28,3%	28,3%	28,3%	28,4%	28,4%
	195	27,4%	27,5%	27,7%	27,7%	27,8%	27,9%	27,9%	28,0%	28,0%	28,0%	28,0%
	200	27,0%	27,2%	27,3%	27,4%	27,5%	27,5%	27,6%	27,6%	27,6%	27,6%	27,6%
	205	26,7%	26,8%	26,9%	27,0%	27,1%	27,1%	27,2%	27,2%	27,3%	27,3%	27,3%

Table 13 Capacity Factor in various levels of RES penetration and % of Shifted Energy

		% Shifted Energy										
		0	1	2	3	4	5	6	7	8	9	10
WF Installed power	174	441,1	443,0	444,6	445,9	447,0	447,9	448,5	449,0	449,3	449,5	449,4
	184	454,8	456,8	458,6	460,0	461,2	462,1	462,9	463,4	463,8	464,0	464,0
	190	462,3	464,4	466,3	467,8	469,0	470,0	470,7	471,3	471,7	471,9	471,9
	195	468,3	470,4	472,3	473,9	475,2	476,2	476,9	477,5	477,9	478,1	478,1
	200	473,9	476,1	478,1	479,7	481,0	482,0	482,8	483,4	483,8	484,0	484,0
	205	479,2	481,5	483,5	485,2	486,5	487,6	488,4	489,0	489,4	489,6	489,6

Table 14 Total Produced Energy (GWh) in various levels of RES penetration and % of Shifted Energy

6.3 Simulation for EVs

This part of the report focuses on the impact on the charging of specific numbers of electric vehicles (denoted as EVs) has, on the total daily load. Realistic and perhaps less so, scenarios will be considered in order to get a preliminary but nevertheless accurate estimate of the way the daily load is affected.

The code

A simulation program has been developed in order to calculate both the extra load the charging of any (user determined) number of cars amounts to, as well as the way this load restructures the daily total at each time point during the day. We implemented the code considering the following EVs:

Car	Battery (kWh)	Outlet (kW)	Time (h)	Range (km)
Nissan Leaf	24	3,3	7,656	135
Tesla Roadster	53	16,8	3,321	393
Mitsubishi iMieV	16	3,6	4,678	100

Table 15 Type of EVs

We assumed the charging to take place at an outlet of 240V supplying a charging current of 13.75A (Nissan Leaf), 70.0A (Tesla Roadster) and 15.0A (Mitsubishi iMieV). We also assumed that the charger used will have an efficiency of 95% for all cars.

Input

The basic degrees of freedom for our code are summarized in the following table:

Independent Variables	Description
Number of cars for each brand considered	The user, during runtime, can select the desired amount of cars for each of the three brands considered – as shown in the table above.

Charging time for each day of the week	The user, during runtime, can select when to charge the cars from a list of pre-determined time points
Battery condition for all cars	The user, during runtime, may specify whether the battery is empty or whether it is partially charged before the charging begins

Table 16 Simulation conditions

The code adds the calculated extra load to the total daily load supplied by the Hellenic Electricity Distribution Network Operator (HEDNO S.A.) based on accumulated 2012 data. However, it is robust enough to perform similar calculations on any text file based load curve.

As far as the charging time is concerned, we divided the day into four segments. Each segment is six hour long. The segments are:

Daily Segment	**Starting – Ending Hours**
Night	00:00 – 06:00
Morning	06:00 – 12:00
Afternoon	12:00 – 18:00
Evening	18:00 – 24:00
Daily Load Minimum	Charge around the minimum of the daily load
Daily Wind Production Maximum	Charge around the maximum of the daily wind production

Table 17 Charging Policy

At runtime, the user selects one of the first four segments above to charge, or selects a dynamic time point based on load minima or wind production maxima.

We chose to implement the code that way – instead, for example, of letting the user specify the exact starting point of charging – so as to be able to adjust the extra load according to the load curve's minima, during the charging segment. Since the cars have different charging time requirements, we thought it appropriate to formulate the extra load (due to the charging of EVs) in such a way so as to maintain its maximum, as best as possible, closer to the corresponding minimum of the load curve during the charging segment.

The user is prompted to select the charging time for each day of the week (seven inputs) and the program then extrapolates the weekly configuration to a yearly prediction.

Output

The simulation can run on any user defined combination of the input parameters. The code can calculate not only the extra load of the cars as a function of time and the way it affects the daily total, but also establish when there is enough wind to support this charging process according to wind speed data measured by HEDNO S.A. at a particular location in Crete. For the purposes of this study we assumed that all wind power farms were at the location where the wind speed measurements were made and consisted of a total of 286 same type wind turbines (Vestas V52 – 850kW).

Scenarios

Suppose one chose to run the code with the following configuration of car fleet and charging times:

Running Scenario I
10,000 Nissan Leaf Cars being fully charged (from zero initial charge) every day of the week when the load is minimal

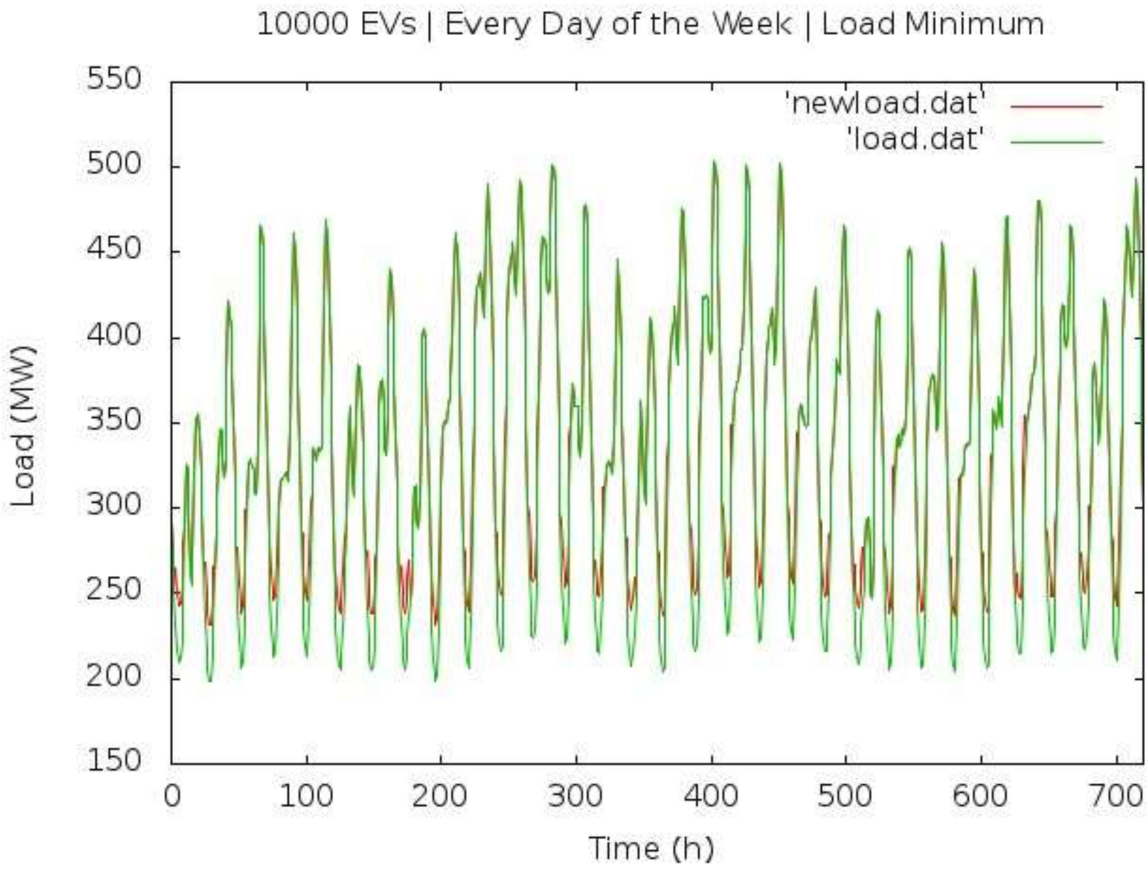


Figure 88: 10000 Nissan Leaf Cars being charged every day of the week when the Load is minimal

The above plot illustrates the effect of the charging on the load curve for the thirty first days of 2012. We see that the load (green line) is shifted upwards by the amount of charging power every day of the week only around the time when there is a minimum in load.

To check whether there is enough wind power production to support that charging we calculated the ratio of load increase as in:

$$a=\frac{P_{new}}{P_{old}}$$

and then appropriately recalculated the wind power penetration load by means of: $P_{wind}\frac{P_{new}}{P_{old}}$ This we then subtracted from the estimated wind power production. If the result was a positive number then we could conclude that there is enough wind power for the charging. The reverse if the result was negative. The wind power penetration load was given to us by HEDNO S.A. and corresponded to 2012 data.

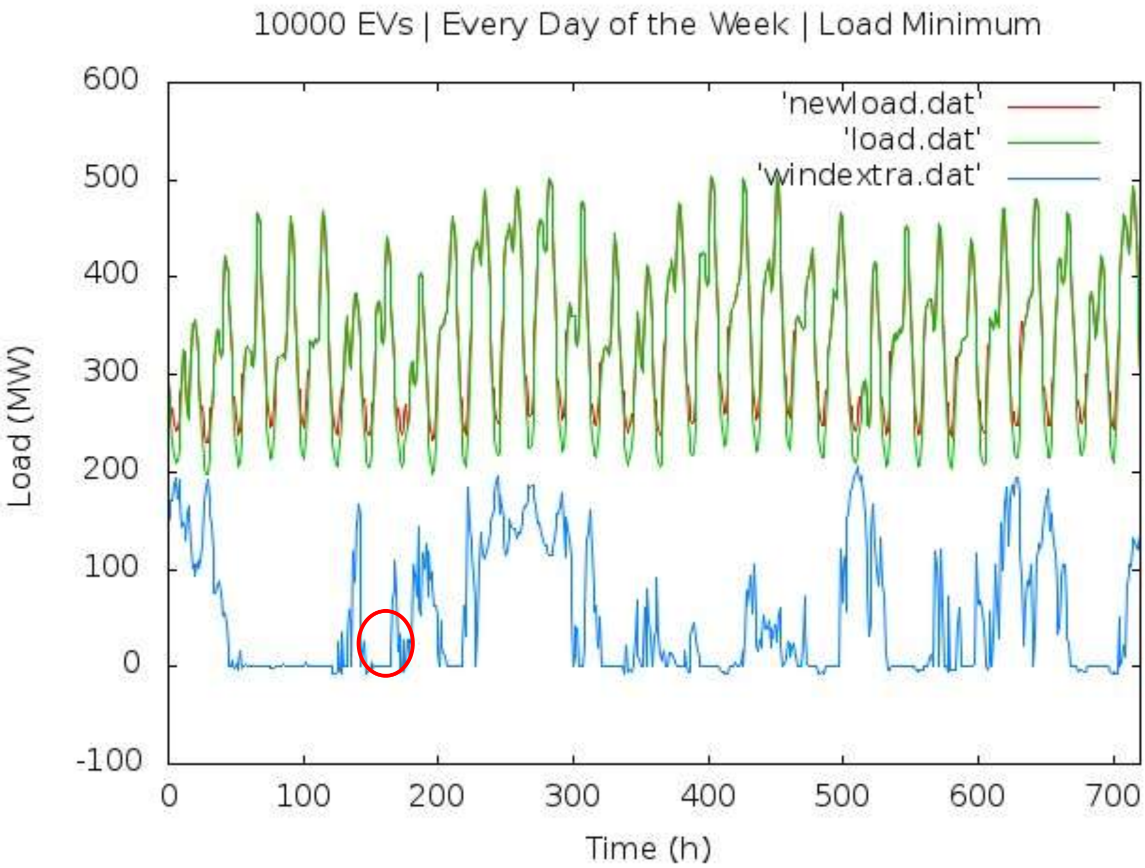


Figure 89: 10000 Leaf Cars charging every day at minimal load times plus wind power penetration

From the plot above we see that there seems to be enough wind to support this charging for most days, even though during a significant amount of intervals there seemed to be an insufficiency in wind power production. At those times there was not enough wind to support the charging scenario we chose, and therefore other power generation devices would have to come into play.

Suppose one chose to run the code with the following configuration of car fleet and charging times:

Running Scenario II
6000 Nissan Leaf Cars and 6000 Mitsubishi iMieV Cars being fully charged (from zero initial charge) every day when the load is minimal.

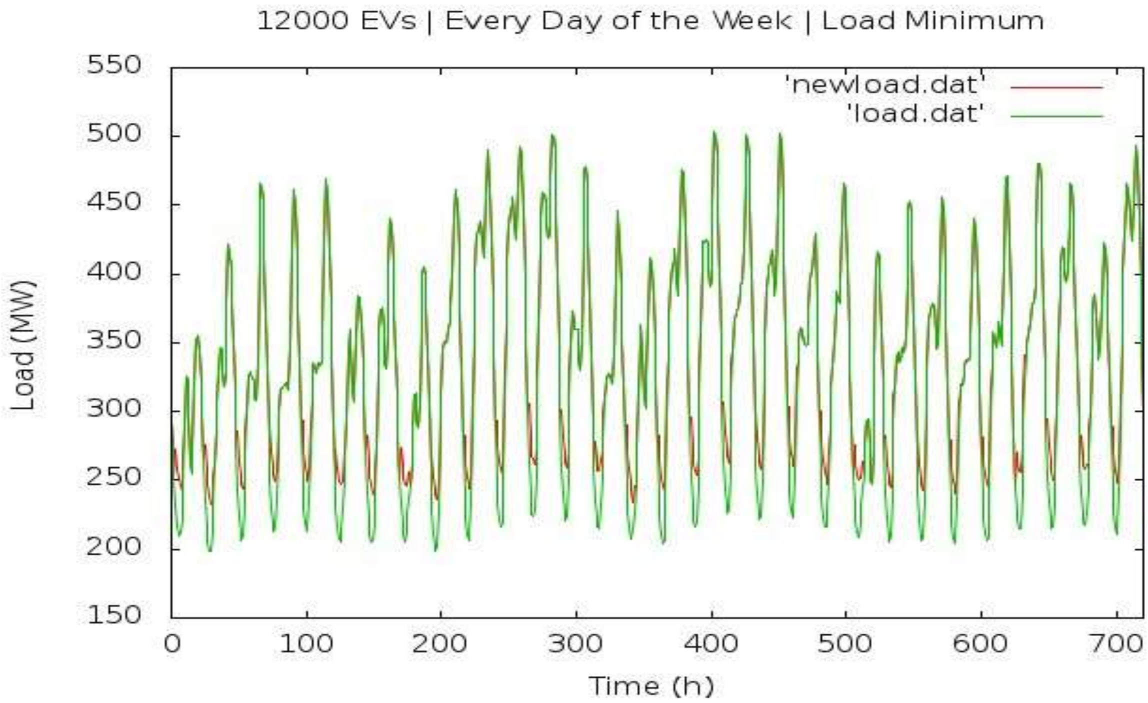


Figure 90 12000 EVs being charged every day when the Load is Minimal

As before, we see that the load minimum (green lines) is shifted upwards by the amount of charging load (red lines) every day of the week.

Next the cost and CO2 reduction has been calculated for scenario 1. The basic assumption is that, without the control this load would be randomly shared in the various hours.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
No Control	71,26	60,85	52,16	38,66	72,03	91,01	146,9	134,0	87,48	70,40	40,56	67,29	932,6
With Control	68,51	58,75	50,48	37,54	69,62	89,16	147,3	133,6	85,51	68,58	39,35	65,23	913,7
	3,9%	3,5%	3,2%	2,9%	3,4%	2,0%	- 0,3%	0,3%	2,2%	2,6%	3,0%	3,1%	2,0%

Table 18 CO2 reduction

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
No Control	63,05	54,33	47,49	36,50	63,31	78,05	122,0	112,2	75,56	62,03	38,30	59,39	812,35
With Control	61,15	52,86	46,40	35,82	61,81	76,74	122,1	111,9	74,06	60,81	37,63	57,98	799,34
	3,0%	2,7%	2,3%	1,9%	2,4%	1,7%	- 0,1%	0,3%	2,0%	2,0%	1,7%	2,4%	1,6%

Table 19 Cost reduction

7 Business Models

As mentioned in the description of work the Key end-users of SmartKYE project results targeted are the municipalities who can monitor and manage key indicators in neighbourhoods with the goal of better energy efficiency and CO2 reduction, even though data will be acquired from all stakeholders (DSO, Facility management and ESCOs), processed in the platform based on business related rules and communicated to the cockpits. Thus this Business models will take into account all the Stakeholders. The three proposed business models, according to the DoW are:

Business model 1: “Mandatory deployment”: According to this business model, in case a municipality implements SmartKYE results in order to control and manage the energy of its facilities more efficiently, the rest of municipality end-users (DSO, Facility management and ESCOs) are obliged to publish the required data.

Business model 2: “Incentives from the municipality”: In this business model, the end-users (DSO, Facility management and ESCOs) will not be obliged to publish their data. However, the municipality will incentivize the end-users who decide to publish the data, for example discounts in municipal taxes. Apart from it, they will be also able to access to SmartKYE Open Energy Service Platform with their own interfaces, as in Business model 1.

Business model 3: “Incentives from the rest of end-users”: In this business model the end-users will not be obliged to publish their data, as in business model 2. However, as benefits, they will receive incentives from the rest of end-users, but not the municipality.

The data that the other actors will provide to the Municipal are:

- Flexible tariffs
- Control Commands
- Request to the Municipal (e.g. provide me the number of EVs connected to the charging station)
- Billing info especially regarding the EVs.

- Weather predictions

Another significant issue is about the incentives to the other stakeholders mentioned in the description of the business models. This assumes a Municipal with advanced responsibilities: transportation, education, security, public services etc. The size of infrastructure in such a municipal will be sufficient to negotiate with stakeholders such as the DSO or the ESCO and give the various incentives to participate in the open platform.

These business models will require some further changes/adaptations that are beyond the scope of work of the SmartKYE project. The changes concern the ICT related adaptations required by the actors and the regulatory changes

7.1 ICT infrastructure

The core changes in the infrastructure concern the communication with the other stakeholders. We assume that all stakeholders will adopt the SmartKYE Data Model except the DSO. In this case a wrapper should be developed.

Communication with the DSO: Typically the DSO has each own standards for communication such as IEC 61970/CIM (data models), IEC 61850 (Substation automation) etc. Special interfaces to these protocols should be developed.

Communication with the ESCO: The ESCO might have each own information system and will be responsible to adopt the guidelines of OESP. The main problem is about billing information and more specific a standardised method should be develop in order to monitor and record all control commands/requests from the ESCO.

Communication with the Facility manager: The Facility manager might have each own information system and will be responsible to adopt the guidelines of OESP.

Some other technical changes will be discussed next to the regulatory framework since they are coupled with it.

7.2 Regulatory

The most difficult part of the changer is the regulatory framework. The main changes are described next:

Flexible Tariffs: The existence of Flexible tariffs is important for the operation of the SmartKYE platform. However flexible tariffs require significant technical and regulatory changes. The technical changes are related with electronic meters mainly since you cannot have flexible tariffs using the old electromechanical meters. Furthermore flexible tariffs require significant changes in the billing system of the responsible party for the invoicing. Next, in the regulatory framework it should be decided who the responsible actor is to provide these tariffs as well their calculation methodology (including ancillary services).

Control of RES: The large penetration of RES may cause significant problems in the distribution and transmission networks. In order to cope with these problems and to increase the hosting capacity is mandatory to have a certain level of control. However the problem in small distributed generators is the huge number and the small size. DSOs require a control system that is cheap and capable to accomplish the task. However besides the German Act there is no other initiative towards this direction.

8 SEC thresholds

Following the results of the literature survey and the simulations, the next table includes threshold for the various System Evaluation Criteria defined in D7.1. For the estimation on the impact on cost and CO2 mainly the tables 10-14 have been considered.

SEC #	SEC Description	Threshold
SEC-01	Efficient Monitoring of the Facility (EMF)	20-40%
SEC-02	Increased RES production (IREP)	5-10%
SEC-03	Efficient Market Participation (EMP)	5-10%
SEC-04	Cost Reduction (CR)	5-15%
SEC-05	Increase of the Hosting Capacity of RES/DG (IHC)	5-10%
SEC-06	Availability of ancillary services across transmission and distribution grids (AAC)	10-20%
SEC-07	Increase in the Building Efficiency (IBE)	5-15%
SEC-08	Increase in the Energy Efficiency in the Neighbourhood (EEC)	5-15%
SEC-09	Efficient EV Management (EEVM)	10-15%
SEC-10	EV hosting capacity (EVHC)	5-10%
SEC-11	CO2 reduction of the system (CORS)	5-15%
SEC-12	CO2 reduction via EV management (COREV)	5-15%
SEC-13	CO2 reduction due to increased RES capacity (PV, Wind etc.) (CORES)	5-15%
SEC-14	Increase in the PLS efficiecy (IPLS)	15%
SEC-15	Better Utilisation of Distribution Network (BUD)	5-10%
SEC-16	Forecasting Performance (FOPE)	20%

Table 20 SEC Thresholds

9 Conclusions

The challenges in the management of Municipal infrastructure and buildings are significant; however the expected benefits are sufficient to cover the expected costs. For example saving about 30% in electricity consumption through intelligent management of lighting is very important since lighting is one of the core services provided by the municipals. Furthermore buildings are one of the fastest growing energy consuming sectors. It is estimated that the amount of the energy consumed in the European Union's (EU) buildings reaches 40–45% of total energy consumption. Furthermore EVs should be considered as the main consumption in the near future.

The key issue in the active load and production management is the current legal framework. Currently both in Spain and in Greece there is no framework to support flexible tariffs or active control of small PVs and Wind Turbines. However taking the example of Crete where the MV Wind Farms are controlled the simulations revealed that there is a great potential to manage RES in order to cope with the technical problems and increase the RES penetration. The technical problems and the RES penetration will require new type of management such as the German act, and must be adopted in the case of municipal infrastructure.

Another interesting conclusion of this study is that SmartKYE platform and the integrated Energy Management System can achieve their goal in large scale applications, namely involving large number of assets e.g. buildings, EVs etc. Thus the municipal infrastructure is ideal since typical includes many energy consuming buildings and installations. Considering also the fact that these buildings are managed actively by a single authority, municipals may become the ideal customer for Energy Retailers. Furthermore the concept of creating an open platform (OESP) and the associate Business and Control Cockpits is in the correct path, namely the system will be able to integrate many municipal buildings and infrastructure

Finally a great potential for load shifting exists in Electric Vehicles where the shiftable load is higher than the HVAC or other appliances. Electric Vehicles will become the main electrical load in the future. Furthermore the ability to manage Electric Vehicles and shift load is higher than in the case of HVAC. This will allow the municipals to increase the profits through flexible tariffs and reduce the $CO2$ emissions.

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11 Appendix

11.1 Acronyms

Acronyms List	
BC	Business Cockpit
EMS	Energy Management System
EPL	EMS of Public Lighting
ESB	Enterprise Service Bus
ETS	EMS of Traffic System
EV	Electric vehicle
GUI	Graphical User Interface
HVAC	Heating ventilation and air conditioning
ICT	Information and communication technologies
WM	Washing Machine
KPI	Key Performance Indicator
MCC	Monitoring and Control Cockpit
OESP	Open Energy Service Platform
PHEV	Plug-in Hybrid Electrical Vehicles
PLS	Public lighting system
PV	Photovoltaic
QoS	Quality of Service
SOA	Service Oriented Architecture
SEC	System Evaluation Criteria
UC	Use Case
UI	User Interface
PLS	Public lighting system
NOPL	Neighbourhood Oriented Public Lighting Monitoring and Control System
WP	Work packages

12 Annex 1

The simulation of NOBLE project consists in a NOPL system controlling two different sets of simulated lamps. The nominal power of those elements has been extracted from the report provided by Local authorities of Alginet, which contains real information about the structure and elements of the public lighting system of the town.

In order to make the simulation, it is necessary to highlight that that Alginet public lighting network is composed by:

- 17electrical panels
- 1.667 points of lights
- 245 KW of Nominal power

First round of pilots

The first phase of NOBEL pilot tests took place in Alginet of Spain during the period 1/02/2012 – 30/04/2012 and involved a segment of lights in “Reyes Catolicos” avenue testing first version of NOPL. The results of the first round were critical and provided feedback for enhancements of the system to be applied in the second phase, especially in terms of technical problems encountered during the first phase and user interface issues. In the following sections, the process of the first round evaluation is presented, providing preliminary results of the project. These results will be compared with the second phase, where advanced and enhanced versions of the prototypes were implemented.

Energy Impact

The impacts related to energy usage and management will be investigated. This analysis will consider the pilot results analysis and compare them with a baseline scenario in order to conclude over the efficiency of the integrated system.

Comparison of User application system results with the baseline case

In this section the energy usage data extracted from the pilot tests will be compared to the baseline case. As the two phases of testing took place during different weather conditions the comparisons will be performed per phase and not for aggregated values.

Senior prosumer consumption (lighting system)- NOPL application

The following table presents the energy impact of NOPL for the lighting segment in AVENIDA REYES CATOLICOS. A remarkable energy consumption reduction of 39,40% is observed in relation to the reference case .

Indicator	First Pilot phase	Baseline case	Difference (%)
Total consumption (kWh)	6562,81	10830	-39,40
Total February consumption (deducted) (kWh)	2610	4218	-38,12
Total March consumption (kWh)	2894,63	4772	-39,34
Total April Consumption (kWh)	2498,18	4167	-40,05
Average Daily Consumption (kWh)	88,88	148,36	-40,09
Average Consumption Interval 1 (kWh)	43,06	72	-40,19
Average Consumption Interval 2 (kWh)	0,45	2,2	-79,55
Average Consumption Interval 3 (kWh)	0,27	0,26	3,8
Average Consumption Interval 4 (kWh)	45,06	73,9	-39,03

Table 21 First pilot phase energy impact on public lighting consumption

Economic Impact

First Phase

Senior prosumers economic impact – NOPL application

The remarkable energy consumption reduction due to NOPL, led also to economic benefits for the public lighting system operator. The following table presents the economic impact for the Reyes Catolicos avenue.

Indicator	First Phase of pilots	Reference Case	Impact
Costs for consumption (€)	813,80	1342,92	Reduction of 39%

Table 22 First Phase Economic impact for senior prosumers