COMPARISON OF VARIOUS CONSUMER WORKLOAD CHARTS TO AVAILABILITY OF RENEWABLE ENERGY PRODUCTION CHARACTERISTICS

Alo Allik, Jaanus Uiga, Andres Annuk
Estonian University of Life Sciences
alo.allik@emu.ee, jaanus.uiga@emu.ee, andres.annuk@emu.ee

Abstract. Rural development depends greatly on how energy issues are dealt with. Distributed energy solutions tend to have good influences on the local economy, but the amount of planning for these solutions might be similar or even more than for central energy systems. Usage of applications for harvesting the energy of renewable energy sources like solar- and wind have to be designed with especial care and expertise due to their fluctuating nature. The benefits of using distributed energy generation are revealed when the majority of the energy generated is consumed at site. Therefore, the energy exchange with the main electricity grid depends, to a substantial extent, on the consumption behavior of various entities. In this article, the suitability of the workload graphs of different consumer types for utilizing maximal amount of energy produced from renewable energy sources is analysed. For that, the load curves and the possible energy production are compared with each other. The simultaneity of the consumers and the consumption shares are also considered in the article. The three main consumer types in Estonia (residential-, municipal- and industrial consumers) have comparable shares, each having approximately one third of the total consumption. Based on these three main groups the interactions arising between the different producers and consumers are calculated to estimate the energy exchange over the grid.

Keywords: workload graphs, renewable energy production, energy exchange, distributed electricity generation.

Introduction

As of the beginning of 2013, the price of electricity will not be a fixed-price for some of the consumers of Estonia. This is caused by the fact that at the beginning of 2013 Estonia fully joined the power market Nord Pool Spot (NPS). For the consumers that do not choose a fixed-tariff, the price of electricity will start to fluctuate, depending on the market situation. As there are subsidies for producing electricity from renewable sources, the idea of producing one's own electricity is gaining more popularity. The maximal profitability is reached when the energy produced on-site is consumed directly, since approximately 60 % of the electricity price is composed of the network fees (dependent on the network provider). In order to consume the produced energy maximally on-site, the optimal configuration generation devices have to be chosen. In this article the suitability of two of the most fluctuating renewable energy sources, wind and solar, is analyzed. The optimal configuration of generation devices is dependent on the consumer's behavior, which is described by a standard consumption schedule – a workload graph that shows how much electrical energy is used during one hour periods.

As the consumer awareness rises, the workload graphs will be more influenced by the availability of renewable energy production. This trend is expected to follow the installation of remote metering devices that will allow people to see their hourly consumption [1]. In the current article the compatibility of installation various configurations of photovoltaic and wind generation devices to different consumer types are investigated.

Materials and Methods

The purpose of the research is to lessen the need for balancing capacities in networks that have renewable electricity generation devices installed. For that the share of directly consumed energy is increased. This allows, as a technical benefit, to achieve a drop in network losses. As indicators, renewable fractions and grid interactions are analyzed. The renewable fraction is the ratio of the produced renewable energy to the total energy consumed on-site, whereas the grid interactions are defined as the electrical energy purchases and sales (feed in) to the grid [2].

The economical motivation to decrease the energy flows with the main grid is due to the network fees. In previous studies it is concluded that the profitability of a residential PV-system depends mostly on the price of electricity and the consumption pattern [3]. Presently, the load curve is dictated by the needs of the consumers.

As for the method of this analysis various consumption time-series were scaled in a way that the average consumption power equaled to 1 kW. This consequently meant that the annual amount of the consumed energy is in all analyzed cases 8760 kWh. The reason for using this method is the comparability of different consumer types. In addition, this method makes it possible to analyze both small and large scale installations.

The natural conditions – wind speed, temperature and solar irradiation data, used in the modelling process were measured in Tõravere in 2010 [4]. This location is representative because it describes sufficiently due to location the inland weather conditions in Estonia.

The analysis was performed for a renewable energy system with an installed capacity of 11 kW. This configuration was chosen in order to comply with the demands and rules of Elektrilevi, the largest electricity network provider in Estonia. The installed capacity is derived from the simplified grid connection requirements for a producer with a main fuse of ≤ 3·16A [5]. As the constraint is set by the main grid operator, most of the installed small-scale renewable energy production systems in Estonia will remain in this range. For the analysis a wind generator with a power curve of $P = 0.0078 \cdot v^2 - 0.0229 \cdot v + 0.00866022$ (if $v < 2.5$, then $P = 0$ kW and if $v > 12$ m·s^{-1} then $P = 1$ kW) was chosen [6]. The simulated photovoltaic array is a polycrystalline array with 14 % efficiency and 59 degrees slope, the slope is equal to the latitude of Estonia. Storage devices are not considered in the calculations, in order to be able to estimate the direct gird interactions for each configuration.

The characteristics of daily consumer workload charts can be seen from Fig. 1. The graph describes the yearly consumption expressed in hourly averages. For calculating the average hourly price of electrical energy (network fees and taxes not included), Nord Pool Spot (NPS) electricity prices for Estonia [7] were used.

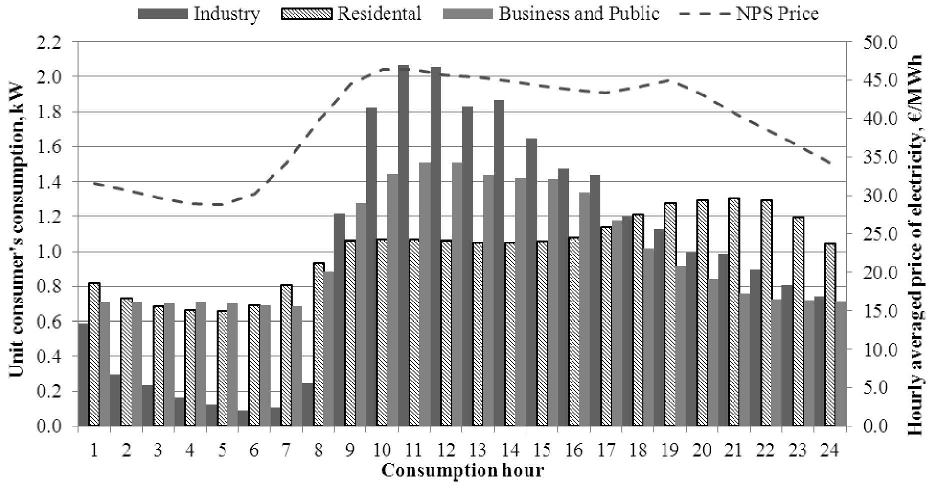

Fig. 1. **Characteristics of the three main consumer groups compared to the averaged hourly price of electricity in Estonia in NPS**

Fig. 1 describes the characteristics that are common for most Estonian consumers. The municipal consumer chart has a higher nighttime load than in the industries. This is due to the fact that municipal consumers are responsible for street lightning. The industrial data were measured in a small scale metal-working and in woodworking factories. This specific characteristic is chosen to represent Estonian industries, because the industries of Estonia are generally relatively small and normally do not work in multiple shifts. An additional reason is that renewable energy sources are more suitable for smaller industries. The space requirements for renewable energy applications which are able to cover the demand could be inconsistent with the available space. The residential data [8] is synthetic to neglect the size effect of the consumption data, because small residential consumers tend to have bigger relative fluctuations. This occurs because of individual devices that can give a significant share of the total consumption of a time step, for example, electric water kettles. The residential consumption chart has a quite level daytime demand, because a big share of the population is on daytime at home. The municipal consumer has a quite high base consumption at night hours.

From Table 1, that describes the average electricity consumption in Estonia during 2009…2011, it can be seen that the three selected types are the main consumer types of Estonia. They have relatively similar proportions from the total consumption. It can be seen that the share of industrial consumption is smaller than generally in developed countries. The term "Business and Public" describes, in addidion to the electricity consumption in the public sector, the consumption in agriculture, transport, construction and in the commercial sector.

Table 1

Average electricity consumption in Estonia during 2009…2011 [9]

Type of consumer	Average consumption	
	MWh	%
Industrial	2509	34.7
Residental	1947	27.0
Business and Public	2766	38.3
Total	7222	100.0

The average price of electricity for consumers is higher in some specific hours of the day when the overall electricity consumption is higher. Therefore, it is reasonable to cover one's own peak demands with renewable electricity. The economic effect of solar arrays is more visible because the production falls on daytime when the price is usually higher [3].

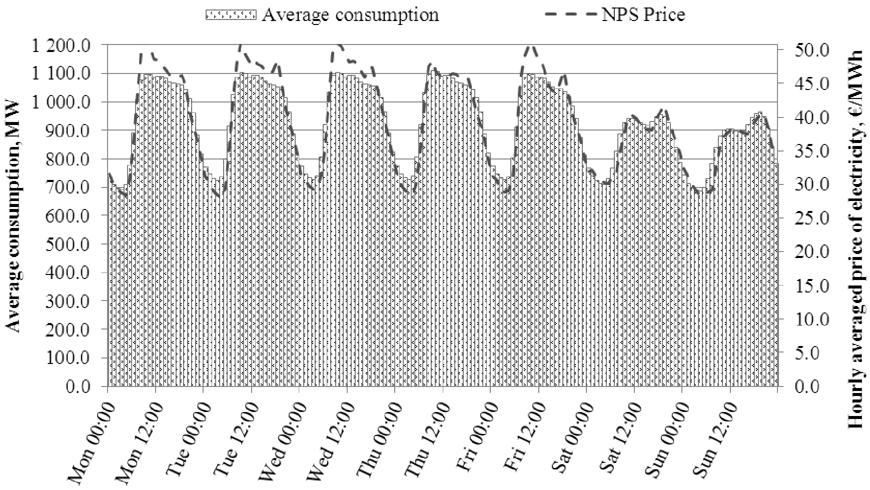

Fig. 2. **Average weekly consumption in Estonia in 2012 compared to the price in NPS**

One of the aims in network planning is to keep the need for storage equipment as low as possible. In the case when there are no storage devices in a small on-grid system then the share of directly consumed renewable energy is equal to the renewable fraction. The renewable fraction in this research is calculated by using the following formula [2]:

$$f_{ren} = \frac{W_{PV} + W_W}{W_{Gp} + W_{PV} + W_W}, \tag{1}$$

where f_{ren} – renewable fraction, ratio;
W_{PV} – energy received by the consumer from PV arrays, kWh·year^{-1};
W_W – energy received by the consumer from wind generators, kWh·year^{-1};
W_{Gp} – energy purchased from grid, kWh·year^{-1}.

The renewable fraction that reflects the directly consumed renewable energy is considered in this study as the main indicator for the planning of wind and PV generation devices installation. From Fig. 2. it can be seen that the curve of the hourly energy prices is similar, but changes more rapidly than consumption in times of peak demands and therefore causes evidential economic pressure to lessen the peak loads.

Results and discussion

According to the simulation results that are shown in Table 2, a PV and Wind energy system with 11 kW installed capacity can produce, in average Estonian inland conditions, 8053…9870 kWh of electrical energy per year. This depends on the share of the installed capacity of wind and PV, because the capacity factors are different. The amount of the produced energy is in the same range as the annual consumption of the unit consumers. The capacity factors derived from the produced energy and maximal output are 10.24 % for wind generators and 8.36 % for the chosen PV array.

Table 2

Various consumers' suitability to meet renewable energy production

Energy production				**Energy consumption**								
Wind generator		Photovoltaic array		Industrial			Residential			Municipal		
				Grid interactions		Rene-wable fraction	Grid interactions		Rene-wable fraction	Grid interactions		Rene-wable fraction
Installed capacity, kW	Annual energy produced, kWh	Installed capacity, kW	Annual energy produced, kWh	Purch-ases, kWh	Sales kWh	%	Purch-ases, kWh	Sales kWh	%	Purch-ases, kWh	Sales, kWh	%
0	0	11	8053	5445	3950	59.7	6036	4524	57.2	5696	4188	58.6
1	897	10	7321	5155	3801	61.5	5535	4171	59.8	5220	3859	61.2
2	1795	9	6589	4956	3750	62.8	5200	3986	61.7	4916	3704	63
3	2692	8	5857	4832	3774	63.9	5015	3948	63	4734	3670	64.4
4	3589	7	5125	4770	3862	64.6	4896	3979	64	4631	3716	65.3
5	4486	6	4393	4760	4000	65.1	4892	4060	64.8	4576	3810	66
6	5384	5	3661	4801	4191	65.3	4797	4177	65.3	4563	3946	66.5
7	6281	4	2928	4906	4446	65.2	4794	4322	65.8	4597	4130	66.7
8	7178	3	2196	5087	4777	64.8	4832	4509	66	4704	4386	66.6
9	8076	2	1464	5325	5167	64.2	4939	4764	65.9	4882	4714	66.1
10	8973	1	732	5595	5593	63.4	5187	5161	65.2	5125	5107	65.4
11	9870	0	0	5876	6054	62.7	5522	5645	64.1	5446	5582	64.4

Form Table 2 and Fig. 3 it can be seen that various consumer behaviors have a noticeable effect on the interactions with the main electricity grid. The usage of PV should especially be considered for industrial consumers and municipal buildings as the consumption coincides with the production.

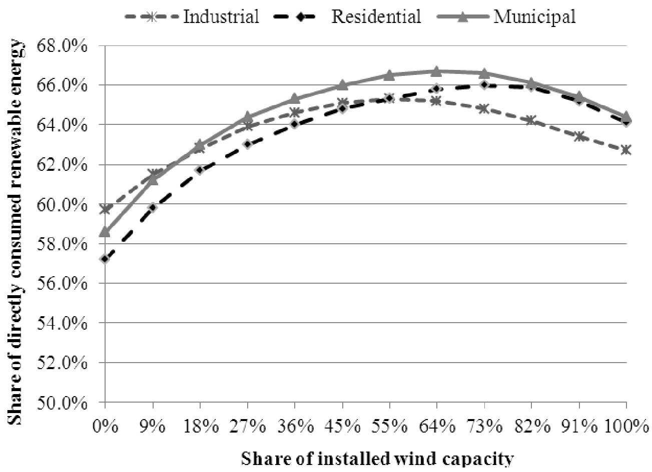

Fig. 3. **Share of directly consumed energy of different consumers in cases of different wind and PV energy generation configurations**

The residential consumer has more compatibility with wind energy applications than the industrial. This is mainly because of the peculiarity of the diurnal consumption. The maximum direct usage is at an installed wind energy capacity of 73 %. A possible incompatibility of the residential characteristic in relation with wind and solar energy sources may occur in accordance with a relatively low daytime consumption. The maximum direct renewable energy usage of the municipal consumer is at 64 % installed wind energy capacity. On the other hand, the municipalities might not have the financial capacity to install renewable energy sources.

On the basis of this analysis industrial facilities are the most suitable for the installation of solar panels. This property suits also with the large areas of the roofs of industrial buildings. The maximum direct usage occurs in the case when nearly half of the generation capacity of the installed renewable generation is received from PV-panels (45 % PV and 55 % wind generators). The better suitability to solar energy applications is due to the characteristic daytime consumption. The night-time wind energy is difficult to utilize due to a drop of consumption in the industries. It has to be noted that this is strongly dependent on the type of industry. Concentrated consumption centers may be incompatible with renewable energy applications due to space requirements. According to the concept of distributed energy generation the small consumers and producers should be as close as possible to each other to consume the energy directly and not transport it through the main energy grid. Good preconditions for the installation of renewable energy devices exist in rural areas. This can be a factor for attracting industries.

Conclusions

The research was made to identify the influence of different combinations of wind generators and PV-arrays to the availability of direct energy consumption. The main conclusions are:

1. The consumer charts can, dependent on the facility, vary to a big extent. The diurnal cycle of each consumer is an important factor when considering the installation of renewable energy devices.
2. In the analyzed cases the optimal combination of a wind generator and PV devices can improve the amount of directly on-site consumed energy up to 8.8 % (in the case of the residential consumer).
3. The standard consumption chart of residential consumers is the most compatible with the wind energy production. The most coincident production and consumption was reached when 73 % of the installed capacity consists of wind generators.
4. The industrial consumer has a good compatibility with solar energy production – at an installed capacity of 45 % the most coincident production and consumption was reached. This is mainly caused by the fact that the Estonian industries have mostly daytime consumption.

Acknowledgment

This article was made possible thanks to the climate data made available by the Estonian Meteorological and Hydrological Institute.

References

1. Römer B. Reichhart P., Kranz J., Picot A. The role of smart metering and decentralized electricity storage for smart grids: The importance of positive externalities, Energy Policy 2012, No. 50, (C) pp. 486-495.
2. Annuk, A., Allik, A., Pikk, P., Uiga, J., Tammoja, H., Toom, K., Olt, J. Increasing Renewable Fraction by Smoothing Consumer´s Power Curves in Grid Connected Wind-Solar Hybrid Systems. Oil Shale 2013, accepted for publishing in 30(1S).
3. Rosin A., Rosin K., Auväärt A., Strzelecki R. Dimensioning of household electricity storage for PV-systems and load scheduling based on Nord Pool Spot prices, Przeglad Elektrotechniczny 2012, No. 88 (4b), pp. 294-299.
4. Estonian Meteorology and Hydrology Institute. [online] [04.02.2013]. Available at: http://www.emhi.ee/index.php?nlan=eng
5. AS Elektrilevi. „Connection for micro producer“. [online] [28.11.2013]. Available at: https://www.elektrilevi.ee/en/liitumine-mikrotootjale
6. Põder V., Lepa J., Palge V., Peets T., Annuk A. The estimation of needed capacity of a storage system according to load and wind parameters // Oil Shale. 2009. Vol. 26, Issue 3S. pp. 283-294.
7. Nord Pool Spot. „Historical market data“. [online] [04.02.2013]. Available at: http://www.nordpoolspot.com/Market-data1/Downloads/Historical-Data-Download1/Data-Download-Page/
8. AS Elektrilevi. „Standard consumption schedules”. [online] [04.02.2013]. Available at: https://www.elektri-levi.ee/en/tyypkoormusgraafikud
9. Statistics Estonia. „KE03: Elektrienergia bilanss“. [online] [04.02.2013]. Available at: http://www.stat.ee (in Estonian)