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Integration of Renewables in Energy Systems of typical Ski-Resorts in Carinthia/Austria - Synergies between Ski-Resorts and Hotels

A Master's Thesis submitted for the degree of
“Master of Business Administration”

supervised by
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Vienna, 08.10.2024

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Affidavit

I, **HERBERT SCHEIBER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "INTEGRATION OF RENEWABLES IN ENERGY SYSTEMS OF TYPICAL SKI-RESORTS IN CARINTHIA/AUSTRIA - SYNERGIES BETWEEN SKI-RESORTS AND HOTELS", 142 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 08.10.2024

Signature

ACKNOWLEDGEMENTS

I would like to thank the following people and organizations for their support and expertise in the completion of this work.

I am very grateful to Ing. Alexander Fischer, MSc, for his constructive feedback and assistance with this thesis. His perspective was invaluable for the completion of this paper.

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Special thanks go to the contacts at various mountain hotels, particularly to the owners and the head of the technical department of a large wellness resort. They provided me with the exceptional opportunity to validate my simulations against real-world data from their energy management system and shared their valuable practical insights.

Finally, I would like to express my deepest gratitude to my wife. Her constant support, not only in mastering our daily lives throughout my studies, but also in actively helping with the proofreading and textual design aspects of this thesis, was essential. Her contribution was my motivation and a cornerstone on my academic path.

Thank you all for your great support.

ABSTRACT

The Austrian decarbonization strategy[1] presents a significant challenge for all sectors, including tourism, with a notable impact on resorts in remote valleys or mountains. Skiing facilities contribute heavily to electrical energy consumption, while hotels, particularly those with spa areas, demand substantial heating energy.

Many ski lifts in Carinthia that were built in the 1970s and 1980s have reached the end of their life cycle. The operating licenses are often outdated and are only renewed for a few years. Some ski resorts may not survive the next decade due to global warming and other problems. Significant investment is needed in new lifts and snowmaking systems, which also provides an opportunity to create a basic infrastructure for renewable energy production.

As ski resorts are under scrutiny for their climate-damaging energy consumption, new investments often include a commitment to using renewable energy. Hotels are also increasingly turning to renewable energy, but cooperation between the two sectors is limited as decisions focus on individual business interests.

This thesis examines the potential synergies between hotels and ski resorts in the implementation of renewable energy systems. The remote ski resort is considered from the perspective of a producer community that includes all businesses on the mountain. A specially developed simulation model adapts an optimal combination of renewable energy sources to the demand profile.

The results show that the use of biomass/wood in remote mountain areas, even those surrounded by forests, must be managed carefully. Wind energy offers strategic advantages over photovoltaics, and PV systems should never be oversized. The simulation shows that there are clear advantages in combining the load profiles of hotels and ski resorts. Systems can be smaller in total and still achieve higher self-sufficiency rates. In addition, possible synergies with reservoirs are highlighted.

The combination of pumped storage and thermal storage is a promising symbiosis that is highly innovative and may be economically viable under certain conditions.

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[1] Austrians strategy for decarbonization: https://www.oesterreich.gv.at/themen/bauen_wohnen_und_umwelt/klimaschutz/1/Seite.1000310.html

Short version published by IEA: https://www.iea.org/countries/austria

"Austria's government is committed to achieving climate neutrality no later than 2040. This will require Austria to substantially enhance de-carbonization efforts across all energy sectors. Austria has set a target of a 100% renewable electricity supply by 2030 (national balance)."

TABLE OF CONTENT

1 INTRODUCTION

When I started my studies in this MSc program in 2022, there were diverse discussions about the energy waste of ski resorts. Skiing is one of my passions. Due to health limitations, ski mountaineering is now only possible to a very limited extent. Therefore, I rely on ski lifts. That was the reason for me to think about the energy system of winter tourism.

The tourism sector emphasizes a clear reality: the highest emissions of greenhouse gases occur during travel to and from mountain resorts. Indeed, that is true! However, what often remains unaddressed are the substantial energy consumptions within the winter tourism facilities themselves, especially hotels, restaurants, etc.

Already in the winter season 2022/23 I initiated discussions and conducted some interviews. I observed that all entities are sensitive to both, energy consumption and greenhouse gas emissions. While some have formulated ideas or plans, only a very few have a clear schedule. However, I did not find any substantial cooperation in long-term activities or planning between the sectors. Furthermore, I identified significant potentials within the energy system of a ski region. The mountains offer substantial energy yields through sunlight, wind and occasionally waterpower. In addition, ski resorts possess significant potentials in terms of energy management and storage (e.g. such as lakes for snowmaking). In contrast, the surrounding hotels require electricity and heat energy even in summer, whereas ski resorts predominantly consume electricity during the winter.

By analyzing energy loads and various options for renewable energy supply, I want to identify preferred solutions and uncover synergies between hotels and ski resorts. These analyses aim to determine, for the combined energy system, the conditions under which (for instance) wind energy surpasses photovoltaics or when heat pumps are preferable over CHP, among other considerations. Furthermore, exploring synergies between both sectors could potentially lead to a reduction in installed power. Hotels could leverage energy from ski resort utilities during off-peak hours, such as nighttime and summer, while, conversely, during peak skiing hours, hotels may encounter a decrease in energy demand.

These are the questions I want to address in my master's thesis. I hope that the results will be useful for decision making in some specific mountain resorts.

1.1 Outline of the main research question

As mentioned earlier, this thesis examines the integration of renewable energy sources for ski resorts and mountain hotels, with a focus on remote areas that are not directly connected to a local village. The key research questions are:

- How do various renewable energy sources align with the combined energy demand of ski lifts and hotels on the mountain, considering annual, daily and hourly time scales?
- Are there preferred solutions for the combined energy system, and what circumstances influence the suitability of these solutions?
- What synergies can be identified within the combined energy system of ski lifts and mountain hotels?
- How can lakes for snowmaking contribute to the energy system?
- Do synergies offer potential for energy communities or similar arrangements?
- Which sources of renewable energy would I choose if I were responsible for a producer community on a ski mountain?

These questions aim to uncover optimal renewable energy strategies, explore influential factors, and investigate the potential for coordinated energy systems and energy communities in mountain tourism.

1.2 Hypothesis

In my personal opinion, every ski resort must integrate renewable energy generation facilities in the future. On the one hand because the infrastructure (grid connection) is available there, and on the other hand because winter energy in particular is extremely important in our Austrian energy system. In winter, solar yields are better in mountain regions than in the valley, and wind yields are better in winter anyway.

But what is better suited to the local energy system of the ski mountain? On the one hand, ski operations correspond directly with the hours of sunshine, on the other hand, wind energy is more available in winter. My hypothesis was that wind energy is much better suited to the energy requirements of a ski mountain. This, my preconceived opinion, does not correspond to the opinion of the owners/managers responsible there.

Most owner/operators on the mountain have already invested in PV systems of limited size. And they do not believe that wind power is necessary. Here are a few quotes from my interviews:

A discussion was held with a manager of a ski resort[2] in the spring of 2023.

> *"We have drafted a project for a large PV system. For this we need to cut down approx. 2 ha. forest, but we can cover almost half of our energy needs."*

→ Why exactly at this place? And why cutting down forest?

> *"Because we are allowed to do that here. This area has been commissioned for ski operations, but we will not be building a slope there and can therefore use this area to generate energy for ski operations."*

Discussion with a hotel owner[2] in autumn 2023:

> *"In general, we are not happy with wind turbines here on the mountain. Our guests would not accept them. In any case, the wind turbines would have to be installed somewhere hidden - just like ground-mounted PV."*

> *"But strictly speaking, wind power does not fit the energy profile of hotels - PV is much more suitable. Wind might suit a ski resort with the need for snow production in winter and at night."*

1.3 Aims and structure of the Thesis

My personal objective was to verify or revise the personal opinions and evaluations I had formed in my initial discussions and investigations. In any case, I wanted to do this on the basis of solid data. Unfortunately, most of the people I talked to were only able to provide an annual energy consumption figure at best. Measuring devices or more detailed records are generally unknown. Therefore, I first created simulation models for the energy consumers on the ski mountain and verified them through discussions and comparisons with measured data. Thereafter, I created a simulation model with the renewable energy sources included.

[2] Neither individuals nor the companies associated with them are mentioned by name in this work, as this is not desired by them.

2 BACKGROUND AND FRAME-CONDITIONS

2.1 Ski-resorts in Carinthia

There are almost 30 small and medium-sized ski resorts in Carinthia:

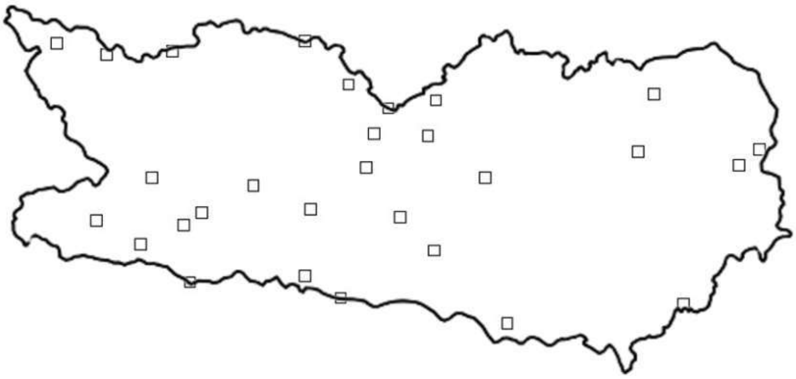


Figure 1 – Ski-resorts in Carinthia

As everywhere, climate change poses a particular challenge for ski areas. Snow reliability is steadily decreasing, measures for artificial snowmaking must be taken or continuously expanded. In addition, the operating licenses for many lifts will expire in the next 5-10 years. This situation leads to increased investments. Some small ski resorts will probably not be able to survive. Others are planning higher investments and an increase in capacity.

Such major investments, which usually also require an expansion of the energy supply and often also underground installations, present a clear opportunity to set up facilities for generating renewable energy and benefit from infrastructure synergies.

2.2 Political background

Carinthia has already offered generous subsidies for private households in the past, particularly for energy-saving measures through residential renovation, but also for the installation of (smaller, private) PV systems. On the other hand, the approval procedures for larger, commercial systems were very complicated. After the last elections the situation should improve.

The Carinthian government program for 2023-2028 states the following:

> *"The goal is to further establish an ambitious energy mix from renewable production without jeopardizing Carinthia's biodiverse and exceptional natural environment. Regional independence in energy matters is more important than ever, particularly in light of international crises……………….*
> *It is our ambition to develop Carinthia into a region that sets an example and finds a practical way to achieve the energy turnaround, protect natural resources and combine the economically beneficial with the ecologically acceptable. In this sense, exemplary projects should be supported and realized in the long term." [1, p. 28]*

.... and further on ....

> *"ACCELERATION OF SUSTAINABLE ENERGY SUPPLY FOR TOURISM*
> *The coalition partners are committed to supporting Carinthian tourism businesses in switching to sustainable forms of energy, such as photovoltaic systems, and in implementing energy self-sufficient tourism infrastructure, for example in ski resorts, in order to become energy producers themselves." [1, p. 32]*

As a first step, it was decided in June 2024 that renewable energy installations are in the predominant public interest. In future, all renewable energy installations will only require notification under building law, which means that lengthy approval procedures will no longer be necessary. In electricity law, the threshold for the licensing requirement has been raised from 5 kW to 500 kW. *(cf. press release Office of the Carinthian Government June-17th-24* [2] *)*

The next challenging step is the creation of guidelines for the placement of renewable energy systems. A government bill is currently being prepared for PV systems. Wind turbines are still subject to the law from 2016, which only permits wind turbines in areas where visibility from residential areas is almost impossible. *(cf. wind power location directive* [3]*)*

2.3 State-of-the-art

In my research for this paper, I did not come across any studies or documentation that dealt with the joint energy system of ski resorts and hotels. These two tourism sectors are discussed separately in many papers. Some examples are listed here:

- Climate change exacerbates snow-water-energy challenges for European ski tourism (2023: Hugues François, Raphaëlle Samacoïts, David Neil Bird, Judith Köberl, Franz) [4]
- The climate and energy balance of ski resorts with technical snowmaking, taking into account the albedo effect (2017: Hannes Schwaiger, David Neil Bird, Andrea Damm, Dominik Kortschak, Franz Prettenthaler) [5]
- Perception of the sustainability measures of mountain railroads - Findings from Germany, Austria and Switzerland (2021: Anna Amacher Hoppler, Barbara Rosenberg-Taufer, David K. Walter, Ursina Meier-Crameri, Carmen Heinrich) [6]
- Implementation of renewable forms of energy - such as photovoltaics - in alpine cable car projects (2019: Werner Mair) [7]
- Guideline - Energy in indoor and outdoor pools (2018: Kannewischer Ingenieurbüro AG) [8]
- Energy-efficient swimming baths (2013: Herwig Ronacher et al.)

2.4 General assumptions

This work is not focused on a single, specific ski/tourism area. The simulation model developed for this purpose should be able to be used for any resort in the Alps. I have therefore decided to use a virtual ski resort for the results presented here. On the one hand, because the data from older resorts is no longer state of the art and, on the other hand, because the owners do not want to publish specific data about such a study. This also applies to the affiliated hotels.

But the simulations are quite accurate. In the case of the hotels, it was possible to carry out a very detailed review (see fact check in Appendix (4), page 128 ff).

2.5 Topics in / out of focus

The overall energy system of a ski/tourism mountain is very complex. My focus is on the main energy requirements of electricity and heat for ski & hotel operations.

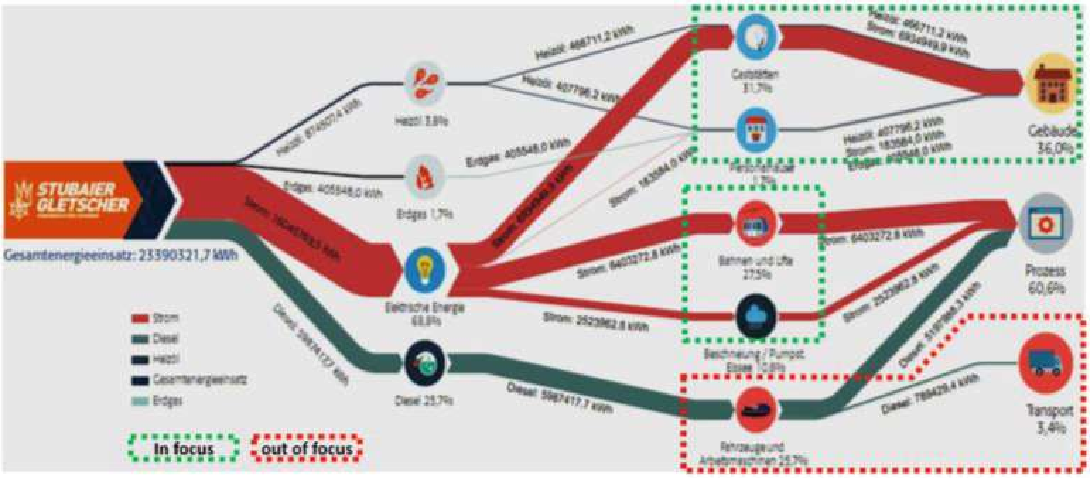


Figure 2 - Exemplary energy flow diagram of the Stubai Glacier lifts[3]

In focus are:

- Electricity for ski lifts - winter and summer operation
- Electricity for synthetic snow production
- Electricity-demand for hotels, chalets, culinary lodges, etc
- Heat-demand for hotels, chalets, culinary lodges, etc.
- Future perspective: charging electric vehicles

[3] figure from the Austrian Cable Car Association factsheet [9, p. 71] with individual supplement. Note: The energy quantities shown in the figure are not comparable with the (virtual) ski resort in this study. In particular because there is no mountain spa resort on the Stubai Glacier.

Out of focus are:

- Energy for snow groomers.
  Manufacturers of snow groomers and snow vehicles are moving in all directions. Although battery-powered machines are already on the market, e.g. for grooming cross-country ski trails, the future of snow grooming on the mountain is more likely to be powered by e-fuels or bio-fuels.
- Logistics from/to the mountain resort.
  Any kind of goods deliveries, waste disposal traffic, employee arrivals and departures, company cars, etc. are not considered in the simulations.
- Arrival and departure of guests.
  Even if the ski resorts (rightly) note that arrival and departure represent the greatest CO_2 impact of ski tourism, the current situation (> 90% fossil fuels) is not taken into account in the ski- and hotel-simulation model. However, the future electricity demand for charging electric vehicles is estimated. This is included in special simulation scenarios.
- Any energy consumption in connection with investments, construction measures to build and maintain the ski and hotel facilities.
- Heating of administrative buildings and control rooms for ski operation.
  Modern systems already use waste heat from the lifts to heat the control rooms. In future, this should be state of the art and require no significant additional energy input. On the other hand, administrative buildings need to be heated, but these are not necessarily located close to the lift operations in every ski resort.

3 METHODICAL APPROACH

3.1 Simulation model

This work is based on an extremely complex simulation model, which was created specifically for this purpose in MS Excel.

The basic principles of the simulation consist of mapping formula-based energy profiles (based on weather data and tourist capacity utilization) of the hotels and the ski resort to formula-based renewable energy yields. This results in values for self-consumption, excess feed-in, and required grid consumption for each of the 8760 hours per year. The earnings are calculated using the prices on the electricity market. A deeper insight into the simulation model can be found in the appendix (1), page 117 ff.

3.2 How to assess the different renewable energy sources?

The objective of this study is to identify the most appropriate methodology for assessing the relative merits of different renewable energy sources. Ultimately, it's all about the money! That's what determines which solution is the best.

Today, owners/operators in tourism sector mostly calculate with annual, on-balance self-sufficient rates. This calculation will work as long as we have flat-fee purchase and feed-in tariffs. But in flat fees, the positive and negative effects on the energy system are kind of lost in the shuffle. Ultimately, the flat prices include safety factors that help to balance out the strong price peaks. Let's be clear: the flat feed-in tariffs often include subsidies. But we cannot count on this in the long term. The strong expansion of PV and wind power will not allow subsidized flat rates to be paid for surplus energy in the event of enormous overproduction.

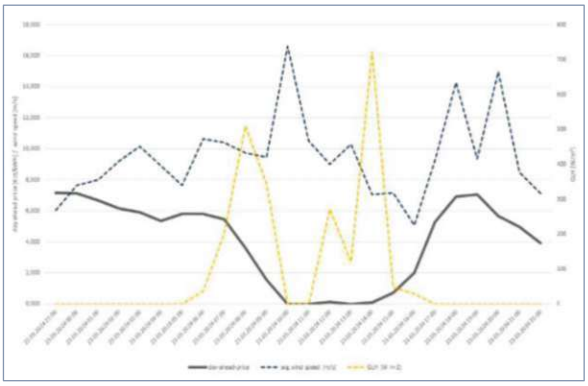


Figure 3 - GLH and windspeed vs. day ahead price

Figure 3 shows the situation at the site selected for the following simulations on March 22nd, 2024. At noon, strong wind and solar yields are possible. At the same time, the variable price of electricity is zero. During this time, the energy produced is worthless for the electricity retailer and may even be negative for the producer (retailer margin, grid tariff).

Due to this fact, we're only looking at variable prices in this paper to see what the pros and cons of different renewable energy sources are.

3.3 Simulation timeframe

The following evaluations include data for the years 2015-2024. In tourism, a year should start with the winter or summer season. In order to use the most recent data, I decided to use the annual slices from May 1st to April 30th of the following year.

Unless otherwise stated, a year in this paper always refers to the period from May and also includes the data up to the end of April of the following year.

Due to the energy crisis, 2021 and 2022 should not be considered. Also, the data for the Covid-19 years 2020-2022 must be considered in a special way. Here, comparisons with actual data from tourism are impossible due to the frequent lockdowns.

3.4 Perspective: (virtual) energy producer community

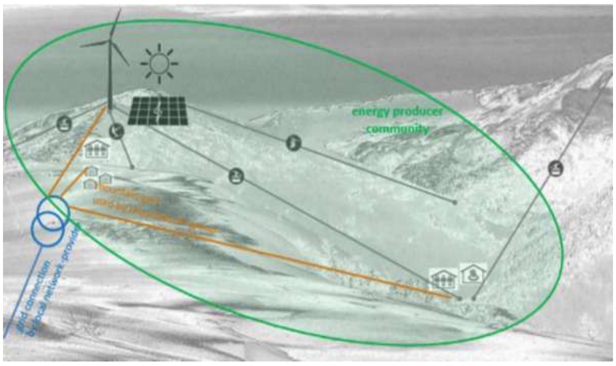


Figure 4 - energy producer community

For a better understanding of the following analyses, I would like to choose the perspective of a (virtual) producer group consisting of all the operations located on the mountain. On this virtual ski mountain, consumers are connected to a central grid node, so they don't have to pay grid fees.

This is basically just an assumption on which this thesis is based.

On the other hand, there is usually a comprehensive private electricity grid on ski mountains, which is needed for snow production. Every snow-gun and -lance needs electricity. The farmers and foresters on whose land these lines are buried are usually not happy about it. In my opinion, farmers should play a major role in generating energy on their mountains in the future and build and operate energy plants in cooperative ventures (with or without ski resorts and hotels in the cooperative). So why shouldn't the (already existing) power lines be sufficiently dimensioned to supply also some of the local consumers in the future?

3.5 Electricity price

As already mentioned under 3.1, variable electricity prices are used. Specifically, these are the hourly day-ahead prices of the MC auction[4] or, if not available (in older data), those of the EXAA[5] auction.

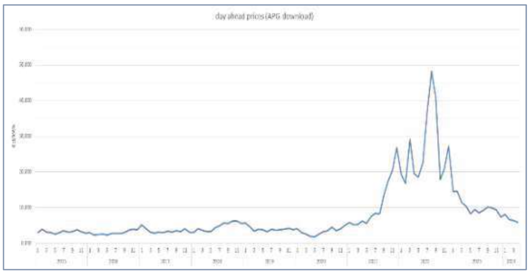


Figure 5 - day ahead price (average per month)

As the hourly price is always given for the following day, this pricing also offers an optimal opportunity for energy management. This is taken into account in the simulation model for e.g. charging electric cars, as well as for pumped storage.

The simulation model also supports an increase or reduction in price variance. As larger standard deviations are to be expected in the future, such situations can be simulated to some extent.

It is assumed that a **1.5 €ct/kWh reseller mark-up** is applied to both purchased power and feed-in charges for reseller contracts (I am personally aware of contracts that include similar terms).

3.6 Network-fee

Grid fees represent a significant value for energy producers, as they represent a substantial saving that directly influences the profit of the energy producer community.

The tariffs were taken from the official price list-2024 of the local grid operator. They include grid usage and a fee for losses. It was assumed that the main load is supplied via a shared connection at grid level 5.

At level 5, the grid fees, which form a significant part of the benefit of the energy

Netznutzungs- und Netzverlustentgelt	LP	SHT	SNT	WHT	WNT	Verluste		Netzbereitstellungsentgelt	Kosten für Blindenergie
NE 3 gemessene Leistung	52,20	0,85	0,85	0,85	0,85	0,348	0,468	13,98	0,67
NE 4 gemessene Leistung	60,60	0,91	0,91	0,91	0,91	0,383	0,468	67,75	0,67
NE 5 gemessene Leistung	66,84	1,89	1,43	2,18	1,43	0,450	0,468	76,12	1,90
NE 6 gemessene Leistung	68,64	2,02	1,32	2,63	1,53	0,864	0,468	152,24	1,90
NE 7 gemessene Leistung	90,36	4,48	2,46	5,63	2,60	1,154	0,468	239,15	3,30
NE 7 nicht gemessene Leistung in €/Jahr	36,00	8,08	8,08	8,08	8,08	1,154	0,468	239,15	
NE 7 unterbrechbar		4,56	4,56	4,56	4,56	1,154	0,468	239,15	

NETZZUTRITTSENTGELT (IN €) 1.411

Kärnten Netz

REDUZIERUNG DES ARBEITSBEZOGENEN NETZNUTZUNGSENTGELTS BEI ERNEUERBAREN-ENERGIE-GEMEINSCHAFTEN

Die Arbeitspreise für das Netznutzungsentgelt werden für teilnehmende Netzbenutzer einer Erneuerbaren-Energie-Gemeinschaft in Bezug auf jenen Verbrauch, der durch zugeordnete eingespeiste Energie einer Erzeugungsanlage abgedeckt ist, um folgende Prozentwerte reduziert:

Lokalbereich
- Netzebenen 6 und 7 ....57 %

Regionalbereich
- Netzebenen 6 und 7 ....28 %
- Netzebenen 4 und 5 ....64 %

Figure 6 - fees of local network provider

[4] Market-Coupling: European auction process that links the electricity markets of different countries in order to generate efficient cross-border price signals and optimize trading across borders.
[5] Energy Exchange Austria: local spot market in Austria that handles day-ahead trading in electricity via a uniform price auction process.

community, are very low. The resulting income is the worst scenario for the producer group in terms of grid benefits.

On the other hand, some small consumers will probably be connected via grid level 7. In this case, there is a 57% discount on the grid fees for energy communities. In terms of value, this is very similar to the fees at level 5.

The local network operator charges different rates depending on the season, day or night. These differences were fully taken into account in the simulation model.

Unless otherwise stated, the 2024 tariffs are used in the simulation for past years from 2015 onwards. Network charges are not expected to decrease in future, increases can be set as a percentage in the simulation model. .

3.7 Principle of simulations and assessment

The model supports the multiple simulation of almost 30 parameters. Two key-figures are used for the primary evaluation:

a) earnings per kWh

If the production community is viewed as a company or profit center, avoided external procurement costs are to be counted as sales. In other words, the amounts that lead to internal cost allocation. The higher this value per kWh, the more high-valued energy can be covered by self-supply.
Subtracting the LRGC basically gives us the profit of the producer cooperative. But without deducting the LRGC (which varies depending on the configuration), we cannot consider this value as the only indicator.

b) relation own-use-price / buy-from-grid-price

The higher the better! Values close to 100% are good. This shows that the self-produced energy is purchased at relatively high-priced times and that the remaining external procurement is not (significantly) more expensive. In the best case (>100%), external procurement even falls within the cheaper times. This ratio enables an analysis independent of the general electricity price level in the observation period. In principle, it is therefore also suitable for the years 2021 and 22 with their extremely high energy prices.

To calculate these values, the following equations are required:

$$EP_{buy} = EP_{da} + RM_{buy} + NF_{cons} \quad [1]$$

$$EP_{sell} = EP_{da} + RM_{sell} + NF_{feed} \quad [2]$$

EP_{buy}..... hourly price for electricity consumption including all fees [€ct/kwh]
EP_{sell}..... hourly price for electricity feed in including all fees [€ct/kwh]
EP_{da}...... hourly day ahead price like defined under 3.5 (page 10) [€ct/kwh]
RM_{buy}.... reseller markup for consumption, like defined under 3.5: 1,5 €ct/kwh
RM_{sell}.... reseller markup for feed in, like defined under 3.5: 1,5 €ct/kwh
NF_{cons}... variable consume-rate like defined under 3.6 (page 10) [€ct/kwh]
NF_{feed}.... feed-in-rate, assumed by zero[6] [€ct/kwh]

$$REN_{gen} = REN_{wind} + REN_{PV} \quad [3]$$

$$ED_{total} = ED_{st} + ED_{ht} \quad [4]$$

$$REN_{ou} = \min\left(ED_{total},\ REN_{gen}\right) \quad [5]$$

$$EC_{grid} = ED_{total} - REN_{ou} \quad [6]$$

$$REN_{sp} = \max\left(REN_{gen} - ED_{total}\,, 0\right) \quad [7]$$

REN_{wind}. hourly renewable energy, generated by wind-power [kWh]
REN_{PV}.. hourly renewable energy, generated by PV [kWh]
REN_{gen}.. total generated renewable electrical energy in a given hour [kWh]
ED_{st}...... total hourly electrical demand of skiing-resort [kWh]
ED_{ht}...... total hourly electrical demand of hotels & lodges [kWh]
ED_{total}.... total hourly electrical demand of skiing-resort, hotels & lodges [kWh]
REN_{ou}... own used renewable energy in a given hour [kWh]
REN_{sp}... surplus renewable energy in a given hour (for grid feed-in) [kWh]
EC_{grid}.... electricity consumed from grid a given hour [kWh]

$$AE_{ou} = \sum_{h=1}^{8670}\left(REN_{ou}\right) \quad [8]$$

$$AE_{grid} = \sum_{h=1}^{8670}\left(EC_{grid}\right) \quad [9]$$

$$AE_{sp} = \sum_{h=1}^{8670}\left(REN_{sp}\right) \quad [10]$$

$$AV_{ou} = \sum_{h=1}^{8670}\left(REN_{ou} \times EP_{buy}\right) \quad [11]$$

$$AV_{grid} = \sum_{h=1}^{8670}\left(EC_{grid} \times EP_{buy}\right) \quad [12]$$

$$AV_{sp} = \sum_{h=1}^{8670}\left(REN_{sp} \times EP_{sell}\right) \quad [13]$$

$$AA_{ou} = \frac{AV_{ou}}{AE_{ou}} \quad [14]$$

$$AA_{grid} = \frac{AV_{grid}}{AE_{grid}} \quad [15]$$

$$AA_{sp} = \frac{AV_{sp}}{AE_{sp}} \quad [16]$$

$$f_{our} = \frac{AE_{ou}}{AE_{ou}+AE_{sp}} \quad [17]$$

[6] Like shown in Figure 6 (page 10), feed-in rates are only relevant for systems > 5MW. Even if some of the following simulations are of larger systems, this only illustrates oversizing. In this case, as well, no grid tariffs for the feed-in are taken into account.

$$f_{ssp} = \frac{AE_{ou}}{AE_{ou}+AE_{grid}} \quad [18]$$

$$f_{cob} = \frac{AE_{ou}+AE_{sp}}{AE_{ou}+AE_{grid}} \quad [19]$$

Here are the Key-figures:

$$\boldsymbol{AA_{earn}} = \frac{\boldsymbol{AV_{ou}+AV_{sp}}}{\boldsymbol{AE_{oe}+AE_{sp}}} \quad [20]$$

$$\boldsymbol{f_{ub}} = \frac{\boldsymbol{AA_{ou}}}{\boldsymbol{AA_{grid}}} \quad [21]$$

h .... hour 1 – 8760 of analyzed period [7]
AE_{ou} ...... annual own used renewable energy [kWh]
AE_{sp} ...... annual surplus renewable energy (for grid feed-in) [kWh]
AE_{grid} .... annual electricity consumed from grid [kWh]
AV_{ou} ...... value of annual own used renewable energy [€ct]
AV_{sp} ...... value of annual surplus renewable energy (for grid feed-in) [€ct]
AV_{grid} ..... value of annual electricity consumed from grid [€ct]
AA_{ou} ...... annual weighted average value of own used renewable energy [€ct/kWh]
AA_{sp} ...... annual weighted surplus value of renewable energy (for grid feed-in) [€ct/kWh]
AA_{grid} .... annual weighted average value of electricity consumed from grid [€ct/kWh]
AA_{earn} ...... annual weighted earnings of generated electricity [€ct/kWh]
f_{our} .... own use ratio [%]
f_{ssp} .... self-sufficiency ratio (autarky) [%]
f_{cob} .... coverage on balance ratio [%]
f_{ub} .... factor use-value / buy from grid value

To illustrate the method and the different evaluations, a practical example is given below with two extreme configurations. It is true that the results for 3/30/2024 do not show particularly high returns. The plants could never be refinanced at these average prices. Nevertheless, the 24 hours (UTC) of this day shows a very good self-consumption profile.

The load profile[8] "B0010 - Hotels & Ski-Resort with Snow-Making, w/o eCar-load&Heatpumps" was selected for both cases. The only differences are the configuration of the number of wind turbines[9] and the size of the ground-mounted PV area[10]:

---

[7] Even if a leap year is included, only 8760 hours are evaluated in the simulation model. In such cases, the analysis period is from May 1st to April 29th of the leap year.
[8] Load-profiles and related scenarios are described later under sections 4 and 6
[9] Documentation on the wind turbines appears below under 5.2 - Wind turbines
[10] Documentation on the PV system appears below under 5.1 - Photovoltaic

Configuration I: 4 ha PV and 1 turbine

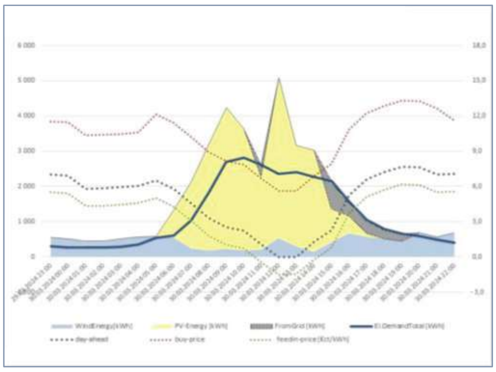


Figure 7 – Conf.I - demand- vs. gen.-profile

Configuration II: 0,5 ha PV and 4 turbines

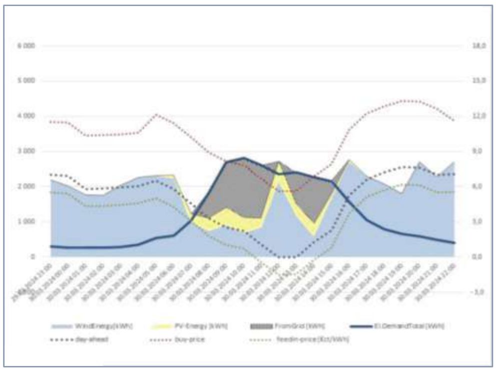


Figure 8 - Conf.II - demand- vs. gen.-profile

Table 1 - Conf.I - simulation results

total energy-demand	28 555	kWh	
total REN-generation	37 686	kWh	
thereoff PV	10 733	kWh	
thereoff wind	26 953	kWh	
buy from grid	2 372	kWh	
surplus energy sold to grid	11 503	kWh	
self-sufficiency (autarky) factor	92%		
coverage-rate on balance	132%		
payment for electricity from grid	-€ 235,80		9,94 €ct/kWh
earnings from energy sold to grid	€ 145,17		1,26 €ct/kWh
avoided costs by internal use of REN	€ 2 234,12		7,82 €ct/kWh
internal earnings from producer community	€ 2 143,50		**5,69 €ct/kWh**
relation own-use-price / buy-from-grid-price			79%

Table 2 - Conf.II - simulation results

total energy-demand	28 555	kWh	
total REN-generation	46 302	kWh	
thereoff PV	42 933	kWh	
thereoff wind	3 369	kWh	
buy from grid	7 750	kWh	
surplus energy sold to grid	25 496	kWh	
self-sufficiency (autarky) factor	73%		
coverage-rate on balance	162%		
payment for electricity from grid	-€ 569,93		7,35 €ct/kWh
earnings from energy sold to grid	€ 1 269,70		4,98 €ct/kWh
avoided costs by internal use of REN	€ 1 900,00		6,65 €ct/kWh
internal earnings from producer community	€ 2 599,77		**5,61 €ct/kWh**
relation own-use-price / buy-from-grid-price			90%

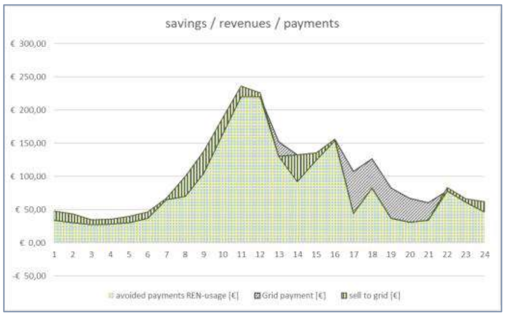


Figure 9 - Conf.I - earnings/payments

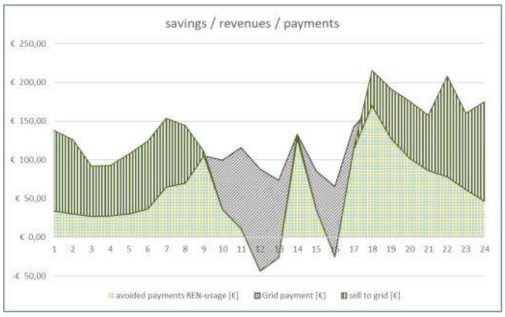


Figure 10 - Conf.II - earnings/payments

Figure 7 and Figure 8 show the common energy demand in the blue line. In contrast, the diagram areas show the production from wind (light blue) and PV (yellow) as well as the necessary purchase from the grid (gray).

Figure 7 illustrates that the energy demand is predominantly met by wind and PV, with only a minimal requirement for grid purchases during the afternoon. Configuration II in Figure 8, on the other hand, shows relatively high overproduction at night, while significant amounts of electricity have to be purchased from the grid during the day.

As the energy price at midday is almost zero, the costs for the more than 3 times larger grid-quantity in Conf.II (7750/2372 kWh) are only slightly more than twice as high (€ 570/236). These values can be found in Table 1 and Table 2, where we can also see that while Conf. II requires more than twice the electricity to be fed into the grid (25496/11503 kWh), the return is almost 9 times as high (1270/145 €).

In total, Conf.II leads to a better daily income of the producer community compared to Conf.I (2600/2144 €). The relative values are very similar (5.61/5.69 €ct/kWh).

Despite the very similar values of returns per kWh, the ratio of average prices for self-used and purchased electricity is very different. Conf. I shows 79%, Conf.II 90%, which means that the average value of self-used electricity is 90% of the average value of purchased electricity. As this value is significantly higher in Conf.II, it shows that the hours of own generation fall within those of the higher-value variable electricity prices.

Figure 9 and Figure 10 show the assessed energy flows in EUR. The vertically shaded areas represent the earnings from grid feed-in. The green square areas show the avoided costs for energy procurement by own use. Gray areas represent the reduction in income by the amount of electricity purchased from the grid. Although negative amounts can be seen at noon, Figure 10 shows slightly higher earnings than Figure 9. This is due to the higher yield at night.

All in all, this means that Configuration II with the higher ratio of average prices is better on this specific day. Better in the sense of more robust against volatile energy prices. But we must never derive decisions based on the results of a single day. This is why the simulation always works with annual values and also compares the results of several years.

3.8 Assumptions for assessment

Here are my thoughts and assumptions on evaluating the results shown later in chapter 7 (p. 53 ff):

- I am assuming a degree of self-sufficiency of at least 30%. I am certain that a significant level of self-sufficiency will help us operate in terms of marketing and generating subsidies.
- The annual balance of supply is not really a relevant evaluation criterion. However, systems with high rates should be considered as pure feed-in systems. In this case, the focus is on feed-in tariffs, PPAs, etc. and not on the avoided costs by own consumption. This work is focused on optimizing the yields for self-consumption by the producer/consumer community and minor surplus feed-in. We therefore aim to ensure that this value does not significantly exceed 100% and, in the case of preferred solutions, never exceeds 150%.

- For a long-term view, changes over the next 10-20 years must be anticipated. This includes energy-saving measures, but also foreseeable developments. In this sense, the following must be taken into account:
    - Changes due to investments in ski operations and hotels. Both sectors are making great progress in terms of energy efficiency, but at the same time capacities are being increased significantly.
    - Charging electric vehicles will increase significantly over the next few years
    - Heat pumps are also increasingly being used in cool mountain regions.
    - etc.

  For this reason, the simulation model provides a number of scenarios as well as the option of percentage adjustments to particular parameters.

- There are certainly large-scale plants (PV and/or wind power) that show LRGCs in the range of only 6-7 €ct/kWh. In some cases, this is achieved with corresponding investment subsidies. Or they are installed at locations with very high yields. On the Carinthian mountains, I expect significantly higher investment and operating costs due to the local conditions. This must be taken into account when evaluating the results.

3.9 Methods for the economic appraisal of solutions

Economic performance is measured by calculating NPV (net present value) and LRGC (long run generation cost).

Nominal cash flow and break-even are also calculated. However, this is only done using an assumed discount rate (average interest rates of various investors, banks, owners, etc.). Since a virtual producer association is assumed, but no specific company form is defined, and the use of equity capital is not further defined, calculations of profit & loss, balance sheet or specific bank loans & repayments are not feasible or do not make sense.

As described above, the simulations (which are based on historical data) use the variable prices from the electricity market. The internal “customers” of the energy community are charged the same prices as if the electricity were purchased externally. In principle, we want to stick to this model for the economic evaluation, but we can only assume average prices for the future. This is described later under section 9.1 (p. 91 ff).

Definition of commercial indicators:

Net Present Value (NPV) is a financial metric used to evaluate the profitability of an investment or project. It measures the difference between the present value of cash inflows and outflows over a specified period of time, discounted at a specified rate of return.

$$\mathbf{NPV} \;=\; \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - C_0 \qquad [22]$$

$$\boldsymbol{CF_t} \;=\; R_t - C_t \qquad [23]$$

NPV: ....net present value [€]
T: ....Investment horizon [years]
t: ....year-count
CF_t: ......Cash flow in the year t [€]
C_0: ....initial investment [€]
C_t: ....annual operating & investment costs [€]
R_t: ....annual revenues [€]
r: ....risk adjusted discount rate / WACC

To calculate NPV, the cash flows associated with the investment or project for each period and the discount rate must be determined. The cash flows can be positive (inflows) or negative (outflows). The discount rate represents the desired rate of return or cost of capital.
Each cash flow is discounted by dividing it by (1+r) raised to the power of the period number. All discounted cash flows are then summed to calculate the NPV. A positive NPV indicates that the investment or project is expected to generate a positive return and can be considered worthwhile. A negative NPV indicates that the investment may not be profitable.
The annuity of cost is a series of equal cash flows received or paid at regular intervals over a period of time. In this case, it represents the annual average total cost of energy production, taking into account the value of money, and is defined by the following formulas:

$$\boldsymbol{a} = NPV * CFR \qquad [24]$$

$$\boldsymbol{CFR} = \frac{r * (1+r)^T}{(1+r)^T - 1} \qquad [25]$$

a: ....Annuity [€]
CFR: .....Capital recovery factor

Basically, long-run generation costs (LRGC) are the sum of capital costs, O&M costs, including external energy or fuel costs. It is important to note that LRGC calculations can become more complex when taking into account factors such as inflation, escalation rates for various cost components, and adjustments for capacity factors or load factors, which reflect the actual output of a power plant relative to its maximum capacity.

In our case, we simply calculate as follows:

$$\boldsymbol{LRGC} = \frac{a}{P_{rc} * FLH} = \frac{a}{E_{pa}} \qquad [26]$$

$$\boldsymbol{FLH} = \frac{E_{pa}}{P_{rc}} \qquad [27]$$

LRGC: ..long run generation costs [€]
Prc:.......rated capacity of the power-plant [MW]
FLH: .....Full load hours [hrs]
Epa:......average annual produced energy of the plant [MWh]

The resulting FLH and LRGC now allow comparisons with other generation plants The LRGC can also be compared with electricity market prices or the achievable sales price for the self-generated energy.

To calculate the break-even point, we first need the cumulative cash flow:

$$\boldsymbol{CCF_t} = \sum_{t=1}^{T} CF_t - C_0 \qquad [28]$$

CCF_t .....Cumulative Cash Flow [€]

The break-even point is reached when the cumulative cash flow becomes positive (i.e., greater than or equal to zero):

$$\boldsymbol{CCF_t} \geq \boldsymbol{0} \qquad [29]$$

4 VIRTUAL MOUNTAIN-RESORT

4.1 Overview

The (currently not existing) skiing area is placed on a central Carinthian mountain with excellent wind and solar potential. The large spa resort will be right on the mountain shoulder (~1800m sea level), just below the highest mountain station (~2000m sea level).

For reasons already explained under 2.4 (page 6), this paper does not deal with any of the existing Carinthian ski resorts. It is more or less a greenfield approach. The next topics in section 4 all show configured energy profiles. Of course, real load profiles (with adjustment configuration for foreseeable changes) would be much more suitable for a real project. Unfortunately, such high-quality data is often not available.

4.2 Ski-resort

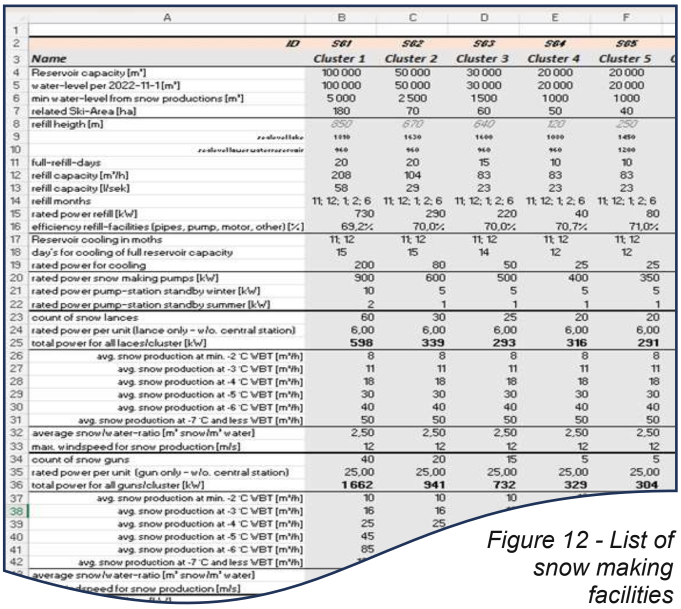
A medium-sized virtual ski resort was configured with 13 different lift types - 17 lifts in total:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1															
2	ID	L01	L02	L03	L04	L05	L06	L07	L08	L09	L10	L11	L12	L13	L14
3	**Name**	***Lift 1***	***Lift 2***	***Lift 3***	***Lift 4***	***Lift 5***	***Lift 6***	***Lift 7***	***Lift 8***	***Lift 9***	***Lift 10***	***Lift 11***	***Lift 12***	***Lift 13***	***Lift 14***
4	Units	1	1	1	1	1	1	1	1	1	1	1	4	2	0
5	Type	2 Gondola	3 chairlift-bubble	4 chairlift	4 chairlift	4 chairlift	4 chairlift	4 chairlift	4 chairlift	4 chairlift	5 drag lift	5 drag lift	5 drag lift	5 drag lift	
6	Usage	3 feeder lift	1 regular	1 regular	1 regular	4 low utilization	4 low utilization	1 regular	1 regular	2 shuttle	1 regular	1 regular	4 low utilization	4 low utilization	1 regular
7	max. wind speed [m/s]	25	18	22	18	20	20	18	18	22	25	25	25	25	20
8	Lenghts [m]	2 664	1 889	1 905	2 017	400	650	859	1 315	324	1 286	860	150	100	
9	Heigth [m]	915	464	480	414	68	152	200	288	78	340	281	50	50	0
10	*sealevel lower station*	530	1443	1003	1497	1444	1507	1702	1620	1712	1420	1630			
11	*sealevel upper station*	1445	1907	1483	1911	1512	1659	1902	1908	1790	1760	1911			
12	cabins/chairs/units	120	130	140	140	60	70	50	70	40	180	120	20	30	
13	seats per unit	4	4	4	4	2	2	6	8	4	2	2	1	1	
14	max. speed [m/s]	5,00	5,00	5,00	5,00	2,50	2,30	5,00	5,00	2,40	2,50	2,50	2,00	1,00	
15	*min journey time*	8:52	6:17	6:00	6:36	2:00	4:37	2:52	4:00	2:00	8:36	5:07	1:00	1:00	
16	capacity [max. persons / hr]	1 500	2 400	2 400	2 400	1 400	900	2 500	3 400	2 100	1 200	1 200	500	500	
17	rated power [kW]	600	500	500	450	40	60	220	420	75	160	150	10	6	
18	*standby [kW]*	0,5	0,3	0,3	0,3	0	0	0	0,20	0	0	0	0	0	
19	*theoretical net energy per person/journey [kWh]*	0,199	0,101	0,105	0,090	0,015	0,033	0,044	0,063	0,017	0,074	0,061	0,011	0,007	0,000
20	total capacity per system [max. persons / hr]	1 500	2 400	2 400	2 400	1 400	900	2 500	3 400	2 100	1 200	1 200	2 000	1 000	0
21	total rated power per system [kW]	600	500	500	450	40	60	220	420	75	160	150	40	12	0
22															
23	Winter saison-start [weeks to Christmas]	-4	-4	-3	-4	-2	-2	-4	-4	0	0	0	0	0	0
24	*start-date winter 2021/2022*	*Saturday, 27.11.2021*	*Saturday, 27.11.2021*	*Saturday, 04.12.2021*	*Saturday, 27.11.2021*	*Saturday, 11.12.2021*	*Saturday, 11.12.2021*	*Saturday, 27.11.2021*	*Saturday, 27.11.2021*	*Saturday, 25.12.2021*	*Saturday, 25.12.2021*	*Saturday, 25.12.2021*	*Saturday, 25.12.2021*	*Saturday, 25.12.2021*	*Saturday, 25.12.2021*
25	*start-date winter 2022/2023*	*Saturday, 26.11.2022*	*Saturday, 26.11.2022*	*Saturday, 03.12.2022*	*Saturday, 26.11.2022*	*Saturday, 10.12.2022*	*Saturday, 10.12.2022*	*Saturday, 26.11.2022*	*Saturday, 26.11.2022*	*Sunday, 25.12.2022*	*Sunday, 25.12.2022*	*Sunday, 25.12.2022*	*Sunday, 25.12.2022*		
26	*start-date winter 2023/2024*	*Saturday, 25.11.2023*	*Saturday, 25.11.2023*	*Saturday, 02.12.2023*	*Saturday, 25.11.2023*	*Saturday, 09.12.2023*	*Saturday, 09.12.2023*	*Saturday, 25.11.2023*	*Saturday, 25.11.2023*	*Monday, 25.12.2023*					
27	Winter saison-end [+/- weeks to Easter]	1	1	0	0	0	-2	1	1						
28	*season end winter 2021/2022*	*Sunday, 24.04.2022*	*Sunday, 24.04.2022*	*Monday, 18.04.2022*	*Monday, 18.04.2022*	*Monday, 18.04.2022*	*Sunday, 03.04.2022*								
29	*season end winter 2022/2023*	*Sunday, 16.04.2023*	*Sunday, 16.04.2023*	*Monday, 10.04.2023*	*Monday, 10.04.2023*	*Monday, 10.04.2023*									
30	*season end winter 2023/2024*	*Sunday, 07.04.2024*	*Sunday, 07.04.2024*	*Monday, 01.04.2024*	*Monday, 01.04.2024*										

Figure 11 - configuration of ski lifts

The configuration for synthetic snow production comprises 5 reservoirs of different sizes and the associated snow cannons and lances.

Further details on the configuration of lifts and snowmaking systems can be found in the appendix (2), page 120 ff.

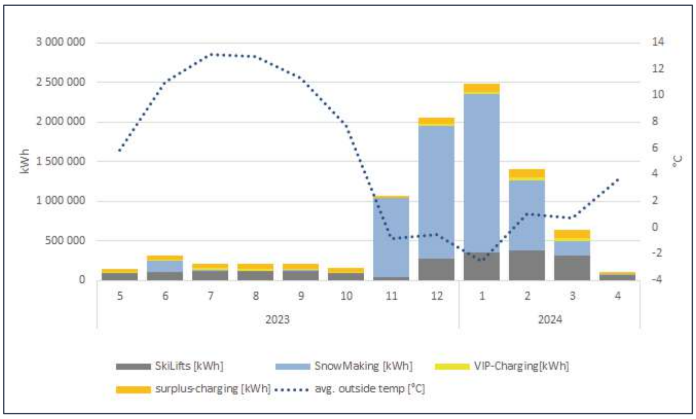


	A	B	C	D	E	F
1						
2	ID	SG1	SG2	SG3	SG4	SG5
3	Name	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
4	Reservoir capacity [m³]	100 000	50 000	30 000	20 000	20 000
5	water-level per 2022-11-1 [m³]	100 000	50 000	30 000	20 000	20 000
6	min water-level from snow productions [m³]	5 000	2 500	1500	1000	1000
7	related Ski-Area [ha]	180	70	60	50	40
8	refill heigth [m]	850	670	640	120	250
9	[illegible]	1810	1630	1600	1000	1450
10	[illegible]	960	960	960	960	1200
11	full-refill-days	20	20	15	10	10
12	refill capacity [m³/h]	208	104	83	83	83
13	refill capacity [l/sek]	58	29	23	23	23
14	refill months	11; 12; 1; 2; 6	11; 12; 1; 2; 6	11; 12; 1; 2; 6	11; 12; 1; 2; 6	11; 12; 1; 2; 6
15	rated power refill [kW]	730	290	220	40	80
16	efficiency refill-facilities (pipes, pump, motor, other) [%]	69,2%	70,0%	70,0%	70,7%	71,0%
17	Reservoir cooling in moths	11; 12	11; 12	11; 12	11; 12	11; 12
18	day's for cooling of full reservoir capacity	15	15	14	12	12
19	rated power for cooling	200	80	50	25	25
20	rated power snow making pumps [kW]	900	600	500	400	350
21	rated power pump-station standby winter [kW]	10	5	5	5	5
22	rated power pump-station standby summer [kW]	2	1	1	1	1
23	count of snow lances	60	30	25	20	20
24	rated power per unit (lance only - w/o. central station)	6,00	6,00	6,00	6,00	6,00
25	total power for all laces/cluster [kW]	**598**	**339**	**293**	**316**	**291**
26	avg. snow production at min. -2 °C WBT [m³/h]	8	8	8	8	8
27	avg. snow production at -3 °C WBT [m³/h]	11	11	11	11	11
28	avg. snow production at -4 °C WBT [m³/h]	18	18	18	18	18
29	avg. snow production at -5 °C WBT [m³/h]	30	30	30	30	30
30	avg. snow production at -6 °C WBT [m³/h]	40	40	40	40	40
31	avg. snow production at -7 °C and less WBT [m³/h]	50	50	50	50	50
32	average snow/water-ratio [m³ snow/m³ water]	2,50	2,50	2,50	2,50	2,50
33	max. windspeed for snow production [m/s]	12	12	12	12	12
34	count of snow guns	40	20	15	5	5
35	rated power per unit (gun only - w/o. central station)	25,00	25,00	25,00	25,00	25,00
36	total power for all guns/cluster [kW]	**1 662**	**941**	**732**	**329**	**304**
37	avg. snow production at min. -2 °C WBT [m³/h]	10	10	10		
38	avg. snow production at -3 °C WBT [m³/h]	16	16			
39	avg. snow production at -4 °C WBT [m³/h]	25	25			
40	avg. snow production at -5 °C WBT [m³/h]	45				
41	avg. snow production at -6 °C WBT [m³/h]	85				
42	avg. snow production at -7 °C and less WBT [m³/h]					
	average snow/water-ratio [m³ snow/m³ water]					

Figure 12 - List of snow making facilities

As mentioned above (2.5, page 6), this work only includes data for ski/lift operation and snow production. Energy consumption for snow grooming, logistics, etc., as well as travel to/from the resort are not included. For special future scenarios, the charging of electric vehicles is also simulated.

Energy requirements for $S2023_{SW}$[11]:



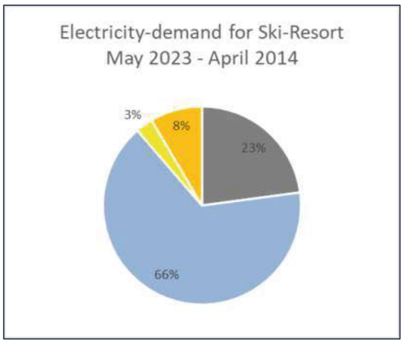


Figure 13 - Electricity demand for ski resort '23/24

Table 3 - electricity demand skiing 2023/24

year starts with summer-season on May 1st 2023		
	electricity demand	
SkiLifts	2 057 845	kWh
SnowMaking	5 916 885	kWh
VIP-Charging	252 368	kWh
surplus-charging	764 582	kWh
TOTAL	**8 991 679**	**kWh**

The ski resort is the largest consumer of electricity on the mountain. Table 3 shows almost 9 GWh of electricity demand for $S2023_{SW}$. What resort operators will notice is the very high proportion of energy used for snowmaking - double that used for ski operations (see pie chart in Figure 13). This has been configured on purpose (see

[11] $S2023_{SW}$ stands for the analyzing period with 8760 hours, beginning with May 1st 2023 to April 29th 2024,

below). The high energy input for snow preparation in January is also a little unusual. This is due to the poor climatic conditions for snow production in Nov./Dec.'23.

Some further key figures, shown in Table 4, are necessary to explain the (excessively) high energy consumption for artificial snow:

Table 4 - key figures snow production

technical snow produced in season W-23/24	3 145 028	m³
related skiing area	400	ha
avg. height of snow produce in season	0,79	m
el. energy for snowmaking incl. resavoir refill	5 916 885	kWh
el. energy consumed per m³ snow	1,88	kWh/m³
water consumption for snow-making	1 258 011	m³
water consumption / m³ snow	0,40	m³w/m³s

3 million m³ of technical snow is a lot. In many ski resorts today, it is not necessary or possible to produce this quantity. However, the average height of the technical snow of approx. 80 cm seems reasonable when taking into account that the snow produced also melts or evaporates during the season. But due to optimizations (e.g. exact snow depth measurement of the slopes via satellite), it is currently possible to manage with such or lower average values.

These values were chosen for this study because further climate changes are assumed. The demand for technical snow production will continue to increase. And those ski resorts that invest in these facilities must maintain unrestricted ski operations with the highest possible capacity utilization until the end of the season for economic reasons. This is also the reason why Figure 13 also shows an energy requirement for snow production in March. In many ski resorts, this is not common practice. Instead, the ski area is reduced to a minimum. The simulation assumes that snow is also produced in March, as long as the climatic conditions allow it. This requires a wet-bulb temperature of -2°C[12] or below.

These factors mean that snow production in the configured ski area accounts for 2/3 of the electricity requirement. On average, Austrian ski resorts account for around 35% only (cf. [9, p. 168]). But this average also includes areas in high mountain regions and on glaciers without a high demand for technical snow. In the ski area configured here, skiing takes place in the range of 900-2000 m above sea level.

The estimation of the snow requirement was set relatively high in terms of future requirements. However, this is matched by the efficiency factors of very modern systems. The key figures (see Table 4) are significantly below the typical average values. The rule of thumb "2 m³ of artificial snow requires 6 kWh of energy and 1 m³

[12] Wet-bulb temperature (WBT) combines air temperature and humidity. In case of very dry air, snow production is technically possible even at air temperatures slightly above freezing point

of water" (cf. [10]) still applies in average. The same applies to ski lifts. The configuration uses average values of the latest, efficient systems from leading manufacturers.

Here are a few insights into the energy profile:

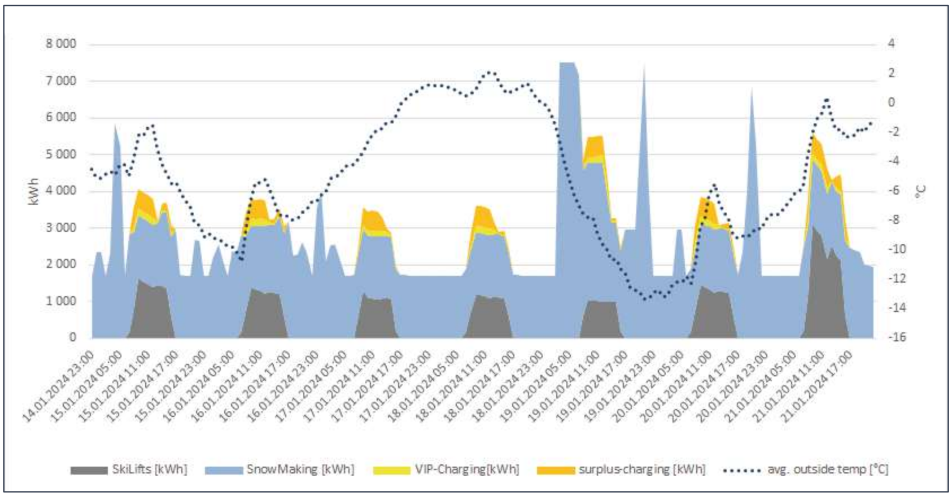


Figure 14 - Ski resort energy profile cw03, 2024

Figure 1Figure 14 shows a week in the mid-season of January. The utilization of the ski area is significantly lower on working days, but also depends on the weather. The snowmaking reservoirs are already mostly empty and need to be refilled. This requires continuous pumping. The snowmaking systems run when the weather conditions are suitable, but they sometimes stop due to a lack of water.

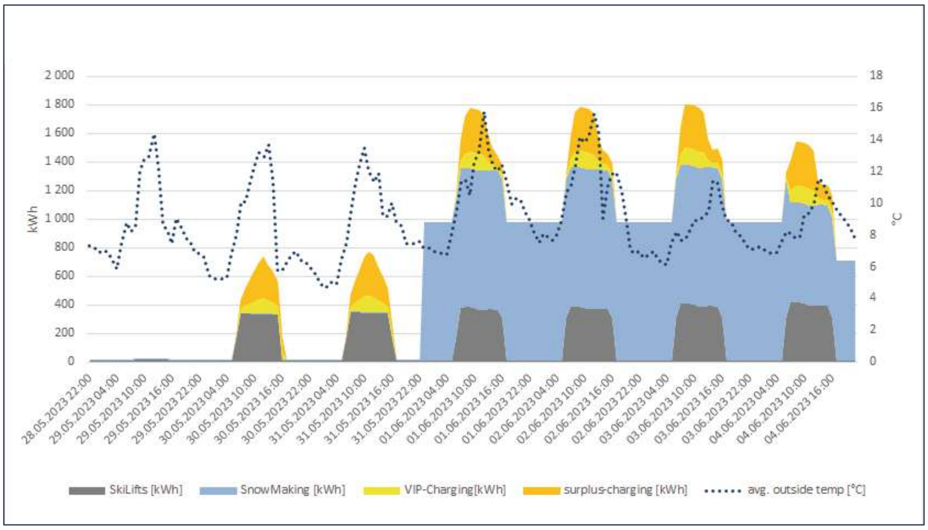


Figure 15 - Ski resort energy profile cw22, 2023

A few lifts start the summer season at the end of May. Figure 15 shows a low but relatively constant load at operating times. Capacity utilization is low during summer. Here, the transport load is not the key factor for the energy demand.

As can already be seen in Figure 13, energy is required for snow production in June. This is because the reservoirs could not be completely filled from natural sources. However, summer tourism requires a refill for a positive visual appearance.

Both figures show scenarios that have been created for future energy requirements. The charging of guests' electric vehicles is also included here. This is based on the following services and assumptions:

a) VIP-Loading

   In this special area, parking fees are charged. However, these fees are offset by the cost of the energy charged. The agreement is to get a full load during a full day on the mountain, regardless of renewable yields.

   Assumptions:

   - 25 places
   - max. 5% of guests arriving by car would like to use this option
   - avg. load-request winter/summer: 40 / 30 kWh
   - 15 kW max. load-power (reduced in morning peak-hours)

b) surplus-loading

   These parking spaces are not free either, but they are significantly cheaper. They provide very cheap electricity for electric vehicles, but only if surplus energy is available from own production.

   Assumptions:

   - 100 places
   - max. 35% / 20% (winter/summer) of guests arriving by car would like to use this option
   - avg. load-request winter/summer: 30 / 20 kWh
   - 8 kW max. load power (as long as surplus-energy is available)

Some further details could be found in section (2), in the Appendix (page 120 ff).

4.3 Hotels, cottages and other buildings

This work and the associated simulation are based on the assumption that a number of hotels, apartments and chalets are located on the ski mountain at an altitude of 1500-2000m, far away from the villages in the valley. The different facilities offer a combined maximum of 1048 beds in hotels and lodges, as well as 320 seats in separate culinary lodges.

Here you can see the corresponding configuration list from the simulation tool:

Total for seasons W-23/24 & S-23								
heat-demand	4 641 766	546 059	413 482	397 247	457 023	1 794 336	335 052	0
electricity-demand	1 955 824	208 640	29 870	195 612	308 325	730 510	566 874	0
Name	*SPA-Resort 1*	*Chalet Village A*	*Cottages*	*Hostel*	*Apartment-House*	*lower Apartment resort*	*culinary mountain lodges*	*Hotel 8*
ID	*H01*	*H02*	*H03*	*H04*	*H05*	*H06*	*H07*	*H08*
Units	1	8	20	2	1	1	4	0
Capacity (max. guests)	400	16	4	50	60	280	80	0
building outer skin per unit [m²]	14 000	480	120	1 500	1 800	8 400	640	0
building volume [m³]	23 200	800	200	2 500	3 000	13 900	1 100	0
air volume [m³]	18 600	600	200	2 000	2 400	11 100	900	0
sun-orientated window-area [m²]	350	12	3	38	45	210	16	0
U-value - mixed [W/m2/K] *(passive-house ~0,18; modern ~0,4; <2010 ~0,5, old ~0,6)*	0,35	0,50	0,70	0,60	0,40	0,50	0,70	0,40
Efficiency of heat-distribution (losses of pipes, heat-exchanger, etc.; excl. the heating-appliance itself)	90%	95%	95%	95%	90%	90%	95%	
Air change factor *[changes per hr]* (leaking window seals: 1,0; leakproof: 0,6; usual: 0,7; high person frequency >>1]	0,95	1,10	1,20	0,70	0,90	0,90	1,20	0,70
Air change factor night *[changes per hr]*	0,33	0,25	0,60	0,50				
Heat-recovery factor (ventilation heat exchanger)	50%	0%	0%					
Installed ventilation-power [kW]	7,0							

Figure 16 - List of hotels and chalets

The energy profile generated by the simulation tool is a mixture of different types of buildings and services. In any case, the main consumers are the large hotels with their wellness facilities. However, gastronomy, with the energy used to prepare meals, is also a major consumer of electricity.

4.3.1 Heat-demand

Just as snow production is the main demand in the ski resort, heat makes up the largest proportion of the hotels on the ski mountain - especially for wellness hotels:

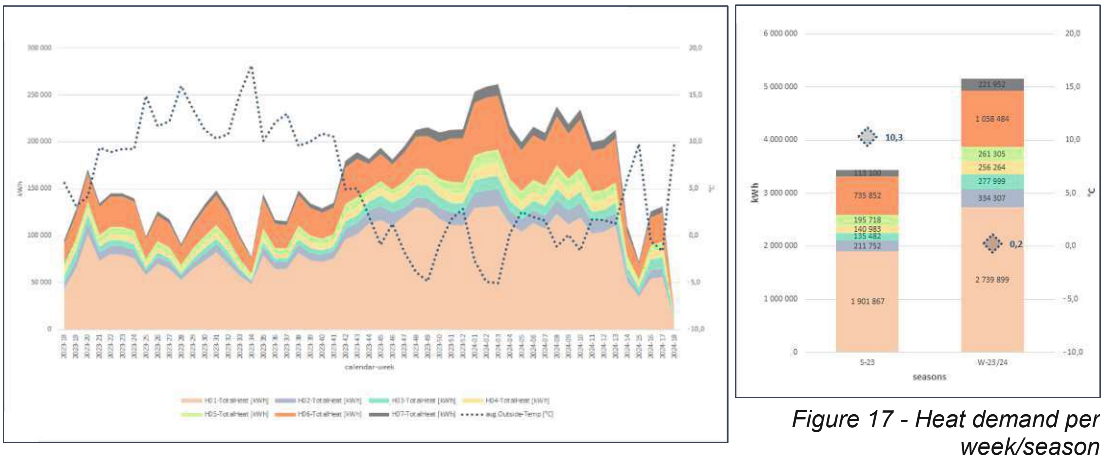


Figure 17 - Heat demand per week/season

For the very warm year 2023/24, the energy requirement for heating is 8.6 GWh. 60% in the winter season and 40% in summer and autumn (which is considered the summer season[13] on the ski mountain). This value includes the losses of the (in-house) heat distribution (incl. pipes, heat exchangers, etc.), but not the losses of the heating appliance itself.

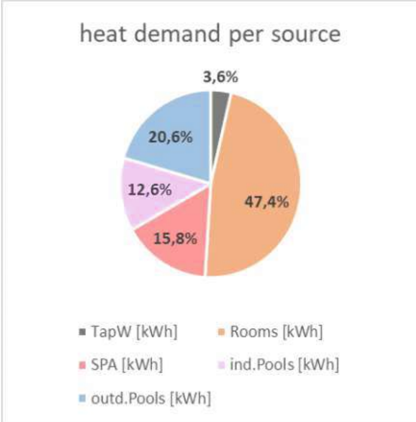


Figure 18 - heat demand per source

The main source of heat demand is space heating, as Figure 18 shows. Almost the same amount of heat is needed for the wellness facilities, including indoor and outdoor pools. At only 3.6%, hot tap water has a minor role in total heating energy. The maximum demand per hotel-type and hour are as follows:

Table 5 - max heat demand

max. heat-demand [kWh] for S-23 & W-23/24						
H01	H02	H03	H04	H05	H06	H07
1 490	177	156	180	179	570	130

I assume that the installed heating capacity must be at least 30% higher than these values to cover also colder years. The usual calculation using U-factors and HDD is insufficient, especially for wellness hotels.

All further details on the heat requirement can be found in section (3) of the Appendix (page 125 ff).

4.3.2 Electricity-demand

The electricity demand for $S2023_{SW}$ is almost exactly 4 GWh. 52% in the winter season, 48% in the summer13. But there is also a huge difference in electricity requirements between the different types of hotels and lodges:

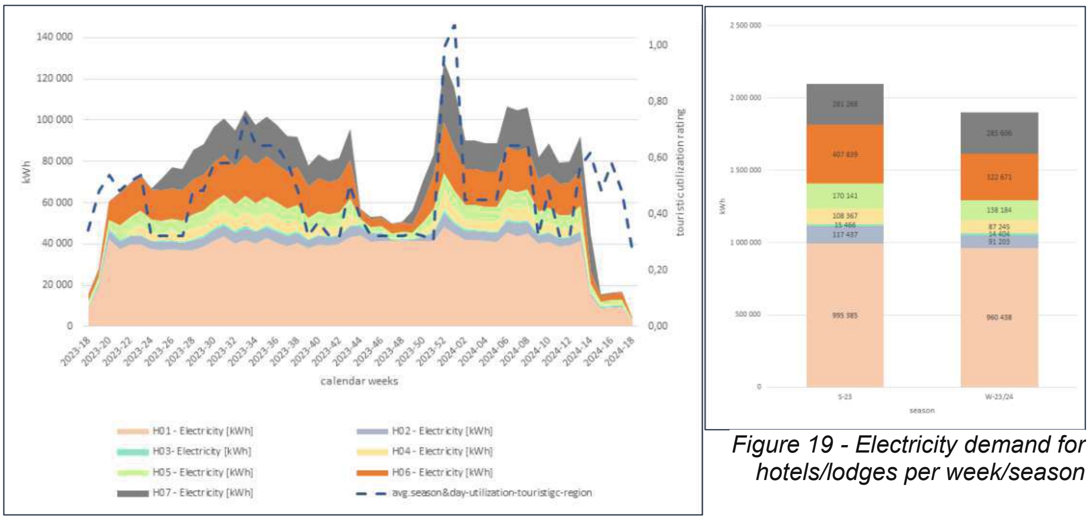


Figure 19 - Electricity demand for hotels/lodges per week/season

In Figure 19 we can see that the large wellness hotel requires around 50% of the electricity consumption on the mountain - and this is relatively constant in both summer and winter. While the electricity demand of the other accommodations and restaurants follows the tourist utilization quite closely.

The difference between the summer and winter seasons is not particularly great. This is due to the fact that there are more opening days in summer[13]. The configuration of these opening periods was chosen by me based on personal experience.

For electricity, when considering the combination with wind power and PV, the daily profiles are particularly interesting:

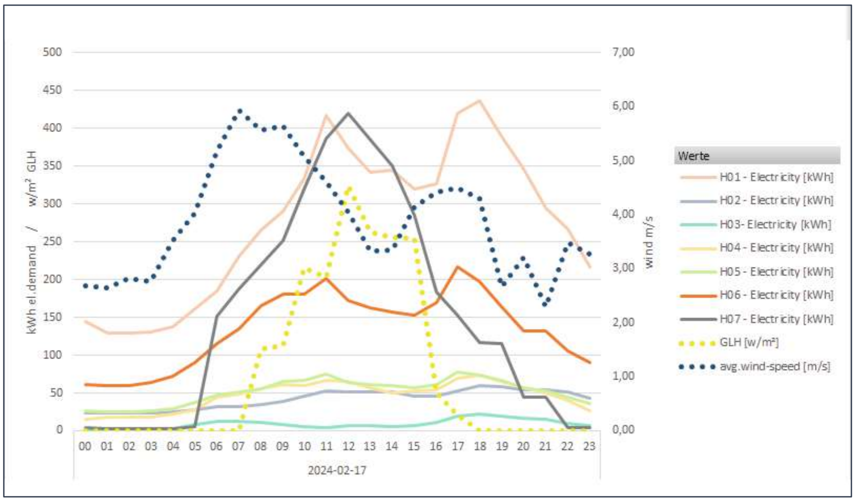


Figure 20 - Electricity day profile for hotels/lodges

[13] The summer season in this thesis is generally defined as the period from May 1 to October 30.

This selected day in February 2024 (peak season on the mountain) shows that the two hotels (H01 and H06) are very dominant in the daily profile. However, the culinary lodges H07 are also remarkable. At noon, these lead to the highest load.

It is not surprising that cooking requires a lot of electricity. Just look at the figures from various publications. For example, 1.4 kWh is calculated as the average energy consumption per skier per day for restaurants (see [9, p. 45], even if only a small number of skiers consume a hot meal). According to the sector indicators for restaurants, an average of 6 kWh of energy is required per meal (see [11, p. 128] - including refrigeration, premises, but also non-electrical energy). These factors were taken into account when configuring the energy requirements of both culinary lodges and hotels.

The first comparison (see Figure 19) with wind and solar radiation already shows that the restaurants have a very high affinity to solar radiation, while the hotels, especially on this day, could be well supplied with wind energy. But that's just a single day. The following results will show how this applies over a longer period of time.

All further details on the configured electricity demand can be found in section (3) of the Appendix (page 125 ff).

4.3.3 Electricity demand for heat-pumps

Why should heat pumps be implemented in cold mountain regions? The corresponding aspects can be found in section 5 (page 32 ff).

Many well-known manufacturers now have buildings in alpine or very cold regions on their reference list. In most cases, ground source heat pumps[14] are used, but air source heat pumps[15] are also possible in such environmental conditions.

This thesis places a significant focus on the electrical energy demand in a future scenario spanning the next 10-15 years.

For this purpose, the heat demand must be converted into the electrical demand of the heat pumps. Today, manufacturers of modern heat pumps specify COP values in the range of 4-5. Sometimes even up to 6 for water heat sources, but these are average annual values under optimum conditions. However, the value also includes

[14] iDM reference: Wimbachexpress mountain station ski area Hochzillertal
[15] Kronoterm reference: Apartment house Alpska perla in the ski resort of Cerkno, Slovenia

the losses within the heating system, possibly including an integrated hot water storage tank (excluding the losses of the subsequent heat distribution).

This paper does not use annual average COP values, but more realistic, manufacturer-independent, outdoor temperature-dependent values derived from the study "Performance of air and ground source heat pumps" (see [12, p. 5]:

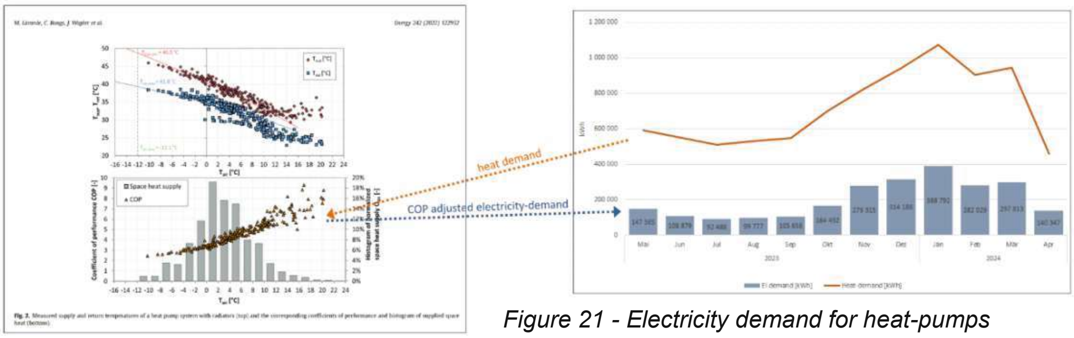


Figure 21 - Electricity demand for heat-pumps

If the entire heating output of 8.6 GWh were to be provided by such heat pumps, this would require ~2.4 GWh of electricity - 1.7 GWh in winter and 0.7 GWh in summer. This exceptionally warm year leads to very good efficiency ratings. The average COP is 3.0 in winter and 4.8 in summer. However, there are also colder years: in winter 2017/18, the same parameters would have resulted in an average COP of 2.68.

But I can't imagine that the total heat demand on the ski-mountain will be provided by heat pumps in the next few decades. Even if better performance factors would be possible with ground source heat pumps. The following simulations therefore assume that 50% of the heat is provided by heat pumps. For the other 50%, complete decarbonization will probably be achieved with biomass. This is already being used in some of the smaller huts and buildings.

4.3.4 Energy demand for charging electric vehicles for hotel guests

As already mentioned in section 3.8 (page 15 ff), there will be a significant increase in guest demand for electric vehicle charging over the next decade. This also offers hotels an additional source of income, as long as a significant share of this energy is produced from own facilities. As the guests' cars are parked at the hotel for several days, energy management with varying charging power offers advantages here.

Hotel guests spend more time on the mountain than day guests in the ski area. However, there is an unrestricted need for charging. Pure surplus charging is not enough. Therefore, the assumptions for the following simulations are:

	Name	SPA-Resort 1	Chalet Village A	Cottages	Hostel	Apartment-House	lower Apartment resort	culinary mountain lodges	Hotel 8	Hotel 9	Hotel 10
6	ID	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10
95	eCAR Plugs	100	20	0	0	10	30	0			
96	% of guests comming by car	90%	90%	100%	60%	80%	90%	60%			
97	average guests per car	2,20	2,4	1,9	2,8	1,9	2,6	2,8			
98	average lengh of stay [days]	3,20	3,8	1,8	3,5	3,5	4,2	3,5			
99	assumed % of cars with load-demand after 2030	50%	50%	0%	0%	50%	50%	0%			
100	assumed load-demand per car [kWh]	35	35	0	0	35	35	0			

Figure 22 - assumptions for electric vehicle load demand

It should also be noted that the vehicles arrive on the mountain with low batteries after a long journey, but they should only be charged to a maximum of 85%. Depending on the type of vehicle, the battery is automatically charged with 5-10 kWh during the descent. We therefore assume an average charge requirement of 35 kWh. This results in the basic charging demand of 395 kWh for the 12 months after May 1st 2023:

Figure 23 - El.vehicle load-demand hotel guests

The primary charging demand is optimized in the following simulations. Surplus energy is used primarily, and the most favorable electricity purchase prices within 18 hours are also used. This ensures that guests always receive the required charging power during their stay.

4.3.5 Combined electricity-demand for hotels and lodges

Including the two additional functions described above (heat pumps and electric cars), this results in a combined electricity demand of ~6.8 GWh for S2023$_{SW}$. Figure 24 shows some examples from the energy profile:

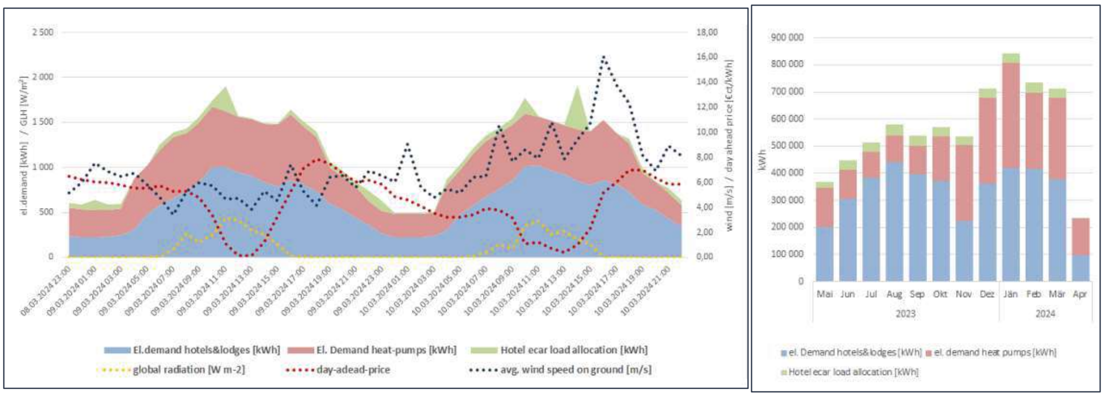


Figure 24 - combined el. day/month profile for hotels & lodges

These additional demands increase the affinity to solar radiation in the hourly profile of the 2 days shown here. On the other hand, the price on the electricity market at peak load times is close to zero. Is wind energy, with its yields at times of significantly better market prices and its higher yields in winter, perhaps more economical after all? The simulations should show this.

4.4 Metrological frame conditions

In addition to tourist capacity utilization, the weather data is of key importance for the simulations used here. All weather data are obtained from GeoSphere Austria[16] via the INCA data model. Weather data from Jan.-1st-2015 to Apr.-30th-2024 has been extracted here (in total 81792 lines of data). The data shows average values per hour in a mesh of 1000x1000 m.

Parameters and Usage:

- GLH - global, horizontal radiation [W m²]
  Is used for the specific PC yield in the given hour. But also for daily changes in the utilization of the ski area and wellness facilities (in bad weather). And the simulation also reduces the heating demand when the sun is shining.

- P0 - mean sea level pressure [Pa]
  Used to calculate the wind yield (together with wind speed).

- RH2M - relative humidity, 2 m above ground [percent]
  For calculating the evaporation of outdoor pools, but also the wet bulb temperature for snow-making (both together with air-temperature).

- RR - 1-hour precipitation sum [kg m²]
  This factor is taken into account when estimating the daily load of the ski area and vice versa when estimating the load of the wellness facilities.
  But the precipitation values have no influence on snowmaking. It is assumed that artificial snowmaking always takes place regardless of the natural snow, if the conditions allow it. However, the snow is then not stored on the slopes, but in snow depots.

[16] GeoSphere Austria, former ZAMG: https://www.zamg.ac.at/cms/de/aktuell
https://data.hub.zamg.ac.at/

- T2M - air temperature 2, m above ground [° Celsius]
  The air temperature is of course the primary factor used for the heat requirement, but also plays an important role in many other calculations (see above).

- UU - wind speed in eastward direction [m/s] and
  VV - wind speed in northward direction [m/s]
  Together, these two factors are used to calculate the wind speed (for wind yields) and wind direction.

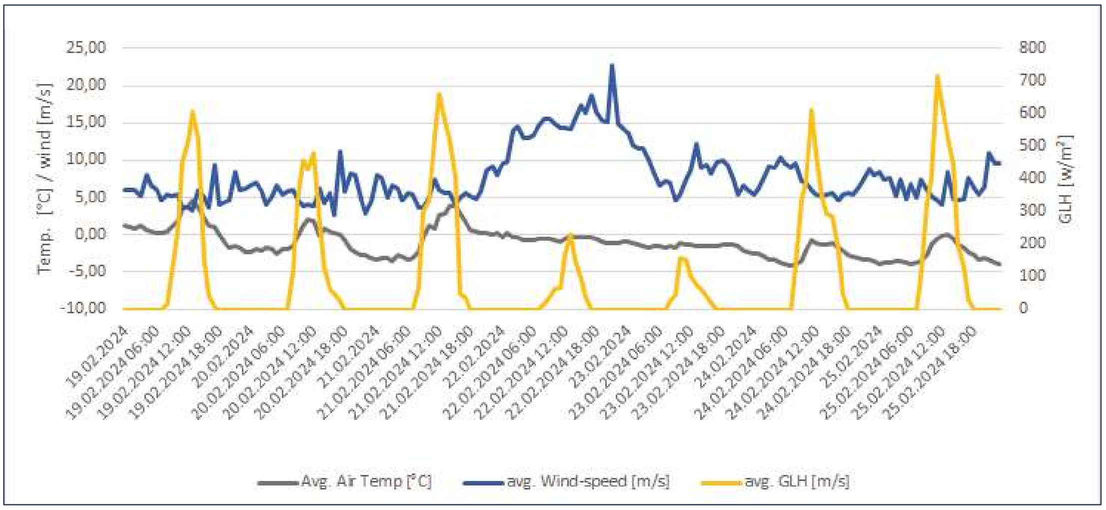


Figure 25 - Extract from INCA climate data

Figure 25 shows a small section of the INCA data with the resulting wind speed, global radiation and air temperature for the chosen Carinthian location at 1850 m above sea level.

5 OPTIONS FOR GENERATION OF RENEWABLE ENERGY

The following section describes configurations of renewable energy generation systems as they are used in the simulation model. However, some alternatives are not used. In this case, the reasons why these were not chosen are discussed.

5.1 Photovoltaic

PV systems are particularly valuable in mountain regions, as they (if installed well) have a higher yield in winter than in the valley where there is often fog. An additional yield can be achieved through the albedo effect (solar radiation reflected by the snow). Rooftop PV panels are to be welcomed, but they are not sufficient in terms of size and power output for the following configurations.

For our simulations, we assume ground mounted PV areas of different sizes from 0.5 to 6 hectares. As Figure 26 shows, the installation is specially adapted to the mountain region:

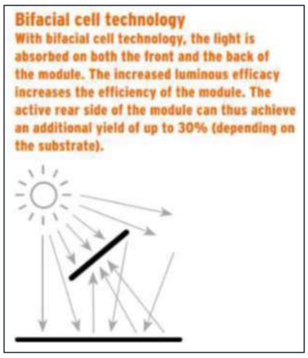


Figure 26 - rough design of ground mounted PV panels on ski-mountain

As the inclination of the panels is 65°, snow does not remain on them. In addition, due to the flat solar radiation, the yield is higher in winter than in summer. By installing double-glazed modules with bifacial cell technology, the yield increases by up to 30% in winter when the sunlight is reflected by the snow and hits the panels from behind. Although this installation with high elevation is complex and more expensive, but also avoids the need for a fence and protects the modules from contact with tourists and wildlife. In addition, this type of installation is characterized by extremely low land consumption and minimal land sealing, which is great for biodiversity.

Using this method, we can install 3360 modules (1.92 m2 each) per hectare of land. At 400 Wp per module, this makes 1344 kWp per hectare.

At the site selected for the simulations, a long-term average annual yield of 1174 kWh per kWp can be expected[17] for a south orientated PV-field. The albedo effect will further increase the yield. However, we cannot rely on the manufacturer's specifications of 30% at this point. As can be seen in Figure 27, the assumptions in this work range from 5 to 25% (depending on the snow coverage). The assumed efficiency of 87% covers the solar inverter, line losses and the grid connection (assuming 2 transformers). All in all, this results in an average annual yield of 1495 MWh per hectare. In the simulation model, the hourly yield is calculated proportionally using the GLH values specified by the climate data.

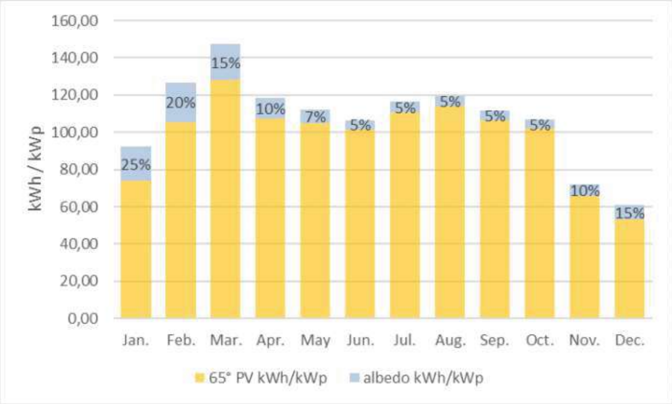


Figure 27 - PV yield at 65° tilt plus albedo-effect

All further details on the PV calculations can be found in the appendix under section (5) on page 131.

5.2 Wind turbines

Ski mountains are well suited for the installation of wind turbines. On the one hand, nature has already been impacted by the construction of ski lifts. On the other hand, much of the necessary infrastructure is already there. The existing grid connections are mostly in the power range of single wind turbines or even small wind farms. But most importantly, access roads are available. If necessary, bulky parts can even be brought up the mountain via the ski-slopes.

[17] source: https://globalsolaratlas.info/ [23]

Figure 28 - Wind turbine Vestas V52[18]

I decided to use a low-power model for the simulations in this thesis. Vestas 52 is a relatively old model. I am convinced that current systems could provide even better values in terms of efficiency. But this model, which is more than 20 years old, is very suitable here for the following reasons:

- The rotor blades with a length of only 25.3 m and the nacelle with only 22 to can be relatively easy lifted up the mountain.
- The wide range of possible tower heights is well suited to the requirements on the mountain. While very low heights (V52 min. 36.5 m) are required on the hilltop, high towers (V52 max. 86 m) are needed in wooded areas.
- The low nominal power of 850 kW is very well suited for simulations, so that an ideal energy model can be found with one, two or more turbines, and there are no large power steps in between.

Wind energy is a function of wind speed to the third power. Therefore, twice the wind speed means 8 times the wind energy. That is why an optimal location is important. Hilltops or the peaks of a mountain shoulder are generally very good locations. The last one was assumed in this paper. However, the lower air density must be taken into account at the installation altitude of 1850 m. As the INCA data contains the air pressure at sea level, this must be converted to the local pressure at the installation altitude. The following barometric formula[19] is used for this:

$$\boldsymbol{P_n} = \left(\mathbf{1} - \frac{\boldsymbol{L \times h}}{\boldsymbol{T_0} + (\boldsymbol{L \times h})}\right)^{\frac{\boldsymbol{g \times M}}{\boldsymbol{R \times L}}} \qquad [30]$$

P_0 .... air pressure at sea level [Pa or hPa]
P_n .... Air pressure at altitude h [Pa or hPa]
L .... Temperature lapse rate (typically about 0.0065 K/m)
h .... Altitude above sea level [m]
T_0.......... Standard temperature at sea level (typically 288.15 K)

[18] These photos are free for use from the data pool of wind-turbine-models.com [24]
[19] The barometric formula describes how air pressure decreases with altitude. Its valid for altitudes up to about 11 km (within the troposphere) and assuming a constant temperature.

g .... Gravitational constant (9.80665 m/s)
M .... Molar mass of Earth's air (0.0289644 kg/mol)
R........... Universal gas constant (8.3144598 J/(mol·K))

With this value we can then calculate the wind power. Related formulas are:

$$\rho \quad = \frac{P_n}{R \times T_n} \qquad [31]$$

$$P_{th} \quad = \frac{\rho}{2} \times A \times v^3 \qquad [32]$$

$$c_{p\,max} \frac{16}{27} = 0,593 \qquad [33]$$

$$P\_(th-u) \quad = P\_th \times c\_(p\,max) \qquad [34]$$

$$E\_(th\,max) \quad = P\_(th-u) \times t \qquad [35]$$

ρ .... Air density [kg/m3]
R ….. ... 287,05 J/kg/K for air
T_n …… ... Temperature at installation site in Kelvin
P_{th} .... Theoretical power, contained in the wind [W]
A ……... Vertical surface or rotor swept area at right-angles (90°) to the wind [m²]
v ….. ... Wind speed [m/s]
$C_{p\ max}$…. coefficient according to Betz
$P_{th\text{-}u}$ …. . Theoretical useable power, contained in the wind in [W]
t …… .... time in hrs

Based on these calculations, we get the maximum wind energy that we could theoretically generate. However, wind turbines cannot achieve the maximum feasible Cp value of 0.593 even under optimal conditions. Our Vestas V52 shows the maximum value of 0.462 at a wind speed of 9 m/s.

The actual wind yield for Vestas V52 was determined using these formulas and the specific cp curves. In addition, an efficiency of 94% was calculated for line losses, feed-in (assumption: 2 transformers) and all associated equipment. The resulting wind yield for $S2023_{SW}$ is as follows:

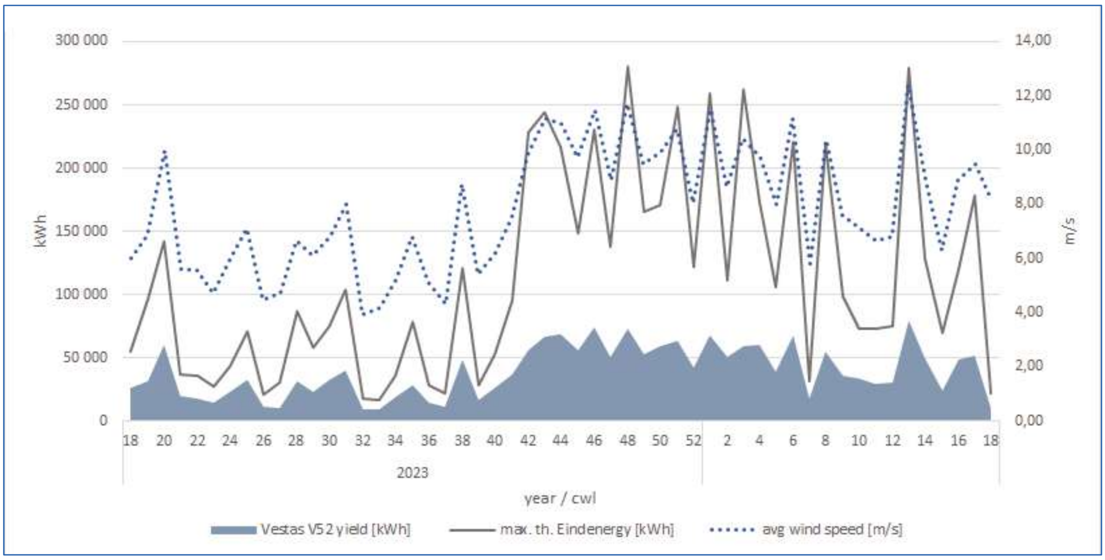


Figure 29 - wind yield by Vestas V52 per week

The calculated annual yield for the 12 months after May 1th, 2023 is ~2.07 GWh. 36% in the summer season and 64% in winter. Figure 29 shows a very strong deviation from the theoretical maximum wind energy, particularly in winter. This is due to the fact that the cp value decreases at wind speeds above 9 m/s (peak power of the turbine), at 25 m/s the turbine switches off completely.

The 2.07 GWh is the result for a specific year. Figure 30 shows the very different values for the years and months from 2015 onwards:

Vestas V52	Energy yield [kWh]											
Years / Months	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	min	max.
Qrtl1	613 547	579 648	509 162	575 154	669 817	582 544	534 563	651 019	633 749	625 789		
Jän	259 233	168 311	217 821	258 921	256 950	175 536	232 797	283 455	254 200	244 042	168 311	283 455
Feb	156 770	224 407	143 954	131 243	199 216	243 622	169 070	243 995	169 420	191 566	131 243	243 995
Mär	197 543	186 929	147 387	184 989	213 651	163 386	132 695	123 569	210 129	190 181	123 569	213 651
Qrtl2	390 640	384 472	318 192	370 654	392 381	350 698	374 800	347 918	385 328	255 339		
Apr	176 321	162 095	127 399	173 038	149 558	99 981	143 858	156 763	149 946	185 777	99 981	185 777
Mai	133 842	145 166	107 556	90 965	153 320	142 070	161 650	86 453	151 856	69 563	86 453	161 650
Jun	80 477	77 211	83 237	106 651	89 504	108 648	69 293	104 703	83 527		69 293	108 648
Qrtl3	267 284	231 231	261 999	220 379	210 643	222 242	240 583	290 240	297 650			
Jul	53 591	75 593	71 794	73 876	57 226	66 701	112 049	76 235	101 945		53 591	112 049
Aug	61 921	66 745	72 616	74 725	64 538	84 776	67 819	102 071	97 001		61 921	102 071
Sep	151 773	88 893	117 588	71 778	88 878	70 765	60 715	111 934	98 704		60 715	151 773
Qrtl4	382 204	472 192	619 178	515 954	618 373	496 606	605 728	508 130	730 229			
Okt	150 511	151 078	147 072	137 005	174 959	197 869	178 277	115 096	211 367		115 096	211 367
Nov	135 185	205 591	216 140	157 389	189 669	81 887	151 559	180 073	267 947		81 887	267 947
Dez	96 507	115 523	255 965	221 559	253 746	216 851	275 892	212 960	250 915		96 507	275 892
Gesamtergebnis	1 653 674	1 667 542	1 708 530	1 682 141	1 891 215	1 652 090	1 755 674	1 797 307	2 046 956	881 129	1 148 567	2 318 274

Figure 30 - wind per month 2015-2024

While the yield per calendar year still shows relatively manageable variations with values between 1.65 and 2.05 GWh, deviations of +/- 50% can be found in individual months. Especially in November and December. Even if we can rely on the wind yield to be higher in winter than in summer, there can be very large deviations in individual months. This is another reason why we always look at several years in the following simulations.

Further information on the specification of the wind turbines can be found in section (6) on page 133 ff in the appendix.

5.3 Solar thermal heating

Personally, I am a big supporter of solar thermal systems. Especially wellness hotels, which have also a high heat demand in summer, should use solar thermal panels to supplement their primary heating system.

However, solar thermal panels are not suitable as a primary heating system or as a significant source of heat in winter on the ski mountain. The size of the associated buffer tanks (day/night storage tanks) alone would be enormous for larger ground-mounted systems. For this reason, these systems are not used in the following simulations.

5.4 Small hydropower

Small hydropower is great, if available. In ski resorts, however, the water on the mountain is needed to make snow. The combination with small hydropower would compete with the natural refilling of the reservoirs. Or more water would have to be pumped back up from below the power plant.

For this reason, small hydropower is not included in this simulation of the energy system on the ski mountain. In special cases, however, this can make a lot of sense. Nevertheless, a rough calculation of the upside-potential with pumped storage can be found later in this paper (see next page and 8.2, p 83).

5.5 Pump power station connected to snowmaking reservoirs

For the pump power plant, we have to calculate both the pump and the generator operation. Figure 31 shows a schematic illustration of the ski area with the reservoir.

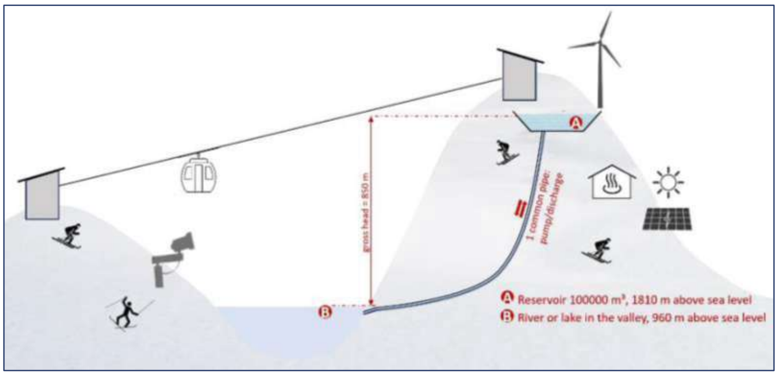


Figure 31 - Snow making reservoir with pump power plant

There is only one pipe that can be used either in pumping or discharging mode. The power that we can transmit in this configuration is limited by the capacity of the pipe and the power of the pump or turbine. In all the following calculations and simulations, we assume a pump capacity of 800 kW (possibly divided into several pump stages) and an electrical generator capacity of 560 kW.

Pumping and discharging should always be balanced within 24 hours[20]. We assume that the same amount of water is always used in pump- and generator-mode. In the case of pure pumped storage power plants, we would have to consider water losses due to evaporation and leaks. However, these losses are already present in the primary function as a snowmaking lake. In addition, water losses are compensated by a small, natural inflow.

The following formula is therefore applicable in pumping mode:

$$\boldsymbol{Q_p} \quad = \frac{\boldsymbol{P_p} \times \eta_{\boldsymbol{p}}}{\boldsymbol{\rho} \times \boldsymbol{g} \times \boldsymbol{h}} \qquad [36]$$

Q_p .... volumetric pump-flow rate [m³/s]
P_p ....pump power [W]
ρ .... density of water (approximately 1000 kg/m³)
g ....gravity (approximately 9.81 m/s²)
η_p...............total efficiency incl. transformer, motor, pump and pipe, assumed by 0,82
h ....head height [m] (to be adjusted in case of overhead inflow)

In our case:

$$\boldsymbol{Q_p} \quad = \frac{\mathbf{800000 \times 0{,}82}}{\mathbf{1000 \times 9{,}81 \times 850}} = \mathbf{0,0787}\,\frac{\mathbf{m^3}}{\mathbf{s}} = \ \mathbf{283}\,\frac{\mathbf{m^3}}{\mathbf{h}}$$

If we assume that only the amount pumped up can be discharged within 24 hours, we can also assume the same flow rate of 283 m3/h for generator operation. The formula we use is as follows:

$$\boldsymbol{P_g} \quad = \ \eta_{\boldsymbol{g}} \times \ \boldsymbol{\rho} \ \times \mathbf{10^{-3}} \ \times \ \mathbf{g} \times \boldsymbol{Q_g} \ \times \boldsymbol{h_n} \qquad [37]$$

Q_g .... volumetric pump-flow rate for generation [m³/s] (= Q_p = 283 m³/h)
Pg ....generation power [kW]
η_g...............total efficiency incl. transformer, motor, pump, assumed by 0,85
h_n ....net-head [m], assumed by 825 (~ -3%)

In our case:

$$\boldsymbol{P_p} = \ \mathbf{0,85 \times 1000 \times \ 10^{-3} \times \ 9,81 \times 0,0787 \times 825 = 541\,kW}$$

This is the electrical power that we generate in pumping mode.

[20] Background information can be found in section 8.1 (p. 53 ff)

When should we pump, when can we generate? Basically, there is a restriction that we trigger maximum level variations of +/- 7500 m3 (=15000 m^3) by pumping (see 8.1, p. 77 ff). At 283 m^3/h, there is no risk at all. In 12 hours, we would only change the water level by 2400 m^3. However, the simulation model would take such a restriction into account, as well as the very rare case that the lake is completely empty.

Now we come to the formulas that are used for the simulations. The prices for pump and generator operation must be calculated differently here than for normal own use and grid supply:

$$EP_{pump} = \begin{cases} EP_{sell} & if\ \ REN_{sp} > P_p \times 1h \\ \frac{EP_{buy} \times (P_p - REN_{sp})}{P_p \times 1\,h} + \frac{EP_{sell} \times REN_{sp}}{P_p \times 1\,h} & otherwise \end{cases} \quad [38]$$

If the pumping capacity is fully covered by surplus energy from our own generation, we can pump at the feed-in price. If not, we have to charge the market purchase price on a pro rata basis.

$$EP_{gen} = \begin{cases} EP_{buy} & if\ \ EC_{grid} > P_g \times 1h \\ \frac{EP_{sell} \times (P_g - EC_{grid})}{P_g \times 1\,h} + \frac{EP_{buy} \times EC_{grid}}{P_g \times 1\,h} & otherwise \end{cases} \quad [39]$$

If the current feed-in is higher than the generator line, we can calculate the electricity purchase price, as this is billed to the producer association. However, if we feed in less or nothing, the feed-in tariff valid at the current hour must be charged on a pro rata basis.

The description of all variables not defined here can be found above from page 11.

EP_{pump} .. hourly electricity-price for pump operation [€ct/kwh]

EP_{gen} .... hourly price for electricity generated by pump power plant [€ct/kwh]

As the day-ahead market prices are always known the day before, also pump- and generation prices could be predefined. This enables the most favorable hours for pumping and the most valuable hours for generator operation to be calculated. The simulation model always calculates these useful pumping and generator hours before zero o'clock:

First define an array with 24 prices for the next 24 hours for pump-power and sort them in ascending order:

$$EP_{pump(1)} \leq\ EP_{pump(2)}\ \leq \cdots\ EP_{pump(n)} \ldots \leq EP_{pump(24)} \quad [40]$$

The same with generation prices in descending order:

$$EP_{gen(1)} \leq\ EP_{gen(2)}\ \leq \cdots\ EP_{gen(n)} \ldots \leq EP_{gen(24)} \quad [41]$$

We can now compare the 12 smallest pump-prices with the 12 largest generate-prices and decide about pump and generate hours:

$$PE_{(h)=}\ Q_P \qquad and \qquad GE_{(h)=}\ Q_g$$

$$\text{if} \ldots.. \left(EP_{pump(n)} - EP_{gen(n)} - \Delta EP_{min}\right) > 0 \qquad [42]$$

If the entire energy demand of the community is already covered by wind and PV, the pumped storage power plant must feed into the grid. Otherwise, the generated electricity is used internally:

$$PE_{(h)=}\ 0 \qquad and \qquad GE_{(h)=}\ 0 \qquad [43]$$

n ....n^{th} largest/smallest value in the set
h ....specific hour of the year (1-8760)
here identified by the n^{th} largest/smallest values of the next 24 hours

$EP_{pump(n)}$ n-th smallest pump-price in the next 24 hours [€ct/kwh]
$EP_{gen(n)}$.. n-th largest generation price in the next 24 hours [€ct/kwh]

ΔEP_{min} .. minimal difference between buy and sell price (2,0[21] €ct/kwh)
$PE_{(h)}$...... Pump-energy in the hour of the n-th smallest price [kWh]
$GE_{(h)}$ ..... Generated-energy in the hour of the n-th largest price [kWh]

Based on this calculation, pump operation takes place during the hours with the cheapest possible prices, while generator operation takes place during the most expensive hours. If there is not at least a 2.0 €ct (=ΔEPmin) price difference, pump and generator operation will not take place.

The hourly energy-use is now calculated as follows:

$$\mathrm{GE}_{ou(\mathrm{h})} = \min\left(EC_{\mathrm{grid(h)}},\ \mathrm{GE}_{(\mathrm{h})}\right) \qquad [44]$$

$$\mathrm{GE}_{sp(\mathrm{h})} = \max\left(\mathrm{GE}_{(\mathrm{h})} - \mathrm{GE}_{ou}, 0\right) \qquad [45]$$

$$AGV_{ou} = \sum_{h=1}^{8670}\left(GE_{ou} \times EP_{buy} \right) \qquad [46]$$

$$AGV_{sp} = \sum_{h=1}^{8670}\left(GE_{sp} \times EP_{sell} \right) \qquad [47]$$

$$AGE_{tot} = AGV_{ou} + AGV_{grid} \qquad [48]$$

$GE_{ou(h)}$ .. Generated electricity for own use in the hour of the n-th largest price [kWh]
$GE_{sp(h)}$... Generated electricity fed in to grid in the hour of the n-th largest price [kWh]
AVG_{ou} ... annual generated electricity from pump power plant for own use [€]
AGV_{sp} ... annual generated electricity from pump power plant fed in to grid [€]
$GE_{sp(h)}$... total annual earnings from pump power plant [€]

[21] Multiple simulations have identified 2.0 as the optimum value for the years 2015-2023. A lower value leads to higher pump/generator use per year, but not to higher earnings. Higher values reduce the operation hours, but the earnings are also lower.

These formulas are used in the simulations to adjust the electricity price and variance of the hourly day-ahead price:

$$\boldsymbol{EP_{daya}} = \frac{\boldsymbol{1}}{\boldsymbol{n}} \sum_{h=1}^{8670} \times EP_{da} \quad [49]$$

$$\boldsymbol{EP_{adj(h)}} = \boldsymbol{EP_{daya(h)}} \times \boldsymbol{f_{pr}} + (EP_{da(h)} - \boldsymbol{EP_{daya}}) \times \boldsymbol{f_{pv}} \quad [50]$$

EP_{daya} ... yearly average day ahead price like defined under 3.5 (page 10) [€ct/kwh]
EP_{adj} ..... adjusted hourly variable electricity-price [€ct/kWh]
f_{pr} .... price-factor, usually 100%, proportional increase or decrease
f_{pv}.......... price-variance-factor, usually 100%, increase or decrease volatility

5.6 CHP

Biomass, and wood in particular, are extremely valuable renewable energy sources. This enables long-term storage and thus a balance between summer and winter energy demands. Does this mean that combined heat and power plants should preferably be used in mountain resorts, since the ski resorts in Carinthia are mostly surrounded by forests? Not necessarily - it depends!

At first glance, the benefits seem very attractive. CHP generates both heat and electrical energy with a very high overall efficiency. Table 6 shows the total energy-demand based on Scenario B0111 (see page 50):

Table 6 - energy demand heat / electricity

season	heat [GWh]		electricity [GWh]	
S-23	3,4	49%	3,6	51%
W-23/24	5,2	34%	9,8	66%
total	8,6	39%	13,4	61%

In winter, we need 66% electrical energy and only 34% heat on the mountain. In summer, the demand is almost identical. Efficient CHP's with biomass combustion work roughly in the opposite ratio - with up to 30% electrical energy. So there is no way we can generate all the electricity we need from biomass in a conventional CHP plant.

But let's assume that we could generate 8.6 GWh and 3.7 (30%) GWh of electricity, 12.3 GWh in total. That is 28% of the annual electricity demand or 56% of the combined energy demand for electricity and heat. To supply all the mountainside buildings, a district heating pipeline is needed, of course. Let's assume an overall efficiency for the heating plant, fired by woodchips, and the pipe losses of 82%. So we need 15 GWh on prime-energy.

Carinthia is very rich in wood - 75%[22] of the total area is covered with forest. As Figure 32 shows, spruce is dominant. And the average forest stock is 378 Vfm/ha.

Figure 32 - tree species and coverage Carinthia [28]

However, a large part of the woodland is protected. Only the green areas shown in Figure 33 can be harvested. That represents ~4263 km² or ~45%[23] of the country's territory. Multiplied by the average factor of 378 Vfm/ha, this results in a forest stock of ~161.1 million Vfm.

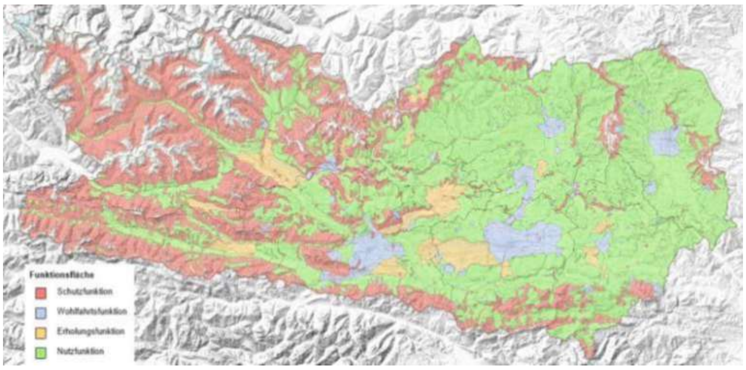


Figure 33 - Forest areas by function [29]

To convert our energy requirement of 15 GWh, we use generally applicable factors from forestry publications as follows:

$$V_{SRM} = \frac{E_p \times 10^6}{f_{eSrm}} = \frac{15 \times 10^6}{770} = 19481 \text{ SRM} \qquad [51]$$

$$m_{SRM} = V_{SRM} \times f_{m30} \times 10^{-3} = 19481 \times 223 \times 10^{-3} = 4344 \text{ to} \qquad [52]$$

V_{SRM}...... Volume loose m³ of wood-chips [SRM = loose m³]
F_{eSrm} ..... energy factor wood chips, 770 kWh/SRM for 30% watercontent
E_p .... demand for prime energy (= biomass energy demand) [GWh]
m_{srm} ...... mass of wood chips [to]
f_{m30}........ mass-factor; for wood chips with 30% water content 223 kg/SRM

For S2023$_{SW}$ (the year from May 1. 2023) we would therefore need 19481 Srm wood chips. Converted into truck deliveries, this results in 513 trips per year (38 Srm & 8,5 to per trip – see Table 7 (p. 44). That's an average of ~10 trips per week or 2 per

[22] Source: Wikipedia
[23] Identified via pixel-count: The image area of 1454976 pixels represents 17972 km². 345122 pixel are green, which corresponds to 4263 km²

working day. In winter even more. That's a lot when we consider that such mountain hotels/villages are usually only accessible via very narrow, twisting mountain roads.

But why bring the wood up the mountain when the forest is right in front of the resort? Let's take a look at the quantity of 19481 Srm - that's a soccer field, about 3 m high covered with wood chips. And that’s equal to 7792 Srm of wood (factor 0,4 – see convertion on page 116).

If we assume a recreation-time of ~80 years for spruce, we need 623377 Vfm in the forest, which is equal to 1650 ha[24], but calculated in a non-sustainable usage.

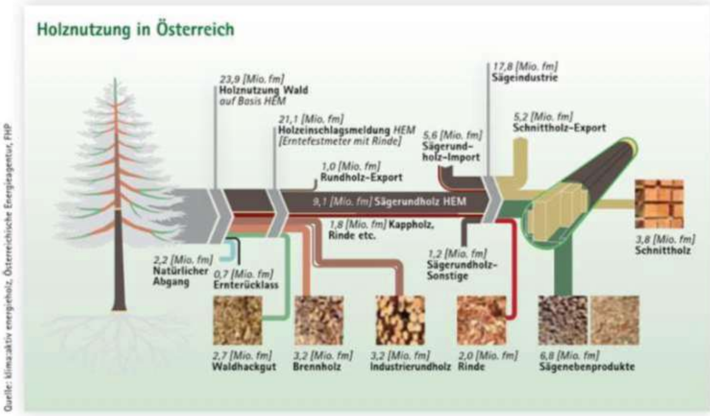


Figure 34 - usage of wood in Austria

For sustainable use, we must consider that the primary usage of wood should be sawn timber. Figure 34 shows that only 40 % of raw saw timber will be waste wood. So, the total land-usage is 4123 ha with 1,6 Mio Vfm. Thereof 60 % should be processed to sawn timber, 40 % is for combustion or industrial usage.

Conclusion: 4123 ha - that's more than 10 times the area of our ski resort, which reaches from the valley to the top of the mountain. Even if non-protected forest of this size is available all around, complex paths have to be used across the mountain or from the very bottom to the top. So, we have to bring most of the wood from the valley to the resort via the access road. In reality, damaged timber from more distant areas is usually taken for economic reasons. The average of 2 trucks per working day is therefore more than realistic.

[24] Average value of 378 Vfm per ha in Carinthia – see Figure 32 on page 37

Table 7 - Truck trips caused by different feedstock

energy carrier	wood chips	pellets	oil	propane
energy-demand	15 GWh	15 GWh	15 GWh	15 GWh
energy-density	770 kWh/Srm	5,0 kWh/kg	10,0 kWh/l	12,9 kWh/l
feedstock-demand	19 481 Srm	3 000 to	1 500 m³	1 163 m³
truck-load	38 Srm	13,5 to	19,5 m³	24 m³
truck-count per year	513	222	77	48
Small trucks for mountain access				

When comparing transportation with other fuels, wood chips perform very poorly. Pellets would reduce the transportation frequency by a factor of 2 1/2. The old, fossil fuels are even more efficient in terms of transportation: Heating oil would only result in 77 trips and propane gas only 48 trips per year. That is one eleventh of wood chip transports.

A higher frequency of heavy trucks leads to more conflicts with arriving and departing guests, but most of all to a significantly higher need for repair of the narrow, winding roads on the mountain.

Let's take a second look at the forest area required. What if all ski resorts were to use wood chip CHP plants? Let's assume that in the next 2 decades 50% of the ~30 ski resorts in Carinthia have to give up, but the remaining 15 resorts are being developed and have the average size of our virtual example. This would lead to a wood chip consumption that would require 618 km² of forest area. And it looks like this:

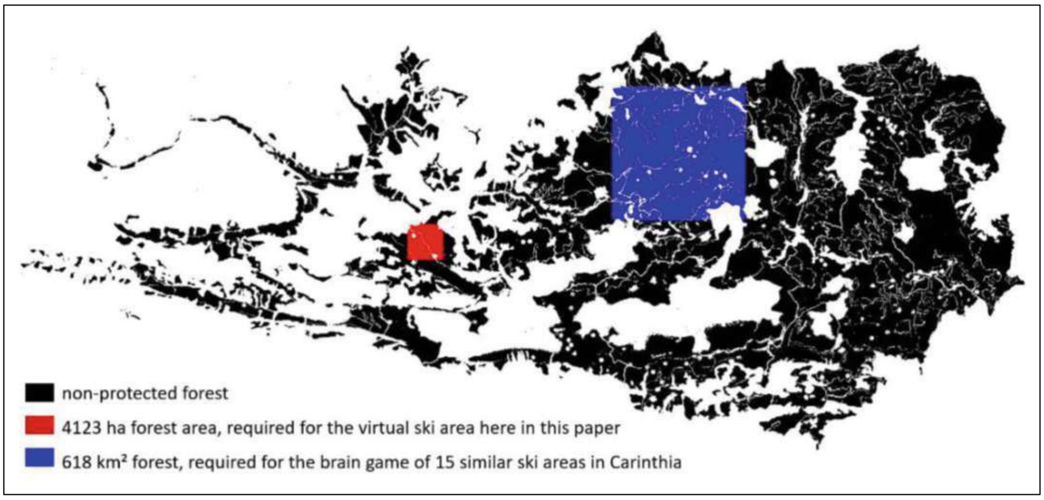


Figure 35 - proportional area of forest-needs

This mental game results in a huge area. This forest could then be used neither for industrial purposes nor for domestic heating.

Many ski and tourist resorts have already implemented biomass heating systems. They have done the right thing and made their contribution to decarbonization! But we need to take a very close look at further developments.

For the reasons mentioned here, I decided not to use CHP for a ski resort whose hotels are only accessible via distant, narrow mountain roads. Therefore, it is not included in the following simulations and results.

5.7 Biomass heating

Even if only 8.6 GWh is needed instead of 12.3 GWh, the same arguments as above apply. Therefore, conventional biomass heating systems are also not included in the following analysis.

But when using heat pumps, I assume that 50% of the heat output will be provided by various biomass systems in the future. For small units, these may be simple wood stoves. For medium-sized apartments, I suspect that pellet systems are more likely.

But, as already mentioned, these details are not part of the further analyses.

5.8 Heat pumps

As already mentioned in the previous chapters, biomass heating systems are not well qualified for large heating requirements in remote mountain villages due to complicated transportation of the feedstock. In terms of decarbonization, there are not many alternatives left for heating. Heat pumps should therefore be considered.

As shown in Table 5 (page 25), the maximum heating output was 2882 kW in total. But the heating systems should be designed for at least 30% higher output - let's assume 3800 kW.

It is described under 4.3.3 (page 27 ff), we assume for the following simulations that only 50% of the heating output is provided by heat pumps. This is 1900 kW, which is about the heating capacity needed for the large wellness hotel H01.

It is also mentioned under 4.3.3. that ground source heat pumps are the preferred option. These offer significantly higher efficiency, especially in winter. But what does ground source energy mean in reality? On the mountain, this would have to be sourced with deep boreholes.

I was able to take a look at a guide price offer that was designed for a heating capacity of 600 kW in a similar environment/sea level. A drilling length of 17200m was offered there. I assume these are 200m deep boreholes - meaning 86 individual boreholes. A conversion based on these values means: 7 kW per 200 m borehole. So for our output of 1900kW, 272 wells would be required. Assuming a distance of 10 m between each borehole, an area of 150x160 m is required, means 2.4 ha or more than 3 soccer fields.

But apart from the area required and the enormous costs (on the mountain certainly more than 100€/meter of drilling, i.e. > 20000€ per borehole), the time required for drilling is an obstacle. Even if several drills were working at the same time, this could not be done in 1-2 months. In tourist areas this time frame is usually not available. I can hardly see any possibility to realize something like this in the context of renovations, but it is feasible for new buildings, although economic decisions are a key factor here.

In reality, a combination of air-to-air and air-to-water heat pumps with booster systems for hot tap water will probably be used in renovation projects. A concrete dimensioning would exceed the scope of this paper. There is also no need, as the focus of this work is on electrical energy on the generator side. Therefore - as already described under 4.3.3 (page 27 ff) - only generally valid COP's are used to calculate the electricity demand.

But are the COP factors assumed under 4.3.3 realistic? Well, it depends - perhaps even better if the rest of the heating system is adapted to heat pumps. The lower the supply/return temperature level, the better the efficiency. This fact is highlighted both in manufacturer publications and in scientific studies. The following quote, as well as Figure 36, are taken from a study that deals specifically with this topic:

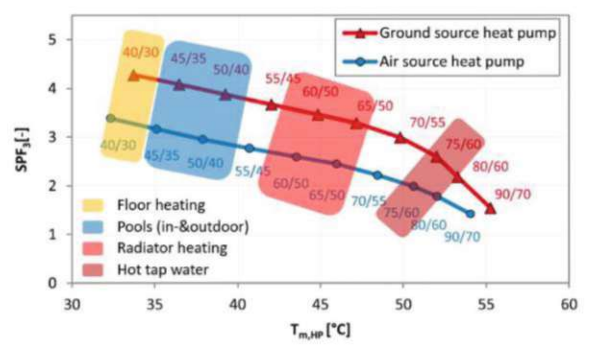


Fig. 7. Seasonal performance factor SPF_3 at varying nominal supply and return temperatures $T_{sup,nom}/T_{ret,nom}$ of the space heating circuit.

Figure 36 -Seasonal performance factor per heat-temperature [12, p. 8] with own supplement

> *"The seasonal performance factor SPF_3 increases with lower system temperatures clue to a higher COP and due to a smaller share of the backup heating system. Comparing the heat pump technologies in absolute terms, shows that the GSHP achieves a SPF_3 of 0.9 points above the ASHP. Both curves are in good agreement with the experimental results from the field*

measurements in Fig. 3. On average, SPF3 increases by 0.1 points for each Kelvin of lower mean heat pump temperatures until the curve bends distinctly above Tm : 50 °C." [12, p. 8]

Figure 36 shows SPF-values (SPF = seasonal performance factor). In contrast to COP (coefficient of performance), which in simple terms shows laboratory results for defined operating conditions, SPF shows a realistic picture of the various operating conditions over an entire heating period. The SPF_3 factor mentioned in the quote includes not only the heat pump, but also the backup system and the energy required for heat distribution. This is different from the present paper. Here, the distribution losses are already included in the heat demand. The comparable SPF values would therefore be slightly higher than the values shown in Figure 36.

Now take a look at the graphs in Figure 36 - I have color coded 4 temperature ranges.

Warm tap water (dark red): In hotels, circulation systems and heat storage tanks must be operated at this teamperature level. The return temperature must never fall below 60°C to prevent legionella. However, as Figure 18 (page 25) shows, hot tap water is of secondary importance in terms of energy consumption. At the lower end of the scale are underfloor and pool heating systems (yellow & blue). Together with room heating, these are responsible for 96% of the heating demands. Half of this (47.4% - see Figure 18) is used for space heating. If this is done with conventional radiators, then we need a temperature level of ~65°C or even higher, if we work with underfloor or ventilation heating, then we are at the very bottom end of the scale with SPF > 3.

The COP factors described under 4.3.3 are therefore also realistic for air source heat pumps, if conventional radiators are removed from the heating system and replaced with underfloor or ventilation heating systems.

5.9 Thermal ice storage

The section 8.2 - Snow-making-lakes used as source for heat-pumps (p. 83 ff) also integrates an ice store, among other things. The most important basics about thermal ice storage can be found here.

The ice storage utilizes the enormous amount of energy that is released during the changeover from water to ice. This allows very large amounts of energy to be stored over a longer period of time. Strictly speaking, storing/creating ice corresponds to the extraction of energy; while defrosting (we are talking about regeneration) corresponds to the supply of energy.

For all our calculations we use the factors for the specific heat capacity as follows:

Table 8 - heat capacity factors

	heat capacity	**conversion to Watt**
Water (0°C - ~100°C)	4.186 J / kg K	= 1.163 W / kg K ≈ 1.163 kW / m^3 K[25]
Aggregate change to ice at 0° C	335.5 J / kg K	= 93.19 W / kg K ≈ 93.19 kW / to K
Ice (-273,15°C – 0°C)	2.1 J / kg K	= 0.583 W / kg K ≈ 0.583 kW / to K

The manufacturers of ice storage tanks calculate a total heat storage capacity of ~120 kW / m^3 of water. This is based on the assumption that the water starts at ~+20°C in summer and can be cooled down to -8 or even -10°C. In our calculations we use 107.2 kW/m^3 because we assume a temperature range of +8°C to -8°C. Figure 38 shows this graphically:

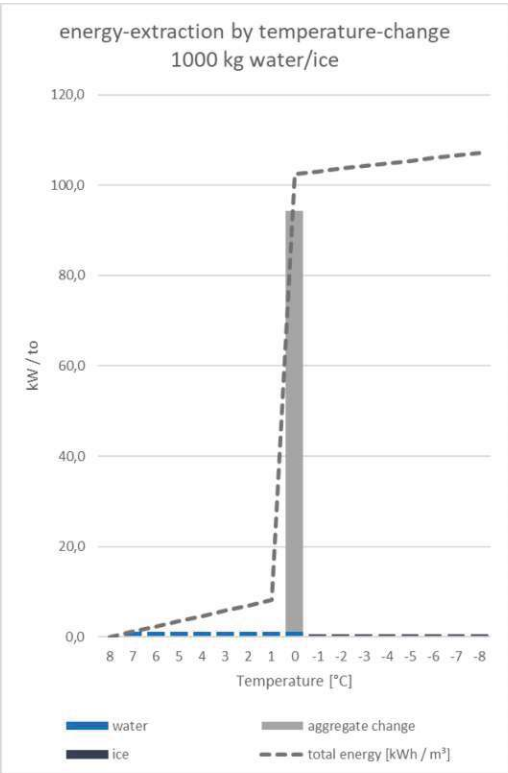


Figure 38 - heat extraction water-ice

Ice storage tanks are on offer for single-family homes as well as for large heating systems. According to the manufacturer Viessmann, the largest system installed in Austria consists of a 2000 m^3 storage cistern with a heat-capacity of 240 MWh, and has a heating output of 1500 kW. Figure 37 shows a section of such a large ice storage[26]:

Figure 37 - large scale ice-storage [33]

Heating, which means extracting heat from the ice store, takes place using a heat pump that has been specially adjusted to

[25] Assuming that the mass of 1 M³ of water is 1 ton
[26] This image has been extracted from the Viessmann folder and approved verbally

this heat source. The crucial issue for ice storage tanks, however, is the regeneration (i.e. defrosting) of the ice. Various solutions are available here, e.g. solar thermal energy is often included. Viessmann offers special air absorbers, also known as solar fences. At the end, the heat pump decides at any time whether the primary heat source is used for direct heating or for regeneration of the ice storage. If the primary heat source fails or is unable to supply enough energy, the heat pump switches to the ice store for heat-extraction.

Ice storage tanks require very precise dimensioning, which is tailored to the primary heat source as well as to the heating demand and the energy profile. According to Viessmann, the mistake of overdimensioning has often been made in the past. As a result, the heating system does not work optimally and economically.

It is also remarkable that there are generally no energy losses within the ice storage tank - only gains! When the storage tank has cooled down or ice has already formed, it slowly and continuously collects energy from the ground heat and will defrost itself.

6 SCENARIOS FOR SIMULATIONS

By mapping the different load scenarios with different sized renewable energy generation systems, an optimal system size and combined configuration of wind turbines and PV should be determined.

6.1 Electrical load

With reegard to the scenarios of the simulations, the electrical load under 4.2 (p. 19 ff) and 4.3.5 (p. 29) has been defined in different categories. For $S2300_{SW}$, this results in a theoretical total load of ~14.6 GWh:

Table 9 - combined max. electricity demand

year starts with summer-season on May 1st 2023		
	electricity demand	
SkiLifts	2,06	GWh
SnowMaking	5,92	GWh
VIP-Charging	0,25	GWh
surplus-charging	0,76	GWh
subtotal ski	8,99	GWh
Hotel	3,99	GWh
heat-pumps (50%)	1,21	GWh
e-cars	0,39	GWh
subtotal hotels	5,60	GWh
TOTAL	14,59	GWh

Please note that surplus charging is assigned depending on the configuration of the renewable generation systems. This share could be operated between 0 and 100%, depending on whether excess energy is available or not.

The following scenarios/combinations are simulated:

Table 10 - load scenaros for simulations

Hotels	w/o eCar-load & Heatpumps	H0000
	incl. Heatpumps, w/o eCar-load	H1000
	incl. eCar-load, w/o Heatpumps	H0100
	with eCar-load & Heatpumps	H1100
Ski-Resort	w/o Snow-Making & eCar-load	S0000
	with 50% Snow-Making, w/o eCar-load	S00h0
	with Snow-Making, w/o eCar-load	S0010
	with eCar-load, w/o Snow-Making	S0001
	with Snow-Making & eCar-load	S0011
together	w/o eCar-load & Heatpumps & Snow-Making	B0000
	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0
	with Snow-Making, w/o eCar-load & Heatpumps	B0010
	with Snow-Making & Heatpumps, w/o eCar-load	B1010
	with Snow-Making & eCar-load, w/o Heatpumps	B0111
	with eCar-load & Heatpumps & Snow-Making	B1111

When these two sectors think about renewable energy systems today, only scenarios H0000 (hotels without heat pumps and electric cars) and S0000/S00h0 (ski operations with/without demand for limited snow production) are considered. However, the simulations will show that it is especially the combination with other demand groups that makes sense and leads to higher profits. A brief description of the scenarios follows:

- **H0000:** Hotels only, without any need for heat pumps and without charging facilities for electric vehicles.
- **H1000:** Hotels only, including the electricity demand for heat pumps, which cover 50% of the heat demand on the mountain.

- **H0100:** Hotels only, without the electricity demand for heat pumps, but including the assumed future demand for charging guests' electric cars.
- **H1100:** Hotels only, including the electricity needs for heat pumps (for 50% of the heat demand on the mountain) and including the assumed future demand for charging guests' electric cars.
- **S0000:** Ski resort only, with the energy demand for lift operation (winter & summer), but without snow production.
- **S00h0:** Ski resort only, with the energy demand for lift operation (winter & summer) and 50 % of the energy requirement for snow production according to the simulation model. In recent years, many ski resorts will have produced snow on this scale. This option therefore corresponds more to an actual situation.
- **S0010:** Ski resort with the energy demand for lift operation (winter & summer) and 100 % of the energy demand for snow production according to the simulation model. Assuming that the surviving ski resorts will have to provide more slope area and operate longer into the spring, a significantly higher snow production was assumed for the future.
- **S0001:** Ski resort only, with the energy demand for lift operation (winter and summer), without snow production but with the possibility to charge the electric cars of visitors.
- **S0011:** Combination of S0001 and S0010 - ski resort only, including snow production (100%) and including charging facilities for electric vehicles.
- **B0000:** Combination of H0000 and S0000. Hotels, together with ski resort without any additional option.
- **B00h0:** Combination of H000 and S00h0.
- **B0010:** Combination of H000 and S0010.
- **B1010:** Combination of H100 and S0010.
- **B0111:** Combination of H010 and S0111.
- **B1111:** Combination of H1100 and S0011 – all options included.

6.2 Wind turbines & PV plants

In order to find an optimum, several power levels must be simulated.

For wind power, we use 0 to 10 turbines, as described under 5.2 (page 33), each with an output of 850 kW. The annual yield is thus simulated in steps of ~ 2 GWh between 0 and 20 GWh. Compared to the maximum electricity demand for $S2023_{SW}$ (see Table 9, p. 50) of ~ 15.8 GWh, including all options, this results in coverage on balance per year of up to 137%.

For ground-mounted PV systems, we proceed in steps of 0.5 ha, starting from 0 up to 6 ha. As we install an output of 1344 kWp per hectare, which generates an average yield of 1495 MWh per year, this results in a maximum of 8.97 GWh with 6 hectares. This corresponds to a maximum coverage on balance per year of only 61%. This seems low compared to the maximum output of wind. However, the simulations will show that even this magnitude leads to enormous overcapacity in peak-hours. In addition, it is absolutely unrealistic to find 6 ha or more (forest-free) areas with southern orientation, outside the ski slopes on such a mountain.

6.3 Pump power plant

There are no specific scenarios for pumped storage operation with the snowmaking reservoirs.

Only the scenarios and energy profiles listed above are used. The tables and diagrams in this paper always use the configuration with 2 wind turbines and 1.5 ha of PV for pumped storage analyses.

7 RESULTS

In this section, some of the simulation results mentioned under 6 (p. 50 ff) are presented and discussed. The scope of this work does not allow all the simulations that have been performed to be presented in detail. The selection was made in such a way that the findings described under “Conclusions” (chapter 10, p. 104 ff) can be well understood. All scenarios are based on the S2023sw data (365 days from May 1st 2023).

The following tables are mostly color-coded. Green always appears here as a "positive" assessment, red means "negative". Blue digits mean that the values for self-sufficiency (>= 30%) and coverage on balance per year (not significantly above 100%) are within the limits defined under 3.8 (p. 15 ff).

7.1 Hotels only

7.1.1 H0000 – Electricity without any optional demands

In this first stage, we will present and discuss the results in detail. This should also make it easier to interpret the results for the subsequent variants.

Table 11 - H0000: earnings per kWh

REN earnigs/kWh [€ct/kWh] Hotels only H0000 - w/o eCar-load & Heatpumps 365 days starting 2023-5-1 9,436		wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	11,47	9,92	9,09	8,60	8,28	8,06	7,88	7,75	7,64	7,55
672	0,5	11,68	11,32	9,94	9,15	8,66	8,34	8,10	7,92	7,79	7,67	7,58
1 344	1,0	11,03	10,88	9,76	9,06	8,62	8,31	8,08	7,91	7,78	7,67	7,58
2 016	1,5	10,07	10,27	9,44	8,87	8,48	8,21	8,01	7,85	7,73	7,63	7,54
2 688	2,0	9,30	9,71	9,10	8,64	8,32	8,09	7,91	7,77	7,66	7,57	7,49
3 360	2,5	8,72	9,24	8,80	8,43	8,17	7,97	7,81	7,69	7,59	7,51	7,44
4 032	3,0	8,30	8,85	8,53	8,24	8,02	7,85	7,72	7,61	7,52	7,45	7,38
4 704	3,5	7,96	8,53	8,31	8,07	7,89	7,74	7,63	7,53	7,45	7,39	7,33
5 376	4,0	7,70	8,27	8,10	7,92	7,76	7,64	7,54	7,46	7,39	7,33	7,28
6 048	4,5	7,48	8,04	7,93	7,78	7,65	7,55	7,46	7,39	7,33	7,28	7,23
6 720	5,0	7,30	7,85	7,77	7,66	7,55	7,46	7,38	7,32	7,27	7,22	7,18
7 392	5,5	7,15	7,68	7,64	7,54	7,45	7,38	7,31	7,26	7,21	7,17	7,14
8 064	6,0	7,03	7,53	7,51	7,44	7,37	7,30	7,25	7,20	7,16	7,13	7,09

These “earnings per kWh” represents the value AA_{earn} from equations on page 13.

At first glance, the results show that oversizing leads to a decrease in average prices. This is due to the necessary feed-in at times when market prices are low. And the larger the overcapacity, the more often this happens.

While small PV arrays still provide quite valuable contributions (> 11 €ct/kWh) on average, the values decrease rapidly with oversizing (down to 7 €ct/kWh). Only one wind turbine supplies half of the annual electricity demand (see Table 14) and shows better values than PV (see 3 ha PV = ~50%: 8.3 €ct/kwh versus 1 turbine: 11.47 €ct/kWh). Even with the smaller steps for PV, the values decrease faster than for wind.

Looking only at the values, it may not be necessary to combine PV and wind. Separately, both 1ha PV and one wind turbine are in the target range (blue number) and at values > 11 €ct/kWh.

Table 12 - H0000: relation own-use-price / buy-from-grid-price

relation own-use-price / buy-from-grid- Hotels only H0000 - w/o eCar-load & Heatpumps 365 days starting 2023-5-1 0,920		wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	1,021	1,021	1,024	1,024	1,023	1,022	1,021	1,020	1,019	1,018
672	0,5	0,916	0,971	0,976	0,979	0,980	0,981	0,981	0,982	0,982	0,982	0,983
1 344	1,0	0,911	0,939	0,942	0,946	0,947	0,948	0,950	0,951	0,952	0,953	0,953
2 016	1,5	0,903	0,918	0,920	0,923	0,924	0,925	0,927	0,928	0,929	0,930	0,931
2 688	2,0	0,899	0,907	0,908	0,910	0,912	0,913	0,914	0,916	0,917	0,917	0,918
3 360	2,5	0,897	0,901	0,901	0,903	0,904	0,905	0,906	0,907	0,908	0,909	0,910
4 032	3,0	0,896	0,896	0,896	0,897	0,898	0,899	0,900	0,901	0,902	0,903	0,904
4 704	3,5	0,896	0,893	0,892	0,893	0,894	0,895	0,896	0,897	0,898	0,899	0,899
5 376	4,0	0,897	0,892	0,890	0,891	0,891	0,892	0,894	0,895	0,896	0,896	0,897
6 048	4,5	0,897	0,890	0,888	0,889	0,889	0,890	0,892	0,893	0,894	0,894	0,895
6 720	5,0	0,898	0,889	0,887	0,887	0,888	0,889	0,890	0,892	0,892	0,893	0,894
7 392	5,5	0,898	0,889	0,886	0,887	0,887	0,889	0,890	0,891	0,892	0,892	0,893
8 064	6,0	0,899	0,888	0,886	0,886	0,887	0,888	0,890	0,891	0,892	0,892	0,893

The ratio shown in Table 12 corresponds to the formula for f_{ub} on page 13.

Remarkable is the relatively constant value of ~1.02 for all configurations of wind power (without PV). The values for PV are all lower and also fall slightly the larger the system becomes. This shows us that wind gives us yields at hours with higher market prices, which we need in our energy profile. Wind is therefore a better fit for our energy profile than PV (at least when looking at $S2023_{SW}$).

In order to sharpen the understanding and relevance of this ratio, we will go into more detail here. To do this, we need to take the view of the (virtual) producer group described under 3.4 (p. 9 ff). Within this producer group, the energy used is always the same price for the individual consumer, regardless of whether it is produced internally or purchased from the grid. In the case of in-house production, the market price and (avoided) surcharges (grid fees, etc.) are passed on to the producer group. This refinances the investment and operating costs of the system. But the value is the same as with grid procurement, depending only on the market price of the particular hour.

The following Figure 39 and Figure 40 show the data from column 3 (2 turbines) in Table 12 with the gray frame. We follow the ratio from 1.021 without PV to 0.886 for 6 ha PV:

The absolute figures show the quantities and values for the electricity required in the producer group for S2023$_{SW}$. Self-consumption is shown in green and positive. These values are mainly intended to cover the costs of the plant. The revenues for feed-in overcapacities are not shown here on purpose. In contrast, the electricity purchases (quantity and value) are shown in negative and gray. Not surprisingly, Figure 39 shows that with higher installed capacity, self-consumption increases and the necessary additional purchases decrease. Without showing the feed-in values, which would allow a profit assessment, it is not possible to see any advantages or disadvantages of the several configurations.

Figure 39 - own use / buy (absolute values)

In Figure 37, we can see that on the far left (without PV) the self-generated energy is valued slightly higher than the purchased energy. The two wind turbines therefore supply us with electricity in hours for S2023$_{SW}$ at slightly higher market prices than the average cost of the remaining purchased electricity. The rightmost figure (6 ha PV) shows that the average price for the (much smaller) additional purchase is significantly higher, while the value for the slightly higher own consumption has decreased. All in all, this ratio should give us an indicator of whether the configuration fits our consumption profile (regardless of commercial considerations).

Figure 40 - ratio own use / buy price

Once again in simple words. Assuming the producer group had invested in 4 ha of PV, the following discussions would arise based on the results of S2023$_{SW}$:

> *"We have invested a lot. Now it turns out that the bills from our electricity supplier have not fallen much. The electricity we produce ourselves costs almost nothing at midday, while we are still buying in expensive electricity from outside. Our investment can practically only be refinanced through the avoided grid fees, but this is not enough. Now we are supposed to pay additional money for the loans?"*

The following tables shows the yields in relation to the energy production group's own consumption.

Table 14 shows the degree of self-sufficiency, while Table 13 shows the annual balance between consumption and self-generated energy (including grid feed-in). These two tables are also used to define the blue digits, as described in the assumptions under 3.8 (p. 15 ff).

Table 13 - H0000: self sufficiency

self-sufficiency (autarky) factor		wind turbine installed power [kW]										
Hotels only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
H0000 - w/o eCar-load & Heatpumps		wind turbine count										
365 days starting 2023-5-1	0,768	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	0%	37%	50%	56%	60%	62%	64%	66%	67%	68%	69%
672	0,5	17%	52%	63%	68%	71%	73%	74%	75%	76%	77%	77%
1 344	1,0	31%	63%	72%	76%	78%	80%	81%	82%	82%	83%	83%
2 016	1,5	39%	69%	77%	80%	82%	84%	85%	85%	86%	86%	86%
2 688	2,0	44%	72%	79%	82%	84%	86%	86%	87%	87%	88%	88%
3 360	2,5	46%	74%	81%	84%	86%	87%	87%	88%	88%	89%	89%
4 032	3,0	49%	75%	82%	85%	86%	88%	88%	89%	89%	89%	90%
4 704	3,5	50%	76%	83%	86%	87%	88%	89%	89%	90%	90%	90%
5 376	4,0	52%	77%	83%	86%	88%	89%	89%	90%	90%	90%	91%
6 048	4,5	53%	78%	84%	87%	88%	89%	90%	90%	90%	91%	91%
6 720	5,0	54%	78%	84%	87%	88%	89%	90%	90%	91%	91%	91%
7 392	5,5	54%	79%	85%	87%	89%	90%	90%	91%	91%	91%	91%
8 064	6,0	55%	79%	85%	88%	89%	90%	90%	91%	91%	91%	92%

Table 14 - H0000: coverage on balance per year

coverage on balance per year		wind turbine installed power [kW]										
Hotels only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
H0000 - w/o eCar-load & Heatpumps		wind turbine count										
365 days starting 2023-5-1	1,601	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	0%	52%	104%	155%	207%	259%	311%	362%	414%	466%	518%
672	0,5	19%	71%	122%	174%	226%	278%	330%	381%	433%	485%	537%
1 344	1,0	38%	89%	141%	193%	245%	297%	348%	400%	452%	504%	556%
2 016	1,5	57%	108%	160%	212%	264%	315%	367%	419%	471%	523%	574%
2 688	2,0	75%	127%	179%	231%	283%	334%	386%	438%	490%	541%	593%
3 360	2,5	94%	146%	198%	250%	301%	353%	405%	457%	509%	560%	612%
4 032	3,0	113%	165%	217%	268%	320%	372%	424%	476%	527%	579%	631%
4 704	3,5	132%	184%	236%	287%	339%	391%	443%	494%	546%	598%	650%
5 376	4,0	151%	203%	254%	306%	358%	410%	462%	513%	565%	617%	669%
6 048	4,5	170%	221%	273%	325%	377%	429%	480%	532%	584%	636%	688%
6 720	5,0	189%	240%	292%	344%	396%	447%	499%	551%	603%	655%	706%
7 392	5,5	207%	259%	311%	363%	415%	466%	518%	570%	622%	673%	725%
8 064	6,0	226%	278%	330%	382%	433%	485%	537%	589%	641%	692%	744%

If we look at the 4 tables altogether, we can see that wind power tends to fit the energy profile of H000 better than PV. In addition, we get up to 10% higher average prices for wind power than for PV (compare 3 ha PV and 2 turbines separately - both variants ~50% autarky rate). However, we can only assess this commercially if we determine the LRGC for both variants.

The variant with 0.5 ha PV and one turbine seems very attractive and balanced in all key figures: 52% self-sufficiency, 71% annual coverage on balance, 11.32 €ct/kWh. And the price ratio of 0.971 is only just below 1.0. But how will this be affected by future changes in the energy profile or growth? The next scenarios will show this.

7.1.2 H1100: Electricity, including heat pumps (for 50% of heat demand) and including electric vehicle charging

The higher the load, the better the results. Instead of the 4 GWh at H000, we now have an electricity demand of about 5.2 GWh for $S2023_{SW}$ with scenario H1100.

Table 15 - H1100: earnings per kWh

REN earnigs/kWh [€ct/kWh] Hotels only H1100 - with eCar-load & Heatpumps	365 days starting 2023-5-1 10,410	wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	12,45	10,99	9,98	9,35	8,92	8,61	8,38	8,20	8,05	7,93
672	0,5	11,83	12,19	10,93	9,99	9,38	8,96	8,65	8,42	8,23	8,08	7,95
1 344	1,0	11,49	11,81	10,75	9,90	9,34	8,93	8,64	8,41	8,23	8,08	7,95
2 016	1,5	10,80	11,24	10,41	9,70	9,20	8,84	8,56	8,35	8,18	8,04	7,92
2 688	2,0	10,06	10,63	10,03	9,45	9,02	8,70	8,46	8,26	8,11	7,98	7,87
3 360	2,5	9,44	10,10	9,67	9,20	8,84	8,56	8,34	8,17	8,03	7,91	7,81
4 032	3,0	8,96	9,66	9,36	8,97	8,66	8,42	8,23	8,08	7,95	7,84	7,75
4 704	3,5	8,58	9,29	9,07	8,76	8,50	8,30	8,13	7,99	7,87	7,77	7,69
5 376	4,0	8,28	8,98	8,83	8,58	8,36	8,17	8,02	7,90	7,79	7,71	7,63
6 048	4,5	8,02	8,70	8,61	8,41	8,22	8,06	7,93	7,82	7,72	7,64	7,57
6 720	5,0	7,81	8,47	8,42	8,25	8,09	7,95	7,84	7,74	7,65	7,58	7,52
7 392	5,5	7,62	8,26	8,25	8,11	7,98	7,86	7,75	7,67	7,59	7,52	7,47
8 064	6,0	7,47	8,09	8,10	7,98	7,87	7,77	7,68	7,60	7,53	7,47	7,41

Table 16 - H1100: relation own-use-price / buy-from-grid-price

relation own-use-price / buy-from-grid- Hotels only H1100 - with eCar-load & Heatpumps	365 days starting 2023-5-1 0,942	wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	1,012	1,017	1,017	1,019	1,018	1,018	1,017	1,016	1,015	1,015
672	0,5	0,920	0,976	0,984	0,984	0,987	0,986	0,987	0,986	0,986	0,986	0,986
1 344	1,0	0,921	0,953	0,959	0,959	0,960	0,961	0,962	0,962	0,963	0,963	0,964
2 016	1,5	0,920	0,939	0,942	0,942	0,942	0,944	0,945	0,944	0,946	0,945	0,946
2 688	2,0	0,919	0,930	0,931	0,931	0,931	0,932	0,932	0,932	0,933	0,934	0,934
3 360	2,5	0,917	0,925	0,926	0,925	0,926	0,924	0,925	0,925	0,928	0,928	0,928
4 032	3,0	0,917	0,922	0,922	0,922	0,921	0,919	0,921	0,920	0,922	0,924	0,924
4 704	3,5	0,918	0,920	0,920	0,918	0,917	0,916	0,917	0,917	0,919	0,919	0,918
5 376	4,0	0,918	0,918	0,918	0,916	0,915	0,914	0,916	0,914	0,916	0,916	0,917
6 048	4,5	0,919	0,917	0,916	0,914	0,912	0,912	0,912	0,912	0,914	0,914	0,914
6 720	5,0	0,920	0,917	0,915	0,913	0,911	0,910	0,911	0,909	0,911	0,912	0,912
7 392	5,5	0,921	0,916	0,914	0,911	0,910	0,909	0,909	0,907	0,910	0,911	0,910
8 064	6,0	0,922	0,916	0,913	0,911	0,908	0,908	0,909	0,906	0,908	0,909	0,910

Wind continues to show better key figures than PV. However, the values for PV systems have also improved.

The combination of 1 wind turbine and 1 ha PV area seems to be particularly attractive. The level of self-sufficiency is very high at 54% and is close to the annual balanced coverage of 64%. The price ratio of 0.953 is still at a good level and the average revenue, which also includes the feed-in income, is good at 11.81 €ct/kWh.

Table 17 - H1100: self sufficiency

self-sufficiency (autarky) factor Hotels only H1100 - with eCar-load & Heatpumps 365 days starting 2023-5-1 0,714		wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	0%	32%	48%	55%	59%	62%	64%	66%	68%	69%	70%
672	0,5	13%	44%	58%	64%	68%	70%	72%	74%	75%	76%	76%
1 344	1,0	24%	54%	66%	71%	75%	77%	78%	79%	80%	81%	81%
2 016	1,5	32%	60%	71%	76%	79%	80%	82%	83%	84%	84%	85%
2 688	2,0	37%	64%	74%	78%	81%	83%	84%	85%	85%	86%	86%
3 360	2,5	40%	66%	76%	80%	82%	84%	85%	86%	87%	87%	87%
4 032	3,0	43%	68%	77%	81%	83%	85%	86%	87%	87%	88%	88%
4 704	3,5	44%	69%	78%	82%	84%	86%	87%	87%	88%	88%	89%
5 376	4,0	46%	70%	79%	83%	85%	86%	87%	88%	88%	89%	89%
6 048	4,5	47%	71%	80%	83%	85%	87%	88%	88%	89%	89%	90%
6 720	5,0	48%	72%	80%	84%	86%	87%	88%	89%	89%	90%	90%
7 392	5,5	49%	72%	81%	84%	86%	87%	88%	89%	89%	90%	90%
8 064	6,0	50%	73%	81%	84%	86%	88%	89%	89%	90%	90%	90%

Table 18 - H1100: coverage on balance per year

coverage on balance per year Hotels only H1100 - with eCar-load & Heatpumps 365 days starting 2023-5-1 1,141		wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	0%	37%	74%	111%	148%	184%	221%	258%	295%	332%	369%
672	0,5	13%	50%	87%	124%	161%	198%	235%	272%	308%	345%	382%
1 344	1,0	27%	64%	101%	138%	174%	211%	248%	285%	322%	358%	395%
2 016	1,5	40%	77%	114%	151%	188%	225%	261%	298%	335%	372%	409%
2 688	2,0	54%	91%	128%	164%	201%	238%	275%	312%	348%	385%	422%
3 360	2,5	67%	104%	141%	178%	214%	251%	288%	325%	362%	398%	435%
4 032	3,0	81%	118%	154%	191%	228%	265%	301%	338%	375%	412%	449%
4 704	3,5	94%	131%	168%	204%	241%	278%	315%	352%	388%	425%	462%
5 376	4,0	108%	144%	181%	218%	255%	291%	328%	365%	402%	439%	475%
6 048	4,5	121%	158%	195%	231%	268%	305%	342%	378%	415%	452%	489%
6 720	5,0	135%	171%	208%	245%	281%	318%	355%	392%	429%	465%	502%
7 392	5,5	148%	185%	221%	258%	295%	332%	368%	405%	442%	479%	516%
8 064	6,0	161%	198%	235%	271%	308%	345%	382%	419%	455%	492%	529%

7.2 Ski resorts only

7.2.1 S0000 – Electricity for ski-lifts, without any optional demand

It is very unusual to consider ski resorts without snow production. But in fact, some resorts have produced little or no snow in the past. These are either very high-altitude resorts / glacier ski regions, or very small family ski areas. Both types will need to invest more in this direction in the future to survive. Scenario S0000 can be used as a comparison with the past and covers ~2.1 GWh only for $S2023_{SW}$.

Table 19 - S0000: earnings per kWh

REN earnigs/kWh [€ct/kWh]		wind turbine installed power [kW]										
Ski-Resort only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
S0000 - w/o Snow-Making & eCar-load		wind turbine count										
365 days starting 2023-5-1	7,963	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	N/A	8,24	7,87	7,62	7,46	7,34	7,25	7,19	7,14	7,09	7,06
672	0,5	10,76	8,76	8,14	7,79	7,58	7,43	7,33	7,25	7,19	7,14	7,10
1 344	1,0	**9,93**	8,69	8,11	7,78	7,57	7,43	7,33	7,25	7,19	7,14	7,10
2 016	1,5	9,22	8,43	7,96	7,68	7,50	7,37	7,28	7,21	7,15	7,11	7,07
2 688	2,0	8,64	8,14	7,78	7,56	7,41	7,30	7,22	7,16	7,11	7,07	7,03
3 360	2,5	8,18	7,87	7,61	7,43	7,31	7,22	7,15	7,10	7,06	7,02	6,99
4 032	3,0	7,82	7,64	7,44	7,31	7,22	7,14	7,09	7,04	7,01	6,98	6,95
4 704	3,5	7,54	7,44	7,30	7,20	7,13	7,07	7,02	6,99	6,96	6,93	6,91
5 376	4,0	7,31	7,27	7,18	7,10	7,04	7,00	6,96	6,93	6,91	6,89	6,87
6 048	4,5	7,13	7,13	7,06	7,01	6,97	6,93	6,91	6,88	6,86	6,85	6,84
6 720	5,0	6,98	7,01	6,96	6,93	6,90	6,87	6,85	6,84	6,82	6,81	6,80
7 392	5,5	6,85	6,90	6,88	6,85	6,83	6,82	6,80	6,79	6,78	6,77	6,76
8 064	6,0	6,75	6,80	6,80	6,78	6,77	6,76	6,75	6,75	6,74	6,73	6,73

Table 20 - S0000: relation own-use-price / buy-from-grid-price

relation own-use-price / buy-from-grid-		wind turbine installed power [kW]										
Ski-Resort only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
S0000 - w/o Snow-Making & eCar-load		wind turbine count										
365 days starting 2023-5-1	1,048	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	N/A	1,100	1,093	1,091	1,091	1,089	1,086	1,084	1,082	1,080	1,078
672	0,5	0,981	1,046	1,060	1,068	1,072	1,073	1,073	1,073	1,073	1,072	1,072
1 344	1,0	**0,975**	1,034	1,052	1,061	1,066	1,067	1,069	1,071	1,072	1,073	1,073
2 016	1,5	0,970	1,028	1,048	1,056	1,063	1,067	1,070	1,073	1,075	1,076	1,076
2 688	2,0	0,961	1,020	1,039	1,050	1,058	1,063	1,066	1,069	1,070	1,071	1,072
3 360	2,5	0,954	1,012	1,032	1,044	1,052	1,057	1,061	1,063	1,064	1,065	1,067
4 032	3,0	0,948	1,005	1,025	1,037	1,044	1,049	1,052	1,054	1,055	1,056	1,058
4 704	3,5	0,943	0,998	1,017	1,029	1,036	1,040	1,043	1,045	1,046	1,048	1,049
5 376	4,0	0,939	0,991	1,009	1,021	1,027	1,031	1,034	1,035	1,036	1,037	1,038
6 048	4,5	0,934	0,984	1,002	1,013	1,019	1,022	1,024	1,025	1,026	1,027	1,028
6 720	5,0	0,930	0,977	0,995	1,004	1,009	1,012	1,013	1,014	1,015	1,016	1,016
7 392	5,5	0,927	0,971	0,987	0,995	0,999	1,002	1,003	1,003	1,004	1,004	1,004
8 064	6,0	0,924	0,965	0,979	0,987	0,991	0,993	0,994	0,994	0,994	0,994	0,994

With a small load of only ~2.1 GWh, it is difficult to find a configuration that does not immediately lead to high surplus energy. Only the option of 1 ha PV without wind is within the tight limits that we have defined under 3.8. (p. 15). Due to the relatively low earnigs/kWh, I would not consider a wind turbine with such a low load. Unless you dimension the system as a feed-in plant.

Looking only on the price-ratio, it is interesting to note that the ski area has a better affinity to wind even without snow production. Once again, wind power provides us with electricity during the hours of higher market prices. While the PV power is generated relatively synchronously with the lift operating hours, the market prices are lower during these hours. At these periods, electricity could also be purchased cheaply from the grid.

Table 21 - S0000: self sufficiency

self-sufficiency (autarky) factor		wind turbine installed power [kW]										
Ski-Resort only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
S0000 - w/o Snow-Making & eCar-load		wind turbine count										
365 days starting 2023-5-1	0,792	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	0%	23%	35%	42%	46%	49%	52%	54%	55%	57%	58%
672	0,5	29%	**49%**	58%	62%	65%	67%	69%	70%	71%	72%	73%
1 344	1,0	**49%**	65%	71%	75%	77%	78%	79%	80%	81%	81%	82%
2 016	1,5	**61%**	75%	79%	81%	83%	84%	85%	85%	86%	86%	87%
2 688	2,0	**69%**	80%	84%	86%	87%	88%	88%	89%	89%	90%	90%
3 360	2,5	74%	84%	87%	88%	89%	90%	90%	91%	91%	92%	92%
4 032	3,0	78%	86%	89%	90%	91%	91%	92%	92%	93%	93%	93%
4 704	3,5	80%	88%	90%	91%	92%	93%	93%	93%	94%	94%	94%
5 376	4,0	82%	89%	91%	92%	93%	94%	94%	94%	94%	95%	95%
6 048	4,5	84%	91%	92%	93%	94%	94%	95%	95%	95%	95%	95%
6 720	5,0	85%	92%	93%	94%	95%	95%	95%	95%	96%	96%	96%
7 392	5,5	86%	92%	94%	95%	95%	95%	96%	96%	96%	96%	96%
8 064	6,0	87%	93%	94%	95%	96%	96%	96%	96%	96%	97%	97%

Table 22 - S0000: coverage on balance per year

coverage on balance per year		wind turbine installed power [kW]										
Ski-Resort only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
S0000 - w/o Snow-Making & eCar-load		wind turbine count										
365 days starting 2023-5-1	3,108	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	0%	100%	201%	301%	402%	502%	603%	703%	804%	904%	1005%
672	0,5	37%	**137%**	238%	338%	439%	539%	640%	740%	841%	941%	1042%
1 344	1,0	**73%**	174%	274%	375%	475%	576%	676%	777%	877%	978%	1078%
2 016	1,5	**110%**	210%	311%	411%	512%	612%	713%	813%	914%	1014%	1115%
2 688	2,0	**146%**	247%	347%	448%	548%	649%	749%	850%	950%	1051%	1151%
3 360	2,5	183%	283%	384%	484%	585%	685%	786%	886%	987%	1087%	1188%
4 032	3,0	220%	320%	421%	521%	622%	722%	823%	923%	1024%	1124%	1224%
4 704	3,5	256%	357%	457%	558%	658%	759%	859%	960%	1060%	1161%	1261%
5 376	4,0	293%	393%	494%	594%	695%	795%	896%	996%	1097%	1197%	1298%
6 048	4,5	329%	430%	530%	631%	731%	832%	932%	1033%	1133%	1234%	1334%
6 720	5,0	366%	466%	567%	667%	768%	868%	969%	1069%	1170%	1270%	1371%
7 392	5,5	403%	503%	604%	704%	805%	905%	1005%	1106%	1206%	1307%	1407%
8 064	6,0	439%	540%	640%	741%	841%	942%	1042%	1143%	1243%	1344%	1444%

It should be emphasized that the 1 ha PV system leads to almost 50% self-sufficiency. The same value would be achieved by 1 wind turbine together with 0.5 ha of PV. In terms of self-sufficiency, PV is more suitable here (without snow production), but the value of the electricity is rather low at these times.

7.2.2 S00h0 – Electricity for ski-lifts including 50% snowmaking

This scenario is adapted to a current average ski resort in terms of snow production. An operation that minimizes snow production is assumed, even if limited skiing is possible later in the season. For this purpose, the model calculates 5 GWh of electricity for S2023SW.

Table 23 - S00h0: earnings per kWh

REN earnigs/kWh [€ct/kWh]		wind turbine installed power [kW]										
Ski-Resort only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
S00h0 - with 50% Snow-Making, w/o eCar-load		wind turbine count										
365 days starting 2023-5-1	9,269	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	N/A	10,200	9,591	9,111	8,760	8,491	8,280	8,108	7,969	7,854	7,759
672	0,5	11,061	10,260	9,653	9,165	8,805	8,530	8,314	8,138	7,997	7,881	7,783
1 344	1,0	10,196	9,956	9,498	9,069	8,739	8,483	8,279	8,112	7,976	7,864	7,769
2 016	1,5	9,532	9,585	9,269	8,910	8,623	8,394	8,208	8,054	7,928	7,823	7,733
2 688	2,0	9,050	9,243	9,030	8,736	8,492	8,290	8,124	7,984	7,868	7,771	7,688
3 360	2,5	8,660	8,932	8,795	8,561	8,355	8,181	8,033	7,908	7,802	7,713	7,637
4 032	3,0	8,336	8,650	8,575	8,391	8,220	8,071	7,941	7,829	7,734	7,653	7,583
4 704	3,5	8,064	8,401	8,373	8,231	8,091	7,964	7,850	7,751	7,666	7,593	7,530
5 376	4,0	7,831	8,179	8,189	8,083	7,970	7,862	7,763	7,676	7,600	7,535	7,477
6 048	4,5	7,630	7,984	8,024	7,947	7,855	7,765	7,680	7,603	7,536	7,477	7,426
6 720	5,0	7,458	7,811	7,874	7,821	7,749	7,674	7,602	7,534	7,475	7,422	7,376
7 392	5,5	7,310	7,658	7,740	7,706	7,651	7,589	7,527	7,468	7,416	7,369	7,327
8 064	6,0	7,179	7,522	7,618	7,601	7,560	7,510	7,457	7,406	7,360	7,319	7,281

Table 24 - S00h0: relation own-use-price / buy-from-grid-price

relation own-use-price / buy-from-grid-		wind turbine installed power [kW]										
Ski-Resort only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
S00h0 - with 50% Snow-Making, w/o eCar-load		wind turbine count										
365 days starting 2023-5-1	0,975	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	N/A	1,002	1,011	1,021	1,025	1,029	1,034	1,037	1,038	1,040	1,041
672	0,5	0,955	0,978	0,991	1,003	1,007	1,013	1,019	1,022	1,024	1,026	1,027
1 344	1,0	0,951	0,967	0,981	0,991	0,996	1,002	1,008	1,011	1,013	1,015	1,015
2 016	1,5	0,948	0,961	0,975	0,984	0,988	0,994	0,999	1,002	1,004	1,006	1,007
2 688	2,0	0,948	0,959	0,972	0,979	0,984	0,989	0,994	0,996	0,998	0,999	1,000
3 360	2,5	0,951	0,960	0,971	0,978	0,982	0,986	0,991	0,993	0,995	0,996	0,997
4 032	3,0	0,954	0,962	0,971	0,978	0,981	0,985	0,989	0,991	0,993	0,994	0,995
4 704	3,5	0,957	0,963	0,972	0,977	0,979	0,983	0,988	0,990	0,992	0,993	0,993
5 376	4,0	0,960	0,964	0,971	0,976	0,978	0,982	0,986	0,988	0,989	0,990	0,990
6 048	4,5	0,962	0,965	0,971	0,976	0,977	0,980	0,984	0,986	0,987	0,988	0,988
6 720	5,0	0,964	0,966	0,971	0,975	0,976	0,979	0,983	0,984	0,985	0,985	0,986
7 392	5,5	0,966	0,967	0,970	0,974	0,975	0,977	0,981	0,982	0,982	0,983	0,983
8 064	6,0	0,967	0,968	0,970	0,973	0,973	0,976	0,979	0,980	0,980	0,981	0,981

A PV field the size of 2 ha would be enough to achieve the target rate of 30% for self-generated electricity. But it's better with wind power. A turbine, combined with 0.5 ha of PV provides a much better key figures and also 40% self-sufficiency.

Table 25 - S00h0: self sufficiency

self-sufficiency (autarky) factor Ski-Resort only S00h0 - with 50% Snow-Making, w/o eCar-load 365 days starting 2023-5-1	0,572	wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	0%	22%	36%	45%	51%	55%	59%	61%	63%	65%	67%
672	0,5	13%	33%	46%	54%	60%	64%	67%	69%	71%	72%	73%
1 344	1,0	21%	40%	53%	60%	65%	69%	72%	74%	75%	77%	78%
2 016	1,5	27%	45%	57%	64%	69%	72%	75%	77%	78%	80%	81%
2 688	2,0	32%	49%	61%	67%	72%	75%	77%	79%	80%	82%	83%
3 360	2,5	36%	53%	63%	69%	74%	77%	79%	81%	82%	83%	84%
4 032	3,0	39%	55%	65%	71%	75%	78%	80%	82%	83%	84%	85%
4 704	3,5	41%	57%	67%	72%	76%	79%	81%	83%	84%	85%	86%
5 376	4,0	43%	58%	68%	73%	77%	80%	82%	83%	85%	86%	86%
6 048	4,5	44%	59%	69%	74%	78%	81%	83%	84%	85%	86%	87%
6 720	5,0	45%	60%	69%	75%	78%	81%	83%	84%	86%	86%	87%
7 392	5,5	46%	61%	70%	75%	79%	81%	83%	85%	86%	87%	88%
8 064	6,0	47%	61%	70%	76%	79%	82%	84%	85%	86%	87%	88%

Table 26 - S00h0: coverage on balance per year

coverage on balance per year Ski-Resort only S00h0 - with 50% Snow-Making, w/o eCar-load 365 days starting 2023-5-1	1,275	wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	0%	41%	82%	124%	165%	206%	247%	289%	330%	371%	412%
672	0,5	15%	56%	97%	139%	180%	221%	262%	304%	345%	386%	427%
1 344	1,0	30%	71%	112%	154%	195%	236%	277%	319%	360%	401%	442%
2 016	1,5	45%	86%	127%	169%	210%	251%	292%	334%	375%	416%	457%
2 688	2,0	60%	101%	143%	184%	225%	266%	307%	349%	390%	431%	472%
3 360	2,5	75%	116%	158%	199%	240%	281%	322%	364%	405%	446%	487%
4 032	3,0	90%	131%	173%	214%	255%	296%	337%	379%	420%	461%	502%
4 704	3,5	105%	146%	188%	229%	270%	311%	352%	394%	435%	476%	517%
5 376	4,0	120%	161%	203%	244%	285%	326%	367%	409%	450%	491%	532%
6 048	4,5	135%	176%	218%	259%	300%	341%	382%	424%	465%	506%	547%
6 720	5,0	150%	191%	233%	274%	315%	356%	397%	439%	480%	521%	562%
7 392	5,5	165%	206%	248%	289%	330%	371%	412%	454%	495%	536%	577%
8 064	6,0	180%	221%	263%	304%	345%	386%	428%	469%	510%	551%	592%

Looking only at this scenario, without the outlook for further developments (e-cars, hotels, heat-pumps, growth, etc.), I would prefer the 2 ha PV field. Although the 2 ha have a larger land use, the combination of 2 technologies would not be advisable due to the relatively limited load. The earnings/kWh are a little lower, but the operation of a single technology leads to less complexity.

7.2.3 S0011 – Electricity for ski-lifts including snow-making and e-car loading

Here is the future scenario for ski resorts. The load with increased snow production and additional charging options for guests' electric vehicles leads to ~9 GWh of electricity demand for S2023SW.

Table 27 - S0011: earnings per kWh

REN earnigs/kWh [€ct/kWh] Ski-Resort only S0011 - with Snow-Making & eCar-load 365 days starting 2023-5-1	9,974	wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	10,49	10,10	9,80	9,49	9,22	8,99	8,81	8,65	8,51	8,38
672	0,5	11,19	10,57	10,16	9,85	9,54	9,26	9,03	8,84	8,67	8,53	8,41
1 344	1,0	10,95	10,50	10,13	9,84	9,53	9,26	9,03	8,84	8,68	8,54	8,41
2 016	1,5	10,42	10,24	9,97	9,73	9,45	9,20	8,98	8,80	8,64	8,51	8,39
2 688	2,0	9,92	9,93	9,77	9,57	9,33	9,10	8,90	8,73	8,59	8,46	8,34
3 360	2,5	9,53	9,65	9,56	9,41	9,20	8,99	8,81	8,66	8,52	8,40	8,29
4 032	3,0	9,22	9,40	9,36	9,24	9,06	8,88	8,72	8,58	8,45	8,34	8,24
4 704	3,5	8,95	9,16	9,16	9,08	8,93	8,77	8,62	8,49	8,38	8,27	8,18
5 376	4,0	8,71	8,95	8,98	8,93	8,80	8,66	8,53	8,41	8,30	8,21	8,12
6 048	4,5	8,49	8,75	8,81	8,78	8,67	8,55	8,43	8,33	8,23	8,14	8,06
6 720	5,0	8,29	8,56	8,64	8,63	8,55	8,44	8,34	8,24	8,16	8,08	8,00
7 392	5,5	8,12	8,40	8,49	8,50	8,43	8,34	8,25	8,17	8,09	8,01	7,95
8 064	6,0	7,97	8,24	8,35	8,37	8,32	8,24	8,16	8,09	8,02	7,95	7,89

Table 28 - S0011: relation own-use-price / buy-from-grid-price

relation own-use-price / buy-from-grid- Ski-Resort only S0011 - with Snow-Making & eCar-load 365 days starting 2023-5-1	0,964	wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	1,002	0,998	1,002	1,009	1,013	1,016	1,018	1,020	1,021	1,024
672	0,5	0,959	0,981	0,983	0,989	0,997	1,001	1,005	1,007	1,009	1,011	1,014
1 344	1,0	0,953	0,968	0,972	0,979	0,987	0,991	0,994	0,997	0,998	1,000	1,003
2 016	1,5	0,947	0,959	0,964	0,972	0,979	0,983	0,986	0,988	0,990	0,992	0,995
2 688	2,0	0,944	0,955	0,960	0,968	0,974	0,978	0,981	0,983	0,984	0,986	0,989
3 360	2,5	0,942	0,952	0,958	0,965	0,971	0,975	0,977	0,979	0,980	0,981	0,984
4 032	3,0	0,943	0,953	0,958	0,965	0,970	0,973	0,975	0,977	0,978	0,979	0,981
4 704	3,5	0,946	0,954	0,959	0,965	0,969	0,972	0,974	0,975	0,976	0,977	0,979
5 376	4,0	0,949	0,956	0,960	0,965	0,969	0,972	0,974	0,975	0,975	0,976	0,978
6 048	4,5	0,951	0,958	0,961	0,966	0,970	0,972	0,974	0,975	0,975	0,976	0,978
6 720	5,0	0,954	0,959	0,963	0,967	0,970	0,972	0,974	0,974	0,975	0,976	0,977
7 392	5,5	0,956	0,961	0,964	0,967	0,970	0,972	0,974	0,974	0,974	0,975	0,977
8 064	6,0	0,958	0,963	0,965	0,968	0,970	0,972	0,974	0,974	0,974	0,975	0,976

Once again, the greater the load, the better the figures. A solution with PV alone no longer seems to make much sense. You would need at least 3.5 ha. When comparing one or two turbines, it is noticeable that the two turbines show a significantly better ratio between market prices from additional purchases and own generation. However, the earnings / kWh is slightly lower, which is due to the significantly higher surplus generation that has to be fed into the grid.

In view of possible future developments on the electricity market (see 7.6, p. 74), I would opt for the 0.5 ha PV plus 2 wind turbines variant.

Table 29 - S0011: self sufficiency

self-sufficiency (autarky) factor		wind turbine installed power [kW]										
Ski-Resort only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
S0011 - with Snow-Making & eCar-load		wind turbine count										
365 days starting 2023-5-1	0,414	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	0%	14%	25%	34%	41%	46%	50%	54%	57%	59%	61%
672	0,5	8%	21%	32%	41%	47%	52%	56%	59%	62%	64%	66%
1 344	1,0	15%	27%	37%	46%	52%	56%	60%	63%	66%	68%	69%
2 016	1,5	20%	32%	41%	50%	55%	59%	63%	66%	68%	70%	72%
2 688	2,0	23%	35%	45%	52%	58%	62%	65%	68%	70%	72%	74%
3 360	2,5	27%	38%	47%	55%	60%	64%	67%	69%	72%	74%	75%
4 032	3,0	29%	40%	49%	57%	62%	65%	68%	71%	73%	75%	76%
4 704	3,5	32%	42%	51%	58%	63%	67%	69%	72%	74%	76%	77%
5 376	4,0	34%	44%	53%	59%	64%	68%	70%	73%	75%	77%	78%
6 048	4,5	35%	45%	54%	61%	65%	68%	71%	74%	76%	77%	79%
6 720	5,0	37%	47%	55%	61%	66%	69%	72%	74%	76%	78%	79%
7 392	5,5	38%	48%	56%	62%	66%	70%	72%	75%	77%	78%	80%
8 064	6,0	39%	48%	56%	63%	67%	70%	73%	75%	77%	79%	80%

Table 30 - S0011: coverage on balance per year

coverage on balance per year		wind turbine installed power [kW]										
Ski-Resort only		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
S0011 - with Snow-Making & eCar-load		wind turbine count										
365 days starting 2023-5-1	0,748	0	1	2	3	4	5	6	7	8	9	10
PV [kWp]	**PV-area [ha]**											
0	0,0	0%	25%	49%	74%	98%	122%	146%	170%	194%	218%	242%
672	0,5	9%	34%	58%	82%	107%	131%	155%	178%	202%	226%	250%
1 344	1,0	18%	42%	66%	91%	115%	138%	162%	186%	209%	233%	257%
2 016	1,5	27%	51%	75%	99%	122%	146%	170%	193%	217%	241%	264%
2 688	2,0	35%	59%	83%	107%	131%	154%	178%	201%	225%	248%	272%
3 360	2,5	44%	68%	92%	115%	139%	162%	186%	209%	233%	256%	280%
4 032	3,0	53%	76%	100%	124%	147%	170%	194%	217%	241%	264%	288%
4 704	3,5	61%	85%	108%	132%	155%	179%	202%	225%	249%	272%	295%
5 376	4,0	70%	93%	117%	140%	163%	187%	210%	233%	257%	280%	303%
6 048	4,5	78%	102%	125%	148%	172%	195%	218%	242%	265%	288%	312%
6 720	5,0	87%	110%	133%	157%	180%	203%	227%	250%	273%	297%	320%
7 392	5,5	95%	118%	142%	165%	188%	212%	235%	258%	282%	305%	328%
8 064	6,0	104%	127%	150%	173%	197%	220%	243%	267%	290%	313%	336%

7.3 Together: Hotels and Ski resort

As the following simulations demonstrate, the combination of ski resort and hotels results in significantly better figures for all key indicators.

7.3.1 B00h0 - Combination of H0000 and S00h0

Scenario S00h0, with half the load for snow production (as was necessary in the past) and the electricity demand of hotels without further future scenarios, results in an electricity demand of ~9 GWh for $S2300_{SW}$.

This is almost identical to the demand for scenario S0011 described above. However, most of the key figures are much better. This is not due to the increased load, but to the combination of the two different load profiles.

Table 31 - B00h0: earnings per kWh

REN earnigs/kWh [€ct/kWh] Hotels & Ski-Resort B00h0 - with 50% Snow-Making, w/o eCar-load & Heatpumps 365 days starting 2023-5-1 11,086		wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	12,25	11,31	10,59	10,06	9,65	9,32	9,05	8,83	8,64	8,49
672	0,5	11,79	12,05	11,29	10,62	10,10	9,69	9,36	9,09	8,87	8,68	8,52
1 344	1,0	11,63	11,86	11,22	10,60	10,10	9,70	9,37	9,10	8,88	8,70	8,54
2 016	1,5	11,38	11,62	11,09	10,52	10,05	9,67	9,35	9,09	8,88	8,69	8,54
2 688	2,0	11,00	11,30	10,88	10,38	9,95	9,59	9,29	9,05	8,84	8,66	8,51
3 360	2,5	10,58	10,94	10,62	10,19	9,80	9,48	9,20	8,97	8,78	8,61	8,47
4 032	3,0	10,18	10,58	10,34	9,98	9,64	9,35	9,10	8,88	8,70	8,55	8,41
4 704	3,5	9,82	10,24	10,08	9,77	9,47	9,21	8,99	8,79	8,62	8,48	8,35
5 376	4,0	9,49	9,93	9,82	9,57	9,31	9,08	8,87	8,69	8,54	8,40	8,29
6 048	4,5	9,20	9,65	9,59	9,38	9,15	8,95	8,76	8,60	8,46	8,33	8,22
6 720	5,0	8,94	9,39	9,37	9,19	9,00	8,82	8,66	8,51	8,38	8,26	8,16
7 392	5,5	8,71	9,16	9,17	9,03	8,86	8,70	8,55	8,42	8,30	8,19	8,10
8 064	6,0	8,50	8,95	8,98	8,87	8,73	8,59	8,46	8,33	8,22	8,12	8,04

Table 32 - B00h0: relation own-use-price / buy-from-grid-price

relation own-use-price / buy-from-grid- Hotels & Ski-Resort B00h0 - with 50% Snow-Making, w/o eCar-load & Heatpumps 365 days starting 2023-5-1 0,979		wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	1,024	1,026	1,030	1,031	1,032	1,035	1,037	1,038	1,038	1,039
672	0,5	0,936	0,996	1,005	1,011	1,014	1,016	1,019	1,021	1,023	1,023	1,024
1 344	1,0	0,937	0,981	0,991	0,997	1,001	1,003	1,006	1,008	1,010	1,011	1,012
2 016	1,5	0,935	0,969	0,979	0,986	0,989	0,991	0,994	0,997	0,998	0,999	1,000
2 688	2,0	0,932	0,961	0,970	0,976	0,979	0,981	0,985	0,987	0,988	0,989	0,990
3 360	2,5	0,932	0,956	0,965	0,971	0,973	0,976	0,979	0,981	0,982	0,982	0,983
4 032	3,0	0,932	0,954	0,962	0,968	0,970	0,972	0,975	0,977	0,978	0,978	0,978
4 704	3,5	0,932	0,952	0,960	0,966	0,968	0,969	0,972	0,973	0,974	0,974	0,975
5 376	4,0	0,933	0,952	0,959	0,964	0,966	0,967	0,969	0,971	0,971	0,972	0,972
6 048	4,5	0,934	0,951	0,959	0,963	0,964	0,965	0,967	0,968	0,969	0,969	0,969
6 720	5,0	0,935	0,951	0,958	0,962	0,963	0,963	0,965	0,966	0,967	0,967	0,967
7 392	5,5	0,935	0,951	0,958	0,961	0,962	0,962	0,963	0,965	0,965	0,965	0,965
8 064	6,0	0,936	0,951	0,957	0,960	0,960	0,960	0,962	0,963	0,963	0,963	0,963

Let's compare the results with scenario S0011 one by one:

- 3 turbines w/o PV
  - Earnings 10,59 €ct/kWh / 9,80 €ct/kWh
  - Price-ratio 1,030 / 1,002
  - Autarky 40% / 34%

- 3,5 ha w/o turbines
  - Earnings 9,82 €ct/kWh / 9,46 €ct/kWh
  - Price-ratio 0,932 / 0,946 (a very large PV only fits a little better to S0011)
  - Autarky 38% / 32%
- 1,5 ha and 2 turbines
  - Earnings 11,09 €ct/kWh / 9,97 €ct/kWh
  - Price-ratio 0,979 / 0,964
  - Autarky 51% / 41%

Table 33 - B00h0: self sufficiency

self-sufficiency (autarky) factor Hotels & Ski-Resort B00h0 - with 50% Snow-Making, w/o eCar-load & Heatpumps 365 days starting 2023-5-1	0,513	wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	0%	19%	32%	40%	46%	51%	54%	57%	59%	61%	62%
672	0,5	8%	27%	39%	47%	53%	57%	60%	62%	64%	66%	67%
1 344	1,0	15%	34%	46%	53%	58%	62%	65%	67%	69%	70%	72%
2 016	1,5	22%	40%	51%	58%	63%	67%	70%	72%	73%	74%	75%
2 688	2,0	28%	45%	56%	63%	67%	70%	73%	75%	76%	77%	78%
3 360	2,5	32%	49%	59%	66%	70%	73%	75%	77%	78%	79%	80%
4 032	3,0	35%	52%	62%	68%	72%	75%	77%	79%	80%	81%	82%
4 704	3,5	38%	54%	64%	70%	74%	76%	78%	80%	81%	82%	83%
5 376	4,0	40%	56%	65%	71%	75%	77%	79%	81%	82%	83%	84%
6 048	4,5	42%	57%	67%	72%	76%	78%	80%	82%	83%	84%	85%
6 720	5,0	43%	59%	67%	73%	76%	79%	81%	82%	83%	84%	85%
7 392	5,5	45%	60%	68%	74%	77%	80%	82%	83%	84%	85%	86%
8 064	6,0	46%	60%	69%	74%	78%	80%	82%	83%	84%	85%	86%

Table 34 - B00h0: coverage on balance per year

coverage on balance per year Hotels & Ski-Resort B00h0 - with 50% Snow-Making, w/o eCar-load & Heatpumps 365 days starting 2023-5-1	0,710	wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	0%	23%	46%	69%	92%	115%	138%	161%	184%	207%	230%
672	0,5	8%	31%	54%	77%	100%	123%	146%	169%	192%	215%	238%
1 344	1,0	17%	40%	63%	86%	109%	131%	154%	177%	200%	223%	246%
2 016	1,5	25%	48%	71%	94%	117%	140%	163%	186%	209%	232%	255%
2 688	2,0	33%	56%	79%	102%	125%	148%	171%	194%	217%	240%	263%
3 360	2,5	42%	65%	88%	111%	134%	157%	180%	202%	225%	248%	271%
4 032	3,0	50%	73%	96%	119%	142%	165%	188%	211%	234%	257%	280%
4 704	3,5	59%	81%	104%	127%	150%	173%	196%	219%	242%	265%	288%
5 376	4,0	67%	90%	113%	136%	159%	182%	205%	228%	250%	273%	296%
6 048	4,5	75%	98%	121%	144%	167%	190%	213%	236%	259%	282%	305%
6 720	5,0	84%	107%	129%	152%	175%	198%	221%	244%	267%	290%	313%
7 392	5,5	92%	115%	138%	161%	184%	207%	230%	253%	276%	299%	321%
8 064	6,0	100%	123%	146%	169%	192%	215%	238%	261%	284%	307%	330%

The difference in self-sufficiency is remarkable. Due to the almost identical load compared to S0011, there are only minimal differences in the annual coverage factor. However, the self-sufficiency rate is significantly higher in the combined scenario B00h0.

7.3.2 B1111 – Combination of H1100 and S0011

This maximum scenario with all optional loads on both sides (hotels & ski operation), leads to ~14.6 GWh combined electricity demand. It is therefore not comparable with any of the separate scenarios. The significantly better key figures for B00h0 are therefore due to the load increase and the load balance (charging management for electric vehicles).

Table 35 - B1111: earnings per kWh

REN earnigs/kWh [€ct/kWh] Hotels & Ski-Resort B1111 - with eCar-load & Heatpumps & Snow-Making 365 days starting 2023-5-1 11,681		wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	12,75	11,96	11,40	10,95	10,55	10,23	9,94	9,70	9,49	9,31
672	0,5	11,91	12,48	11,89	11,38	10,96	10,58	10,25	9,97	9,73	9,52	9,33
1 344	1,0	11,76	12,26	11,79	11,34	10,94	10,58	10,26	9,98	9,74	9,53	9,34
2 016	1,5	11,64	12,07	11,68	11,28	10,91	10,55	10,24	9,97	9,73	9,53	9,34
2 688	2,0	11,48	11,87	11,55	11,19	10,84	10,51	10,21	9,94	9,71	9,51	9,33
3 360	2,5	11,23	11,62	11,37	11,05	10,74	10,43	10,14	9,89	9,67	9,47	9,30
4 032	3,0	10,93	11,34	11,15	10,89	10,60	10,32	10,05	9,81	9,60	9,41	9,25
4 704	3,5	10,63	11,05	10,92	10,70	10,45	10,19	9,94	9,72	9,52	9,35	9,19
5 376	4,0	10,35	10,77	10,70	10,52	10,30	10,06	9,83	9,63	9,44	9,27	9,12
6 048	4,5	10,08	10,51	10,48	10,33	10,14	9,93	9,72	9,52	9,35	9,20	9,06
6 720	5,0	9,85	10,28	10,26	10,15	9,99	9,79	9,60	9,43	9,26	9,12	8,99
7 392	5,5	9,62	10,04	10,06	9,98	9,83	9,66	9,49	9,33	9,18	9,04	8,92
8 064	6,0	9,41	9,83	9,87	9,81	9,69	9,53	9,38	9,23	9,09	8,96	8,85

Table 36 - B1111: relation own-use-price / buy-from-grid-price

relation own-use-price / buy-from-grid- Hotels & Ski-Resort B1111 - with eCar-load & Heatpumps & Snow-Making 365 days starting 2023-5-1 0,984		wind turbine installed power [kW]										
		0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
		wind turbine count										
PV [kWp]	PV-area [ha]	0	1	2	3	4	5	6	7	8	9	10
0	0,0	N/A	1,018	1,021	1,018	1,020	1,022	1,023	1,023	1,024	1,025	1,026
672	0,5	0,938	0,996	1,005	1,005	1,008	1,010	1,012	1,013	1,014	1,015	1,016
1 344	1,0	0,941	0,983	0,993	0,995	0,998	1,001	1,003	1,004	1,006	1,007	1,008
2 016	1,5	0,941	0,974	0,984	0,986	0,990	0,993	0,995	0,996	0,998	0,999	1,000
2 688	2,0	0,941	0,968	0,977	0,979	0,983	0,986	0,988	0,989	0,991	0,992	0,993
3 360	2,5	0,939	0,962	0,970	0,973	0,977	0,980	0,982	0,983	0,985	0,986	0,987
4 032	3,0	0,938	0,959	0,966	0,969	0,974	0,976	0,978	0,979	0,980	0,981	0,981
4 704	3,5	0,938	0,957	0,964	0,967	0,971	0,973	0,975	0,976	0,977	0,978	0,979
5 376	4,0	0,939	0,956	0,963	0,966	0,970	0,971	0,973	0,974	0,975	0,976	0,977
6 048	4,5	0,939	0,955	0,962	0,965	0,969	0,970	0,972	0,973	0,974	0,974	0,975
6 720	5,0	0,940	0,955	0,962	0,965	0,968	0,970	0,971	0,972	0,973	0,973	0,973
7 392	5,5	0,941	0,955	0,962	0,965	0,967	0,969	0,971	0,971	0,972	0,972	0,972
8 064	6,0	0,942	0,955	0,962	0,965	0,968	0,969	0,971	0,971	0,971	0,971	0,971

The earnings per kWh for configurations that are within the narrower limits defined under 3.8 (p. 15 ff) are all above 11 €ct/kWh, as long as wind turbines are included- even for 3 wind turbines without PV.

For PV without wind, the enormous area of at least 4 ha is a challenge. The earnings per kWh are ~10% below those in combination with wind turbines.

The significantly poorer price ratio is remarkable. While values > 1 are sometimes achieved for wind turbines (in combination), the PV-only areas are ~0.94. In other words, the value of the self-generated energy is 6% lower than the remaining electricity purchased from the grid.

Table 37 - B1111: self sufficiency

self-sufficiency (autarky) factor Hotels & Ski-Resort B1111 - with eCar-load & Heatpumps & Snow-Making 365 days starting 2023-5-1 0,372		wind turbine installed power [kW] 0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
PV [kWp]	PV-area [ha]	wind turbine count 0	1	2	3	4	5	6	7	8	9	10
0	0,0	0%	14%	24%	31%	38%	43%	47%	50%	53%	55%	57%
672	0,5	5%	19%	28%	36%	42%	47%	51%	54%	57%	59%	61%
1 344	1,0	10%	23%	33%	40%	46%	51%	55%	58%	60%	63%	64%
2 016	1,5	15%	28%	37%	45%	50%	55%	58%	61%	64%	66%	67%
2 688	2,0	19%	32%	41%	48%	54%	58%	61%	64%	66%	68%	70%
3 360	2,5	23%	36%	44%	51%	57%	61%	64%	66%	69%	70%	72%
4 032	3,0	26%	38%	47%	54%	59%	63%	66%	68%	70%	72%	74%
4 704	3,5	29%	41%	49%	56%	61%	64%	67%	70%	72%	73%	75%
5 376	4,0	31%	43%	51%	57%	62%	66%	69%	71%	73%	74%	76%
6 048	4,5	33%	44%	52%	59%	63%	67%	70%	72%	74%	75%	77%
6 720	5,0	35%	46%	54%	60%	64%	68%	71%	73%	75%	76%	78%
7 392	5,5	36%	47%	55%	61%	65%	69%	71%	73%	75%	77%	78%
8 064	6,0	37%	48%	56%	62%	66%	69%	72%	74%	76%	77%	79%

Table 38 - B1111: coverage on balance per year

coverage on balance per year Hotels & Ski-Resort B1111 - with eCar-load & Heatpumps & Snow-Making 365 days starting 2023-5-1 0,457		wind turbine installed power [kW] 0	850	1 700	2 550	3 400	4 250	5 100	5 950	6 800	7 650	8 500
PV [kWp]	PV-area [ha]	wind turbine count 0	1	2	3	4	5	6	7	8	9	10
0	0,0	0%	15%	30%	44%	59%	74%	88%	103%	118%	132%	147%
672	0,5	5%	20%	35%	50%	64%	79%	94%	108%	123%	137%	152%
1 344	1,0	11%	26%	40%	55%	70%	84%	99%	114%	128%	143%	157%
2 016	1,5	16%	31%	46%	60%	75%	90%	104%	119%	133%	148%	162%
2 688	2,0	22%	36%	51%	66%	80%	95%	109%	124%	138%	153%	167%
3 360	2,5	27%	42%	56%	71%	85%	100%	114%	129%	143%	157%	172%
4 032	3,0	32%	47%	61%	76%	90%	105%	119%	133%	148%	162%	177%
4 704	3,5	37%	52%	66%	81%	95%	110%	124%	138%	153%	167%	182%
5 376	4,0	43%	57%	72%	86%	101%	115%	129%	143%	158%	172%	187%
6 048	4,5	48%	62%	77%	91%	106%	120%	134%	149%	163%	177%	192%
6 720	5,0	53%	68%	82%	96%	111%	125%	139%	154%	168%	182%	197%
7 392	5,5	58%	73%	87%	101%	116%	130%	144%	159%	173%	187%	202%
8 064	6,0	63%	78%	92%	107%	121%	135%	149%	164%	178%	192%	207%

Although the limited system sizes do not result in too high values for annual coverage factor (< 80% in most configurations), the degree of self-sufficiency shows extraordinarily good values of up to 60%. Large amounts of grid feed-in are therefore avoided. This results in much better earnings.

Let's look at one result in detail: 1.5 ha of PV and 2 wind turbines. 46% annual coverage factor brings a degree of self-sufficiency of 37%.

7.4 Comparison of scenarios for years from 2015

For the year 2023 (1.5.23 to 29.4.24), this results in earnings of 11 €ct/kWh and even more with the appropriate configuration. For the further simulations, I have chosen a combination of 1.5 ha of PV and 2 wind turbines. This variant delivers results in almost all scenarios that remain within the range of the values specified under 3.8 (p. 15) in terms of self-sufficiency and coverage per year (< 150%).

Table 39 shows the electricity demand on which the different simulations are based. However, these values are only valid for $S2023_{SW}$. It should also be noted that the real load is slightly lower in all scenarios with electric vehicle load. Depending on the overcapacity in the hours of charging demand, more or less energy is allocated to the charging stations. In this respect, the maximum possible values are shown here. In the other years, there are different electricity demands and earnings in any case. The climate data on which the model is based and shifts in public holidays lead to different tourist utilization for ski operations and hotels. Different loads due to outside temperature and wind are also taken into account.

Table 39 - max. load per scenario ($S2023_{SW}$)

Scenario		$S2023_{SW}$ - max.:	GWh
H0000	Hotels only	w/o eCar-load & Heatpumps	3,99
H1000	Hotels only	incl. Heatpumps, w/o eCar-load	5,20
H0100	Hotels only	incl. eCar-load, w/o Heatpumps	4,39
H1100	Hotels only	with eCar-load & Heatpumps	5,60
S0000	Ski-Resort only	w/o Snow-Making & eCar-load	2,06
S00h0	Ski-Resort only	with 50% Snow-Making, w/o eCar-load	5,02
S0010	Ski-Resort only	with Snow-Making, w/o eCar-load	7,97
S0001	Ski-Resort only	with eCar-load, w/o Snow-Making	3,07
S0011	Ski-Resort only	with Snow-Making & eCar-load	8,99
B0000	Hotels & Ski-Resort	w/o eCar-load & Heatpumps & Snow-Making	6,05
B00h0	Hotels & Ski-Resort	with 50% Snow-Making, w/o eCar-load & Heatpumps	9,01
B0010	Hotels & Ski-Resort	with Snow-Making, w/o eCar-load & Heatpumps	11,97
B1010	Hotels & Ski-Resort	with Snow-Making & Heatpumps, w/o eCar-load	13,18
B0111	Hotels & Ski-Resort	with Snow-Making & eCar-load, w/o Heatpumps	12,36
B1111	Hotels & Ski-Resort	with eCar-load & Heatpumps & Snow-Making	14,59

The years 2021 and 2022 are not being considered in any of the figures due to the extremely high market prices caused by the energy crisis.

Table 40 - earnings per kWh for different scenarios and years

REN earnigs/kWh [€ct/kWh] 2 turbines / 1,5 ha PV field		11,681	year starts with summer-season on May 1st								
			2015	2016	2017	2018	2019	2020	2021	2022	2023
Hotels	w/o eCar-load & Heatpumps	H0000	4,90	5,59	5,01	6,89	5,31	6,28	18,97	23,36	9,44
	incl. Heatpumps, w/o eCar-load	H1000	5,60	6,37	5,82	7,70	6,09	7,10	19,81	24,14	10,17
	incl. eCar-load, w/o Heatpumps	H0100	5,12	5,82	5,23	7,16	5,55	6,53	19,21	23,58	9,71
	with eCar-load & Heatpumps	H1100	5,79	6,57	6,01	7,93	6,30	7,30	20,01	24,33	10,41
Ski-Resort	w/o Snow-Making & eCar-load	S0000	3,41	4,20	3,63	5,47	3,92	4,84	17,64	21,95	7,96
	with 50% Snow-Making, w/o eCar-load	S00h0	4,55	5,61	5,12	7,05	5,33	6,19	19,24	23,29	9,27
	with Snow-Making, w/o eCar-load	S0010	4,77	5,91	5,42	7,33	5,59	6,46	19,55	23,57	9,59
	with eCar-load, w/o Snow-Making	S0001	4,05	4,87	4,24	6,17	4,53	5,47	18,05	22,21	8,50
	with Snow-Making & eCar-load	S0011	5,26	6,41	5,87	7,81	6,02	6,92	19,88	23,78	9,97
together	w/o eCar-load & Heatpumps & Snow-Making	B0000	5,83	6,67	5,96	8,01	6,34	7,27	20,12	24,41	10,35
	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0	6,39	7,45	6,81	8,85	7,08	7,96	21,04	25,11	11,09
	with Snow-Making, w/o eCar-load & Heatpumps	B0010	6,47	7,56	6,92	8,93	7,17	8,05	21,12	25,22	11,21
	with Snow-Making & Heatpumps, w/o eCar-load	B1010	6,74	7,80	7,19	9,16	7,46	8,36	21,37	25,49	11,50
	with Snow-Making & eCar-load, w/o Heatpumps	B0111	6,71	7,75	7,15	9,15	7,37	8,27	21,28	25,38	11,42
	with eCar-load & Heatpumps & Snow-Making	B1111	6,93	7,95	7,38	9,33	7,62	8,53	21,50	25,62	11,68

As noted above, the previous analyses for 2023 have in many cases led to earnings of >= 11 €ct/kWh. The years 2015 - 2020 show a completely different picture. The yields are very clearly below this level. This is due to the much lower prices on the electricity market in the past (see Figure 41).

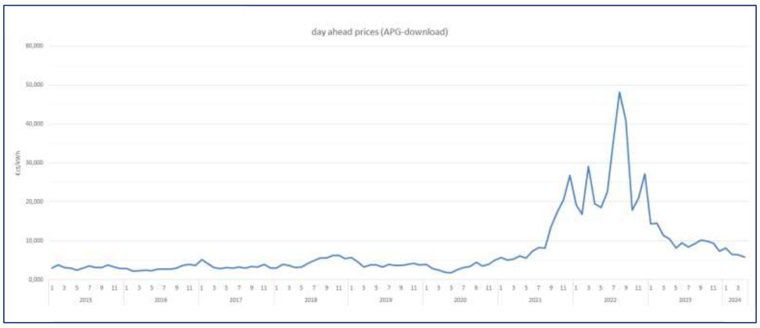


Figure 41 - day ahead prices since 2015

Well, the comparison with 2015, with earnings of significantly less than 7 €ct/kWh, is not realistic. The average day-ahead prices in the period May-1st-2015 – April-30th-2030 were 2.959 €ct/kWh in contrast to 8.263 for S2023$_{SW}$ - a drop of -64%. I don't think this level is realistic for the future. But we're facing falling market prices. That's something we have to consider.

Table 41 - relation own-use-price / buy-from-grid-price for different scenarios and years

relation own-use-price / buy-from-grid-price 2 turbines / 1,5 ha PV field		0,984	year starts with summer-season on May 1st 2015	2016	2017	2018	2019	2020	2021	2022	2023
Hotels	w/o eCar-load & Heatpumps	H0000	0,990	1,004	0,990	0,981	0,980	0,995	1,057	0,852	0,920
	incl. Heatpumps, w/o eCar-load	H1000	0,985	0,994	0,976	0,975	0,979	0,985	1,018	0,884	0,934
	incl. eCar-load, w/o Heatpumps	H0100	0,997	1,017	0,998	0,994	0,988	1,009	1,061	0,855	0,930
	with eCar-load & Heatpumps	H1100	0,990	1,002	0,983	0,984	0,984	0,995	1,024	0,884	0,942
Ski-Resort	w/o Snow-Making & eCar-load	S0000	0,995	0,956	0,970	0,986	1,000	0,913	0,925	1,112	1,048
	with 50% Snow-Making, w/o eCar-load	S00h0	0,998	0,952	0,973	0,970	0,986	0,958	0,943	0,993	0,975
	with Snow-Making, w/o eCar-load	S0010	1,005	0,953	0,983	0,973	0,990	0,962	0,943	0,975	0,965
	with eCar-load, w/o Snow-Making	S0001	1,002	0,980	0,988	1,025	1,022	0,945	0,893	1,099	1,084
	with Snow-Making & eCar-load	S0011	1,006	0,946	0,981	0,975	0,992	0,953	0,914	0,980	0,964
together	w/o eCar-load & Heatpumps & Snow-Making	B0000	0,986	0,982	0,975	0,985	0,990	0,967	1,020	0,926	0,988
	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0	0,989	0,943	0,966	0,965	0,981	0,945	0,938	0,985	0,979
	with Snow-Making, w/o eCar-load & Heatpumps	B0010	0,999	0,934	0,975	0,963	0,985	0,939	0,911	1,014	0,977
	with Snow-Making & Heatpumps, w/o eCar-load	B1010	0,995	0,932	0,972	0,960	0,983	0,938	0,906	1,006	0,975
	with Snow-Making & eCar-load, w/o Heatpumps	B0111	0,998	0,942	0,977	0,969	0,989	0,945	0,912	1,008	0,986
	with eCar-load & Heatpumps & Snow-Making	B1111	0,994	0,939	0,974	0,965	0,987	0,944	0,908	1,001	0,984

Since we are not comparing different solutions/dimensioning of wind and PV in these simulations, this price ratio in Table 41 - relation own-use-price / buy-from-grid-price for different scenarios and years makes not really sense. However, what can be observed, is that this ratio has gotten worse over the last 8 years. More on this later under section 0(p. 74 ff).

Table 42 - self sufficiency for different scenarios and years

self-sufficiency (autarky) factor 2 turbines / 1,5 ha PV field		0,372	year starts with summer-season on May 1st								
			2015	2016	2017	2018	2019	2020	2021	2022	2023
Hotels	w/o eCar-load & Heatpumps	H0000	72%	71%	74%	74%	74%	73%	76%	75%	77%
	incl. Heatpumps, w/o eCar-load	H1000	65%	65%	67%	69%	70%	66%	71%	70%	72%
	incl. eCar-load, w/o Heatpumps	H0100	69%	69%	72%	72%	73%	71%	74%	73%	76%
	with eCar-load & Heatpumps	H1100	64%	63%	66%	67%	68%	65%	69%	68%	71%
Ski-Resort	w/o Snow-Making & eCar-load	S0000	77%	76%	80%	79%	80%	76%	84%	81%	79%
	with 50% Snow-Making, w/o eCar-load	S00h0	50%	47%	50%	54%	52%	50%	58%	51%	57%
	with Snow-Making, w/o eCar-load	S0010	33%	32%	33%	36%	34%	33%	39%	34%	40%
	with eCar-load, w/o Snow-Making	S0001	69%	70%	74%	76%	73%	75%	84%	79%	79%
	with Snow-Making & eCar-load	S0011	34%	33%	34%	38%	35%	35%	40%	35%	41%
together	w/o eCar-load & Heatpumps & Snow-Making	B0000	59%	58%	62%	62%	63%	60%	66%	64%	65%
	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0	45%	43%	46%	47%	47%	45%	51%	47%	51%
	with Snow-Making, w/o eCar-load & Heatpumps	B0010	34%	32%	34%	36%	35%	34%	38%	35%	40%
	with Snow-Making & Heatpumps, w/o eCar-load	B1010	33%	30%	32%	34%	34%	32%	36%	34%	38%
	with Snow-Making & eCar-load, w/o Heatpumps	B0111	32%	30%	32%	34%	33%	32%	37%	34%	39%
	with eCar-load & Heatpumps & Snow-Making	B1111	31%	29%	31%	32%	32%	31%	35%	33%	37%

Table 43 - coverage on balance for different scenarios and years

coverage on balance per year 2 turbines / 1,5 ha PV field		0,457	year starts with summer-season on May 1st								
			2015	2016	2017	2018	2019	2020	2021	2022	2023
Hotels	w/o eCar-load & Heatpumps	H0000	138%	131%	154%	139%	149%	141%	151%	149%	160%
	incl. Heatpumps, w/o eCar-load	H1000	105%	99%	113%	106%	113%	105%	113%	112%	123%
	incl. eCar-load, w/o Heatpumps	H0100	125%	119%	140%	126%	135%	129%	137%	136%	145%
	with eCar-load & Heatpumps	H1100	97%	92%	105%	98%	105%	97%	105%	105%	114%
Ski-Resort	w/o Snow-Making & eCar-load	S0000	262%	234%	298%	255%	276%	262%	282%	280%	311%
	with 50% Snow-Making, w/o eCar-load	S00h0	108%	89%	102%	99%	104%	101%	108%	105%	127%
	with Snow-Making, w/o eCar-load	S0010	68%	55%	62%	62%	64%	62%	67%	64%	80%
	with eCar-load, w/o Snow-Making	S0001	178%	165%	206%	184%	192%	194%	233%	242%	236%
	with Snow-Making & eCar-load	S0011	60%	50%	57%	57%	58%	58%	64%	62%	75%
together	w/o eCar-load & Heatpumps & Snow-Making	B0000	90%	84%	101%	90%	97%	92%	98%	97%	106%
	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0	60%	53%	61%	58%	61%	59%	63%	61%	71%
	with Snow-Making, w/o eCar-load & Heatpumps	B0010	45%	39%	44%	43%	45%	43%	46%	45%	53%
	with Snow-Making & Heatpumps, w/o eCar-load	B1010	41%	35%	40%	39%	41%	39%	42%	41%	49%
	with Snow-Making & eCar-load, w/o Heatpumps	B0111	41%	35%	40%	40%	41%	40%	44%	43%	50%
	with eCar-load & Heatpumps & Snow-Making	B1111	37%	32%	37%	36%	38%	37%	40%	39%	46%

Table 44 - grid feed-in ratio for different scenarios and years

Grid feed-in percentage 2 turbines / 1,5 ha PV field		0,186	year starts with summer-season on May 1st								
			2015	2016	2017	2018	2019	2020	2021	2022	2023
Hotels	w/o eCar-load & Heatpumps	H0000	48%	46%	52%	47%	50%	49%	50%	49%	52%
	incl. Heatpumps, w/o eCar-load	H1000	38%	34%	40%	35%	38%	37%	37%	38%	41%
	incl. eCar-load, w/o Heatpumps	H0100	45%	42%	49%	43%	46%	45%	46%	46%	48%
	with eCar-load & Heatpumps	H1100	35%	31%	37%	32%	35%	33%	34%	35%	37%
Ski-Resort	w/o Snow-Making & eCar-load	S0000	71%	67%	73%	69%	71%	71%	70%	71%	75%
	with 50% Snow-Making, w/o eCar-load	S00h0	54%	47%	51%	45%	50%	51%	46%	51%	55%
	with Snow-Making, w/o eCar-load	S0010	51%	42%	47%	41%	46%	47%	42%	47%	50%
	with eCar-load, w/o Snow-Making	S0001	61%	58%	64%	58%	62%	61%	64%	67%	67%
	with Snow-Making & eCar-load	S0011	43%	35%	40%	34%	40%	40%	37%	44%	45%
together	w/o eCar-load & Heatpumps & Snow-Making	B0000	35%	30%	38%	31%	35%	34%	33%	34%	39%
	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0	26%	19%	26%	18%	24%	24%	19%	23%	28%
	with Snow-Making, w/o eCar-load & Heatpumps	B0010	25%	17%	24%	17%	22%	23%	18%	22%	26%
	with Snow-Making & Heatpumps, w/o eCar-load	B1010	21%	13%	20%	13%	18%	18%	14%	18%	21%
	with Snow-Making & eCar-load, w/o Heatpumps	B0111	21%	14%	20%	14%	19%	19%	16%	19%	22%
	with eCar-load & Heatpumps & Snow-Making	B1111	18%	11%	17%	11%	16%	15%	12%	16%	19%

Table 44 shows the yields in relation to electricity demand from the opposite perspective: How much of the self-produced energy must be fed into the grid? We can see that in our initial scenarios H0000 and S00h0, slightly more than 50% of our own production has to be passed on to the grid. The other scenarios with increased load reduces this factor down to 19% (for $S2023_{SW}$).

In the opposite view, this leads to autarky rates starting at 77% for H0000 (see Table 42). At the maximum load of B1111, 37% self-sufficiency remains.

7.5 Influence on the grid load

The increase on the consumption side, with charging requirements for electric cars and heat pumps, could reach the limits of the available capacity for the grid connection. Transformers could still be replaced relatively easily, but when the load limits of the lines are reached, this becomes a real problem.

The same problem could occur on the producer side. The installed capacity of wind power and/or PV must not be higher than the grid connection allows.

Since several consumers are usually connected to one grid node, a diversity factor is taken into account in practice. This is calculated on the basis of empirical values during design. There are not yet many empirical values for ski resorts with wind power. In strong winds, ski operations are partially suspended and the load drops to zero. The installed capacity would therefore be limited to the capacity of the grid connection.

Again, we simulate 2 wind turbines together with 1.5 ha of PV, resulting in an installed capacity of 3716 kW. The installed capacity on the load side is certainly higher in the scenarios that include snow production. However, the hotels will most likely have a higher total load - just think of the heat pumps, which are assumed to have a rated electrical output of ~1000 kW. With the current grid connection, however, a simultaneity factor is certainly taken into account. It is therefore quite possible that the grid power is below or close to 3.7 MW. For this reason, we consider how the maximum grid load relates to the existing load when PV and wind power are integrated.

The following simulations also show that the potential for reducing the grid load is only very small:

Table 45 - max power from grid by different scenarios

max. from grid factor 2 turbines / 1,5 ha PV field		0,958	year starts with summer-season on May 1st 2015	2016	2017	2018	2019	2020	2021	2022	2023
Hotels	w/o eCar-load & Heatpumps	H0000	88%	91%	81%	80%	80%	70%	77%	81%	87%
	incl. Heatpumps, w/o eCar-load	H1000	91%	70%	76%	83%	90%	76%	94%	82%	87%
	incl. eCar-load, w/o Heatpumps	H0100	88%	79%	89%	79%	80%	68%	75%	70%	94%
	with eCar-load & Heatpumps	H1100	91%	71%	82%	82%	90%	77%	89%	71%	85%
Ski-Resort	w/o Snow-Making & eCar-load	S0000	83%	78%	70%	86%	80%	77%	79%	72%	80%
	with 50% Snow-Making, w/o eCar-load	S00h0	86%	83%	83%	88%	83%	81%	87%	77%	86%
	with Snow-Making, w/o eCar-load	S0010	100%	100%	98%	98%	98%	100%	99%	100%	99%
	with eCar-load, w/o Snow-Making	S0001	86%	77%	75%	86%	80%	75%	78%	74%	83%
	with Snow-Making & eCar-load	S0011	100%	99%	96%	98%	97%	100%	99%	100%	99%
together	w/o eCar-load & Heatpumps & Snow-Making	B0000	86%	83%	74%	89%	83%	83%	80%	81%	86%
	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0	89%	86%	83%	90%	85%	85%	84%	82%	91%
	with Snow-Making, w/o eCar-load & Heatpumps	B0010	98%	100%	96%	96%	96%	95%	95%	98%	96%
	with Snow-Making & Heatpumps, w/o eCar-load	B1010	100%	100%	95%	96%	96%	95%	96%	95%	96%
	with Snow-Making & eCar-load, w/o Heatpumps	B0111	98%	100%	96%	96%	96%	96%	95%	97%	96%
	with eCar-load & Heatpumps & Snow-Making	B1111	100%	100%	95%	96%	96%	96%	96%	96%	96%

Many individual values show 100%, which means that the maximum grid load occurs in one of the 8760 hours of this specific year in which no (significant) energy is generated from PV and wind. In some scenarios for hotels without ski operations, a (theoretical) reduction in the grid load of no more than ~9% can be seen (the worst value over all years always applies). In practice, this would not be taken into account.

But what about the other way around? How does the maximum power that PV and wind generate together relate to the maximum load?

Table 46 - max. feed-in power in relation to max. load

max. to grid factor 2 turbines / 1,5 ha PV field			0,288	year starts with summer-season on May 1st								
				2015	2016	2017	2018	2019	2020	2021	2022	2023
Hotels	w/o eCar-load & Heatpumps	H0000		194%	184%	182%	162%	183%	155%	178%	182%	199%
	incl. Heatpumps, w/o eCar-load	H1000		147%	117%	134%	127%	137%	115%	136%	131%	153%
	incl. eCar-load, w/o Heatpumps	H0100		184%	160%	173%	157%	172%	143%	155%	146%	161%
	with eCar-load & Heatpumps	H1100		141%	113%	129%	121%	131%	110%	125%	108%	146%
Ski-Resort	w/o Snow-Making & eCar-load	S0000		72%	78%	81%	50%	56%	59%	77%	69%	71%
	with 50% Snow-Making, w/o eCar-load	S00h0		61%	54%	57%	41%	47%	46%	64%	53%	59%
	with Snow-Making, w/o eCar-load	S0010		38%	33%	34%	29%	34%	32%	38%	32%	35%
	with eCar-load, w/o Snow-Making	S0001		61%	65%	67%	48%	50%	54%	74%	66%	60%
	with Snow-Making & eCar-load	S0011		38%	28%	33%	28%	33%	29%	38%	32%	35%
together	w/o eCar-load & Heatpumps & Snow-Making	B0000		56%	40%	54%	34%	47%	38%	45%	39%	54%
	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0		50%	34%	46%	29%	41%	33%	38%	30%	47%
	with Snow-Making, w/o eCar-load & Heatpumps	B0010		32%	23%	29%	21%	29%	24%	23%	21%	31%
	with Snow-Making & Heatpumps, w/o eCar-load	B1010		30%	21%	27%	19%	27%	22%	22%	20%	29%
	with Snow-Making & eCar-load, w/o Heatpumps	B0111		31%	22%	29%	21%	28%	24%	23%	21%	30%
	with eCar-load & Heatpumps & Snow-Making	B1111		30%	21%	27%	19%	27%	22%	21%	20%	29%

Table 46 shows values coded in red for the “hotels-only” scenarios. Hotels certainly have a high installed capacity, but due to the simultaneity factor there is never a load behavior where all consumers are in full operation at the same time. The maximum output within the simulated 8760 hours is therefore much lower than in the ski resort, where all lifts run simultaneously, or all snow guns are in operation when the weather is suitable.

The output of the renewable generation plants is a multiple of the maximum hotel load, but only low compared to the maximum output of the ski resort. So if planning to connect the generation systems to the hotel transformer, it would be necessary to pay close attention to the power limits. Connecting to the ski resort grid should not be limited with the current configuration.

7.6 Influence of renewable energy sources on market prices

We have already noted in previous chapters (e.g. 8.2.3.) that PV usually shows a worse price ratio between own production and purchase than wind turbines. Table 41 (p. 70, in section 7.4) shows that this ratio varies over the years from 2015 upwards. We would like to take a closer look at this here:

It is not necessary to read the ratio in exact figures, just look at the color coding, which shows high values (usually slightly above 1.0) in green and lower values (usually around 0.8 - 0.9) in red. In 2015, the values marked in green can be clearly assigned to PV in the left-hand column. PV had advantages from 2015 to 2019 with production at the power peak at midday. Relatively good prices were paid for this on the electricity market.

From 2019, this ration began to swing towards the wind. By 2023 at the latest, it will become evident that the hours with wind yield clearly achieve better prices than the hours with PV yield. What happened? Just look at the development of PV over the years:

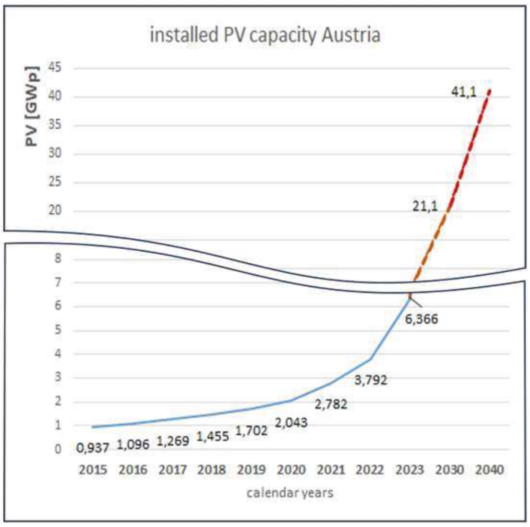


Figure 43 - installed PV capacity Austria[27]

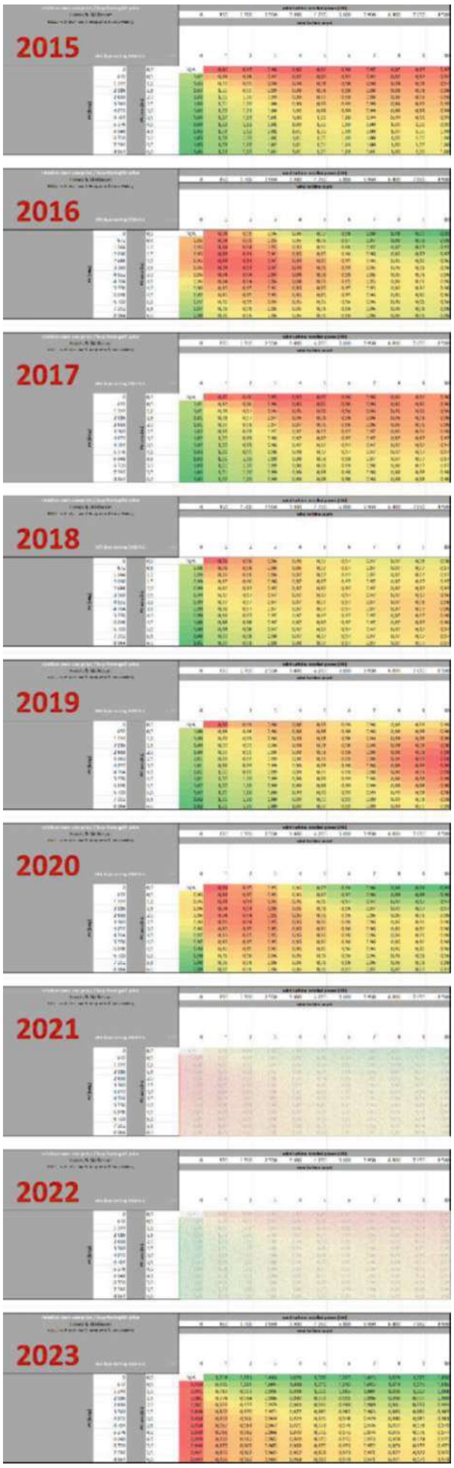


Figure 42 - Price ratio for 2015 - 2023

[27] Source: Data from web access https://pvaustria.at/dashboard/; data origin 2015 to 2023: Federal Ministry for Climate Environment, Energy, Mobility, Innovation and Technology

Figure 43 shows that the development of installed PV capacity increased rapidly during this period. Between 2018 and 2019, 1.5 GWp was reached, and by 2023 we already had ~6.4 GWp. This already covers a lot of the electricity demand in Austria's energy system on sunny days, and this drops the price of PV peak production.

This indicates that we need to be very careful when installing large PV areas. Especially with possible oversizing, which only leads to grid feed-in at very low prices. With our 65° tilt and installation in the mountains, we have already addressed better price levels anyway. In winter, the yield is much higher than in the valley, where the large areas define the price, but can produce less at this time. But that is already priced in.

Can the same thing happen with wind energy? If Austria continues to invest massively in wind energy? Yes and no! There is a big difference with wind: regional and time shifts in the amount of wind. South of the Alps we usually have different weather conditions than north of the Alps. However, the immense wind farms in the north-east of Austria will continue to influence market-prices for electricity.

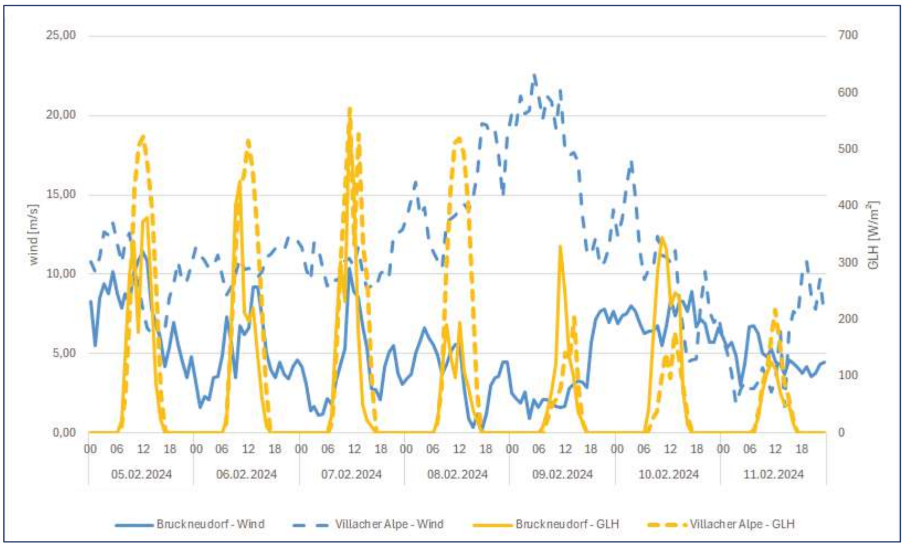


Figure 44 - Wind / solar radiation north and south of Austria

Figure 44 shows solar radiation and wind speed from 2 weather stations[28] south and northeast of the Alps for a selected week in February 2024. The intensity of wind and sun sometimes differs strongly between the two stations. But while the hours of sunshine are synchronized, there are time shifts in the peaks of the wind. Therefore, wind turbines on mountains south of the Alps will not be so strongly affected by price influences during peaks from the large wind farms.

[28] Villacher Alpe and Bruckneudorf - please note that the wind data comes from the measuring station close to the ground. The Villacher Aple station is located at over 2000 m above sea level.

8 UPSIDE POTENTIALS FOR ENERGY STORAGE AND SPECIFIC SOLUTIONS

The focus of the work is on the optimized self-generation of energy for the production community's own energy demand on the ski mountain. For the reasons given in 5.6 / 5.7, biomass is not used as an energy source. Small hydropower is also out of the question (as described under 5.4). This leaves wind and PV as possible sources. But are there no other energy sources or synergies on a ski mountain like this?

It is easy to recognize reservoirs as a source of energy if you observe them with open eyes and energy awareness. Medium to large ski resorts usually have several reservoirs, the larger ones having a volume of 100,000 to 250,000 cubic meters.

Our “virtual” ski area has 5 reservoirs with a total capacity of 220000 m3. The largest lake has 100,000 m3, is located at 1810 m above sea level and has an altitude difference of 850 m to the nearest valley/river. All further illustrations and calculations deal entirely with only this large reservoir.

Let's take a closer look at the amount of energy stored in this 100000 m³ of water:

a) Potential energy

This is calculated using the following formula:

$$\mathbf{E}_{\boldsymbol{pot}} = \boldsymbol{m} \times \boldsymbol{g} \times \boldsymbol{h} \qquad [53]$$

E_{pot} .... potential energy in Joules (J)
m .... mass kilograms (kg), 1m³ water equals 1000 kg
g .... acceleration due to gravity, 9.81 m/s²
h .... head height in meters (m)

$$\mathbf{E}_{\boldsymbol{pot}} = 10^8\,\mathrm{kg} \times 9.81\,\frac{m}{s^2} \times 850\,m = 8.3385 \times 10^{11}\ \mathrm{J}$$

This corresponds to 232 MWh of electrical energy[29], which is roughly equivalent to what the ski resort needs to operate the lifts in the two summer months of July and August.

b) Stored thermal energy

In summer, the lake warms up to 15°C. The optimum temperature for snow production would be 2°C. We use the following formula to calculate the energy content for the 13° temperature difference:

[29] Calculated without any losses/efficiencies

$$\mathbf{Q} \;=\; \boldsymbol{m} \times \boldsymbol{c} \times \Delta\boldsymbol{T} \qquad [54]$$

Q .... Heat energy (in Joules)
m............... Mass of the water (in kg)
c................ Specific heat capacity of water (appr. 4186 J/kg K)
ΔT......... Temperature difference (in °C)

$$\mathbf{Q} \;=\; 10^{8}\,\mathrm{kg} \times 4186\,\frac{\mathrm{J}}{\mathrm{kg\,K}} \times 13\,\mathrm{K} = 5.4308 \times 10^{12}\,\mathrm{J}$$

This corresponds to 1.511 GWh of heat energy[29], which is ~45% of the heating demand of all the hotels and lodges in the entire summer season.

That looks like enormous potential. Can we make use of it?

8.1 Snow-making-lakes used as pump storage plants

8.1.1 Definition and dimensioning of pump power

Well - the snowmaking reservoirs are of course primarily there to provide the water for snowmaking as high up on the mountain as possible. We cannot simply discharge the water to extract energy from it - at least in winter. But even in summer there are restrictions. For reasons of appearance, summer tourism requires that the lakes are always full. But it makes no sense to simply discharge the water into a power plant anyway. You have to pump it back up again to make snow later in the year. But that's exactly how pumped storage power plants work.

Let's take a closer look at the 232 MWh of energy calculated above for our 100000 m³ reservoir. Figure 46 shows a real snowmaking reservoir in a small ski resort. It has only 75000 m³ and is located at 1742 m above sea level. The base station is located on the banks of the River Drau at 542 m above sea level. With a difference in altitude of 1200 m, this results in an energy quantity of 245 MWh (calculation as before). This is very similar to the "virtual" example we use for the following simulations.

Figure 46 - 75000 m³ reservoir, partly empty

Figure 46 - 20,6 MWh battery storage plant

Figure 46 on the left, shows the reservoir shortly after it was serviced. This photo shows the empty artificial lake, which should not be viewed in this way. This can also be dangerous for children playing at the edge.

The picture on the right (Figure 46) shows a battery storage power plant that was recently commissioned in southern Carinthia. The key figures mentioned in all the media were the investment sum of €15 million, an output of 10.3 MW and a storage capacity of 20.6 MWh. The reservoir's capacity is therefore 12 times larger than that of the costly battery storage system.

According to a ski resort employee, the lake must be filled in summer and may only show deviations of +/- 0.5 m as a rule. Depending on the shape of the cone, this height of 1 m (+/- 0.5 = 1 m) corresponds to around 15% of the total filling volume and therefore 15% of the stored energy volume. For the 100000 m³ reservoir of our virtual ski resort, the 15% would still be 34.7 MWh and therefore almost twice as much as the capacity of the large battery storage power plant. It would be great if we could make use of that.

Unfortunately, this is not comparable. The big difference to the battery storage power plant is the output. With 10.3 MW, the battery storage system is able to discharge or charge its entire capacity in 2 hours. Applying this to the 15% of our 100,000 m3, this would mean that we would have to pump up or discharge 7500 m3 per hour and feed it to the generator. That would be 2083 liters of water per second. You can imagine that the dimensions of the pipes required for this would be enormous. In addition, the moving masses of water would certainly damage the relatively simple lakes.

Therefore, excessive use does not seem possible/reasonable. However, it is possible to use the existing infrastructure for snow production. In other words, the existing pipes and pumps. Only the turbine, generator, control system and minor modifications would have to be added. One example is the Davos ski resort in Switzerland, which has integrated multiple generators into its snowmaking infrastructure of the ski area Jakobshorn[30]. Figure 47 shows a very small turbine (probably ~20kW).

Figure 47 - small turbine/generator of Davos ski resort [13]

However, the information provided by the Swiss ski resort shows that the small hydroelectric power plants are not (mainly) operated as pumped power plants, but instead use the naturally collected water to feed the generator outside the ski season. This is only possible with lower reservoirs. The lakes closer to the top of the mountain don't have any or only a small natural water inflow.

In the virtual ski area of this study, this would also be imaginable with the small reservoirs. However, most of the energy would be generated during the snowmelt. As the ski resort and hotels are closed at precisely this time, the energy would have to be fed into the grid, which would drastically limit its economic success. For this reason, this variant is not included in the analyses here.

However, the Jakobshorn ski resort now claims that it was possible to produce 800 MWh of electricity per year with very little investment, resulting in an amortization period of just 4 years. Would something similar be possible with pumped storage operation? The simulations will answer this question.

[30] The information and images were taken from an advertising/image film of the ski resort that focuses on the self-generation of renewable energy [13]

8.1.2 Simulation of an integrated pump power plant

Using the same simulation methods and the assumptions defined above, Figure 48 shows the distribution of the pump volume and earnings for $S2023_{SW}$:

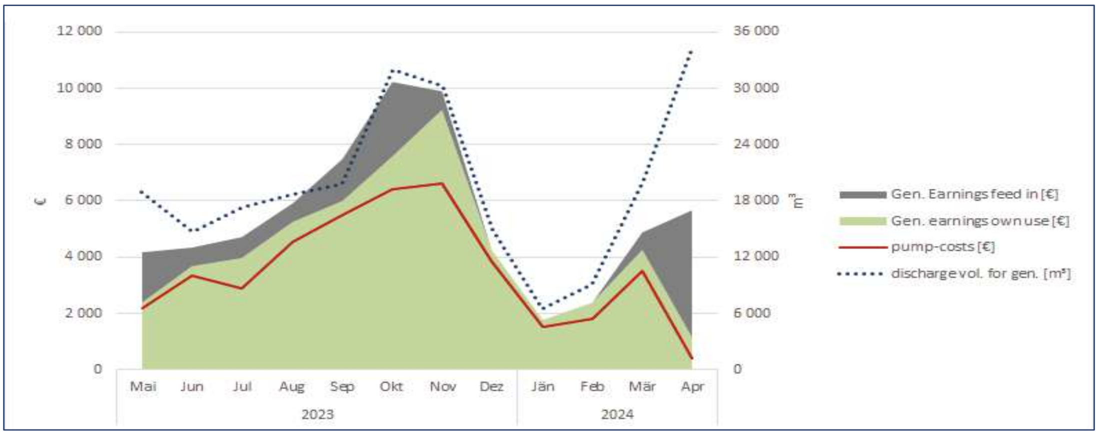


Figure 48 - pump-storage monthly usage/earnings

In the entire year, 236,871 m3 of water would be pumped and discharged. This generates income of € 51,946 for own use in the production community and € 13,760 for feeding into the grid. However, there are costs of € 42,564 for pump operation[31]. The red line represents the energy costs for pump operation. This means that the areas above the red line show the cumulative income from pumping costs and generated sales. As it turns out, the operation can be completely dispensed with in the period from December to February. The earnings in these months are close to zero. Over these 12 months, € 23,142 remains in our pockets. If the ski area and hotels were not closed for the most part in April/May, significantly higher income could be generated through own use.

But what are the earnings in other years? Table 47 shows that $S2023_{SW}$ obviously represents a strong positive deviation. Even the years with very high energy costs lead to very low earnings. But the years with low energy prices also have poorer earnings.

It is less surprising that scenarios with low loads result in higher pumped storage earnings. That is the purpose of energy storage: Charge them when costs are low and discharge them when prices are high. When the load is lower, more cheap surplus energy can be used for pumping, which results in a much higher pump-frequency and earnings.

[31] Of course, there are also additional costs for O&M. But these are not shown here.

Table 47 - Pump storage earnings for different scenarios / years

	gross income pump power plant 2 turbines / 1,5 ha PV field	23 142	2015	2016	2017	2018	2019	2020	2021	2022	2023
			year starts with summer-season on May 1st								
Hotels	w/o eCar-load & Heatpumps	H0000	€ 15 717	€ 17 903	€ 19 952	€ 13 412	€ 16 215	€ 13 983	€ 9 296	€ 11 795	€ 36 329
Hotels	incl. Heatpumps, w/o eCar-load	H1000	€ 18 147	€ 19 467	€ 21 949	€ 16 343	€ 19 205	€ 15 395	€ 9 654	€ 12 000	€ 37 460
Hotels	incl. eCar-load, w/o Heatpumps	H0100	€ 15 616	€ 17 869	€ 19 984	€ 12 953	€ 16 283	€ 13 574	€ 8 598	€ 10 983	€ 34 982
Hotels	with eCar-load & Heatpumps	H1100	€ 17 117	€ 18 636	€ 21 073	€ 15 062	€ 18 232	€ 14 272	€ 8 461	€ 10 694	€ 35 729
Ski-Resort	w/o Snow-Making & eCar-load	S0000	€ 11 495	€ 11 437	€ 15 591	€ 9 663	€ 11 486	€ 8 174	€ 8 850	€ 11 513	€ 33 453
Ski-Resort	with 50% Snow-Making, w/o eCar-load	S00h0	€ 5 300	€ 6 723	€ 9 748	€ 6 669	€ 6 515	€ 4 742	€ 4 910	€ 8 947	€ 29 917
Ski-Resort	with Snow-Making, w/o eCar-load	S0010	€ 4 406	€ 5 418	€ 7 456	€ 5 407	€ 4 694	€ 3 468	€ 4 094	€ 6 737	€ 27 933
Ski-Resort	with eCar-load, w/o Snow-Making	S0001	€ 19 508	€ 16 437	€ 20 720	€ 13 308	€ 17 165	€ 11 115	€ 8 806	€ 11 307	€ 29 895
Ski-Resort	with Snow-Making & eCar-load	S0011	€ 7 934	€ 8 479	€ 9 264	€ 7 731	€ 7 222	€ 5 721	€ 3 795	€ 6 114	€ 24 080
together	w/o eCar-load & Heatpumps & Snow-Making	B0000	€ 22 000	€ 19 956	€ 23 785	€ 19 556	€ 20 156	€ 16 723	€ 10 837	€ 12 736	€ 33 236
together	with 50% Snow-Making, w/o eCar-load & Heatpumps	B00h0	€ 11 833	€ 11 687	€ 13 313	€ 10 982	€ 9 221	€ 9 551	€ 5 482	€ 7 182	€ 26 331
together	with Snow-Making, w/o eCar-load & Heatpumps	B0010	€ 11 117	€ 11 093	€ 11 966	€ 10 479	€ 8 859	€ 8 943	€ 5 224	€ 6 350	€ 25 262
together	with Snow-Making & Heatpumps, w/o eCar-load	B1010	€ 10 618	€ 10 678	€ 11 973	€ 10 120	€ 8 483	€ 8 682	€ 4 920	€ 5 973	€ 25 120
together	with Snow-Making & eCar-load, w/o Heatpumps	B0111	€ 11 635	€ 11 618	€ 12 542	€ 10 646	€ 9 195	€ 9 145	€ 4 666	€ 5 542	€ 23 394
together	with eCar-load & Heatpumps & Snow-Making	B1111	€ 10 245	€ 10 494	€ 12 007	€ 9 590	€ 8 316	€ 8 219	€ 4 284	€ 5 034	€ 23 142

How does this relate to the decline in earnings observed in previous years? To better understand this, we will simulate price changes in terms of both amount and variance:

Table 48 - Pump storage earnings with change of price-level and variance

gross income pump power plant 2 turbines / 1,5 ha PV field 23 142			50%	80%	100%	120%	150%	200%
			electricity market-price factor					
1.5.23 - 29.4.24	variance lever for day-ahead	80%	€ 29 621	€ 19 070	€ 13 669	€ 10 104	€ 6 273	€ 2 559
1.5.23 - 29.4.24	variance lever for day-ahead	100%	€ 42 965	€ 30 055	€ 23 142	€ 17 827	€ 11 283	€ 5 294
1.5.23 - 29.4.24	variance lever for day-ahead	120%	€ 58 777	€ 43 127	€ 34 990	€ 27 993	€ 19 583	€ 9 553
1.5.23 - 29.4.24	variance lever for day-ahead	150%	€ 86 064	€ 66 856	€ 56 239	€ 47 102	€ 35 926	€ 21 957
1.5.23 - 29.4.24	variance lever for day-ahead	200%	€ 136 896	€ 112 836	€ 99 214	€ 86 667	€ 71 357	€ 50 681

The data is clear: the annual yield reacts significantly to both the level and the variance in electricity prices. While a higher price variance leads very clearly to an increase in earnings, a proportional increase in the price level has a negative impact.

To understand this, we need to recall the pricing for pump and generator operation (see formulas on page 39).

It is described there that the very low feed-in price is only charged for the pumping capacity during hours when the full pumping capacity (800 kW in our case) would be fed into the grid. As soon as only a part of the remaining generation systems (PV and wind) is fed into the grid or everything is subject to self-consumption, we have to (proportionally) accept the expensive electricity purchase costs for the pumps.

Our systems have been optimally tailored to requirements and energy profiles. It is therefore very rare for the full pumping capacity (800 kW !!) to be available as surplus energy. In most cases, the pump price/kWh is made up of a mixture of expensive purchase costs and a cheap feed-in tariff. If the prices now increase proportionally, then many individual hourly mixed tariffs become more expensive and drop out of the list of the cheapest hours, which would still be 2.0 €ct lower than the most valuable feed-in hours. So we pump and produce much less, and in most cases also have a reduced margin.

But isn't that exactly what we expect to see on the electricity market in the future? Slightly lower prices with increasingly high price variance due to an increasing share of volatile, renewable energy sources. If these forecasts materialize, pumped storage operation of snowmaking lakes will become highly economically attractive!

A final look at the effects of the self-sufficiency rate:

Table 49 - self-sufficiency including pump-power-plant

contribution to self-sufficiency 2 turbines / 1,5 ha PV field			electricity market-price factor					
			50%	80%	100%	120%	150%	200%
1.5.23 - 29.4.24	variance lever for day-ahead	80%	3%	2%	2%	1%	1%	1%
		100%	3%	3%	2%	2%	2%	1%
		120%	4%	3%	3%	2%	2%	1%
		150%	5%	4%	3%	3%	3%	2%
		200%	6%	5%	5%	4%	4%	3%

As can be seen, the assumed development in energy prices (high variance at a low price level) not only leads to financial success with pumped storage operation, but also to a significant improvement in the degree of self-sufficiency. The initial situation without pumped storage is 37% in scenario B1111 (see Table 42, p. 71). Depending on the price development, up to an additional 6% can be achieved.

8.2 Snow-making-lakes used as source for heat-pumps

As already mentioned on page 77, the amount of heat contained in the reservoir is enormous. More than 1.5 GWh at a temperature difference of 13°C. Can we use this as a source for a heat pump? And does that make sense? In the winter, the lake is either empty or the water is very cold. Especially in winter, when we need more heat, this heat source obviously disappears.

However, the energy used to heat the hotels and lodges is matched by another requirement: The ski resort wants/needs to cool down the water in the reservoir at an early stage so that snow can be produced early on in the season. For this, cooling towers are already installed in many ski resorts today. Can we generate a win-win situation from this? Heating a hotel and cooling the water at the same time.

Before we look at this in more detail, I must point out that no precise project design is to be expected here. That would clearly exceed the scope of this paper. I would also like to take this opportunity to thank Mr. Gamperl from Viessmann. He took the time to clarify some basic points in telephone and personal meetings. However, it is not possible for Viessmann to carry out a complete design without a concrete project. I can therefore only point out potentials and provide some inspiration for a possible real project.

First of all, two quotes in connection with snow production:

> *"Artificial snow: criticism of chilled water*
>
> *The Green Party has strongly criticized the .... ski resort. There, water from reservoirs is cooled down using a high amount of energy in order to produce artificial snow despite the warm weather. This technology is also used in other ski resorts."*
>
> … *[14]* …. article from the ORF web portal (local TV station) back in 2011, meanwhile it is getting warmer from year to year and more difficult to make snow early.
>
> *"Cooling towers increase power by up to 50%.*
>
> *A cooling tower system makes a big difference, even at limit temperatures. 4°C water temperature corresponds to approx 1°C wet bulb temperature. At extreme limit temperatures, the water temperature can be the difference between the system operating or being out of commission. System power is also significantly increased by optimum water temperatures: At limit temperatures, a mid-range fan gun delivers 50% more power at water temperatures of 1°C than at 9°C. But even colder temperature windows up to -10°C are difficult to make the most of if the water is too warm. The snow guns are simply not able to convert the same amount of water into snow as they could at optimum water temperatures. This makes the entire snowmaking system less effective, as it increases snow time."*
>
> …. *[15]* ... the manufacturer's view: Cooling increases efficiency and ensures that the snow-making systems can work ….

But these complex and expensive cooling towers are in place 365 days a year at the edge of the snowmaking lakes and are only used for 2-3 weeks in advance of the initial snowmaking.

Let us now turn to the data and assumptions. It makes little sense to set up an entire heating network on the mountain for the heat source of heat pumps, so we will only take the heat demand of the large wellness hotel H01 for the further calculations. This is shown in Table 50:

Table 50 - heat-demand H01

Heat-Load		heat demand [kWh]	avg. outside temp [°C]	assumed avg. COP of heat-pump	heat pump extraction energy [kWh]
2023	May	319 536	5,9	2,9	210 343
	Jun	306 758	11,0	5,3	248 360
	Jul	287 159	13,1	5,8	237 383
	Aug	299 218	13,0	5,7	247 110
	Sep	303 380	11,3	5,3	246 369
	Oct	385 817	7,8	4,6	301 077
	Nov	505 051	-0,8	2,9	332 989
	Dev	526 209	-0,5	3,0	348 204
2024	Jan	547 512	-2,6	2,8	351 461
	Feb	468 030	1,0	3,2	321 706
	Mar	486 095	0,7	3,1	331 490
	Apr	207 002	3,8	3,8	151 978
total		**4 641 766**	**5,3**	**3,5**	**3 328 469**
	summer	1 901 867	10,3	4,6	1 490 642
	winter	2 739 899	0,3	3,0	1 837 827

The annual demand is ~4.64 GWh, during the summer season (May-Oct) H01 requires ~1.9 GWh. The demand for heat pump extraction[32] energy is ~1.5 GWh in summer and 1.84 GWh in winter.

Table 51 shows the assumed minimum volume and assumed average temperatures. The 4th column shows the thermal energy resulting from the difference to 2°C.

In this section, all thermal energy calculations related to water are carried out using the simplified formula:

$$\mathbf{Q}_{kW} = m_{to} \times c_{kW} \times \Delta T \qquad [55]$$

Q_{kW} .... Heat energy [kW]
m_{to} .... Mass of the water [to] where 1 M3 = 1 to is assumed
c_{kW} .... Specific heat capacity of water (appr. 1,16 kW/to K)
ΔT .... Temperature difference (in °C)

[32] At this point, all values are calculated without further losses. The internal losses of the heat pump are included in the COP anyway. Any additional losses are system-dependent. And it is precisely this (complex) system configuration that will be supplemented many times in the next steps.

As we can now see that the maximum heat content in the lake is 1.276 GWh. It is important to note that we cannot simply sum up the months, as the heat is being built up slowly and should only be taken once.

However, the energy demand is 1.5 GWh. This is higher than the available heat, but the cooling capacity is more than sufficient to cool the lake to 2°C by the end of October.

Let's take a closer look at the energy system of the reservoir:

Table 51 - assumptions for lake

Lake	*assumed min. waterlvl. [m³]*	*assumed avg. water temp [°C]*	*heat-content for t_{min} = 2°C [kWh]*
May	50 000	6,0	232 000
Jun	80 000	8,0	556 800
Jul	100 000	10,0	928 000
Aug	100 000	12,0	1 160 000
Sep	100 000	13,0	1 276 000
Oct	100 000	13,0	1 276 000
Nov	30 000	8,0	208 800
Dec	5 000	5,0	17 400
Jan	5 000	4,0	11 600
Feb	5 000	4,0	11 600
Mar	10 000	4,0	23 200
Apr	20 000	4,0	46 400
average	**50 417**	**7,6**	**478 983**
summer	88 333	10	904 800
winter	12 500	5	53 167

The main inflow of energy comes from ground heat and solar/global radiation as well as water inflow. Constant outflows are mainly due to convection, radiant heat and, above all, heat loss through evaporation.

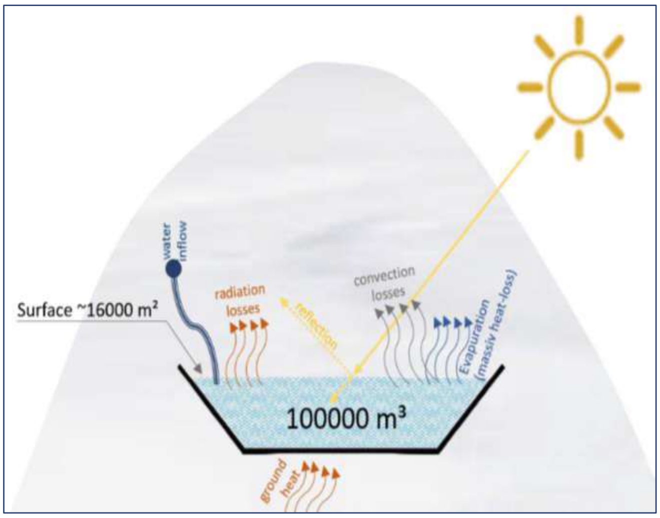


Figure 49 - Reservoir energy system

If we constantly remove heat from the water and thus lower the temperature, which reduces all energy outflows and the inflow from the ground heat increases. A detailed calculation is not possible within the scope of this work, but the lake will definitely provide a significantly higher heat supply than the 1.276 GWh. This will be sufficient for the heat pump in summer. Cooling down to 2°C is probably not realistic. Nevertheless, the temperature reduction would be significant.

But in winter there is obviously no sufficient source of heat?! Not quite true, the inflow is continued in winter and is increased by pumping in the water that has been taken out. Table 52 - winter heat source by inflow waterTable 52 shows that we could also extract ~ 1.23 GWh of thermal energy in winter due to natural inflow and refilling by pumps. The summer values should not be taken into account here. These are already included in the temperature increase of the reservoir. But 1.23 GWh is significantly too low in winter. According to Table 50, we need 1.84 GWh. So, 0.6 GWh are missing.

Table 52 - winter heat source by inflow water

inflow	refilled (pump) water: assumed avg. inflow per day [m³]	refilled (pump) water: assumed avg. refill temp [°C]	natural inflow water: assumed avg. inflow per day [m³]	natural inflow water: assumed avg. inflow temp [°C]	heat-content for t_{min} = 2°C [kWh]
May	0		1 000	7	176 417
Jun	500	8	900	8	296 380
Jul	0		500	8	105 850
Aug	0		200	8	42 340
Sep	0		100	8	21 170
Oct	0		100	7	17 642
Nov	1 000	7	100	6	190 530
Dec	2 500	6	100	5	363 418
Jan	2 400	5	50	4	257 568
Feb	2 300	5	100	4	250 512
Mar	100	6	500	5	67 038
Apr	0		700	6	98 793
total	267 667		47 146		1 887 658
summer	15 208	8	85 167	8	659 798
winter	**252 458**	**6**	**47 146**	**5**	**1 227 860**

This leads us to a further possible use of additional synergies. Under 8.1.2 (p. 80) we have simulated the integration of pumped storage operation in the snowmaking lakes. In pumped storage operation, we are continuously supplied with additional pumped water. This may even have a slightly higher temperature because most of the losses (turbine, pump, pipe, ...) are transferred to the water as heat. The values for the daily inflow listed in Table 53 were taken from the pump plant simulation (based on and S2023SW and B1111), converted to average values and rounded.

Table 53 - inflow pump power plant

pump power plant inflow	pump-storage load: assumed avg. inflow per day [m³]	pump-storage load: assumed avg. Inflow temp [°C]	heat-content for t_{min} = 2°C [kWh]
May	600	7	105 850
Jun	500	8	105 850
Jul	600	9	148 190
Aug	600	9	148 190
Sep	700	8	148 190
Oct	1 100	7	194 058
Nov	1 000	7	176 417
Dec	500	6	70 567
Jan	200	5	21 170
Feb	300	5	31 755
Mar	700	6	98 793
Apr	1 200	6	169 360
total	**243 333**	**6,9**	**1 418 390**
summer	124 708	8,0	850 328
winter	118 625	5,8	568 062

The pumped power plant operation would supply us with an additional 0.56 GWh in winter. This means we are only missing ~0.04 GWh any more - theoretically. In practice, natural water inflow and pumped water inflow are by no means synchronized with the daily profile of the heat demand. We need a large-scale heat storage facility anyway and we must be protected against medium-term outages of the heat sources. At this point I have been thinking about an ice energy storage, like described under 5.9 (p. 47).

Table 54 - ice storage - energy for counter generation

	counter-generation					5000 m³ ice storage	
Ice storage	***assumed ground heat [kwh]***	***refill-(pump) inflow [kwh]***	***natural inflow-water [kwh]***	***lake circulation [kwh]***	***total counter generation [kWh]***	***energy-request for freezing [kWh]***	***new ice [m³]***
May	10 534	0	176 417	77 333	264 284	0	0
Jun	13 020	105 850	190 530	159 822	469 223	0	0
Jul	14 016	0	105 850	230 281	350 147	0	0
Aug	13 964	0	42 340	230 854	287 159	0	0
Sep	13 153	0	21 170	192 570	226 892	19 477	182
Oct	11 455	0	17 642	192 570	221 667	79 411	741
Nov	7 323	176 417	14 113	192 570	390 422	0	0
Dec	7 448	352 833	10 585		370 867	0	0
Jan	6 463	254 040	3 528		264 032	87 429	816
Feb	8 191	243 455	7 057		258 703	63 003	588
Mar	8 060	14 113	52 925	11600	86 698	244 791	2 284
Apr	9 549	0	98 793	58 000	166 342	0	0
total	**123 177**	**1 146 708**	**740 950**	**1 345 600**	**3 356 435**	**494 111**	**4 609**
summer	76 142	105 850	553 948	1 083 430	1 819 371	98 887	922
winter	47 035	1 040 858	187 002	262 170	1 537 064	395 224	3 687

Table 54 first shows the possible amount of energy for regeneration without a pumped-storage power plant. The natural regeneration via ground heat[33], pump operation of the reservoir for regular snow production, the natural inflow and in summer the direct extraction from the snowmaking-reservoir, which is heated by the sun and air, are taken into account. After comparing these monthly energy inflows with the heat requirement of the heat pump, there is a deficit of ~0.5 GWh, which could be compensated for with an ice storage reservoir of ~4000-5000m³.

But that is clearly too big. Ice storage units of this size are not yet known and are also far too expensive for our requirements. We therefore look at the same values again, including pumped storage operation:

The result in Table 55 shows, that with integrated pumped storage operation, the additional inflow is sufficient to reduce the size of the ice storage by more than half - that's amazing!

Table 55 - counter-generation including pump power plant operation

steady flow by pump power plant	***add. counter-generation by power plant[kwh]***	***total counter-generation TOTAL [kwh]***	***energy-request for freezing [kWh]***	***new ice [m³]***
May	105 850	370 134	0	0
Jun	105 850	575 073	0	0
Jul	148 190	498 337	0	0
Aug	148 190	435 349	0	0
Sep	148 190	375 082	0	0
Oct	194 058	415 725	0	0
Nov	176 417	566 839	0	0
Dec	70 567	441 433	0	0
Jan	21 170	285 202	66 259	618
Feb	31 755	290 458	31 248	291
Mar	98 793	185 492	145 998	1 362
Apr	169 360	335 702	0	0
total	**1 418 390**	**4 774 825**	**243 505**	**2 272**
summer	850 328	2 669 699	0	0
winter	568 062	2 105 126	243 505	2 272

33 Calculated for the 5000 m³ cistern with 3 W / m2 K and rough estimated ground temperatures by month

The result is now a total ice generation of 2272 m³, mainly in March, when we are short of pumped water for normal snow production as an energy source.

~2300 m3 is also a lot, but perhaps not too much if additional measures of a manageable magnitude are added. For example, solar thermal panels could be installed on some hotel roofs, which could provide very good yields in March and be used to regenerate the ice storage tanks. Or air-source heat pumps could be integrated into the hotel to slightly reduce the heating demand. With such accompanying measures, it should be possible to reduce the size of the ice storage tank to 1500-2000 m³.

Figure 50 shows a scheme of the basic operating principle:

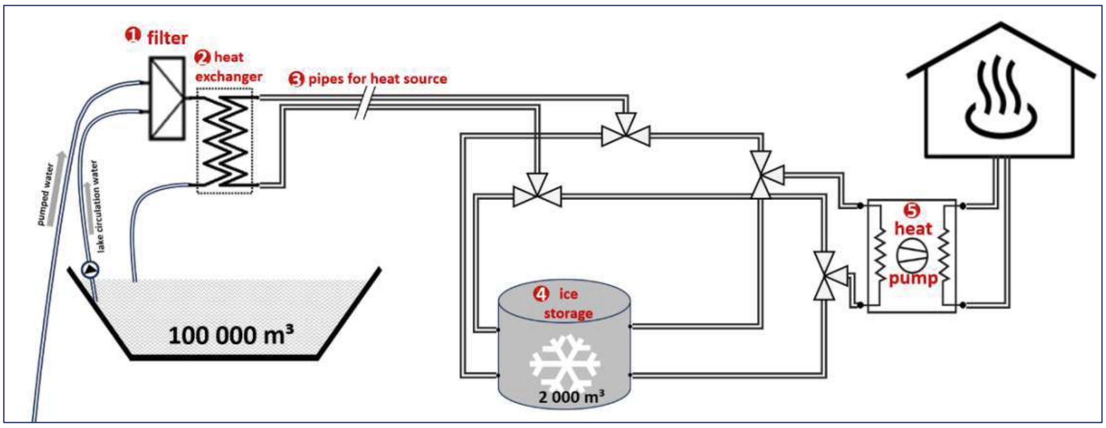


Figure 50 - integration of ice storage

- The water from the heat source must first be fed into a filter ❶. This filter is either supplied from the pump pipe or it draws water directly from the lake via a circulation pipe.
- The water flows from the filter into a heat exchanger ❷. Due to the heat output of >= 1.5 MW, this must probably have an output of close to 1 MW. In relation to the very small temperature differences that we extract from the water, this heat exchanger will have an enormous size. Technically, however, this is possible; river heat pumps have many times the output, similar temperatures and also require a heat exchanger of this type.
- This is followed by the supply pipe❸. A glycol mixture flows in this, similar to geothermal heat pumps. The length of this pipe could be critical to the system. The pipe must be insulated, otherwise we would lose the cooling effect for the lake and also be subject to heat losses. But it also has to be very thick in order to be capable of transporting the amount of energy at low temperature differences. Only an extensive and detailed design can clarify whether a thinner

pipeline with a very high flow rate would be an alternative solution. However, this requires higher operating costs for the increased pumping capacity. The longer the pipe, the more expensive and more wasteful the system.

- The "warm" glycol mixture can now be sent either to the ice storage tank ❹ for countergeneration or directly to the heat pump ❹. The heat pump decides on the basis of the current heating demand and the respective temperatures.

All in all, this is a complex system. But if we can keep the ice storage tank somewhat smaller with a few additional heating sources, then at least the time required is probably less than with the boreholes for ground probes described under 5.8 (p. 45 ff).

Very inspiring here is the symbiosis between the ski resort, the energy producer cooperative and the hotel, as well as the multiple use of synergies. The hotel supplies the ski resort with cooling energy, ensures early snowmaking without additional energy consumption and the ski resort saves on the high investments for the cooling towers.

In the reverse direction, the ski resort and the producer association make it possible for the hotel to get sufficient energy for heating via the pumped storage operation. Here, part of the power loss during pumping/generation is also utilized in the heating system via the slightly heated return water.

And last but not least, the heat pumps are powered by the energy community's own electricity. Some of this also comes also from the pumped storage operation. This closes the circle several times over.

If we introduce such measures, we completely take the wind out of the sails of criticizers (as quoted on page 83).

8.3 Heat-storage potential of pools in wellness hotels

Without going into great depth, I do not want to leave this point unnoticed. Our hotels and lodges together hold a total of 840 m^3 of water in their pools. One degree of temperature difference therefore corresponds to 977 kWh of energy. This, in turn, is exactly the average heat requirement per hour in summer for all hotels and lodges together. In winter, the average is 1179 kWh.

Most guests would hardly notice or complain about a difference of one degree for a short time. So if we preheat at times of low energy prices or suspend the pool heating for a short time and move it to the rear, this can have a significant financial impact with variable electricity prices over the year.

This example is only intended to show the effects that can be achieved through systematic energy management. There are certainly many similar examples in the ski mountains' energy system. Once variable pricing is accepted, energy management measures automatically will be implemented and they pay off. This in turn has extremely positive effects on the common energy system in Austria and beyond.

9 ECONOMICAL EVALUATION OF RESULTS

To assess the commercial evaluation, I would again like to focus on the producer group. Legally, this could be represented by a cooperative or an association. Each member could/should have shares in this producer association and pay the association for the energy purchased (from their own generation and possibly also from external procurement). In addition, profits and losses are to be shared between the shareholders/members.

9.1 Price composition and expected price-development

Of course, the pricing for the settlement within the producer group can be defined as desired. If necessary, with flat rates that are periodically reviewed. In our example, we stay with the market price charging model. This means that the members of the producer group are always charged the market price plus surcharges and grid fees for the energy they consume, regardless of whether the energy is purchased externally or generated internally.

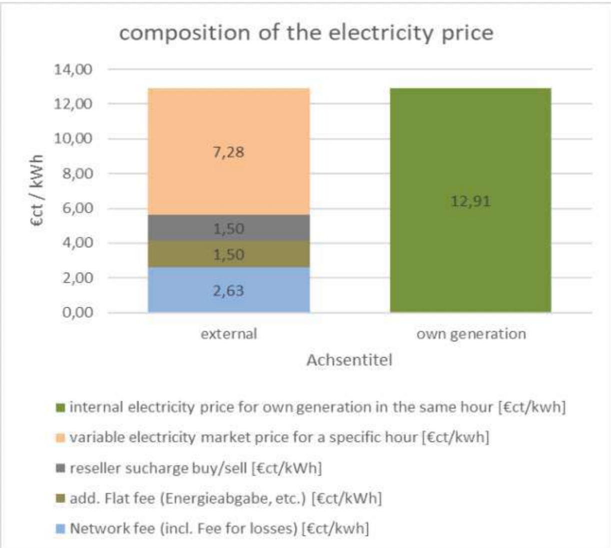


Figure 51 - composition of electricity-prices

Figure 51 shows the price composition for external procurement on the left-hand side. The 7.28 €ct/kWh corresponds to the average price for consumption in the winter season 23/24. The right-hand side shows the average price for internal use in the producer group.

The 12.91 €ct/kWh is exactly the same as the total external procurement costs.

But how will prices develop in the future? The last 2-3 years have seen extremely high electricity prices on the market. The electricity price is one thing, but there is also a development in network charges. Here, too, there have been continuous or, in some cases, steep increases in recent years.

Figure 52 shows the development of network tariffs including loss charges for grid level 5 in Carinthia since 2010[34]. The mostly sudden increase corresponds to an average annual increase of 5% over 15 years.

If this 5% is continued, the fees for 2035 amount to 6.34 €ct/kWh.

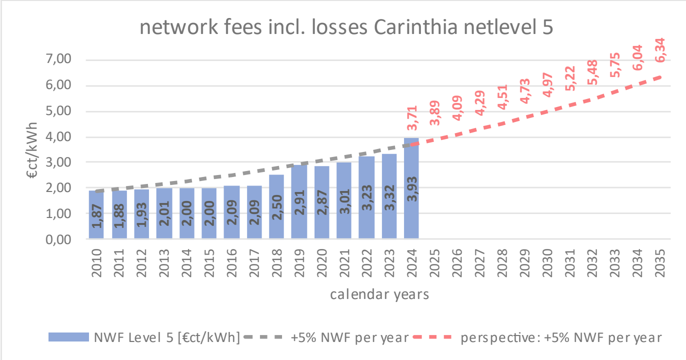


Figure 52 - network fees since 2015

However, prices on the electricity market behave differently. There were extreme price jumps in 2021-23. We are currently still observing a downward price trend. Our average prices, which we show in the simulations for S2023$_{SW}$, are not realistic for the near future.

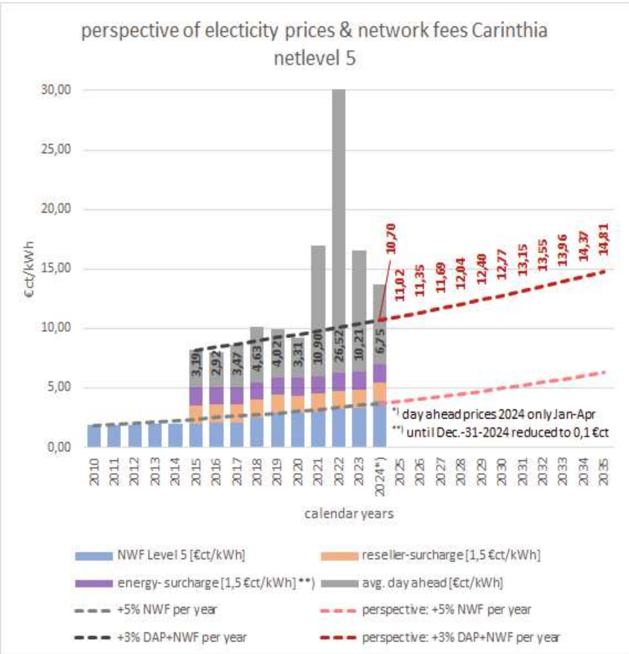


Figure 53 - perspective of electricity prices

Figure 53 shows the development of day-ahead prices since 2015. Assuming an average annual price increase of 3%, the average price at the end of 2024 including grid fees and charges would be 10.70 €ct/kWh. If the grid fees of 3.93 and charges of 3,00 are deducted, the pure electricity price would then only be 3.77 €ct/kWh, which corresponds to the average of the year 2016-2019. From the perspective of the past three years, this seems unrealistically low.

On the other hand, if we continue the 3% increase, we can expect the average price to be around 14.81 €ct/kWh including grid fees and charges in 2035, which equals to 5.47 €ct/kWh for the pure energy-price. This also seems quite low, but it's a cautious forecast, so it's probably best to go with it.

[34] Source: Own illustration based on the data published annually by E-Control “System usage tariffs for electricity” [32]

9.2 Assumptions for commercial calculations

Implementation is assumed to be in 2 sub-projects, separated into PV and wind.

Sub-project PV:

- Project planning and development: 2024/25
- Implementation: 2025
- Commissioning: before the start of the winter season 2025/26
- Installed power: 2 196 kWp
- annual yield: 2 341 MWh / year (avg. 2015-2023)
- Loss in performance: 1% per year[35]
- Total Investment: 2,42 Mio.€
- Subsidy: 0,73 Mio.€ (30%)

Sub-project Wind:

- Project planning and development: 2024-2028
- Implementation: 2029 - 2030
- Commissioning: before the start of the winter season 2030/31
- Installed power: 1 700 kWp
- annual yield: 3 525 MWh / year (avg. 2015-2023)
- Loss in performance: 1% per year[35]
- Total Investment: 4,08 Mio.€
- Subsidy: 0,80 Mio.€ (~20%)

Electricity-demand:

- Starting in 2026 with Scenario B00h0
- Demand-growth 0,5% per year with energy-profile of B00h0
- Continue including wind-power in 2031 with B00h0
- Demand-growth 2032-2035 2,0% per year with energy-profile of B00h0
- Switch to Scenario B1111 in 2036, no further growth

[35] Recovery of 50% of the previously lost performance after the general overhaul

9.3 Subsidies

A project of this kind in the Carinthian mountains is significantly more expensive than in the lowlands. Without subsidies, electricity from wind and PV cannot be produced competitively. As the plants are intended for self-consumption, subsidized feed-in tariffs make no sense. Investment subsidies of ~25-30% are required. The following funding instruments are imaginable, some of them can/must be combined:

- KPC / Climate Energy Fund - Model and lighthouse projects photovoltaics [16, p. 7]:

  Due to the special design for winter energy with a tilt of 65°, high racks and low panel density, which is aimed at simultaneous alpine farming and tourism operations in summer, this project can be classified as very innovative. Funding as a model/lighthouse project should therefore be possible.

  The investment costs for PV systems from 10 kWp to 5 MWp are subsidized by 35%. In addition, the following bonuses are possible depending on company size and degree of innovation:

  - 20% for small companies, natural persons
  - 10% for medium-sized companies
  - 5% or 10% innovation bonus (only for projects selected for accompanying research)

- EAG investment support for PV category D - up to 1MWp [17, p. 5]:

  For one of the 3-4 calls per year a maximum of 140 €/kWp can be applied for. For particularly innovative projects there is the possibility of a 30% increase. In our case, that would be up to €182000 for the maximum subsidized 1 MWp.

- EAG investment support for wind turbines 20kW - 1MW [17, p. 7]:

  This funding scheme of the Federal Ministry for Climate Protection must be applied for via the EAG administration office.

  A maximum of €500/kW is subsidized, although it is not clear from the documents whether this applies per wind turbine (i.e. 2 x €425,000) or only once per project (i.e. max. €500,000).

- KPC / Climate Energy Fund - Support for renewable energy communities, citizen energy communities and community generation plants with an innovative character [18, p. 7]:

  Funding can be granted for intangible services (e.g. project planning) up to up to 50% of the net costs can be granted. The maximum funding including bonus is €20,000.

- K-EIWOG funding from the Carinthian state government [19, p. 3]
  Systems or system components are subsidized with a maximum of 50% of the eligible costs (excluding taxes). The maximum funding volume of a sponsored project may not exceed 300,000 euros per year.
  For our 2 separate project phases, 2 x € 300,000 are therefore imaginable.

From a broader perspective, EU funding pots should also be possible. Especially if this (pilot) project could be duplicated in other ski resorts or if particularly innovative solutions (see section 8, p. 76 ff) were integrated. These EU subsidies are associated with much more administrative effort, but the possible funding amounts are also higher. There are many funding opportunities from the EU, some examples are mentioned here:

- Innovation fund [20]
  As Figure 45 shows, the Innovation Fund offers very high levels of funding in the various project phases. If the implementation project also includes the multiple energy use of reservoirs (see 8.2, p. 83), it can be considered a very innovative project.

Figure 54 - EU innovation fund [20]

- JTF (Just Transition Platform) - support can be provided to [21]:
  - productive investments in small and medium-sized enterprises
  - the creation of new firms
  - environmental rehabilitation
  - investments in clean energy
  - the transformation of existing carbon-intensive installations, when these investments lead to substantial emission cuts and job protection
  - etc.

  Message from Elisa Ferreira, commissioner for cohesion and reforms [21]:

  > *"The Just Transition Platform puts people and communities at the centre of the transformation, by listening to their aspirations and giving them the tools to realise their ideas."*

As Figure 55 shows, the mountain on which our “virtual” ski area is located is one of the JTF territories. Here, as well as for some other ski areas in Central/Eastern Carinthia, such funding would be possible.

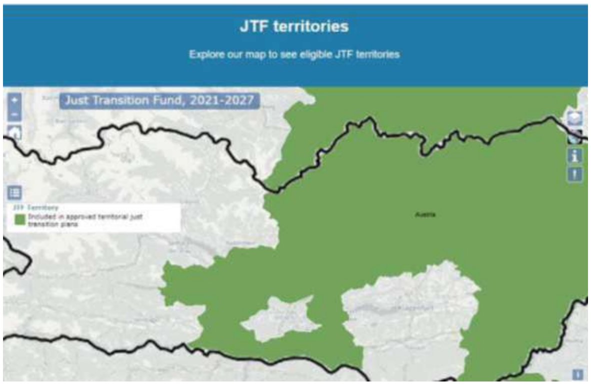


Figure 55 - JTF territories – Carinthia [21]

Specific funding amounts are not defined here. JTF provides grants and technical support for projects in advance, but sees itself primarily as a lever for public funding [21]:

> *“The European Investment Bank (EIB) provides up to €10 billion in loans as finance partner, while the Commission provides up to €1.5 billion in grants. These loans and grants support public sector entities to meet their development needs in the transition towards a climate-neutral economy.”*

9.4 Implementation costs for PV and wind turbines

As the project is divided into 2 sub-projects with different time frames, the key figures and costs are presented in 2 tables:

Table 56 - project-step 1 PV - costs and key data

	1,5 ha PV field with 65° tilt on mountain					**PV**
PV ground mounted						
	count of pannels					5 490
	rated power per pannel				kWp	0,400
	installed power total				kWp	2 196
Total energy yield						
	PV energy total (avg. 2015-2023)				kWh/year	2 341 000
I) Implementation						
I.1)	Architect, designers, permissions, etc.					€ 150 000
I.2)	Land for solar field and grid-connection					€ 0
I.3)	Panels incl. assembly on site					€ 1 100 000
I.4)	mounting racks & construction works					€ 550 000
I.5)	inverter, transformers & grid-connection					€ 450 000
I.6)	electrical installation / grid-connection					€ 120 000
I.7)	other onetime costs					€ 50 000
I.8)	required subsidies					-€ 726 000
	Total investment					**€ 1 694 000**
II) annual operation costs						
II.1)	internal monitoring & operation (wages, etc)					€ 15 000
II.2)	maintenance					€ 17 000
II.3)	insurance					€ 3 000
II.4)	electrical energy consumption					€ 2 600
II.5)	land rental fee	1,5	ha	3000		€ 4 500
II.6)	others incl spare parts					€ 11 000
	annual costs					**€ 53 100**
III) other otc and residual value						
III.1)	major overhaul after 15 years					€ 519 500
III.2)	residual value after 30 years					€ 364 000
IV) input-parameters for NPV						
IV.1)	Investment Horizon				years	30
IV.2)	Rated Capacity				Mwpeak	2,20
IV.3)	electricity generation				MWh/year	2 341
IV.4)	Decrease in system performance / year					-1,00%
IV.5)	Investment Costs				€/MW	€ 771 403
IV.6)	Full Load Hours				FLh	1 066
IV.7)	Operation Costs				€/MWh	€ 23
IV.8)	Repair workes after 15 years				€/MW	€ 236 566
IV.9)	residual value after 30 years				€/MW	€ 165 756

The panels are relatively expensive due to the bifacial design and the complex installation on the high racks on a sloping surface. The mounting racks are knocked into the ground without foundations. This is also much more complex on a hillside than on a flat field. It is assumed that the cost of connecting to the power grid will be manageable, as the lift and snowmaking facilities are located in the vicinity with sufficient grid access.

Table 57 - project-step 2 wind & total - costs and key data

2 wind-turbines			Vestas V52	together
Wind turbine				
	turbine count		2	
	rated power per trubine	kW	850	
	installed power total	kW	1 700	3 896
Total energy yield				
	Wind energy total (avg. 2015-2023)	kWh/year	3 525 000	5 866 000
I) Implementation				
I.1)	Project planning, wind-measurement, permissions, etc.		€ 250 000	€ 400 000
I.2)	Land for turbine and grid-conection		€ 0	€ 0
I.3)	turbine and logistics		€ 2 800 000	€ 3 900 000
I.4)	construction / foundation / errection		€ 600 000	€ 1 150 000
I.5)	transformers & grid-connection		€ 250 000	€ 700 000
I.6)	electrical installation / grid-connection		€ 80 000	€ 200 000
I.7)	other onetime costs		€ 100 000	€ 150 000
I.8)	required subsidies		-€ 800 000	-€ 1 526 000
	Total investment		**€ 3 280 000**	**€ 4 974 000**
II) annual operation costs				
II.1)	internal monitoring & operation (wages, etc)		€ 30 000	€ 45 000
II.2)	maintenance		€ 80 000	€ 97 000
II.3)	insurance		€ 20 000	€ 23 000
II.4)	electrical energy consumption		€ 4 400	€ 7 000
II.5)	land rental fee 1,3 ha 3000		€ 3 900	€ 8 400
II.6)	others incl spare parts		€ 37 000	€ 48 000
	annual costs		**€ 175 300**	**€ 228 400**
III) other otc and residual value				
III.1)	major overhaul after 15 years		€ 330 000	€ 849 500
III.2)	residual value after 25 years		€ 430 000	€ 794 000
IV) input-parameters for NPV				
IV.1)	Investment Horizon	years	25	
IV.2)	Rated Capacity	Mwpeak	1,70	3,90
IV.3)	electricity generation	MWh/year	3 525	5 866
IV.4)	Decrease in system performance / year		-1,00%	
IV.4)	Investment Costs	€/MW	€ 1 929 412	€ 1 276 694
IV.5)	Full Load Hours	FLh	2 074	1 506
IV.6)	Operation Costs	€/MWh	€ 50	€ 39
IV.7)	Repair workes after 15 years	€/MW	€ 194 118	€ 218 044
IV.8)	Residual Value	€/MW	€ 252 941	€ 203 799

Table 57 shows that higher costs are also budgeted for wind than for turbines as part of a large wind farm. The 2 smaller turbines have the advantage that a foundation of only a limited size is required. However, the logistical effort on the mountain is immense. Due to the small size, no measures are required for the access roads. Transport and crane vehicles can use the existing roads. Costs for repairing damage are taken into account under I.4.

9.5 NPV, annuity and LRGC for PV and wind turbines

A CPI of 2% as a long-term average and a discount rate of 6.5% as a mixed rate of various financing/participation instruments are assumed as the commercial framework for calculating the LRGC (long run generation costs). The initial prices for the energy generated are, as shown in Figure 53 (p. 92), 113.50 for internal use/distribution and 42.50 for supply to the grid. As described on page 92, we assume an annual increase in the average price of 3% (incl. grid tariff and surcharges), while the feed-in tariffs will probably be gradually reduced at times of peak/overproduction. An annual -1% is assumed here.

Table 58 - financial key figures

financials		together
V) financal parameters		
V.1)	CPI	2,00%
V.2)	Discount rate	6,50%
V.3)	CFR	7,66%
V.4)	internal price el. Energy 1st year	€ 113,50
V.5)	SalesPrice-incr. / year	3,00%
V.6)	sales price to the grid 1st year	€ 42,60
V.7)	Feed-in Price-incr. / year	-1,00%
VI) results		
VI.1)	NPV	€ 10 056 184
VI.2)	Annuity	€ 770 077
VI.3)	NPV of costs	-€ 7 391 606
VI.4)	Ann. of costs	-€ 566 030
VI.5)	LRGC (incl.CostEsc.)	**-€ 116,58**

The resulting LRGC of €116.58/kWh is far too high compared to large feed-in systems. Large wind/PV parks must deliver values significantly below €100/kWh in order to be commercially successful. However, we are planning a combined power plant that is oriented towards self-consumption (in the producer association) and has been optimized for the local energy demand. Although the €11.66/kWh (= €116.58/MWh) is higher than most values shown in Table 40 on page 69, this is an average value for the next 30 years. Taking price increases into account (see Figure 53 on page92), this is a very respectable result in terms of self-consumption.

9.6 Cash flow and break even

Figure 52 shows the development of the cumulative cash flow under the assumptions outlined above. The price curve starts at 11.35 €ct/kWh (incl. fees), which is significantly below the current price level. Assuming an annual 3% increase, the price level that exists on the market today will be reached in 2033.

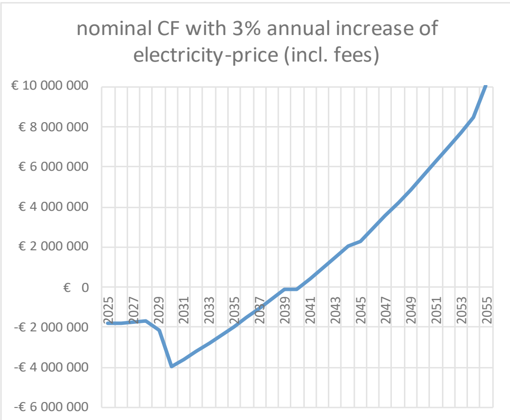


Figure 56 - CF PV+Wind, 3% incr. el.price

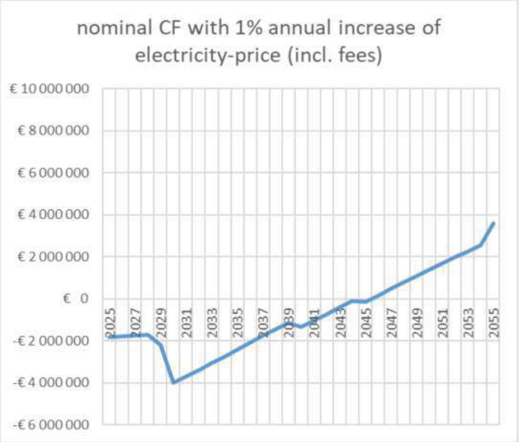


Figure 58 - CF PV+Wind, 1% incr. el.price

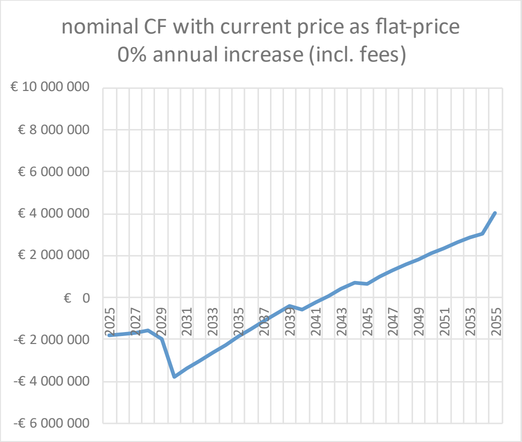


Figure 57 - CF PV+Wind, flat price of today

This leads to a break-even point in 2041, i.e. 15.1 years after commissioning of the PV system, or 10.1 years after commissioning of the second project step - the 2 wind turbines. These values correspond to the information above or the details in Appendix (7) on page 135.

The two other variants show the nominal cash flow for a price curve with a 1% annual increase in Figure 58 on the left-hand side. In this case, the current electricity price level would not be reached again until 2045. This is actually not a price increase; the low price steps are already fully utilized by the grid tariff increases. Here, the break-even point is reached in 2045, 20.5 years after commissioning stage 1 (PV) or 15.5 years after project completion with the 2 wind turbines.

Figure 57 on the right shows the variant with a constant price as it can be found on the market at the moment. Very similar to the 3% variant, in this case the break-even point is reached 16.8 years after commissioning the PV system, or 11.8 years after project completion. That is in the year 2042.

9.7 Commercial evaluation of the integrated pump power plant

At this point, I do not want to present results as in 9.4. There are too many uncertain assumptions required to evaluate this project. Nevertheless, I have made calculations and give a rough outline.

First, the necessary investment: As already described in section 7.1, we can neither build a high-performance pumped storage power plant, nor can we assume generator operation based on naturally inflowing water. For the energy we generate, all the water must first be pumped up. However, these pumps already exist for snowmaking and would only be used and exhausted much more frequently. The investment is therefore limited to the addition of turbine(s) and generator(s). A very simple investment (I'm assuming 3 turbines of 180 kW each) could certainly be made with € 300,000 to € 500,000. But it depends. As soon as new buildings are erected and/or down-pipes/pump-pipes have to be relocated on a larger scale, these costs are no longer sufficient.

My assumptions are therefore based on rather low costs:

- Investment-/Projectcosts € 400,000
  (turbines, generators, implementation in existing pump-house, electric, control-system, etc.)
- Repair after 15 years: € 28,000
- Residual value after 25 years € 108,000
- Operating-costs (mainly electricity for pump-operation) € 49,900
  Thereof only € 6400 for O&M incl. additional pump-O&M
  The main pump-energy costs are extremely variable.
- Sales: own use in group: € 52,000
  feed-in: € 13,700

These assumptions and a consumer price index of 2 %, a discount rate of 6.5 %, a financing period of 25 years and no adjustment of sales (in quantity and price) lead to a slightly positive NPV, as long as electricity prices remain constant over the entire financing period. But this is not realistic. Even with an annual electricity price increase of 1% per year, the net present value is negative.

However, if the energy price variance is also increased, the break-even point is reached within 15-17 years, assuming the variance is twice the price increase. A precise assessment is not useful as it depends on too many assumptions about price trends. In any case, there should be a positive return in the short term. Falling electricity prices combined with a significantly higher variance are a boost for the pumped storage business.

But I would evaluate the operation of pumped storage more strategically - or as a hedge against (partly foreseeable) price fluctuations in the future. A bit like liability insurance for a car. It doesn't pay off if nothing happens.

Under the condition that the turbines can be integrated cheaply and easily, and that these measures may also be subsidized in the sense of an integral solution, I would warmly recommend the investment, even if the forecast is very uncertain.

9.8 Commercial evaluation of snow making reservoirs as heat-source

As already explained under section 8.2 (p. 83 ff), this complex solution requires an extremely precise and extensive design in the form of a separate (pilot-) project. For a reasonably accurate assessment, at least temperature and flow measurements over a longer period of time would be necessary, similar to what was done in the study for Madonna di Campiglio [22, p. 7]. Unfortunately, the relevant data is not available to public in detail.

It would therefore be unprofessional to state any estimated costs here and to draw up a profitability calculation.

I would just like to mention a few points that came out of the discussions with Viessmann and describe some relationships of costs:

- Whatever the cost of this system, the resort saves a very large investment in cooling towers, related construction, high-pressure pumps, etc. Depending on the capacity, this can be estimated at several hundred thousand euros. Components such as filters, heat exchangers and piping (see ❶❷❸ in Figure 50, page 88) should therefore be (substantially) financed by the ski-resort. These components should always be considered in relation to the investment sum for the water cooling systems.
- The operating/energy costs of the cooling towers are rather insignificant in comparison. The energy required 365 days a year for the hydraulics of the

water supply between the lake and the heat pump/ice storage tank is probably even higher than the energy saved by the cooling towers.

- The costs for the line are very critical. Viessmann roughly estimates € 1,000 to € 1,200 per meter (thick, insulated pipes buried in the ground). Hotels are usually not located near large reservoirs. If the distance is only 200-300 meters, a detailed calculation makes sense. However, if the lake is more than a kilometer away from the hotel, the cost, as well as the thermal losses of the pipeline and hydraulics, are likely to be an obstacle to the project.

All in all, this innovative solution with multiple synergies certainly opens up the possibility of innovation funding. And the marketing aspect should not be underestimated either.

10 CONCLUSIONS

As noted under 1.2, even before this study I was of the opinion that our mountains are very well suited to wind energy and that this form of renewable energy is better suited to the requirements of a ski mountain than photovoltaics. This was clearly confirmed by the simulations. The only scenario in which smaller PV systems offer a better result than wind turbines is S000 - the ski resort without snow production, separated from the electricity demand of the hotels and lodges. All other scenarios show clear advantages for wind. Small to medium-sized PV fields complement and optimize the generation profile of wind turbines.

Furthermore, my assumption that the joint view on ski resort and hotels would lead to benefits has also been confirmed. Apart from the fact that hotels would not invest in wind turbines on their own (see statement from hotel-owner under 1.2, p. 2), the combination of the load profile for ski operations also reduces the jointly required capacity of renewable energy sources to be installed.

The facts are that individually 2 ha of PV are required for 32% self-sufficiency in the ski resort (scenario S00h0), while 1 ha of PV leads to 31% self-sufficiency in the hotels (H0000). In the joint profile (B00h0), 32% self-sufficiency is also achieved with 2.5 ha of PV only. Individually, these two tourism sectors require 20% more area to achieve the same results in terms of sustainability in their marketing folders. The same with wind: one turbine and 0.5 ha of PV lead to 52% self-sufficiency for the hotels (H000). For the ski resort (S00h0), a turbine in combination with 2.5 ha of PV would be required for 53%. Together, the values of 52% and 53% are achieved with either only one wind turbine and 3 ha of PV, or 2 wind turbines with only 1.5 ha of PV - i.e. half the PV area.

During the research on the heating needs of the hotels, I was shown a CHP proposal for a similar hotel. The configuration was obviously strongly influenced by the extreme electricity prices at the end of 2022. However, I quickly realized that although this real existing hotel is surrounded by forest, it is mostly protected forest next to the slopes. The subsequent problems associated with building a CHP plant were not considered further due to the energy crisis. Because of the transportation and the long-term environmental impact, I decided against this option, even though it might make sense elsewhere. However, this also made me realize the importance of heat pumps in remote mountain regions. I have therefore included this demand in the future scenarios for electricity requirements.

Therefore, if CHP or biomass heating systems cannot be recommended in such regions, the advice must be that hotels should primarily invest in changes to the internal heating system. Temperature levels need to be reduced so that heat pumps can operate effectively. The historical situation is usually such that all heating loads are supplied with a flow temperature of 75-80°, even if they would be satisfied with 35-40° in the wellness area, for example. This requires a switch to radiant floor heating and forced-air heating systems. And the internal heating pipes usually need to be enlarged to transfer the same amount of energy at lower temperatures. Compared to this, the cost of the heating system (whether biomass or heat pump) is relatively low. Nevertheless, it's the way hotels should go. They're constantly renovating anyway, and most of their heating loads can be handled at low temperatures. We need to use our valuable biomass for heat generation where we have no alternative to high temperature levels.

The heat pumps now take us to the reservoirs. Besides their potential as pumped-storage power plants, they also contain an enormous amount of thermal energy. For me, the most interesting and unexpected finding of this work was that it is possible to heat a hotel with these reservoirs even in winter. However, this only works with an ice energy storage and in symbiosis with the pumped power plant operation, which provides additional heat energy through a constant, additional water supply. Even if the costs of a pilot/lighthouse project cannot be precisely estimated yet, and even if precise measurements (temperature, water flow, etc.) are required, this possibility offers an impulse for a much broader exploitation of potential and synergy effects.

However, using the potential of reservoirs as a pumped storage plant is also recommended, as long as easy integration into existing pumping stations is possible (like described under 9.7 p. 101). This would be recommended for new installations anyway, as future electricity prices are likely to be much more volatile than we are currently used to.

The economic evaluation shows that a producer cooperative can refinance the high investments through market-oriented (variable or fixed) prices. However, given current electricity market prices, subsidies remain essential for refinancing. Low electricity prices pose a significant barrier to the financial sustainability of a producer cooperative. Nevertheless, a lower price level than we have seen in recent months was chosen as the starting point. Price increases of between 1 and 3% are realistic, since grid fees will continue to show an upward trend during the energy transition. It cannot and must not be the aim of a producer cooperative to generate high profits in the short term. It is important that prices are charged in line with the market over a longer period of time and that it is possible to finance replacement systems at the end of the life cycle. This is demonstrated by the model calculations.

During the energy transition, subsidies (as previously outlined) are a crucial element in the financial support structure. Firstly, the technologies in question have not yet reached the price point of mass-produced items (e.g. wind turbines, optimized for mountains or racks for PV modules for snow-covered mountain slopes). Secondly, the cost base of alternative technologies is frequently based on investments that have already been written off.

However, it is important to note that subsidies and especially short-term, additional financial returns should never be the driving force behind investment decisions regarding renewable energy systems. The primary motivation must always be the long-term future perspective: energy security through local generation using renewable resources as well as decarbonization and limiting environmental damage for our descendants. The economic calculations presented in this paper are therefore not intended as a basis for decision-making in the sense of a financial investment. The objective is to mitigate concerns about potential financial disadvantages compared to continuing with traditional energy sources.

In any case, the recommendation to integrate locally generated renewable energies into the marketing strategy applies to all parties on the mountain. Private households are currently investing heavily in heating replacements, PV systems, etc. This also increases the expectation that the tourism facilities chosen for vacation and leisure will also take measures in this direction.

I would like to say a few words about variable electricity prices. I am personally convinced that in the medium term we will be increasingly dealing with variable prices. Flat rates will have a higher risk premium when prices are very volatile. And this would also be paid at times when energy costs nothing or is even traded at negative prices (which is already the case in some rare hours). Of course, a community of producers on a ski mountain does not have to do so; it is also possible to charge flat rates that are adjusted on a regular basis. However, the big advantage of variable prices is that each participant will set a certain level of energy management on his own initiative if variable prices are used for billing. And this is one of the most important effects for our common regional and cross-regional energy system. Even if it is difficult to convince all participants in an energy- or “prosumer”- community, this approach should at least be considered.

Furthermore, some thoughts and discussions are also required when it comes to interventions in nature. Renewable energy plants are visible. They often lead to heated debates, especially in mountainous areas. Let's make a comparison: Back in 1978, Austria made the decision not to go ahead with nuclear power, and in particular, not to commission the Zwentendorf power plant. This led to a huge investment in hydropower. The numerous projects had a significant impact on the natural environment throughout the country. Today, these power plants are the backbone of our electrical energy system. These plants have been in place for decades and are now accepted, even though they still have a significant impact on nature. It's easy to overlook the hidden impact of fossil fuels on our natural environment. CO_2 is a slow but steady, invisible enemy of our natural environment. We need to consider the long-term consequences of our actions, just as we did in 1978. Unfortunately, we have to think about making selective, local changes to nature if we want to maintain our long-term wellbeing. With this in mind, it makes sense to focus on ski resorts where the infrastructure is already in place.

Last but not least, a comment on the landowners on the mountain - the farmers or foresters. Here, too, my opinion was only formed in the course of this work. I am convinced that these farmers should play a more important, if not leading, role in the generation of renewable energy on the mountain. They already provide their land for skiing, and most of them own the land on which the reservoirs were built. But their land is already contaminated by a dense network of utility lines. At the same time, they are concerned that climate change will cause problems for ski resorts. So they may be left with a dead infrastructure. Wouldn't it be better if these farmers took energy production into their own hands? In the worst-case scenario, this would also provide an option for subsequent use. Or better yet, they should work jointly to make sure it doesn't come to that, and supply the tourism businesses on the mountain with the land for skiing and hiking, agricultural products for the kitchens of the hotels, lodges and inns, and additionally the energy they need.

Today we know the term AGRI-PV specifically for PV systems. We should consider the term AGRI-Energyprovider for the future.

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List of figures/charts/diagrams

Note: All figures, tables and illustrations that do not state a source reference have been created or photos have been taken by the author.

List of tables

List of abbreviations and symbols

APG	Austrian power grid (Austrians grid operator)
ASHP	Air sourced heat pump
CEST	Central European summer time (corresponds to MESZ)
CET	Central European time
CFR	Capital recovery factor
CHP	Combined heat and power
COP	Coefficient of Performance
CPI	Consumer price index
EXAA	Energy Exchange Austria
€ct	EURO-cent
FM or Fm	Festmeter = solid cubic meter of wood in m^3
GLH	Global horizontal irradiance (sum of direct and diffuse solar radiation, which is scattered by the atmosphere)
GSHP	Ground sourced heat pump
hPa	Hectopascal – air pressure
INCA	Weather model INCA-CE – Nowcasting for Central Europe see also: https://www.zamg.ac.at/cms/de/forschung/wetter/inca http://www.zamg.ac.at/incaanalyse/ https://data.hub.zamg.ac.at/dataset/inca-v1-1h-1km https://data.europa.eu/data/datasets/inca?locale=en
KPC	Kommunalkredit Public Consulting GmbH
LRGC	Long Run Generation Costs
MESZ	Mitteleuropäische Sommerzeit = Central European summer time (corresponds to CEST)
N/A	Not applicable
NPV	Net present value
Pa	Pacal (air pressure), often also hPa for Hectopascal
prosumer	Combination of producer and consumer - an individual or entity that both produces and consumes energy
PV	Photovoltaic
RM or Rm	Raummeter = stacked cubic meter of wood
$S2023_{SW}$	Seasons 2023 summer/winter – means a period of 9760 hrs (= 365 days) starting from May 1^{st} 2023 00:00 UTC (due to the leap year 2024, it ends on April 29^{th}, 2024 24:00)
SPF	Seasonal performance factor (heat pumps)
Srm	Schütt-Raummeter = loose cubic meter (e.g. for wood-chips)
Vfm	Vorrats-Festmeter = solid cubic meter of timber in the forest
Vrm	Vorrats-Raummeter = stock in the forest in unit RM
UTC	Universal time coordinated (globally standardized time as a contrast to local time in different zones)
WBT	Wet-bulb temperature - combines air temperature and humidity
w/o	without

Conversion factors

Biomass conversions for wood[36]:

unit / type	FM round timber
1 FM round wood	1,00
1 RM blocks of wood with length of 1 m, stacked	0,70
1 RM small blocks of wood, ready for stove, stacked	0,85
1 SRM small blocks of wood, ready for stove, scattered	0,50
1 SRM wood-chips G 30	0,40
1 SRM wood-chips G 50	0,33

Biomass conversions for woodchips (spruce)[37]:

water-content %	weight [kg/FM]	Calorific value [MJ/kg]	Woodchips weight [kg/SRM]	Woodchips calorific value [kWh/SRM]
0	430	18,8	177	925
10	457	16,7	188	872
20	488	14,6	201	812
30	541	12,4	223	770
40	631	10,3	260	745
50	758	8,2	312	709
60	947	6,1	390	656

36 translated from „Holzeinschlagsmeldung über das Kalenderjahr 2021" [31, p. 9/10]
37 translated from „Heizwerttabellen für verschiedene Holzarten [30, p. 2]

APPENDIX

(1) MS-Excel simulation model

The simulation model consists of 3 sections:

- Data-sources
- Calculations
- Input/Output-section with simulation results

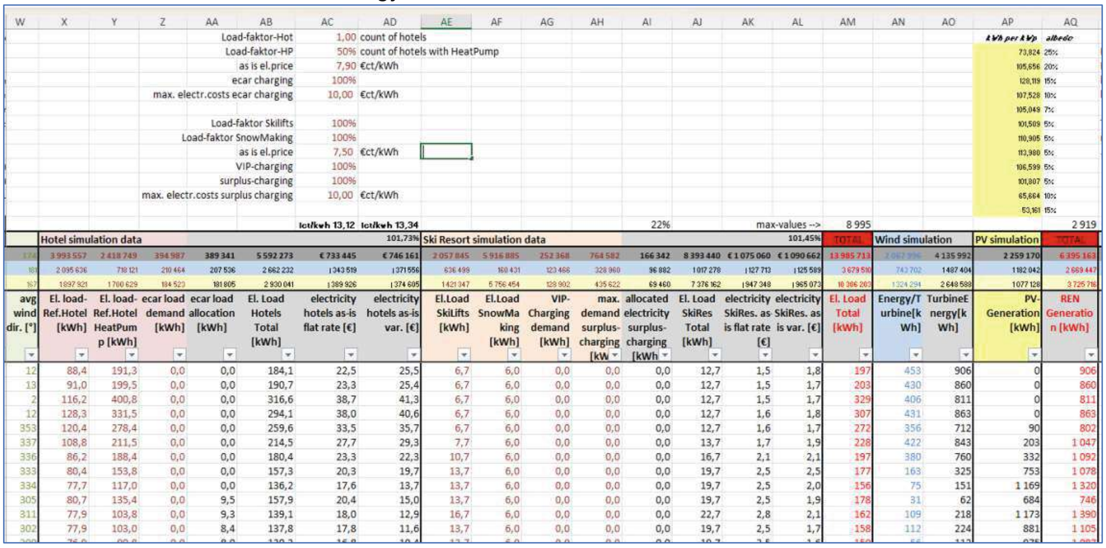
The Data Sources section (called “InputData” in Excel) contains hourly climate data and energy profiles of the ski resort and the hotels for the period 2015-2024, totaling more than 80,000 records. It is also possible to directly access the original data of the simulation models (separate Excel-file) for the energy profiles (see appendix (2) and (3)), but then the multi-year simulations run unacceptably slow. For this reason, the results of the corresponding energy profile calculations have been copied into this model.

The heart of the simulations is the Calculations area (called “EnergyData”). Here, calculations are always made for one year (or 365 days from a specific date). The 8760 data records from the data sources are therefore mapped from the start date. In the present work, the results are always computed with the start date of May 1 - the switch from the winter to the summer season.

Table 59 - Simulation model - EnergyData 1/3

	A	B	D	E	F	G	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1							summer months from/to		4	9										
2							day hours from/to		6	22										
3								Network fees	buy	sell										
4							summer day [€ct/kWh]		2,02	0,00										
5							summer night [€ct/kWh]		1,32	0,00										
6							winter day [€ct/kWh]		2,63	0,00										
7							winter night [€ct/kWh]		1,53	0,00										
8							NW fee faktor		100%	0%										
9																				
10							add. Flat fee (Energieabgabe, etc.) [€ct/kWh]		1,50	0,00										
11							reseller sucharge buy/sell [€ct/kWh]		1,50	1,50										
12	red header data to be changed in tab "Simulations"!						total MAX. surcharge buy/sell [ct/kWh]		5,63	1,50										
13							variance:	15,61	15,61											
14								price level 100%												
15							day ahead prices	variance lever 100%		NW-fees		Electricity prices		INCA data (geosphere.at)						
16								8,27	8,27	5,06	1,50	13,33	6,77	812,76	0,76	1 743	5,30	1 308 942	5,86	174
17							S-23	9,25	9,25	4,90	1,50	14,15	7,75	815,15	0,80	0,26	10,32	873 033	4,85	181
18							W-23/24	7,28	7,28	5,23	1,50	12,51	5,78	810,34	0,72	0,13	0,19	435 910	6,88	167
19	Date	Saison (tour)	cw	MM	DD	WD	hour end-time (UTC)	Day Adead Price [€ct/kWh]	adjusted Day Adead Price [€ct/k	buy fees [€ct/kWh]	feedin fees [€ct/kWh]	buy price [€ct/kW	feedin price [€ct/kWh]	Pn 1850m [hPa]	rel.humidity [%]	precipitation [kg m-2]	Outside Temp [°C]	GLH [W m-2]	avg. wind speed ground [m,	avg wind dir. [°]
20	2023-05-01	S-23	18	5	1	MO	01.05.2023 01:00	9,55	9,55	4,32	1,50	13,87	8,05	813,71	88%	0,00	1,64	0	8,27	12
21	2023-05-01	S-23	18	5	1	MO	01.05.2023 02:00	9,00	9,00	4,32	1,50	13,32	7,50	813,50	0,88	0,00	1,24	0	7,93	13
22	2023-05-01	S-23	18	5	1	MO	01.05.2023 03:00	8,74	8,74	4,32	1,50	13,06	7,24	813,21	0,86	0,00	0,96	0	7,58	2
23	2023-05-01	S-23	18	5	1	MO	01.05.2023 04:00	8,80	8,80	5,02	1,50	13,82	7,30	812,88	0,87	0,00	0,53	0	7,94	12
24	2023-05-01	S-23	18	5	1	MO	01.05.2023 05:00	8,73	8,73	5,02	1,50	13,75	7,23	813,10	0,89	0,00	0,57	60	7,18	353
25	2023-05-01	S-23	18	5	1	MO	01.05.2023 06:00	8,65	8,65	5,02	1,50	13,67	7,15	813,35	0,88	0,00	1,32	136	7,81	337
26	2023-05-01	S-23	18	5	1	MO	01.05.2023 07:00	7,32	7,32	5,02	1,50	12,34	5,82	813,75	0,83	0,00	2,01	221	7,36	336
27	2023-05-01	S-23	18	5	1	MO	01.05.2023 08:00	7,50	7,50	5,02	1,50	12,52	6,00	814,59	0,75	0,00	3,52	502	5,55	333
28	2023-05-01	S-23	18	5	1	MO	01.05.2023 09:00	5,02	5,02	5,02	1,50	10,04	3,52	815,67	0,64	0,00	5,61	780	4,24	334
29	2023-05-01	S-23	18	5	1	MO	01.05.2023 10:00	4,50	4,50	5,02	1,50	9,52	3,00	814,87	0,64	0,00	4,83	456	3,30	305
30	2023-05-01	S-23	18	5	1	MO	01.05.2023 11:00	4,26	4,26	5,02	1,50	9,28	2,76	815,65	0,61	0,00	6,71	782	4,80	311

Table 60 - Simulation model - ErnergyData 2/3



Load-faktor-Hot 1,00 count of hotels
Load-faktor-HP 50% count of hotels with HeatPump
as is el.price 7,90 €ct/kWh
ecar charging 100%
max. electr.costs ecar charging 10,00 €ct/kWh
Load-faktor Skilifts 100%
Load-faktor SnowMaking 100%
as is el.price 7,50 €ct/kWh
VIP-charging 100%
surplus-charging 100%
max. electr.costs surplus charging 10,00 €ct/kWh

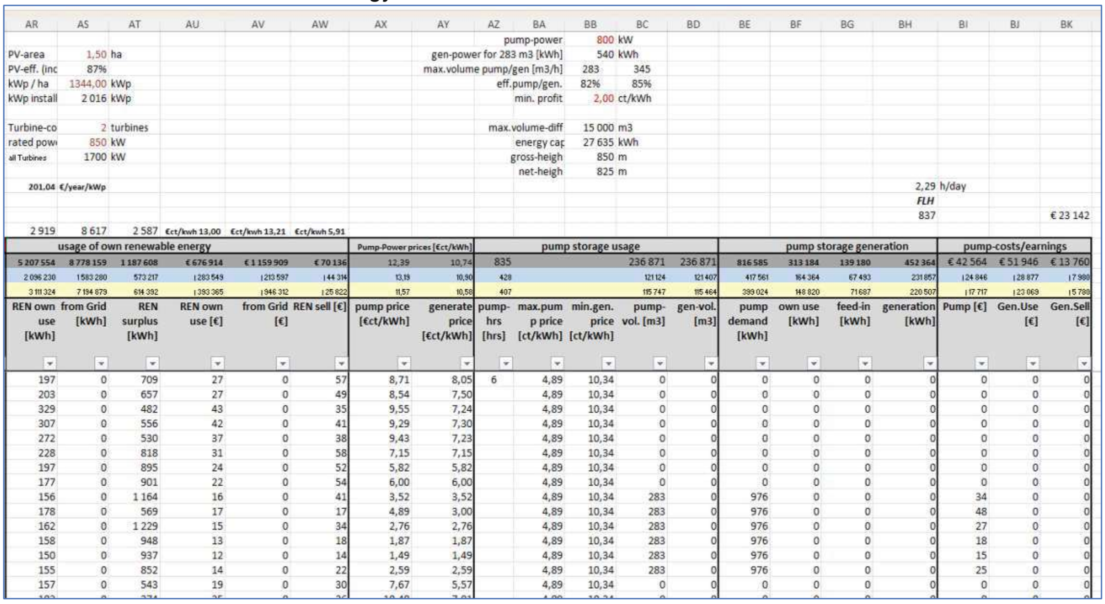
kWh per kWp / albedo: 73,824 25%; 105,656 20%; 128,119 15%; 107,528 10%; 105,049 7%; 101,509 5%; 110,905 5%; 113,980 5%; 106,599 5%; 101,807 5%; 65,664 10%; 53,161 15%

€ct/kwh 13,12 €ct/kwh 13,34 22% max-values --> 8 995 2 919

Hotel simulation data 101,73% | Ski Resort simulation data 101,45% | TOTAL | Wind simulation | PV simulation | TOTAL

avg wind dir. [°]	El. load-Ref.Hotel [kWh]	El. load-Ref.Hotel HeatPump [kWh]	ecar load demand [kWh]	ecar load allocation [kWh]	El. Load Hotels Total [kWh]	electricity hotels as-is flat rate [€]	electricity hotels as-is var. [€]	El.Load SkiLifts [kWh]	El.Load SnowMaking [kWh]	VIP-Charging demand [kWh]	max. demand surplus-charging [kWh]	allocated electricity surplus-charging [kWh]	El. Load SkiRes Total [kWh]	electricity SkiRes. as is flat rate [€]	electricity SkiRes. as is var. [€]	El. Load Total [kWh]	Energy/Turbine[kWh]	TurbineEnergy[kWh]	PV-Generation [kWh]	REN Generation [kWh]
174	3 993 557	2 418 749	394 987	389 341	5 592 273	€ 733 445	€ 746 161	2 057 845	5 916 885	252 368	764 582	166 342	8 393 440	€ 1 075 060	€ 1 090 662	13 985 713	2 067 996	4 135 992	2 259 170	6 395 163
181	2 095 636	738 121	210 464	207 536	2 662 232	343 519	371 556	636 499	160 431	123 466	328 960	96 882	1 017 278	127 713	125 589	3 679 510	743 702	1 487 404	1 182 042	2 669 447
167	1 897 921	1 700 629	184 520	181 805	2 930 041	389 926	374 605	1 421 347	5 756 454	128 902	435 622	69 460	7 376 162	947 348	965 073	10 306 203	1 324 294	2 648 588	1 077 128	3 725 716
12	88,4	191,3	0,0	0,0	184,1	22,5	25,5	6,7	6,0	0,0	0,0	0,0	12,7	1,5	1,8	197	453	906	0	906
13	91,0	199,5	0,0	0,0	190,7	23,3	25,4	6,7	6,0	0,0	0,0	0,0	12,7	1,5	1,7	203	430	860	0	860
2	116,2	400,8	0,0	0,0	316,6	38,7	41,3	6,7	6,0	0,0	0,0	0,0	12,7	1,5	1,7	329	406	811	0	811
12	128,3	331,5	0,0	0,0	294,1	38,0	40,6	6,7	6,0	0,0	0,0	0,0	12,7	1,6	1,8	307	431	863	0	863
353	120,4	278,4	0,0	0,0	259,6	33,5	35,7	6,7	6,0	0,0	0,0	0,0	12,7	1,6	1,7	272	356	712	90	802
337	108,8	211,5	0,0	0,0	214,5	27,7	29,3	7,7	6,0	0,0	0,0	0,0	13,7	1,7	1,9	228	422	843	203	1 047
336	86,2	188,4	0,0	0,0	180,4	23,3	22,3	10,7	6,0	0,0	0,0	0,0	16,7	2,1	2,1	197	380	760	332	1 092
333	80,4	153,8	0,0	0,0	157,3	20,3	19,7	13,7	6,0	0,0	0,0	0,0	19,7	2,5	2,5	177	163	325	753	1 078
334	77,7	117,0	0,0	0,0	136,2	17,6	13,7	13,7	6,0	0,0	0,0	0,0	19,7	2,5	2,0	156	75	151	1 169	1 320
305	80,7	135,4	0,0	9,5	157,9	20,4	15,0	13,7	6,0	0,0	0,0	0,0	19,7	2,5	1,9	178	31	62	684	746
311	77,9	103,8	0,0	9,3	139,1	18,0	12,9	16,7	6,0	0,0	0,0	0,0	22,7	2,8	2,1	162	109	218	1 173	1 390
302	77,9	103,0	0,0	8,4	137,8	17,8	11,6	13,7	6,0	0,0	0,0	0,0	19,7	2,5	1,7	158	112	224	881	1 105

Table 61 - Simulation model - EnergyData 3/3



PV-area 1,50 ha
PV-eff. (inc 87%
kWp / ha 1344,00 kWp
kWp install 2 016 kWp
Turbine-co 2 turbines
rated pow 850 kW
all Turbines 1700 kW
201.04 €/year/kWp

pump-power 800 kW
gen-power for 283 m3 [kWh] 540 kWh
max.volume pump/gen [m3/h] 283 345
eff.pump/gen. 82% 85%
min. profit 2,00 ct/kWh
max.volume-diff 15 000 m3
energy cap 27 635 kWh
gross-heigh 850 m
net-heigh 825 m

2,29 h/day
FLH
837 € 23 142

2 919 8 617 2 587 €ct/kwh 13,00 €ct/kwh 13,21 €ct/kwh 5,91

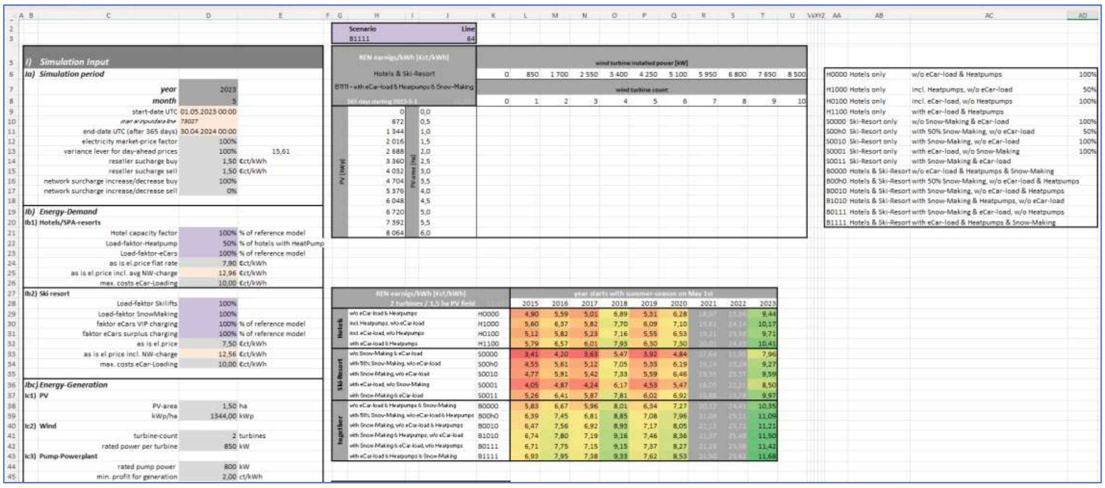
usage of own renewable energy | Pump-Power prices [€ct/kWh] | pump storage usage | pump storage generation | pump-costs/earnings

REN own use [kWh]	from Grid [kWh]	REN surplus [kWh]	REN own use [€]	from Grid [€]	REN sell [€]	pump price [€ct/kWh]	generate price [€ct/kWh]	pump-hrs [hrs]	max.pump price [ct/kWh]	min.gen. price [ct/kWh]	pump-vol. [m3]	gen-vol. [m3]	pump demand [kWh]	own use [kWh]	feed-in [kWh]	generation [kWh]	Pump [€]	Gen.Use [€]	Gen.Sell [€]
5 207 554	8 778 159	1 187 608	€ 676 914	€ 1 159 909	€ 70 136	12,39	10,74	835			236 871	236 871	816 585	313 184	139 180	452 364	€ 42 564	€ 51 946	€ 13 760
2 096 230	1 583 280	573 217	283 549	213 597	44 314	13,19	10,90	428			121 124	121 407	417 561	164 364	67 493	231 857	24 846	28 877	7 980
3 111 324	7 194 879	614 392	393 365	946 312	25 822	11,57	10,58	407			115 747	115 464	399 024	148 820	71 687	220 507	17 717	23 069	5 780
197	0	709	27	0	57	8,71	8,05	6	4,89	10,34	0	0	0	0	0	0	0	0	0
203	0	657	27	0	49	8,54	7,50		4,89	10,34	0	0	0	0	0	0	0	0	0
329	0	482	43	0	35	9,55	7,24		4,89	10,34	0	0	0	0	0	0	0	0	0
307	0	556	42	0	41	9,29	7,30		4,89	10,34	0	0	0	0	0	0	0	0	0
272	0	530	37	0	38	9,43	7,23		4,89	10,34	0	0	0	0	0	0	0	0	0
228	0	818	31	0	58	7,15	7,15		4,89	10,34	0	0	0	0	0	0	0	0	0
197	0	895	24	0	52	5,82	5,82		4,89	10,34	0	0	0	0	0	0	0	0	0
177	0	901	22	0	54	6,00	6,00		4,89	10,34	0	0	0	0	0	0	0	0	0
156	0	1 164	16	0	41	3,52	3,52		4,89	10,34	283	0	976	0	0	0	34	0	0
178	0	569	17	0	17	4,89	3,00		4,89	10,34	283	0	976	0	0	0	48	0	0
162	0	1 229	15	0	34	2,76	2,76		4,89	10,34	283	0	976	0	0	0	27	0	0
158	0	948	13	0	18	1,87	1,87		4,89	10,34	283	0	976	0	0	0	18	0	0
150	0	937	12	0	14	1,49	1,49		4,89	10,34	283	0	976	0	0	0	15	0	0
155	0	852	14	0	22	2,59	2,59		4,89	10,34	283	0	976	0	0	0	25	0	0
157	0	543	19	0	30	7,67	5,57		4,89	10,34	0	0	0	0	0	0	0	0	0

The Data Sources and Calculations sections should not be changed during simulations. All variables are controlled through the Input/Output section and all results are returned there.

The user interface is the “Simulations” area. Almost 30 parameters are available here that can be changed by the simulations. And another 40 parameters are available as results. Originally there were even more, but non-interesting parameters were discarded during the analyzes.

Table 62 - Simulation model - Parameter/Overview



In the simulation area, the input parameters that are changed by the simulations are on the left. Further down are the result parameters, which will then be displayed (color-coded) in the simulation tables. In the center there are about a dozen different simulation structures. And the 15 load scenarios are defined on the right.

Table 64 - Simulation input parameter

I) Simulation Input			
Ia) Simulation period			
year	2023		
month	5		
start-date UTC	01.05.2023 00:00		
start at inputdata line	*73027*		
end-date UTC (after 365 days)	30.04.2024 00:00		
electricity market-price factor	100%		
variance lever for day-ahead prices	100%		15,61
reseller surcharge buy	1,50	€ct/kWh	
reseller surcharge sell	1,50	€ct/kWh	
network surcharge increase/decrease buy	100%		
network surcharge increase/decrease sell	0%		
Ib) Energy-Demand			
Ib1) Hotels/SPA-resorts			
Hotel capacity factor	100%	% of reference model	
Load-faktor-Heatpump	50%	% of hotels with HeatPump	
Load-faktor-eCars	100%	% of reference model	
as is el.price flat rate	7,90	€ct/kWh	
as is el.price incl. avg NW-charge	12,96	€ct/kWh	
max. costs eCar-Loading	10,00	€ct/kWh	
Ib2) Ski resort			
Load-faktor Skilifts	100%		
Load-faktor SnowMaking	100%		
faktor eCars VIP charging	100%	% of reference model	
faktor eCars surplus charging	100%	% of reference model	
as is el.price	7,50	€ct/kWh	
as is el.price incl. NW-charge	12,56	€ct/kWh	
max. costs eCar-Loading	10,00	€ct/kWh	
Ibc) Energy-Generation			
Ic1) PV			
PV-area	1,50	ha	
kWp/ha	1344,00	kWp	
Ic2) Wind			
turbine-count	2	turbines	
rated power per turbine	850	kW	
Ic3) Pump-Powerplant			
rated pump power	800	kW	
min. profit for generation	2,00	ct/kWh	

Table 63 - Simulation results parameter

R) RESULTS		
Ra) usage of own renewable energy		
PV-Generation	2,26	GWh
Wind-Generation	4,14	GWh
REN own use	5 207 554	kWh
from Grid	8 778 159	kWh
REN surplus	1 187 608	kWh
own use factor	81%	
self-sufficiency (autarky) factor	37%	
coverage on balance per year	46%	
Grid feed-in percentage	19%	
REN own use	€ 676 914	
buy from grid	€ 1 159 909	
REN sell to grid	€ 70 136	
REN earnigs/kWh	**11,681**	**€ct/kWh**
REN own use	**12,999**	€ct/kWh
buy from grid	**13,214**	€ct/kWh
REN sell to grid	**5,906**	€ct/kWh
relation own-use-price / buy-from-grid-price	**98%**	
max.load	8 995	kW
max. from grid	8 617	kW
max. surplus	2 587	kW
max. from grid factor	96%	
max. to grid factor	29%	
Rb) pump power plant		
pump-hrs	835	h
pump-volume	236 871	m³
generation-volume	236 871	m³
pump demand	816 585	kWh
own use	313 184	kWh
feed-in	139 180	kWh
pump-plant total generation	452 364	kWh
contribution to self-sufficiency	2%	
self-sufficiency total	39%	
Pump costs	€ 42 564	
Generaton earnings own use	€ 51 946	
Generation earnings sell2grid	€ 13 760	
gross income pump power plant	€ 23 142	
gross income pump per kWh	0,051	€ct/kWh
el.price-variance	15,61	

(2) Simulation-model for ski-resort and snow making facilities

As detailed consumption profiles are not available in most ski resorts, these can be simulated here by configurations. This model consists of the following sections:

- General settings
- Climate data
- Resort utilazation
- Parameter settings for skilifts
- Energy data for lifts
- Parameter settings for snow-making
- Energy data for snow-making
- Parameter settings for electric vehicle loading
- Energy data for electric vehicle loading

The General Settings mainly define the time period for which the electricity demand is to be simulated.

Table 65 - Ski resort configuration - general settings 1/2

	A	B	C	D	E	F	G	H
1								
2	**reporting-year start/end**	**01.05.2023**	**/**	**29.04.2024**				
3	*period for simulation dataset*	*01.11.2022*	*/*	*30.04.2024*				
4	**Reference season for Simulation**	**2023**	**/**	**2024**				
5	*Season-ID's*	W-23/24		S-23				
6	*ClimateData starts at line*	*94 970*						
7	*last skiing-day in season*	07.04.2024						
8								
9		**winter**		**summer**				
10	months winter/summer	11; 12; 1; 2; 3; 4		5; 6; 7; 8; 9; 10				
11								
12	Seasonal utilization factor	95%		(e.g. Covid19, economic effects, etc.)				
13	wind resilience of tourists	75%		(100% means 50% of tourists will ski/walk also at windspeeds up to 100 km/h)				
14								
15								
16	Hours for complete initial snowmaking	150		(12,5 days for initial snowmaking)				
17	Refill at the same time as snow-making	Y		(if "N", refill will be stopped during snow-production)				
18	max. snow-production during skilift operation	40%						

Table 66 - Ski resort configuration - general settings 2/2

	AB	AC	AD	AE	AG	AH	AI	AJ	AK	AL	AN	AO	AP	AQ	AR	AS
3																
4	**Weekday utalization**				**Fixed and variable Holydays**						**Holiday-seasons per calendar-week**					
5																
6	1	MO	60%	Monday	2023	Sunday, 01 01 2023	60%	NY	New Year	Neujahr	1		120%	TS-NY	top season - New Year	Top-Hochsaison - Neujahr
7	2	TU	50%	Tuesday	2023	Friday, 06 01 2023	0%	EP	Epiphany	Heilige 3 Könige	2		70%	LS-JA	low season - January	Jännerloch
8	3	WE	50%	Wednesday	2023	Monday, 01 05 2023	0%	LD	Labor Day	Tag der Arbeit	3		70%	LS-JA	low season - January	Jännerloch
9	4	TH	50%	Thursday	2023	Tuesday, 15 08 2023	0%	AD	Assumption Day	Mariä Himmelfahrt	4		70%	LS-JA	low season - January	Jännerloch
10	5	FR	75%	Friday	2023	Tuesday, 03 10 2023	0%	GU	German Unity Day	Tag der Deutschen Einheit	5		70%	LS-JA	low season - January	Jännerloch
11	6	SA	90%	Saturday	2023	Thursday, 26 10 2023	0%	AN	Austrian National Day	Österreichische Nationalfeiertag	6		100%	HS-SH	high season - Semester holidays	Hochsaison - Semesterferien
12	7	SO	100%	Sunday	2023	Tuesday, 31 10 2023	0%	RD	Reformation Day	Reformationstag	7		100%	HS-SH	high season - Semester holidays	Hochsaison - Semesterferien
13					2023	Wednesday, 01 11 2023	0%	AS	All Saints' Day	Allerheiligen	8		100%	HS-SH	high season - Semester holidays	Hochsaison - Semesterferien
14					2023	Friday, 08 12 2023	0%	IC	Immaculate Conception	Mariä Empfängnis	8		75%	MS-CH	mid season - Carnival holidays	Nebensaison - Faschingsferien
15					2023	Sunday, 24 12 2023	0%	CE	Christmas Eve	Weihnachsabend	14		90%	HS-EH	high season - Easter holidays	Hochsaison - Osterferien
16					2023	Monday, 25 12 2023	0%	CD	Christmas Day	Christtag	15		75%	MS-EH	mid season - Easter holidays	Nebensaison - Osterferien
17					2023	Tuesday, 26 12 2023	0%	BD	Boxing Day	Stefanitag	20	2023-20	75%	MS-WH	mid season - With holidays	Nebensaison - Pfingstferien
18					2023	Sunday, 31 12 2023	0%	NE	New Year Eve	Sylvester	21	2023-21	75%	MS-WH	mid season - With holidays	Nebensaison - Pfingstferien
19					2023	Wednesday, 22 02 2023	100%	AW	Ash Wednesday	Aschermittwoch	28	2023-28	75%	MS-SH	mid season - Summer holidays	Nebensaison - Sommerferien
20					2023	Friday, 07 04 2023	0%	GF	Good Friday	Karfreitag	29	2023-29	75%	MS-SH	mid season - Summer holidays	Nebensaison - Sommerferien
21					2023	*Sunday, 09 04 2023*	0%	ES	Easter Sunday	Ostersonntag	30	2023-30	90%	HS-SH	high season - Summer holidays	Hochsaison - Sommerferien
22					2023	Monday, 10 04 2023	0%	EM	Easter Monday	Ostermontag	31	2023-31	90%	HS-SH	high season - Summer holidays	Hochsaison - Sommerferien
23					2023	Thursday, 18 05 2023	0%	AD	Ascension Day	Christi Himmelfahrt	32	2023-32	90%	HS-SH	high season - Summer holidays	Hochsaison - Sommerferien
24					2023	Sunday, 28 05 2023	0%	WS	With Sunday	Pfingstsonntag	33	2023-33	100%	HS-SH	high season - Summer holidays	Hochsaison - Sommerferien
25					2023	Monday, 29 05 2023	0%	WM	With Monday	Pfingstmontag	34	2023-34	100%	HS-SH	high season - Summer holidays	Hochsaison - Sommerferien
26					2023	Thursday, 08 06 2023	0%	CC	Corpus Christi	Fronleichnam	35	2023-35	100%	HS-SH	high season - Summer holidays	Hochsaison - Sommerferien
27					**Potential bridge-days**						36	2023-36	100%	HS-SH	high season - Summer holidays	Hochsaison - Sommerferien
28					2023						37	2023-37	90%	MS-SH	mid season - Summer holidays	Nebensaison - Sommerferien
29					2023						38	2023-38	75%	MS-SH	mid season - Summer holidays	Nebensaison - Sommerferien
30					2023						43	2023-43	70%	MS-AH	mid season - Autumn holidays	Nebensaison - Herbstferien
31					2023	Monday, 14 08 2023	0%	xB	Bridge Day	Fenstertag	52	2023-52	110%	TS-CM	top season - Christmas	Top-Hochsaison - Neujahr
32					2023	Monday, 02 10 2023	0%	xB	Bridge Day	Fenstertag	53	2023-53	120%	TS-CM	top season - Christmas	Top-Hochsaison - Neujahr

Regardless of which period is selected, the simulation always begins on November 1st before the selected start date. It is assumed that the reservoirs are 100% full and snow production has not yet started, even if the weather would have allowed this in the weeks before.

The public holidays and vacation periods shown in Table 66 are calculated automatically. Both Austrian conditions and those of countries with frequent ski tourists are taken into account. Only the influencing factors (% values) on capacity utilization need to be entered.

As in the other simulations, the climate data are taken 1:1 from the INCA model of Geosphere-Austria. The different daily and hourly loads are also simulated on this basis. Depending on the weather data, weekdays and holidays as well as the general seasonal tourist load, a different load is determined for each operating hour and each lift.

Table 67 - Utilization per lift and hour

	A	B	C	D	E	F	G	H	I
1									
3									
4	Seasonal utilization								
5	Date	cw	season	week day	holi day	season rating	day-rating	climate-rating	total rating
6	2022-11-01	44	LS	TU		48%	50%	53%	13%
7	2022-11-02	44	LS	WE		48%	50%	87%	21%
8	2022-11-03	44	LS	TH		48%	50%	41%	10%
9	2022-11-04	44	LS	FR		48%	75%	26%	9%
10	2022-11-05	44	LS	SA		48%	90%	37%	16%
11	2022-11-06	44	LS	SO		48%	100%	87%	41%
12	2022-11-07	45	LS	MO		48%	60%	102%	29%
13	2022-11-08	45	LS	TU		48%	50%	60%	14%
14	2022-11-09	45	LS	WE		48%	50%	50%	12%
15	2022-11-10	45	LS	TH		48%	50%	59%	14%
16	2022-11-11	45	LS	FR		48%	75%	94%	34%
17	2022-11-12	45	LS	SA		48%	90%	59%	25%
18	2022-11-13	45	LS	SO		48%	100%	49%	23%
19	2022-11-14	46	LS	MO		48%	60%	74%	21%
20	2022-11-15	46	LS	TU		48%	50%	51%	12%
21	2022-11-16	46	LS	WE		48%	50%	38%	9%
22	2022-11-17	46	LS	TH		48%	50%	56%	13%
23	2022-11-18	46	LS	FR		48%	75%	41%	15%
24	2022-11-19	46	LS	SA		48%	90%	95%	41%
25	2022-11-20	46	LS	SO		48%	100%	88%	42%
26	2022-11-21	47	LS	MO		48%	60%	96%	27%
27	2022-11-22	47	LS	TU		48%	50%	17%	4%
28	2022-11-23	47	LS	WE		48%	50%	49%	12%
29	2022-11-24	47	LS	TH		48%	50%	60%	14%
30	2022-11-25	47	LS	FR		48%	75%	110%	39%
31	2022-11-26	47	LS	SA		48%	90%	63%	27%
32	2022-11-27	47	LS	SO		48%	100%	98%	47%
33	2022-11-28	48	LS	MO		48%	60%	95%	27%
34	2022-11-29	48	LS	TU		48%	50%	70%	17%
35	2022-11-30	48	LS	WE		48%	50%	40%	9%
36	2022-12-01	48	LS	TH		48%	50%	47%	11%
37	2022-12-02	48	LS	FR		48%	75%	83%	29%
38	2022-12-03	48	LS	SA		48%	90%	59%	25%
39	2022-12-04	48	LS	SO		48%	100%	41%	20%
40	2022-12-05	49	LS	MO		48%	60%	78%	22%
41	2022-12-06	49	LS	TU		48%	50%	109%	26%
42	2022-12-07	49	LS	WE		48%	50%	100%	24%

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
1											
3											
4	Utilization per hour for each month						Lift 1	Lift 2	Lift 3	Lift 4	Lift 5
5	month	hour	Std	from [std:min]	to [std:min]	MM-HH	L01	L02	L03	L04	L05
6	1					*operation hrs*	**08:15**	**07:29**	**07:15**	**07:04**	**07:00**
7	1			2		*setup morning*	07:30	08:00	08:15	08:25	08:55
8	1			3		*morning*	08:15	08:30	08:45	08:55	09:00
9	1			4		*before noon*	09:54	10:00	10:12	10:20	10:24
10	1			5		*noon*	11:33	11:30	11:39	11:45	11:48
11	1			6		*afternoon*	13:12	13:00	13:06	13:10	13:12
12	1			7		*last hours*	14:51	14:30	14:33	14:35	14:36
13	1			8		*setup evening*	16:30	16:00	16:00	16:00	16:00
14	1			9		*setup end*	17:00	16:30	16:30	16:30	16:05
15	1					***average per operating-hour***	**66%**	**91%**	**91%**	**91%**	**40%**
16	1		00	00:00	01:00	01-00					
17	1	1	01	01:00	02:00	01-01					
18	1	2	02	02:00	03:00	01-02					
19	1	3	03	03:00	04:00	01-03					
20	1	4	04	04:00	05:00	01-04					
21	1	5	05	05:00	06:00	01-05					
22	1	6	06	06:00	07:00	01-06					
23	1	7	07	07:00	08:00	01-07	5%				
24	1	8	08	08:00	09:00	01-08	93%	54%	31%	14%	1%
25	1	9	09	09:00	10:00	01-09	116%	100%	100%	100%	40%
26	1	10	10	10:00	11:00	01-10	80%	100%	100%	100%	40%
27	1	11	11	11:00	12:00	01-11	62%	90%	93%	95%	40%
28	1	12	12	12:00	13:00	01-12	40%	80%	80%	80%	40%
29	1	13	13	13:00	14:00	01-13	48%	90%	89%	88%	40%
30	1	14	14	14:00	15:00	01-14	47%	85%	86%	86%	40%
31	1	15	15	15:00	16:00	01-15	30%	80%	80%	80%	40%
32	1	16	16	16:00	17:00	01-16	20%	5%	5%	5%	1%
33	1	17	17	17:00	18:00	01-17	0%				
34	1	18	18	18:00	19:00	01-18					
35	1	19	19	19:00	20:00	01-19					
36	1	20	20	20:00	21:00	01-20					
37	1	21	21	21:00	22:00	01-21					
38	1	22	22	22:00	23:00	01-22					
39	1	23	23	23:00	24:00	01-23					
40	2					*operation hrs*	**08:45**	**07:59**	**07:30**	**07:19**	**07:00**
41	2			2		*setup morning*	07:15	07:45	08:00	08:10	08:55
42	2			3		*morning*	08:00	08:15	08:30	08:40	09:00

The operating data of up to 20 lifts are each defined with more than 60 parameters:

Table 68 - Parameter settings for skilifts

	A	B	C	D	E	F
1						
2	ID	L01	L02	L03	L04	L05
3	**Name**	**Lift 1**	**Lift 2**	**Lift 3**	**Lift 4**	**Lift 5**
4	Units	1	1	1	1	1
5	Type	2 Gondola	3 chairlift-bubble	4 chairlift	4 chairlift	4 chairlift
6	Usage	3 feeder lift	1 regular	1 regular	1 regular	4 low utilization
7	max. wind speed [m/s]	25	18	22	18	20
8	Lenghts [m]	2 664	1 889	1 905	2 017	400
9	Heigth [m]	915	464	480	414	68
10	sealevel lower station	530	1 443	1 003	1 497	1 444
11	sealevel upper station	1 445	1 907	1 483	1 911	1 512
12	cabins/chairs/units	120	130	140	140	60
13	seats per unit	4	4	4	4	2
14	max. speed [m/s]	5,00	5,00	5,00	5,00	2,50
15	*min journey time*	8:12	6:12	6:00	6:36	2:00
16	capacity [max. persons / hr]	1 500	2 400	2 400	2 400	1 400
17	rated power [kW]	600	500	500	450	40
18	standby [kW]	0,5	0,3	0,3	0,3	0
19	theoretical net energy per person/journey [kWh]	0,199	0,101	0,105	0,090	0,015
20	total capacity per system [max. persons / hr]	1 500	2 400	2 400	2 400	1 400
21	total rated power per system [kW]	600	500	500	450	40
22						
23	Winter saison-start [weeks to Christmas]	-4	-4	-3	-4	-2
24	*start-date winter 2022/2023*	*Saturday, 26 11 2022*	*Saturday, 26 11 2022*	*Saturday, 03 12 2022*	*Saturday, 26 11 2022*	*Saturday, 10 12 2022*
25	*start-date winter 2023/2024*	*Saturday, 25 11 2023*	*Saturday, 25 11 2023*	*Saturday, 02 12 2023*	*Saturday, 25 11 2023*	*Saturday, 09 12 2023*
26	*start-date winter 2024/2025*	*Saturday, 30 11 2024*	*Saturday, 30 11 2024*	*Saturday, 07 12 2024*	*Saturday, 30 11 2024*	*Saturday, 14 12 2024*
27	Winter saison-end [+/- weeks to Easter]	1	1	0	0	0
28	*season end winter 2022/2023*	*Sunday, 16 04 2023*	*Sunday, 16 04 2023*	*Monday, 10 04 2023*	*Monday, 10 04 2023*	*Monday, 10 04 2023*
29	*season end winter 2023/2024*	*Sunday, 07 04 2024*	*Sunday, 07 04 2024*	*Monday, 01 04 2024*	*Monday, 01 04 2024*	*Monday, 01 04 2024*
30	*season end winter 2024/2025*	*Sunday, 27 04 2025*	*Sunday, 27 04 2025*	*Monday, 21 04 2025*	*Monday, 21 04 2025*	*Monday, 21 04 2025*
31	Summer saison-start [+/- weeks to Easter]	4	4	closed	closed	closed
32	*start-date summer 2023*	*Saturday, 06 05 2023*	*Saturday, 06 05 2023*			
33	*start-date summer 2024*	*Saturday, 27 04 2024*	*Saturday, 27 04 2024*			
34	Summer saison-end [weeks to Christmas]	-8	-8	closed	closed	closed
35	*season-end summer 2023*	*Sunday, 29 10 2023*	*Sunday, 29 10 2023*			
36	*season-end summer 2024*	*Friday, 01 11 2024*	*Friday, 01 11 2024*			
37	setup-time (before official start) [std:min]	00:45	00:30	00:30	00:30	00:05
38	Start-time .... before Nov.	08:00	08:15			
39	Nov.	08:30	08:45	08:45	08:55	09:00

The result of the parameterization is hourly data on power consumption per lift:

Table 69 - Energy data for lifts

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1																		
2															Utilization Persons/hour			
3															Lift 1	Lift 2	Lift 3	
4															L01	L02	L03	
5		total for season	W-23/24			443 345	6,88	1 302	5 859 128	1 229	240	1 436 248	35%		422 647	851 519	692 099	6
6			S-23			873 033	4,85	624	659 344	1 662	27	638 090	11%		340 704	318 639	0	
7	date (UTC)	season	cw	week-day	hour	hor.irradiation [W/m²]	wind [m/s]	thSpecWindPower[kW/m2]	journies	resort operating hrs	total resort utilization	el. Energy [kWh]	rated power coverage					
1352	2022-12-27	W-22/23	2022-52	TU	01	0	2,6	0,008	0	0	0%	7	0%		0	0	0	
1353	2022-12-27	W-22/23	2022-52	TU	02	0	4,8	0,056	0	0	0%	7	0%		0	0	0	
1354	2022-12-27	W-22/23	2022-52	TU	03	0	7,1	0,175	0	0	0%	7	0%		0	0	0	
1355	2022-12-27	W-22/23	2022-52	TU	04	0	5,4	0,076	0	0	0%	7	0%		0	0	0	
1356	2022-12-27	W-22/23	2022-52	TU	05	0	3,3	0,018	0	0	0%	7	0%		0	0	0	
1357	2022-12-27	W-22/23	2022-52	TU	06	0	4,7	0,051	0	0	0%	7	0%		0	0	0	
1358	2022-12-27	W-22/23	2022-52	TU	07	0	2,7	0,009	40	0	0%	167	5%		40	0	0	
1359	2022-12-27	W-22/23	2022-52	TU	08	0	2,8	0,010	2 073	1	8%	846	26%		744	691	394	
1360	2022-12-27	W-22/23	2022-52	TU	09	123	0,8	0,000	10 832	1	44%	2 028	62%		933	1 287	1 287	1
1361	2022-12-27	W-22/23	2022-52	TU	10	259	1,1	0,001	10 779	1	44%	1 930	59%		643	1 287	1 287	1
1362	2022-12-27	W-22/23	2022-52	TU	11	248	1,8	0,003	10 299	1	42%	1 756	54%		499	1 160	1 197	1
1363	2022-12-27	W-22/23	2022-52	TU	12	204	1,0	0,000	8 784	1	36%	1 491	46%		322	1 030	1 030	1
1364	2022-12-27	W-22/23	2022-52	TU	13	404	1,8	0,003	9 735	1	40%	1 570	48%		386	1 158	1 145	1
1365	2022-12-27	W-22/23	2022-52	TU	14	276	1,9	0,003	9 543	1	39%	1 547	48%		378	1 094	1 100	1
1366	2022-12-27	W-22/23	2022-52	TU	15	36	1,8	0,003	8 928	1	37%	1 474	45%		241	1 030	1 030	1
1367	2022-12-27	W-22/23	2022-52	TU	16	18	0,8	0,000	424	1	2%	602	18%		161	64	64	
1368	2022-12-27	W-22/23	2022-52	TU	17	0	1,9	0,003	0	0	0%	11	0%		0	0	0	
1369	2022-12-27	W-22/23	2022-52	TU	18	0	4,1	0,033	0	0	0%	8	0%		0	0	0	
1370	2022-12-27	W-22/23	2022-52	TU	19	0	5,1	0,065	0	0	0%	7	0%		0	0	0	

For the simulation of snow production, the systems are each assigned to a reservoir in clusters. Just over 60 values are required for the parameterization of each cluster:

Table 70 - parameters for snow making utilities

	A	B	C	D	E	F
1						
2	ID	S01	S02	S03	S04	S05
3	**Name**	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
4	Reservoir capacity [m³]	100 000	50 000	30 000	20 000	20 000
5	water-level per 2023-5-1 [m³]	100 000	50 000	30 000	20 000	20 000
6	min water-level from snow productions [m³]	5 000	2 500	1 500	1 000	1 000
7	related Ski-Area o be covered with snow [ha]	180	70	60	50	40
8	refill heigth [m]	850	670	640	120	250
9	sealevel lake	1 810	1 630	1 600	1 080	1 450
10	sealevel lower waterreservoir	960	960	960	960	1 200
11	full-refill-days	20	20	15	10	10
12	refill capacity [m³/h]	208	104	83	83	83
13	refill capacity [l/sek]	58	29	23	23	23
14	refill months	11; 12; 1; 2; 6	11; 12; 1; 2; 6	11; 12; 1; 2; 6	11; 12; 1; 2; 6	11; 12; 1; 2; 6
15	rated power refill [kW]	730	290	220	40	80
16	efficiency refill-facilities (pipes, pump, motor, other) [%]	69,2%	70,0%	70,0%	70,7%	71,0%
17	Reservoir cooling in moths	11; 12	11; 12	11; 12	11; 12	11; 12
18	day's for cooling of full reservoir capacity	15	15	14	12	12
19	rated power for cooling	200	80	50	25	25
20	rated power snow making pumps [kW]	900	600	500	400	350
21	rated power pump-station standby winter [kW]	10	5	5	5	5
22	rated power pump-station standby summer [kW]	2	1	1	1	1
23	count of snow lances	60	30	25	20	20
24	rated power per unit (lance only - w/o. central station)	6,00	6,00	6,00	6,00	6,00
25	total power for all laces/cluster [kW]	**598**	**339**	**293**	**316**	**291**
26	avg. snow production at min. -2 °C WBT [m³/h]	8	8	8	8	8
27	avg. snow production at -3 °C WBT [m³/h]	11	11	11	11	11
28	avg. snow production at -4 °C WBT [m³/h]	18	18	18	18	18
29	avg. snow production at -5 °C WBT [m³/h]	30	30	30	30	30
30	avg. snow production at -6 °C WBT [m³/h]	40	40	40	40	40
31	avg. snow production at -7 °C and less WBT [m³/h]	50	50	50	50	50
32	average snow/water-ratio [m³ snow/m³ water]	2,50	2,50	2,50	2,50	2,50
33	max. windspeed for snow production [m/s]	12	12	12	12	12
34	count of snow guns	40	20	15	5	5

The key criteria for snow production are the Wet-Bulp Temperature (WBT), which is a function of the climate data, the ski operation and the availability of water in the reservoir. When the reservoir is empty, it must be refilled slowly. The conditions and energy data for refilling vary from cluster to cluster. Simultaneous snowmaking is very limited during ski operations. This is also defined differently for each cluster.

The result is not only the energy demand. Hourly values are also calculated for water consumption, snow produced, water levels in the lakes and water volumes for refilling:

Table 71 - Energy data for snow-making

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1																									
2																									
3																									
4																			produced snow/hour guns&lances [m³/h/ha]						
5														0,40	M3water/M3snow	1,88	kWh/M3		Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
6																396	kWh/ha		S01	S02	S03	S04	S05	S06	S07
7			total for season	W-23/24		240	1 229	6.88	-2.01	1 058	832	992	7 863	1 258 011	1 094 146	5 752 102	2		7 031	9 192	8 080	7 607	9 273	0	0
8				S-23		27	1 662	4.85	8.10	0	0	0	0	0	41 250	158 358	0		0	0	0	0	0	0	0
9	date (UTC)	season	cw	week-day	hour	total resort utilization	resort operating hrs	wind [m/s]	Wet-bulb temp [°C]	Snow-making usefulness [%]	max. snow-making utilization [%]	snow making operating hrs	technical snow produced per ha [m³/ha]	water-consumption [m³]	refill pump-water [m³]	el. Energy [kWh]	rated power coverage								
10242	2024-01-01	W-23/24	2024-01	MO	09	28%	1	5,6	-6,1	88%	25%	1	11,1	1 776	563	3 174	70%		11	14	13	8	10	0	0
10243	2024-01-01	W-23/24	2024-01	MO	10	28%	1	5,4	-5,6	87%	25%	1	6,6	1 050	563	3 165	69%		6	8	7	5	6	0	0
10244	2024-01-01	W-23/24	2024-01	MO	11	27%	1	7,6	-5,0	86%	25%	1	8,5	1 353	563	3 181	70%		8	10	10	6	8	0	0
10245	2024-01-01	W-23/24	2024-01	MO	12	23%	1	6,3	-5,0	86%	27%	1	3,3	524	563	3 249	71%		3	4	4	3	3	0	0
10246	2024-01-01	W-23/24	2024-01	MO	13	25%	1	4,4	-4,1	85%	25%	1	5,1	820	563	3 181	70%		5	6	6	4	5	0	0
10247	2024-01-01	W-23/24	2024-01	MO	14	25%	1	6,1	-4,8	84%	25%	1	3,6	577	563	3 176	70%		3	4	4	3	4	0	0
10248	2024-01-01	W-23/24	2024-01	MO	15	23%	1	6,4	-5,3	82%	25%	1	7,4	1 192	563	3 171	70%		7	9	8	6	7	0	0
10249	2024-01-01	W-23/24	2024-01	MO	16	1%	1	6,3	-5,7	81%	32%	1	8,1	1 293	563	3 555	78%		8	10	9	6	8	0	0
10250	2024-01-01	W-23/24	2024-01	MO	17	0%	0	4,6	-6,3	79%	79%	1	32,5	5 202	563	6 293	138%		31	40	37	23	29	0	0
10251	2024-01-01	W-23/24	2024-01	MO	18	0%	0	3,6	-6,6	78%	78%	1	29,6	4 731	563	6 206	136%		28	37	33	21	27	0	0
10252	2024-01-01	W-23/24	2024-01	MO	19	0%	0	5,6	-6,9	77%	77%	1	26,5	4 243	563	6 148	135%		25	33	30	19	24	0	0
10253	2024-01-01	W-23/24	2024-01	MO	20	0%	0	4,6	-6,9	75%	75%	1	25,8	4 124	563	6 075	133%		25	32	29	19	23	0	0
10254	2024-01-01	W-23/24	2024-01	MO	21	0%	0	3,7	-6,9	74%	74%	1	26,2	4 191	563	6 020	132%		25	32	30	19	24	0	0
10255	2024-01-01	W-23/24	2024-01	MO	22	0%	0	5,1	-7,1	74%	74%	1	33,0	5 282	563	5 975	131%		32	41	37	24	29	0	0
10256	2024-01-01	W-23/24	2024-01	MO	23	0%	0	6,4	-7,4	73%	73%	1	32,6	5 209	563	5 916	130%		31	40	37	23	29	0	0
10257	2024-01-02	W-23/24	2024-01	TU	00	0%	0	6,0	-7,7	71%	71%	1	32,0	5 119	563	5 844	128%		31	40	36	23	29	0	0
10258	2024-01-02	W-23/24	2024-01	TU	01	0%	0	5,3	-7,2	70%	70%	1	31,3	5 013	563	5 758	126%		30	39	35	22	28	0	0
10259	2024-01-02	W-23/24	2024-01	TU	02	0%	0	6,0	-7,3	69%	69%	1	30,8	4 923	563	5 685	125%		30	38	35	22	27	0	0
10260	2024-01-02	W-23/24	2024-01	TU	03	0%	0	7,0	-7,4	67%	67%	1	30,1	4 820	563	5 602	123%		29	37	34	21	27	0	0
10261	2024-01-02	W-23/24	2024-01	TU	04	0%	0	7,3	-7,4	66%	66%	1	29,5	4 713	563	5 515	121%		28	37	33	21	26	0	0
10262	2024-01-02	W-23/24	2024-01	TU	05	0%	0	6,8	-7,4	64%	64%	1	28,7	4 598	563	5 422	119%		28	36	33	20	26	0	0
10263	2024-01-02	W-23/24	2024-01	TU	06	0%	0	8,7	-7,1	62%	62%	1	28,0	4 486	563	5 332	117%		27	35	32	20	25	0	0

The parameters for the energy profiles for charging electric cars are relatively simple. Ski tourist can choose between two options: VIP (=fast) charging and Surplus charging. With the VIP-option, charging takes place in any case, regardless of whether energy is available from own production or not. With surplus charging, the allocation of charging capacity is sometimes very low. Charging only takes place if there is either a surplus from own production or the current market price (including all surcharges) is very low. For our simulations, we have chosen 10.0 €ct/kWh (incl. all surcharges). This corresponds to a day-ahead price of 4.37 €ct/kWh.

Table 72 - parameter for electric vehicle load

	A	B	C	D
1				
2		**Fixed Load-demand/fast-load area:**		
3		Number of charging points	25	
4				
5		**Surplus loadarea:**		
6		Number of charging points	100	
7				
8				
9		% of resort utalization caused by new arrived persons	***winter***	***summer***
10		hour		
11		07	100%	100%
12		08	85%	100%
13		09	33%	95%
14		10	10%	90%
15		11	15%	80%
16		12	10%	90%
17		13	7%	80%
18		14	4%	60%
19		15	2%	40%
20		16	1%	5%
21		17	0%	0%
22				
23		avg. Journies/day	12	1,8
24		avg duration in resort	5,5	6,5
25		start-hr of stay	1,1	1,0
26		final hr of stay	1,1	0,1
27		avg. Journies/hr	2,2	0,3
28	Journies/hr after 1st & before final hr		2,8	0,1
29		by own car	60%	80%
30		avg. Visitors / car	2,2	1,8
31		cars per visitor	0,27	0,44
32				
33		Cars with fixed load-demand "fast-load"	5%	5%
34		avg. load request [kWh]	40	30
35		avg. Power fast-load [kW]	7,3	4,6
36		Cars with load request when cheap "surplus-load"	35%	20%
37		avg. load request [kWh]	30	20
38		avg Power surplus-load [kW]	5,5	3,1

The use of the charging stations is also dependent on the utilization of the ski resort. All these calculations lead to a resulting electricity demand:

Table 73 - electricity demand for electric vehicle charging

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
4														
5		total for season		W-23/24		240	1 229	5 859 128	813 398	1 931	12	56	132 618	447 851
6				S-23		27	1 662	659 344	471 308	539	11	50	123 798	329 911
7	date (UTC)	season	cw	week-day	hour	total resort utilization	resort operating hrs	journies	visitors (new arrivals per hr)	cars (new arrivals/hr)	cars at VIP-charging	cars at surplus-charging	VIP-Charging demand [kWh]	th.max.surplus-charging demand [kW
1307	2022-12-25	W-22/23	2022-51	SO	04	0%	0	0	0	0	0	0	0,0	0,0
1308	2022-12-25	W-22/23	2022-51	SO	05	0%	0	0	0	0	0	0	0,0	0,0
1309	2022-12-25	W-22/23	2022-51	SO	06	0%	0	0	0	0	0	0	0,0	0,0
1310	2022-12-25	W-22/23	2022-51	SO	07	0%	0	26	24	7	0	2	0,0	10,9
1311	2022-12-25	W-22/23	2022-51	SO	08	6%	1	1 364	1 063	290	15	100	109,1	545,5
1312	2022-12-25	W-22/23	2022-51	SO	09	29%	1	7 125	2 155	588	25	100	181,8	545,5
1313	2022-12-25	W-22/23	2022-51	SO	10	29%	1	7 091	650	177	25	100	181,8	545,5
1314	2022-12-25	W-22/23	2022-51	SO	11	28%	1	6 775	932	254	25	100	181,8	545,5
1315	2022-12-25	W-22/23	2022-51	SO	12	24%	1	5 778	530	144	25	98	181,8	534,5
1316	2022-12-25	W-22/23	2022-51	SO	13	26%	1	6 404	411	112	10	2	72,7	10,9
1317	2022-12-25	W-22/23	2022-51	SO	14	26%	1	6 277	230	63	3	24	21,8	130,9
1318	2022-12-25	W-22/23	2022-51	SO	15	24%	1	5 873	108	29	4	34	29,1	185,5
1319	2022-12-25	W-22/23	2022-51	SO	16	1%	1	279	3	1	4	34	29,1	185,5
1320	2022-12-25	W-22/23	2022-51	SO	17	0%	0	0	0	0	0	0	0,0	0,0
1321	2022-12-25	W-22/23	2022-51	SO	18	0%	0	0	0	0	0	0	0,0	0,0

(3) Simulation-model for hotels and chalets on the ski-mountain

The simulation generates energy profiles for the electricity and heating demand of the hotels and lodges. The heat demand is also converted into an (optionally usable) electricity demand for heat pumps. The model is divided into the following sections:

- General settings
- Climate data
- Seasons and utilization
- Parameter settings for hotels and lodges
- Energy data for hotels and lodges

The General Settings are structured almost identically to the parameters for ski lifts shown in Table 65 and Table 66 (page 120). The year for the simulation is defined here with all the associated conditions (public holidays, vacations, etc.). As Table 74 shows, a few parameters differ from those for ski lifts. These include the assumed performance factors for heat pumps (COP), as well as reflection values for window surfaces, which allow more or less heat per m^2 into the room depending on the position of the sun:

Table 74 - General settings for hotels and lodges

	A	B	C	D
1				
2	reporting-year start/end	01.05.2023	/	29.04.2024
3	*period for simulation dataset*	*01.11.2022*	*/*	*30.04.2024*
4	**Reference season for Simulation**	**2023**	**/**	**2024**
5	*Season-ID's*	W-23/24		S-23
6	*ClimateData starts at line*	*94 970*		
7				
8				
9		**winter**		**summer**
10	months winter/summer	11; 12; 1; 2; 3; 4		5; 6; 7; 8; 9; 10
11				
12	Seasonal utilization factor	95%		(e.g. Covid19, economic effects, etc.)
13	wind resilience of tourists	30%		(100% means 50% of tourists will
14				ski/walk also at windspeeds up to
15				100 km/h)
16				
17		**W-23/24**	**Total**	**S-23**
18	heat-demand [kWh]	5 150 211	**8 584 966**	3 434 755
19	electricity-demand [kWh]	1 899 751	**3 995 655**	2 095 904
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30	(window-reflection reflection is taken into account additionally)			
31	1	162%		
32	2	132%		
33	3	78%		
34	4	43%		
35	5	27%		
36	6	22%		
37	7	24%		
38	8	36%		
39	9	60%		
40	10	100%		
41	11	140%		
42	12	168%		
43	faktor usefull irradiation for room-heating	30%		
44				
45				
46	**Heat-Pump performance factor**			
47	*Outside-Temp*	*COP*		
48	-20	1,40		
49	-10	2,20		

	AB	AC	AD	AE
4	**Weekday utalization**			
5				
6	1	MO	60%	Monday
7	2	TU	50%	Tuesday
8	3	WE	50%	Wednesday
9	4	TH	50%	Thursday
10	5	FR	75%	Friday
11	6	SA	90%	Saturday
12	7	SO	100%	Sunday

	AG	AH	AI	AJ	AK
4	**Fixed and variable Holydays**				
5					
6	2023	Sunday, 01 01 2023	60%	NY	New Year
7	2023	Friday, 06 01 2023	100%	EP	Epiphany
8	2023	Monday, 01 05 2023	90%	LD	Labor Day
9	2023	Tuesday, 15 08 2023	90%	AD	Assumption Day
10	2023	Tuesday, 03 10 2023	90%	GU	German Unity Day
11	2023	Thursday, 26 10 2023	90%	AN	Austrian National Day
12	2023	Tuesday, 31 10 2023	75%	RD	Reformation Day
13	2023	Wednesday, 01 11 2023	90%	AS	All Saints' Day
14	2023	Friday, 08 12 2023	90%	IC	Immaculate Conception
15	2023	Sunday, 24 12 2023	75%	CE	Christmas Eve
16	2023	Monday, 25 12 2023	90%	CD	Christmas Day
17	2023	Tuesday, 26 12 2023	100%	BD	Boxing Day
18	2023	Sunday, 31 12 2023	75%	NE	New Year Eve
19	2023	Wednesday, 22 02 2023	50%	AW	Ash Wednesday
20	2023	Friday, 07 04 2023	75%	GF	Good Friday
21	2023	*Sunday, 09 04 2023*	90%	ES	Easter Sunday
22	2023	Monday, 10 04 2023	90%	EM	Easter Monday
23	2023	Thursday, 18 05 2023	90%	AD	Ascension Day
24	2023	Sunday, 28 05 2023	100%	WS	With Sunday
25	2023	Monday, 29 05 2023	90%	WM	With Monday
26	2023	Thursday, 08 06 2023	90%	CC	Corpus Christi
27	**Potential bridge-days**				
28	2023				
29	2023				
30	2023				
31	2023	Monday, 14 08 2023	90%	xB	Bridge Day
32	2023	Monday, 02 10 2023	90%	xB	Bridge Day
33	2023	Friday, 27 10 2023	90%	xB	Bridge Day
34	2023	Monday, 30 10 2023	90%	xB	Bridge Day
35	2023				
36	2023				
37	2023				
38	2023				
39	2023	Monday, 25 12 2023	90%	xB	Bridge Day
40	2023				
41	2023	Friday, 19 05 2023	90%	xB	Bridge Day
42	2023	Friday, 09 06 2023	90%	xB	Bridge Day
43					
44	**Fixed and variable Holydays**				
45	2024	Monday, 01 01 2024	60%	NY	New Year
46	2024	Saturday, 06 01 2024	100%	EP	Epiphany
47	2024	Wednesday, 01 05 2024	90%	LD	Labor Day
48	2024	Thursday, 15 08 2024	90%	AD	Assumption Day
49	2024	Thursday, 03 10 2024	90%	GU	German Unity Day

A utilization per day is determined in the Seasons and utilization section. This is based on the general tourist utilization, weekdays and public vacations, vacations and closures, which are defined here:

Table 75 - Seasons and utilization for hotels and lodges

Seasonal capacity utilisation in the tourism region							
Date	cw	season	week day	holi day	season rating	day-rating	total rating
2022-11-01	44	LS	TU		48%	50%	24%
2022-11-02	44	LS	WE		48%	50%	24%
2022-11-03	44	LS	TH		48%	50%	24%
2022-11-04	44	LS	FR		48%	75%	36%
2022-11-05	44	LS	SA		48%	90%	43%

	Name	SPA-Resort 1	Chalet Village A	Cottages
ID		H01	H02	H03
	lever region season rating	10%	20%	5%
	lever individual rating	90%	80%	95%
MO	Monday	75%	70%	15%
TU	Tuesday	80%	75%	15%
WE	Wednesday	80%	75%	15%
TH	Thursday	80%	75%	15%
FR	Friday	90%	85%	40%
SA	Saturday	100%	100%	75%
SO	Sunday	95%	90%	75%
xxHD	all holidays	100%	100%	85%
HS-SH	high season - Semester holidays	105%	105%	90%
LS-JA	low season - January	92%	80%	40%
MS-AH	mid season - Autumn holidays	93%	85%	40%
MS-CH	mid season - Carnival holidays	96%	85%	40%
MS-EH	mid season - Easter holidays	94%	90%	60%
MS-SH	mid season - Summer holidays	92%	95%	90%
MS-WH	mid season - With holidays	92%	80%	60%
TS-CM	top season - Christmas	110%	120%	90%
LS	low season	90%	75%	30%
	Hotel closing periods			
	Closing 1 - start [+/- weeks to easter]	0	0	0
	Closing 1 - weeks	5	5	0
	Closing 1 - start	Montag, 10. April 2023	Montag, 10. April 2023	
	Closing 1 - end	Samstag, 13. Mai 2023	Samstag, 13. Mai 2023	
	Closing 1 - start	Montag, 01. April 2024	Montag, 01. April 2024	
	Closing 1 - end	Samstag, 04. Mai 2024	Samstag, 04. Mai 2024	
	Closing 2 - start [+/- weeks to christmas]	-4	-5	-5
	Closing 2 - weeks	0	4	0
	Closing 2 - start		Sonntag, 20. November 2022	
	Closing 2 - end		Freitag, 16. Dezember 2022	
	Closing 2 - start		Sonntag, 19. November 2023	
	Closing 2 - end		Freitag, 15. Dezember 2023	
	Closing 2 - start		Sonntag, 24. November 2024	
	Closing 2 - end		Freitag, 20. Dezember 2024	
	Closing 3 - start [arround date]		15.Sep	15.Sep
	Closing 3 - weeks	0	0	0
	Closing 3 - start			
	Closing 3 - end			
	Closing 3 - start			
	Closing 3 - end			
	Closing 3 - start			
	Closing 3 - end			
		67%	50%	5%
		67%	50%	5%
		67%	50%	5%
		76%	58%	13%
		85%	69%	24%

General | Hotels | Tabelle1 | H-EnergyData | Seasons | Pivot01 | Pivot02 | Pivot03 | Pivot04 | Analyzes05 | ClimateData | Piv

The determination of heat and electricity demand requires more than 250 parameters per hotel, lodge or chalet. The reason for this is because of the many different consumer groups such as indoor/outdoor pools, saunas, kitchens, different types of heating (ventilation, underfloor heating, etc.), hot water supply and much more. Of course, the configuration also takes into account existing measures such as heat recovery systems, etc. etc.

Table 76 - Parameter for hotels and lodges

	A	B	C	D	E	F	G	H
1								
2	***Total for seasons W-23/24 & S-23***							
3	heat-demand	4 641 766	546 059	413 482	397 247	457 023	1 794 336	335 052
4	electricity-demand	1 955 824	208 640	29 870	195 612	308 325	730 510	566 874
5	***Name***	***SPA-Resort 1***	***Chalet Village A***	***Cottages***	***Hostel***	***Apartment-House***	***lower Apartment resort***	***culinary mountain lodges***
6	*ID*	*H01*	*H02*	*H03*	*H04*	*H05*	*H06*	*H07*
7	Units	1	8	20	2	1	1	4
8	Capacity (max. guests]	400	16	4	50	60	280	80
9	*building outer skin per unit [m²]*	14 000	480	120	1 500	1 800	8 400	640
10	*building volume [m³]*	23 200	800	200	2 500	3 000	13 900	1 100
11	*air volume [m³]*	18 600	600	200	2 000	2 400	11 100	900
12	*sun-orientated window-area [m²]*	350	12	3	38	45	210	16
13	U-value - mixed [W/m2/K] *(passive-house ~0,18; modern ~0,4; <2010 ~0,5, old ~0,6)*	0,35	0,50	0,70	0,60	0,40	0,50	0,70
14	Efficiency of heat-distribution (losses of pipes, heat-exchanger, etc.; excl. the heating-appliance itself)	90%	95%	95%	95%	90%	90%	95%
15	Air change factor *[changes per hr]* (leaking window seals: 1,0; leakproof: 0,6; usual: 0,7; high person frequency >>1]	0,95	1,10	1,20	0,70	0,90	0,90	1,20
16	Air change factor night *[changes per hr]*	0,33	0,25	0,60	0,50	0,33	0,33	
17	Heat-recovery factor (ventilation heat exchanger)	50%	0%	0%	0%	0%	0%	
18	total installed ventilation-power [kW]	7,0	0,0	0,0	0,0	0,0	0,0	
19	Efficiency Ventlation-System (inverter-motors 85-95%, ordinary 70-80%)	85%	0%	0%	0%	85%	85%	
20	Installed heating-power by ventilation [kW]	250	0	0	0	0	0	
21	% of heating via ventilation (excluding radiators, underfloor heating, etc.)	40%	0%	0%	0%	0%	0%	
22	Room-Temperature [°C]	24,0	25,0	22,0	23,0	24,0	24,0	23,0
23	Night-reduction [°C]	21,0	21,0	15,0	19,5	21,0	21,0	19,0
24	*starts at [hh]*	23	23	22	22	23	23	18
25	*ends at [hh]*	05	05	05	05	05	05	06
26	SPA-Area [m²]	4 000	0	0	0	300	800	0
27	*SPA outer skin per unit [m²]*	1 200	0	0	0	100	200	0
28	*air volume [m³]*	11 200	0	0	0	800	2 200	0
29	*sun-orientated window-area [m²]*	120	0	0	0	30	60	0
30	U-value - mixed [W/m2/K] *(passive-house ~0,18; modern ~0,4; <2010 ~0,5, old ~0,6)*	0,45	0,70	0,90	0,70	0,40	0,70	0,70
	Air change factor for 100% utilization							

General | **Hotels** | Tabelle1 | H-EnergyData | Seasons | Pivot01 | Pivot02 | Pivot03 | Pivot04 | Analyzes05

As usual, the result are hourly values for heat and electricity demand. The demand for charging electric vehicles is also determined, but is relatively balanced for hotels due to the fact that guests usually stay for several days. This offers an ideal opportunity for energy/charging management.

Table 77 - Energy data for hotels and lodges

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
3							min:	-14,8							65,8	3,03	max:	1 490	177
4															1 327,1	4,78		(sum of single demands + los	
5		total for season		W-23/24	4 367			0,2	72%	101,5	101,8	6,9	0,3	5 150 211	1 899 751	1 702 485	184 523	2 739 899	334 307
6				S-23	4 417			10,3	80%	197,7	77,0	4,8	0,1	3 434 755	2 095 904	718 656	210 464	1 901 867	211 752
7	date	season	cw	week-day	hour	season&day-rating	outdoor activities	Outside Temp [°C]	rel.humidity [%]	GLH [W m-2]	GLV [W m-2]	avg. wind speed [m/s]	thSpecWindPower[kW/m2]	H-TotalHeat [kWh]	H-TotalElectricity [kWh]	H-HeatPump-El.Demand [kWh]	H-eCarDmand [kWh]	H01-TotHeat [kWh]	H02-TotHeat [kWh]
10322	2024-01-04	W-23/24	2024-01	TH	19	114%	0%	-3,0	68%	0	0	9,5	0,42	1 813,2	765,9	656,6	49,9	1 049,2	119,6
10323	2024-01-04	W-23/24	2024-01	TH	20	114%	0%	-3,1	66%	0	0	6,8	0,15	1 202,7	598,5	437,5	49,9	500,4	116,6
10324	2024-01-04	W-23/24	2024-01	TH	21	114%	0%	-2,7	62%	0	0	6,9	0,16	1 078,3	537,8	387,5	49,9	419,6	112,2
10325	2024-01-04	W-23/24	2024-01	TH	22	114%	0%	-2,3	55%	0	0	7,8	0,23	998,6	424,4	354,1	49,9	410,5	109,5
10326	2024-01-04	W-23/24	2024-01	TH	23	114%	0%	-2,1	55%	0	0	9,8	0,46	757,3	343,2	267,6	49,9	326,3	58,3
10327	2024-01-05	W-23/24	2024-01	FR	00	114%	0%	-1,9	52%	0	0	9,1	0,37	742,0	252,9	260,3	49,9	320,3	56,8
10328	2024-01-05	W-23/24	2024-01	FR	01	114%	0%	-1,5	52%	0	0	9,0	0,36	728,6	228,6	253,3	53,7	315,3	55,5
10329	2024-01-05	W-23/24	2024-01	FR	02	114%	0%	-1,5	51%	0	0	9,0	0,36	726,4	228,5	251,9	53,7	314,5	55,3
10330	2024-01-05	W-23/24	2024-01	FR	03	114%	0%	-1,4	53%	0	0	9,1	0,37	723,9	232,4	250,5	53,7	313,6	55,1
10331	2024-01-05	W-23/24	2024-01	FR	04	114%	0%	-1,5	54%	0	0	8,6	0,32	731,1	255,1	253,8	53,7	316,4	55,8
10332	2024-01-05	W-23/24	2024-01	FR	05	114%	0%	-1,7	56%	0	0	10,3	0,54	1 441,7	312,7	503,0	53,7	666,2	112,8
10333	2024-01-05	W-23/24	2024-01	FR	06	114%	0%	-1,4	58%	0	0	9,2	0,38	1 388,0	561,4	481,1	53,7	653,7	108,6
10334	2024-01-05	W-23/24	2024-01	FR	07	114%	0%	-1,6	62%	0	0	9,2	0,38	1 641,1	686,2	571,6	53,7	840,5	111,3
10335	2024-01-05	W-23/24	2024-01	FR	08	114%	0%	-1,6	63%	0	0	8,3	0,28	1 844,2	809,9	641,8	53,7	986,7	113,2
10336	2024-01-05	W-23/24	2024-01	FR	09	114%	5%	-1,9	74%	58	93	9,2	0,38	1 900,3	904,1	667,0	53,7	1 000,9	111,5
10337	2024-01-05	W-23/24	2024-01	FR	10	114%	13%	-0,8	75%	161	260	8,7	0,33	1 787,7	1 027,3	609,4	53,7	954,8	100,4
10338	2024-01-05	W-23/24	2024-01	FR	11	114%	21%	-0,2	75%	262	424	7,8	0,24	1 753,5	1 233,8	587,3	53,7	962,8	92,9
10339	2024-01-05	W-23/24	2024-01	FR	12	114%	17%	0,0	77%	214	345	7,5	0,21	1 833,7	1 258,2	611,2	53,7	1 004,5	96,5

(4) Fact-check: Simulated energy demand versus measured data from a hotel

Thankfully, I was given the unique opportunity to access the data of an energy management system of a similarly sized wellness hotel directly and download it for comparison purposes. Of course, this data must not be published. The hotel is also not mentioned by name.

After entering the primary parameters and opening hours, very good results were already available.

As part of discussions with the technical manager, adjustments were made, such as the power and switch-on times of the saunas, pre-heating times of the pools, etc. The most significant adjustment was required to the kitchen load. In wellness hotels of this type, the lunch kitchen is of secondary importance.

The result after these adjustments was amazing and really surprised me. The real electricity demand is almost identical to the simulation. There were only differences during the business closure, as energy-intensive renovations were made. However, the daily and monthly profiles are unexpectedly accurate:

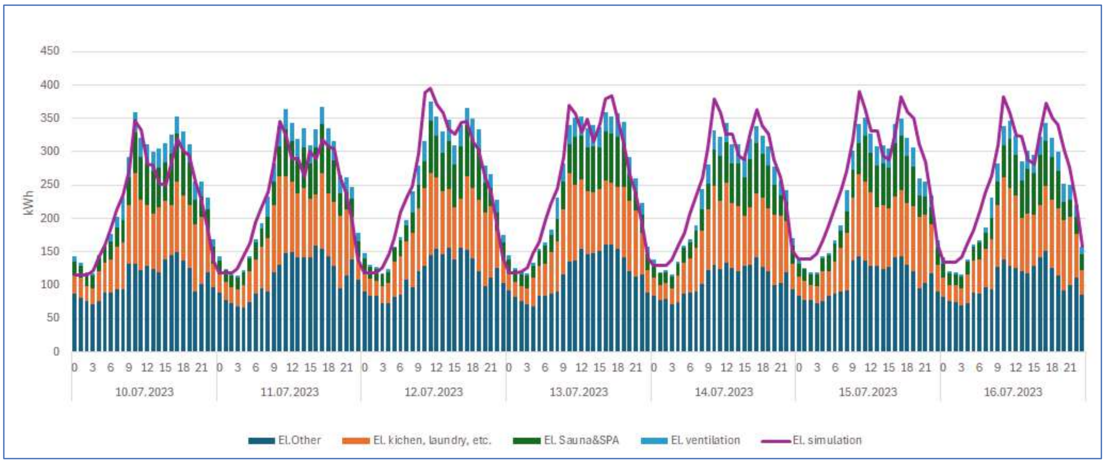


Figure 59 - Electricity demand simulation versus real consumption

The columns in Figure 59 shows the simulated electricity demand per hour for one week in July 2023. The purple line shows the measured values for the same period. The same diagram in Figure 60 shows the annual average loads per time of day - with almost no deviations.

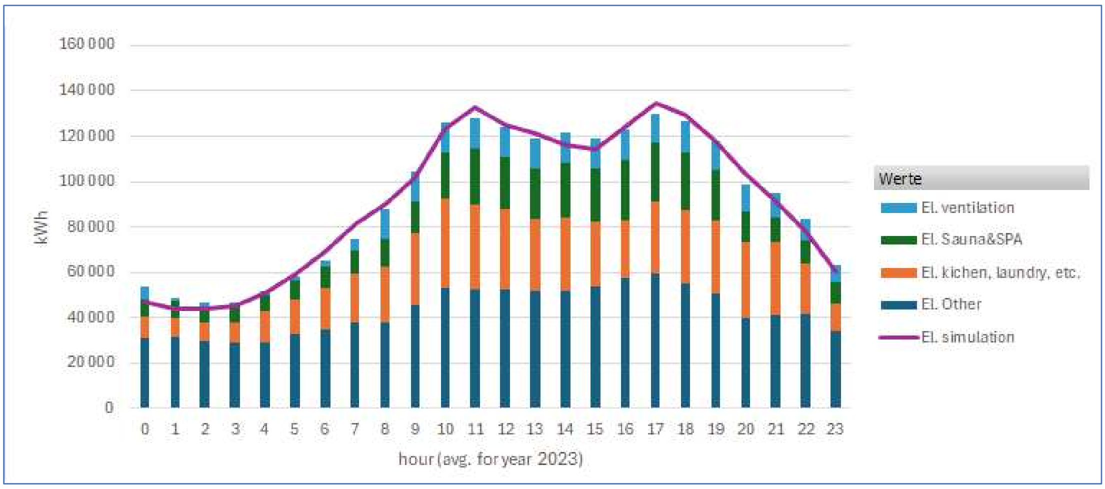


Figure 60 - average electricity demand per hour for 2023

Unfortunately, the hourly heat demand cannot be simulated quite as perfectly. Figure 61 shows that the average values in winter are still reasonably accurate, with slight shifts between daytime and night-time demand:

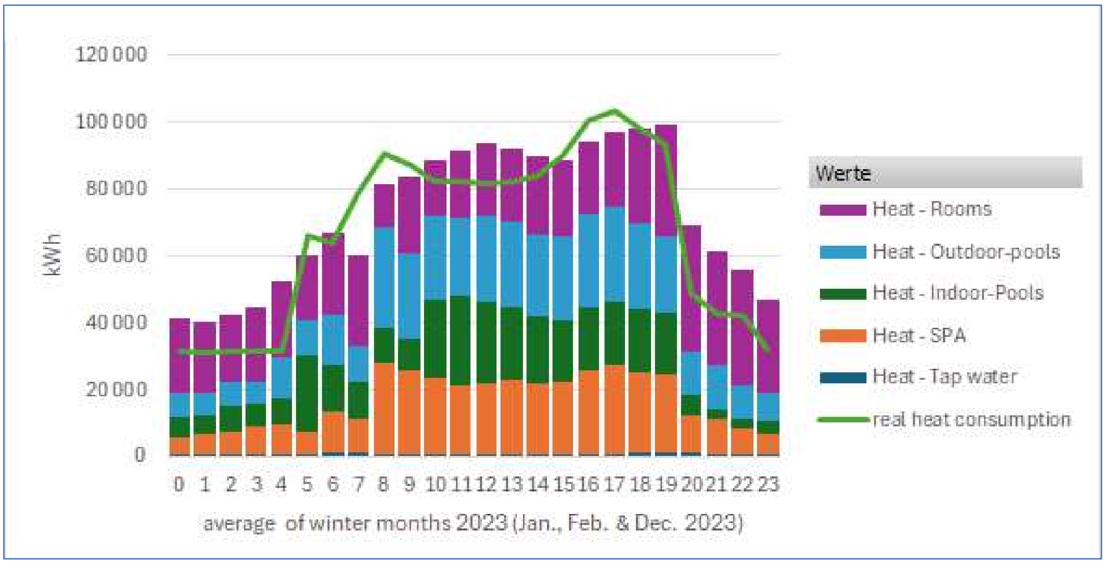


Figure 61 - deviations in heat demand (winter months 2023)

However, if you look at the details in summer, there are some massive deviations. In Figure 62, the roles are now reversed. The bars show measured data, while the red line shows the sum of the simulated heat demand:

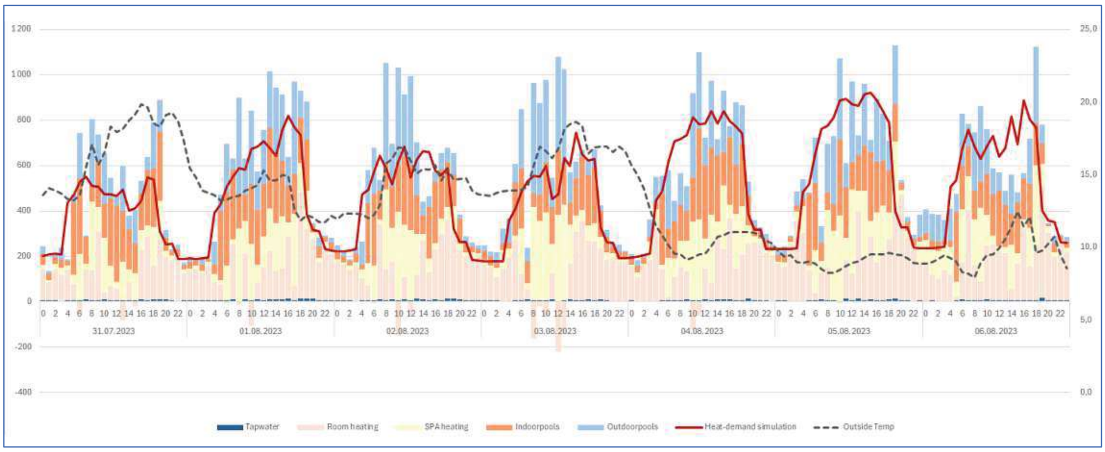


Figure 62 - deviations in heat-demand summer 2023

In this image, an attempt was made to assign the measured data from the various heat distributors to the simulated individual results. This was quite possible for the pools due to the clearly defined measurement facilities, but not so well in other areas. All internal losses (= difference between individual measurements and central heat supply) were allocated to room heating (light red bars).

Very interesting are the negative values. You can actually see from the real data that the return temperature is sometimes higher than the flow temperature. This only shows that there are sometimes problems in the hydraulics. In this hotel, all loads are operated with a flow temperature of > 70°C. This heat distribution is then reduced to the required temperature levels via mixing valves and heat exchangers.

Figure 62 shows the temperature curve as a gray dashed line. The simulation attempts to calculate the heat demand using climate data (outside temperature, humidity for evaporation, solar radiation, etc.). In discussions with the technical manager, we talked about possible causes for the deviations. Some of the causes can also be identified here in the data. For example, the windows in the indoor pool area are opened automatically when the humidity and sunlight are high. This allows moisture and heat to escape, while the heating switches off. Once the high humidity has been reduced, the windows close again and the ventilation heating starts up again. The pools will then probably also have a higher heating demand. Such specific characteristics can never be taken into account by a simulation.

(5) PV configuration and simulation

The PV gains can be easily calculated by the web tool “global solar atlas” [23]. This tool calculates a tilt of 39° for optimal annual PV gains. A tilt of 65° leads to reduced annual energy gains in total, but we get nearly the same irradiation in winter and in summer.

The major effect is, that the snow can slide easily from the 65° tilted panels. The 39° tilted panels would be shaded out by snow during very long periods in winter.

The following figures shows the comparison of 39° and 65° tilted panels with an installed capacity of 1 000 kW_{peak} on the southern hillside of our virtual ski resort:

Figure 63 - monthly PV gains 39° compared to 65° tilt [38]

Figure 50 shows, that the energy production with 65° is relatively flat during the whole year. In winter it is nearly on the same level than 39°, but in summer we get significant less irradiation with 65°. If we look to the differences per hour, we see that during some winter hours, we get sometimes 5 - 10 % more energy with 65°:

hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 4												
4 - 5					-39%	-26%	-35%					
5 - 6				-28%	-25%	-23%	-23%	-28%	-56%			
6 - 7			-12%	-37%	-45%	-45%	-43%	-40%	-23%	-1%		
7 - 8	-30%	10%	-6%	-25%	-37%	-43%	-42%	-32%	-14%	-1%	-5%	-9%
8 - 9	7%	-5%	-5%	-17%	-26%	-31%	-29%	-21%	-10%	1%	-7%	4%
9 - 10	-8%	6%	-4%	-14%	-20%	-24%	-23%	-17%	-9%	-1%	-12%	5%
10 - 11	-17%	4%	-4%	-12%	-18%	-21%	-19%	-14%	-8%	-1%	2%	-19%
11 - 12	-6%	2%	-4%	-11%	-17%	-19%	-18%	-13%	-7%	-1%	5%	-17%
12 - 13	-6%	2%	-4%	-11%	-17%	-19%	-18%	-13%	-7%	-1%	5%	-17%
13 - 14	-11%	3%	-4%	-12%	-18%	-20%	-19%	-14%	-8%	0%	-2%	-19%
14 - 15	-16%	4%	-5%	-14%	-20%	-23%	-21%	-16%	-9%	1%	-17%	5%
15 - 16	6%	4%	-5%	-17%	-25%	-29%	-26%	-20%	-11%	3%	4%	6%
16 - 17	-26%	-14%	-5%	-24%	-35%	-39%	-36%	-28%	-14%	-3%	-25%	
17 - 18		-54%	-10%	-35%	-43%	-46%	-46%	-41%	-22%	-8%		
18 - 19				-29%	-24%	-24%	-25%	-27%	-7%			
19 - 20					-23%	-28%	-24%	-100%				
20 - 24												
Sum	**-9%**	**2%**	**-4%**	**-15%**	**-22%**	**-25%**	**-24%**	**-18%**	**-9%**	**0%**	**-2%**	**-12%**

Figure 64 - percentage of energy-gains from 65° tilted PV compared to 39° [38]

[38] Simulations via https://globalsolaratlas.info/ [23] - screenshots and download of simulation results were used for these figures and tables

As already described on page 33 and shown in Figure 27, the albedo effect is added to the yields from the wind atlas. This is done using the following assumptions per month:

Table 78 - assumed albedo surcharges

kWh per kWp	albedo
73,824	25%
105,656	20%
128,119	15%
107,528	10%
105,049	7%
101,509	5%
110,905	5%
113,980	5%
106,599	5%
101,807	5%
65,664	10%
53,161	15%

The hourly PV yields are converted proportionally using the monthly values from the solar atlas and the monthly average from the INCA data and are adjusted by the respective albedo factor.

With larger PV fields on the mountain, it is probably unrealistic for all panels to be installed with 100% south orientation. In fact, this simulation model currently assumes this. In a real project, several orientations would have to be taken into account. However, this would probably only lead to a slightly lower annual yield, but to better yields at the edge of the day and thus in the higher-value hours of the day (in terms of variable electricity market prices).

The selected bifacial PV-modules for the ground are Sonnenkraft PV400GG2R:

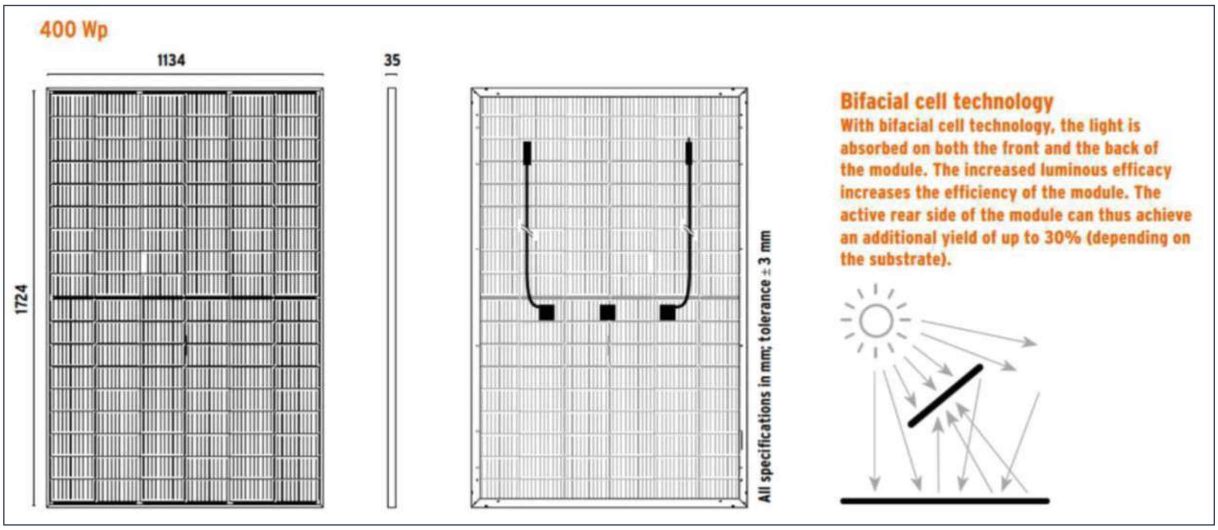


Figure 65 - Sonnenkraft PV-module PV400GG2R

Each module is equipped with 108 half cells and same dimensions: 1 724 x 1 134 mm (1,96 m²), but only 400 kWp. So, we get 204 kWp / m² and 3 320 PV-modules per ha.

(6) Specification of wind-turbine und simulation background

The Vestas V52 wind turbine has been on the market since ~20 years. There are now a large number of offers for used turbines on the market. Prices range from € 80,000 to € 500,000 some of them offered as refurbished.

Table 79 - Vestas V52 technical data [24]

Vestas V52		**Generator**	
Rated power	850.0 kW	Type	Double Fed Asyn
Cut-in wind speed	4.0 m/s	Speed, max	1,620.0 U/min
Rated wind speed	14.0 m/s	Voltage	690.0 V
Cut-out wind speed	25.0 m/s	Grid connection	Asyncron
Survival wind speed	60.0 m/s	Grid frequency	50.0 Hz
Wind zone (DIBt)	II	Manufacturer	Weier / ABB
Wind class (IEC)	Ia	**Tower**	
Rotor		Hub height	36.5/40/44/49/55/
Diameter	52.0 m		60/65/70/74/86 m
Swept area	2,124.0 m²	Type	Steel tube
Number of blades	3	Shape	conical
Rotor speed, max	31.4 U/min	Corrosion protection	coated
Tipspeed	85 m/s	Manufacturer	Vestas
Material	GFK	**Weight**	
Manufacturer	Vestas	Rotor	11.0 t
Power density 1	400.2 W/m²	Nacelle	22.0 t
Power density 2	2.5 m²/kW	Tower, max	100.0 t

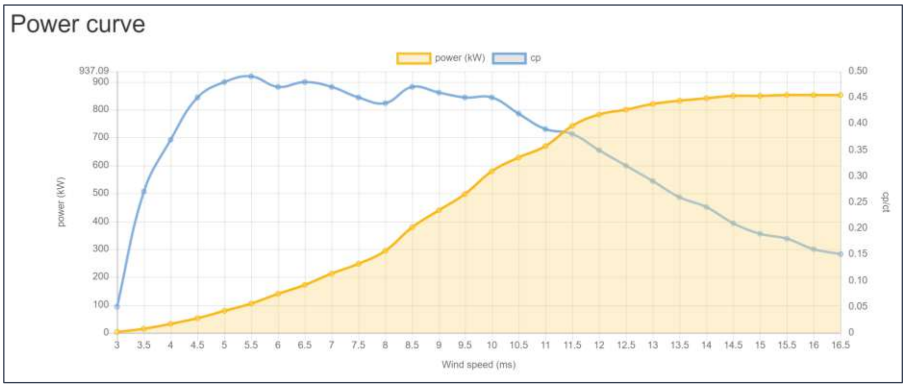


Figure 66 - Vestad V52 Power curve [24]

Description [24]

“The wind turbine V52 is a production of Vestas Wind Systems A/S, a manufacturer from Denmark. This manufacturer has been in business since 1979.

The rated power of Vestas V52 is 850,00 kW. At a wind speed of 4,0 m/s, the wind turbine starts its work. the cut-out wind speed is 25,0 m/s.

The rotor diameter of the Vestas V52 is 52,0 m. The rotor area amounts to 2.124,0 m². The wind turbine is equipped with 3 rotor blades. The maximum rotor speed is 31,4 U/min.

The Vestas V52 is fittet with a spur/planetary gearbox. The gearbox has 3,0 stages. Manufacturer of the transmission is Hansen.

In the generator, Vestas Wind Systems A/S sets to Double Fed Asyn. The manufacturer has used one generator for the V52. The maximum speed of the generator is 1.620,0 U/min. The voltage amounts to 690,0 V. At the mains frequency, the V52 is at 50,0 Hz.

In the construction of the tower, the manufacturer uses Steel tube. As corrosion protection for the tower Vestas focuses on coated. Manufacturer of the tower is Vestas."

The wind data was primarily taken from the INCA data [25] from Geosphere-Austria. However, these reflect the wind near the ground. The wind-potential for the turbine is usually much higher than to ground-wind. Basically, this is shown in the wind-atlas:

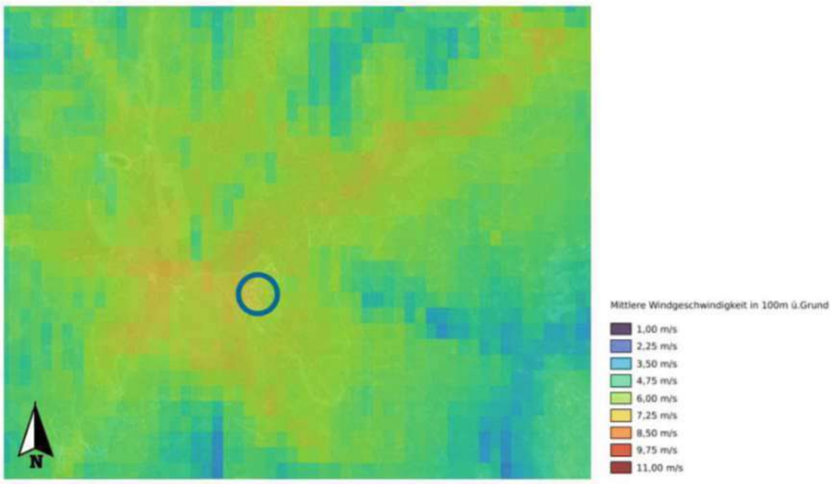


Figure 67 - average windspeed 100m above ground

On the top of the mountain the Windatlas shows average speeds of ~6-8 m/s. Unfortunately, the average windspeed is not sufficient for an estimation of the energy-yield. The wind energy is proportional to the 3rd power of the windspeed. So we need more detailed data. This was done, by converting proportionally to the 100m wind from windatlas.at [23] to the hourly data of the INCA-model.

The difference between the 100m wind and the ground speed is very large in the lowlands. Not so on the mountain top, as Figure 68 Figure 68 - increase in speed over a hilltopshows.

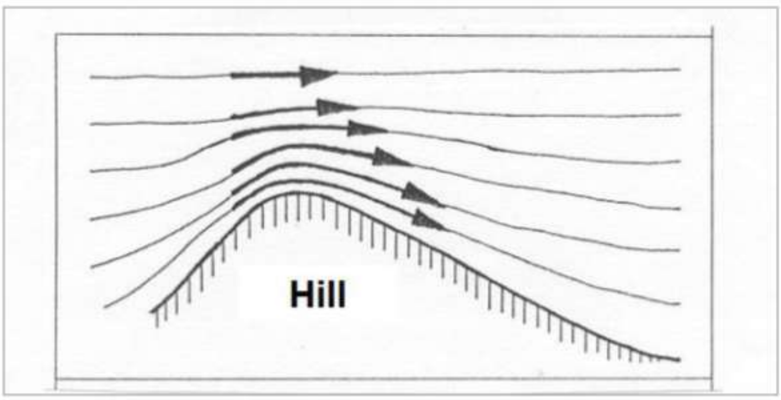


Figure 68 - increase in speed over a hilltop [26]

(7) LRGC Calculation

The details of the LRGC calculation are shown here. The large Excel worksheet has been divided into several parts:

Table 80 - LRGC-calculation 1/5 input-data & key-figures

			PV	wind				
Investment Horizon (incl. Implementation & delay)	30	years	30	30/25	(30 for	CPI	2,00%	per year
Rated Capacity	3 896	MW	2 196	1 700	financing	Discount rate	6,50%	per year
Investment cost (w/o deduction of subsidies)	1 668	€/MW	1 102	2 400	incl. project)	CFR	7,66%	
Full Load Hours	1 506		1 066	2 074				
O&M	38,94	€/MWh	22,68	49,73				
Repair workes	218 044	€/MW	236 566	194 118		repair after	15	years of op.
Residual Value	203 799	€/MW	165 756	252 941				
Electricity Price own use	113,50	€/MWh				SalesPrice-incr.	3,00%	per year
Electricity Sales Price	42,60	€/MWh					-1,00%	per year

Table 81 - LRGC-calculation 2/5 results

				PV	wind
	NPV	€ 10 056 184			
	Annuity	€ 770 077			
				PV	wind
results	NPV of costs	-€ 7 391 606		-€ 2 714 955	-€ 4 676 651
	el. gen./year	4 855	MWh	2 163	2 692
	Ann. of costs	-€ 566 030		-€ 207 904	-€ 358 126
	LRGC	**-€ 116,58**	**€/MWh**	**-€ 96,13**	**-€ 133,01**
	(incl.CostEsc.)				

Table 82 - LRGC-calculation 3/5 annual data year 0-6

1,5 ha PV & 2 wind-turbines	Year	0 2025	1 2026	2 2027	3 2028	4 2029	5 2030	6 2031
	Total							
Energy yield PV [MWh]	*64 882*		*2 341*	*2 318*	*2 294*	*2 271*	*2 249*	*2 226*
Energy yield wind [MWh]	*80 775*							*3 525*
Electricity own use [MWh]	*122 511*		*2 107*	*2 097*	*2 088*	*2 078*	*2 069*	*4 256*
Electricity feed-in [MWh]	*23 146*		*234*	*220*	*206*	*193*	*180*	*1 495*
price own use [€/MWh]			*€ 113,50*	*€ 116,91*	*€ 120,41*	*€ 124,02*	*€ 127,75*	*€ 131,58*
price feed-in [€/MWh]			*€ 42,60*	*€ 42,17*	*€ 41,75*	*€ 41,33*	*€ 40,92*	*€ 40,51*
PV: Investment	-€ 1 694 000	-€ 1 694 000						
Repair	-€ 519 500							
Residual Value after 30 years of operation	€ 364 000							
Wind: Investment	-€ 3 280 000	-€ 125 000	-€ 164 000	-€ 164 000	-€ 164 000	-€ 656 000	-€ 2 007 000	
Repair	-€ 330 000							
Residual Value after 25 years of operation	€ 430 000							
summary Invest & Replacement	**-€ 5 029 500**	-€ 1 819 000	-€ 164 000	-€ 164 000	-€ 164 000	-€ 656 000	-€ 2 007 000	€ 0
PV: O&M	-€ 2 197 248		-€ 54 162	-€ 55 245	-€ 56 350	-€ 57 477	-€ 58 627	-€ 59 799
Wind: O&M	-€ 6 323 302							-€ 197 416
Energy sale a) own use	€ 22 757 737		€ 239 133	€ 245 199	€ 251 411	€ 257 772	€ 264 286	€ 559 986
Energy sale b) to grid	€ 848 497		€ 9 973	€ 9 285	€ 8 622	€ 7 981	€ 7 362	€ 60 579
operation cost/revenue	**€ 15 085 684**	€ 0	€ 194 944	€ 199 239	€ 203 682	€ 208 275	€ 213 021	€ 363 350
Nominal CF	€ 10 056 184	-€ 1 819 000	€ 30 944	€ 35 239	€ 39 682	-€ 447 725	-€ 1 793 979	€ 363 350
Discounted CF	**€ 969 284**	-€ 1 819 000	€ 29 055	€ 31 069	€ 32 851	-€ 348 027	-€ 1 309 391	€ 249 016
Discounted Costs	-€ 7 391 606	-€ 1 819 000	-€ 204 847	-€ 193 300	-€ 182 417	-€ 554 602	-€ 1 507 661	-€ 176 279

Table 83 - LRGC-calculation 3/5 annual data year 7-18

7	8	9	10	11	12	13	14	15	16	17	18
2032	*2033*	*2034*	*2035*	*2036*	*2037*	*2038*	*2039*	*2040*	*2041*	*2042*	*2043*
2 204	*2 182*	*2 160*	*2 139*	*2 117*	*2 096*	*2 075*	*2 054*	*2 034*	*2 184*	*2 174*	*2 164*
3 490	*3 455*	*3 420*	*3 386*	*3 352*	*3 319*	*3 286*	*3 253*	*3 220*	*3 188*	*3 156*	*3 125*
4 327	*4 397*	*4 464*	*4 530*	*4 649*	*4 602*	*4 556*	*4 511*	*4 466*	*4 566*	*4 530*	*4 495*
1 367	*1 240*	*1 116*	*994*	*820*	*812*	*804*	*796*	*788*	*806*	*799*	*793*
€ 135,52	*€ 139,59*	*€ 143,78*	*€ 148,09*	*€ 152,53*	*€ 157,11*	*€ 161,82*	*€ 166,68*	*€ 171,68*	*€ 176,83*	*€ 182,13*	*€ 187,60*
€ 40,11	*€ 39,71*	*€ 39,31*	*€ 38,92*	*€ 38,53*	*€ 38,14*	*€ 37,76*	*€ 37,38*	*€ 37,01*	*€ 36,64*	*€ 36,27*	*€ 35,91*
								-€ 519 500			
€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	-€ 519 500	€ 0	€ 0	€ 0
-€ 60 995	-€ 62 215	-€ 63 459	-€ 64 729	-€ 66 023	-€ 67 344	-€ 68 691	-€ 70 064	-€ 71 466	-€ 72 895	-€ 74 353	-€ 75 840
-€ 201 365	-€ 205 392	-€ 209 500	-€ 213 690	-€ 217 964	-€ 222 323	-€ 226 769	-€ 231 305	-€ 235 931	-€ 240 649	-€ 245 462	-€ 250 372
€ 586 451	€ 613 741	€ 641 878	€ 670 887	€ 709 131	€ 723 101	€ 737 346	€ 751 872	€ 766 684	€ 807 433	€ 825 101	€ 843 290
€ 54 806	€ 49 239	€ 43 872	€ 38 699	€ 31 608	€ 30 979	€ 30 362	€ 29 758	€ 29 166	€ 29 523	€ 28 998	€ 28 486
€ 378 897	€ 395 373	€ 412 792	€ 431 168	€ 456 752	€ 464 413	€ 472 249	€ 480 261	€ 488 453	€ 523 412	€ 534 283	€ 545 564
€ 378 897	€ 395 373	€ 412 792	€ 431 168	€ 456 752	€ 464 413	€ 472 249	€ 480 261	-€ 31 047	€ 523 412	€ 534 283	€ 545 564
€ 243 823	€ 238 897	€ 234 199	€ 229 694	€ 228 473	€ 218 127	€ 208 270	€ 198 876	-€ 12 072	€ 191 095	€ 183 159	€ 175 612
-€ 168 830	-€ 161 696	-€ 154 864	-€ 148 321	-€ 142 054	-€ 136 051	-€ 130 303	-€ 124 797	-€ 321 519	-€ 114 474	-€ 109 637	-€ 105 004

Table 84 - LRGC-calculation 3/5 annual data year 18-25

19	20	21	22	23	24	25	26	27	28	29	30
2044	*2045*	*2046*	*2047*	*2048*	*2049*	*2050*	*2051*	*2052*	*2053*	*2054*	*2055*
2 155	*2 148*	*2 141*	*2 135*	*2 130*	*2 127*	*2 125*	*2 124*	*2 124*	*2 126*	*2 130*	*2 135*
3 093	*3 062*	*3 289*	*3 256*	*3 223*	*3 191*	*3 159*	*3 127*	*3 096*	*3 065*	*3 035*	*3 004*
4 461	*4 428*	*4 615*	*4 582*	*4 551*	*4 520*	*4 491*	*4 464*	*4 437*	*4 413*	*4 390*	*4 368*
787	*781*	*814*	*809*	*803*	*798*	*793*	*788*	*783*	*779*	*775*	*771*
€ 193,23	*€ 199,02*	*€ 204,99*	*€ 211,14*	*€ 217,48*	*€ 224,00*	*€ 230,72*	*€ 237,64*	*€ 244,77*	*€ 252,12*	*€ 259,68*	*€ 267,47*
€ 35,55	*€ 35,19*	*€ 34,84*	*€ 34,49*	*€ 34,15*	*€ 33,81*	*€ 33,47*	*€ 33,14*	*€ 32,80*	*€ 32,48*	*€ 32,15*	*€ 31,83*
											€ 364 000
	-€ 330 000										
											€ 430 000
€ 0	-€ 330 000	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 794 000
-€ 77 357	-€ 78 904	-€ 80 482	-€ 82 092	-€ 83 733	-€ 85 408	-€ 87 116	-€ 88 859	-€ 90 636	-€ 92 448	-€ 94 297	-€ 96 183
-€ 255 379	-€ 260 487	-€ 265 696	-€ 271 010	-€ 276 430	-€ 281 959	-€ 287 598	-€ 293 350	-€ 299 217	-€ 305 202	-€ 311 306	-€ 317 532
€ 862 029	€ 881 346	€ 946 042	€ 967 498	€ 989 655	€ 1 012 553	€ 1 036 239	€ 1 060 760	€ 1 086 170	€ 1 112 525	€ 1 139 889	€ 1 168 329
€ 27 988	€ 27 504	€ 28 376	€ 27 893	€ 27 424	€ 26 969	€ 26 528	€ 26 101	€ 25 688	€ 25 290	€ 24 905	€ 24 535
€ 557 281	€ 569 459	€ 628 240	€ 642 289	€ 656 914	€ 672 155	€ 688 052	€ 704 652	€ 722 005	€ 740 165	€ 759 191	€ 779 150
€ 557 281	€ 239 459	€ 628 240	€ 642 289	€ 656 914	€ 672 155	€ 688 052	€ 704 652	€ 722 005	€ 740 165	€ 759 191	€ 1 573 150
€ 168 435	€ 67 958	€ 167 411	€ 160 709	€ 154 336	€ 148 279	€ 142 522	€ 137 052	€ 131 856	€ 126 923	€ 122 240	€ 237 838
-€ 100 567	-€ 189 971	-€ 92 248	-€ 88 350	-€ 84 617	-€ 81 042	-€ 77 618	-€ 74 338	-€ 71 197	-€ 68 189	-€ 65 307	€ 57 494