Environmental and Climate Technologies
2022, vol. 26, no. 1, pp. 365–376
https://doi.org/10.2478/rtuect-2022-0028
https://content.sciendo.com

Comparison of Changes in Electricity Consumption Distribution in Day and Night Scale Caused by Nord Pool Spot Prices Volatility

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***Abstract* – Under free market conditions, there should be a correlation between price and demand. In the electricity market, it is not possible to shift all consumption to hours that are more favourable. Therefore, free market rules do not fully apply to the electricity exchange market. Household consumers have a better ability to shift their energy consumption. At the same time, a large number of household consumers have fixed-price contracts and are therefore not affected by the sharp price changes, so it can be said that they do not actively participate in the stock market. They do not need to shift their electricity consumption. High-consumption industrial companies have very low possibilities at all to react to the stock market changes. The aim of this study is to find out how much electricity consumption has been able to shift in a situation where electricity prices in Estonian were extremely high and volatile. Electricity prices are usually lower at night-time, so it can be assumed that consumption will be shifted to night-time if possible. Examining the change in the distribution of night- and daytime electrical consumption over the years, it is possible to analyse the effect of energy prices on consumer behaviour during periods of high volatility.**

***Keywords* – Energy market; energy consumption; demand response; non-shiftable load**

1. INTRODUCTION

In an open market situation, it is routine for the consumer to opt for a more favourable product when other parameters are equivalent. The specifications of the product for the customers in the electricity market are the same. The only differences in electricity consumption for the customer are its price and origin [1]. All other parameters must be standard [2]. On April 1, 2010, the Estonian electricity market was opened 35 %, i.e. only for large-scale consumers. Since January 1, 2013, the Estonian electricity market has been open to all customers [3]. On a large scale, it is important to keep the balance between demand and response [4]. The price of electricity should help to maintain this balance. In the case of higher or lower electricity prices, consumers should reschedule their consumption schedule. A small-scale consumer who does not have to strictly follow a daily routine can do electricity consumption restructuring successfully. Smart managing the electricity consumption in buildings that use electricity for heating can reduce both CO_2 emissions and electricity taken from the grid, depending on the type of heating system [5], [6]. Previous studies have shown that the amount of electricity taken from the grid by the air-to-water heat pumps can be reduced by monitoring the COP changes caused by outdoor temperature [7]. In order to reduce the emission of greenhouse gases from powerplants and urban households' furnaces, it is

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possible to store renewable electricity as heat energy in the furnace in the private households [5]. A large-scale energy consumer unit, such as a factory, cannot react to a change in the price of an energy carrier due to its operating routines. Therefore, customary energy price fluctuations may not affect the production processes of large companies.

An important component of Nord Pool electricity exchange price is also the carbon emission quota, which is tradable separately and should channel consumers to prefer electricity from renewable energy sources or reduce the consumption if there are no renewable energy available. [8].

The electricity prices are highly volatile [9]. The second half of year 2021 led to large fluctuations in the stock exchange price of electricity in the Estonian price area. As seen in the Table 1, the average hourly price in the 3rd and 4th quarter of the 2021 were 2 to 3.5 times higher than year before. Therefore, it may be concluded that the price for electricity has some sort of reactions to consumer’s habits.

TABLE 1. AVERAGE HOURLY PRICE IN THE QUARTERS OF THE YEARS

Year	2017	2018	2019	2020	2021
1st quarter price, €/MWh	32.94	41.86	47.71	27.62	51.83
2nd quarter price, €/MWh	30.82	42.08	42.65	28.79	54.50
3rd quarter price, €/MWh	35.97	53.48	48.93	36.84	97.47
4th quarter price, €/MWh	33.05	50.65	44.13	41.13	141.97

The high-cost hours must affect electricity consumption at the extent that it should reflected in wide range consumption data. The high price of electricity should shift consumption to cheaper hours in the same day or operational period of the company if there are no storage unit [10], [11].

2. MATERIALS AND METHODS

In Estonia, the Elering AS is the company responsible for the electricity transmission network [12]. Elering AS collects and stores data on electricity consumption and production volumes. As well as planned electricity production and consumption. Data is collected and stored on an hourly basis from the year 2010 [13].

The Nord Pool power market collects and stores electricity price data hourly basis [14]. From 14 February 2022, this data is no longer available for the common user. This article uses data from January 1, 2017 to December 31, 2021.

By combining these two sets of data according to a time scale, a series of raw data can formed to be examined. The data can be compared by yearly and season basis. As the market should be most affected by the price of electricity, then also under the conditions of the highest and the lowest price conditions.

In Table 2 is presented Estonian annual electricity consumption, its prognosis and how much it was over-planned.

TABLE 2. ANNUAL ELECTRICITY CONSUMPTION IN ESTONIA

Year	**2017**	**2018**	**2019**	**2020**	**2021**
Consumption, GWh	8289	8424	8223	7954	8428
Planned consumption, GWh	8509	8718	8687	8643	9013
Over-planning, %	2.6	3.4	5.3	8.0	6.5

The annual electricity consumption remains at the same level in the years under review. The years 2018 and 2021, when the consumption was the same, can be pointed out.

The planned consumption is slightly higher than the actual consumption through the observed years. The over-planning is a slight upward trending. Comparing the sharp rise in average electricity prices (Table 1) with the projected surplus in planned consumption (Table 2) is in somewhat contradictory.

In Estonian climatic conditions, energy consumption as a calendar quarterly cycle must not be considered. The reason is the local weather cycle: winter, spring, summer and autumn and large temperature differences during the year. As can be seen in Fig. 1, the temperature fluctuations are quite large: in 2019 the minimum has been –19 °C and the maximum +30 °C.

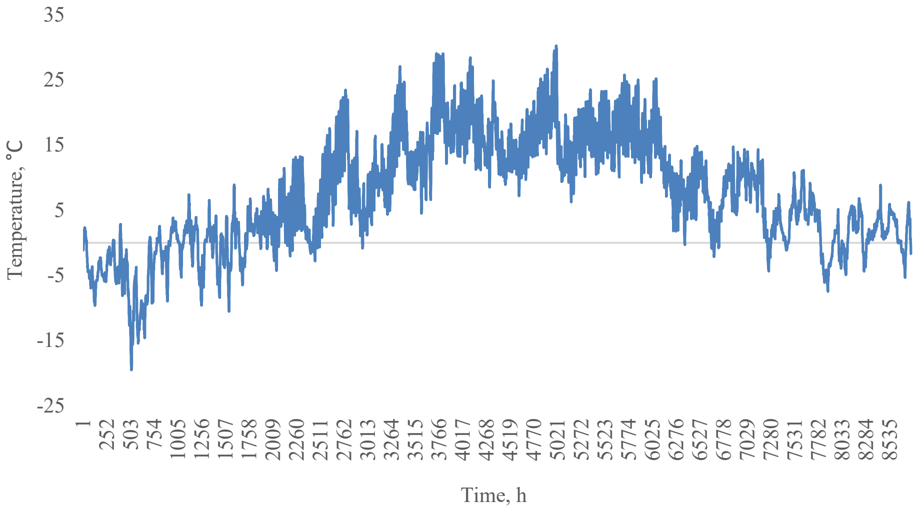

Fig. 1. Hourly average temperature in Tartu 2019 [15].

For example, the January average temperature was –5.7 °C, minimum and maximum were –19.5 °C and 2.8 °C. Therefore, the average monthly or quarter temperature basis is not always good to take into account. More reasonable is to interpret at the basis of user needs. For example, the heating period.

Like the outside temperature is in constant changes, so do the amount of electrical energy consumptions. However, it is more likely dependent of the human behaviour, daily and weekly routine [16]. In the Fig. 2, there is presented the share of electricity consumption by hours on 15 August in the years of 2017, 2018, 2019, 2020 and 2021. The share of electricity consumed per hour is calculated by Eq. (1):

$$S_i = \frac{E_{hi}}{\sum_{i=1}^{24} E_{hi}} \cdot 100\% , \tag{1}$$

where S_i is the percentage of energy consumed in one hour from 24 hours (%), and E_{hi} is the energy consumed in an hour (MW).

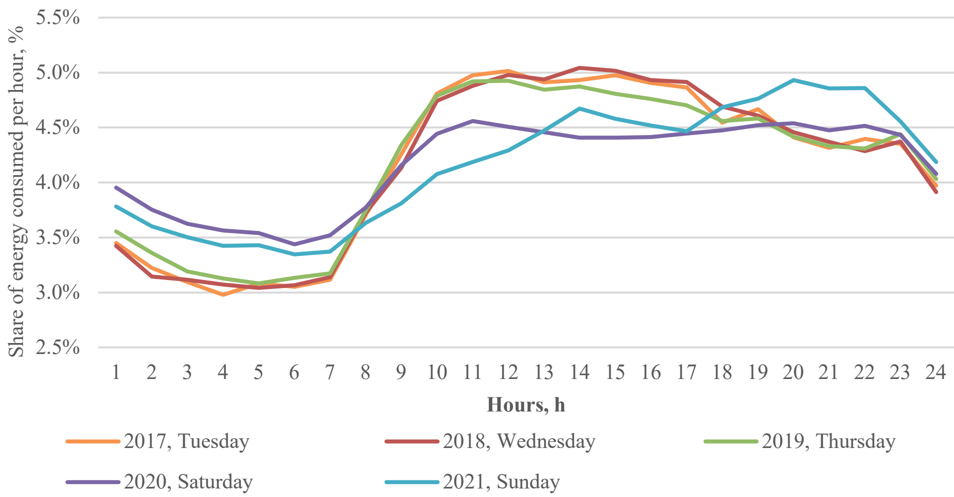

Fig. 2. Electricity consumption share by hours on August 15 [13].

From Fig. 2, it can be seen that consumption share on Saturday and Sunday differs from another days. The share in the Saturday and Sunday is lower in the daytime and is higher on the evenings. In Estonia the largest network operator is Elektrilevi OÜ [17]. Until 28.02.2022, the transmission fees for electricity were in two group, daytime and night-time. The daytime was from 07:00 to 23:00 and the night-time was 23:00 to 07:00. Considering those, the 24-hour consumption can be separated the daytime and the night-time share as seen in Fig. 3.

The daytime and night-time share data is from the beginning of January 4, 2021 to February 21, 2021. It starts on Monday and ends on Sunday, so it includes seven consecutive weeks in a row with no national holidays. The graph shows that there are periodic fluctuations in the weekends: on weekends, the share of electricity consumption at night-time is higher than from Monday to Friday. It is obvious that this is due to industrial shutdowns on weekends. Fig. 3. presents the same period real time consumption and planned consumption, bought the daytime and night-time.

The price of electricity depends on many components and their presence changes over time, such as wind, solar, hydro or some sort of powerplant renovations. Therefore, the electricity price cannot be directly compared at the same time in different years. However, the share of electricity in the total daily price can be compared, similar to electricity consumption. Fig. 4 presents the share of the energy price per day by hours.

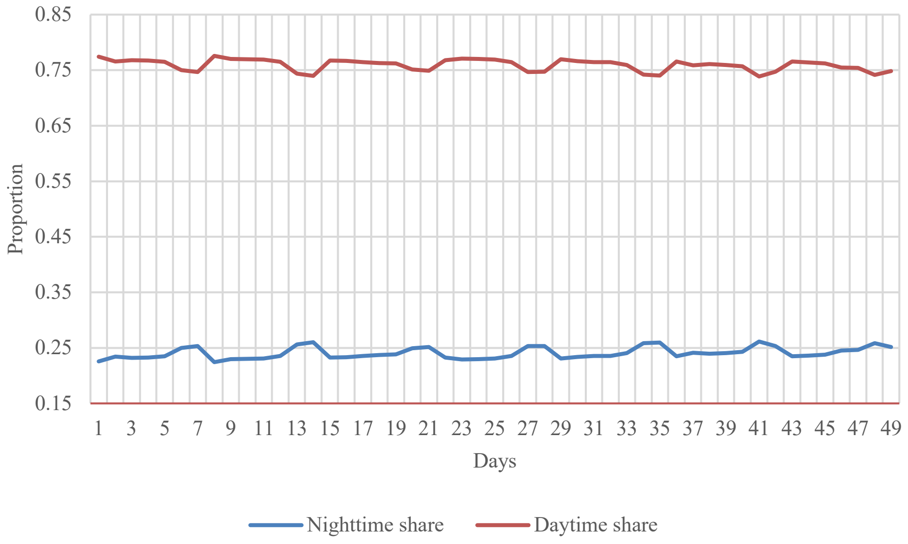

Fig. 3. The share of night-time and daytime consumption.

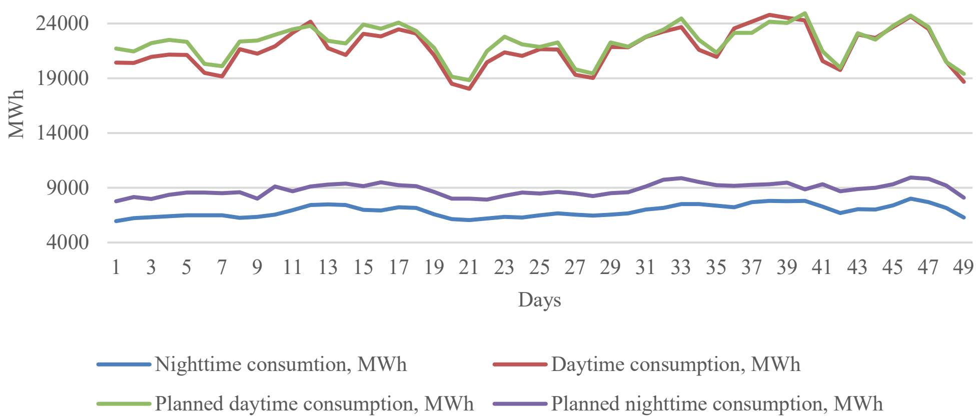

Fig. 4. Electricity planned and real consumption during 04.01.–21.02.2022.

From the data presented in Fig. 4, it can be concluded that before 07:00 the trend of electrical energy price share is falling, around 07:00, the price share is similar in all five compared years. After 7:00 the share of electricity price are different trends and around 18:00, the price share is somewhat same. The trends after 19:00 are similar for the days within a working week.

To understand and find some patterns in the day-night electricity price relation, the electrical energy price in the beginning of 2018 and 2021 is compared in full weeks in Fig. 5.

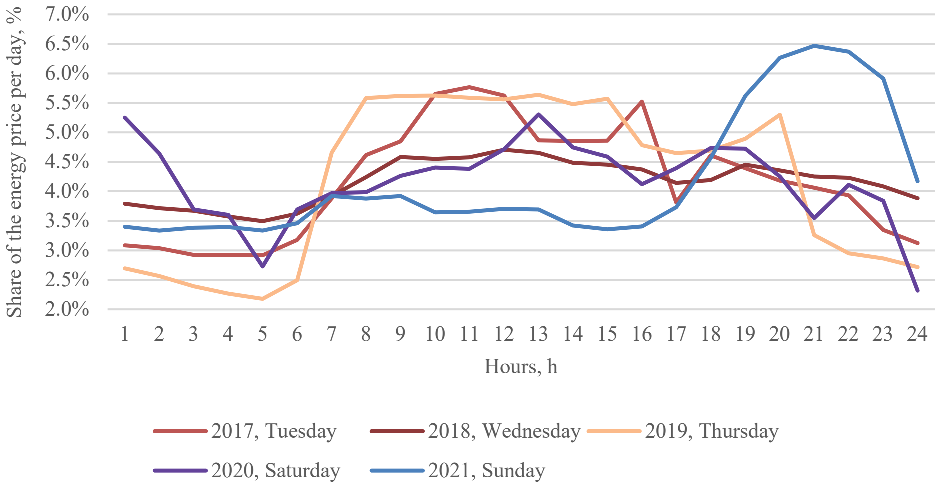

Fig. 5. The share of the energy price per hours on August 15, 2017…2021 [14].

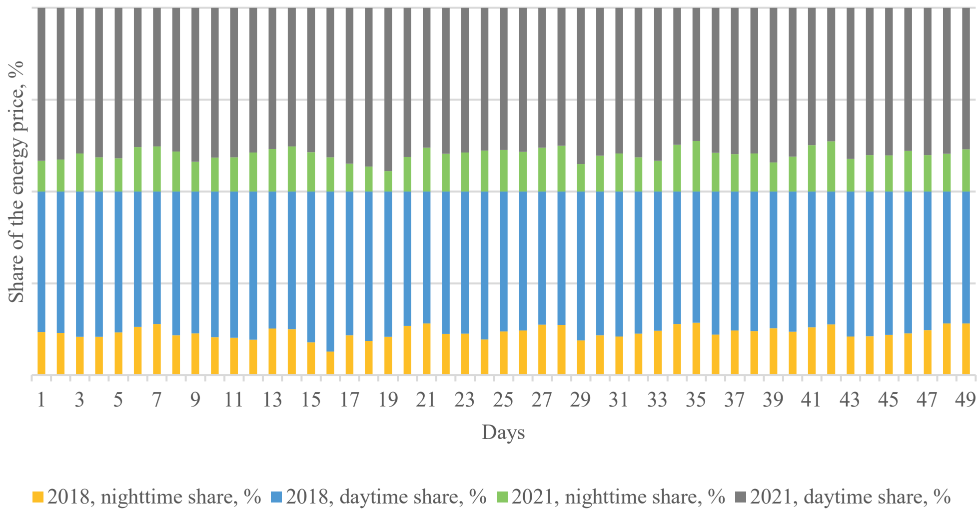

Fig. 6. The share of the energy price on night-time and daytime comparison during 04.01.–21.02.2022.

The patterns in Fig. 6 show that the price of electricity at night has the highest share on Sundays in both years.

3. Methodology

In order to understand whether the rise in electricity prices during its period of great fluctuations peak hours affects electricity consumption, it must be compared with periods of stable electricity prices. It should be borne in mind that in addition to the peak price, there are also periods when the price of electricity is very low. There are periods when the consumer is paid for electricity consumption. These periods also need to be examined in the context of consumption patterns. Hourly electricity prices in Estonia in 2021 were ranked by price. The highest price components for the day turned out to be December 7, Tuesday. A data table covering 11 weeks from early October to mid-December was then compiled for five years (2017–2021). A characteristic consumption curve was drawn for each day of the week during this period. Fig. 7 shows the hourly price of electricity on 07.12.21, electricity consumption, and the characteristics of electricity consumption in a five-year autumn-winter period on Tuesdays.

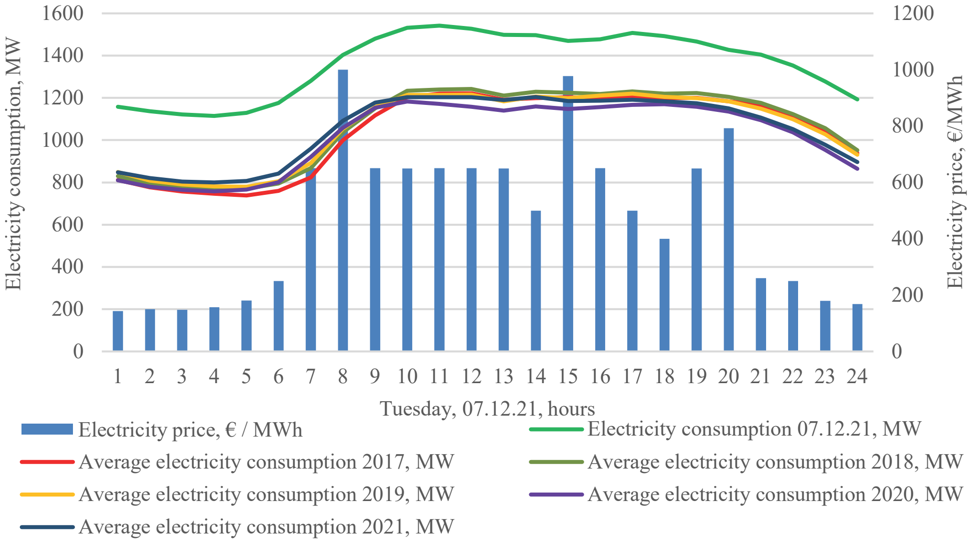

Fig. 7. The comparison of high – cost electricity consumption.

The Pearson correlation method was used to better understand the relationship between consumption curves. In Table 3 are presented the results of the test.

TABLE 3. ELECTRICITY CONSUMPTION PEARSON CORRELATION FOR 07.12.2021

Time	07.12.21	2017	2018	2019	2020	2021
07.12.21	1	–	–	–	–	–
2017	0.955	1	–	–	–	–
2018	0.965	0.999	1	–	–	–
2019	0.976	0.995	0.998	1	–	–
2020	0.991	0.974	0.982	0.991	1	–
2021	0.995	0.968	0.978	0.987	0.998	1

It clarified that all associations with the consumption pattern on 7 December were found to be strong ($r > 0.7$ and $p << 0.001$). All concluded Pearson correlation test showed that the correlation between the hour-based consumption on daily basis are strong.

At the other end of the electricity price, there are situations where the customer is paid for the use of electricity. This is somewhat of typical situations with renewable energy generators [18]. That situation took place at Monday 05.04.2021 from 02:00–07:00 (5 hours). To compare this day consumption, an average daytime consumption curve was compiled by Monday's consumption data for five years. Twelve Monday close to beginning of the April were used. The compiled curves are presented in Fig. 8.

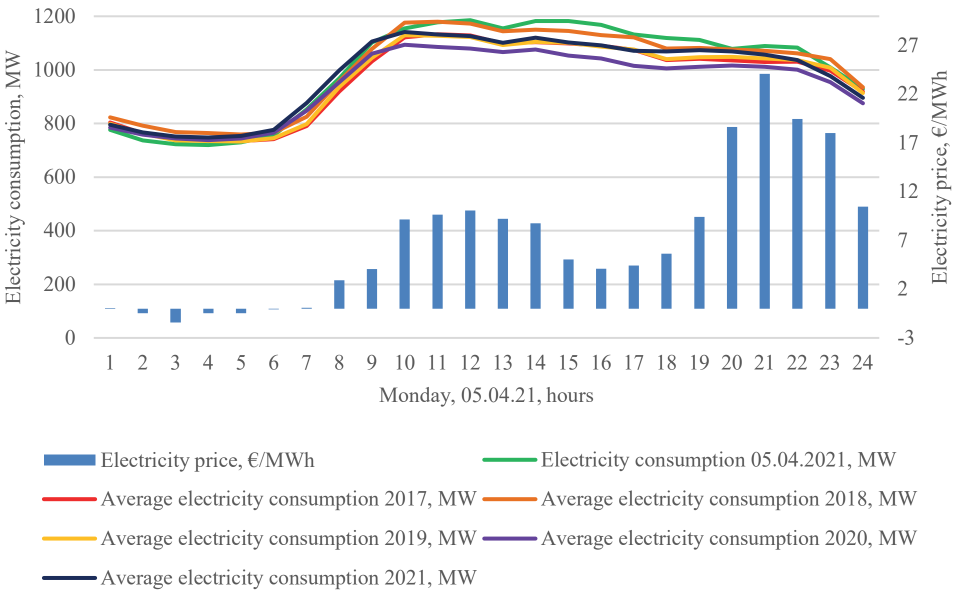

Fig. 8. The comparison of low – cost electricity consumption.

The Pearson's correlation method was used to found out the relationship between consumption curves. Table 4 shows the test results. The consumption patterns of the 05.04.2021 and the averages of the previous year's consumptions are strong ($r > 0.7$ and $p << 0.001$).

TABLE 4. ELECTRICITY CONSUMPTION PEARSON CORRELATION FOR 05.04.2021

Time	05.04.2021	2021	2020	2019	2018	2017
05.04.2021	1	–	–	–	–	–
2021	0.991	1	–	–	–	–
2020	0.990	0.998	1	–	–	–
2019	0.992	0.986	0.989	1	–	–
2018	0.992	0.984	0.987	0.999	1	–
2017	0.991	0.981	0.985	0.999	0.999	1

In order to get a better overview, the middle part of the hours ranked by price was also taken to test. The medium price hour day was Monday, 06.09.2021. As previously, average day consumption by hours was compiled for close Mondays in the beginning of September for five years. The result is presented in Fig. 9.

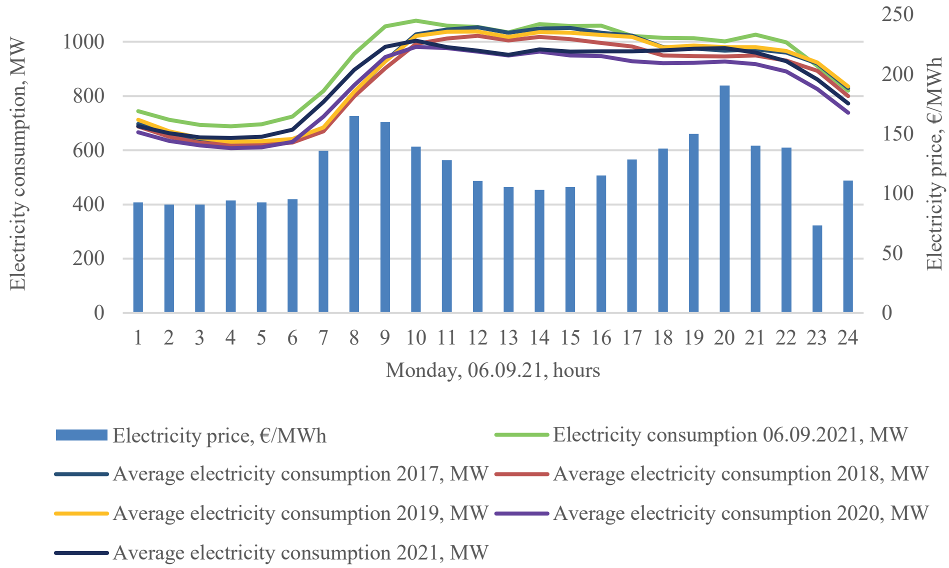

Fig. 9. The comparison of high – cost electricity consumption.

Like the high and low price time, the medium price hour day consumption curve data and the previous five years same period average consumption data were processed with the Pearson's correlation method presented in the Table 5.

TABLE 5. ELECTRICITY CONSUMPTION PEARSON CORRELATION FOR 06.09.2021

Time	**06.09.2021**	**2021**	**2020**	**2019**	**2018**	**2017**
06.09.2021	1	–	–	–	–	–
2021	0.993	1	–	–	–	–
2020	0.997	0.993	1	–	–	–
2019	0.967	0.960	0.977	1	–	–
2018	0.970	0.960	0.979	0.999	1	–
2017	0.967	0.956	0.976	0.999	0.999	1

The consumption patterns of the 06.09.2021 and the averages of the previous year's consumptions are strong ($r > 0.7$ and $p << 0.001$).

4. RESULTS

The input data consists of historical electricity price and consumption throughout Estonia, which was collected for five-year period. From January 1 2017 to December 31 2021. The electricity consumption studied was mainly focused on the peak and low priced periods. Different graphs were compiled to understand the hourly change in electricity consumption. The nature of electricity consumption is similar to a period with the same characteristics: working day, weekend, week, season of a year. In order to compare an event at any point in time (in this case) in another year, the same date in previous years cannot be taken as a reference point. Similar days of the week should be compared.

All three cases (high, middle and low prices hours) showed that the consumption curves are very similar to the averages consumptions in the same and previous years. The Pearson's correlation method confirmed that the characteristics of the data is very strong ($r > 0.7$ and $p \ll 0.001$).

In order to compare the average calculated consumption with the actual consumption, the average consumption was divided by weight over 24 hours. The actual daily consumption was divided according to the percentage obtained by the hour. The result is presented in Fig. 10. The basis of the calculation is 07.12.2021, the day with the highest electricity price.

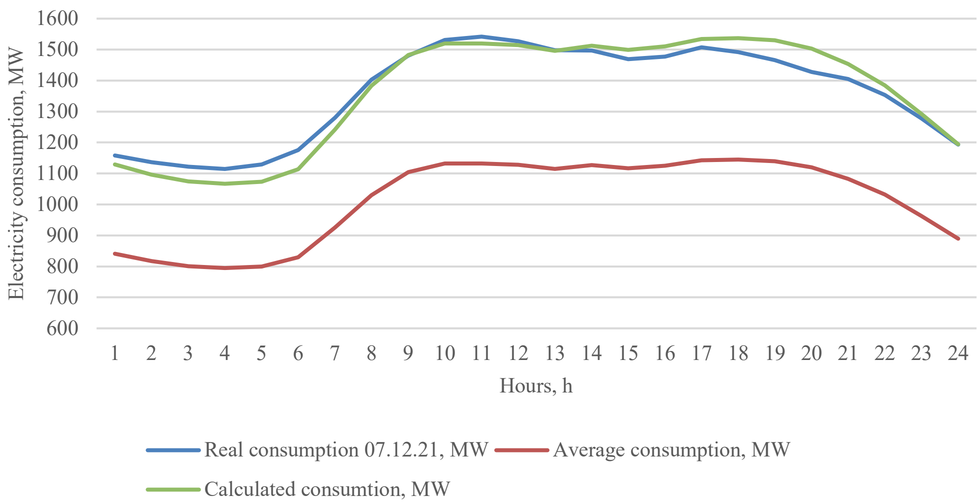

Fig. 10. Calculated electricity consumption by the weight of an hour, high price.

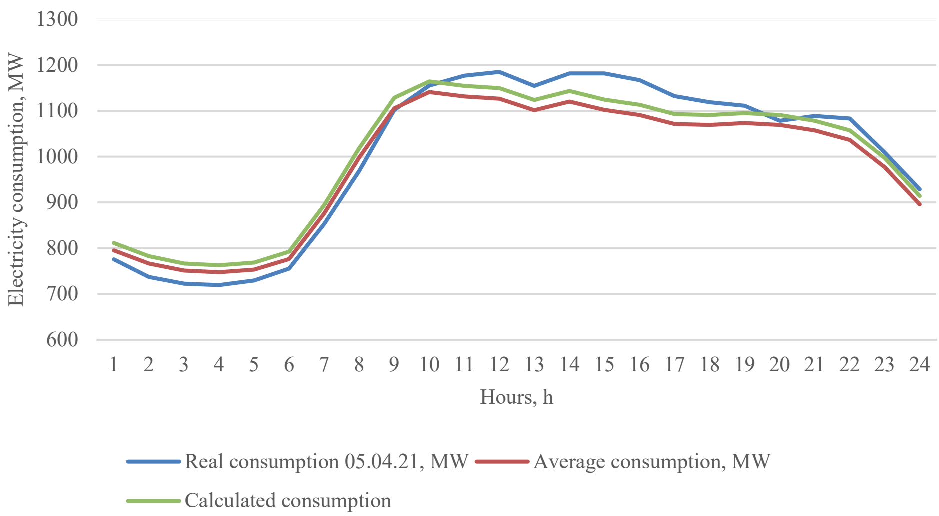

Fig. 11. Calculated electricity consumption by the weight of an hour, low price.

As seen in Fig. 10, the calculated electricity consumption is slightly lower in the morning hours and higher from the midday to midnight. This is reflected in a 1 % higher electricity cost in total. A similar calculation was performed with the lowest electricity price per day. The result is presented in Fig. 11. The calculated electricity consumption is higher in the morning hours, when there was a negative electricity price, and lower from 10:00 to evening time. The calculations show 2 % of lower electricity price in total for that day.

5. CONCLUSIONS

The research revealed that there has been no large-scale shift in energy consumption to a more favourable time for the customer. This is valid for three different electricity price level categories (high, mid and low).

The low price hours are mainly in night-time or early in the morning in the weekends. Therefore, large electricity consumer (i.e. factories) cannot usually take a part of that favour. The residential customers do not have a high capacity energy consumer units operating those times or at all.

Fluctuations in the price of CO_2 emission allowances included in the electricity exchange price do not affect consumer behaviour. Therefore, it does not have the expected effect on the goal of reducing CO_2 emissions into the atmosphere and will need to be re-examined in some cases.

Electricity price volatility has not reached a level that would affect consumer hourly behaviour at the state to be reflected in the national electricity consumption curve. With the addition of renewable energy production capacity and the lack of energy storage capacity, the fluctuation of electricity price may change the electricity consumer's behaviour to more favourable hours inside the daytime.

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