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SCENARIO-BASED MODELLING OF RESIDENTIAL SECTOR CONSUMPTION: A CASE STUDY IN LATVIA

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Promoting the development of energy communities is one of the planned development areas mentioned in the Latvian National Energy and Climate Plan (NECP). Even though energy communities do not yet exist in Latvia, they could improve the quality of the environment and stimulate the local economy. In any case, it is expected that the structure of household energy consumption in Latvia will change as households start to adopt new technologies such as electric cars and heat pumps, as well as participate in energy production and demand response.

Often the starting point for the development of an energy community is the geographic location of consumers. Therefore, for this study, a microdistrict was chosen in one of the most developed suburbs of Riga in Latvia, in which 76 households are located. The study identified five milestones on the path from mere neighborhood to the energy community. The resLoadSIM Residential Load Simulation tool was chosen to simulate realistic energy consumption with a 1-minute time resolution, as well as to model the future solar energy consumption and generation in the community on its way to becoming an energy community and meeting these goals. The network constraints associated with the transformer and lines are taken into account and it is assumed that the district will not invest in the development and expansion of the network.

Based on the results of the modelling, an analysis was made of the impact of the development of the energy community in Latvia and how each stage of development will affect energy consumption, the amount of renewable energy, the energy sent to the grid, the power consumed directly, and the share of solar energy in energy consumption.

Keywords*: energy community development, scenario-based modelling, resLoadSIM, RES.*

1. INTRODUCTION

To address household contribution to climate change and to reduce greenhouse gas emissions, the introduction of local generation and expansion of new demand types (such as electric vehicles (EV) and heat pumps (HP)) are inevitable. The EU Roadmap for Moving to a Competitive Low Carbon Economy in 2050 establishes a long-term vision to cut domestic greenhouse gas emissions by at least 80 % by 2050 compared to 1990. The Winter Package "Clean energy for all Europeans" aims at transition to a more sustainable energy system by placing citizens at the centre of energy policies. According to the Winter Package, the expansion of renewables has a key role in meeting GHG reduction targets.

To achieve the above-mentioned sustainability goals, citizens are creating and joining energy communities that give them the power to engage in clean energy transition. It is a form of social movement in which citizens voluntarily participate in renewable energy projects allowing for more inclusive and democratic processes. Energy communities often start their activities by only producing energy, as it brings many positive benefits to residents. An increasing number of energy communities provide additional services, such as electro-mobility, energy efficiency initiatives (i.e., building renewal, energy audits, consumption monitoring, etc.), the flexibility of uses, energy storage and smart grid integration, energy monitoring and grid management, as well as financial services and consultation services to develop community initiatives [1]. For example, energy efficiency initiatives are a great way to gain expertise and trust in the community, especially in the beginning, whereas an electric car-sharing scheme is a great activity for existing community energy projects [2], [3]. The report [4] focused on an analysis of 24 energy communities and found that, although some communities performed only generation activities, 10 of them participated in energy efficiency activities (such as the renovation of buildings and replacement of inefficient households appliances), and 8 of them offered electro-mobility services.

The residential sector in Latvia shares a significant portion (28.4 % in 2019) of total energy consumption [5]. According to Latvia's NECP, Latvia is planning to increase the share of renewable energy sources (RES) in the production of electricity by significantly increasing the installed capacity of wind and solar energy. The electricity produced by photovoltaic (PV) systems in Latvia is showing an upward trend. In 2019, solar power plants produced 3 GWh of electricity – three times more than in 2018. PV installation to the residential sector is offered by electricity traders, on average installing 5–6 kW systems, which turns residential consumers into prosumers. [6], [7]. The current policy is based on the use of the net settlement system. When energy is transferred from a household to the power grid, this amount is deducted by the household invoice for the next billable month. To support the improvement of energy efficiency in private homes, the Ministry of Economics has approved a programme that supports the installation of solar panels and small wind generators. It must be ensured that the reduction in primary energy is at least 20 %, and produced energy is used for self-consumption [8]. The Ministry of Environmental Protection and Regional Development has developed

a support programme for the use of renewable energy resources in households. One of the supported activities is the purchase of new renewable energy equipment for electricity production [9].

Although the number of EVs is not large in Latvia, it is expected to reach significant levels in the future. In total, at the beginning of 2022, almost 2200 EVs were registered in Latvia (only 0.3 % of the total passenger vehicle fleet). In 2020, the number of EVs in Latvia increased by 85 % [10]. One of the reasons why people in Latvia still prefer internal combustion engines is the unavailability of charging stations. By September 2020, 316 public charging points have been built, but the ratio to land area is still low [11]. Even though some measures have been introduced to promote the use of EVs (free parking, the possibility of using public transport lanes, etc.), the EV infrastructure is developing slowly and is not always accessible to residential users. Since 2022, grants for the purchase of EVs have been available in Latvia. The amount of support is 4500 EUR for a new EV and 2250 EUR for a used car. Given the amount of funding available, it was forecast that the total number of electric vehicles and externally chargeable hybrids purchased could reach 3800 [12].

Potential method that can mitigate unfavourable side effects of intermittent generation is demand response (DR). In the context of this paper, DR is intended to efficiently use the energy surplus produced by the PV panels for self-consumption by shifting high consumption appliances to off-peak hours. By reducing the amount of solar electricity injected into the grid, self-consumption provides benefits on the grid side. Energy communities also have a social objective, so avoiding grid failure, increasing the stability of the electricity system, reducing energy losses in grids and transformers, improving the quality of voltage, and postponing upgrading work, undoubtedly have a positive impact on the whole community [13]. DR is still at the early stage in Latvia and has not been widely researched. However, the Electricity Market Law and the Law on Regulators of Public Utilities, which are in force in Latvia, allow for the use of DR.

The motivation for this paper is to study the realistic development of the energy community in Latvia, considering that Latvia has significant room to expand new social movements and novel technology adoption and would benefit from a planning framework and research findings. The research has been conducted by scenario-based modelling to identify five checkpoints on the path from a simple neighbourhood to an energy community, assuming that the community will increase its generation capacity gradually while increasing the number of collective energy initiatives.

2. RATIONALE FOR SCENARIO DEVELOPMENT

Good quality electrical load modelling tools allow for more accurate prediction of future scenarios. In particular, statistical models can be beneficial to predict building occupancy and thence consumption patterns [14]. Consumption of each appliance is constructed by investigating their frequency of use, turn-on time, operating time, etc. The total load profile is composed of summing up the load of each appliance. The statistical modelling results indicate what is likely to happen rather than revealing an optimal

course of action. In this paper, five scenarios are simulated, with the resLoadSIM modelling tool, which simulates the load profiles of individual households by predicting the switching on/off of each appliance using a probabilistic approach. Each scenario corresponds to a different energy community development step, starting from a simple neighbourhood, and ending with an energy-efficient energy community that offers its residents electro-mobility services.

In this paper, three assumptions are made about the goals of the energy community. Firstly, the community chooses solar energy as a source of their energy production. The paper [15] states that solar PV power should be 25 % of the total generation mix to achieve Paris Climate targets. Also, it is expected that almost half of EU households will produce renewable energy in 2050 [16]. It is assumed that the community aims to reach those two targets.

Secondly, the community chooses to join in EV car-sharing activities and improve energy efficiency while still considering grid restrictions. Energy communities have the potential to provide direct benefits to citizens by advancing energy efficiency and lowering their electricity bills. Likewise, electric mobility services can be used to improve efficiency and sustainability in energy communities. Integration of renewable power generation with electric mobility infrastructures is a way to alleviate the massive connection of numerous fleets of EVs to power grids. The possible advantages are reduction of electricity generation and charging costs, energy efficiency increase (in terms of reduction of renewable energy curtailment), and environmental benefits (increased renewable share in power systems) [17]. However, it is necessary to consider the grid restrictions when planning new energy activities in the community. For instance, the replacement of inefficient household appliances can lead to decreased consumption, which results in increased energy delivered through the grid. An increase in load during peak hours can cause lines to exceed their capacity limits, resulting in increased thermal loads and potential damage. Also, increased share intermittent generation and additional EV charging stations might lead to voltage problems in the existing grid, which require additional investments for solving [18].

The rationale for the first and second assumptions is the new state support mechanisms that support the installation of PV panels and the purchase of EVs by Latvian households. Energy efficiency activities have been selected because one of the targets of Latvia's NECP for 2030 is that society has become more aware of energy efficiency issues and there has been an increase in involvement and the desire to ensure energy efficiency in daily life of the community.

Thirdly, we assume that the energy community will not invest in grid development and expansion but will only take into account the restrictions of the grid. Very high penetration of solar PV can lead to operational and reliability challenges (voltage variations and congestions in the electrical network) and reduction in environmental benefits [19], [20]. In [21], a real distribution feeder is analysed, utilising a residential load profile, against various PV penetration levels. Results show that an increase in PV penetration reduces the instances of under-voltage, yet the occasions of overvoltage increase substantially. Further, DR smooths daily load variations by moving a fraction of consumption from peak to off-peak period and reduces the effects of load fluctuations caused by the increased amount of intermittent energy injected into the grid.

3. METHODOLOGY

This section introduces the method for predicting the future development of energy communities in realistic Latvian conditions. Firstly, load identification was performed to find a suitable location for the development of the energy community in Latvian conditions. Secondly, the load profile was generated for the selected location to obtain electricity consumption in high time resolution for a full year. Thirdly, a scenario-based simulation was performed to describe five scenarios that identify a path from a simple neighbourhood to an energy community.

Load identification was performed to select a location in Latvia where the development of energy communities could be most suitable. As a result, a neighbourhood in a suburban area with 76 households was selected and modelled. The main objectives for the selected location are that residents live there permanently with constant electricity consumption (in contrast to summer houses, where consumption is seasonal) and the electricity network is relatively new and would not require investments in the near future.

The load profile generation process for a selected location consisted of collecting site-specific information (data about annual energy consumption, daily load curves and solar irradiation values) and statistical data on the use of household appliances in Latvian households. Statistical and site-specific data were used with the resLoadSIM tool [22], developed by EC JRC to simulate the base-case that represented the selected location. Later, modelling parameters were adjusted to represent the selected location as accurately as possible. ResLoadSIM is a stochastic bottom-up simulation tool that predicts electric residential load profiles of households with a high time resolution. The resLoadSIM modelling tool was used because it allowed obtaining realistic load profiles by adjusting a wide variety of parameters so that the resulting load profiles were as close as possible to the real ones. Some benefits of this tool are that it is very flexible and allows for the evaluation of the potential of certain energy community development steps.

For the purpose of this paper, five different scenarios were described that combined different deployment levels of solar PV, EVs and energy efficiency initiatives. The scenarios were made by adding new energy technologies to the modelling tool, changing household energy control strategies, and changing parameters and usage patterns of household appliances. All developed scenarios were simulated using resLoadSIM and compared to the base-case simulation. The results were analysed to identify what energy communities would look like in Latvia.

4. CASE STUDY AND DATA COLLECTION

In this study, a residential district located in Latvia was chosen as a testbed. The selected area is suburban and consists of 76 clients, with more than 450 thousand kWh annual consumption. From this area, hourly load curve, number of clients and annual electricity consumption are known. In Fig. 1, the service area of the selected location is shown.

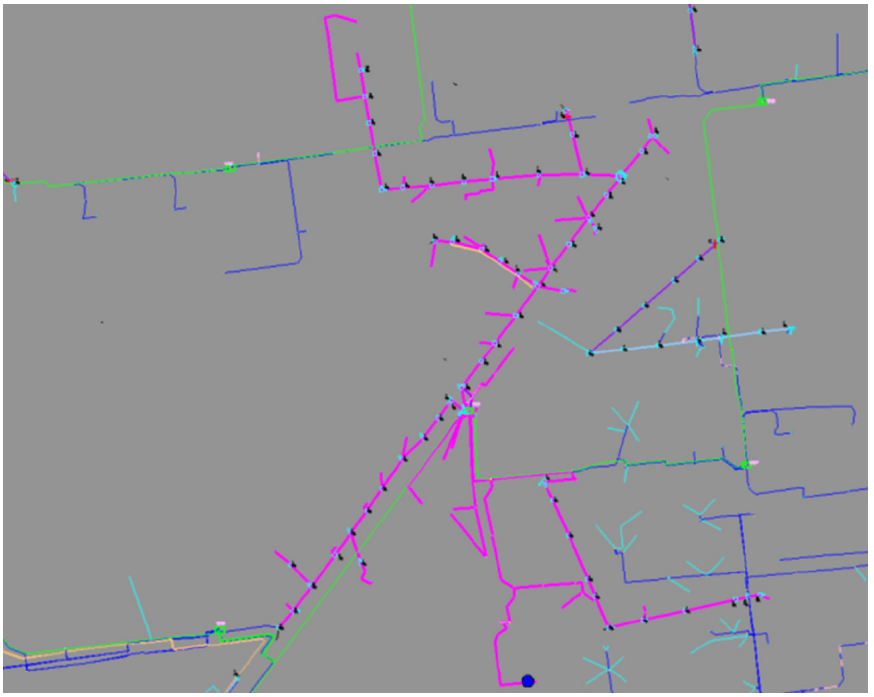


Fig. 1. The service area of existing 20/0.4kV transformer substation.

Full time series of hourly values of temperature and solar irradiation at a given location and year are obtained from the PVGIS [23] database. At first, resident characteristics and appliance usage patterns are selected, based on statistical data from Latvia. Later, they are adjusted to match consumption in a chosen residential location.

5. MODELLING PARAMETERS AND CONSTRAINTS

To model electrical consumption with resLoadSIM, household characteristics (household size, number of residents, etc.) and electrical appliance usage patterns (percentage of houses using each appliance, energy class, etc.) are needed. Before performing scenario-based modelling, it is also necessary to determine parameters for a PV system and EV systems, and rules for DR. Between sunrise and sunset, the power output of a PV system is determined using its nominal power and solar irradiation values, which are obtained from the PVGIS database. To perform PV system modelling, additional information about PV system is needed – information about the estimated system losses of a PV installation, the minimum and maximum size of a solar module per household resident, minimum and maximum efficiency of a solar module.

For EV modelling, the type of location (urban or rural) is required, as well as the energy consumption of the car, the battery capacity, and self-charging rate. ResLoadSIM provides an opportunity to include smart e-vehicles that try to charge their batteries when there is a solar energy

surplus. Lastly, to model peak shaving, the peak shaving threshold needs to be specified. This threshold refers to the maximum peak value, which has been calculated during the first day of the simulation.

6. SCENARIOS

In this paper, the following scenarios have been created. It should be emphasised that the end goal of the selected community is to increase its renewable energy share to 25 % of annual energy consumption and increase its energy efficiency while considering existing grid restrictions.

(S1) The first scenario simulates the real neighbourhood of 76 households. The daily load curve and annual energy consumption are known beforehand. The annual energy consumption of all households is approximately 453 thousand kWh. The residents use household appliances with a large variety of energy classes, drive with vehicles that run on traditional petroleum fuels, and heat their houses from district heating. In the resLoadSIM modelling tool, parameters are adjusted to represent the selected location as accurately as possible. The grid restrictions associated with the transformer and lines are taken into account, and an assumption is made that the neighbourhood will not make investments in grid development and expansion. Based on these restrictions, the maximum amount of energy sent to the grid is 128 kW.

(S2) In the second scenario, the abovementioned neighbourhood starts to form an energy community. The energy communities often start with energy production, for example, by installing PV panels. The not-for-profit nature of energy communities suggests that the profit from energy production is returned to the community, for example, by increasing the number of PV panels. In this scenario, we are looking at the point in community development where approximately a half of the grid restrictions is met. More specifically, the maximum power sent to the grid is 61 kW. On this occasion, 18 households have installed PV panels on their rooftops. On average, 59 % of solar energy is used immediately, and the rest is sent to the grid. Annual solar generation is 17 % of total annual energy consumption. The community aims at increasing the share of solar energy production to 25 % of annual energy consumption, as well as engaging in various energy activities, such as collective self-consumption and electro-mobility, in a way that does not violate grid restrictions.

(S3) In the third scenario, the community begins to implement a peak-shaving control strategy while continually adding new PV panels on their territories. The appliances are not changed in this step, and load shifting is based on the wiring of these appliances. In this step, 26 households have installed PV panels. Due to peak shaving, average energy consumption has decreased a little. 56 % of solar energy is used immediately, and solar production accounts for 23 % of annual energy consumption.

(S4) In the fourth scenario, the community is launching an EV car-sharing initiative, as well as continuing to increase their PV assets. The number of households with PV panels has increased to 38 households and 50 % of households are using EV car-sharing possibility. In this step, the maximum power sent to the grid is 97 kW.

61% of solar energy is used immediately and solar production accounts for 22% of annual energy consumption.

(S5) In the fifth scenario, appliances with low energy class are replaced, and the number of PV panels is increased to a maximum based on grid restrictions. We assume that all appliances below the efficiency class D are changed to class A. The rest of the appliances are used as previously. As a result, 39 households have installed PV and the maximum power sent to the grid is 124 kW. 53 % of solar energy is used immediately and solar production is 31 % of annual energy consumption.

Table 1. Summary of Scenarios.

Scenario	Households with PV	EV car-sharing	Energy efficiency initiatives	Share of PV power	% of solar used immediately	Max power sent to grid
S1	-	-	None	-	-	-
S2	18	-	None	17 %	59 %	61 kW
S3	26	-	Peak shaving	23 %	56 %	80 kW
S4	38	50 %	Peak shaving	22 %	61 %	97 kW
S5	39	50 %	Peak shaving + New appliances	31 %	53 %	124 kW

From Table 1 it can be seen that the community was able to meet its goals. In each step, the community increased its production of solar energy. When new energy efficiency initiatives were introduced, the percentage of immediately used solar energy decreased. The introduction of EV sharing increased the percentage of immediately used energy but decreased the share of PV power as a result of increased energy consumption. In the last step, the share of solar energy was 31%, and more than half of households had PV on their rooftops. The goals were achieved without exceeding grid restrictions.

7. MODELLING RESULTS

This section provides a more detailed analysis of each scenario. In Fig. 2, a load curve of typical daily electricity consumption is presented. The shape of the consumption curve is similar in all five scenarios. However, it can be seen that changes associated with different scenarios affect the evening peak much more than the morning peak. It is evident that EV charging in S4 has a powerful effect on electricity consumption. Moreover, the replacement of low-efficiency household appliances in S5 decreased this consumption.

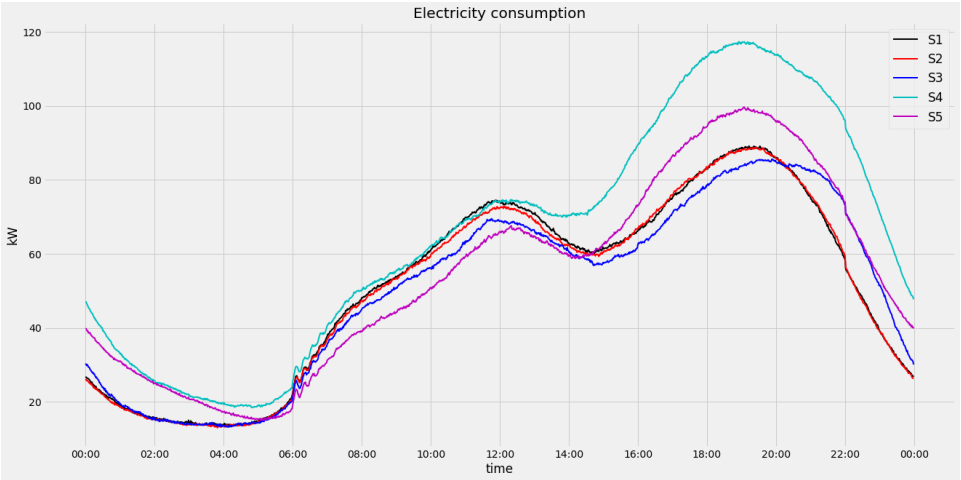


Fig. 2. Electricity consumption for all scenarios.

In Fig. 3 it can be seen that the highest amount of energy used immediately is in the middle of the day and does not change much between 8 am and 2 pm. It is noticeable that S2, S3, and S4 scenarios are quite similar, and only S5 differs the most from the others as the line is much lower.

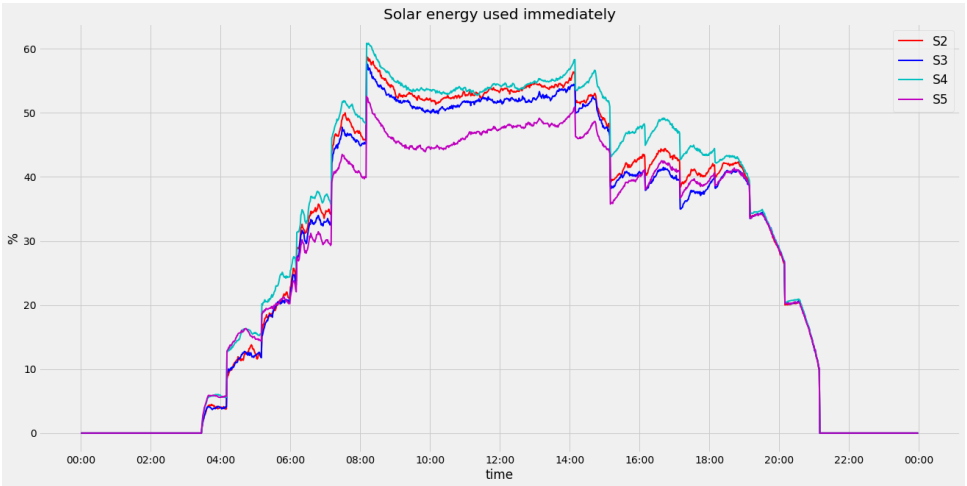


Fig. 3. The amount of solar energy used immediately for S2–S5 scenarios.

Figure 4 shows one week in July for all scenarios with PV generation. It can be seen that S3 produces more solar energy than S2 and uses a load shaving strategy. S4 increased consumption and solar generation compared to S2 and S3 due to an increase in the number of PV installed and the ongoing EV car-sharing initiative, while S5 reduced consumption compared to S4 because of the replacement of low-efficiency appliances.

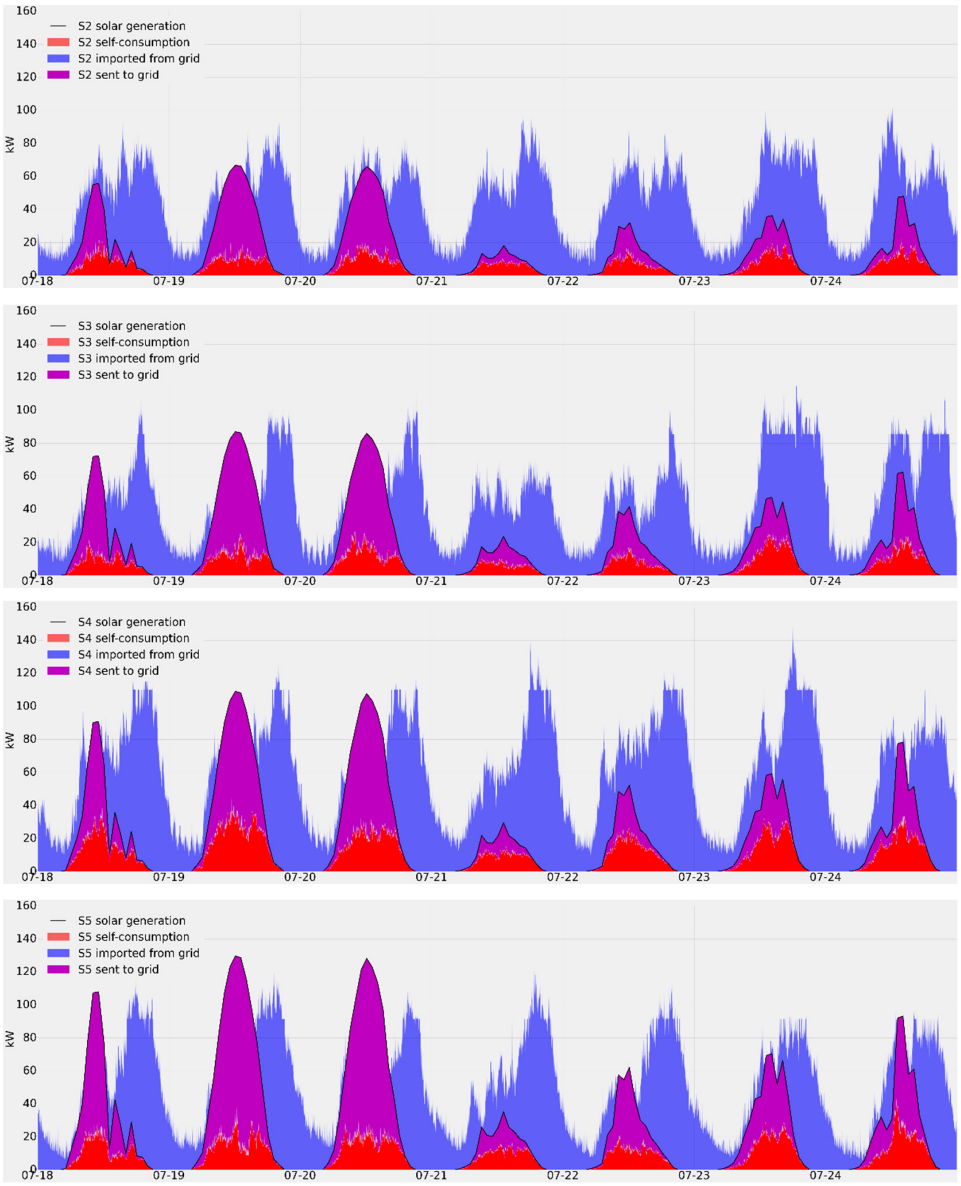


Fig. 4. Energy consumption and solar generation over one week for S2–S5 scenarios.

8. CONCLUSIONS

Energy communities can help achieve various sustainability goals and enable citizens to engage in the clean energy transition. It is a form of social movement, which does not exist yet in Latvia, but could be relevant in the future. This paper has studied what the realistic development of the energy community could look like in Latvia since there is significant room to expand new technology adoption, and research findings can be beneficial. Energy communities provide a wide variety of services; for the

purpose of this paper, we have considered only energy efficiency and electro-mobility services. Additionally, new state support instruments have recently been introduced in Latvia to promote renewable energy and the purchase of EVs.

We consider that the energy community uses solar energy as their renewable energy source. Generation capacity is increasing gradually as the not-for-profit nature of local energy communities suggests that the profit from energy production is returned to the community by increasing the number of PV panels. In the selected location, half of the households can install PV panels, before grid constraints no longer allow for the expansion of the community. The share of solar energy in energy consumption is 31 %, which is higher than initially planned.

Modelling results clearly show the effect of electro-mobility and energy efficiency services on the consumption of the energy community and how it affects the use of solar energy. The next practical steps for the energy community could be investment in the expansion of the internal electricity grid, which will allow the community to increase production capacity, as well as the implementation of energy storage technology and heat pumps.

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