BERLIN

Cost-effective rehabilitation of public buildings into smart and resilient nano-grids using storage

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Priority: B.4.3 - Support cost-effective and innovative energy rehabilitations relevant to building types and climatic zones, with a focus on public buildings
Countries: Cyprus, Greece, Israel, Italy

Output nº: 3.2
Output Title: Optimal integration of 3 cost-effective technologies in public buildings
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3 Copyright

4 Contents

1 Project summary 5
2 Introduction 6
3 Development and application of effective DSM-based scenarios 7
3.1 Objective 8
3.2 Methodology 9
3.3 Development of new ToU tariff rates and relevant time blocks 10
3.4 Application of the DSM-based scenarios 11
3.5 Definitions 12
4 Cyprus 13
4.1 Application of the DSM-based scenarios 14
4.2 Impact of the DSM scenarios on self-consumption and self-sufficiency rates 17
4.3 Impact of the DSM scenarios on operating cost 19
5 Greece 20
5.1 Application of the DSM-based scenarios 21
5.2 Impact of the DSM scenarios on self-consumption and self-sufficiency rates 24
5.3 Impact of the DSM scenarios on operating cost 26
6 Israel 27
6.1 Application of the DSM-based scenarios 28
6.2 Impact of the DSM scenarios on self-consumption and self-sufficiency rates 31
6.3 Impact of the DSM scenarios on operating cost 33
7 Italy 34
7.1 Application of the DSM-based scenarios 35
7.2 Impact of the DSM scenarios on self-consumption and self-sufficiency rates 38
7.3 Impact of the DSM scenarios on operating cost 40
8 Conclusions 41

1 Project summary

In an effort to address high energy consumption in the building sector that is mainly fossil – fuelled, support rural areas and areas powered by weak grids, which are common in the MENA region, and achieve higher grid penetration of Renewable Energy Sources (RES) while maintaining grid stability and power quality, this project aims at the implementation of cross border pilots that will support innovative and cost – effective energy rehabilitation in public buildings based on the nanogrid concept. Thus, BERLIN project focuses on the increase of Photovoltaics (PV) penetration, which coupled with Battery Energy Storage Systems (BESS) and Demand-Side Management (DSM) will increase the Energy Efficiency (EE) of the buildings. The implementation of these technologies in a cost – effective way will result in high level of self – resilient public buildings that are green, smart, innovative, and sustainable. A total of 6 pilot buildings will be implemented: 1 in Cyprus, 2 in Greece, 2 in Israel and 1 in Italy.

The project has started in September 2019 and is expected to be completed within 48 months.

2 Introduction

This report presents the development of practical, yet effective, DSM scenarios that can be applied to the different pilots of the BERLIN project. The application of such effective DSM scenarios through the 'virtual' testing of new Time-of-Use (ToU) tariffs (already developed for each country in deliverable A4.3.2) could have a positive impact on the consumption behaviour of the users. In this study, the scenarios are based on load shifting, which is applied through combined peak shaving and valley filling.

The scenarios can be applied in the pilots through the available monitoring and control devices. Specifically, monitoring is facilitated through the In-Home Display (IHD) screens that are included in each smart meter to provide information related to dynamic energy consumption and other parameters. On the other hand, control is facilitated through smart controllers and automation systems, which can be programmed to accomplish the most cost-efficient operational patterns, which is the objective of these scenarios.

To evaluate the effectiveness of the considered DSM-based scenarios, these are combined with the developed ToU tariffs, to promote a different consumption behaviour, leading to a more cost-efficient operation of the nanogrid systems. Therefore, these scenarios are formulated in such a way as to motivate the consumers to change their consumption behaviour, through a variable ToU tariff rate timetable pattern.

Overall, the purpose of applying these new scenarios is to reach optimum operational patterns in terms of cost for the PV+BESS+DSM systems[1]. Additionally, it is considered how these DSM scenarios affect the self-sufficiency and self-consumption rates.

[1] It is noted that the developed DSM-based scenarios have not been applied on the pilots yet due to delays in the implementation of the pilots, which in turn delayed the collection and validation of the data, and the setup of the pilots for application of these scenarios. However, such actions have been planned for implementation in a later stage.

3 Development and application of effective DSM-based scenarios

In this section, combined DSM-based scenarios including load shifting, valley filling, and peak shaving, are developed for the purpose of applying them in the pilots already developed in the different countries of the BERLIN project (a graphical representation of these methods is given in Figure 1). The main purpose of these scenarios is to investigate their effect on operating costs, which can be quantified and compared with the initial state, i.e., before their application. In this manner, the impact of the scenarios can be analysed to extract conclusions.

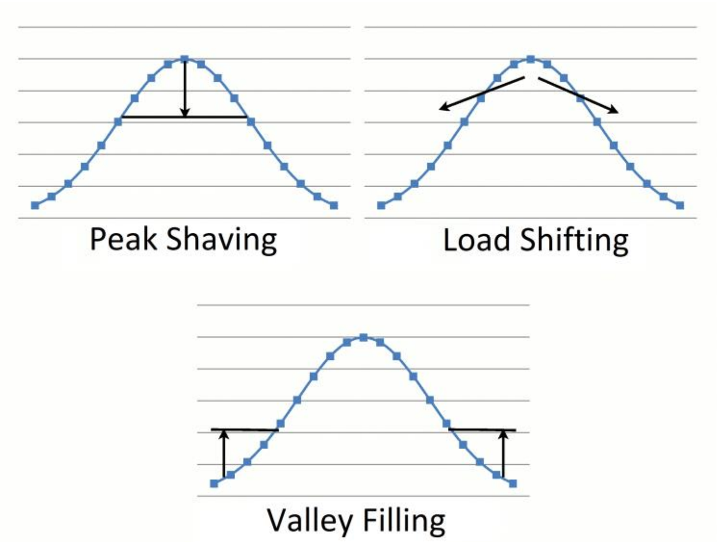

Figure 1: Application of DSM-based scenarios through peak shaving, load shifting, and valley filling actions.

3.1 Objective

Obtaining a more cost-efficient operation of the nanogrid is also directly related to minimizing the interaction of the nanogrid with the central power grid. Specifically, the proposed DSM-based scenarios can help achieve this target since they can lead to user behaviour that facilitates the reduction of electric energy imports, the increase of self-consumption, and the exploitation of ToU tariffs throughout the whole annual operation of the pilots.

When PV-generated electricity exceeds consumption and BESS capacity limits, excess power can be exported, if a net-metering scheme is available. However, when such a scheme is unavailable or inapplicable, excess power must be curtailed or exported without any economic earnings. On the other hand, when consumption exceeds PV-generated electricity and BESS capacity limits, additional power must be imported from the central power grid, which results in money spent to purchase energy.

The application of the DSM-based scenarios developed for the purposes of this study targets the shifting of loads from time periods with high netload power values to time periods with low netload power values. Self-sufficiency and self-consumption rates increase when the load is shifted towards time periods with high PV generation, which in turn results in a reduction of the total operating cost, provided a suitable ToU tariff rate plan is also applied. Therefore, the application of such DSM-based scenarios can reveal in a quantitative way their extent and impact in terms of economic and technical benefits.

3.2 Methodology

The collected and validated data from the available pilot datasets (see deliverable A3.2.2) have been extracted and averaged to represent the three seasons of the year (winter, summer, and midseason)[2] for each pilot[3]. In this way, an average weekly netload[4] profile can be determined and utilized to represent each season.

The consideration of the netload[5] for the analysis of these scenarios is more appropriate than the absolute electricity consumption of the serviced buildings because it takes into consideration the PV-generated electricity. Additionally, the BESS in each pilot is considered in the load shifting of the DSM strategies.

In this manner better DSM strategies can be identified and adopted since the target is to:

- decrease consumption when the netload presents peak values and
- increase consumption when the netload presents valley values.

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[2] In this study the seasons of the year have been defined as follows: (a) Summer: June-September, (b) Midseason: April-May, October-November, and (c) Winter: December-March.

[3] For brevity, in this report, for Greece and Israel only the pilots in the UOWM dormitories and the school in Eilat, respectively, are considered.

[4] The netload of an electric grid is the difference between the total electricity demand, and the electricity generation from behind-the-meter resources such as solar and other distributed generators.

[5] For the purposes of this study, 'netload' takes both positive and negative values (lowest netload values occur at instances with PV generation surplus, i.e., negative values).

3.3 Development of new ToU tariff rates and relevant time blocks

The previously developed methodology for the setup of new ToU tariff rates and relevant time blocks (see deliverable A4.3.2) is followed for each pilot. Specifically, for the purposes of the current study, these time blocks are modified to consider the netload, instead of the absolute consumption, of the buildings.

Accordingly, this is done to reach the following targets:

- *Off-peak* rates are set for the time periods presenting valley (low) netload values, in order to motivate users to increase consumption at these instances.
- *On-peak* rates are set for the time periods presenting peak (high) netload values, in order to motivate users to reduce consumption at these instances.
- *Shoulder* rates are set for the time periods presenting moderate netload values, in order to have intermediate time periods between *on-peak* and *off-peak* rate periods. This serves as a way of smoothening the transition between *on-peak* and *off-peak* rate periods.

The timetables for the ToU tariff rates are based on the initial netload pattern (before the application of the DSM methods). The ToU tariff rate time blocks[6] for each pilot are distinguished between:

- Type of day: Working day (W) vs. Non-working day (NW)
- Season: Winter vs. Summer vs. Midseason

[6] The ToU tariff rates are based on the analogy between on-peak, shoulder, and off-peak tariff pricing found in: https://www.erthpower.com/new-time-of-use-and-tiered-prices-effectives-november-1-2022/

3.4 Application of the DSM-based scenarios

The DSM-based scenarios are applied in 5%, 10%, and 15% load shift percentages to investigate their gradual effect on the operating cost for each season. As shown in Figure 2, load shifting is applied through a combined, simultaneous peak shaving and valley filling action.

Specifically, peak shaving begins with a reduction of the netload power values presenting the highest values, while in the same analogy, load filling begins with an increase of the netload power values presenting the lowest values.

In this manner, the exact same netload energy that was removed from the highest netload values is shifted to the lowest netload values. This ensures that total consumption remains exactly the same after the load shifting, as it was initially before the application of the DSM scenarios.

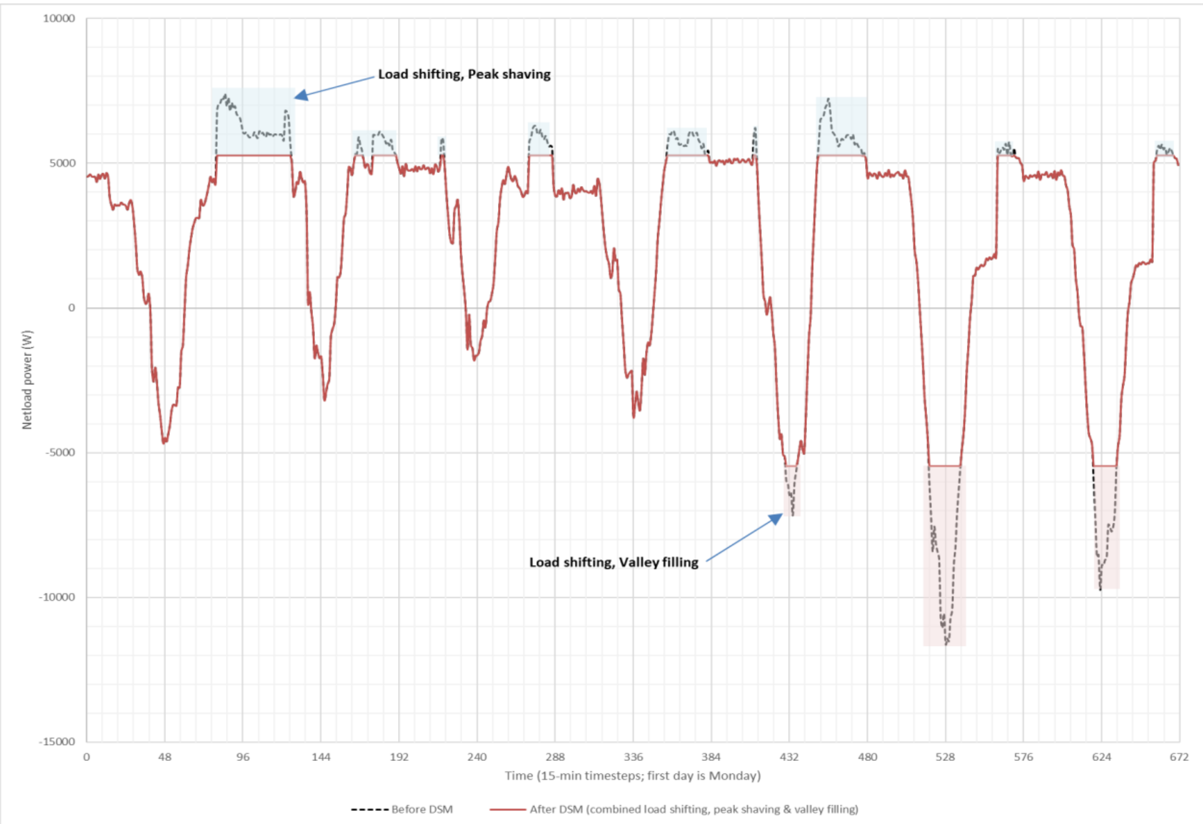

Figure 2: The developed DSM-based scenarios of this study are based on a combined, simultaneous application of peak shaving and valley filling load shifting actions.

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3.5 Definitions

For the purposes of this study, the following definitions for the seasonal self-consumption and self-sufficiency rates are provided.

The seasonal self-consumption rate is defined as the difference between energy generation from the PV system, P_{PV}, and energy export to the grid, $P_{grid,exp}$, over energy generation from the PV system, as follows:

$$SCR = \frac{P_{PV} - P_{grid,exp}}{P_{PV}} 100\%$$

The seasonal self-sufficiency rate is defined as the difference between energy consumption, P_{cons}, and the energy import from the grid, $P_{grid,imp}$, over energy consumption, as follows:

$$SSR = \frac{P_{cons} - P_{grid,imp}}{P_{cons}} 100\%$$

4 Cyprus

For the pilot in Cyprus, the PV capacity and BESS size are 40 kWp and 60 kWh, respectively. The variation of netload power during winter, summer, and midseason is shown in terms of three averaged weeks (one per season) for the pilot in Cyprus in Figure 3. By observation, the frequent occurrences of negative netload power values clearly suggests that there is a lot of room for application of DSM-based scenarios with combined load shifting actions.

Seasonal variation also suggests that there is some deficiency in terms of electrical power during winter, which must be covered through imports from the central power grid. However, it is anticipated that the percentage load shifting will be able to reduce these imports. On the other hand, there is a clear indication that through the application of the DSM-based scenarios the system could become fully self-sufficient during summer and midseason.

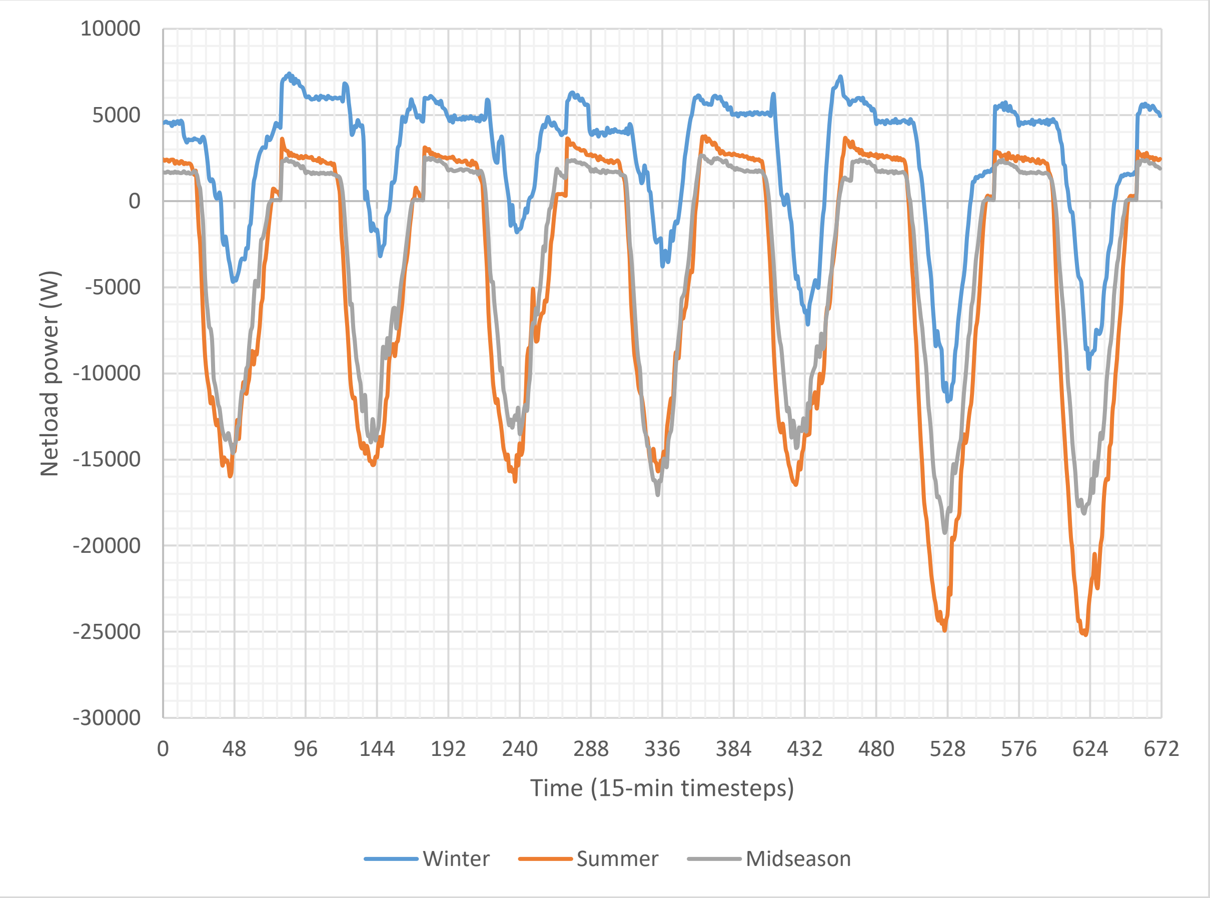

Figure 3: Variation of netload power during winter, summer, and midseason shown in terms of three averaged weeks (one per season) for the pilot in Cyprus.

4.1 Application of the DSM-based scenarios

The considered DSM-based scenarios are applied through 5%, 10%, and 15% peak shaving and valley filling load shifting actions, as shown in Figure 4, Figure 5, and Figure 6, for winter, summer, and midseason, respectively.

For all seasons, load shifting can primarily be shifted from time periods with high netload values (i.e., time periods with limited or no PV generation), which occur mostly in weekdays, to daytime hours with high PV generation and low consumption, which are mostly in weekend days. In the winter season, load shifting appears to be more marginal due to the limited PV generation, in comparison to midseason and summer, where load shifting potential seems very high.

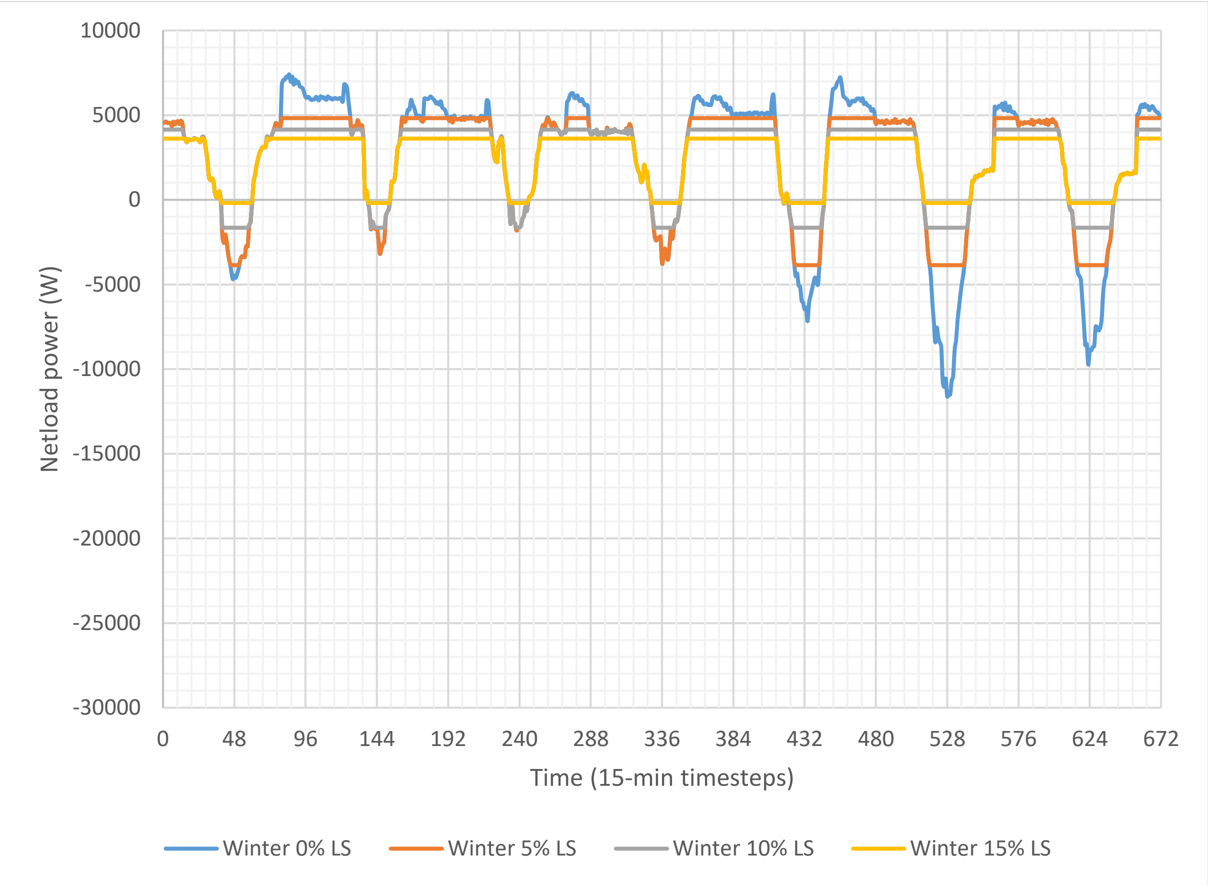

Figure 4: Variation of netload power during winter for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Cyprus.

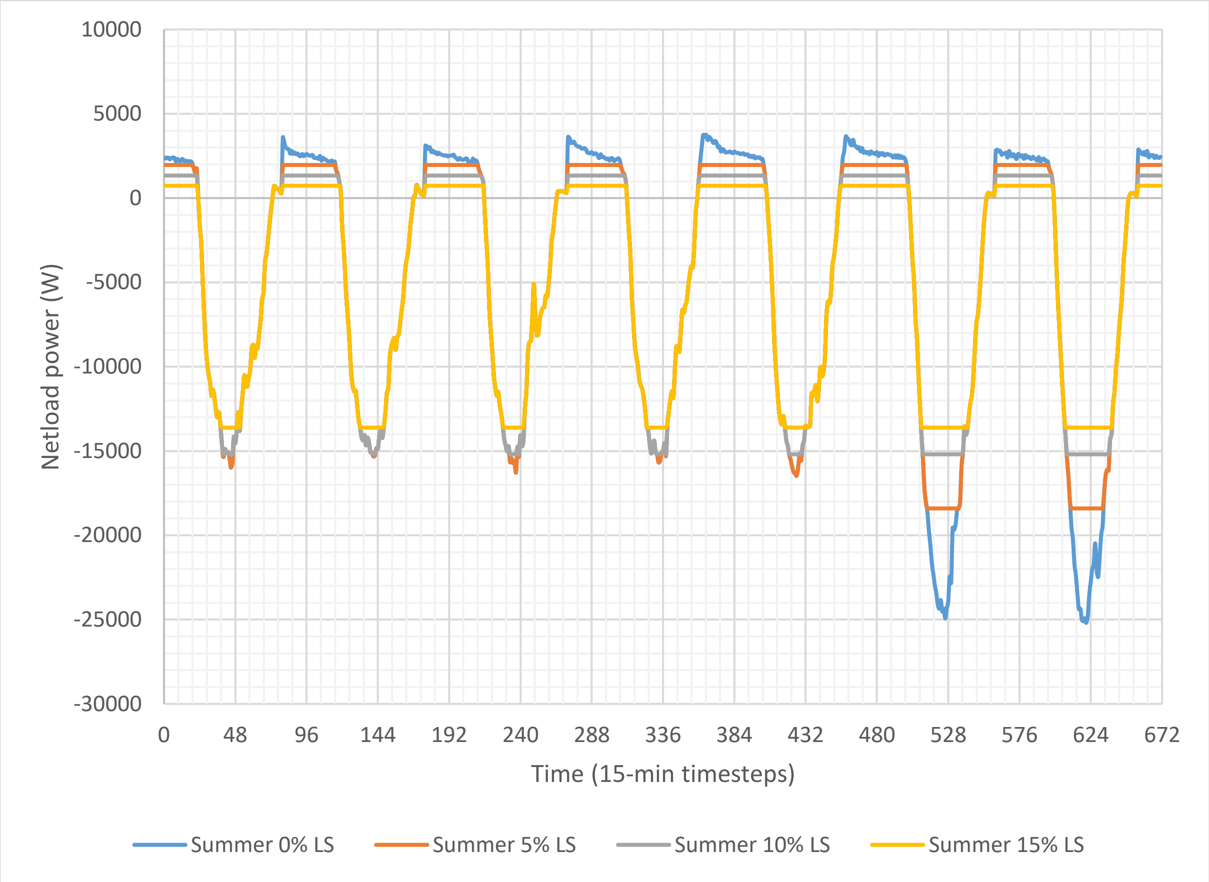

Figure 5: Variation of netload power during summer for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Cyprus.

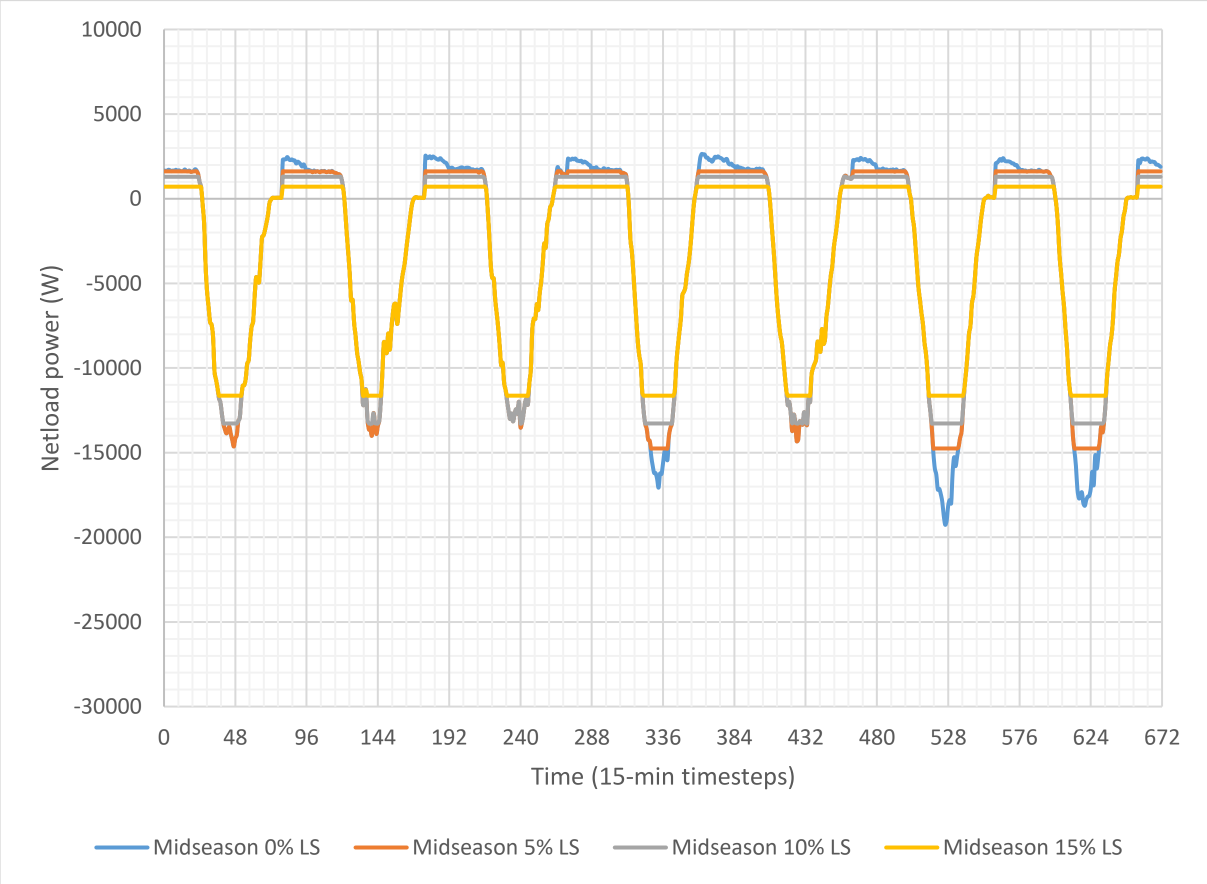

Figure 6: Variation of netload power during midseason for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Cyprus.

4.2 Impact of the DSM scenarios on self-consumption and self-sufficiency rates

The impact of the applied DSM-based scenarios on the self-consumption rate is shown in Figure 7. During winter, self-consumption is already very high (99%), even before the application of the DSM-based scenarios since all PV generation can be utilized for the needs of the pilot buildings. Specifically, the inclusion of a high-capacity BESS in the DSM actions ensures that power exports are infrequent and can be completely eliminated even with a small load shifting percentage.

During summer and midseason, the application of the DSM-based scenarios has a negligible impact on the self-consumption rates which are increased by 1%, since PV generation exceeds by far the consumption needs of the buildings and therefore power needs to be exported to the central grid. If power exporting to the central power grid is undesirable, demand electrification solutions should be implemented, e.g., EV charging, electric heating, air conditioning.

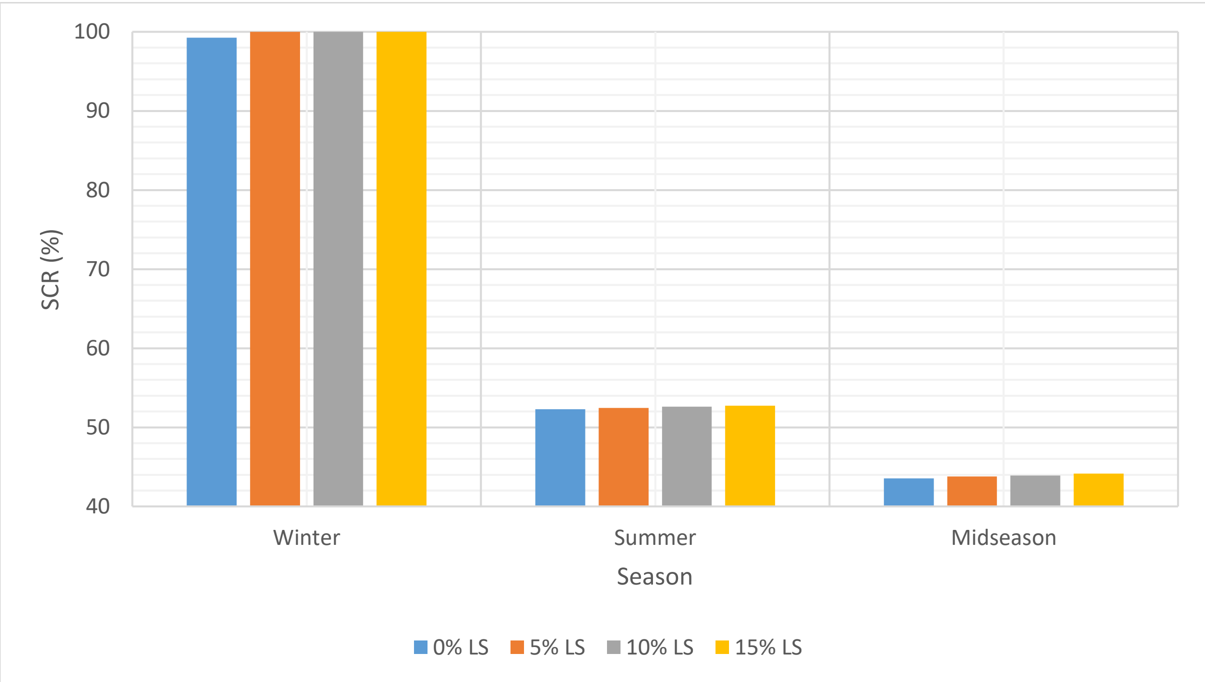

Figure 7: Variation of self-consumption rate during winter, summer, and midseason for 0%, 5%, 10%, and 15% load shifting for the pilot in Cyprus.

The impact of the applied DSM-based scenarios on the self-sufficiency rate is shown in Figure 8. During winter, the self-sufficiency rate increases by around 2% after the application of a 5% load shifting, which is due to the fact that only a small amount of electricity is exported to the central power grid before the application of the DSM-based scenarios, and therefore after the application of the DSM-based scenarios, no power export is needed.

During summer and midseason, the self-sufficiency rates are already 100% before the application of the DSM-based scenarios and therefore there is no room for further improvement. This is due to the presence of a large BESS which is able to store part of the excess power generation and cover the whole night demand.

The uneven pattern between winter and summer/midseason suggests that there should be an integration of seasonal storage to transfer power generation from the summer/midseason to winter. This utilization through seasonal storage (e.g., hydrogen generation) could satisfy the existing winter deficiency; it is anticipated that this would make the system completely self-sufficient for the whole annual operation.

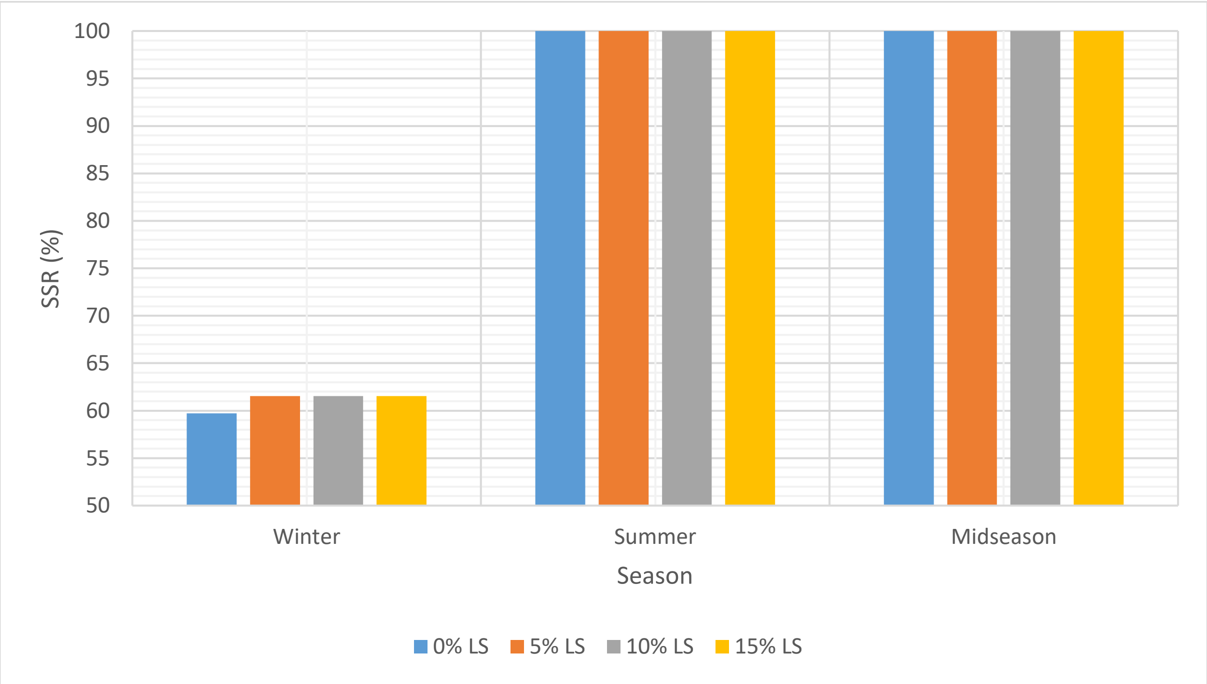

Figure 8: Variation of self-sufficiency rate during winter, summer, and midseason for 0%, 5%, 10%, and 15% load shifting for the pilot in Cyprus.

4.3 Impact of the DSM scenarios on operating cost

The resulting timetable for the ToU tariffs is given in Table 1, while the resulting operating costs before and after the application of the DSM-based scenarios are given in Figure 9. It is evident that even with a limited load shifting (e.g., 5%), there can be a significant impact on the operating cost. Specifically, a 5%, 10%, and 15% load shifting, leads to a cost reduction of 3.6%, 7.2%, and 11.4%, respectively. In terms of actual values, the total annual operating cost is 13931 EUR and 12343 EUR with 0% load shifting and 15% load shifting, respectively.

Table 1: Timetable of the ToU block periods for the pilot in Cyprus.

Block	Price (€/kWh)	Winter	Summer	Midseason
		Weekdays		
On-peak	0.496	18:45-03:29	20:00-05:44	20:00-05:59
Shoulder	0.335	03:30-09:59, 15:00-18:44	05:45-06:14, 17:45-19:59	06:00-06:59, 17:00-19:59
Off-peak	0.243	10:00-14:59	06:15-17:44	07:00-16:59
		Weekends		
On-peak	0.496	20:00-06:59	20:00-05:44	20:00-05:44
Shoulder	0.335	07:00-09:14, 16:00-19:59	05:45-06:14, 18:00-19:59	05:45-06:44, 17:15-19:59
Off-peak	0.243	09:15-15:59	06:15-17:59	06:45-17:14

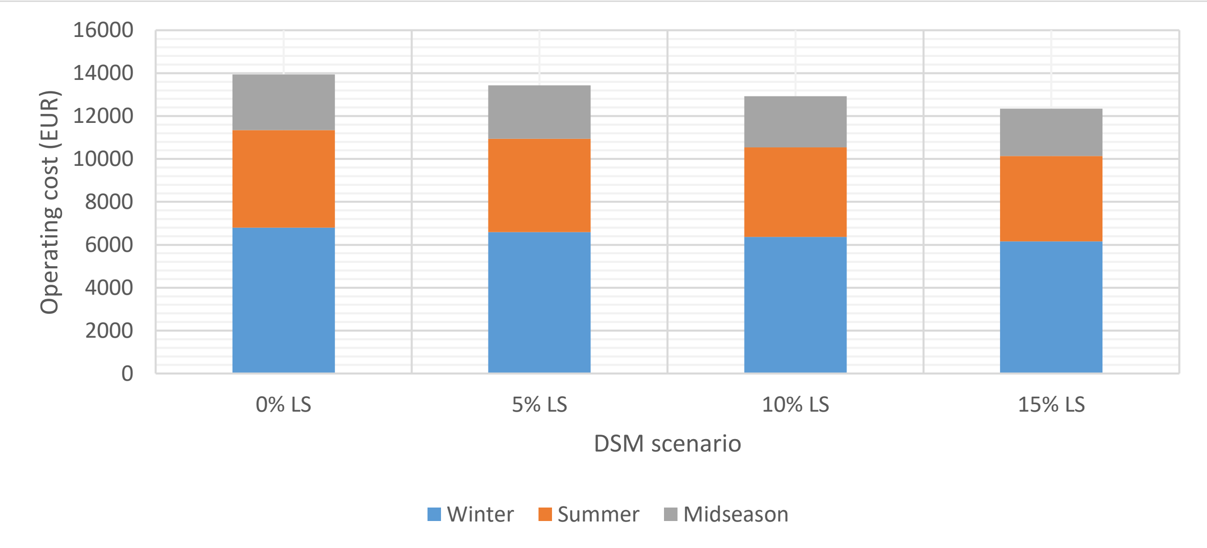

Figure 9: Impact of the applied DSM-based scenarios on the seasonal and annual operating cost for the pilot in Cyprus.

5 Greece

For the pilot in Greece (UOWM dormitories), the PV capacity and BESS size are 12 kWp and 11 kWh, respectively. The variation of netload power during winter, summer, and midseason is shown in terms of three averaged weeks (one per season) for the pilot in Greece in Figure 10. By observation, load shifting is more favourable during summer and midseason, since during these seasons there are frequent time periods that PV generation exceeds consumption.

This means that there is some potential for reducing grid exports to the central power grid through load shifting. On the other hand, there are no time periods with negative netload power, which means that there are already no power exports during winter. In this case, the objective could be to reduce peak consumption and make consumption more aligned to PV generation.

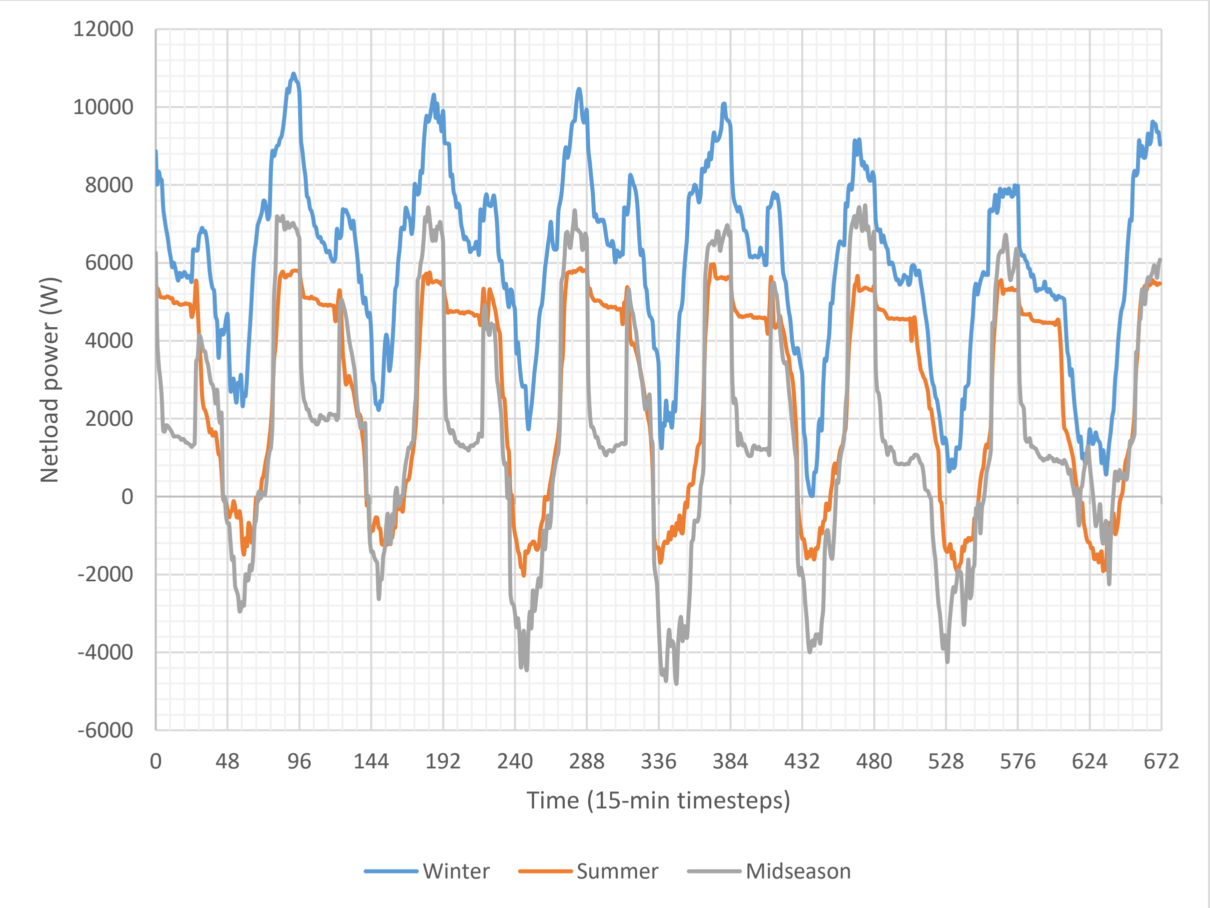

Figure 10: Variation of netload power during winter, summer, and midseason shown in terms of three averaged weeks (one per season) for the pilot in Greece.

5.1 Application of the DSM-based scenarios

The considered DSM-based scenarios are applied through 5%, 10%, and 15% peak shaving and valley filling load shifting actions, as shown in Figure 11, Figure 12, and Figure 13, for winter, summer, and midseason, respectively. During winter, the potential for load shifting is marginal, since the netload cannot be modified much above a 10% load shifting (therefore the 15% load shifting shown in Figure 11 would be unrealistic).

Nevertheless, load shifting can allow the netload power to become much more even than before the application of the DSM-based scenarios. This is clearly shown by the reduction of the difference between peak and minimum netload power values (e.g., ~11 kW and ~3 kW with 0% and 5% load shifting, respectively). During summer and midseason, load shifting is more influential to the operation of the nanogrid, because the negative netload power occurrences clearly suggest that there can be some improvement through the load shifting actions of the DSM-based scenarios.

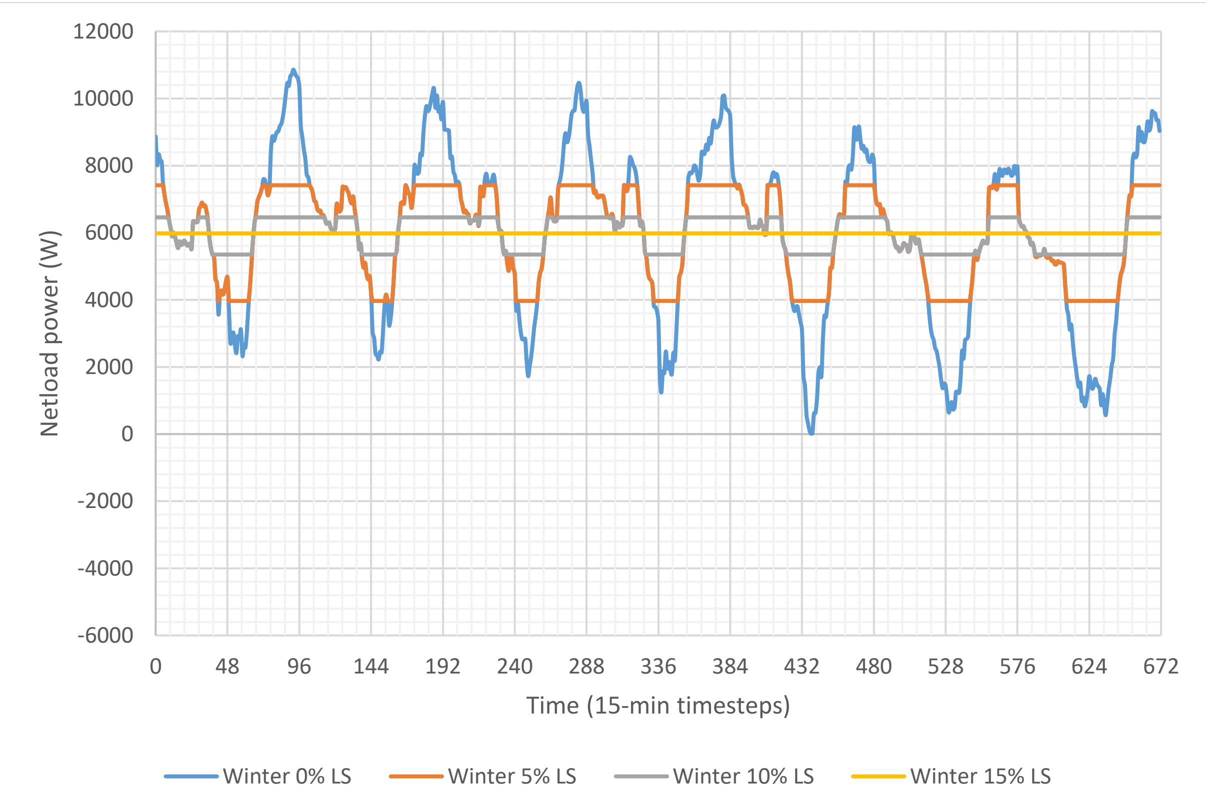

Figure 11: Variation of netload power during winter for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Greece.

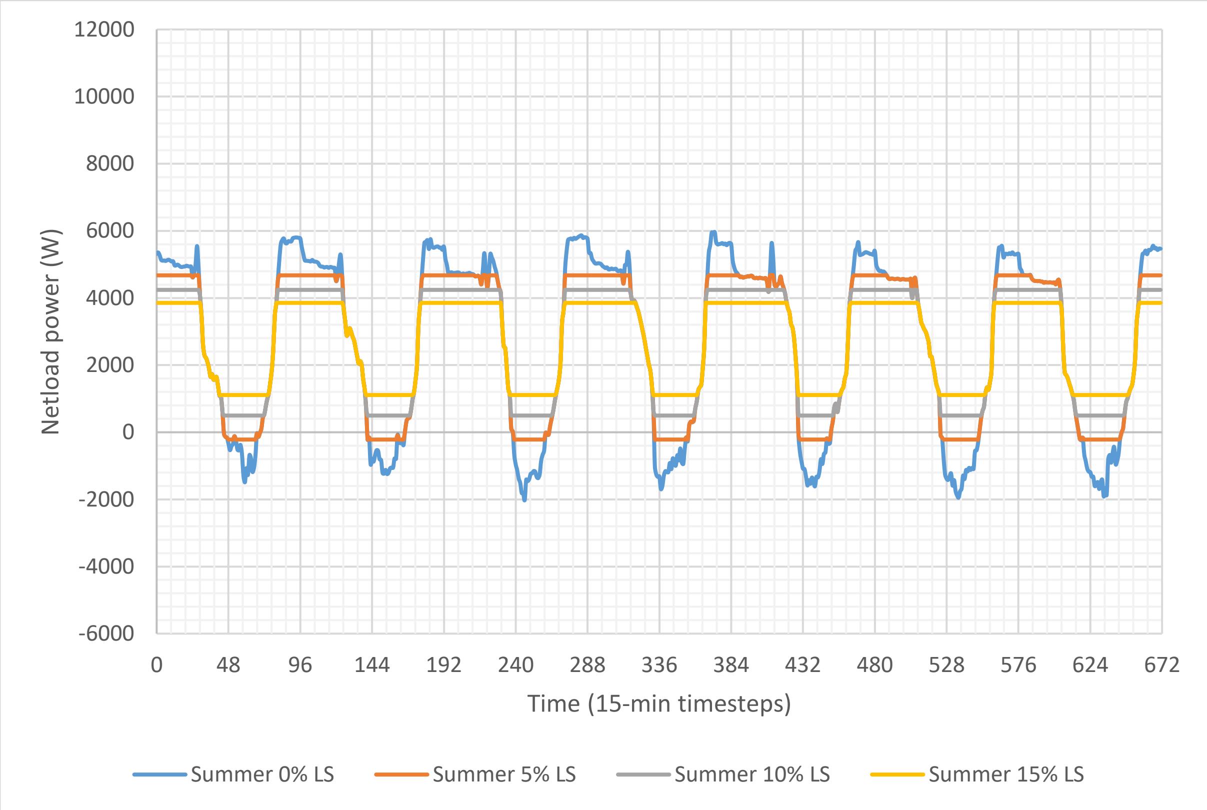

Figure 12: Variation of netload power during summer for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Greece.

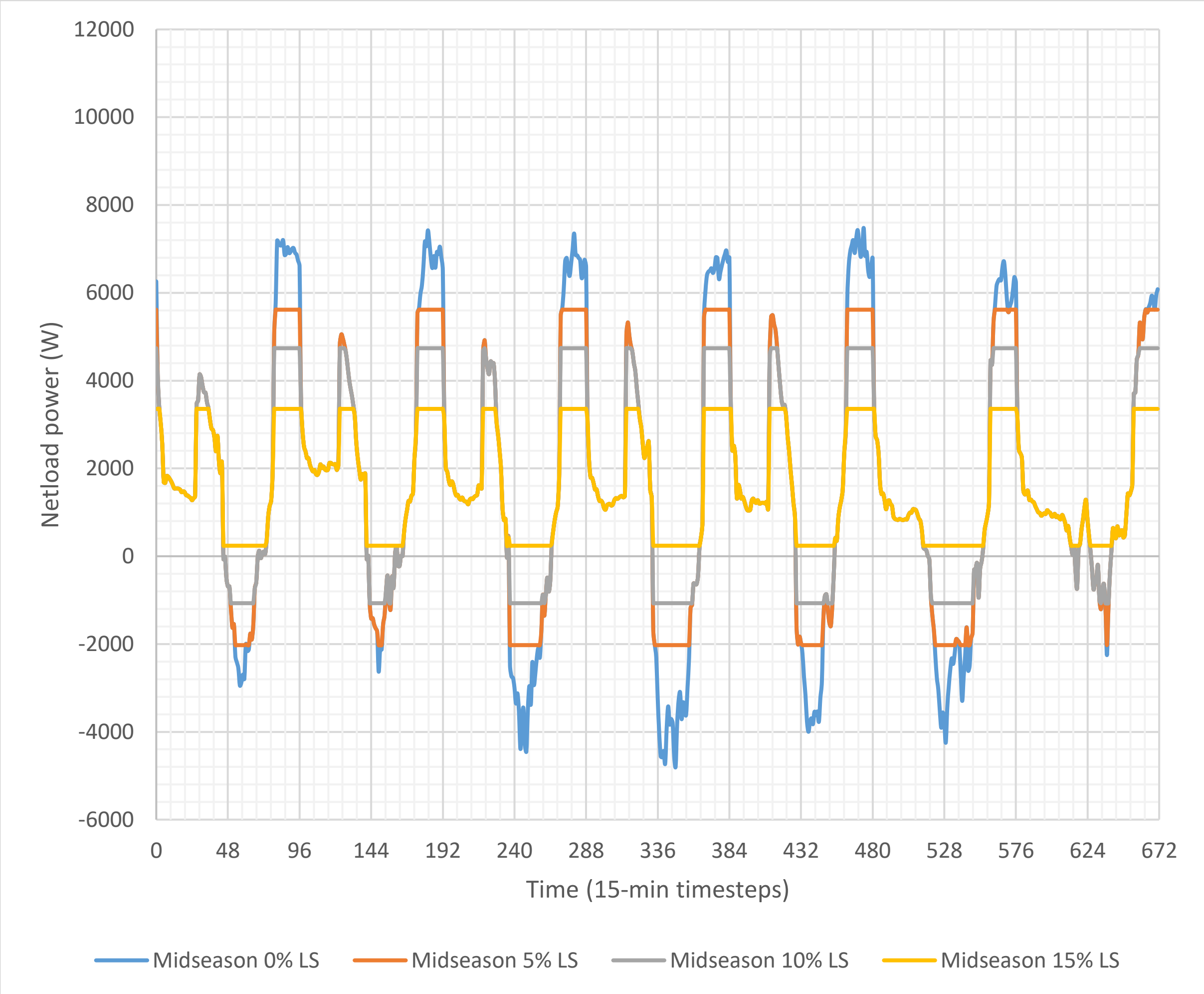

Figure 13: Variation of netload power during midseason for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Greece.

5.2 Impact of the DSM scenarios on self-consumption and self-sufficiency rates

The impact of the applied DSM-based scenarios on the self-consumption rate is shown in Figure 14. During winter, self-consumption is already 100% before the application of the DSM-based scenarios, which suggests that all PV generated electricity is already utilized in the buildings, without any exports to the central power grid.

During summer, with DSM actions, the export is strongly reduced (5%) or completely nullified (10% and 15%). On the other hand, self-consumption is significantly improved during midseason since the load shifting actions manage to reduce, and eventually eliminate, the need for power exports to the central power grid.

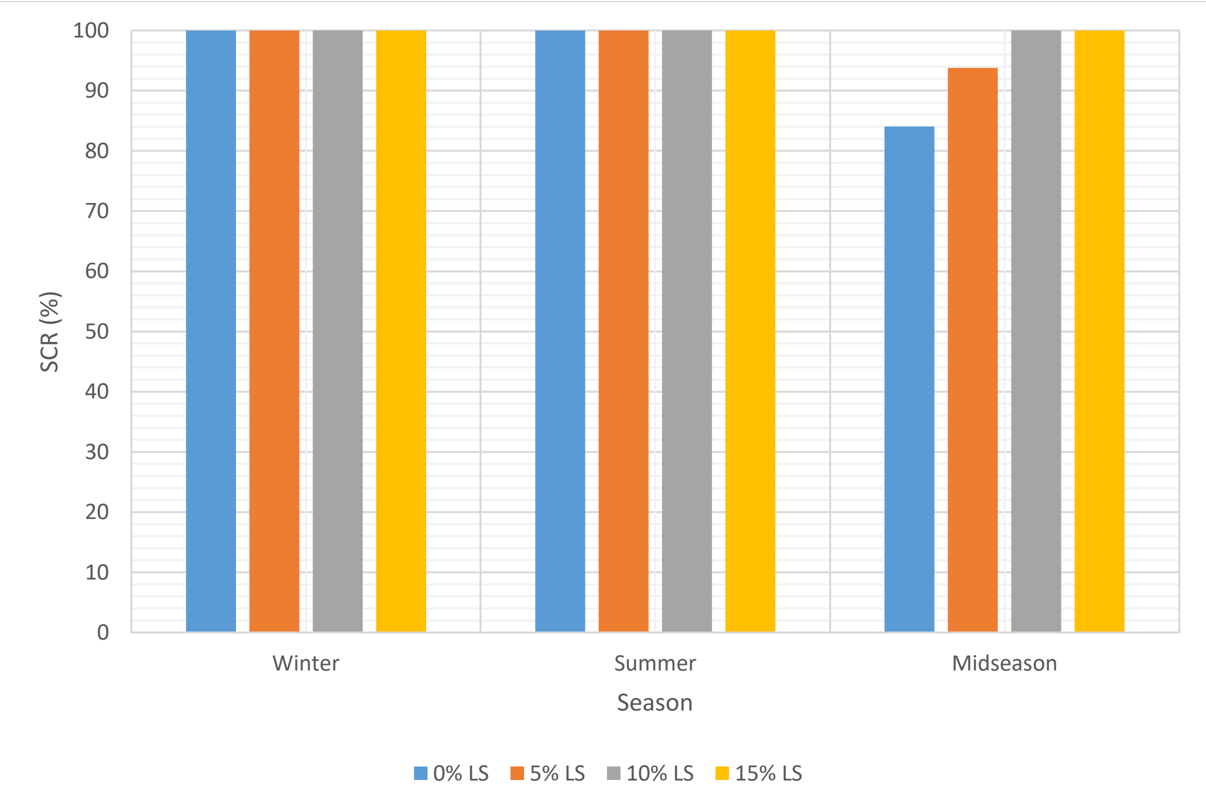

Figure 14: Variation of self-consumption rate during winter, summer, and midseason for 0%, 5%, 10%, and 15% load shifting for the pilot in Greece.

The impact of the applied DSM-based scenarios on the self-sufficiency rate is shown in Figure 15. The trends are analogous to the trends shown for the self-consumption ratio, i.e., load shifting does not affect the self-sufficiency ratio during summer and winter, while during midseason, the self-sufficiency rate improves from an initial value of 42% to 50% with a 10% load shifting.

This is due to the fact that the power that was previously exported to the central power is now fully utilized within the system. Overall, the low self-sufficiency rate values for all seasons, clearly suggests that there is a lot of room to increase the PV capacity of the system in the future.

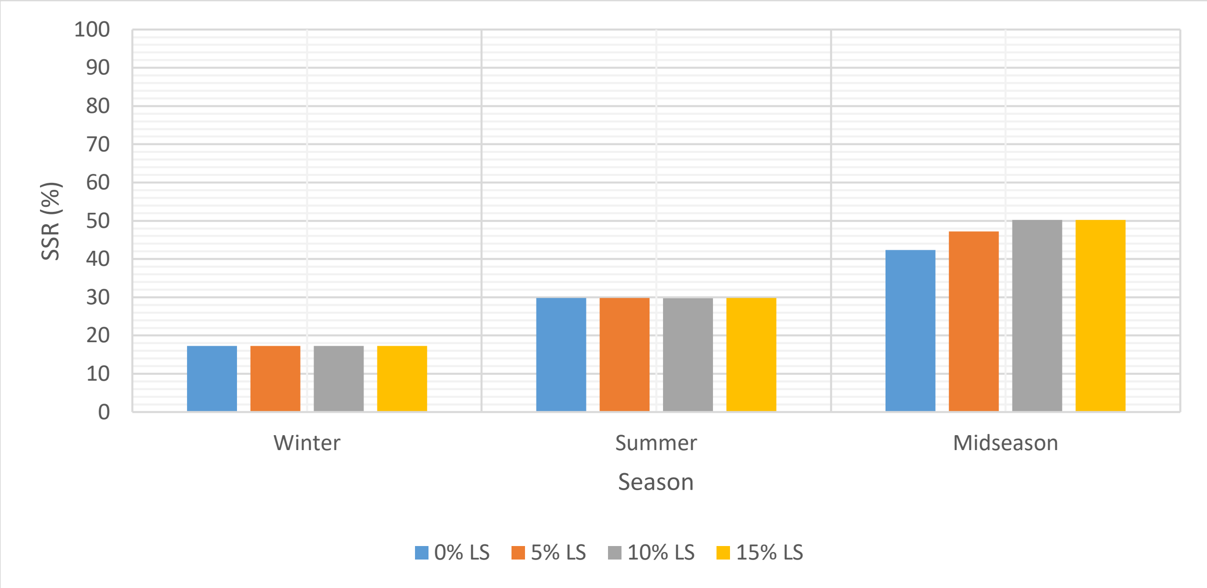

Figure 15: Variation of self-sufficiency rate during winter, summer, and midseason for 0%, 5%, 10%, and 15% load shifting for the pilot in Greece.

5.3 Impact of the DSM scenarios on operating cost

The resulting timetable for the ToU tariffs is given in Table 2, while the resulting operating costs before and after the application of the DSM-based scenarios are given in Figure 16. By observation, the applied DSM-based scenarios manage to significantly reduce the operating cost. Specifically, a 5%, 10%, and 15% load shifting, leads to a cost reduction of 3.2%, 5.9%, and 8.7%, respectively. In terms of actual values, the total annual operating cost is 12158 EUR and 11101 EUR with 0% load shifting and 15% load shifting, respectively.

Table 2: Timetable of the ToU block periods for the pilot in Greece.

Block	Price (€/kWh)	Winter	Summer	Midseason
		Weekdays		
On-peak	0.380	19:15-01:14	20:15-07:29	19:45-00:29
Shoulder	0.257	01:15-12:14, 15:45-19:14	07:30-11:14, 17:30-20:14	00:30-11:14, 17:45-19:44
Off-peak	0.186	12:15-15:44	11:15-17:29	11:15-17:44
		Weekends		
On-peak	0.380	19:15-23:59	20:15-07:14	20:15-00:14
Shoulder	0.257	00:00-08:14, 17:00-19:14	07:15-10:14, 17:15-20:14	00:15-12:44, 16:00-20:14
Off-peak	0.186	08:15-16:59	10:15-17:14	12:45-15:59

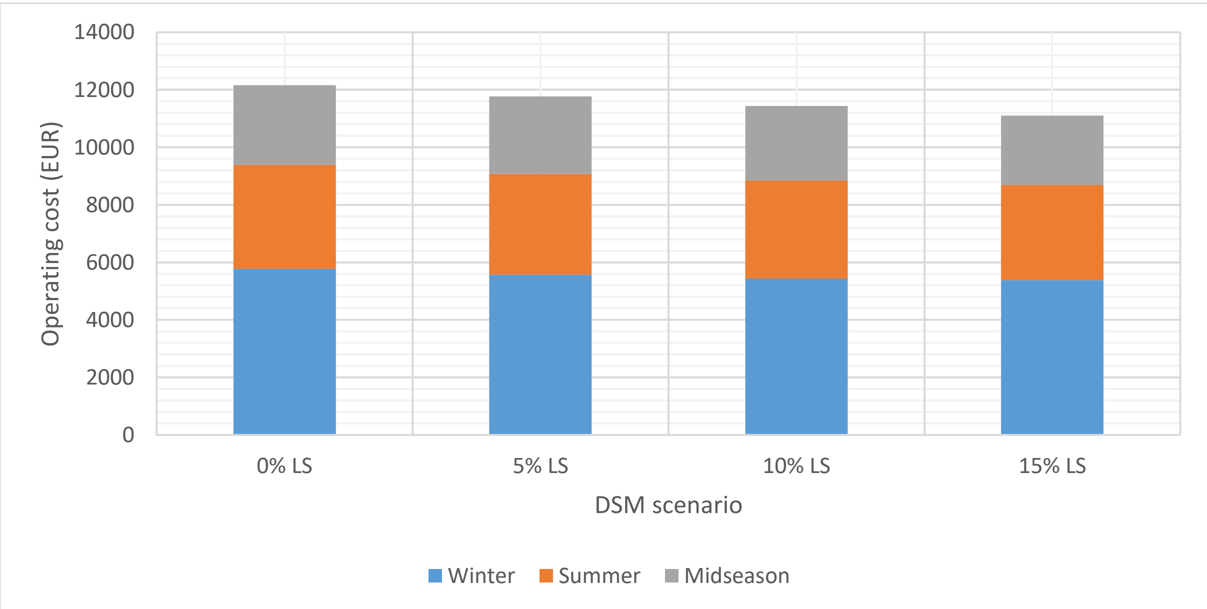

Figure 16: Impact of the applied DSM-based scenarios on the seasonal and annual operating cost for the pilot in Greece.

6 Israel

For the pilot in Israel[7] (Eilat school), the PV capacity and BESS size are 210 kWp and 470 kWh, respectively. The variation of netload power during winter, summer, and midseason is shown in terms of three averaged weeks (one per season) for the pilot in Israel in Figure 17.

By observation, the frequent occurrences of high negative netload power values clearly suggests that there is a lot of room for application of DSM-based scenarios combining peak shaving and valley filling load shifting actions. Variation between the three seasons is almost identical (especially summer and midseason), which clearly suggests that there is no need to integrate seasonal storage in the future.

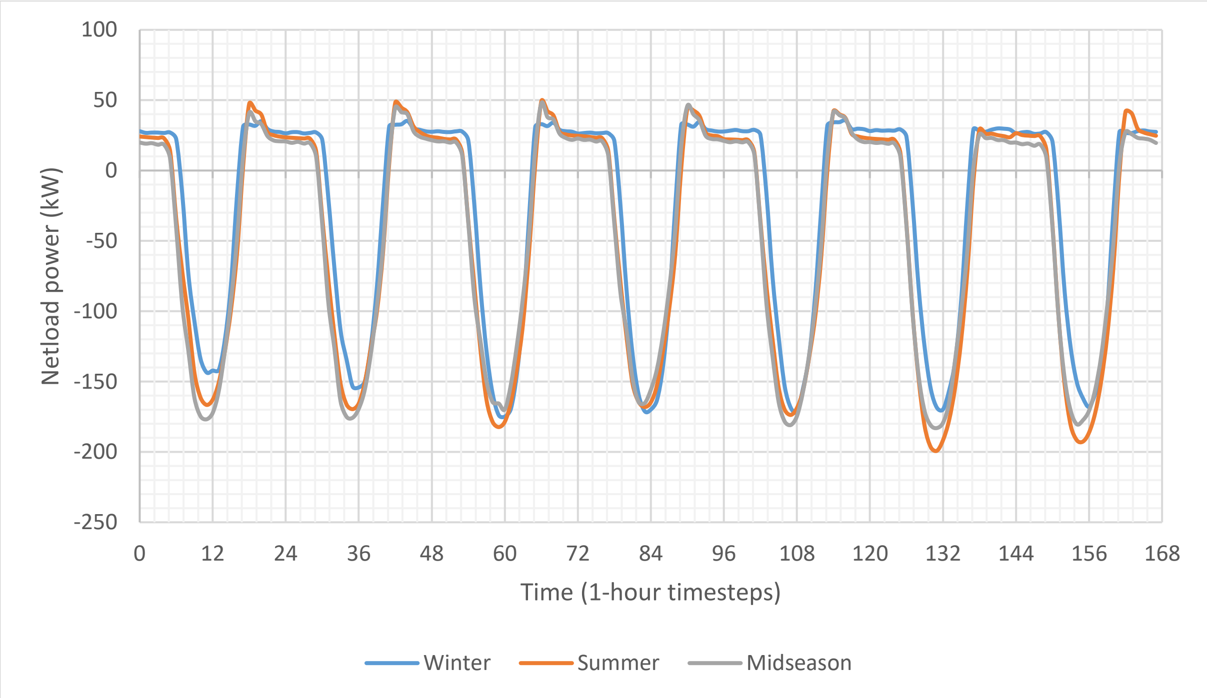

Figure 17: Variation of netload power during winter, summer, and midseason shown in terms of three averaged weeks (one per season) for the pilot in Israel.

[7] In Israel, for the purposes of the BERLIN project, two pilots have been developed in schools in Eilat and Eilot. The two pilots are very similar in most aspects, namely PV generation (210 kWp and 250 kWp, for Eilat and Eilot, respectively) and BESS size (470 kWh and 375 kWh, for Eilat and Eilot, respectively); the pattern of consumption is also identical. The main differences are identified in the type of the installed PV panels; the pilot in Eilat includes a combination of standard and flexible panels, while the pilot in Eilot includes only bifacial panels. Additionally, the pilot in Eilat includes a chiller, which is controlled through a DSM scenario.

6.1 Application of the DSM-based scenarios

The considered DSM-based scenarios are applied through 5%, 10%, and 15% peak shaving and valley filling load shifting actions, as shown in Figure 18, Figure 19, and Figure 20, for winter, summer, and midseason, respectively. By observation, the most significant effect of the load shifting actions is the high reduction of negative peak values of netload (i.e., periods with very high PV generation and moderate consumption). The load shifting actions also manage to reduce the large difference between netload power peak and minimum values, which are more evident during summer and midseason.

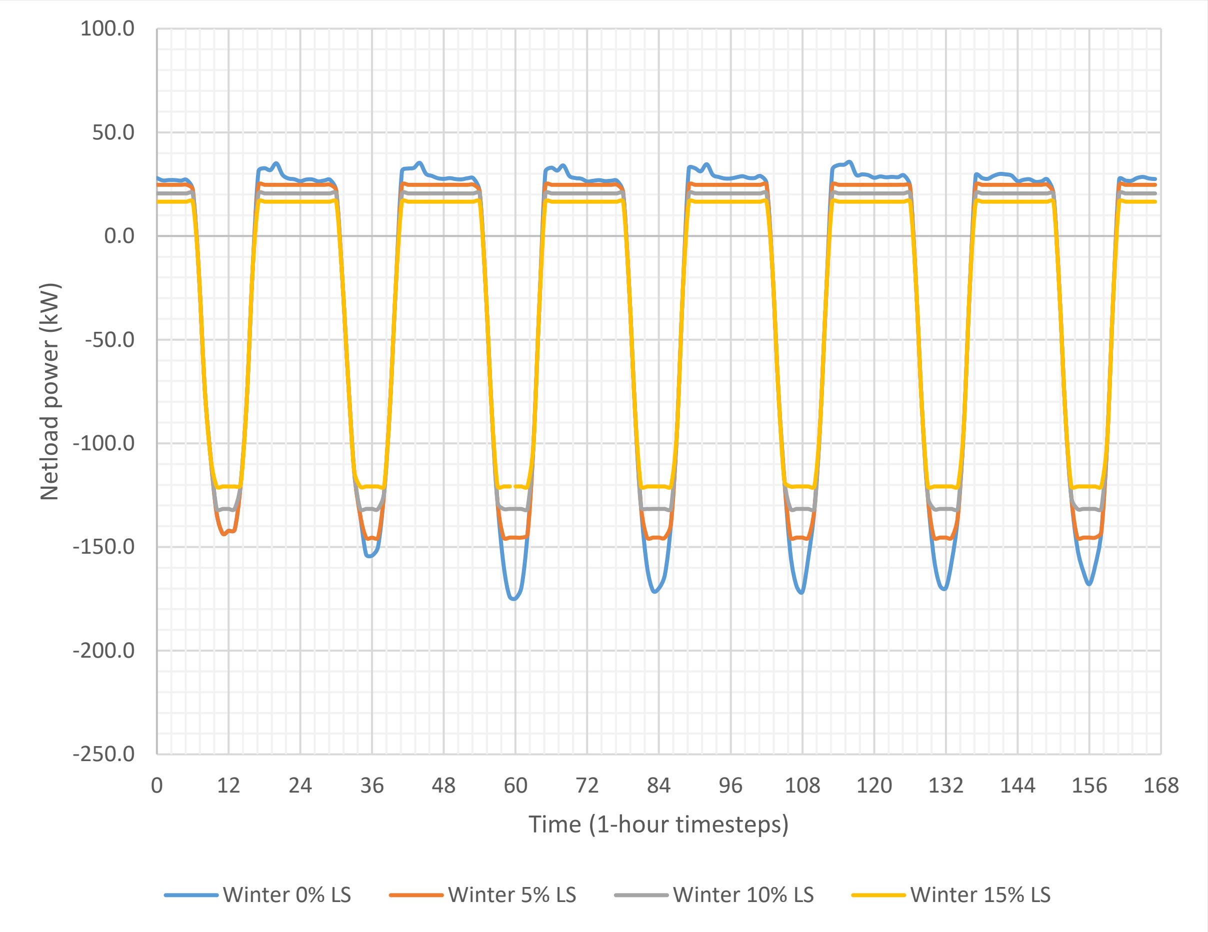

Figure 18: Variation of netload power during winter for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Israel.

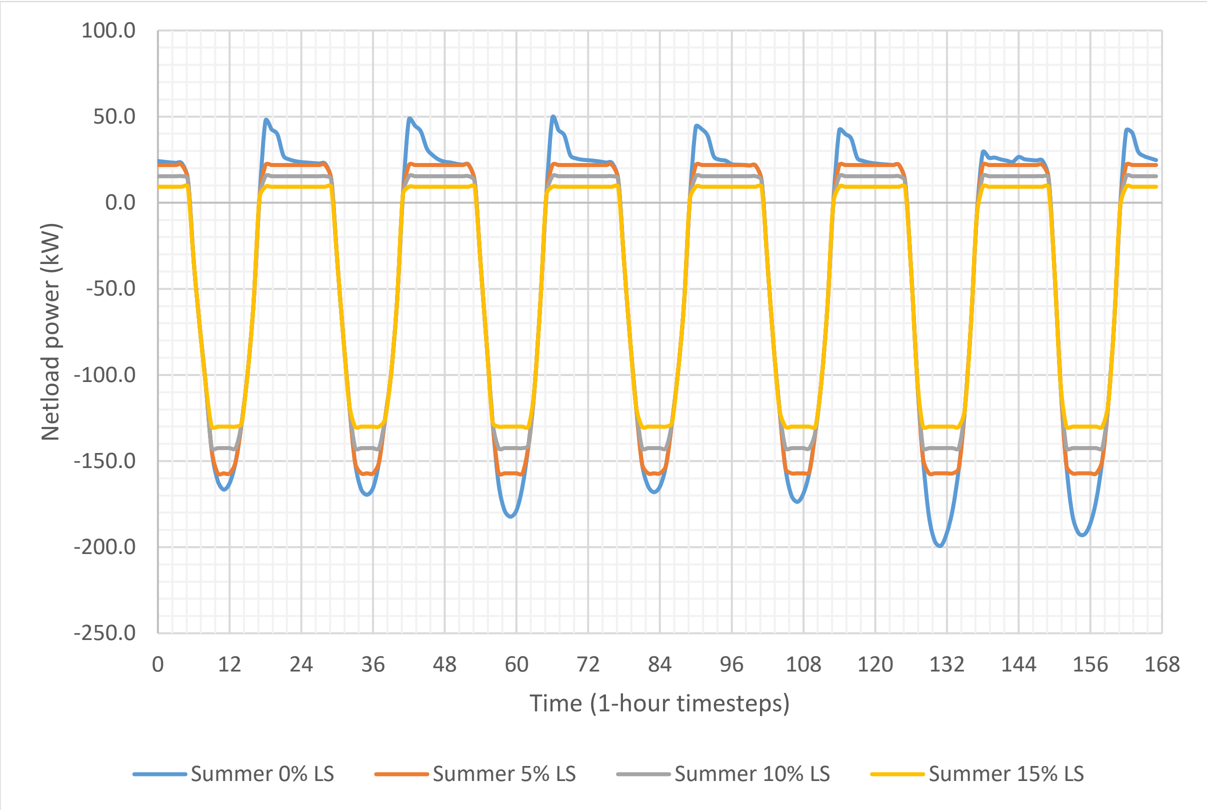

Figure 19: Variation of netload power during summer for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Israel.

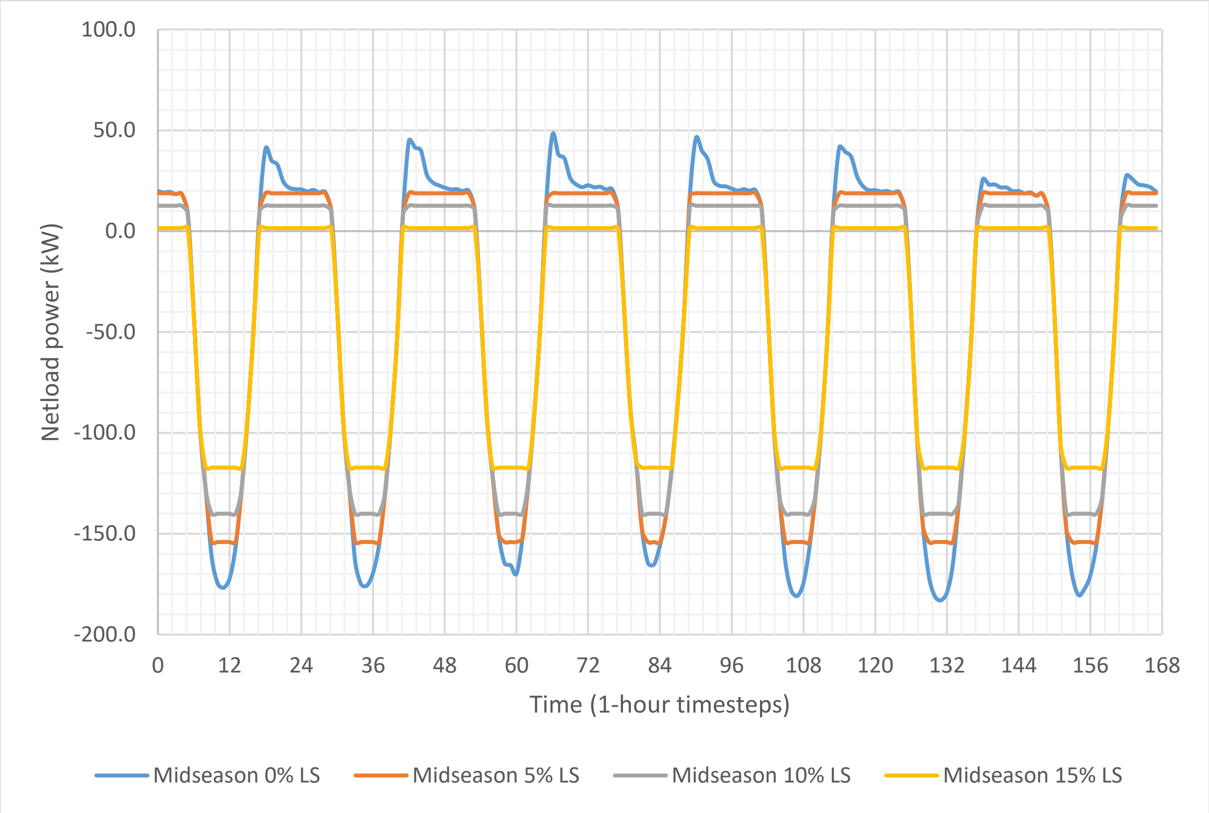

Figure 20: Variation of netload power during midseason for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Israel.

6.2 Impact of the DSM scenarios on self-consumption and self-sufficiency rates

The impact of the applied DSM-based scenarios on the self-consumption rate is shown in Figure 21. For all seasons, there is some marginal increase of the self-consumption rate through the application of the DSM-based scenarios. This is due to the fact that PV generation exceeds consumption by far, as already noted from the pattern of the netload.

Therefore, the need to export PV generated electricity to the grid cannot be significantly reduced by the DSM-based scenarios. On the other hand, this suggests that the existing system capacity could satisfy a much larger load profile.

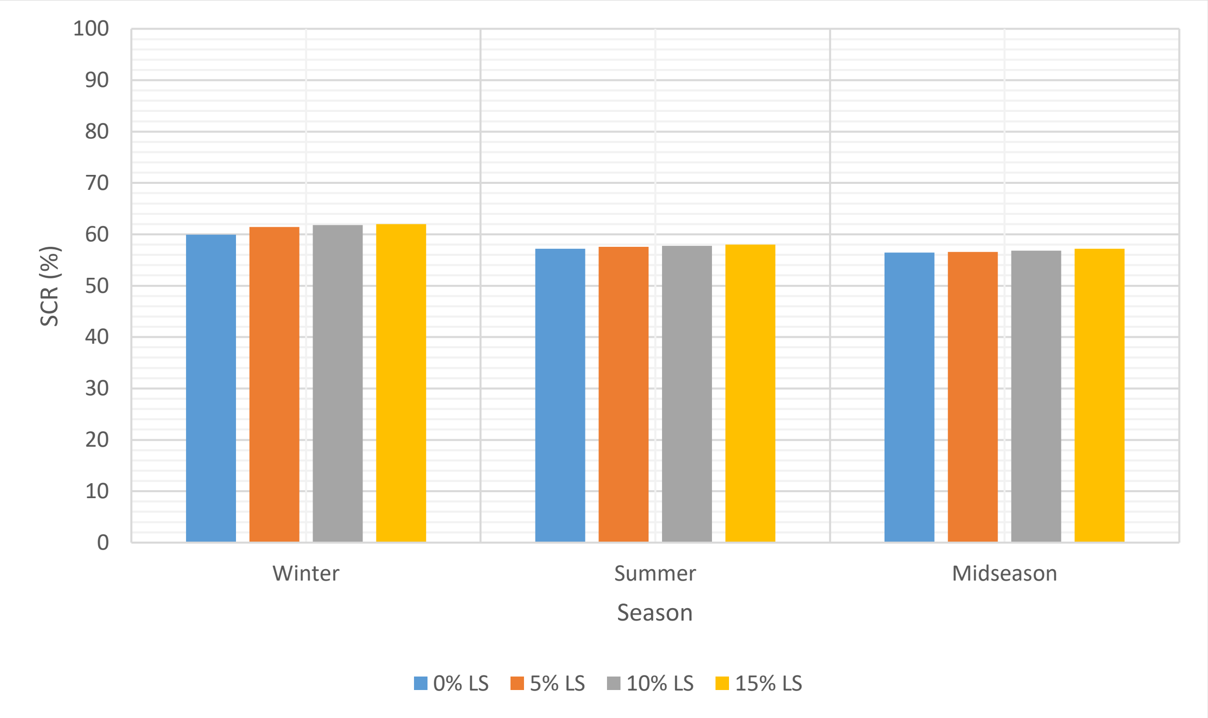

Figure 21: Variation of self-consumption rate during winter, summer, and midseason for 0%, 5%, 10%, and 15% load shifting for the pilot in Israel.

The impact of the applied DSM-based scenarios on the self-sufficiency rate is shown in Figure 22. Before the application of the DSM-based scenarios, the self-sufficiency rate is already very close to 100% during winter (application of just 5% load shifting manages to reach 100% self-sufficiency), and 100% during summer and midseason. This is clearly due to the fact that the PV and BESS capacities are already quite high in relation to the consumption load profile, leaving very little potential for any further improvement.

It is noted that BESS is part of the DSM actions to facilitate the load shifting, as it is used to store PV overgeneration and to supply the night demand. Therefore, other ways to increase consumption should be explored, such as EV charging, etc.

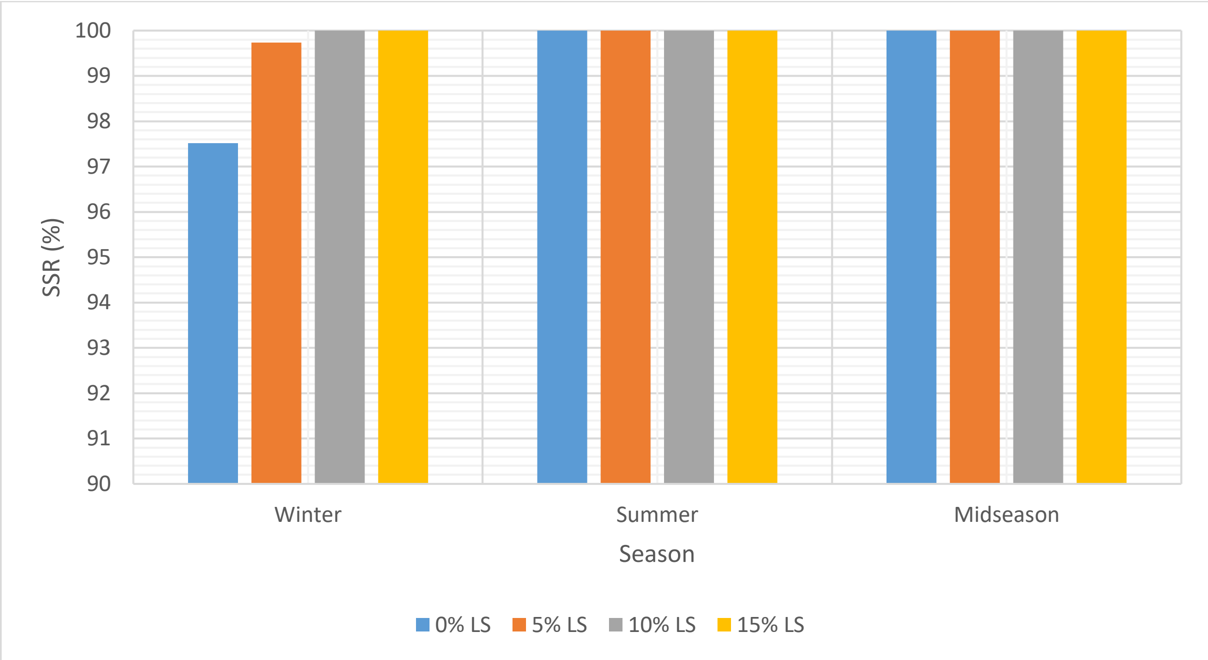

Figure 22: Variation of self-sufficiency rate during winter, summer, and midseason for 0%, 5%, 10%, and 15% load shifting for the pilot in Israel.

6.3 Impact of the DSM scenarios on operating cost

The resulting timetable for the ToU tariffs is given in Table 3, while the resulting operating costs before and after the application of the DSM-based scenarios are given in Figure 23. The applied scenarios have a significant impact on the operating cost. Specifically, a 5%, 10%, and 15% load shifting, leads to a cost reduction of 4%, 8.1%, and 13.4%, respectively. In terms of actual values, the total annual operating cost is 67170 EUR and 58145 EUR with 0% load shifting and 15% load shifting, respectively.

Table 3: Timetable of the ToU block periods for the pilot in Israel.

Block	Price (€/kWh)	Winter	Summer	Midseason
		Weekdays		
On-peak	0.224	18:00-05:59	18:00-04:59	18:00-04:59
Shoulder	0.151	6:00-6:59, 17:00-17:59	05:00-05:59, 17:00-17:59	05:00-05:59, 17:00-17:59
Off-peak	0.110	07:00-16:59	06:00-16:59	06:00-16:59
		Weekends		
On-peak	0.224	18:00-05:59	18:00-04:59	18:00-04:59
Shoulder	0.151	6:00-6:59, 17:00-17:59	05:00-05:59, 17:00-17:59	05:00-05:59, 17:00-17:59
Off-peak	0.110	07:00-16:59	06:00-16:59	06:00-16:59

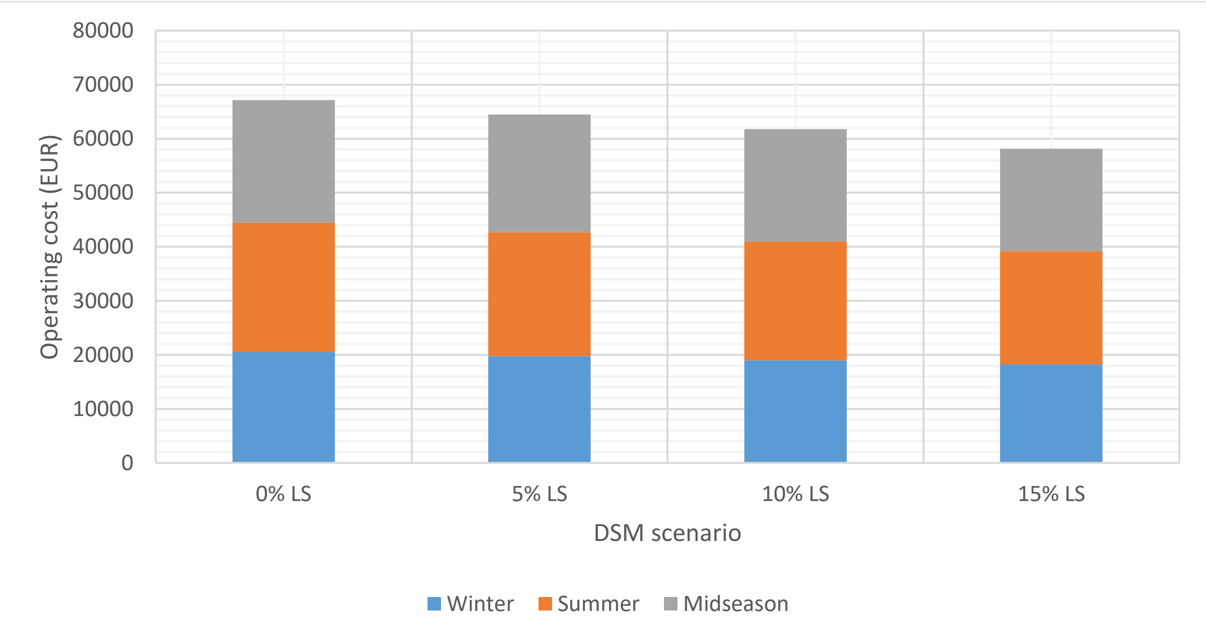

Figure 23: Impact of the applied DSM-based scenarios on the seasonal and annual operating cost for the pilot in Israel.

7 Italy

For the pilot in Italy, the PV capacity and BESS size are 40 kWp and 71 kWh, respectively. The variation of netload power during winter, summer, and midseason is shown in terms of three averaged weeks (one per season) for the pilot in Italy in Figure 24. During the weekdays in summer and midseason, the netload power pattern presents almost even negative to positive values. On the other hand, there is very low consumption during the weekend, which suggests that it will be mostly beneficial to shift some loads from the weekdays to the weekend.

Therefore, provided that there are deferrable loads that can be shifted, there can be a significant potential for improvement of the operation of the system. However, in this case, it is clear that this is only a theoretical observation because, being offices, it is almost impossible to move loads from working days to non-working days. Instead, it could be potentially useful to include a weekly storage that saves the electricity generated in the non-working days and releases it during the working days.

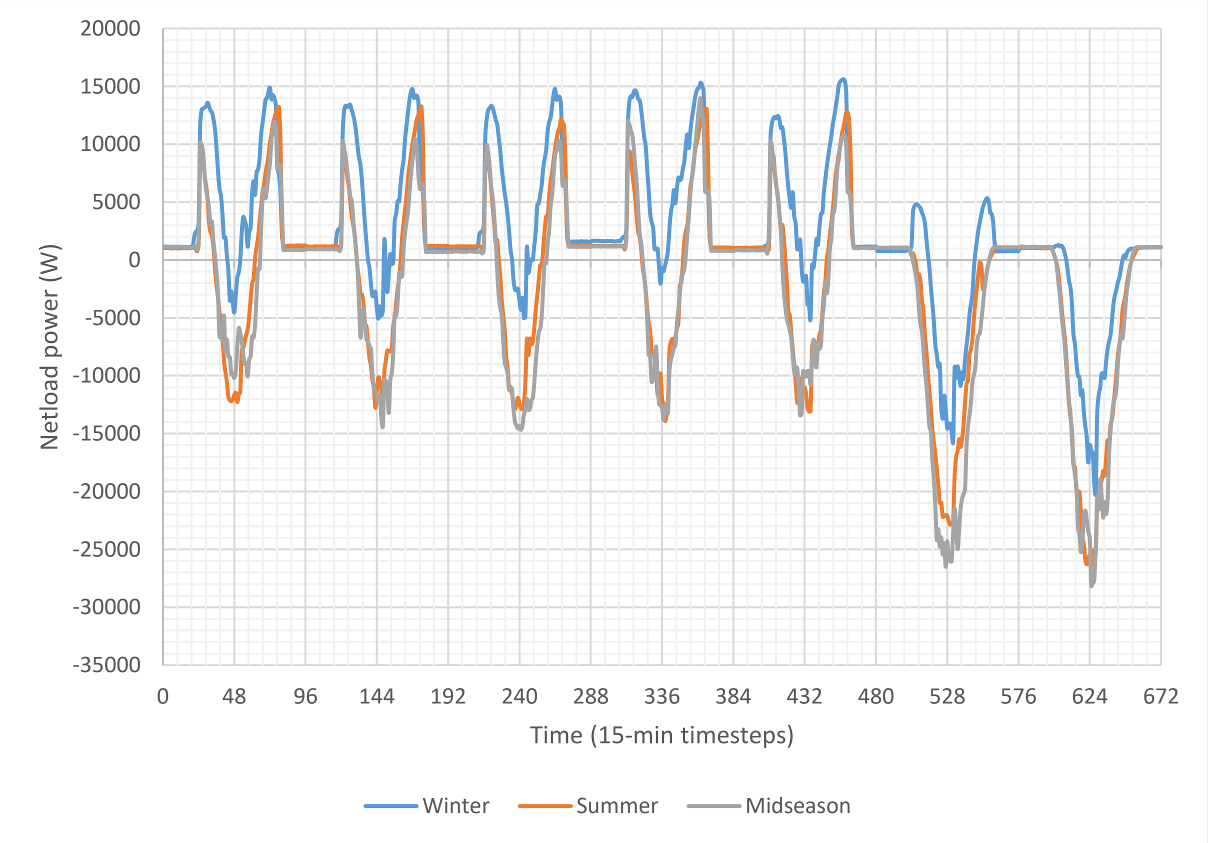

Figure 24: Variation of netload power during winter, summer, and midseason shown in terms of three averaged weeks (one per season) for the pilot in Italy.

7.1 Application of the DSM-based scenarios

The considered DSM-based scenarios are applied through 5%, 10%, and 15% peak shaving and valley filling load shifting actions, as shown in Figure 25, Figure 26, and Figure 27, for winter, summer, and midseason, respectively. In all seasons, the very low netload values during the weekends are utilized to shift the power through peak shaving of the weekdays and shift it to the weekends through valley filling.

As the load shifting percentage increases, load shifting through valley filling during time periods of weekdays presenting low netload values also takes place. During winter, load shifting appears less effective for values above 10% due to the limited availability of negative netload values. During summer and midseason, load shifting has more potential since it is still influential with 15% load shifting.

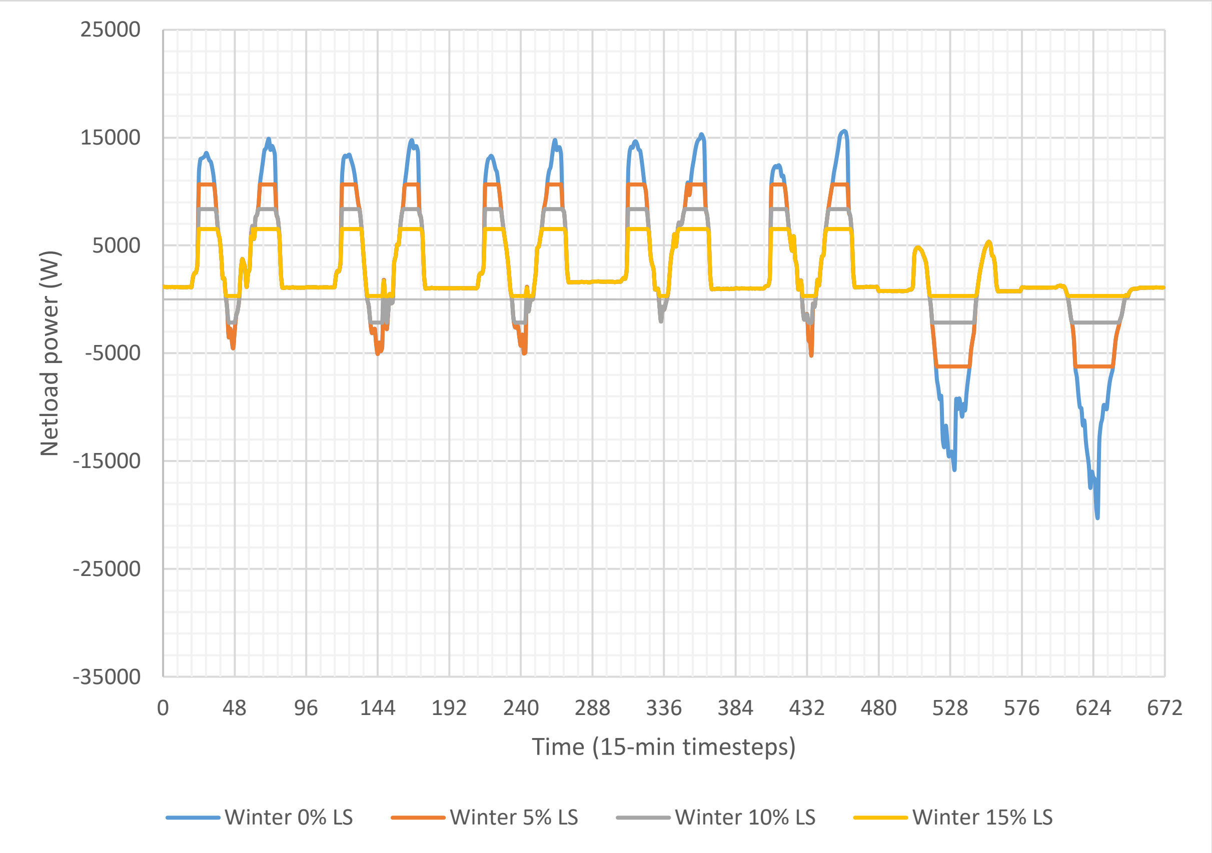

Figure 25: Variation of netload power during winter for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Italy.

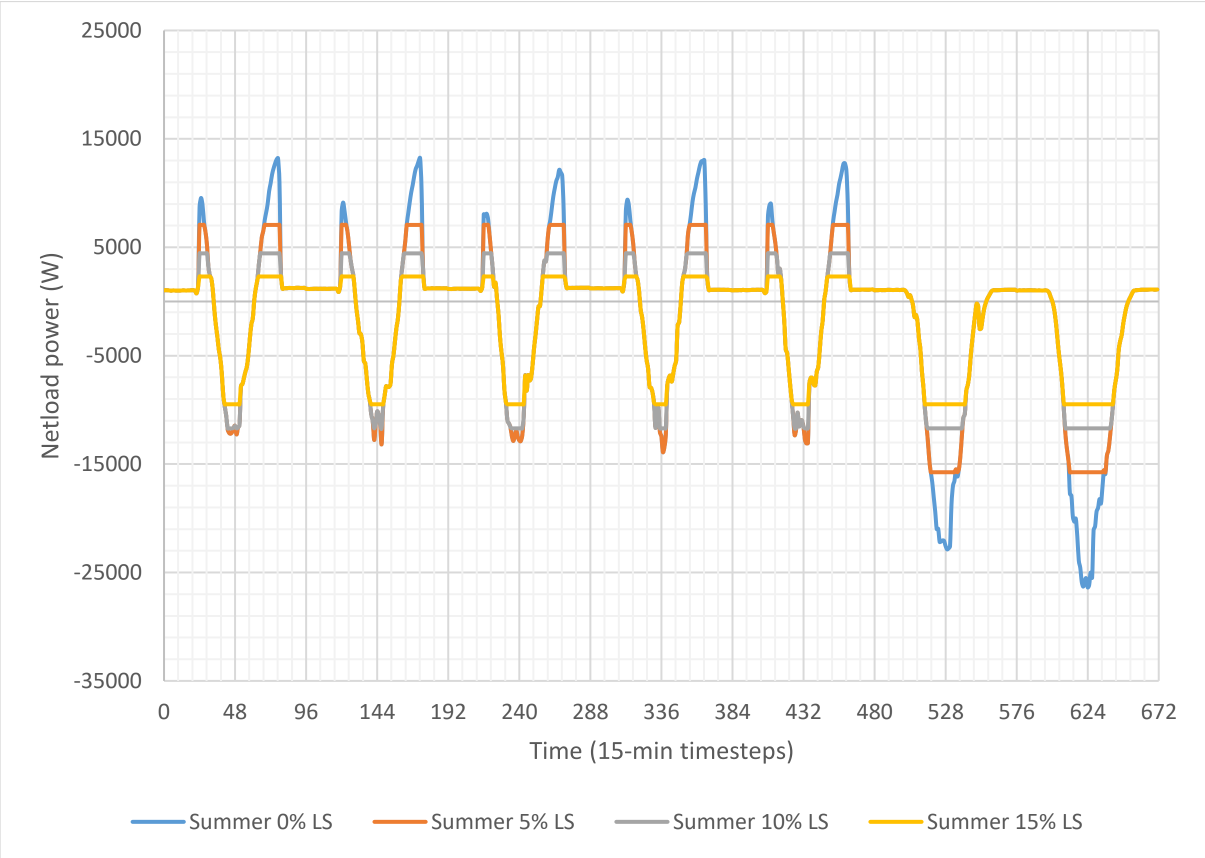

Figure 26: Variation of netload power during summer for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Italy.

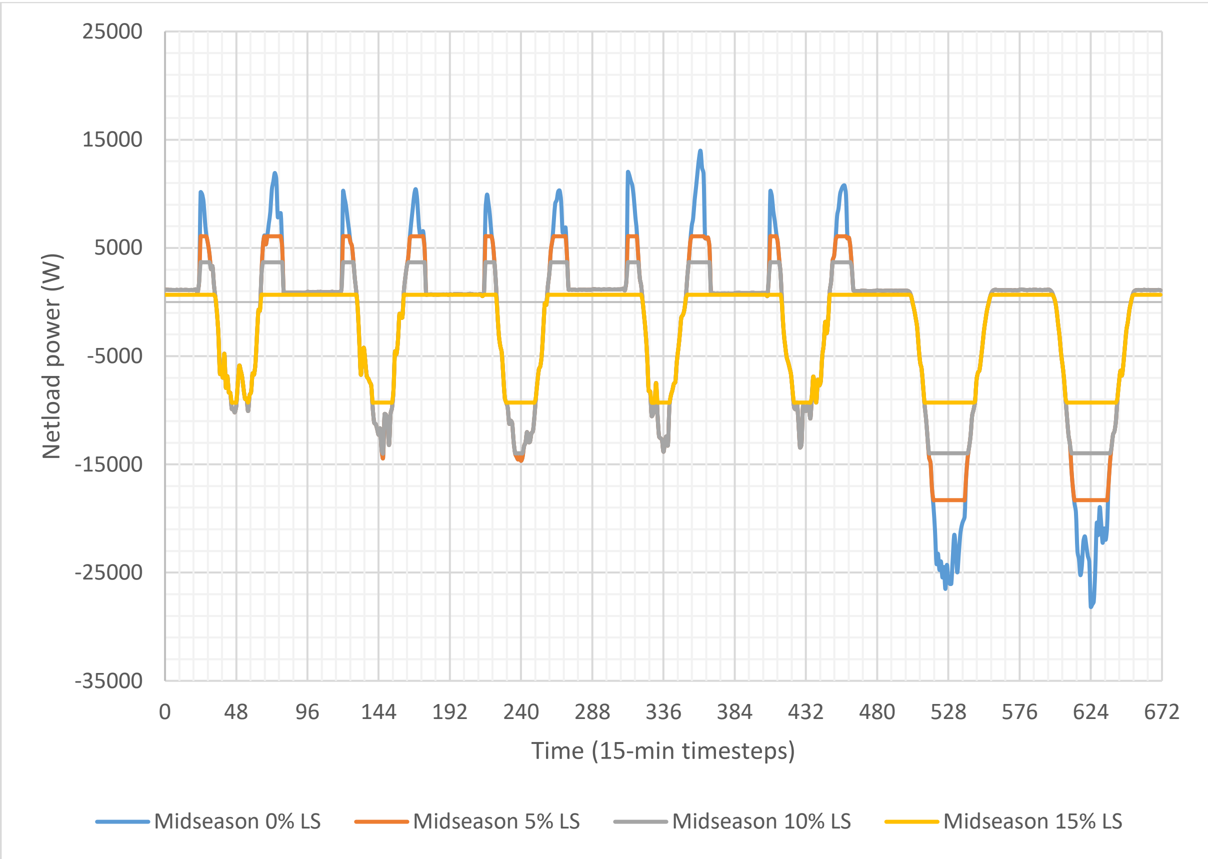

Figure 27: Variation of netload power during midseason for 0%, 5%, 10%, and 15% load shifting (simultaneous peak shaving and valley filling) for the pilot in Italy.

7.2 Impact of the DSM scenarios on self-consumption and self-sufficiency rates

The impact of the applied DSM-based scenarios on the self-consumption rate is shown in Figure 28. Generally, during winter, the applied DSM-based scenarios provide a positive effect on the self-consumption rate. Specifically, negative netload (i.e., grid export) is avoided when load shifting is 15%. This is due to the fact that power exports to the central power grid are reduced through the load shifting actions.

The effect of load shifting is marginal for the summer and does not affect the midseason, which suggests that there were already very limited power exports to the central grid during these seasons. Although negative netload is always present, the effect of load shifting is evident, particularly during weekends, where peak export (negative netload) is reduced from more than 25 kW (no load shifting) to 7 kW (with 15% load shifting).

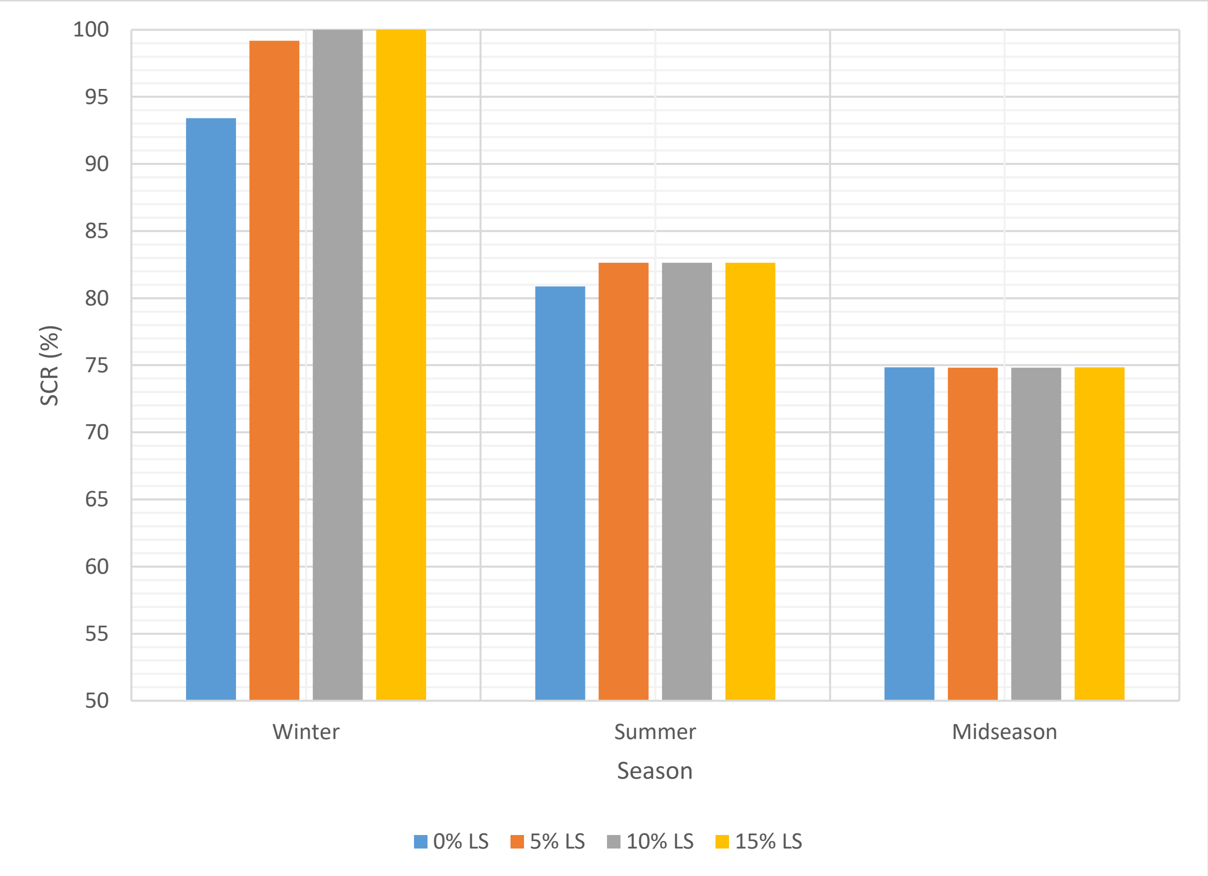

Figure 28: Variation of self-consumption rate during winter, summer, and midseason for 0%, 5%, 10%, and 15% load shifting for the pilot in Italy.

The impact of the applied DSM-based scenarios on the self-sufficiency rate is shown in Figure 29. The increase of self-sufficiency through the load shifting actions is more effective during winter, since the power exports to the central power grid are significantly reduced as load shifting rates increase. Specifically, the self-sufficiency increases from an initial value of 61% to 68% with a 10% load shifting.

For summer and midseason, self-sufficiency is already close to 100%, and therefore load shifting has very little or no effect, respectively. This is due to the fact that total PV generation is significantly higher than total consumption. The uneven pattern between winter and summer/midseason could be smoothened with the integration of seasonal storage to transfer power generation from summer/midseason to winter. Otherwise, other consumption options should be explored, such as valley filling through EV charging, etc.

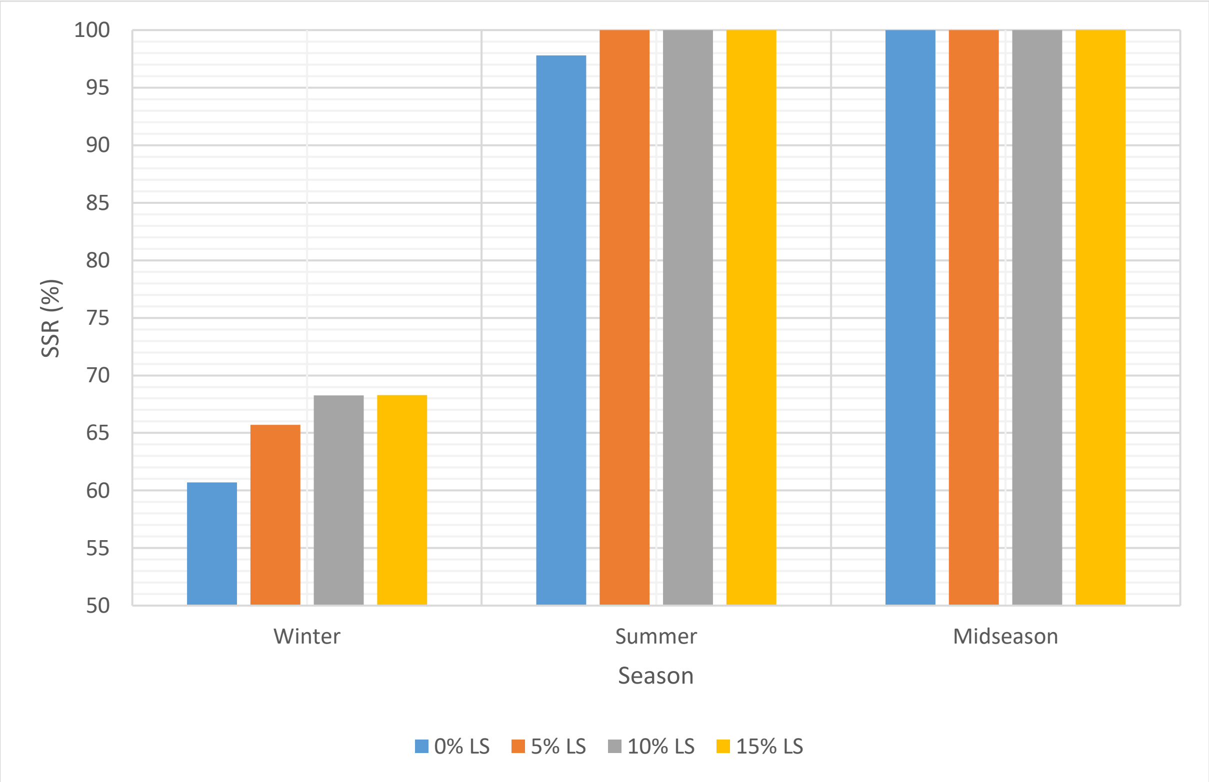

Figure 29: Variation of self-sufficiency rate during winter, summer, and midseason for 0%, 5%, 10%, and 15% load shifting for the pilot in Italy.

7.3 Impact of the DSM scenarios on operating cost

The resulting timetable for the ToU tariffs is given in Table 4, while the resulting operating costs before and after the application of the DSM-based scenarios are given in Figure 30. Specifically, a 5%, 10%, and 15% load shifting, leads to a cost reduction of 3.3%, 6.6%, and 10.8%, respectively. In terms of actual values, the total annual operating cost is 49087 EUR and 43769 EUR with 0% load shifting and 15% load shifting, respectively.

Table 4: Timetable of the ToU block periods for the pilot in Italy.

Block	Price (€/kWh)	Winter	Summer	Midseason
Weekdays				
On-peak	1.063	14:00-09:59	16:00-07:59	17:15-07:59
Shoulder	0.718	10:00-10:59, 13:00-13:59	08:00-08:59, 15:00-15:59	08:00-08:59, 16:15-17:14
Off-peak	0.521	11:00-12:59	09:00-14:59	09:00-16:14
Weekends				
On-peak	1.063	17:00-07:59	18:00-05:14	19:30-05:44
Shoulder	0.718	08:00-08:59 16:00-16:59	05:15-06:14, 17:00-17:59	05:45-06:44, 18:30-19:29
Off-peak	0.521	09:00-15:59	06:15-16:59	06:45-18:29

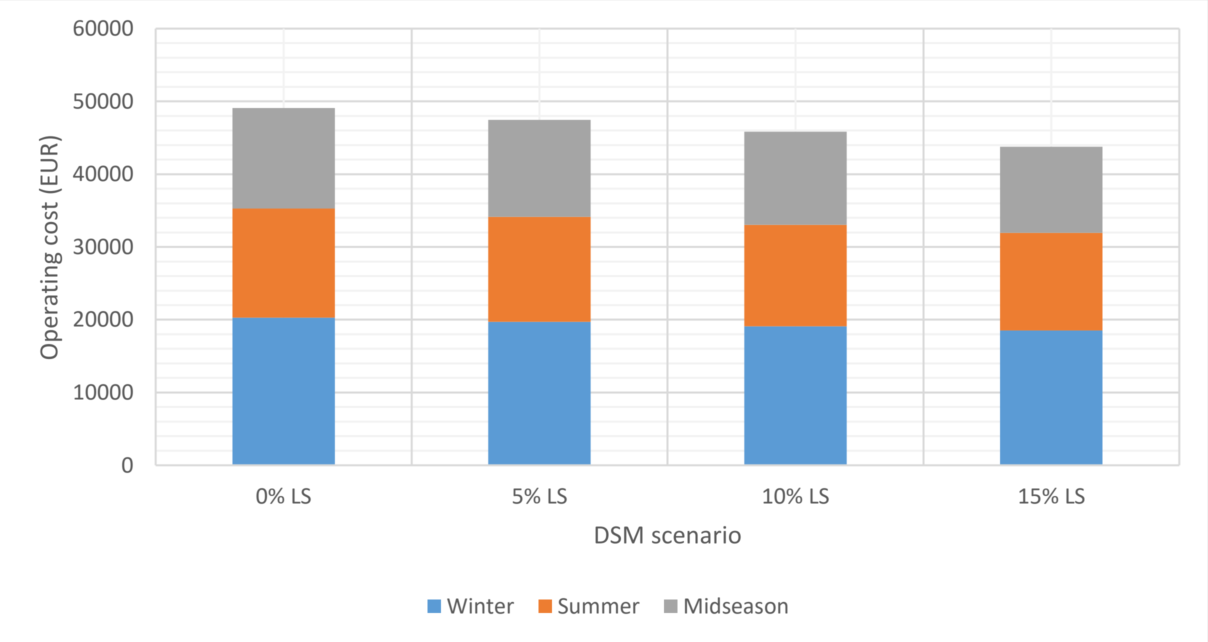

Figure 30: Impact of the applied DSM-based scenarios on the seasonal and annual operating cost for the pilot in Italy.

8 Conclusions

This study considers the development of DSM-based scenarios, which include simultaneous peak shaving and valley filling load shifting actions in combination with relevant new ToU tariffs. Such load shifting actions also manage to reduce the large difference between netload power peak and minimum values. The result of these aforementioned actions is the potential of significantly reducing operating costs. This can be achieved by effectively motivating users to modify their consumption behaviour at specific time periods. Specifically, it is desired to simultaneously reduce consumption during time periods with high netload values and increase consumption during time periods with low netload values. Additionally, in some cases the adopted scenarios manage to increase self-consumption and self-sufficiency rates, which in turn, reduce the interaction of the nanogrid systems with the central power grid. This is highly beneficial because it allows for fewer imports and/or exports. It is particularly effective during winter when there are occurrences of negative netload power, which means that in these cases power needs to be exported to the central power grid. A reduced interaction with the central power grid is also beneficial for the network itself and the central power stations because congestion and power peak demand can be eliminated, respectively.

Another important outcome of this study is the fact that shifting loads from day to night is generally not desirable for the BERLIN pilots, because netload is positive during nighttime, and vice-versa. Here, it must be stressed that the BERLIN pilots cannot always shift their loads towards nighttime, because they are public buildings and are operated during working hours. In more conventional system configurations, with all or most of the electrical power supplied from a central power station, off-peak rates are set for the night hours, since the purpose is to increase consumption at night and decrease consumption at daytime. However, in a PV-BESS nanogrid, on-peak rates can be set at times with positive netload power, which are mostly during late afternoon to early morning hours (i.e., night hours). Moreover, considering the unique nature of the nanogrid system, this is done to avoid increasing the netload during nighttime, where the system operates primarily by discharging power from the BESS. In turn, this ensures that the BESS will not be depleted, or at least to minimize interaction with the central power grid (i.e., to reduce grid power imports). In conclusion, provided realistic deferrable loads exist, the most effective load shifting action is to shift loads from weekday nighttime hours to weekend daytime hours.

In most cases, during summer and midseason, PV generation is significantly higher than consumption, while the opposite is true for winter. Therefore, in these cases it could be beneficial to integrate the nanogrid systems with some type of effective seasonal storage to cover the winter deficiency. Alternatively, additional valley filling actions through EV charging or other loads could be utilized.