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Market Implications on Grid Connection Sizing for Photovoltaic Systems

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Abstract. Market simulations conducted by Swissgrid for 2040 show a correlation between solar irradiation and the marginal costs of the price-setting power plants. This paper utilises results from a fundamental power market model simulation to assess the energy losses and the financial value of solar energy due to curtailment as a function of PV production capacity for various PV systems. Two reference scenarios were considered, in which solar energy accounts for 52% and 55% of the Swiss production mix. However, the simulated market can only absorb 85% and 77% of the annual solar energy production, respectively. Assuming excess production is curtailed, the study calculates the amount of energy and financial income lost due to market curtailment. Additionally, further losses resulting from limited grid connection capacity are analysed. The results show that the top 60% of grid-injected power, particularly in combination with self-consumption, represents less than 3% of a PV system's market-priced financial revenue. Thus, with only 40% of a PV system's capacity, 97% of its market value can still be realised.

Keywords: Curtailment Of Photovoltaic Systems, Market Integration Of Solar Power, Grid Connection

1. Introduction

According to different official energy-economic scenario frameworks for Switzerland (SZR CH), Switzerland is expected to have 25-30 GW of photovoltaic (PV) capacity to be installed by 2040 [1]. As this is much higher than the expected peak load of Switzerland, it will be increasingly likely to encounter situations where available PV power cannot be absorbed by the market and must thus be curtailed, resulting in less solar energy being utilised than is technically available. As different PV systems have strong temporal and spatial correlations, export options might also be limited [2]. This suggests that, in the future the upper power band of PV production, periods of highest power output, will potentially have a low market value during significant periods of the year. Thus, curtailment of available PV power will become more common, unless there is a large increase in flexible offtakers. Curtailment of PV power has already been observed and discussed, but mostly in other contexts of grid stability or limited transmission capacity [3], [4], [5]. However, this is often not considered in the context of possible market saturation due to high PV penetration. In addition to these potential future market limitations, there has been considerable debate about the extent to which the grids need to be expanded to accommodate this decentralised production. The discussion is typically based on certain production capacities and does not consider whether the market will be able to absorb and remunerate these capacities [6].

This paper will first focus on curtailment due to potential future market scenarios, provided by Swissgrid. It then explores the implications of these scenarios on the grid connection capacity of PV systems. Finally, the study investigates how much storage would be required for all scenarios to minimise curtailment losses and how to achieve this.

2. Simulation of the Energy Market and PV-Battery Systems

2.1 Market Simulations

The basis of this study is based on the results of a fundamental market simulation, which was carried out by means of Swissgrid's electricity market simulation models. The fundamental market simulation calculates the hourly energy production in 2040 for all of Europe across the different power generation units according to two scenarios given by the energy-economic scenario framework for Switzerland (SZR CH), as well as inputs for the European countries from ENTSO-E. These scenarios are:

1. Reference 2040 (**REF2040**) with 25 GW PV capacity and
2. Sector Coupling 2040 (**SC2040**) 30 GW PV capacity

In the SC2040 scenario, less energy consumption and a greater contribution from thermal power plants (mainly H2 and natural gas) and PV systems are assumed. The market simulation uses constant parameters for variable costs (operation, maintenance, fuel, CO_2, start-up) and performs weekly optimisation to minimise system costs. Key inputs include ramp-up rates, minimum run times, failure rates, maintenance planning, hydropower inflows, consumption, and cross-border exchange capacity. PV power production is treated as a fixed parameter based on a historical irradiation profile.

For both scenarios, hourly mean solar power generation was calculated using data from the Pan European Climate Database (PECD), which provides feed-in time series for all ENTSO-E regions, with Switzerland represented by a single PECD zone (CH00). Climatic conditions from 2009 were used, with simulation data covering 05.01.2009 to 03.01.2010 (364 days) to align with weekly optimisation (Monday – Sunday) of the system costs.

It is important to note that in the Swissgrid market simulation, no electricity prices are calculated. Power plant dispatch results from hourly demand and the marginal costs of plants required to meet it. To value electricity production, the marginal cost of the most expensive unit operating each hour serves as a proxy for market value of electricity. No negative prices were considered in the simulation due to modelling constraints.

While conventional power plants are modelled to have startup and shutdown costs in the simulation, switching off PV systems is considered technically feasible and cost-free. Consequently, PV systems are curtailed while conventional plants continue running. Figure 1 shows annual curtailed PV profiles for the CH00 zone according to the REF2040 and SC2040 market simulations. Red indicates lost power and black represents fed-in but curtailed PV output. This curtailment is market-driven and unrelated to grid stability and occurs when there is an insufficient number of offtakers.

Market-based curtailment for the CH00 PECD zone is the primary data used to assess the impact of market restrictions on different simulated PV systems in this study. Later, the impact of market curtailment on grid connection capacity will be discussed. Figure 2 displays heatmaps showing the PV power permitted to be fed into the grid by day (x-axis) and by hour (y-axis), according to the market simulations. 0% curtailment represents no power loss which means all energy produced can be fed into the grid. 100% curtailment indicates the opposite. Low PV production during high curtailment hours coincides with increased system costs, as thermal power plants are ramped up to compensate for reduced PV output.

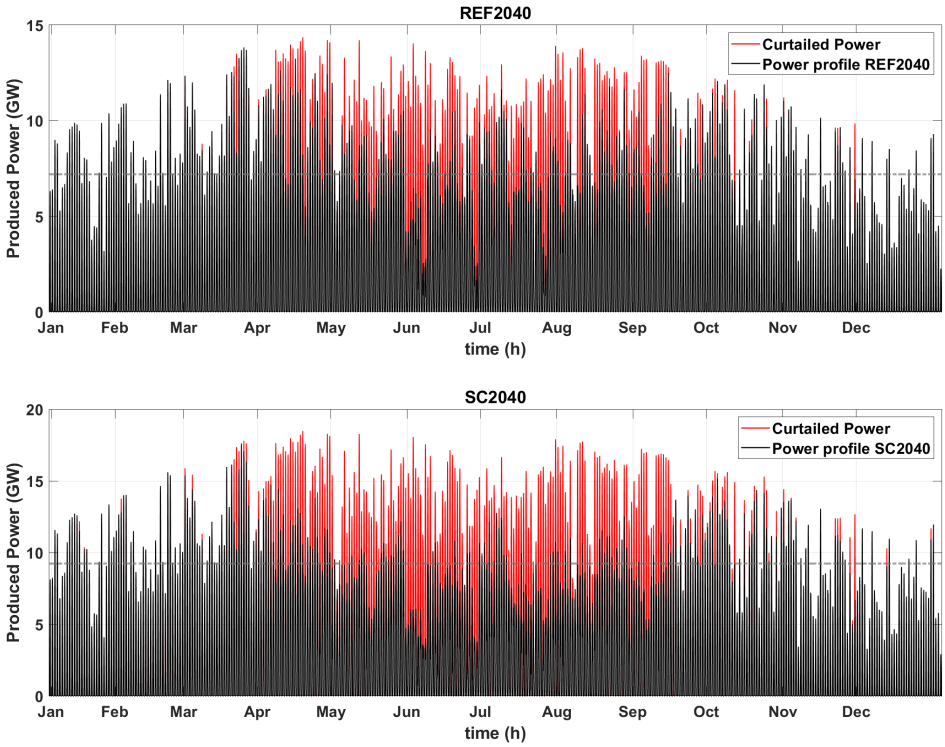

Figure 1. *Hourly mean of the PV power produced in Switzerland. In red, the market curtailed power is shown, while black represents the remaining power profile after curtailment for both the REF2040 and SC2040 scenarios. The gridded line represents 50% of the simulated feed-in peak.*

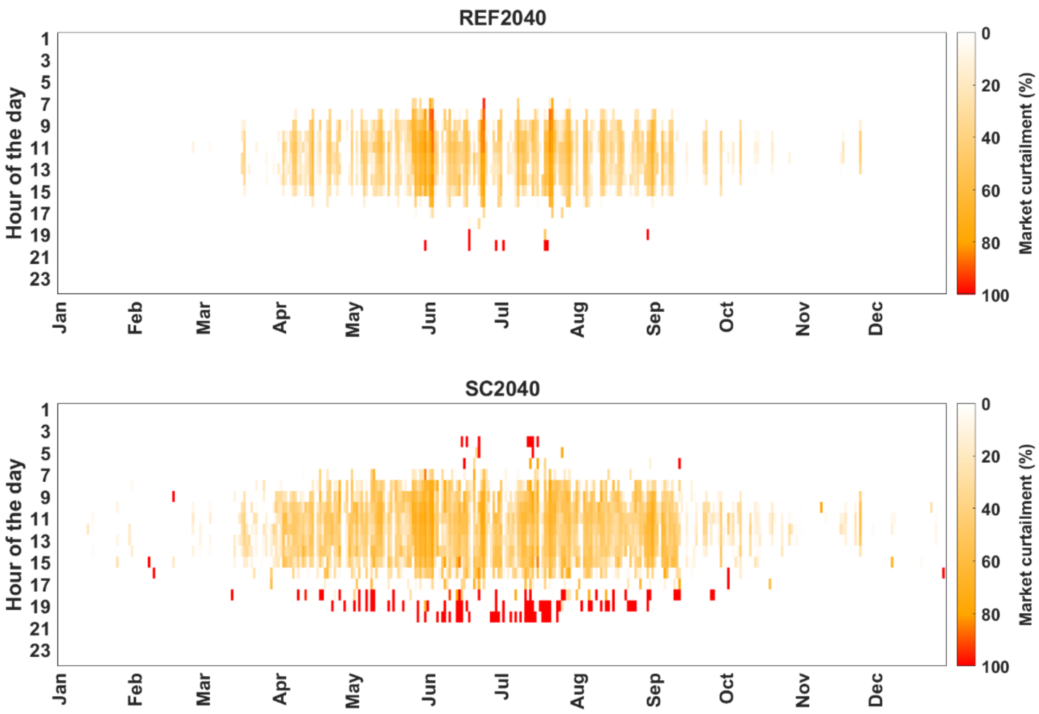

Figure 2. *Yearly overview of market curtailments, for both scenarios REF2040 and SC2040. The y-axis represents the hour and the x axis the corresponding days. The colours represent the amount of market curtailment in percent with relative to the power produced during the corresponding hourly mean power produced at that time. White refers to 0% curtailment and red refers to 100% curtailment. The dark red points visible at the evening and early morning are likely occurring due to the optimisation logic used for the market simulation and have negligible effects on energetic losses, since they occur during low irradiation times.*

2.2 PV System Simulation

In order to study the implications of curtailment at each timestep, which result from the market simulation, different PV systems with varying orientations and tilt angles at two sites in Switzerland, each with a nominal DC capacity of 1 kW, were simulated using hourly values. Meteorological and irradiation data from the government service IDAWEB were used and further processed using the software Meteonorm, to include different tilts and orientations [7], [8]. The actual AC power produced was then calculated using an algorithm developed by the Bern University of Applied Sciences (BFH). The algorithm includes losses based on incident angle (IAM), irradiation efficiencies, ageing, soiling losses, and inverter start-up power to simulate a realistic production of a PV system. The different parameters in this algorithm were chosen such that the PV system located in Zollikofen with an east-west orientation yielded a yearly energy yield of 1000 kWh per nominal DC PV capacity installed. Self-consumption was simulated by using a consumption profile, scaled so that the annual series consumption corresponds to the annual production of the standard PV system (east-west, Zollikofen) [9]. The different PV systems simulated are listed in *Table* 1.

The data for the PV simulation was obtained from IDAWEB. They are based on measurement data from 2009 and therefore correspond to the same year as the data on which the market simulation is based. Like the market simulations, the PV simulations were also carried out with hourly values[1].

Market restrictions, as defined by the fundamental market simulation, were applied to all these PV systems at each timestep and the financial and energetic losses are analysed. In addition to the market restrictions, self-consumption and various grid curtailment scenarios are also discussed.

Table 1. *The two PV systems that were simulated, each with a nominal dc capacity of 1kW.*

Location	Orientations and Tilts
Zollikofen	East-west 10°, South 20°/90°
Grimsel	East-west 10°, South 20°/70°/90°

2.3 Battery Energy Storage System Simulation

A battery energy storage system (BESS) algorithm was used to determine the required battery size needed to mitigate energy losses caused by curtailment. The algorithm captures all curtailed energy at each hourly time step and stores it in a battery with limited capacity, ranging from 0.1 to 6 hours of storage capacity. Once the battery reaches its maximum capacity, any excess energy that cannot be stored is considered lost, and the algorithm tracks these losses for each assumed battery size. The battery can only be discharged when the PV power output falls below the last observed level at which market restrictions were applied. A similar logic applies to grid restrictions, allowing discharge only when power output is below the grid connection capacity limit. Additionally, it is assumed that the battery fully discharges overnight, ensuring it can start each day with full available capacity. It should be noted that this assumption could influence the market simulations as it represents additional “generation” which is not depicted in the given market simulations. In this analysis, the effect is assumed to be negligible.

3. Results: Energetic and Financial Losses due to Curtailment

During the subsequent sections the results of the different calculations that were conducted based on the two market simulation scenarios will be discussed. First, the energetic and financial influence of the market curtailment on the two different local PV systems will be discussed,

[1] In reality, the losses of curtailed PV systems are underestimated in hourly simulations.

with and without self-consumption as a parameter. Different grid capacity limitations will be considered in addition to the previous applied market restrictions. Finally, the results of a battery storage algorithm will be discussed, which defines the battery size needed to minimise the energetic losses that occur due to market curtailment in combination with grid curtailment. In general, the location Zollikofen is represented by the PV system with south orientation and 20° tilt, and the alpine location Grimsel is represented by a south oriented PV system with a 70° tilt. These tilt angles are chosen because they are typical representatives for PV systems at the corresponding locations.

3.1 Energetic Losses due to Market Curtailment

After applying the results of the market simulation (REF2040, SC2040) to the local PV systems simulated, the total energy losses were calculated for each system. Based on the observed curtailment in the market simulation, a corresponding percentage of curtailment was calculated and applied. The difference in energy between the non-curtailed and curtailed profiles was then determined for both scenarios. Figure 3 shows these total energetic losses for all PV systems and for both market restriction scenarios. The numbers in each bar represent the energy curtailed in kWh. The dotted line represents the losses due to market-based curtailment if self-consumption is included as a parameter.

It becomes evident from Figure 3 that more energy is curtailed in scenario SC2040 than in REF2040, which is in accordance with what was observed in Figure 2: more curtailment is needed in the SC2040 scenario with more PV power assumed. Furthermore, a slight trend depending on the orientation of the PV system is observable independent of the location (Alpine, Non-Alpine). East-west orientation has the highest amount of energy curtailed and for the south oriented systems the closer the tilt is to 90° the smaller the energetic losses are. This is because east-west PV systems produce a higher share of their electricity in summer compared to south-facing systems. As a result, their generation profile aligns less well with Switzerland's higher electricity demand in winter. The energetic losses for all PV systems are around 25% of their total energy yield for SC2040 and around 18% for REF2040. Considering self-consumption of the produced power before market curtailment, the energetic losses for all systems are reduced as less energy is available to be curtailed at each timestep.

A frequency analysis was conducted to determine the power levels at which market curtailment occurs and how much each level contributes to total curtailed energy. A power level is defined as the power output observed at each timestep; therefore, a high-power level refers to peak production. The uncurtailed PV power produced, rounded to the first decimal point, was used as the sorting variable to calculate the cumulative curtailed energy for each power level observed. This approach provides insight into the contribution of each power level to total curtailed energy, the results are shown in Figure 4.

Figure 4 illustrates that, for both Grimsel and Zollikofen, peak production powers, exceeding 0.5 kW account for over 60% of the total curtailed energy, showing that most curtailment occurs during peak irradiation and thus production times. Furthermore, for the REF2040 scenario the contribution of peak powers to the total curtailed energy is more pronounced as compared to SC2040. Which shouldn't come as a big surprise as Figure 2, showed that generally more curtailment, also during non-peak hours are applied in SC2040 as compared to REF2040. As more curtailment is applied if PV power makes up a larger portion of the Swiss energy household.

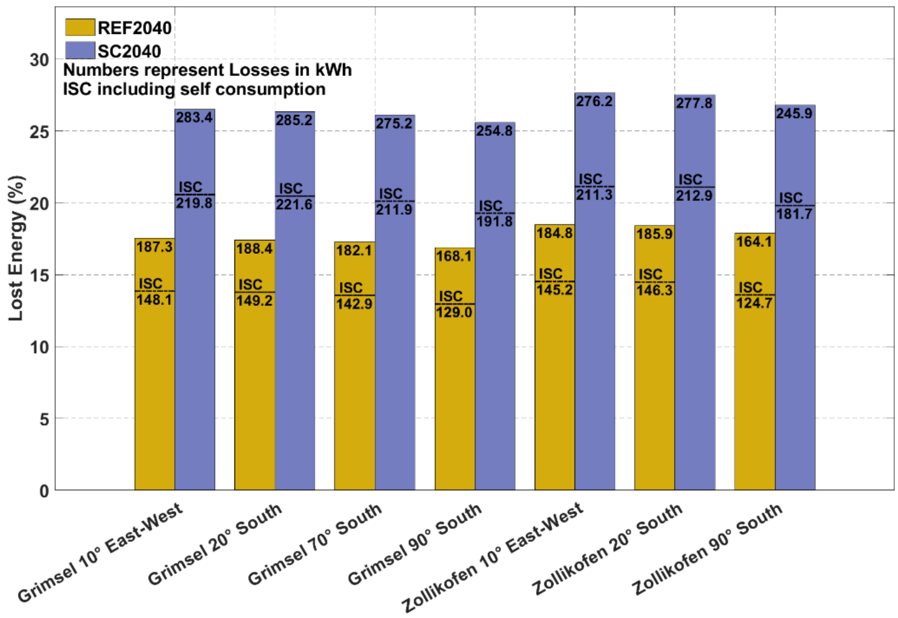

Figure 3. *Total lost Energy due to market curtailment for all PV-profiles simulated. Gridded dashed lines represent the energetic losses after self-consumption has been considered (ISC). All results are based on hourly values. In reality, PV energy yield losses are higher due to short-term fluctuations in irradiation.*

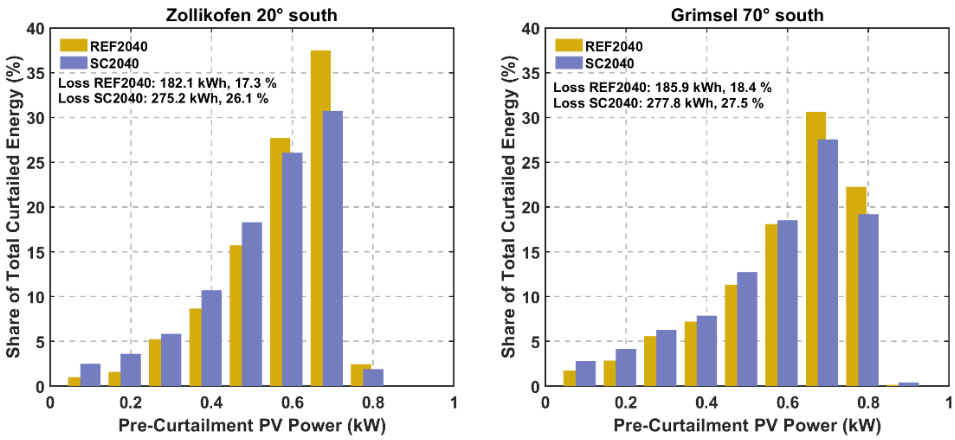

Figure 4. *Energetic losses for each observed power level of the PV system due to market curtailment, for Zollikofen 20° South and Grimsel 70° south. Each hourly mean power observed was rounded to its first decimal point to use them as a sorting variable. The insets kWh and percent represent the amount of total energy lost.*

3.2 Financial Losses due to Market Curtailment

In addition to the energetic losses due to market-based curtailment, the influence of this curtailment on the potential financial revenue of each PV system has been analysed. However, the market simulations do not return electricity prices but only the marginal cost of the most expensive active power generation unit in each hour. The marginal costs of this unit are used as an approximation of the value of electricity in this given hour. For example, if all the demand in one hour is covered by wind, solar and run-of-river hydro, all of which are assumed to have marginal costs of zero, the value of electricity in this given hour would also be zero. Furthermore, it is important to note that the marginal costs at each time step differ between the modelled scenarios (REF2040, SC2040) due to the varying assumed contributions of PV power to Switzerland's total energy mix in each scenario.

For this analysis it is assumed that the PV systems are exposed to the market i.e. they are remunerated according to the hourly value of electricity defined above. This is not the case in today's remuneration scheme, e.g. with fixed infeed tariffs. The relative financial revenue losses for the simulated timeframe are shown in Table 2. Because both market restriction scenarios assume different energy production scenarios for the simulated market areas, there is not only a difference in market restrictions but also a difference in marginal costs between the two scenarios. Table 2 shows that regarding financial revenue loss, similar trends regarding the locations of the PV system occur as observed in Figure *3*. However, a more noticeable difference between the two scenarios is observed. The REF2040 scenario does yield very small financial losses of 0.024-0.031% with respect to the total financial yield. Whereas the SC2040 scenario causes revenue losses ranging from 1.4-2.3%.

Table 2. *An overview of financial revenue losses from market curtailment in both scenarios, relative to total financial revenue without curtailment. Losses for REF2040 and SC2040 are given in percent with respect to their annual uncurtailed revenue.*

Location	Grimsel 10° E-W	Grimsel 20° S	Grimsel 70° S	Grimsel 90° S	Zollikofen 10° E-W	Zollikofen 20° S	Zollikofen 90° S
Revenue Loss REF2040	0.031%	0.030%	0.029%	0.029%	0.025%	0.024%	0.024%
Revenue Loss SC2040	1.7%	1.6%	1.5%	1.4%	2.3%	2.2%	2.1%

One key reason for the generally small total financial loss across all PV systems is probably because when market curtailment is applied the market is saturated with solar (and wind) power. This is then also defining the marginal costs in this given hour. This means the marginal costs will be very small or zero, especially during peak production. It is important to remember here that in the market simulation no negative prices are assumed. Therefore, a bigger financial loss is seen for SC2040, since in this scenario more market curtailment is applied at hours not corresponding to peak production times, when the marginal costs are not solely defined by solar (or wind) plants.

3.3 Energetic Influence of Market Curtailment on Grid Connection Limitations

In the future, the local grid will need to be expanded to accommodate and distribute the anticipated increased production from more installed PV capacity. This has sparked a significant debate regarding the costs of (distribution) grid expansion and the extent to which the grid should be upgraded. Discussions have also considered curtailing PV systems and limiting grid connections to specific percentages of the nominal DC power of installed PV systems [10]. To account for this potential scenario of grid connection limitations and to examine how market restriction scenarios, such as the two scenarios discussed, affect expected losses, several grid restriction scenarios will be introduced and added on top of the market restrictions. This approach was chosen to illustrate that both grid and market curtailment affect peak power production most significantly. Therefore, expanding a grid to accommodate peak production is not meaningful if the market cannot absorb it anyway. However, it is important to note that the market is more flexible, and if more flexible offtakers are available in the future than considered in the market scenarios, the effect of market curtailment on peak hour production might not be as significant as shown here.

The total energetic losses caused by a grid connection limitation, with and without self-consumption taken into consideration, are shown in Figure 5, for Zollikofen (20° south) and Grimsel (70° south). The black lines represent the effect a grid restriction alone has on the energy loss and show the well-known fact that curtailing PV systems to 70% of their nominal

DC power results in small energetic losses, typically not exceeding 3% [10]. If self-consumption is considered, represented by the dashed or dotted lines, the 3% loss point at which energetic losses due to grid restrictions become apparent is shifted further toward stronger connection limitations.

When, in addition to the grid restriction, the market curtailment of the scenarios REF2040 and SC2040 are added, the yellow and blue lines are obtained. Applying market curtailment leads to an initial loss offset, as we assume full market curtailment and thus the total losses visible in Figure *3*, before grid restriction are applied to each hourly power value. Since market curtailment affects peak powers more significantly than bulk production, see Figure 4, the point where grid limitation begins to have a significant impact on the energy loss shifts further towards lower grid connection capacities. This indicates that, regardless of the market restriction scenario, the additional losses on the annual energy yield, due to a limited grid connection capacity only exceed 3% at grid connection capacities between 40-50%, as indicated by the red dots. At levels lower than that losses are dominated by the market curtailments.

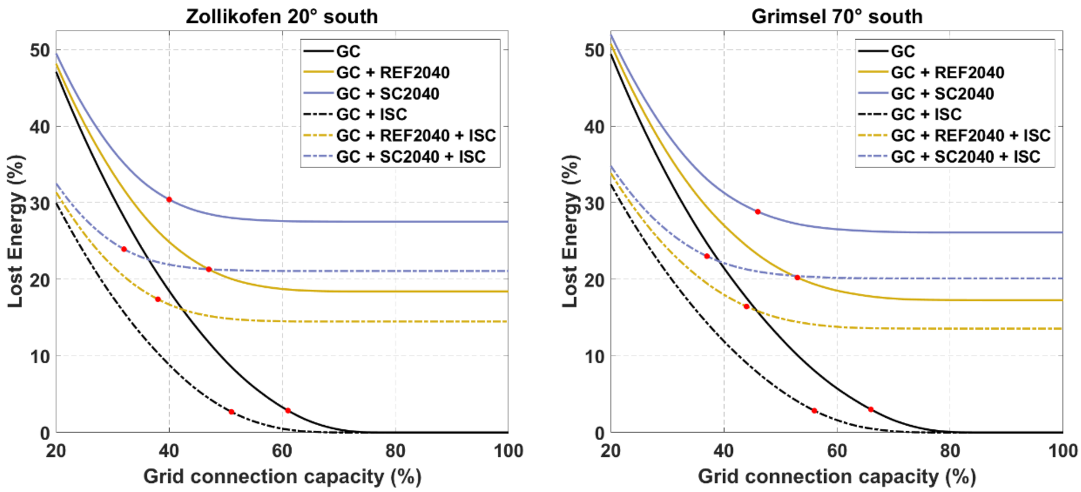

Figure 5. *Energetic losses due to grid curtailment (GC) applied in combination with market curtailment are shown here. The black lines represent losses due to grid restrictions, while the coloured lines represent the additional losses caused by market curtailment when applied on top of grid curtailment. Results where self-consumption (ISC) is included are represented by the gridded lines, and the red points indicate the last point at which grid curtailment causes additional losses below 3%.*

3.4 Financial Influence of Market Restrictions on Grid Connection Limitations

The same analysis conducted in section 3.3, but focusing on the financial revenue lost instead of energetic losses, is presented in Figure 6 for Zollikofen (20° south) and Grimsel (70° south). The filled and dashed black lines illustrate the impact of grid limitations alone, considering the marginal costs defined by both market scenarios, while the coloured lines show the influence of grid limitations in addition to the market restrictions. As the figure indicates, reducing grid connection capacity up to 40-50% of the nominal DC capacity of the system has a negligible effect on the sum of the lost value of electricity. This is because the financial losses are either already driven by the market restrictions or the marginal costs are minimal, as solar power dominates energy production during these periods.

To obtain a more comprehensive understanding, the absolute financial revenues from the simulations should also be considered. The simulated values of electricity multiplied by the production profile of the PV systems result in an annual market value of around 14 EUR to 17 EUR per kW of installed PV capacity. Considering that the costs for a PV system in Switzerland are typically in the range of 1000 EUR/kW for large systems and 2000 to 3000 EUR for smaller systems [11]. The expected annual revenue according to the market simulations is very small if compared to the costs of PV systems.

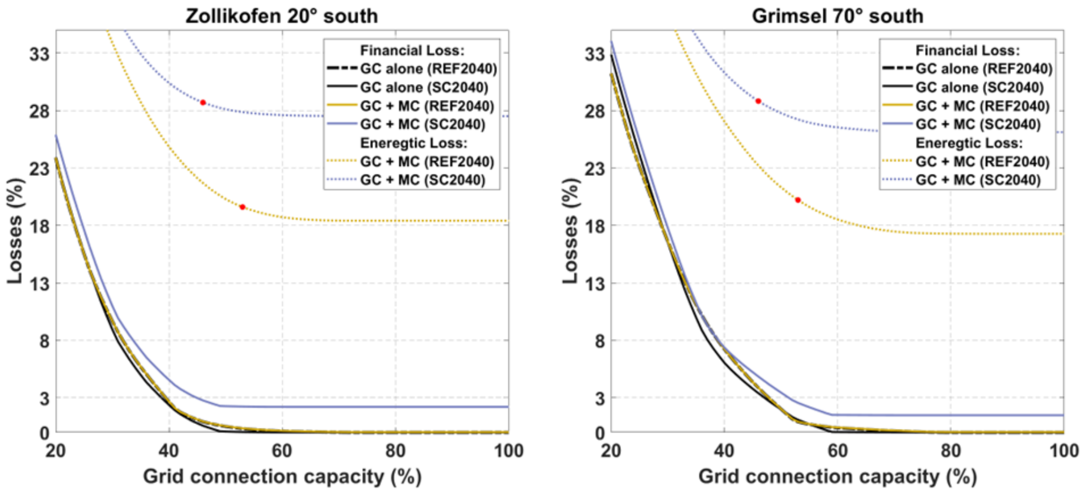

Figure 6. *Financial losses are presented as a function of grid curtailment (GC) alone, as well as in combination with market curtailment, for both Zollikofen (20° south) and Grimsel (70° south). Self-consumption is not included in this analysis. The dotted line represents the energetic loss for REF2040, used for comparison. The red dots represent 3% additional loss due to grid curtailment.*

3.5 Minimising Curtailment Loss with Battery Storage

The battery storage algorithm as discussed in section 2.3 was applied to all PV systems simulated, but the following Figures represent the results obtained for the location Zollikofen (20° south). Figure 7 illustrates the energetic losses as a function of battery capacity and the grid connection capacity, assuming only grid restrictions without taking market restrictions into consideration. The battery size is represented in storage hours (kWh / kW), the number of hours a battery is able to store nominal DC production. The losses shown here are representing the amount of energy lost due to the limited battery size. Battery losses of non-ideal batteries are neglected.

Figure 7 shows the energetic losses for up to 60% nominal power allowed in the grid, are below 3% and if self-consumption is included the energetic losses are less than 1%. Even for the most severe limitation of 20% nominal power allowed, energetic losses can be minimised to roughly 5% if a battery with 3 storage hours is added to the PV system. For self-consumption the same is true for a battery size of 2 storage hours. Overall, Figure 7 indicates that grid restrictions alone cause minimal energetic losses if the curtailed energy is stored inside a battery and 3 storage hours are enough to reduce these energetic losses to a minimum even for the most severe grid connection limitation considered. By considering market curtailment on top of the grid restrictions in the battery storage algorithm the results shown in Figure 8 are obtained.

The battery sizes needed to reduce energetic losses if market restrictions are considered can be seen in Figure 8. To minimise the losses to below 3% of the yearly energy yield 2 h of storage are needed for REF2040 and around 2.2 h for SC2040. Even a storage capacity of 1 h can reduce the energetic losses below 10%, 15% of the yearly energy yield for REF2040, SC2040 respectively, for grid connection limitations above 60%. Considering self-consumption reduces the needed storage capacity, for energetic losses below 3%, further around 1.5 h for REF2040 and 1.8 h SC2040 respectively.

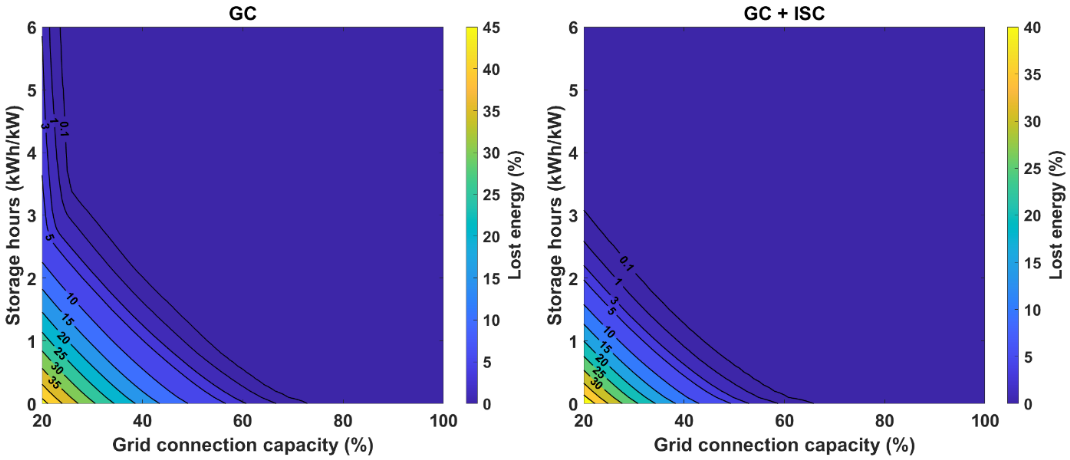

Figure 7. *Energetic losses as a function of battery capacity and the nominal PV power allowed to be fed into the grid, according to the battery storage algorithm. On the left, only grid connection limitations are considered, while on the right, self-consumption is included as well (ISC). The results presented here are for the PV system Zollikofen (20° south).*

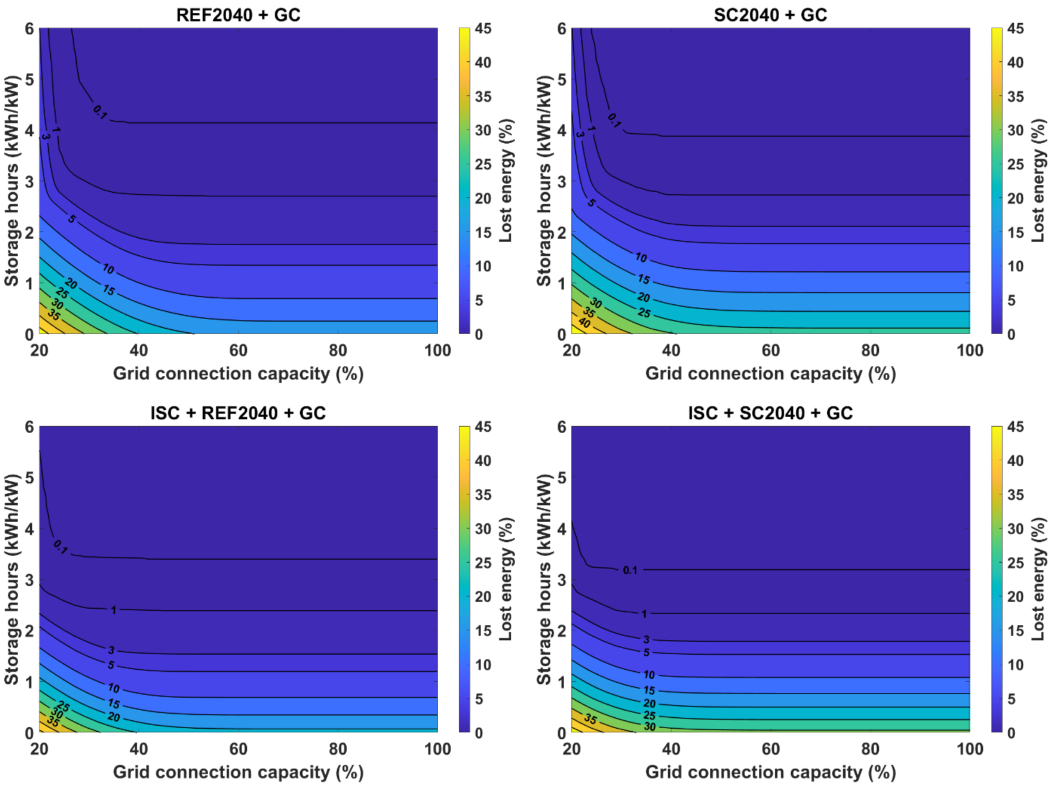

Figure 8. *Energetic losses as a function of battery capacity and the nominal PV power allowed to be fed into the grid, according to the battery storage algorithm. Before grid curtailments were applied, curtailment according to the two market restriction scenarios was considered, as well as self-consumption (ISC). The results presented here are for the PV system Zollikofen (20° south).*

4. Discussion: How Curtailment Affects Losses

Future market restrictions due to a lack of offtakers will lead to revenue losses but will reduce the need for a strong grid connection for PV systems. This paper makes the following observations:

1. Energy Losses: The simulated scenarios indicate that market curtailments primarily occur during peak production periods. Therefore, when grid connection limitations are

considered in addition to market curtailment, they result in only limited additional losses. Market curtailment results in energy losses of approximately 18% for REF2040 and 26% for SC2040 relative to total annual energy yield.

The orientation and tilt of PV modules have a negligible influence on these losses. However, alpine systems suffer more from curtailment or limited grid connection capacity, as they experience clear sky conditions more often than PV systems in the Swiss midlands.

Grid connection limitations further impact energy losses: At 50% grid connection capacity, an additional 3% energy yield loss occurs compared to market curtailment alone. When self-consumption is considered, the 3% limit of additional losses is reduced to 40% grid connection capacity.

2. Financial Losses: Financial losses due to market curtailment are small, as market prices tend to be low during periods of peak production.

Financial benefits come mostly from lower production bands, making market curtailment less impactful on total financial revenue yield. However, the simulated market prices are not sufficient to refinance PV systems.

3. Storage solutions: Storage solutions significantly reduce the curtailment losses.

Energy curtailment losses shown above can be reduced with storage: A storage of one hour of nominal PV module capacity reduces the energetic losses below 10%. Two-hours of storage capacity reduce the losses below 3% and a three-hour of storage reduces the loses below 1%.

Looking forward, further simulations are necessary to explore curtailment at both local and national levels, incorporating a wider range of irradiation profiles and more accurate modelling of local distribution grids. Additionally, investigating decentralised storage solutions, especially for nighttime energy use and feedback into the grid, will be crucial for optimising the performance of PV systems in the future. Future research should also consider the technical feasibility of implementing (market-based) curtailment signals and the possibility of sourcing greater flexibility in energy demand or additional offtakers to support PV integration into the grid.

In general, the market, e.g. self-consumption or new loads, can develop much more dynamically than the electricity grids. If low or highly volatile electricity prices stimulate new demand or new flexibilities, the assumptions in this paper must be revised.

The key to improving grid integration of solar power is not merely reinforcing grid connections but activating decentralised flexibility. This can be achieved through solutions such as storage systems.

Data Availability Statement

The data used in this analysis is not publicly available.

Underlying and Related Material

Additional figures can be found under: https://doi.org/10.5281/zenodo.15041326

Author Contributions

BFH, Christof Bucher: Initial draft and structure, conceptualisation, definition of algorithms and graphs, editing of the introduction, conclusion, and discussion.

BFH, Nicolas Brunner: PV simulations and application of the results to market simulations, editing.

BFH, David Joss: Contribution to the concept, conclusion and discussion.

Swissgrid: Market simulations, contribution to the conclusion and discussion.

Competing Interests

The authors declare that there are no conflicts of interest associated with this paper.

References

[1] Sebastian Willemsen *et al.*, 'Auswirkungen einer starken Elektrifizierung und eines massiven Ausbaus der Stromproduktion aus Erneuerbaren Energien auf die Schweizer Stromverteilnetze', Bundesamt für Umwelt BFE, Oct. 2022. [Online]. Available: https://www.newsd.admin.ch/newsd/message/attachments/74145.pdf
[2] C. Stiewe, A. L. Xu, A. Eicke, and L. Hirth, 'Cross-border cannibalization: Spillover effects of wind and solar energy on interconnected European electricity markets', *Energy Econ.*, vol. 143, p. 108251, Mar. 2025, doi: 10.1016/j.eneco.2025.108251.
[3] E. O'Shaughnessy, J. R. Cruce, and K. Xu, 'Too much of a good thing? Global trends in the curtailment of solar PV', *Sol. Energy Phoenix Ariz*, vol. 208, pp. 1068–1077, Sep. 2020, doi: 10.1016/j.solener.2020.08.075.
[4] L. Bird *et al.*, 'Wind and solar energy curtailment: A review of international experience', *Renew. Sustain. Energy Rev.*, vol. 65, pp. 577–586, Nov. 2016, doi: 10.1016/j.rser.2016.06.082.
[5] B. Frew *et al.*, 'The curtailment paradox in the transition to high solar power systems', *Joule*, vol. 5, no. 5, pp. 1143–1167, May 2021, doi: https://doi.org/10.1016/j.joule.2021.03.021.
[6] Porf. Dr. Christof Bucher and David Joss, 'Netzanschluss von 50 Gigawatt Photovoltaik in der Schweiz'. Accessed: Jan. 27, 2025. [Online]. Available: https://arbor.bfh.ch/server/api/core/bitstreams/69b9a2e3-5006-4ce4-a299-894228e91140/content
[7] *Meteonrom*. Meteotest AG. Accessed: Jan. 27, 2025. [Online]. Available: https://meteonorm.com/download
[8] 'MeteoSwiss IDAWEB'. Accessed: Jan. 27, 2025. [Online]. Available: https://gate.meteoswiss.ch/idaweb/login.do
[9] C. Bucher, 'Analysis and Simulation of Distribution Grids with Photovoltaics', ETH Zürich, Zürich, 2014. [Online]. Available: https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/87702/eth-9025-01.pdf?sequence=1&isAllowed=y
[10] Peter Cuony, Helena Todorov, and Prof. Dr. Christof Bucher, 'Ohne Leistungs-regelung von PV geht es nicht - Bulletin DE', Sep. 12, 2024. Accessed: Jan. 27, 2025. [Online]. Available: https://www.bulletin.ch/de/news-detail/ohne-leistungsregelung-von-pv-geht-es-nicht.html
[11] L. Bloch, P. Sa, Y. Sauter, and P. Sa, 'Photovoltaikmarkt: Preisbeobachtungsstudie 2023', BFE, Final Report, Jul. 2024. [Online]. Available: https://pubdb.bfe.admin.ch/de/suche?keywords=&q=Photovoltaik&from=&to=&nr=