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MASTER'S THESIS

LOAD FORECASTING IN SMART GRID ENVIRONMENT

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Abstract

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Loaf forecasting in Smart Grid environment

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Smart technologies are planned to be widely used in future electrical systems. It means that their future implementation must be taken into account in long-term load forecasting. A problem is a lack of statistical information of these technologies application and uncertainty in future scenarios of electricity developing.

This master’s thesis is focused on the existing smart technologies and evaluation of their effect on grid loads. Several scenarios of different technologies implementation are created and changes in energy consumption and peak load are evaluated. The goal is to determine an impact of smart technologies on future loads.

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Abbreviations and symbols

ANN	Artificial Neural Network
DG	Distributed Generation
ES	Energy Storage
EV	Electrical Vehicle
GA	Genetic Algorithm
IC	Internal Combustion
V2G	Vehicle-to-Grid

E	energy consumption
S	penetration level
N	number of customers
P	power
H	hour
W	energy

Subindexes

max	maximum
a	annual

Foreword or Acknowledgments (Optional)

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1 Introduction

There are three types of load forecasts: short-term, medium-term and long-term.. Long-term load forecasts are made for the period up to ten years or even up to several decades and they help companies to plan their investments, plan and develop generation, transmission and distribution systems. It is made to forecast electrical energy consumption and maximum loads in a grid so that companies could make economical based decisions of installing or replacing electrical equipment in a grid to make it capable to generate, transmit and distribute forecasted energy and provide an acceptable level of power quality and reliability of power supply.

To make a load forecast, first, it is needed to get information about existing loads in an area, statistical information of load growth and trends of loads development. A lot of factors must be taken into account in a forecast: population growth, economical forecast, weather forecast, etc. A specialist needs to choose load factors that would effect on future loads and define their impact on load forecast. An accuracy of a load forecast strongly depends on the load factors taken into account. We also need to take into account new technologies appearing and development as they can also effect on future loads significantly. An example of these new technologies are smart technologies.

Smart technologies are being developing very actively, they allow increasing power quality an power supply reliability, reduce energy consumption and energy flows in a grid. There are several types of smart technologies: smart and efficient end-use devices, distributed energy sources, advanced communication system and smart home systems. All these new technologies will effect on future loads and it is important to define their impact on future energy consumption and maximum power. Some of smart technologies improve energy efficiency and increase energy savings, reduce peak load and load demand. But new loads will appear in the future, for instance electrical vehicles, and they will increase electricity consumption.

Most of existing forecasting principles use statistical information of load growth and changes of load types for decision. But in our case we don't have such historical information for smart technologies and equipment because they are not widely used yet. We can only create different scenarios of their future implementation and evaluate how it would effect on energy consumption and future loads. We can use load models to calculate future electricity consumption and peak loads.

Chapter 2 of this thesis describes smart grid environment and its impact on grid loads. Existing load forecasting principles are presented in chapter 3. Description of a concept of load forecasting in smart grid environment is made in chapter 4. Different scenarios of smart technologies implementation are considered in chapter 5 and analysis of these scenarios is made in chapter 6.

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2 Description of Smart Grid environment and it's impacts on grid loads

Nowadays smart grid technologies are actively under research and they are planned to be actively used in the near future. There is a variety of technologies based on smart grid: smart end-use devices, distributed energy resources, highly advanced control and communication systems. All these technologies will influence on the future electricity load demand, some of them improve energy efficiency, increase permanent energy savings, permanent demand reductions and temporary peak load reductions (Gellings 2009, 131.), but some new electricity loads will appear in the future and they will increase electrical energy consumption.

There are four main types of Smart Grid technologies:

- "Smart energy efficient end-use devices
- Smart distributed energy resources
- Advanced whole-building control systems
- Integrated communications architecture" (Gellings 2009, 131.)

These technologies allow to create a highly energy-efficient and automated system, to optimize its operation based on utility's and consumers' requirements and constraints and other variables.

2.1 Smart energy efficient end-use devices

By smart energy efficient end-use devices are meant:

- Appliances, space conditioning, lighting and industrial process equipment with the highest energy efficiencies.

- Thermal and electrical energy storage systems.

- Intelligent end-use devices with automated control and two-way communications.

- Devices advancements in distributed intelligence (For example a high-efficiency, Internet protocol addressable appliance. It can be controlled by “external signals from the utility, end-user or other authorized entity”). (Gellings 2009, 132.)

Let’s describe energy storage technologies more detailed.

Energy consumption fluctuates depending on the time of a day, the day of the week and season, as well as prices for electricity vary during a day, a week, a year. A load curve has minimums and maximums during a day, energy consumption is minimum at night, when most people sleep, and it has several peaks at the daytime. Prices for electricity are maximum when electricity consumption is maximum, but customers can use alternative energy sources during the time when prices for electricity are high, for instance they can install energy storages in their houses, on industrial objects. This way they can save their money, as ES accumulate energy during the periods of low electricity price, for instance at night, and reduce energy consumption peaks.

Energy storage technologies may be applied to a number of areas that differ in energy and power requirements. Energy storages may accumulate thermal energy and then perform a house heating at periods of time when price for electricity is high. Or storages may accumulate electrical energy and supply a house with electrical energy during the periods of high electricity demand and prices.

Energy storage devices can also help renewable energy stations, whose power output cannot be controlled by grid operators and depends on sunlight intensity, wind power, etc.

As ES store energy produced during the off-peak periods for use during the peak periods, they allow to smooth load curve and decrease load peaks. It means that capacity of equipment, lines and transformer, may be lower than without energy storages usage.

2.2 Smart distributed energy resources

Nowadays distributed generation (DG) technologies are actively under research and development. Electric utilities are seeking for new technologies to increase power quality and reliability provided to their customers. Distributed generation technologies are attractive because they provide producing energy with less environmental impact, they are highly efficient and equipment is easy to site. Distributed generation devices can be installed at or near the load and it can produce from 3 kW up to 100 MW.

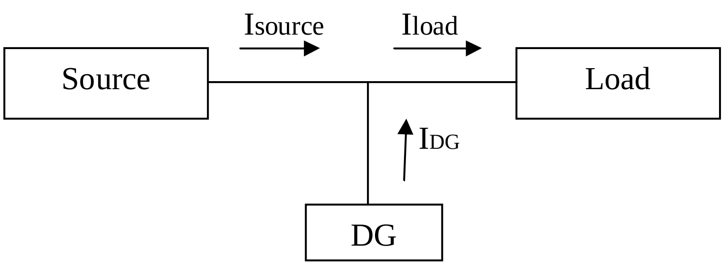


Fig. 3.1. Distributed generation.

There are several types of smart distributed energy resources:

- One-site generation devices: wind energy conversion systems, diesel engines, gas turbines, micro-turbines, gas-fired IC engines, fuel cells and photovoltaic systems. They can provide power alone or together with the grid.

- One site electric energy storage devices: batteries and fly-wheels.

- Dynamically controlled devices to supply baseload, power quality, peak shaving or temporary demand reductions.

- Dynamically controlled devices such that excess power can be sold back to the grid.

At present, the most competitive among all renewable technologies is wind power technology. Maintenance cost of fuel cell and photovoltaic systems is quite low as there are no moving parts in these systems.

Integration of distributed energy technologies into an existing utility results in several benefits: reduced environmental impact, increased overall energy efficiency, reduction of line losses, peak shaving. It decreases transmission and distribution congestion and defer investments to upgrade existing generation, transmission, and distribution systems. Customers also get benefits from integration of distributed generation, they get better quality of energy supply and lower prices for electricity.

2.3 Advanced whole-building control systems

By advanced whole-building control systems are meant:

- Systems that optimize the performance of distributed energy resources and end-use devices. This control is based on operational and user requirements and external signals from the utility, end-user or other authorized entity.

- Systems that control operation of end-use devices, for instance, automatic dimming of lights depending on daylight intensity.

- Control systems with two-way communication, they send data to an external source and accept commands from it. For example they can send information about carbon dioxide concentration in a room and accept commands to operate conditioning system based on forecasted outside air temperature.

- Local, individual control systems. Lighting, space conditioning, security, distributed energy resources, etc., are controlled by a central unit.

- Control systems that can use past experience to operate un future.

Advanced whole-building control systems allow to decrease energy consumption by end users, increase energy efficiency and savings. They can be used in private flats or houses as well as in public places, for instance in universities or business offices. The residential, small office and commercial building sector together consume about 50% of electrical energy in Europe (Kok 2009, 1.). That's why savings in these sectors can be very significant for total energy consumption. Smart house technologies alone and smart houses interacting with smart grid allow to achieve a next level in energy efficiency and sustainability.

The various components are communicating with each other to increase comfort of people lives and energy savings. Technologies used in smart house are: smart lighting, heating, conditioning, etc. For instance smart lighting provides different programs for lighting of a room: special programs for reading, TV watching and so on; it also uses information of sensors installed in a house (sunlight intensity, amount of people in a house and their position) to adjust lighting in a room. These technologies allow to slow down the growth in energy consumption.

Advanced whole-building control systems allow to reduce energy consumption by up to 26-28% per year. Energy savings by using sensors of human presence are about 10%, by using the function “to turn off everything” when everybody leaves a house – about 10% per year. (Charitonov 2009).

Together with intelligent technologies, more efficient technologies can be used in house building. Today very popular became an idea of “passive house”. The authors of this idea are German scientist Wolfgang Falst and professor from Sweden Bo Adamson. In 1999 an apartment house called "Passivhaus Wohnen & Arbeiten" was build based on this idea. Savings in energy, including electrical energy, in this house are about 79 % and cost of its building was only 7% higher compared to usual apartment house. “Passive house” is heated by human and electrical devices heat releasing and sunlight, heat losses are reduced by using energy saving materials and technologies, for instance better thermal insulation. Sunlight heats water for house heating system and for supplying a house with hot water.

2.4 Integrated communications architecture

Integrated communications architecture means:

- Automated control of distributed energy resources and end-use devices depending on the various signals. These signals could be from the utility, for instance, pricing or emergency demand reduction signals; weather forecasts; external alerts, for instance, signals to turn off the outdoor ventilation systems in the case of chemical attack in the region; end-user signals.

- Sending operational data to external parties by end-use devices, control systems and distributed energy resources.

- Communication between devices.

An example is advanced smart meter. It uses communication network and antenna to send electricity consumption data to the utility. They have a similar size as regular meters and digital displays, so a customer can see how much energy he consumes at a certain time. Comparing his consumption and price for electricity, customer can reduce electricity consumption during the peak periods, for instance by decreasing heating or using electrical devices (washing machine, vacuum cleaner) during the off-peak periods , and therefore reduce his bills and decrease peaks of load curve.

Communication technology allows to organize a centralized meter reading system, so after it's installing there is no need for meter readers to visit individual premises for data collection. Utility gets a data of customers' consumption and gets the ability to forecast energy consumption and plan electricity generation more carefully.

2.5 Electrical vehicles

The idea of creation and producing electrical vehicles is very popular nowadays. Electrical vehicles are: electric cars, electric trucks, electric boats, electric motorcycles and scooters, electric trains, electric aeroplanes and electric spacecrafts. They use one or several electric motors for movement. A very big advantage of electrical vehicles is their ability to recover energy normally lost during breaking.

The idea of electrical vehicles became very popular because of the growing problems of environmental pollution (environmental impact of fossil fuel-powered vehicles) and increasing prices for oil. The electricity consumed by electrical vehicles can be generated from the various sources: nuclear power, fossil fuels and renewable sources (solar power, wind power, tidal power, etc.). After charging, energy may be stored on board the vehicle using a flywheel, battery, or super capacitors.

If electrical vehicles would become very popular it will increase the electricity demand. But the most vehicles' would be charging at night, during the off peaks. But it would be a great problem for transmission and distribution systems if all drivers decide to plug in their cars at the same time. The process of charging the EV typically takes hours and it can be performed from conventional power outlets or dedicated charging stations

During the peak periods of high electricity demand electric vehicles can feed electricity into the grid from their batteries while most of their charging is at night, during the period when there is unused generating capacity. The Vehicle to Grid (V2G) connection can even reduce the need for building new power plants.

2.6 Effect of changes in a grid on grid loads

Let's evaluate how smart grid devices, control systems and new loads effect on grid loads.

2.6.1 Energy storages

Large scale energy sources are used to store energy produced at the periods when production exceeds consumption and this energy is then used when consumption exceeds production. With large scale energy storages production is maintained at a more constant level, it is needn't to be drastically scaled up to meet momentary consumption. Fuel-based power plants can be operated more efficiently and easily. As well renewable power plants, that depend on various factors such as weather, benefit from energy storages. Figure 2.2 represents simplified electrical grid with energy storage.

Figure 2.3 represents grid energy flow with and without energy storage during a day. It is seen from the picture that energy storages implementation decreases maximum load in the grid P_{max}, but energy consumed by customers remains the same.

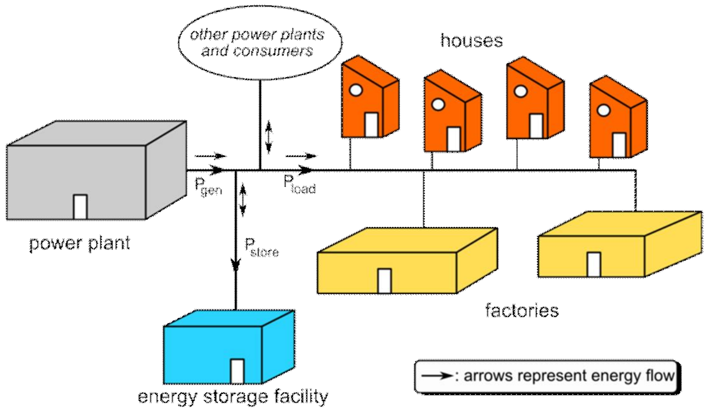
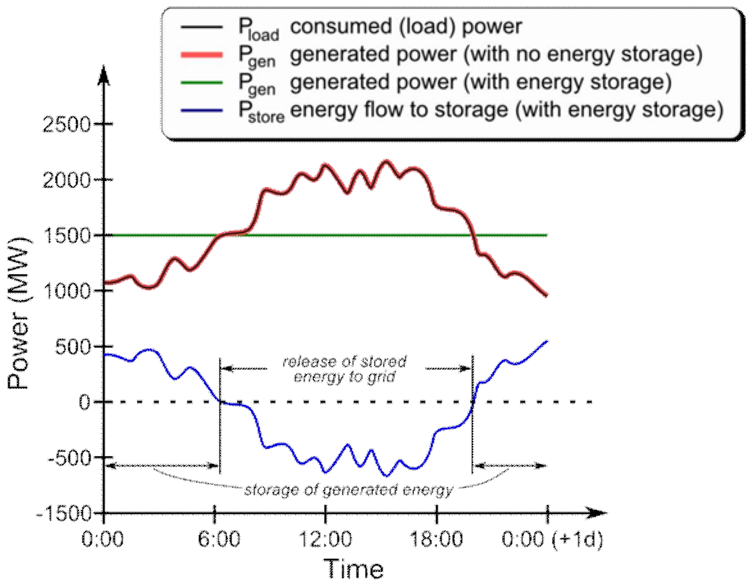


Fig. 2.2. Large scale energy storage (Grid energy storage).



2.3. Grid energy flow with and without energy storage (Grid energy storage).

The amount of maximum power decreased by energy storage implementation depends on the energy fluctuations intensity and capacity of energy storage.

There are several types of energy storages: batteries, flywheel energy storages, electrical vehicles (V2G), hydrogen storages, thermal storages etc. Vanadium redox flow batteries are currently installed in Australia, Japan. A 12 MW·h flow battery is going to be installed at wind farm in Ireland. Electrical vehicle could give energy to a grid, this technology is called “Vehicle to grid” . Vehicle battery of 20 to 50 kW·h can be used as a distributed load-balancing device or emergency power source. If we assume that annual household consumption is 3650 kW·h, then daily consumption is 10 kW·h and one vehicle covers from 2 to 5 days of average household consumption.

Energy storages can also be used directly by a customer and they can be installed in houses, factories. They are charged when the price for electricity is small (during off-peaks, at night) and supply a customer with energy when the price for electricity is high (during peaks of load consumption). They also decrease peak load P_{max}, but consumed energy remains the same. Figure 2.4 represents changes in load curve of a customer with an energy storage installing during a day.

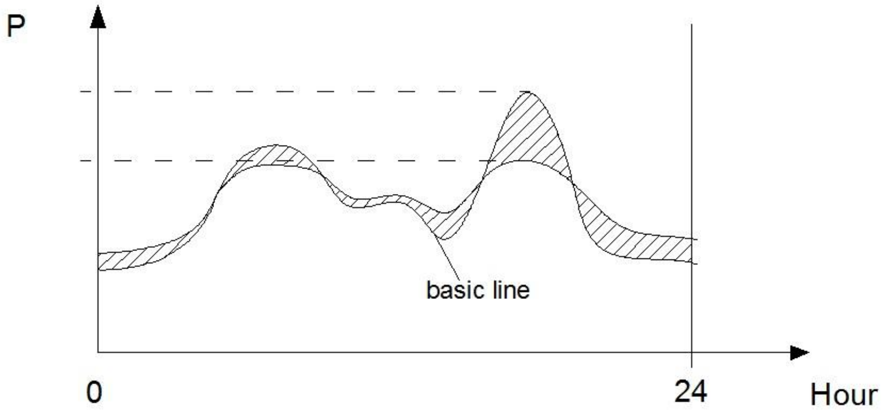


Fig. 2.4. Comparison of load curves of a usual customer (basic line) and a customer with an installed energy storage.

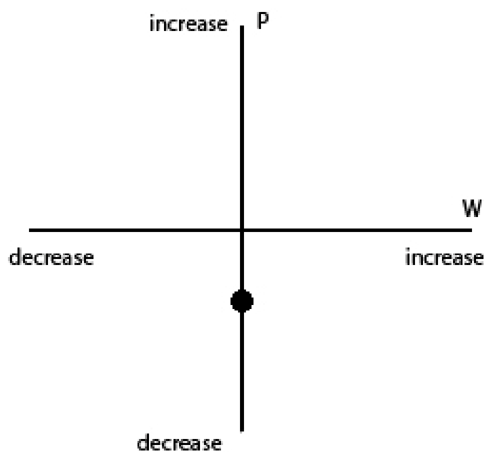


Fig. 2.5. Changes in W and Pmax with energy storage installing.

2.6.2 Distributed energy sources

Distributed energy sources are small-scale power generation sources typically in the range of 3 kW to 100,000 kW. They are used to provide an alternative to the traditional electric power system or an enhancement of it.

Integration of distributed energy technologies into an existing utility increases overall energy efficiency, reduces line losses, shaves peaks. It means that P_{max} decreases as well as W decreases (figure 2.6).

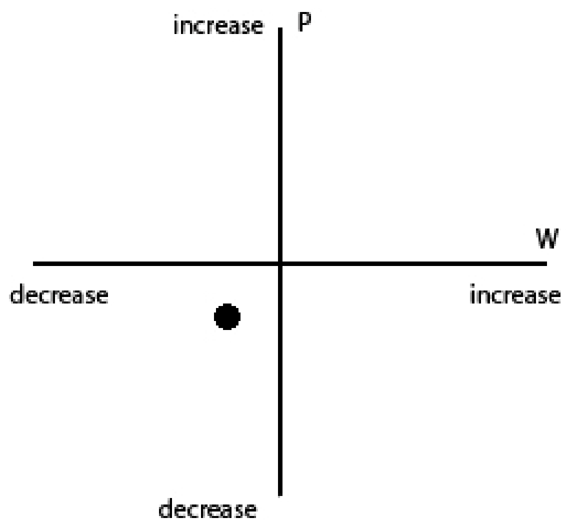


Fig. 2.6. Changes in W and Pmax with distributed energy sources installing.

2.6.3 Local generation by customers

Power can be generated locally by customers. It can be generated by renewable energy sources like solar panels or by non-renewable energy sources like diesel engines. This sources can cover all customer's need of energy and even give its surplus to a grid, or they can be used during consumption peaks. They also can be used together with energy storages, for example energy generated by solar panel depends on the light intensity and it's surplus can be stored to be used later.

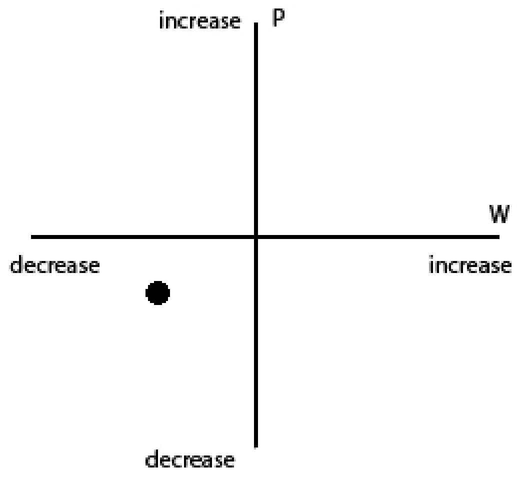


Fig. 2.7. Changes in W and Pmax with implementation of local generation by customers.

In case when power is generated locally during consumption peaks it reduces consumed energy W and reduces power peak P_{max} (figure 2.7).

2.6.4 Electrical vehicles

Figure 2.8 represents comparison of load curve of an area without electrical vehicles with a load curve of an area with electrical vehicles without intelligent charging. Wide use of electrical vehicles without intelligent charging will lead to the peak load increasing and increasing of consumed energy (figure 2.9).

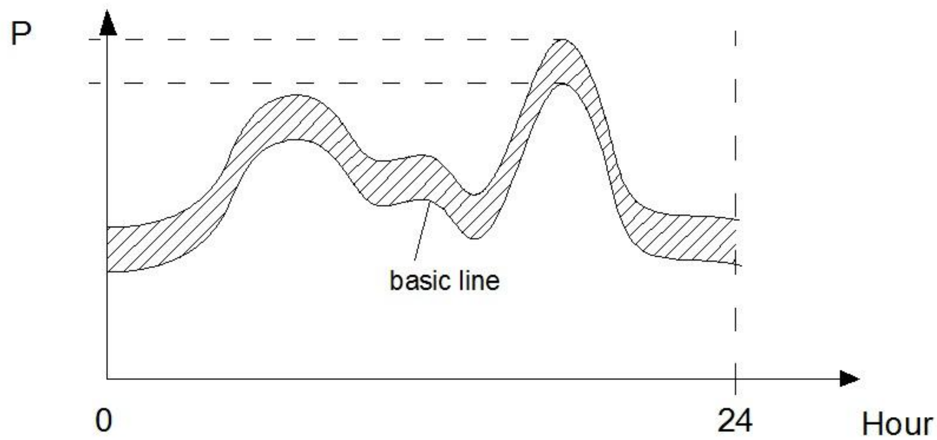


Figure 2.8. Comparison of load curve of an area without electrical vehicles (basic line) with a load curve of an area with electrical vehicles without intelligent charging.

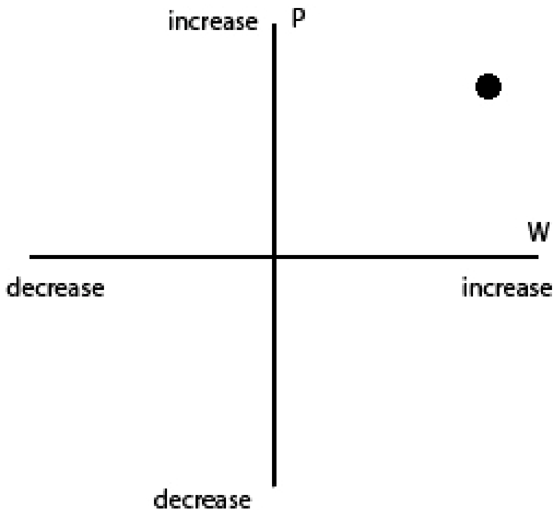


Fig. 2.9. Changes in W and Pmax with implementation of EV without intelligent charging.

Intelligent charging of electrical vehicles means that it is charging during the off-peak periods and it won't increase load peaks. Figure 2.10 represents comparison of load curve of an area without electrical vehicles with a load curve of an area with electrical vehicles with intelligent charging. It will decrease load peaks and Pmax (figure 2.11). And consumed energy will increase. Electrical vehicles can also be used as energy storages and provide power during the consumption peaks.

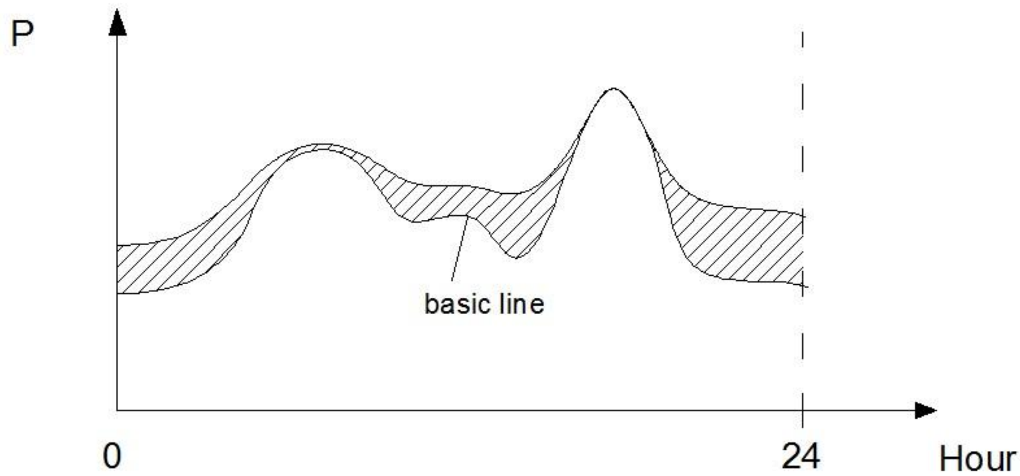


Figure 2.10. Comparison of load curve of an area without electrical vehicles (basic line) with a load curve of an area with electrical vehicles with intelligent charging.

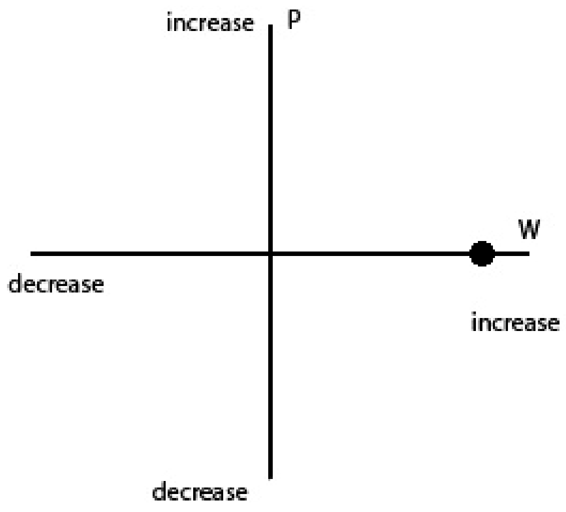


Fig. 2.11. Changes in W and Pmax with implementation of EV with intelligent charging.

2.6.5 *Energy efficiency improving*

By energy efficiency improving is meant improving of efficiency of electrical equipment, losses reduction. With improving of energy efficiency of end-use devices, electrical equipment and implementing of more efficient technologies, energy flow in the grid decreases, as well as maximum power Pmax. Figure 2.12 compares load curves of a usual customer and a customer with more efficient appliances.

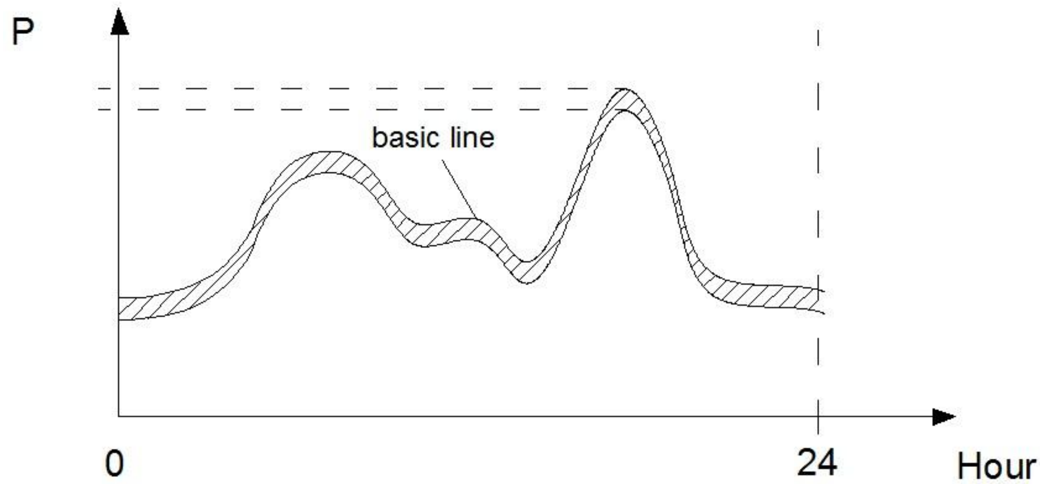


Figure 2.12. Comparison of load curves of a usual customer (basic line) and a customer with more efficient appliances.

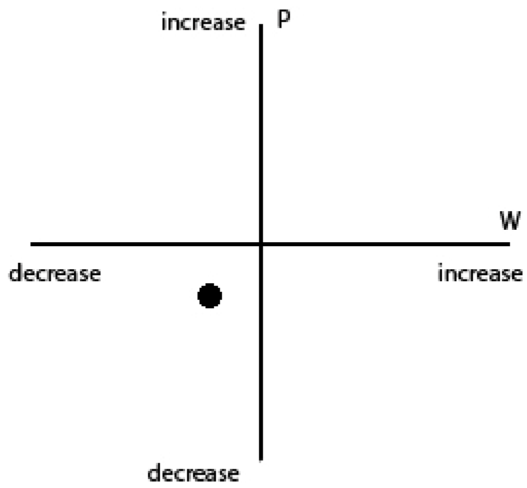


Fig. 2.13. Changes in W and Pmax with energy efficiency improving.

2.6.6 Energy-saving technologies

An example of energy-saving technology is a concept of smart house, when loads (light, air conditioning, etc.) are regulated depending on the need in them (on sun-light intensity, room temperature, etc.). due to this technologies implementation energy flow in grid and P_{max} decrease. Figure 2.14 compares load curves of a usual customer and a customer with smart home system.

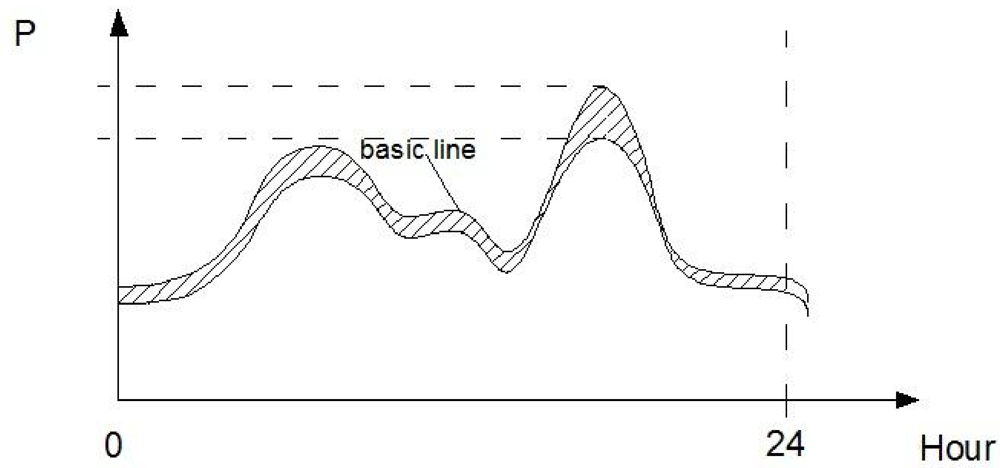


Figure 2.14 Comparison of load curves of a usual customer (basic line) and a customer with smart home system.

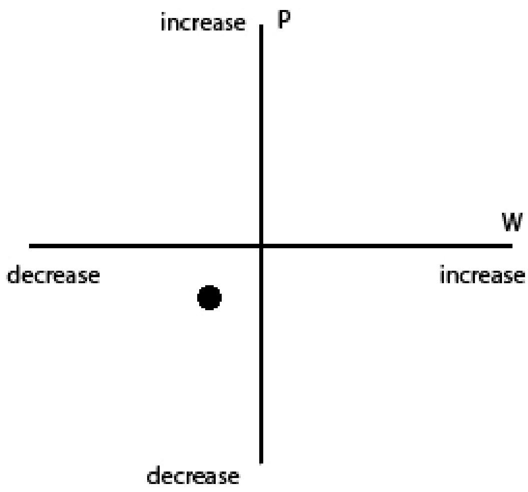


Fig. 2.15. Changes in W and Pmax with implementation of energy-efficiency technologies.

2.6.7 Zero energy house

Zero energy buildings have very low or even zero electrical energy consumption from a grid. They use locally produced electrical energy (from solar or wind energy) and at the same time overall use of energy in this houses is decreased comparing to usual buildings. In case of emergent of such houses energy flow in grid and load peaks will decrease. Figure 2.16 compares load curves of a usual house and a zero energy house with minimum net electricity consumption.

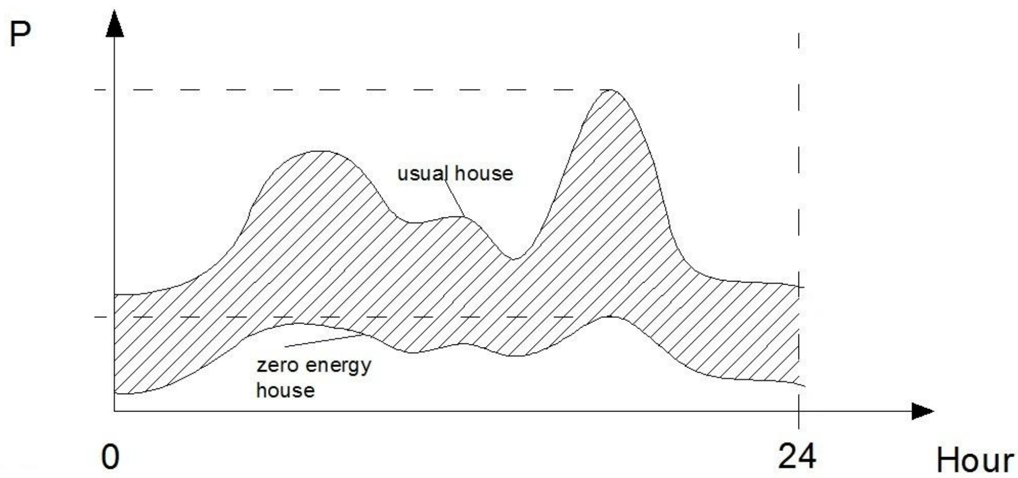


Figure 2.16 Comparison of load curves of a usual house a zero energy house.

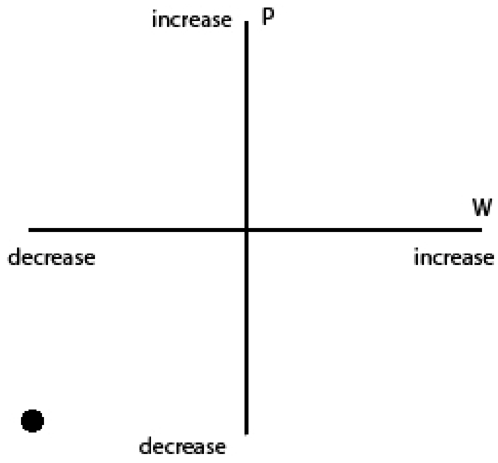


Fig. 2.17. Changes in W and P_{max} in case of zero energy houses emergent.

2.6.8 Heating system

- replacing of electric space hating by heat pump

  Heat pump uses a heat from the atmosphere or from the ground to heat a house. Geothermal heat pump uses 2/3 less energy than direct electric heating to produce heat. Figure 2.18 represents comparison of load curves of a house with direct electric heating and a house with geothermal heat pump heating system.

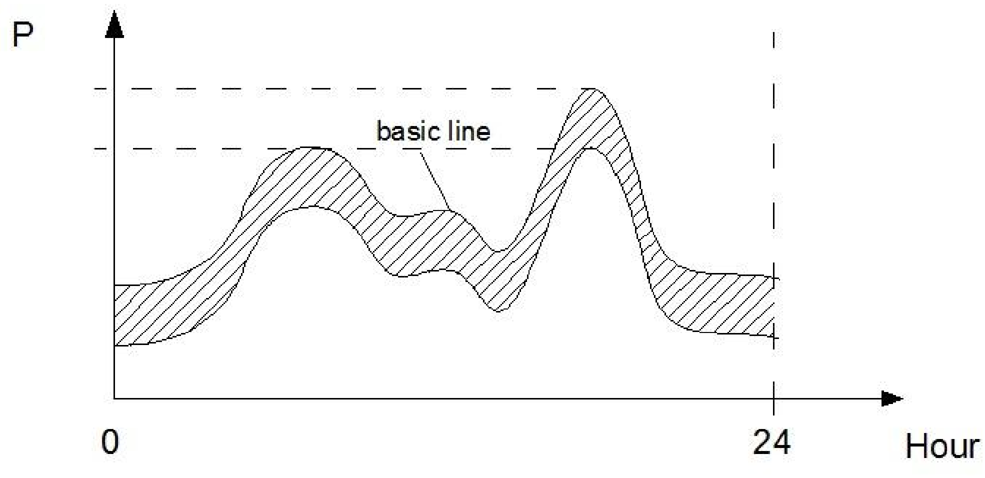


Figure 2.18. Comparison of load curves of a house with direct electric heating (basic line) and a house with heat pump heating system.

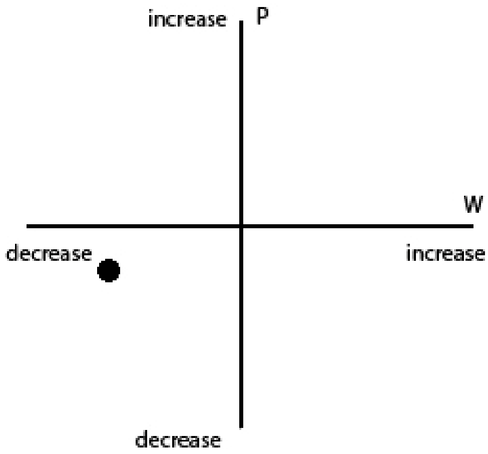


Fig. 2.19. Changes in W and P_{max} in case of replacing of electric space hating by heat pump.

- replacing of gas heating system by heat pump

  In case of gas heating system, no electricity is consumed by a customer for heating. Bu if a customer changes heating system and install heat pump, its annual consumption and peak load increases. Figure 2.20 represents comparison of load curves of a house without electric heating and a house with heat pump heating system.

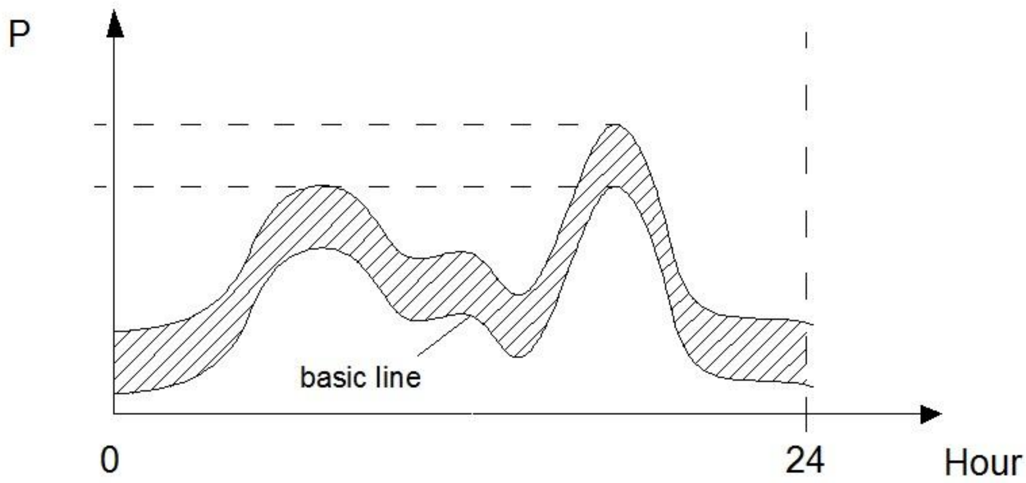


Figure 2.20. Comparison of load curves of a house without electric heating (basic line) and a house with heat pump heating system.

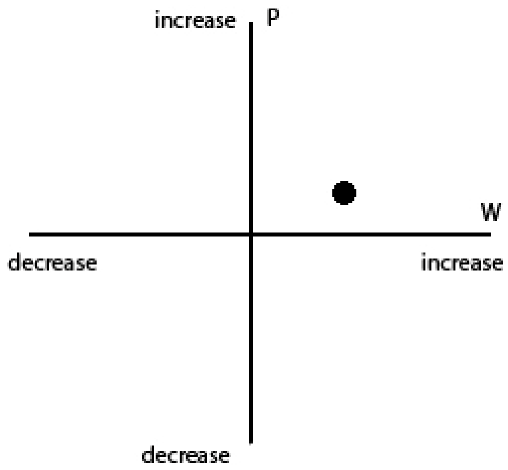


Fig. 2.21. Changes in W and P_{max} in case of replacing of gas hating system by heat pump.

2.6.9 Load control by customers

If customers have information about changes in electricity price during a day they can choose optimal time for using their electrical appliances. They use it when price is lower, i.e. during off-peaks. It shapes load curve, reduces power peaks them. But energy consumption remains the same. Figure 2.22 represents comparison of load curves of a usual customer and a customer with load control.

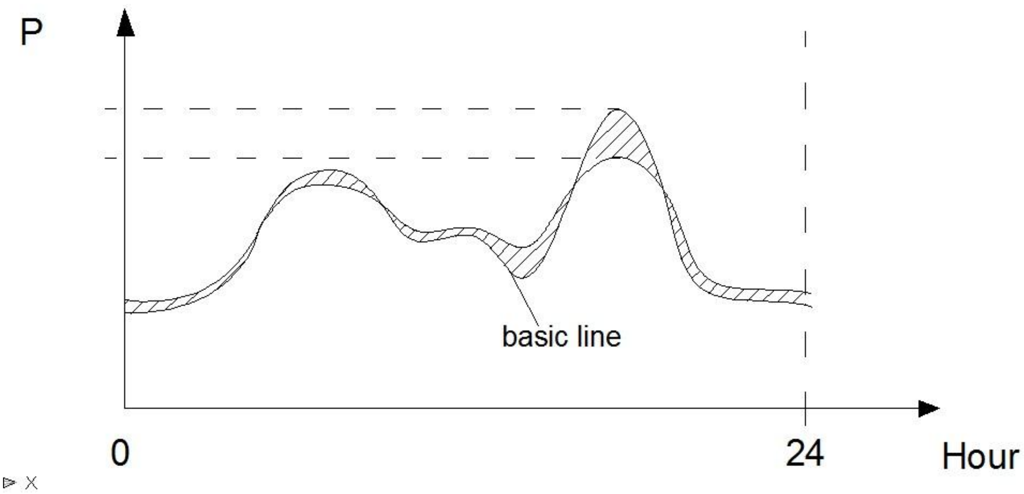


Figure 2.22. Comparison of load curves of a usual customer (basic line) and a customer with load control.

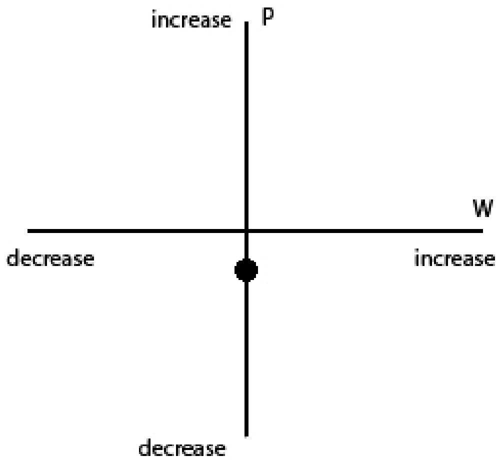


Fig. 2.23. Effect of load control by customers on energy W and maximum load P_{max}.

2.6.10 More electrical appliances

In future more electrical loads will appear because of the scientific and technical progress. From year to year number of electrical appliances, energy consumption and peak load increases.

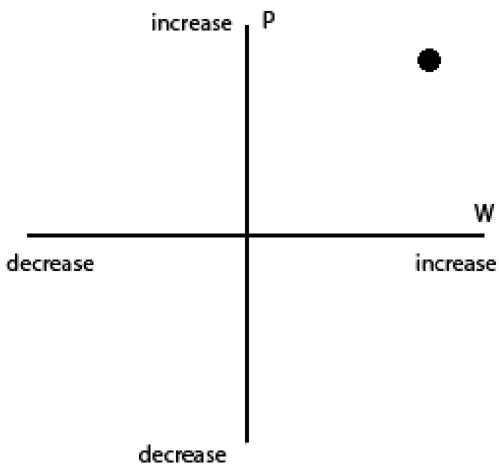


Fig. 2.24. Effect of increasing number of electrical appliances on energy W and maximum load P_{max}.

3 Description of existing load forecasting principles, literature review

Long-term forecasting of electrical loads is the first step in planning and developing of generation, transmission and distribution systems. Based on the results of such forecasts, companies coordinate their resources to meet the forecasted demand. Long-term load forecasts are made for a period up to several decades. They are very important in planning and help to make an economical based decision of buying and installing new equipment and facilities to meet the customers' future electric demand and to provide an acceptable level of power quality and reliability.

Methods, used for long-term load forecasting, can be classified into two categories: parametric methods and artificial intelligence based methods. Parametric load forecasting methods are based on statistical techniques and historical data of loads and factors affecting on loads. Thee parametric methods are described below: trend analysis, end-use modeling and econometric modeling. The artificial intelligence methods are classified into neural networks, genetic algorithms, wavelet networks and fuzzy logics methods.

3.1 Parametric methods

As it was already said, parametric methods take into account historical data of loads, factors affecting on load demand and with the use of statistics make a long term forecast.

3.1.1 Trend analysis

Trend analysis focuses on information about changes in electricity demand in past and based on this information predict changes in electricity demand by extending past rates of electricity demand into the future. Techniques used for this operation vary from hand-drawn straight lines to complex curves produced by computer. Trend forecasts can be modified if some future developments are known and it is known that they will affect somehow on the electricity demand in the future and change the behavior of electricity demand growth.

Advantages of trend analysis are its simplicity, low cost and quickness of implementation. Disadvantage of this method is that it produces only one result, future electricity demand.

In our work we can use trend analysis to forecast changes in existing loads. For instance we can use historical data of heat pumps using in a region and forecast future amount of heat pumps application. An example of such heat pumps application forecast is represented by figure 3.1.

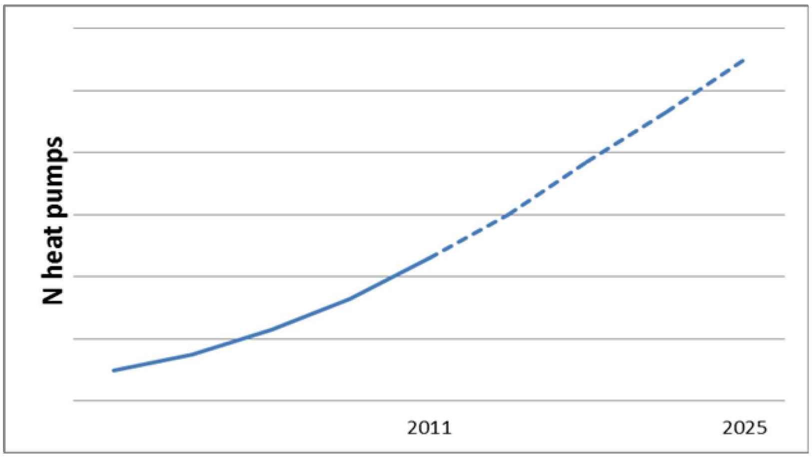


Fig. 3.1. Heat pump application forecast.

3.1.2 End-use models

The end-use approach makes load forecasts based on the statistical information about customers along with dynamics of change of loads. This models use extensive information on end users, for instance, customer size, size of houses and so on. End-use models divide customers for several sectors (residential, commercial, and industrial) and they are based on the principle that electricity demand is derived from customer's demand for light, heating, cooling, etc.

To predict the energy consumption and calculate the load in each section we need to know the load factor in each section. The system load factor is defined as follows (Ghods 2008, 2.):

$$Load\ \ factor = \frac{Average - load\ demand}{Peak - load\ demand} = \frac{AnnualkWhenergy}{Peak - load\ demand \times 8760 hours / year}$$

Ideally, end-use approach is very accurate but it is very sensitive to the quality and amount of the end users data. The disadvantage of this method is that “most end-use models assume a constant relationship between electricity and end-use (electricity per appliance)” (Ghods 2008, 2.)

The following relation defines the energy consumption by the end use methodology (Demand Forecasting for Electricity, 5):

$$E = S \cdot N \cdot P \cdot H$$

Where *E* is energy consumption of an appliance in kWh, *S* is a penetration level in terms of number of such appliances per customer, *N* is a number of customers, *P* is power required by the appliance in kW and *H* is hours of appliance use.

Then, when different end-uses in a sector are summed over, the aggregate energy demand is obtained. This method allows to take into account improvements in efficiency of energy use, utilization rates, inter-fuel substitution etc. in a sector, it is because this changes are captured in the power required by an appliance, P. (Demand Forecasting for Electricity, 5) The approach also captures the price, income and other policy and economic effects as.

The end-use approach is most effective when new technologies have to be introduced as it is in our case. It is effective to use when there is a lack of information of technologies usage and of adequate time-series data on trends in consumption and other variables. But this approach requires a high level of detailed information on each of the end-users.

The main criticism against this method is that it may give a mechanical demand forecast without adequate taking into account of consumers' behavior. It also doesn't take into account demographic, socio-economic and cultural factors.

However we will use this method in our forecast as we need to forecast a demand behavior when new technologies and equipment appear and we don't have any adequate historical data of its application.

3.1.3 Econometric models

The econometric approach estimates the relationship between energy consumption and factors influencing consumption by the least square method or time series methods. To forecast electricity demand it uses economic theory and statistical techniques.

In the econometric models the dependent variable, in our case it is a demand for electricity, is expressed as a function of various economic factors. These cold be various parameters such as population, income per capita or value added or output, price of power, prices of alternative fuels, proxies for penetration of appliances/equipment etc. Thus, we have a formula for electricity demand:

ED = f (Y, Pi, Pj, POP, T)

Where *ED* is electricity demand, *Y* is output or income, *Pi* -own price, *Pj* - price of related fuels, *POP* – population and *T* is technology.

The advantage of using econometric models in load forecasting is that a researched can not only forecast an electricity demand, but also explain its behavior in the future, why is it increasing or not and what factors and how effect on it. A disadvantage of using econometric models in load forecasting is that during the forecasting period the changes in electricity remain the same as in the past in order to get an accurate forecast.

This approach application requires statistical information over a long period of time, but in our case we need to forecast changes in electricity demand made by smart grid application. We don't have enough information as smart grid technologies are still not widely used and some of them are just planned to be used in future.

3.2 Artificial intelligence methods

Nowadays artificial intelligence methods became very popular and they are also used in load forecasting. Some kinds of them are described in this section.

3.2.1 Artificial neural networks

Methods, based on artificial neural networks, can solve various power system problems, such as design, planning, control, protection, security analysis, fault diagnosis and load forecasting. Artificial neural networks are very popular in load forecasting because of their ability in mapping complex non-linear relationships. In most cases ANNs are used in short-term load forecasting, but they are also used in long-term forecasting.

To design a neural network it is needed to choose its' architecture, method of training, and also type, size and number of used neural. The output of ANN is:

$$Y_i = \sum_{i=1}^{n} W_i X_i$$

Where *Xi* is input, *Wi* is weight of network, *Yi* is one of the outputs, *i*=1,2,…,n.

Types of ANNs that can be used for long-term forecasting are: recurrent neural network (for peak load forecasting) and feed-forward back propagation (to fore-cast annual peak load).

Recurrent neural networks have feedback connections, external or internal. Feed-back connections can be different for different types of networks, for instance from output to input or from hidden layer neurons back to input, and they allow RNN to encode temporal context internally. Those additional neurons in input layer, that ensure feedback connections are called context or state neurons and they get input from the upper level and after processing send information to the next layer together with other plan units. RNNs are suitable for forecasting on not very long periods, when forecasting period becomes longer, forecast error in-creases relatively.

Feed-forward back propagation is more widely used for long term load forecast-ing and it can be applied to any problem when pattern mapping is required. It has an updating and learning mechanism when coefficients used in modeling are cor-rected if the network gives a wrong answer. Weights are corrected so that the result of future responses of a network is expected to be more correct. Advantage of feed-forward back propagation is its training technique, it is "mathematically designed to minimize square error across all training pattern" (Ghods 2008, 3.).

To design and to train an artificial neural network it is needed to use information about load demand and about tendencies in equipment and technologies usage. In our case we don't have such information for smart grid technologies as they are not widely used and some of them are just planned to be used. It means that we can't use artificial neural networks to predict future load demand in our case.

3.2.2 Wavelet Networks

Wavelet theory received wide attention in electrical load forecasting. It has an improved forecasting accuracy comparing to tradition load forecasting methods.

This theory provides powerful and flexible tool to decompose load data into different frequency components, after that it is possible to analyze each component and its characteristics.

To get a good forecast by using the wavelet network several features should be taken into account:

- Wavelet function for load forecasting must be selected properly as it is very important for wavelet application, but still there is no general rule for it. Generally, the most important in load forecasting is high accuracy, “it requires less distortion during the wavelet decomposition and reconstruction process”. (Ghods 2008, 3.)

- Border distortion during wavelet transform must be avoided. Border distortion problem appear during the wavelet decomposition process, it happens because of the limited number of data. Because of border distortion wavelet coefficients are distorted and a forecast based on these coefficients will never give an accurate forecasting result.

Figure 3.2 illustrates the structure of wavelet network, it is very similar to Multilayer neural network.

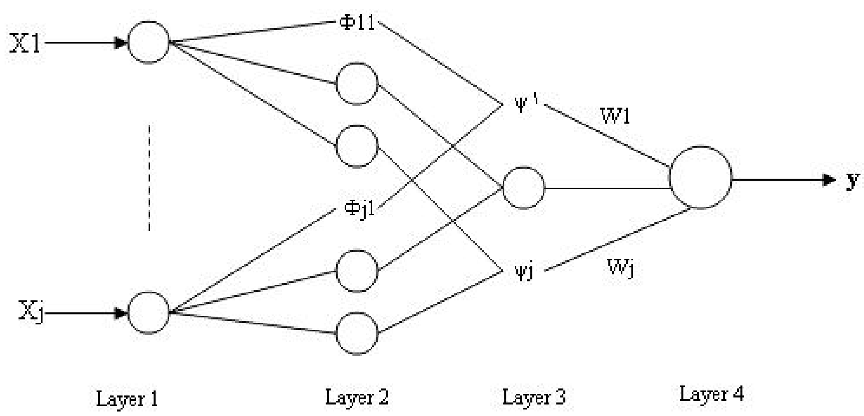


Fig. 3.2. Schematic structure of wavelet network. (Ghods 2008, 3.)

The advantage of wavelet network modeling method is its high accuracy in long term forecasting.

For this method usage, like in artificial neural networks, a lot of statistical information is required to forecast electricity load demand. As we don't have enough information about smart grid technologies usage yet, we can't apply this method.

3.2.3 Genetic Algorithms

Genetic algorithm (GA) is a numerical optimization technique. It is a very popular optimization tool and helps to solve problems in engineering, finance, economics, science, etc. This technique is based on the Darwinian survival-of-the-fittest strategy, on the mechanism of natural selection and natural genetics. Genetic algorithm generates solutions to optimization problem using natural evolution techniques, such as inheritance, selection, crossover and mutation. Figure 3.3 illustrates the structure of genetic algorithm.

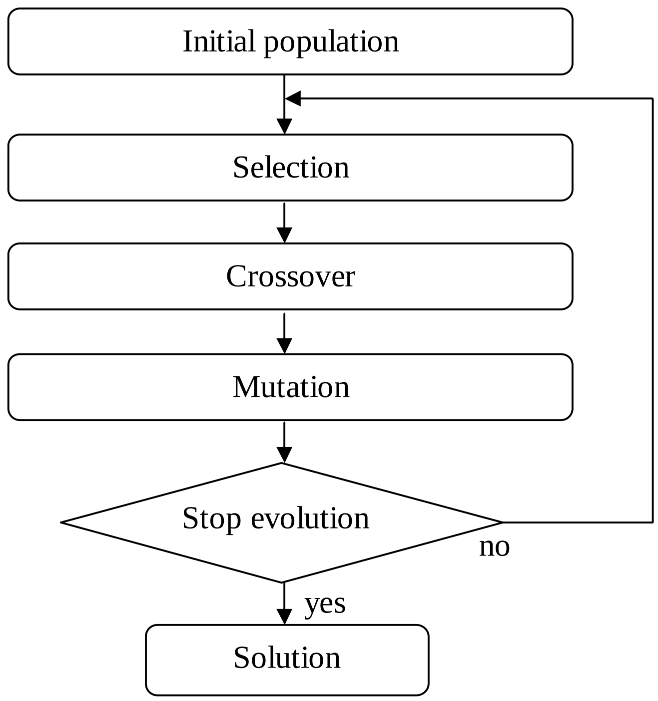


Fig. 3.3. Schematic structure of genetic algorithm.

Population in genetic algorithm is a set of possible solutions. GA calculates a 'fitness' for each possible solution, that is a criteria of its goodness. Than it chooses best solutions by this criteria and applies crossover and mutation for generating new solutions. This cycle repeats until a stopping criteria will be achieved (it can be a number of cycles, fitness value, time of calculation, etc.).

Applying GA to electrical load forecasting, we find the optimum values of the state vector X that minimizes the absolute summation of the forecasting error r(t). r (t) is the error vector associated. Genetic algorithm tries to keep the r (t) in the allowed limitation. If the r (t) is kept in the allowed limitation, the fitness function has the best value for load demand forecasting. Fitness function for GA is calculated by following equation:

$$ff = \frac{1}{1 + k\sum_{k=1}^{m} |r(t)|}$$

Where *k* is a scaling constant (for example, k=0.0001).

With r(t) we can calculate the load demand forecasting by the following equation:

$$P(t) = a_0 + \sum_{i=1}^{n} a_i t^i + r(t)$$

Where *P(t)* is the peak load demand at time *t*, a_o, a_1 are the regression coefficients relating the load demand to time t, *r(t)* is the residual load at year t.

This method is also difficult to implement in our case because of the lack of information.

3.2.4 Fuzzy Logic Model

Fuzzy control system – is a decision mechanism represented by a set of fuzzy rules. The fuzzy logic model provides an algorithm to convert strategy based on expert knowledge into an automatic strategy. A skilled human operator can be replaced with a fuzzy rule-based system. Fuzzy logic models can be combined with neural network to train ANN. This combined system provides better load forecasting result, it combines advantages of both methods: generalization capability of artificial neural network and the ability of fuzzy logic model to use forecasters' knowledge and experience. This methods gives quite accurate load forecasts. Figure 3.4 illustrates the structure of combined ANN and Fuzzy logic methods.

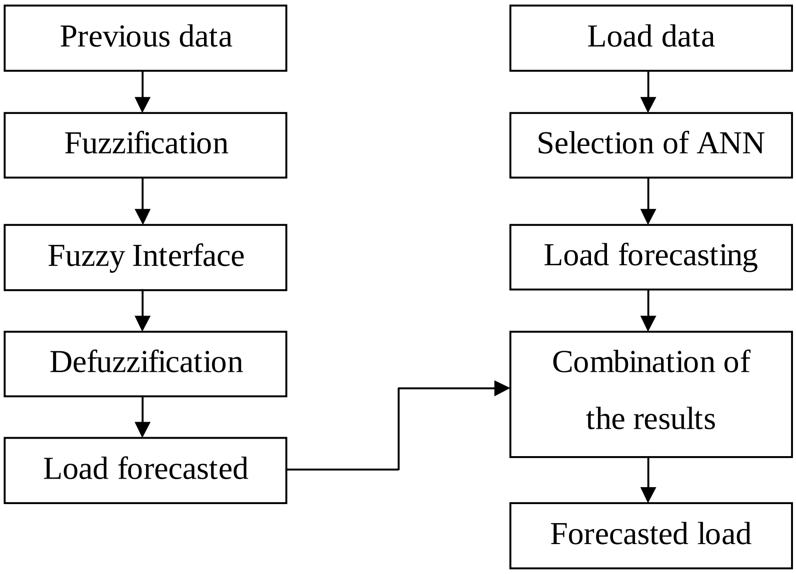


Fig. 3.4. Schematic structure of ANN and Fuzzy logic methods.

Thus, there are a lot of various long-term load forecasting methods existing. They are based on statistics, historical data, data on customers, expert knowledge and experience, artificial intelligence methods, etc. They all have advantages and disadvantages and for better forecasting result a combination of several methods can be used.

In our case we need to forecast load behavior when new types of loads will appear and new technologies will be implemented. We don't have any adequate information about these technologies and equipment historical implementation. And for our purpose we can use only end-use modeling. We can model behavior of different types of loads, different scenarios of equipment and technologies future usage. We also can use trend analysis to forecast future usage of existing loads.

4 Concept level description of long term forecasting of grid loads in Smart Grid environment

Long-term load forecasts are made for the period of one to ten years and sometimes up to several decades. Accurate load forecast is very important for generation, transmission, distribution and feeder systems planning. It is very important for investments planning, for minimizing cost and maximizing profit. For accurate load forecasting it is needed to take into account existing loads in a region, statistical information of the load growth and new tendencies in developing of electrical loads and technologies.

There are a lot of new technologies developed and planned to be widely used in the future. Smart grid technologies (distributed energy resources, smart end-use devices, advanced control and communication systems) are among them. They will effect on the future electrical energy consumption, decrease load peaks, improve energy efficiency, increase energy savings. At the same time new electrical loads will appear in the future and load demand will increase.

To begin electric load growth forecasting, first, it is needed to divide the utility service territory into several small areas. This areas can be chosen as service areas of substations or feeders in the system or they can be square areas divided by a grid. Figure 4.1 illustrates methods of dividing the territory into areas.

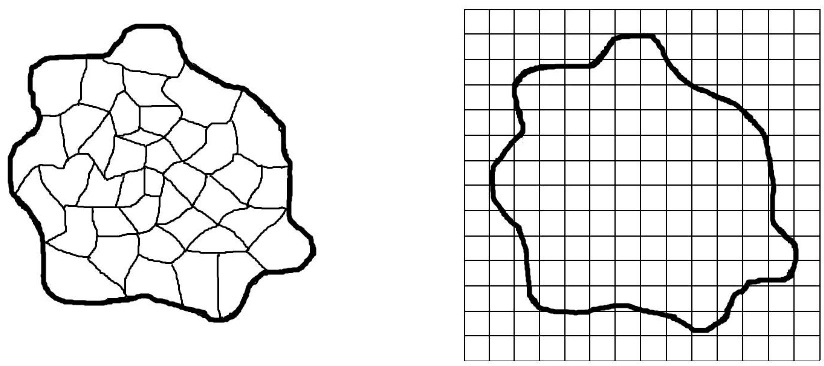


Fig. 4.1. Dividing the utility service territory into small areas.

The next step is to determine consumers and types of loads in each area and their maximum loads and annual energy consumption. They might be industrial plants, detached houses, apartment houses, transport, commercial buildings. Historical data of the load growth is also needed to be taken into account for a forecast. Different types of loads have different growth during a period. Residential loads have high seasonal fluctuations due to using conditions and heaters and they have the most uniform annual load growth. Commercial loads also have seasonal fluctuations due to weather changing. Industrial loads don't have so appreciable seasonal load fluctuations but they may have special operation shifts and therefore unique load consumption characteristics.

Doing the long-term load forecast a specialist takes into account a wide range of parameters (Daneshi 2008, 1.):

- Historical data on loads and weather;
- Number of customers;
- Regional development;
- Economic data and it's forecast;
- Demographic data and it's forecast;
- Energy supply and price;
- Time factors;
- Facilities investments;
- Random disturbances.

Identifying factors that would effect on future loads and the relation among corresponding factors is a very important step. The accuracy of a load forecast strongly depends on the load factors taken into account. Fig. 4.2 illustrates the relation between load and major factors affecting on it.

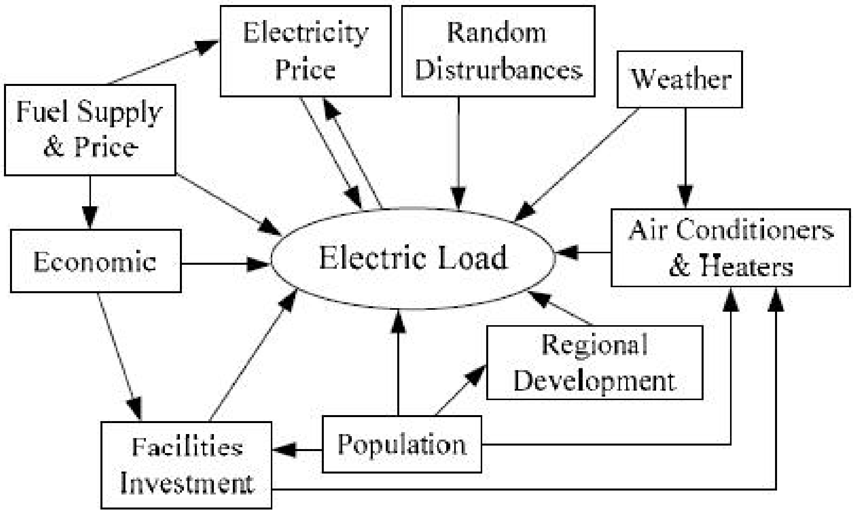


Fig. 4.2. Electric load and corresponding load factors. (Daneshi 2008, 1.)

For making a good forecast model a specialist needs to define load factors and determine the impact of load factors on load forecast, to identify the proper way of selecting load factors and a proper forecasting method. Population growth will increase load consumption, more new houses will be built in an area, electricity price growth can reduce electricity consumption, weather changes effect on air conditioners and heaters using and therefore effect on total electricity consumption. We also have to take into account new technologies development, for instance smart devices development. The may effect significantly on future loads, energy flows in a grid and on peak load. Different types of loads have different response to load factors. The total forecast is made as combination of forecasts for different types of loads.

In this thesis we need to define the impact of smart grid developing and implementation on grid loads. Different smart technologies have a different effect on grid loads. Energy storages don't change electricity consumption, but reduce peak load; air heat pumps reduce electricity consumption, but don't reduce peak load and in some cases may even enlarge it; geothermal heat pumps reduce electrical energy consumption and maximum load; smart home systems eliminate excessive lightning, conditioning, heating, controls electrical appliances working and reduce electricity consumption and peak load; distributed generation reduces electricity consumption from a grid. At the same time new loads may appear in the future, for example electrical vehicles. Their wide using can lead to electricity consumption growth. If an electric car has an intelligent charging, it doesn't increase peak load in an area, but if it hasn't – maximum power in the area will increase. We need to define this impact of smart technologies on different types of loads, to create scenarios of smart devices and technologies using in the future and make a long-term load forecast taking into account new technologies implementation.

A lot of methods exist to forecast electric demand growth. They all can be divided on parametric and artificial intelligence methods. Most of the methods use historical, statistical information of load growth in a region and about tendencies in load types changing. In our case we don't have enough historical information about smart equipment and technologies usage and it means that for our purpose, to forecast electricity load demand, we will use end-use modeling and create different scenarios of smart equipment and technologies implementation. First, we will evaluate how new technologies and equipment effect on different types of loads and then we will create scenarios of overall area loads developing and estimate how electricity demand will change.

5 Development of scenarios of long-term forecasting and their analysis

Let's assume that we have an area and we know number of customers in this area, their types and annual energy consumption for 2011 year (table 5.1).

Table 5.1. Customers located in the area.

	Customer	Number of customers	W, kWh/a
1	Detached house, individual room heating, - Usage of water boiler <300 l - Usage of water boiler 300 l - floor heating> 2 kW	163	3 037 301
2	Detached, semi-electric storage heating, - short closing times - long-term shut-off times	17	388 153
3	Detached house, - electric storage heating	2	68050
4	Detached house, - heat pump heating	10	119014
5	Detached houses, no electric heating, - electric stove	234	2 009 002
6	Row and apartment, no electric heating, - electric stove	1	23 370
7	High-rise building, - residential	17	33 317
8	Townhouse, the entire property, - individual room heating	2	25 020
9	Agriculture, crop production, - housing involved	2	49 550
10	Agriculture, livestock and dairy, - housing involved	2	45 300
11	Industry - 1-shift of industrial, chemical, petroleum, rubber and plastic products	1	8980
	Total	451	5807057

This area may be a service area of a 20 kV feeder in a system. In this area there are different types of loads: residential, agriculture and industrial loads. Residential loads are divided into detached houses with different types of heating, high-rise buildings, townhouses, rows and apartments. Number of customers and their annual energy consumption is given for each type of customer. Total number of customers in 2011 year is 451 and their total annual energy consumption is 5807057kWh.

We also have 2-week and hour indexes for all of these customer types. Using this indexes we can calculate a combined index:

$$Combined\ \ index = \frac{2 - week\ index \times hour\ index}{100} \tag{5.1}$$

After that, knowing the annual consumption of customer groups, we can calculate their energy consumption for each hour of a year:

$$W\_hour = \frac{W\_annual \times combined\ index}{8760 \times 100} \tag{5.2}$$

After that we can define maximum load P_{max} for each customer and for the whole area.

Maximum power in our area in 2011, calculated by this way, is 1698,6kW.

By changing the customers amount we can see impact of these changes on loads of different customer types and on total consumption. We will evaluate changes in heating types, energy efficiency improving, increasing amount of electrical appliances, development of energy saving technologies using this model.

But for example for electrical vehicles we don’t have 2-week and hour indexes. In this case we can simplify our calculations and estimate their impact on annual energy consumption and peak load approximately.

5.1 Impact of electrical appliances amount increasing and new houses building

Finnish household customers are well equipped, practically every house has a refrigerator and electric stove, more than 80 % of houses have dishwashers and freezers and more than 70 % of houses have microwave ovens.

According to the information published on the official web site of Enrgiateollisuus [Electricity Consumption 1996-2006] total energy consumption in Finland increased from 70TWh in 1996 to 90TWh in 2006 (figure 5.1). It means that total energy consumption increased for 20TWh during 10 years and average load growth was 2.5%. And according to this information losses in 2007 year were 3,6% from the total electricity consumption.

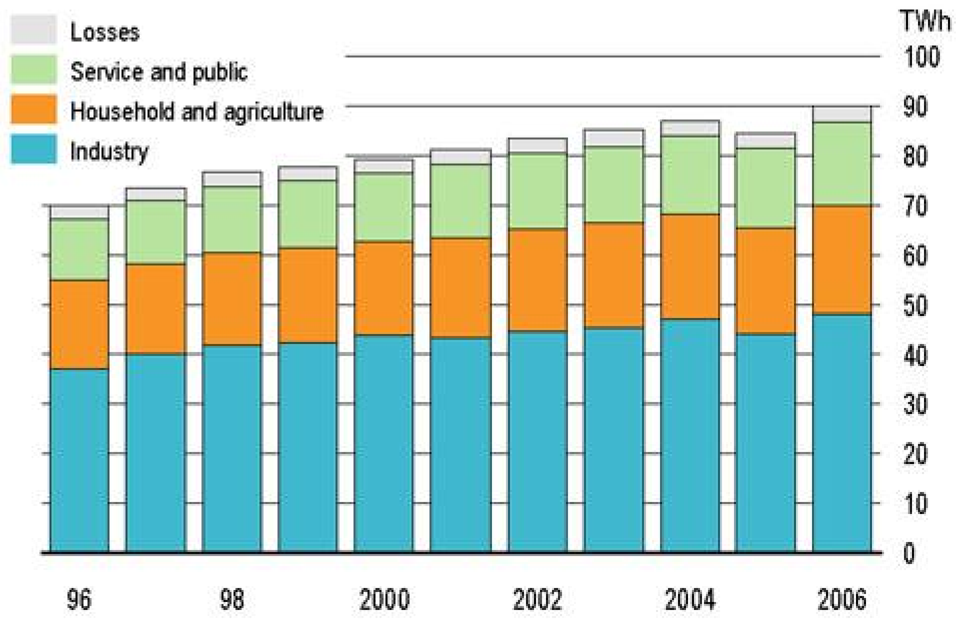


Fig. 5.1. Electricity consumption 1996-2006 [Electricity consumption 1996-2006].

This value of load growth is summarized from electrical appliances amount increasing and from new houses and factories building. Let’s assume that in our scenario load growth will be 2,5% . Assume that new houses are built in the same proportion as it was earlier; agriculture and industrial consumers increase their production, number of used appliances, but their amount doesn't increase. Let's evaluate how this growth effects on energy consumption W and peak load Pmax. (figure 5.2, figure 5.3 and table 5.2)

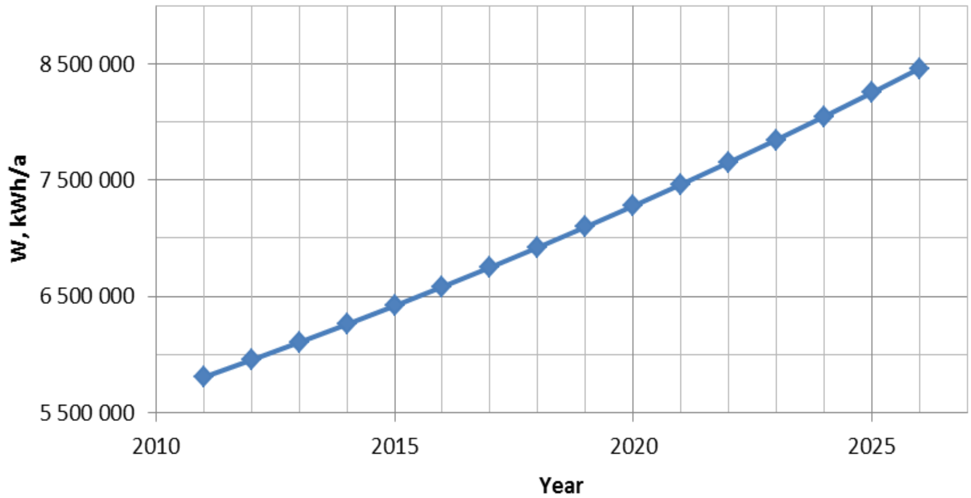


Fig. 5.2. Annual energy consunption in 2011-2026 in the area.

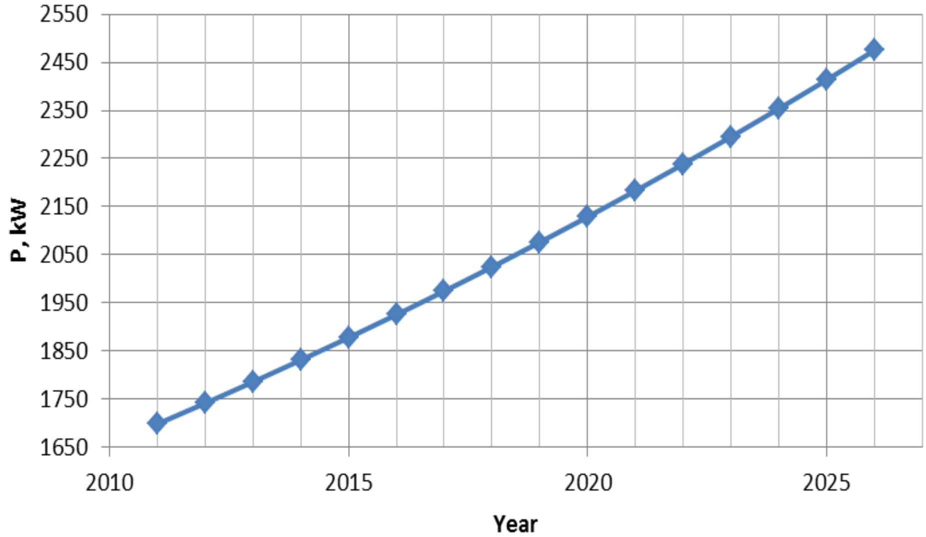


Fig. 5.3. Peak load in 2011-2026 in the area.

Table 5.2. represents electricity consumption and peak load in 2011 and 2026 for this case.

Table 5.2. Electricity consumption and peak load in 2011 and 2026.

Year	W, MWh/a	Pmax, kW
2011	5807	1698
2026	8459	2474

We can see that Wa increases to appr. 8459 MWh by 2026 year; Pmax increases from 1698kW in 2011 to 2474kW in 2026.

5.2 Energy efficiency improving and losses reduction.

Together with a process of load growth caused by new houses and factories building and increasing amount of electrical appliances an opposite process of load decreasing caused by energy efficiency improving and losses reduction takes place.

Energy efficiency of electrical equipment and electrical appliances is always being improved. Modern energy-efficient appliances use significantly less energy than older appliances. For example, current energy efficient refrigerators consume 40 percent less energy than models of 2001 year. Assume that customers in our area change their appliances gradually and energy efficiency of electrical appliances and electrical equipment improving decreases energy consumption for 1% per annum. Then load growth slows down.

Let’s evaluate how energy efficiency improving effects on energy consumption in case when there is no load growth caused by new houses building and electrical appliances amount increasing. Figures 5.4 and 5.5 represent electricity consumption and peak load growth during the period from 2011 to 2026 for this case.

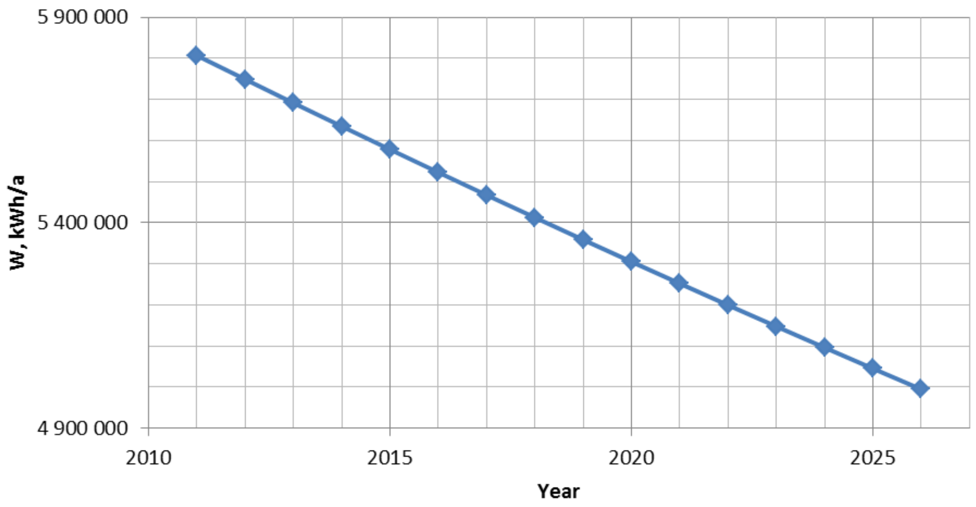


Fig. 5.4. Energy consumption in 2011-2026, energy efficiency improoving is taken into account.

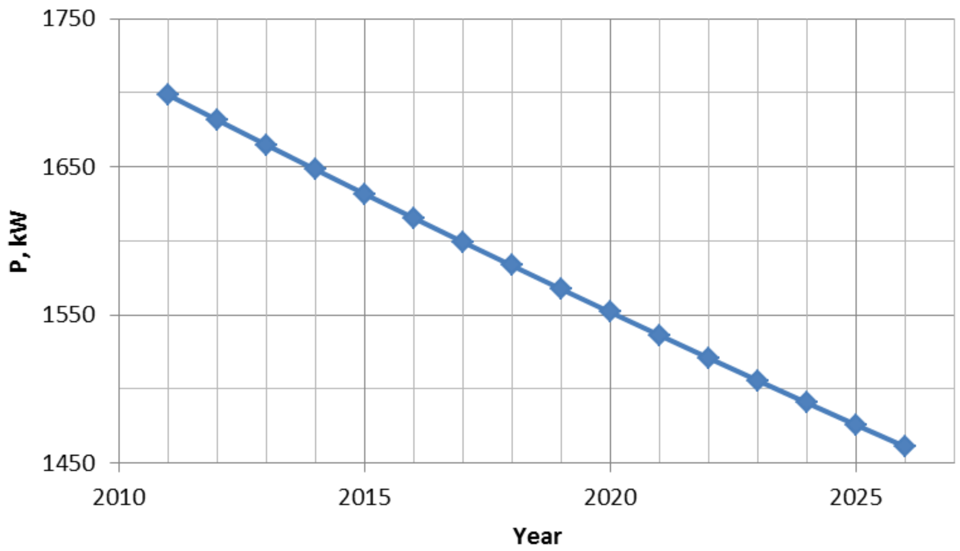


Fig. 5.5. Peak load in 2011-2026, energy efficiency improving is taken into account.

In this case energy consumption Wa decreases to appr. 4999MWh or about 14% by 2026 year; Pmax decreases from 1698kW in 2011 to 1461kW in 2026. Assume that in our scenarios load growth caused by electrical appliances amount growth is compensated by their efficiency improving.

Table 5.3 illustrates transmission and distribution losses reduction in Finland in 1980 - 2007.

Table 5.3. Transmission and distribution losses in Finland (Electricity distribution losses 2003, 12.).

Year	1980	1990	1999	2000	2007
Losses	6.2%	4.8%	3.6%	3.7%	3.6%

Energy consumption growth causes losses increase in a grid if it's architecture doesn't change over time and no actions are made to reduce transmission and distribution losses. But in the case if we reduce energy consumption, for example by changing of heating system, and improve architecture of a grid, losses in the grid remain the same or they change insignificantly. Let's assume in our scenario that losses remain at the same level as in 2011.

5.3 Changes in heating system

In our area we have 446 household customers. Their annual consumption is shown in table 5.1. Let's evaluate how changes in heating system effect on annual energy consumption and peak load.

Detached house, individual room heating

In 2011 there are 163 customers with this type of heating. But price for electricity is rather high and it always grows. Some of the customers may change their heating system to reduce energy consumption and therefore reduce payments for electricity. Let's assume that about fifty percent of detached houses with individual room heating will choose heat pump heating as it will let them save their money. Part of these customers, 10 percent will install energy storages.

Annual electricity consumption of detached houses with individual room heating in 2011 is 3 037 301kWh or 18633kWh/a/customer. If a customer installs a heat pump, it's electricity consumption for heating decreases on average by around 2/3 or it will be about 11901kWh/a/customer. If air heat pump is installed in a house, it doesn't decrease peak load as it can't be used during the winter cold period, when the peak load is maximum, but it can even increase a value of peak load because of its possible irrational using. Assume that air source heat pump increases peak load for about 5% or from 5kW to 5,25kW. If a customer installs geothermal heat pump, its peak load decreases from 5kW to 3.5kW as heat pump of this type can be used regardless of weather conditions. If a customer chooses energy storage, its annual electricity consumption will not change, but peak load will decrease. Pak load reduction depends on capacity of a storage, assume that peak load decreases on average to 4,2 kW.

Figures 5.6 and 5.7 represent changes in electricity consumption and peak load during the period of fifteen years if customers with electric heating install heat pumps and energy storages in their houses. Assume that growth in amount of electrical appliances is compensated with their efficiency improving.

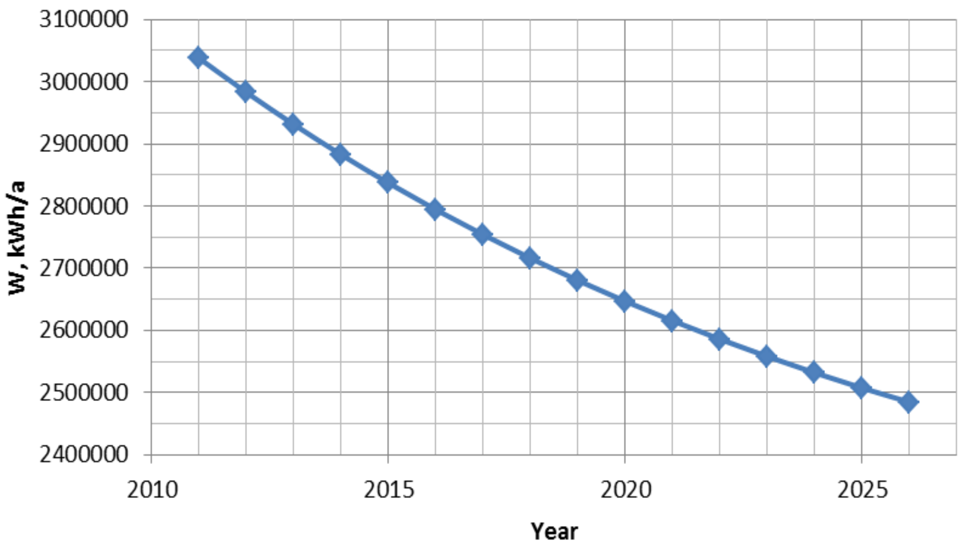


Fig. 5.6. Electricity consumption of detached houses of group 1 if 50% of them will change their heating system on heat pump hating and 10% will install energy storages.

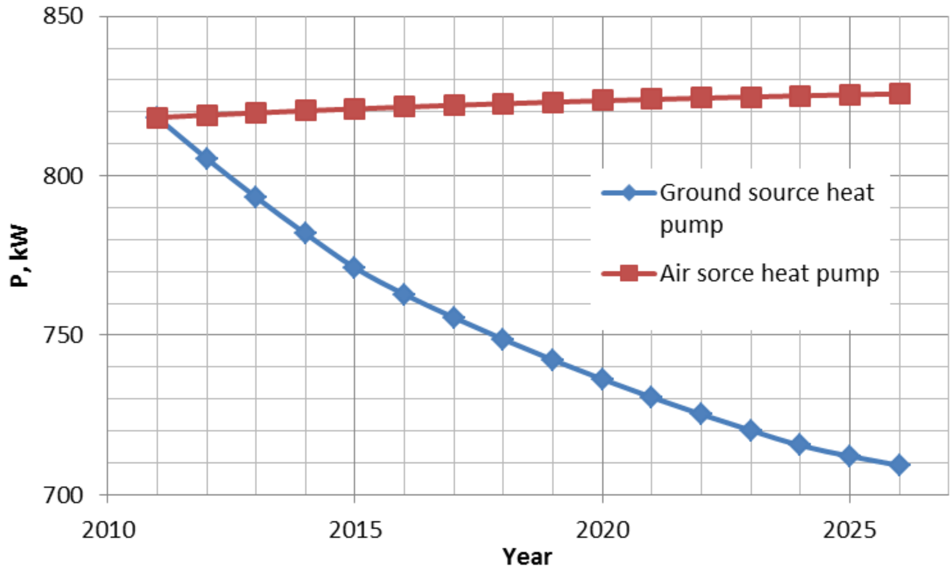


Fig. 5.7. Maximum load of detached houses of group 1 if 50% of them will change their heating system on air-source and geothermal heat pumps hating and 10% will install energy storages.

Table 5.4. represents electricity consumption and peak load in 2011 and 2026 for this case.

Table 5.4. Electricity consumption and peak load in 2011 and 2026 for group 1 customers.

Year	W, MWh/a	Pmax, kW (ground source heat pump)	Pmax, kW (air-source heat pump)
2011	3037	818	818
2026	2484	709	825

Heat pump heating system allows to reduce consumption of electricity needed for heating as it can generate 3-4kW of heating energy from 1kW of input energy [The share of heating in energy consumption in low energy house]. Maximum load needed for a house with heat pump heating also decreases. In our case fifty percent of customers of group 1 will change their heating system on heat pump heating system. We see that it reduces electricity consumption of customers from group 1 significantly, from 3037MWh/a to 2484MWh/a. Changing electrical heating system to heat pump systems will allow customers to save their money and reduce bills for electricity. 10 percent of customers from group 1 will choose electric storage heating instead of direct electric heating. Their annual electricity consumption will not change, but they will be able to store energy during off-peak periods, for example at night, and use it during load peaks. It shapes the load curve and reduces load peaks.

We can see from our calculations that peak load for customers from group 1 reduces from 818kW to 709kW during the forecasting period of 15 years in case of geothermal heat pumps using. It happens due to peak load reduction caused by a ground source heat pump and peak reduction caused by energy storage. But in case of air-source heat pumps installing, peak load increases to approximately 825kW. It happens because peak load reduction caused by energy storage using was lower than peak load growth caused by air-source heat pumps installing.

Houses with electric storage heating

Assume that customers with electric storage heating will not change their heating system as energy storages allow them using cheap off-peak electricity during the peaks of load consumption and reduce their payments for electricity. Their electricity consumption is at the same level if they had direct electric heating, but maximum power is lower.

House with heat pump heating

Customers of this type of heating already have low energy consumption. Assume that they will not change their heating system. Electricity consumption of customers with heat pump heating is lower due to the capability of heat pump to produce 3-4 times more heating energy than consumed by this pump input energy. Peak load of this type of customer is also lower than peak load of customers with direct electric heating.

Detached houses without electric heating

Houses of this type use for heating oil or gas burning. Today gas and oil heating is cheaper than heating by electricity. Assume that some of this customers change their heating system. They can choose electric storage heating or heat pump heating. Electric storage heating doesn't lead to lower electricity consumption, but it allows to use cheap off-peak electricity during the periods of high prices for electricity. Electric storages are also rather expensive, but they become cheaper quite rapidly. Heat pump reduces consumption of electricity used for heating comparing to direct electric heating by around 2/3. The most widely used heat pumps are air-source heat pumps as they are relatively easy and inexpensive to install, but they can't be so used in winter in Finland because of the freezing climate. Geothermal heat pumps are more suitable for Finland and in addition they have higher efficiency. The main drawback of geothermal heat pump is it's high installation cost, but it has rather short payback period for replacing. Let's assume in our scenario that 50% of customers will choose heat pumps to reduce their payments for heating.

Annual electricity consumption of detached houses without electric heating in 2011 is 2009002kWh or 8585,5kWh/a/customer and peak load is about 3,6kW per customer. In case of heat pump heating electricity consumption per customer will be around 13500kWh/a and maximum power will be around 3,8kW in case of geothermal heat pump and it will be around 4kW in case of air-source heat pump.

Figures 5.8 and 5.9 represent changes in electricity consumption and peak load during the period of fifteen years if customers without electric heating install heat pumps in their houses. Assume that growth in amount of electrical appliances is compensated with their efficiency improving.

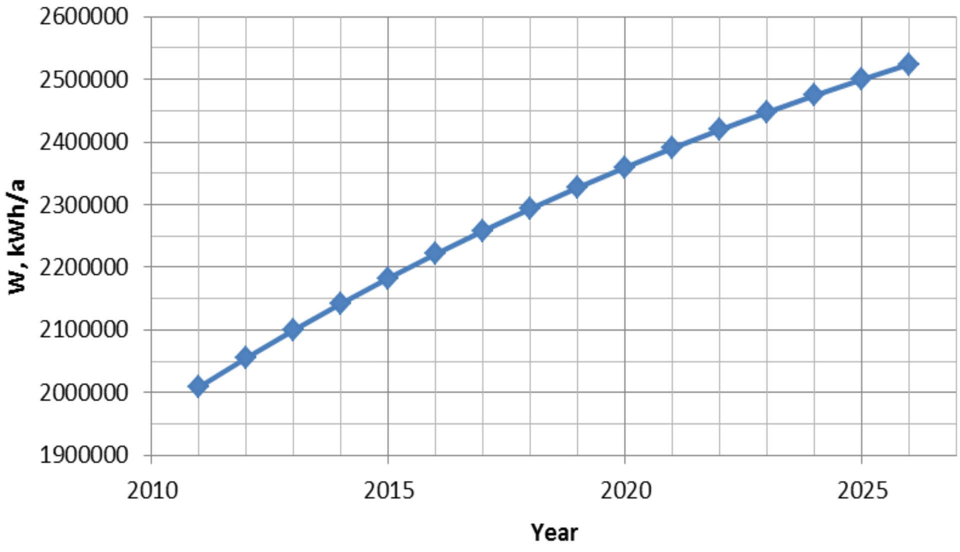


Fig. 5.8 Electricity consumption of detached houses of group 5 if half of them will change their heating system on heat pump hating.

Table 5.5. represents electricity consumption and peak load in 2011 and 2026 for group 5 in case when part of them change their heating system and choose heat pump heating.

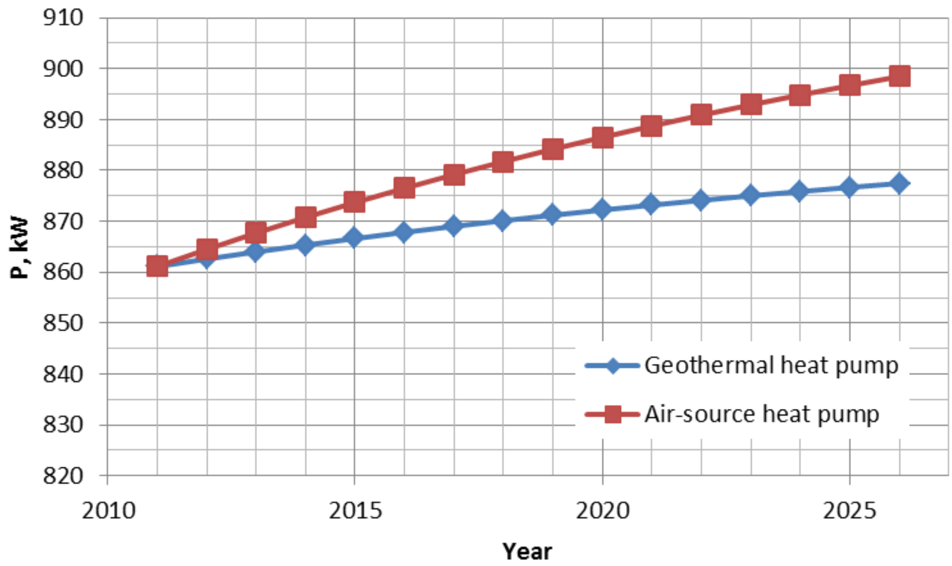


Fig. 5.9 Maximum load of detached houses of group 5 if half of them will change their heating system on heat pump hating.

Table 5.5. Electricity consumption and peak load in 2011 and 2026 for group 5 customers.

Year	W, MWh/a	Pmax, kW (ground-source heat pump)	Pmax, kW (air-source heat pump)
2011	2009	861	861
2026	2524	877	898

Changing of heating system for this group of customers will lead to electricity consumption increasing. Houses without electric heating use gas or oil for heating. It is cheaper to use gas or oil heating today, cost of 1kWh of heat produced by this way is cheaper than 1kWh of electricity produced heat energy. But in future prices for fuel may increase and it would become disadvantageous to use this type of heating system. That's why some customers with this type of heating can choose other heating system. It was assumed in our scenario that 50% of customers without electric heating will install heat pump heating in their houses. As heat pumps consume electrical energy to produce heat, electricity consumption of this group of customers will increase if they will choose electric pump heating. We can see from our calculations that electricity consumption increases from 2009MWh/a in 2011 to 2524MWh/a in 2026. Annual electricity consumption of a house with heat pump system is lower than annual electricity consumption of a house with direct electric heating, but of course it is higher than consumption of house with gas heating. If customers of group 2 change their heating system to heat pump heating system, they can benefit from it as and it can be even cheaper to install heat pump than to use gas or oil heating. In case of 50% changing of heating system peak load of customers of group 2 also increases from 861kW in 2011 to 877kW in 2026 in case of geothermal source heat pump installing and it increases from 861kW to 898kW due to geothermal heat pumps installing.

Assume that other household customers (rows and apartments, high-rise buildings, townhouses) will not change their heating systems.

Let's evaluate how total electricity consumption by household customers changes if some of them change their heating as it is described above. Figures 5.10 and 5.11 represent annual electricity consumption in 2011-2026 and maximum load for household customers. It is assumed in this scenario that growth of amount of electrical appliances is compensated by their efficiency improving.

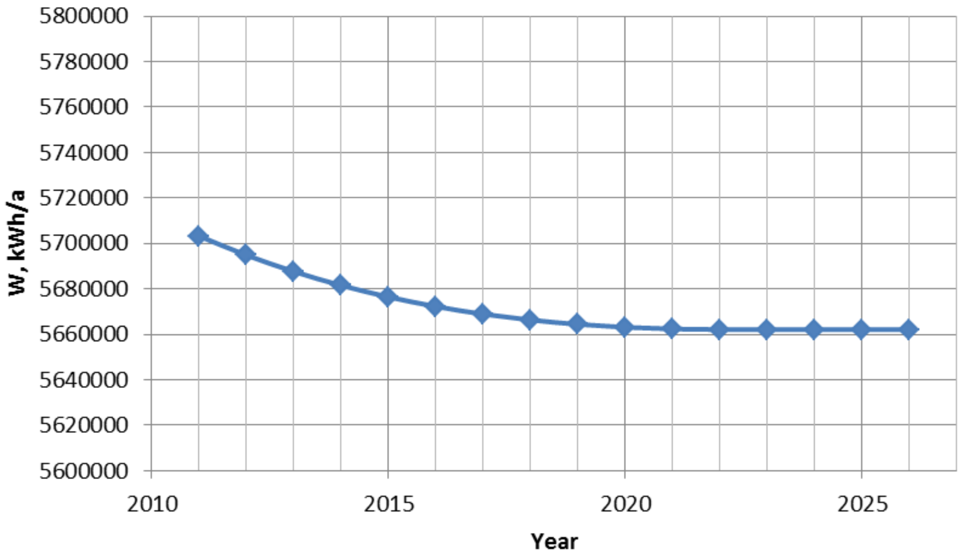


Fig. 5.10. Electricity consumption of household customers in 2011-2026 if part of them change their heating system.

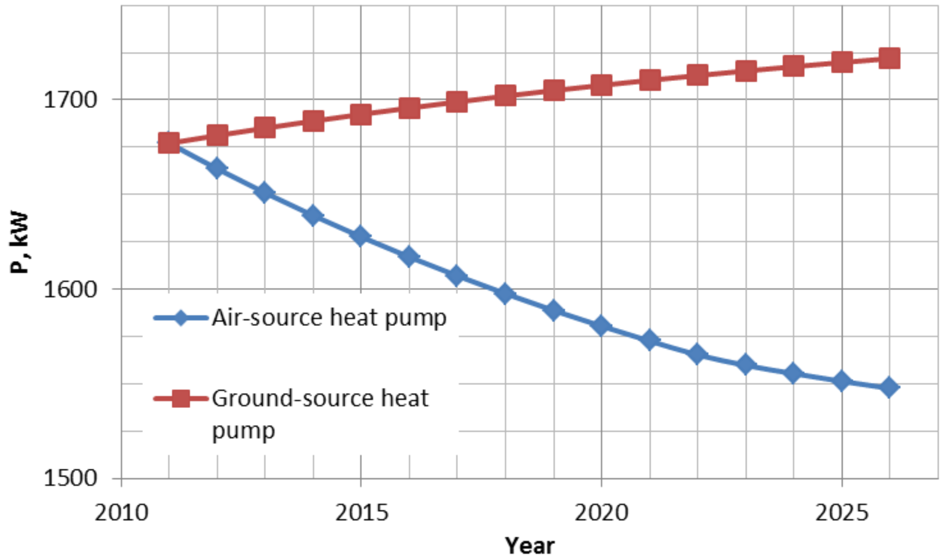


Fig. 5.11. Maximum load of household customers in 2011-2026 if part of them change their heating system.

Table 5.6. represents electricity consumption and peak load in 2011 and 2026 for household customers in case when part of them change their heating system.

Table 5.6. Electricity consumption and peak load in 2011 and 2026 for household customers.

Year	W, MWh/a	Pmax, kW (ground-source heat pump)	Pmax, kW (air-source heat pump)
2011	5703	1677	1677
2026	5662	1547	1721

We can see from figures 5.10 and 5.11 and from our calculations that due to changes in heating system it is possible to reduce electrical energy consumption of household customers, it reduces from 5703MWh/a in 2011 to approximately 5662MWh/a in our scenario. It happens because of electricity consumption reduction of houses with direct electric heating. Electrical energy consumption of customers of group 1 decreases (fig 5.6), but electricity consumption of customers of group 5 increases (fig. 5.8). This changes together lead to reduction of electricity consumption of household customers on 0,7% during 15 years. Maximum load of household customers decreases in case when customers choose geothermal heat pumps during fifteen years of forecasting period, it changes from 1677kW in 2011 to 1547kW in 2026. It happens due to energy storages and heat pumps installing. Energy storages accumulate energy produced during off-peak periods and this energy can be used during load peaks. It reduces load peaks and shapes load curves. Geothermal heat pumps reduce electricity consumption of customers and reduce load peaks. But in the case when customers use air-source heat pumps, peak load increases from 1677kW in 2011 to 1721kW. We can say that scenario of changing heating system where geothermal heat pumps are used is "positive" scenario, as electricity consumption and peak load decrease in this case. But in the case when customers prefer air-source heat pumps, electricity consumption decreases, but peak load increases, this scenario can be named as "negative" scenario.

5.4 Energy savings technologies impact

In case when houses are equipped with smart home systems and smart metering, electricity consumption can be lower than without it. Smart home systems include intelligent lighting, heating, air conditioning, window blinds, etc. If a smart home system is integrated with heating, over 30% (in some cases up to 48%) of energy can be saved (Economic heating) because redundant heating of rooms is excluded.

Let's evaluate how smart home system effects on energy consumption of different types of customers, this effect is presented in table 5.7. Assume that on average a smart home systems saves about 10% of energy used by appliances and 20% of energy used for heating.

Table 5.7. Changes in electricity consumption with smart home system installing.

	Customer	W, kWh/a/customer without smart home system	W, kWh/a/customer with smart home system
1	Detached house with individual room heating	18633,7	15765
2	Detached house with semi-electric storage heating	22832,5	19317
3	House with electric storage heating	34025	28785
4	House with heat pump heating	11901,4	10380
5	Detached houses without electric heating	8585,5	7727
6	Row and apartment without electric heating	23370	21033
7	High-rise building, - residential	1959,8	1764
8	Townhouse, the entire property, - individual room heating	12510	10584

Assume in our scenarios that some customers install smart home systems in their houses (table 5.8).

Table 5.8. Scenarios of smart home system using.

Scenario1	Scenario2	Scenario3
% of customers in 2026	% of customers in 2026	% of customers in 2026
10	50	90

Let's evaluate how smart home systems installing would effect on future energy consumption and maximum load of household customers. Figures 5.12 and 5.13 represent these changes for different scenarios and for case when customers don't install smart home systems. Electricity consumption and peak load are calculated in assumption that customers change their heating system as it was described in 5.3 and choose geothermal heat pumps.

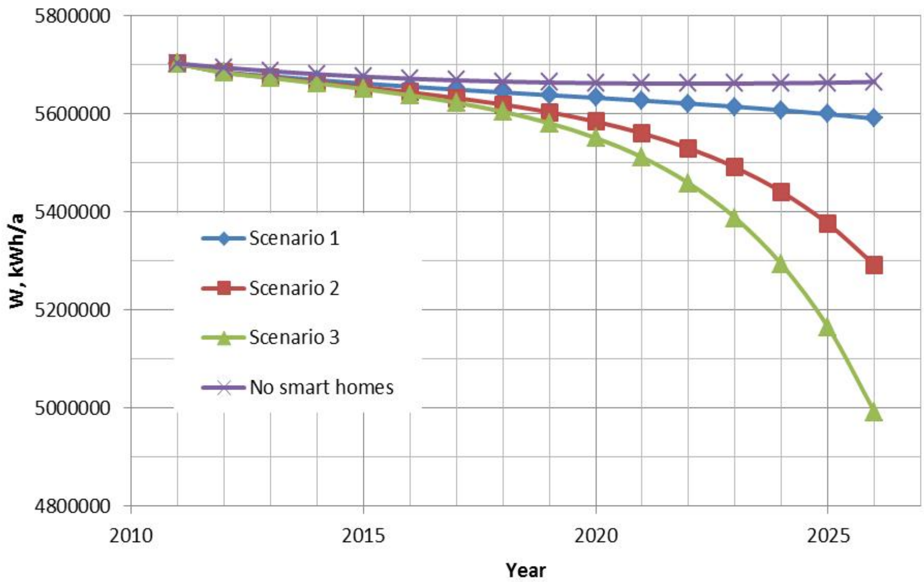


Fig. 5.12. Electricity consumption of household customers in 2011-2026 if part of them change their heating system and part install smart home systems.

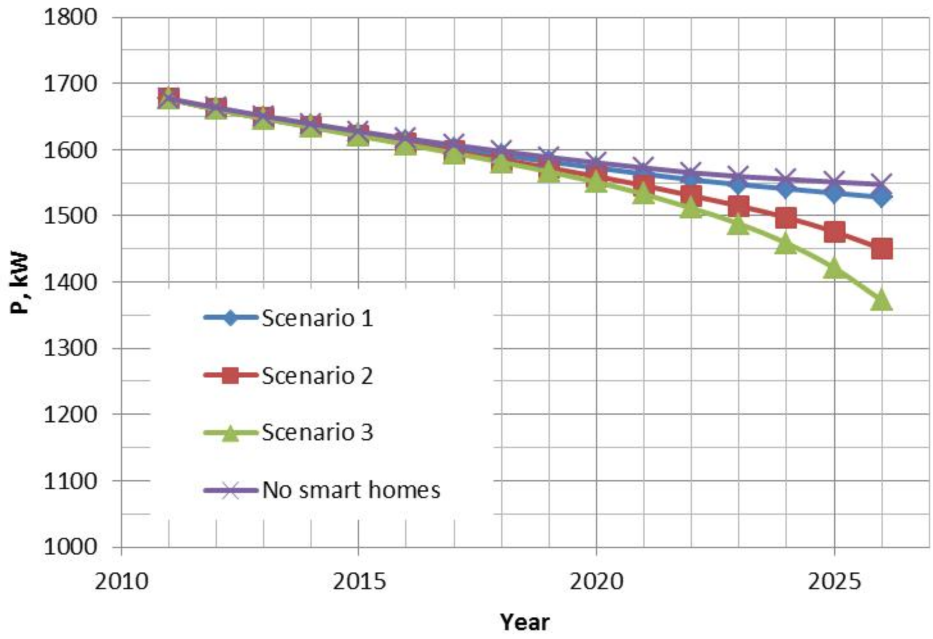


Fig. 5.13. Maximum load of household customers in 2011-2026 if part of them change their heating system and part install smart home systems.

Table 5.9. represents electricity consumption and peak load in 2011 and 2026 for household customers in case when part of them change their heating system and part – install smart home systems.

Table 5.9. Electricity consumption and peak load in 2011 and 2026 for household customers.

Year	Scenario 1		Scenario 2		Scenario 3	
	W, MWh/a	Pmax, kW	W, MWh/a	Pmax, kW	W, MWh/a	Pmax, kW
2011	5703	1677	5703	1677	5703	1677
2026	5591	1528	5292	1450	4992	1372

We can see from figures 5.12 and 5.13 and table 5.9 that smart home systems reduce electrical energy consumption comparing to the case without them for

1,25% in case when 10% of customers install smart home systems, for 6,53% in case when 50% of customers install these systems and for 11,83% in case if 90% of customers install smart home systems in their houses by 2026. Peak loads also decrease for 8,8%, 13.5% and 18.2% in cases if 10%, 50% and 90% respectively of household customers install smart home systems. These reductions in electricity consumption and peak load take place because a system of smart home makes it possible to eliminate excessive lightning, condensing, heating, etc. and controls electrical appliances in a house.

5.5 Scenarios of zero energy houses building

In 2011 amount of zero energy houses in our area is zero. But let's assume that part of newly built houses will have very low, less than 5MWh/a electricity consumption. Scenarios of zero energy houses building are represented in table 5.10.

Table 5.10. Amount of newly built by 2026 zero energy houses in percentage ratio of all newly built houses.

Scenario1	Scenario2	Scenario3
% in 2026	% in 2026	% in 2026
5	40	80

Assume that 200 new houses will be built by 2026 and electricity consumption of a zero energy house is on average 4MWh annually. Assume also that heating systems of other houses are direct electric heating (20% of other houses), semi-electric electrical storage heating (5%), electric storage heating (5%), heat pump heating (50%) and gas heating (20%).

Figure 5.14 represents electrical energy consumption of newly built houses for different scenarios of zero energy houses building and for a case when no zero houses are built during the period.

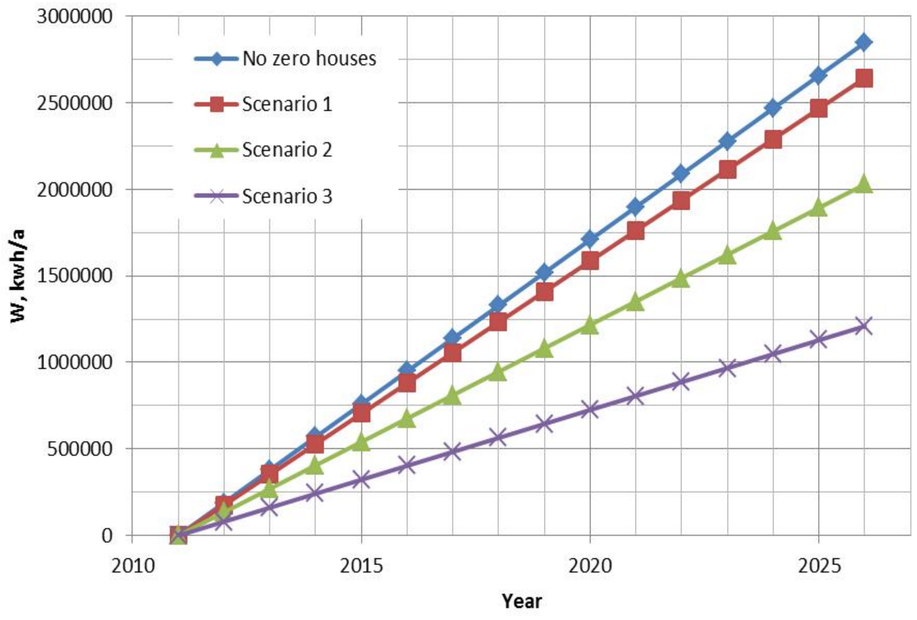


Fig. 5.14. Energy consumption of newly built houses in 2011-2026.

Table 5.11 represents electricity consumption and peak load in 2011 and 2026 of new houses.

Table 5.11. Electricity consumption in of new houses 2011 and 2026.

Year	Scenario 1	Scenario 2	Scenario 3
	W, MWh/a	W, MWh/a	W, MWh/a
2011	0	0	0
2026	2642	2028	1209

It can be seen from figure 5.14 and table 5.11 that in case when there are no zero energy houses among newly built houses, electricity consumption by these newly built houses in 2026 is 2847MWh/a, but if there are 10%, 40% or 80% of zero energy houses from total amount of new houses, electrical energy consumption is 2642MWh/a, 2028MWh/a and 1209MWh/a respectively. Zero energy houses need less energy for heating as they have good insulation, they can be heated by heat pumps and they can generate part of electricity needed for consumption by themselves (by solar panels, wind generators, etc.). Zero energy house has a very low, less than 5MWh/a, or even zero electricity consumption.

5.6 Scenarios of electrical vehicles using

Assume that 446 household customers in our area have 800 cars in 2011, but there are no electric cars among them. In the future some of these cars will be replaced by electric cars, scenarios of these changes are presented in table 5.12.

Table 5.12. Amount of electrical cars in 2026 in % of total amount of cars.

Scenario1	Scenario2	Scenario3
% in 2026	% in 2026	% in 2026
10	50	90

Each electric car consumes approximately 4MWh/a. If a car has intelligent charging - it doesn't increase peak load, if not – maximum power increases. Let's evaluate how electric cars would effect on future loads. Figure 5.15 represents electricity consumption of electric cars in a region for different scenarios of their application.

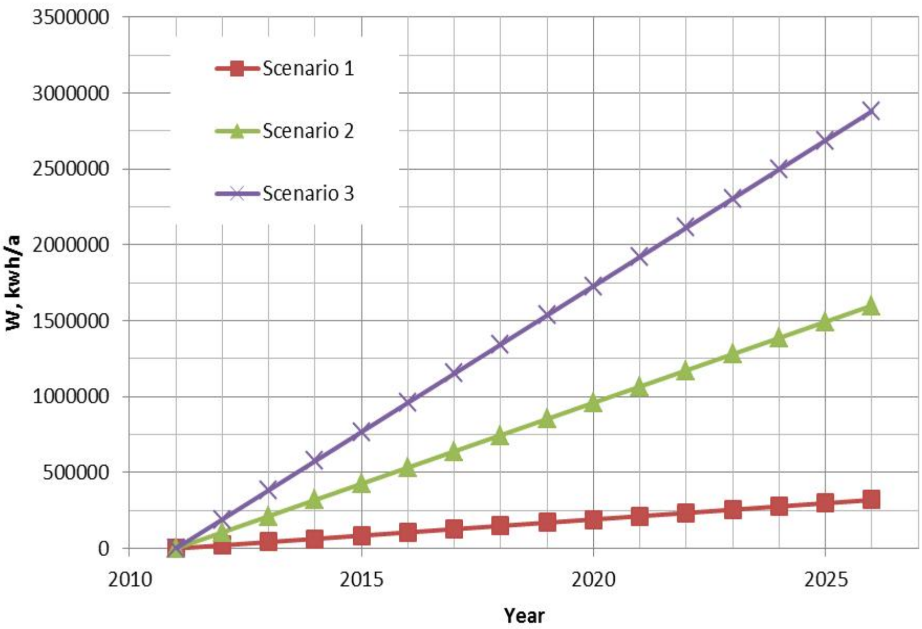


Fig. 5.15. Electricity consumption by electric cars in 2011-2026.

If a car has intelligent charging, it doesn't increase peak load in the area, but if it hasn't – peak load in the area increases. Each electric car has 3,6kW maximum load, but they are being charged at different time and total peak load for all electric cars will be lower. Assume that in scanario 1 electric cars increase peak load for 10% by 2026 year compared with the peak load in the area in 2011, in scenario 2 – for 30%, scenario 3 – for 50%. Figure 5.16 represents peak load of electric cars in the area in 2011 - 2026.

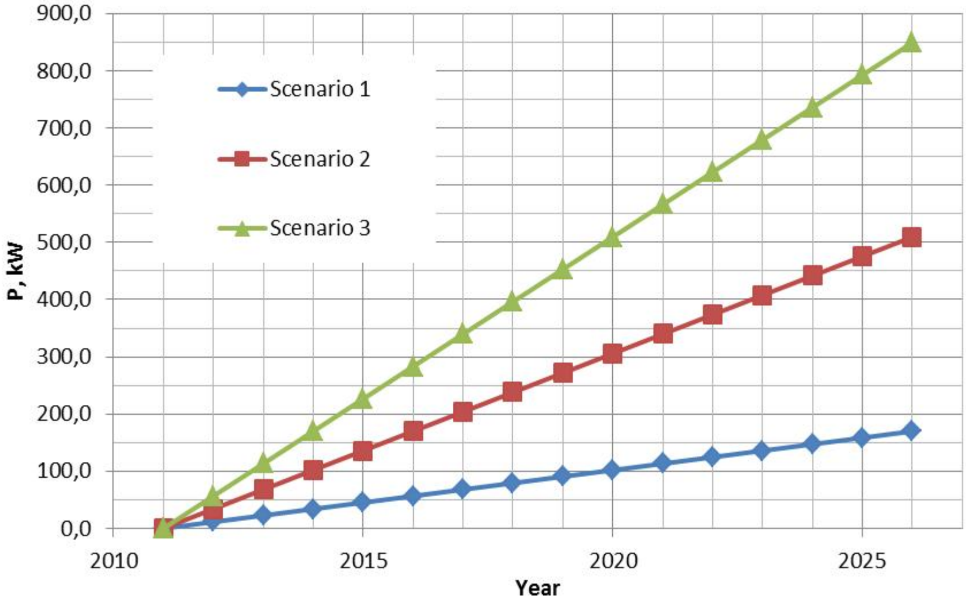


Fig. 5.16. Electricity consumption by electric cars in 2011-2026.

Table 5.13 represents electricity consumption and peak load in 2011 and 2026 of electric cars.

Table 5.13. Electricity consumption of electric cars in 2011 and 2026.

Year	Scenario 1		Scenario 2		Scenario 3	
	W, MWh/a	Pmax, kW	W, MWh/a	Pmax, kW	W, MWh/a	Pmax, kW
2011	0	0	0	0	0	0
2026	320	170	1600	510	2880	849

If electric cars would be widely used in the future, it will increase future electricity consumption and energy flows in a grid. If there will be 10%, 50% and 90% of electric cars from total amount of cars in 2026, electricity consumption by these cars would be 320MWh/a, 1600MWh/a and 2880MWh/a respectively. Electric cars developing and usage can significantly increase electricity consumption in the area. In case if these electric cars have intelligent charging, peak load in the area would not increase because they can be charged during off-peak periods. But if electric cars don't have intelligent charging, their using can increase peak load significantly.

5.7 Distributed generation.

In 2011 there are no distributed generation systems in the area. Assume that 20 % of customers have their own generation in 2026. It can be wind, solar or other generation system and on average each local generation system produces approximately 2MWh/a for customer's needs. It means that customers consume less electricity from a grid. Distributed generation from renewable sources together with electrical energy storage also reduce peak load. But if there is no electrical storage, then distributed generation might not reduce peak load because it might not work during the load peaks, for instance because of weather conditions. In our scenario it is assumed that local generation by customers reduces maximum power.

Let's evaluate how distributed generation effects on energy consumption in case when loads in an area remain the same and electrical appliances amount growth is compensated by their efficiency improving. Figures 5.17 and 5.18 represent electrical energy consumption and peak load in 2011-2026 for household sector for this case.

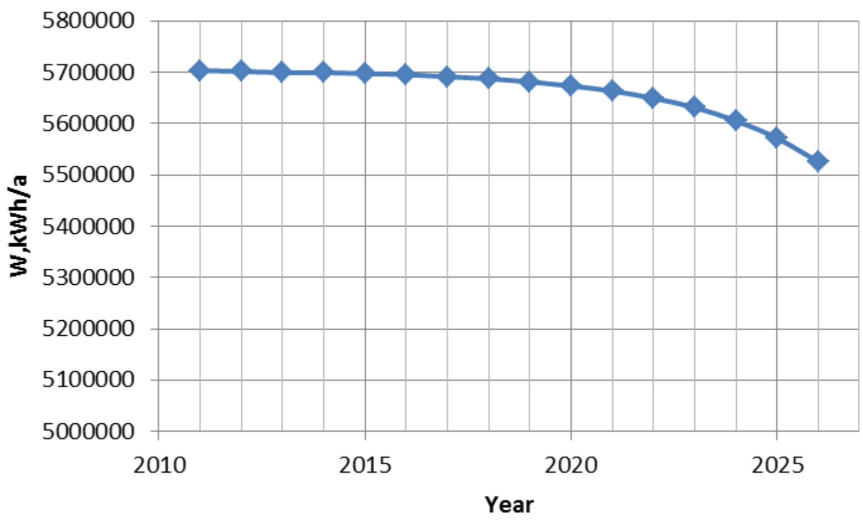


Fig. 5.17. Energy consumption by houshold customers in 2011-2026 in case when loads remain the same as in 2011 and 20% of customers have local generation by 2026.

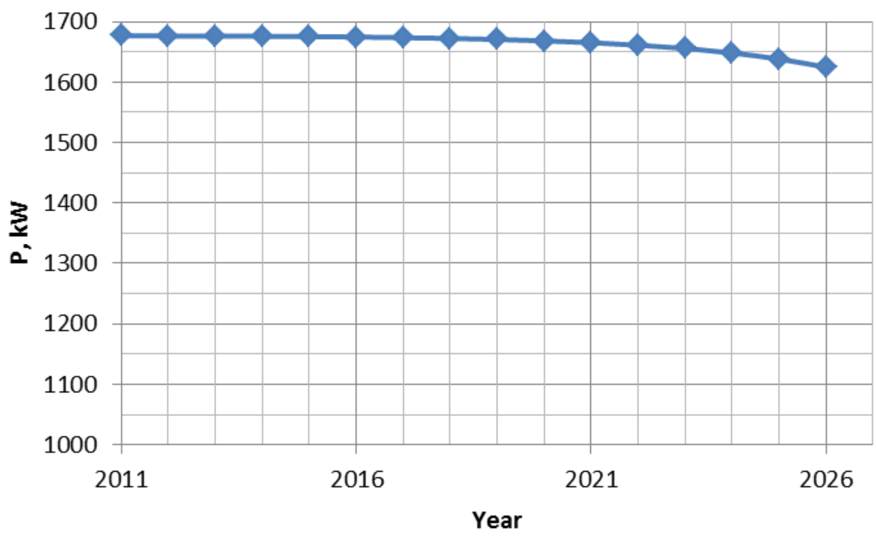


Fig. 5.18. Maximum load of houshold customers in 2011-2026 in case when loads remain the same as in 2011 and 20% of customers have local generation by 2026.

Table 5.14 represents electricity consumption and peak load in 2011 and 2026 of household customers in case when 20% of household customers have local generation and there are no changes in heating system and no smart home systems installed.

Table 5.14. Electricity consumption and peak load in 2011 and 2026 of new houses.

Year	Wa, MWh/a	Pmax, kW
2011	5703	1677
2026	5525	1625

Let's evaluate how distributed generation effects on energy consumption in case of heating system changing described in 5.3 (geothermal heat pumps are chosen) and smart home systems installing by 50% of customers. Figures 5.19 and 5.20 represent electrical energy consumption and peak load in 2011-2026 for household sector for this case.

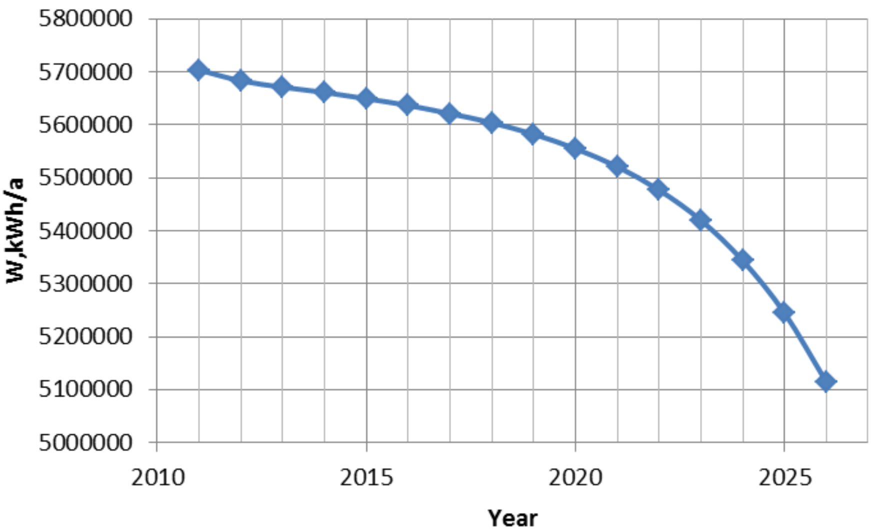


Fig. 5.19. Energy consumption by houshold customers in 2011-2026 in case when customers change their heating systems, install smart home systems and 20% of customers have local generation by 2026.

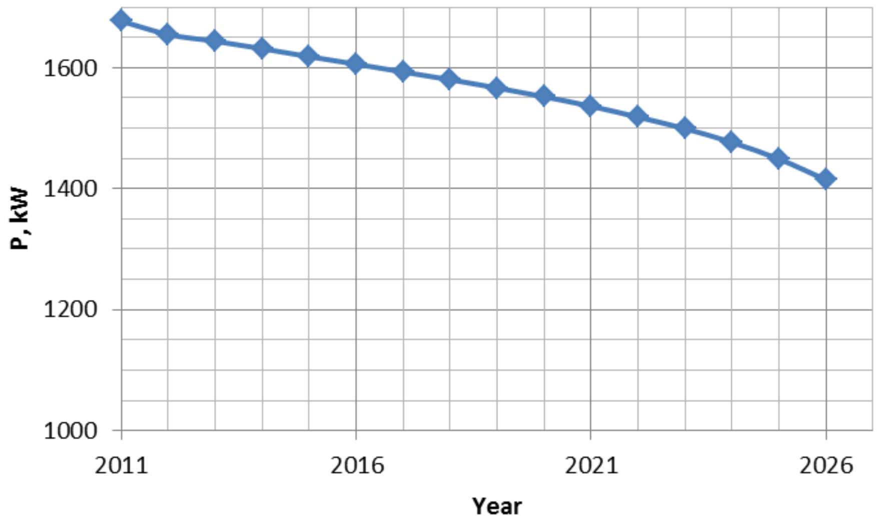


Fig. 5.20. Maximum load of houshold customers in 2011-2026 in case when customers change their heating systems, install smart home systems and 20% of customers have local generation by 2026.

Each customer can install local generation system in his house, for instance it could be solar panels. By this way customers can generate on average 2MWh/a and consume less electricity from the grid. In our scenario it was assumed that 20% of customers have local generation by 2026. We can see from figure 5.17 that due to distributed generation electricity consumption decreases for about 10,3% comparing to the case when there is no distributed generation in the area. Peak load also decreases for 3% due to distributed generation by 20 % of customers.

5.8 Complex scenario of loads changing

Let's create a scenario of electricity consumption and peak load changes in the area taking into account all changes described above. We will take into account this changes, new houses building and calculate how it will effect on energy consumption and peak load of household customers and overall energy consumption and peak load in the area. Table 5.15 represents changes in area loads.

Table 5.15. Changes in area loads.

Electrical appliances amount increasing and their efficiency	Assume that growth in amount of electrical appliances is compensated by their efficiency improving
Changes in heating system	Assume that 50% of houses with direct electric heating will choose heat pump heating by 2026 and 10% will install energy storages. 50% of houses without electrical heating will be heated by heat pump in 2026.
Smart home systems	Assume that 50 % of customers will install smart home systems in their houses by 2026.
New houses	Assume that 40% of newly built houses will be zero energy houses and will have very low electricity consumption.
Electrical vehicles	Assume that 50 % of cars in the area will be replaced by electric cars by 2026.
Distributed generation	Assume that 20% of customers will have their own generation of 2mWh/a.

Let's evaluate how this changes would effect on future consumption of household customers. Consider two scenarios: positive, when electric cars in the area have intelligent charging and customers install geothermal heat pumps when change their heating system and negative, when electric cars don't have intelligent charging, customers install air-source heat-pumps and don't install smart home systems local generation systems. Figures 5.21 and 5.22 represent energy consumption and maximum load in 2011-2026 for household customers.

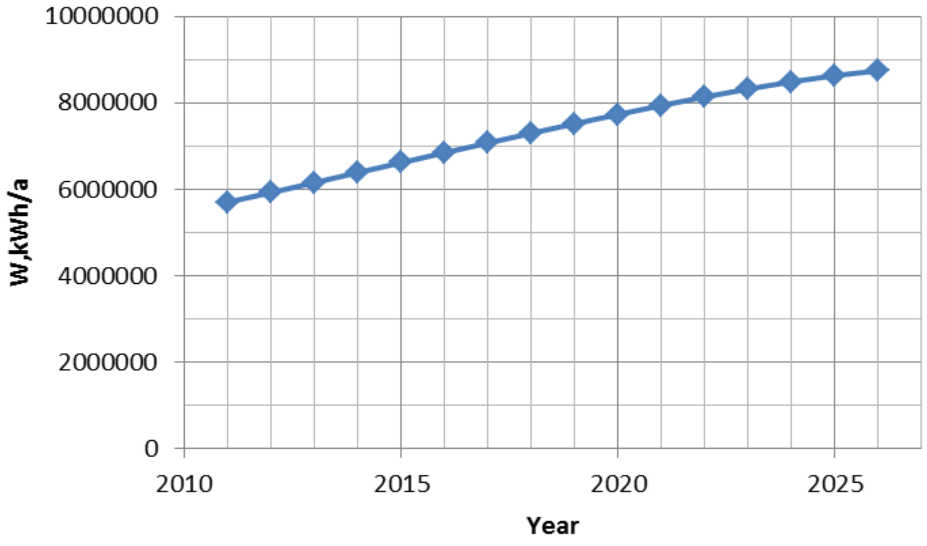


Fig. 5.21. Energy consumption in 2011-2026 for household customers.

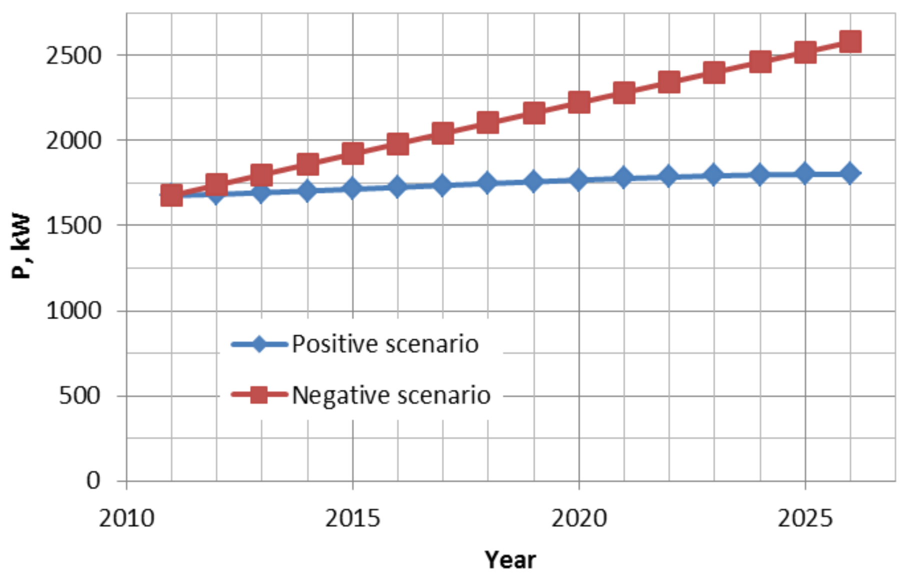


Fig. 5.22. Peak load in 2011-2026 for household customers.

Table 5.16 represents electricity consumption and peak load in 2011 and 2026 of household customers for the case described above in table 5.15.

Table 5.16. Electricity consumption and peak load in 2011 and 2026 of household customers for the case described in table 5.15.

Year	W, MWh/a	Pmax, kW (positive scenario)	Pmax, kW (negative scenario)
2011	5703	1677	1677
2026	8743	1802	2578

We can see from figure 5.21 that electricity consumption by household customers increases in our scenario from 5703MWh/a in 2011 to 8743MWh/a in 2026. Maximum power in positive scenario increases from 1677kW in 2011 to 1802kW in 2026 and in negative scenario – to 2578kW. Positive scenario shows slower peak load growth because it was assumed in it that customer use smart technologies that decrease or don't change peak load: install geothermal heat pumps, smart home systems and local generation systems, electric vehicles have intelligent charging. In negative scenario electrical non-intelligent charging and air-source heat pumps cause more rapid peak load growth.

Table 5.17 represents electricity consumption and peak load in 2011 and 2026 of all customers in the area for the case described in table 5.15.

Table 5.17. Electricity consumption and peak load in 2011 and 2026 of all customers in the area for the case described in table 5.15.

Year	W, MWh/a	Pmax, kW (positive scenario)	Pmax, kW (negative scenario)
2011	5807	1698	1698
2026	8873	1829	2605

Figures 5.23 and 5.24 represent total electricity consumption in the area in 2011-2026 in case described in the table 5.7.

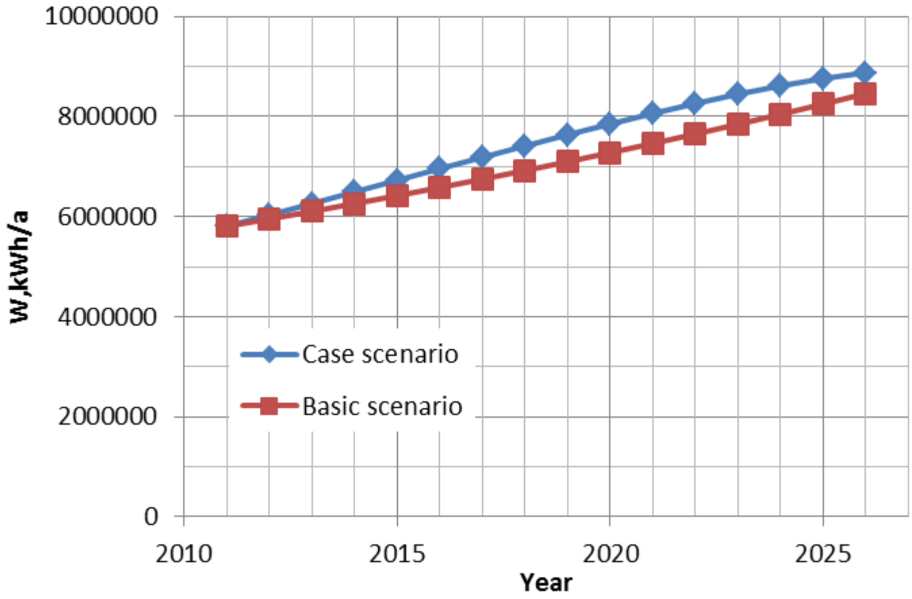


Fig. 5.22. Energy consumption in 2011-2026 in the area.

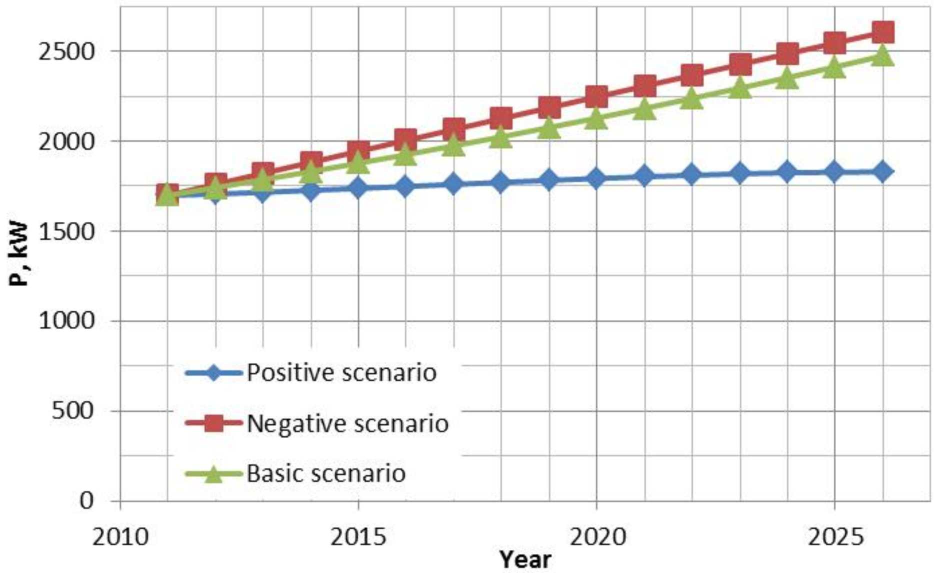


Fig. 5.23. Peak load in 2011-2026 in the area.

We can see from figure 5.22 and table 5.17 that electricity consumption in our scenario by customers in the area increases from 5807MWh/a in 2011 to 8873MWh/a in 2026. Maximum power increases from 1698kW in 2011 to 1829kW in 2026 in positive scenario and to 2605 in negative scenario. If we compare this changes with a scenario presented in 5.1, where Wa increases to approximately 8459 MWh by 2026 year and Pmax increases from 1665kW in 2011 to 2426kW in 2026, we can notice that load growth in scenario 5.8 is higher. It happens because of electric cars appearing and replacing usual cars by electric cars.

Smart technologies, energy storages, heat pumps, smart home systems, distributed generation reduce customers' electricity consumption from a grid as it was shown in 5.3, 5.4, 5.5 and 5.7 sections of this chapter. But it was assumed in our scenario that electric cars will be widely spread in the future and that there would be 50% of electric cars from total amount of cars in our area. This wide electric cars usage increases electricity consumption significantly and total electricity consumption increases even in the case of its reduction by smart technologies. Electricity consumption growth caused by electric cars using and by new houses building is higher in our scenario than electrical energy consumption reduction caused by smart technologies implementation. Load growth in the case scenario became even higher that in the basic scenario because of electrical cars appearing.

It was assumed in positive scenario that electrical vehicles in our area have intelligent charging and that they don't effect on peak load and don't increase it. They also choose geothermal heat pumps when change their heating system on heat pump heating. It leads to slower peak load growth than in the basic scenario. In the negative scenario it was assumed that customers choose air-source heat pumps and their vehicles don't have intelligent charging, they don't install smart home systems and don't have local generation. In this scenario peak load grows even faster than in the basic scenario. It happens because of wide electric cars using, peak load could be even higher, but we assumed that a part of new houses are zero energy houses. Electric storage heating also reduces peak load in the area.

The real situation of electrical energy consumption depends on prices of smart equipment, amount of customers decided to use it and on parameters of these equipment. It depends on the characteristics and prices of electric cars.

The real peak load could be between ‘positive’ and ‘negative’ scenario estimations. It strongly depends on the method of electric cars charging, on the type of heat pumps used in heat pump heating as well as on amount of customers decided to apply smart technologies in their houses.

6 Conclusion

Long-term load forecast result strongly depends on factors taken into account. It is needed to take into account demographic and weather forecasts, prices of fuel and electricity, etc. It is also necessary to take into account smart technologies developing as their implementation can effect significantly on grid loads. Among the most popular smart technologies are heat pumps, energy storages, smart home systems and smart metering, zero energy houses, distributed generation.

These technologies implementation effect on electricity consumption, peak load and energy flows in a grid. Energy storages don't change electricity consumption, but reduce peak load as they can accumulate energy produced during off-peak periods to use it during load peaks. Smart home systems eliminate excessive lightning, heating and condensing and control electrical appliances and by that way reduce electrical energy consumption and peak load. Heat pump heating reduce electricity consumption by a grid, geothermal heat pumps also reduce peak load, but air source heat pumps don't reduce maximum power, but they can even enlarge it. Zero energy houses produce energy for their needs by themselves and have very low electricity consumption from a grid. New loads can appear in the future, for instance electrical vehicles. If they will be widely used in the future, it will increase electricity consumption significantly. Electric cars may have intelligent charging that allows their charging during off-peak periods and electric cars don't enlarge peak load. But is they don't have such system of charging, their using will have a great effect on peak load.

If a distribution company makes a long-term load forecast, it should take into account new technologies development including smart technologies developing. As we can see from the examples from chapter 5, these technologies may influence significantly on customers' electricity consumption and peak load in an area. A company should estimate changes that would happen in the grid loads. In most cases, it can be made on the basis of historical information of load changes. But there is no such information for smart technologies and equipment implementation as they are not widely used yet. A company may monitor new technologies development, monitor changes of prices and characteristics of smart equipment and estimate how popular will be these equipment using in the future. A distribution company should take into account amount of customers in an area, their types and types of their heating systems, and estimate changes in their heating systems as it influences on electricity consumption and peak load in an area. It should know how many cars have customers and estimate precisely future electric cars using as wide electric cars using has a great impact on electricity consumption and peak load (in case if cars don’t have intelligent charging).

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Appendix 1.1