NEFI - New Energy for Industry

Publishable final report

Programme control:
Climate and Energy Fund

Programme management:
The Austrian Research Promotion Agency (FFG)

Final Report
created on
30.09.2022

Project Title:

CleanEnergy4Tourism

Project number: 868857

DISCLAIMER

This project has received funding from the Austrian Climate and Energy Fund within the Energy Model Region New Energy for Industry (NEFI). The sole responsibility for the content of this document lies with the Clean Energy for Tourism project and does not necessarily reflect the opinion of the funding authority.

Call	2nd Call FTI Initiative Energy Model Region
Project Starting Date	01.10.2018
Project Ending Date	30.09.2022
Total duration of project (in months)	48
Project holder (Institution)	Salzburg AG
Contact persons for further questions	Energy trading: Bernhard Gotthard (Salzburg AG) Skiing resorts: Roland Steiner (Salzburg AG) VPP/Dashboard/SCADA: Tarek Ayoub (World Direct) Stakeholder engagement: Tanja Tötzer (AIT)
Postal address	Bayerhamerstraße 16
Telephone	0662 8884-0
Website	www.salzburg-ag.at

CleanEnergy4Tourism

CE4T

Authors:

Norbert Dorfinger (Salzburg AG)
Thomas Anfang (Salzburg AG)
Christoph Groiß (Salzburg Netz GmbH)
Hannes Passegger (Faradis)
Tarek Ayoub (World Direct)
Clemens Korner (AIT)
Branislav Iglar (AIT)
Tanja Tötzer (AIT)
Martin Jung (AIT)
Helfried Brunner (AIT)
Klara Maggauer (AIT)
Pascal Liedtke (BEST)
Michael Zellinger (BEST)
Julia Vopava-Wrienz (MUL)
Christoph Schmuckermayer (Sattler Energie Consulting)

1 Table of content

2 Introduction

2.1 Context and placement within the NEFI-Lab

Clean Energy for Tourism (CE4T) is one of the lead projects within the Austrian innovation network NEFI. NEFI hast the aim to identify pathways to decarbonize the Austrian Industry by using technology „Made in Austria". This should help strengthening the position of the Austrian industry and boost research efforts in the field of energy. CE4T is focusing on the winter tourism industry, even more precise on the challenges and chances within the sector of the ski resort operators. The project area is situated in the region of Salzburg (see blue box in Figure 1):

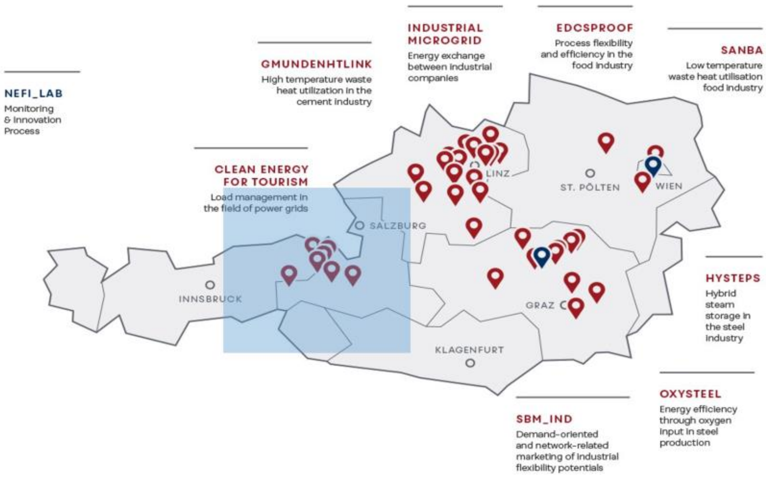


Figure 1: CE4T within NEFI

Among the skiing areas participating in the project, 8 of them are located in the grid area of Salzburg Netz GmbH (4 of them are skiing area operators in Saalbach/Hinterglemm), one is located in the grid area of TINETZ (Bergbahnen Fieberbrunn):

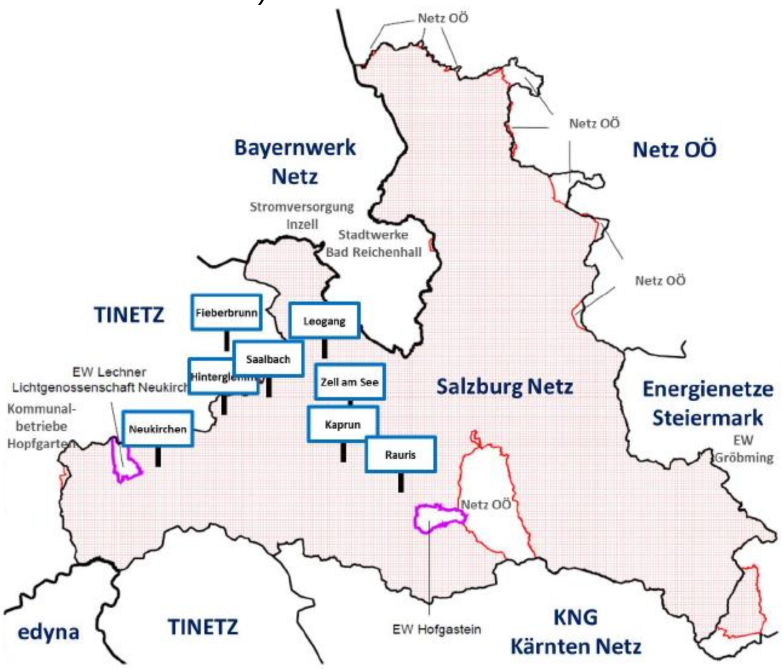


Figure 2: Location of participating Ski resorts

The sector of the ski resort operators is very essential for the whole touristic industry in Austria – even more in the western districts of Salzburg, Tirol and Vorarlberg. For example the 6% of the Austrian inhabitants live in Salzburg, but they generate 14% of the adding value in the area of gastronomy and accommodation. Winter sport tourists generate a adding value of approx. € 6 Mrd. (or 5,3%) as contribution to the gross domestic product of Austria[1] (using lift, accommodation, gastronomy, transport, shopping..)

2.2 Winter sport in the context of the energy transition pathways

2.2.1 Energy transition in Austria

The Austrian government has committed to achieve 100% renewable energy in the electricity system until 2030[2] (basis: balance accounting p.a.). In this context, additional 10 TWh of wind power, 11 TWh of photovoltaic power, 5 TWh of hydropower and 1 TWh of bioenergy power have to be provided until 2030. To enable such big amounts of fluctuating energy, digitalization, flexibilization and system coupling is one requirement (see Figure 3). This is getting even more important to meet the Austrian objectives to be climate neutral until 2040.

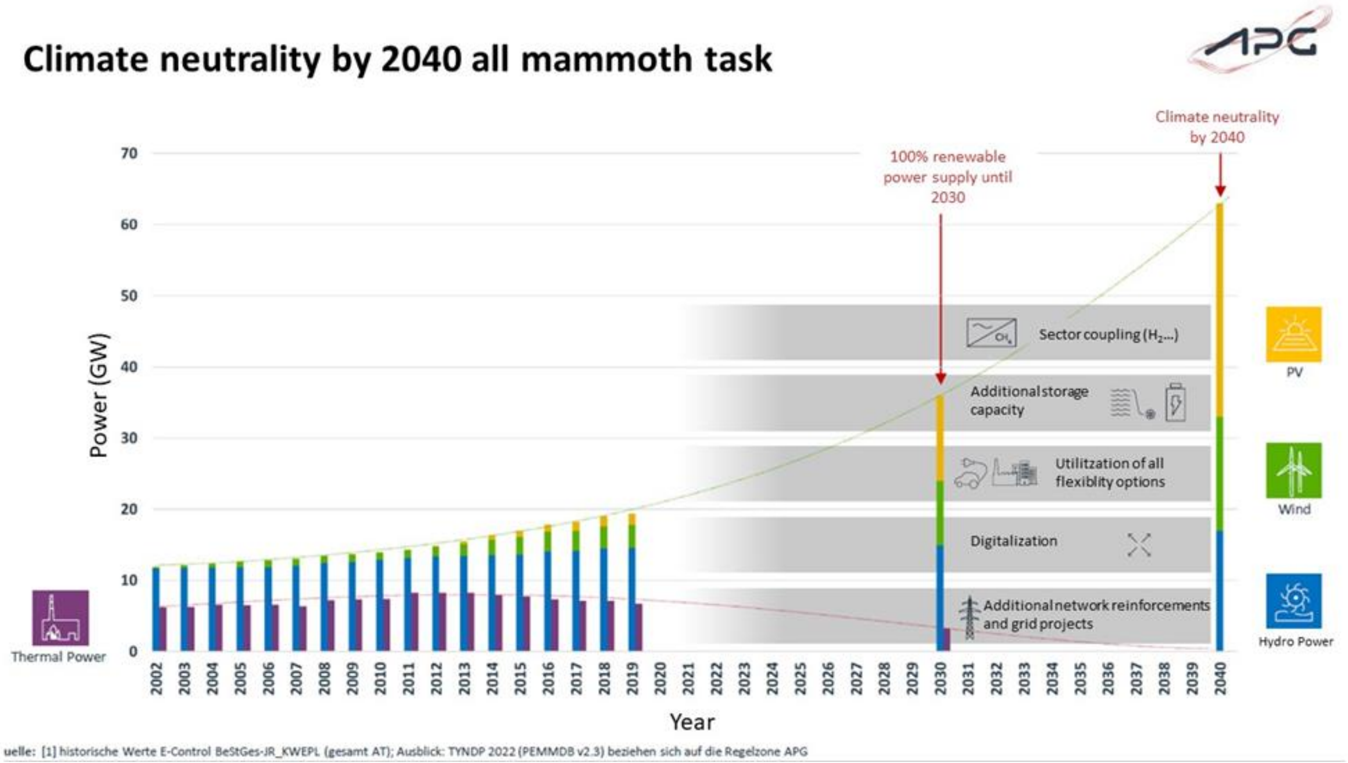


Figure 3: Energy transition pathway in Austria (Source: Austrian Power Grid, APG)

2.2.2 CO2 emissions in skiing areas

Concerning CO_2 emissions there has been ongoing discussions how to find a suitable approach to address the issue. Considering common CO_2-neutral electric power products (and offerings) from local energy supply companies, lowering CO_2 emissions is an issue in the field of piste preparation and the approach of guests as well (see Figure 4):

[1] https://www.wko.at/branchen/transport-verkehr/seilbahnen/ZahlenDatenFakten.html
[2] Energiewende für Österreich eingeleitet: Bundesregierung präsentiert Erneuerbaren-Ausbau-Gesetz (bmk.gv.at)

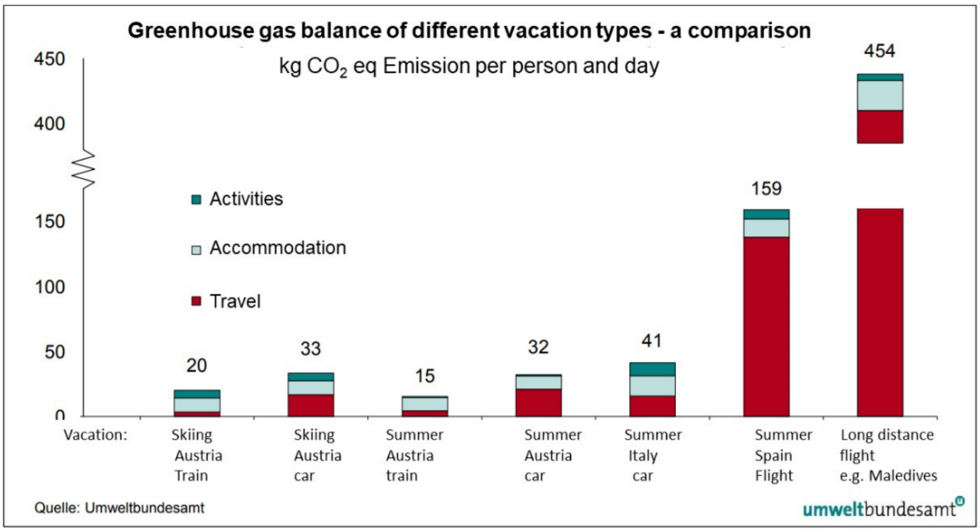


Figure 4: CO2 emissions (skiing holidays compared to other forms of holidays in Austria)

For considering carbon emissions in the optimization and to assess the impact of project measures, data sets for carbon intensity of the electricity in the Austrian grid were prepared. To do so, data of ENTSO-E's transparency platform was analyzed, using carbon emission factors that are being applied by the regulator for the Austrian electricity disclosure system. The calculation considered electricity imports, exports and storage. The result is a dataset for the carbon intensity (in g_{CO2}/kWh) in hourly resolution[3]. An exemplary visualization of this data is shown in Figure 5. The chart shows the daily average carbon intensity in the Austrian electricity mix for each month of the year.

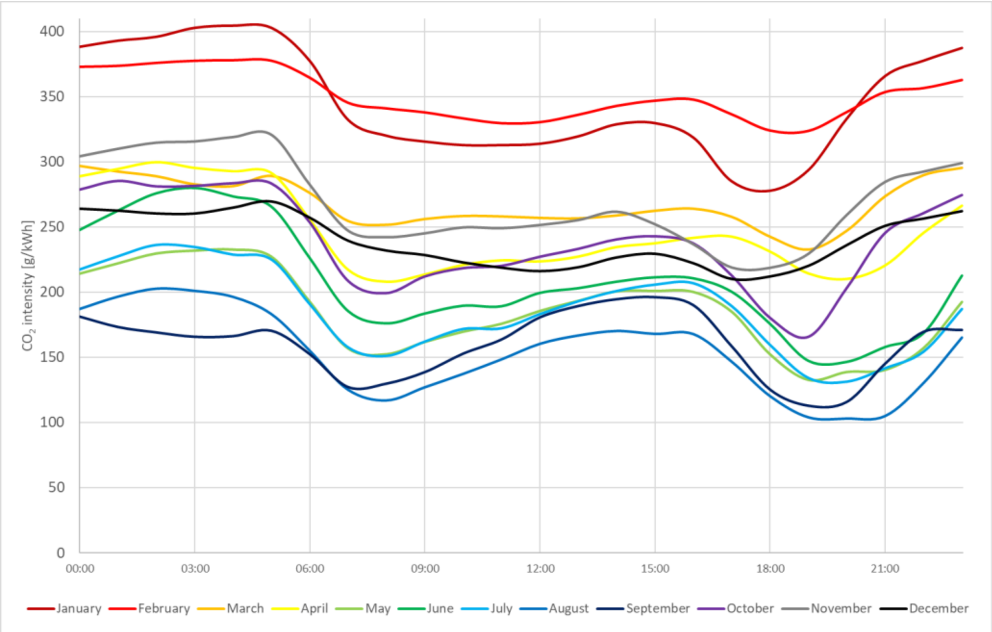


Figure 5: Daily average carbon intensity for each month of the year 2017 (source: AIT)

2.2.3 Energy prices and upcoming challenges

The actual and ongoing problems within the energy sector (rising prices, uncertainty, problems within the natural gas supply) have not been the main issues addressed in the project proposal in the year 2018.

[3] 15-minutes resolution is not possible since the cross-border physical flow data has hourly resolution for most of Austria's neighbouring countries

Nevertheless, the goal of cushioning rising energy prices has more and more become the main issues of the ski resort operators in the last years – especially within the last year of the project. In Salzburg, ski resort operators consume approximately 165 GWh electricity (4,7% of the overall electrify consumption) and therefore they are important customers of Salzburg AG too.

When asked, what are the key aspects of sustainability issues, ski resort operators have identified energy efficiency first (see:https://www.wko.at/branchen/transport-verkehr/seilbahnen/zukunftsfit-mit-nachhaltigkeit.pdf). So the ski resort operators within the project have mentioned, that they have already taken a lot of measures to optimize energy consumption in the past.

1 skier day (one person per day) needs an amount of 4,2 kWh/day on energy consumption.[4]

2.3 Focal points of the project

The aim of the project is to promote the decarbonization by developing and field testing optimization algorithms, related interfaces and an ICT framework for maximizing energy efficiency, flexibility options & integration of renewables in skiing areas. A systemic approach and related technologies to decarbonize the Austrian winter tourism industry should help additionally to provide flexibility for the power system and the electricity market (see Figure 6). This includes the integration of renewables while taking into consideration the energy demand pattern of touristic infrastructure.

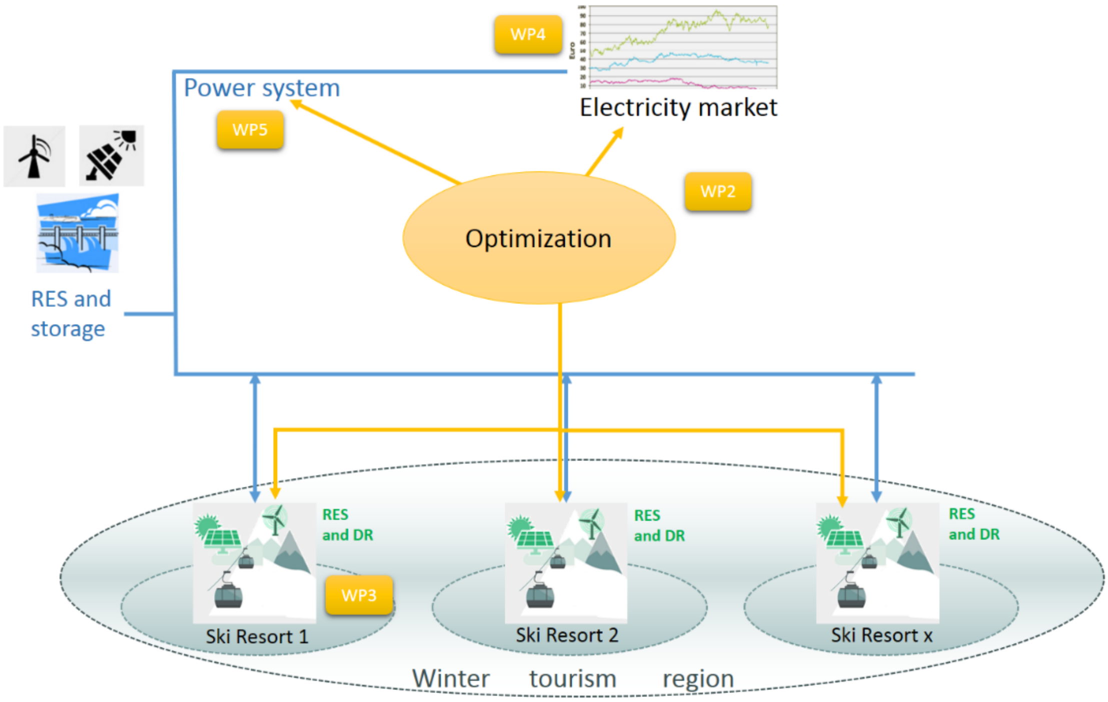


Figure 6: CE4T Approach

In order to address the mentioned focal points of the project corresponding to the proposal, but not neglecting ongoing transformations and challenges (see chapter 2.2), the developed process gives a structured guideline to detect answers for identifying new approaches, products and technology for skiing areas. The following key aspects of the proposal, besides energy prices and security of supply, had been under investigation:

1. **Prototype of a highly automated monitoring and energy management system**

[4] Source: https://www.wko.at/branchen/transport-verkehr/seilbahnen/infografik-seilbahnen.pdf

2. **Possibilities of additional renewable based electricity generation**
3. **Energy costs optimization and development of a framework to integrate additional renewable energy (identifying flexibility potentials and SCADA automation)**
4. **Grid friendly operation**
5. **Optimization - overall system & scenario evaluation**
6. **Regulatory assessment, cost-benefit evaluation and business opportunities**
7. **Identifying new energy services and products**
8. **Living lab, stakeholder engagement and KPI development**
9. **Transferability to the energy-intensive industry**

2.4 used methods & structure

To support the energy transition and to address the above-mentioned focal points, a complex interaction of various stakeholder is requested. This includes ski-resort operators, energy suppliers, grid operator, technology providers as well as research. At the same time, with technical, legal, and economical aspects three different dimensions need to be considered around the provision of flexibility for increasing self-sufficiency and decarbonization of ski resorts, enabling flexibility for the electricity markets and for power system operation, including requested technology developments. To tackle the complexity and to enable a successful project execution, the overall structure of the project is defined along the project objectives:

- WP1: Project Management
- WP2: Technology Development and Optimization
- WP3: Increasing self-sufficiency and decarbonization of ski resorts
- WP4: Enabling Flexibility for the Electricity Market
- WP5: Enabling Flexibility for the power system operation
- WP6: Scientific monitoring and evaluation
- WP7: Cost Benefit Analysis and Conclusions

To execute the different work packages and tasks, spanning from scientific support to technology development and demonstration, a huge variety of methods is required:

- living labs
- modelling and simulation
- scenario development
- optimization
- demonstration (in field testing)
- product development
- data analytics
- methods for scientific monitoring
    - KPI development and evaluation
    - cost benefit analysis
    - scalability and replicability analysis

Figure 7 presents an overview of all applied methods in context of the project structure. More details on the individual methods and their application are included in chapter 3 and 4.

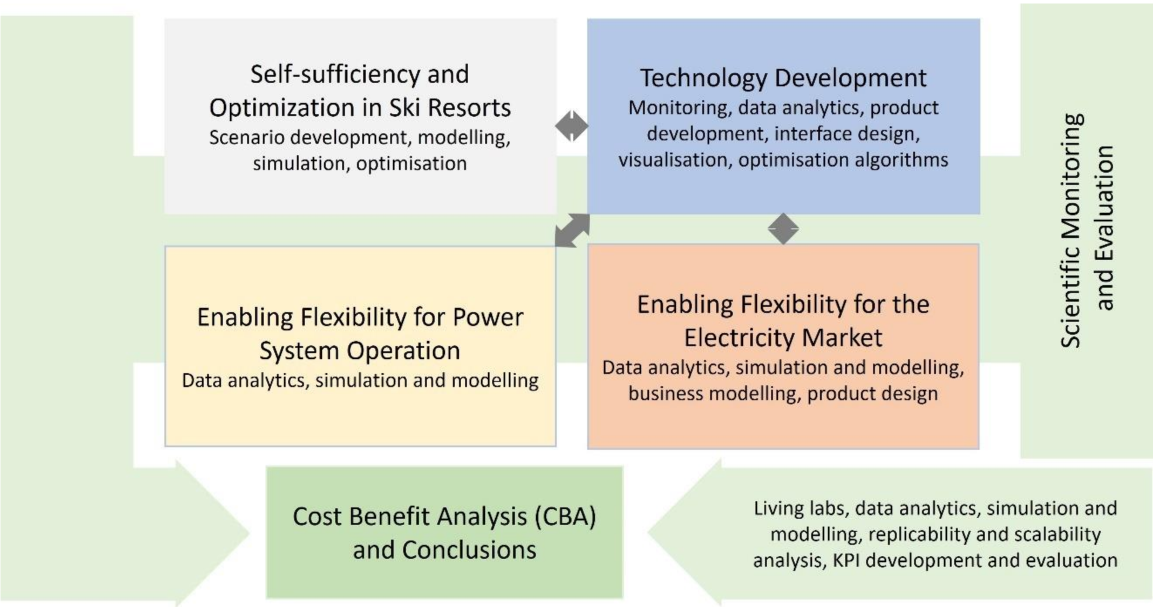


Figure 7: CE4T structure and methods

3 Content presentation

3.1 Prototype of a highly automated monitoring and energy management system for skiing area

3.1.1 Hybrid VPP platform architecture

The infrastructure of the Hyprid VPP platform operates on 4 layers (Figure 8).

- **Layer 1 technical units:** includes all technical units which are connected to the system and which send data to a central IoT platform (Layer 3).
- **Layer 2 gridcontrol:** enables the communication between technical units and the central IoT platform (Layer 3).
- **Layer 3 central IoT platform:** the applications on this layer ensure the exchange of switching commands, measurements, alarms and information between the connected units. The application also interprets the received values and reacts according to the program logic. It includes data exchange with related systems from Salzburg AG and the DSO SalzburgNetz. Supports visualization, alerting and operator interfaces.
- **Layer 4 Optimization:** optimization algorithms

Communication and data security are a basic matrix feature over all layers.

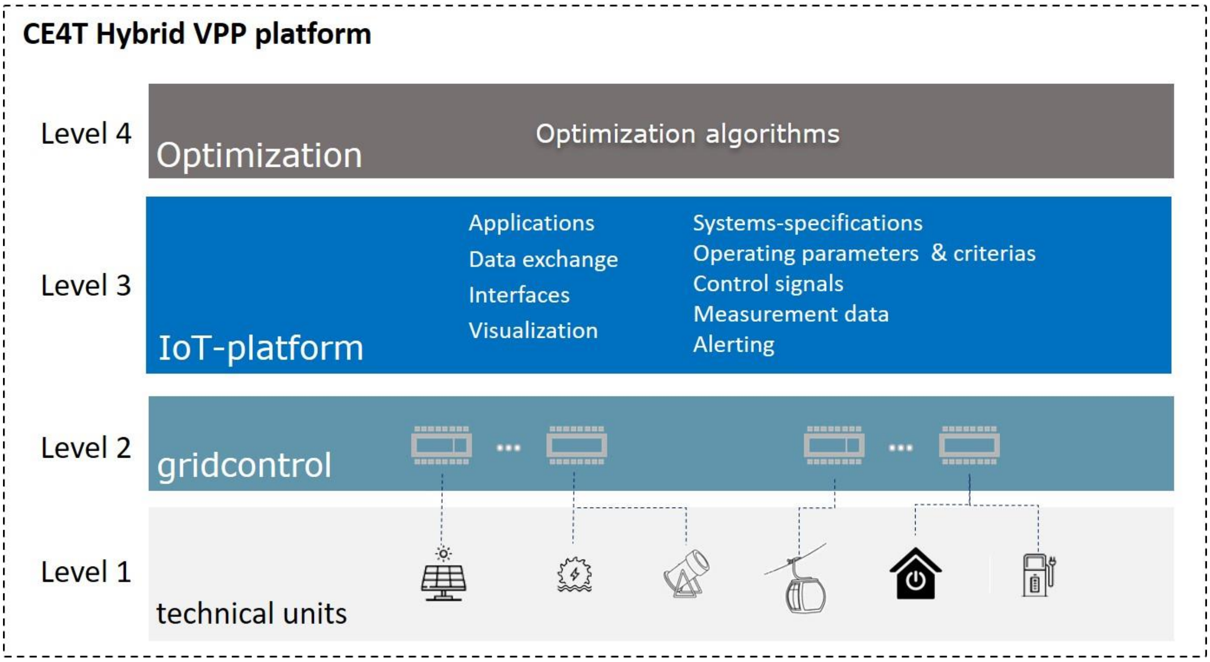


Figure 8: VPP platform architecture

3.1.2 Overall visualization and forecasting tool

Technologies for energy monitoring and related technologies (hardware and software) are already available as well as energy management systems in different applications, like industrial processes. What was needed is a solution for ski areas, taking into consideration the different energy dense processes like snowmaking, ropeway systems and lifts, gastronomy and e-mobility in an integrated way, to support energy efficiency and the decarbonization of Austrian winter tourism.
To be able to make optimal decisions for the use of all integrated systems, a visualization representing all sites is a fundamental requirement. Compared to other industries, a specific challenge in ski areas is that individual operating sites (ropeways, snowmaking systems, operating buildings, etc.) are spread over different locations. Each location has its own power supply and sometimes different metering points. Therefore, a complete energy monitoring is a very complex and often cost-intensive task for skiing areas.

The developed overall visualization and forecasting tool supports energy reduction strategies and a cross-area operational resource scheduling for energy intensive processes. It gives the skiing area the possibility to identify and implement energy reduction strategies. Future units and locations can be added with little effort. It delivers Salzburg AG with information that can be used in energy trading at electricity markets and optimizing the power system in parallel.

The application includes a monitoring dashboard, evaluation and alerting functions for the individual ski resorts but also for energy supplier Salzburg AG and distribution system operator SalzburgNetz. The innovative approach of CE4T VPP overall visualization gives ski resort operators and Salzburg AG a better overview of the status of energy situation in the hole resort. This helps them too to coordinate better the use of systems.

Figure 9 shows the evaluated data sources and how they will be used on the visualization and forecasting.

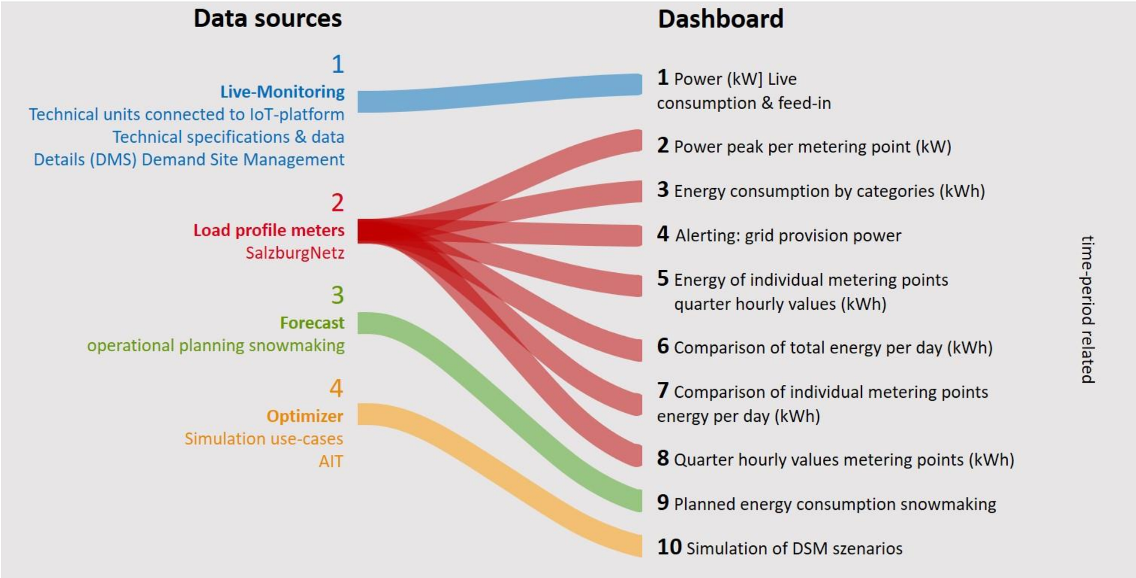


Figure 9: Overall visualization and forecasting dashboard data sources and data exploitation

Figure 10 shows the VPP overall visualization and forecasting dashboard.

Figure 10: CE4T VPP overall visualization and forecasting dashboard

In addition to live monitoring of individual technical units (connected directly to the IoT platform), an overall monitoring dashboard was developed. For general monitoring and to keep connection costs as low as possible, an innovative methodology was set up that allows to transfer data of all associated load profile meter metering points in the network of Salzburg Netz GmbH towards the IoT platform via a single XML interface. This metering point data is available on the dashboard day-1 (following day). Since most skiing areas have many metering points, this approach gives the operators an excellent overview of the energy states in the entire resort. It helps them to optimize the utilization of systems.

3.2 Possibilities of additional renewable based electricity generation

Renewable energy sources play a major role in the decarbonization. For this reason, an optimization-based planning process addresses the designing and implementing of renewable energy sources (RES), assessing energy management and increasing energy efficiency as well as self-sufficiency. In the preliminary stage, the expertise of skiing area operators as well as energy-relevant data have been collected. This chapter deals with the procedure identifying potentials and barriers of the expansion of renewables, obtaining expertise, the optimized planning process and the defined use case for the ski areas.

3.2.1 Registration of the status quo and involvement of the ski area operators

The project applied identification of additional renewable resources as well as efficiency improvement of existing technologies. For this reason, all energy-relevant data were collected involving energy prices, load profiles and energy demands, existing technologies, potentials for energy savings and further renewable technologies. Diverse data could be provided by energy supply company (Salzburg AG), for instant detailed reports of electricity costs and load profiles of metering points of several years. A first characteristic feature of ski resorts was already evident in this data, because unlike normal industries, e.g. a manufacturing company, a large number of metering points were listed.
Data on existing technologies, fuel demand (expect natural gas), potentials for energy savings and technologies were collected in workshops at ski resorts on-site. Also, preferences for consideration and barriers for renewable technologies were discussed in that workshops. To create first potential analysis in the conceptional planning process, not detected information were organized with the help of literature research or inquired through manufacturing companies and planning offices. These data include exemplary investment and maintenance costs for special renewable technologies, e.g. hydropower plants and wind turbines or heating systems like heat pump and combined heat and power (CHP) plants. Due to the diversity in ski areas, some use cases are scalable to other ski areas and others are too individual.
Within all these data, the status quo related to energy costs could be calculated and first potential analysis were made. After first evaluation of all workshops, the output of the workshops and the first potential analysis were discussed in consortium meetings, thus skiing area operators could exchange their experiences, strategic plans in term of renewables and future scenarios. Moreover, disadvantageous results were also presented to focus on use cases that show a promising benefit analysis. As a negative example, small-scaled wind turbines or building renovation projects can be mentioned, showing a low profitability due to high specific investment costs (€/kW) or relatively-low energy potential in relation on the total energy consumption (electricity consumption by lifts, pumps, etc. as well as diesel-driven snow groomer are very dominant).

The following graphic summarize process steps of involving the skiing area operators, sharing ideas and scenarios, creating initial potential analysis until use cases are defined for evaluation through the optimized-planning process:

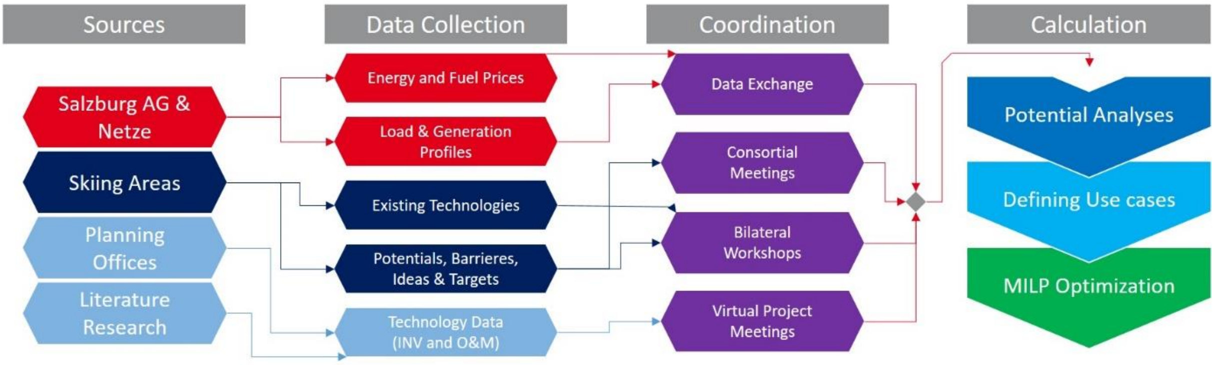


Figure 11: Schematic process of involving the operators, sharing ideas and scenarios, creating initial potential analysis and defining use cases

The reason for the still very low expansion of renewable energy and storage systems in ski resorts, lies in the variety of geographical, regulatory and economic barriers. The most difficult and dominant barriers are listed below:

- Strong seasonal differences between generation and consumption: in winter, very high consumption in skiing areas due to pumping stations and lift stations but low generation from renewable energy sources. In summer, the balance is the opposite.
- Land availability for renewable energy sources and storage technologies appear to be large. Due to ownership structures (rental and lease agreements) and regulatory barriers, major hurdles stand in the way of implementation.
- Energy intensity and diversity of energy sources (electricity, heating, cooling, fuels);
- Broad ownership structure (rental and lease agreements) allowing no impact on the land surface
- Geographic and meteorological conditions (e.g. wind storm or speeds, snow burdens, shading of mountains) make it difficult to implement larger solar or wind installations
- Characteristic of ski resorts is that all consumers are dispersed over a large area. An exemplary skiing area has between six to 80 metering points. This fact leads to small decentral plants with high investment cost, but even small consumers have low electricity prices.
- Ski areas are among other inhabitants for wildlife and are subject to nature protection or water laws. Placing technologies is regulated by a lot of authorities
- In addition, the Alps are obliged to ensure the preservation of the local and landscape image for further generations
- Low energy prices as competition to renewable energy technologies.

3.2.2 Optimization-based planning process and mathematical models

The used method to calculate the optimal renewable resources and efficiency measurements is the mixed integer linear programming (MILP) optimization. In the project, the optimization program OptEnGrid was used which based on DER-CAM and is extended by BEST GmbH. These MILP optimizations can identify efficiency measurements and an optimal technology mix as well as the ideal operation and synergies in a defined energy system. The MILP optimization involve a variety of information, parameter and profiles. Thus, the energy design includes generation profiles for renewable energy sources (RES) and load profiles for electricity, heating, cooling or fuel demands. Economic and ecological parameter reflect the cost structure for energy imports, technologies or operation strategies. Exemplary, the MILP optimization consider investment and operation costs for RES, energy prices (Flat rates, time-of-use rates, dynamic markets, demand rates and monthly fees), CO_2 taxes or infrastructure costs. Furthermore, the operation of several technologies can be modified and modelled by efficiency parameter or option of maximal or minimal operation, etc. The optimization calculates a variety of scenarios based on all considered technologies, boundary conditions and models. A key setting in the MILP optimization is the selection of the optimization or project target (objective function) to optimize energy costs or to reduce emitting CO2 emissions. Accordingly, the most cost-efficient or sustainable scenario is selected from all calculated scenarios by the MILP optimization.
In the course of the project, extensions of the MILP optimization OptEnGrid were implemented in order to react to the changed framework conditions. The implementation and review of the laws novels (EAGElWOG) allows the foundation of renewable energy communities (REC)whereby an energy transfer model were implemented into the MILP optimization to consider exchanging electricity. Thus, an instrument for a profitable integration of RES in a skiing area with many metering points were created.

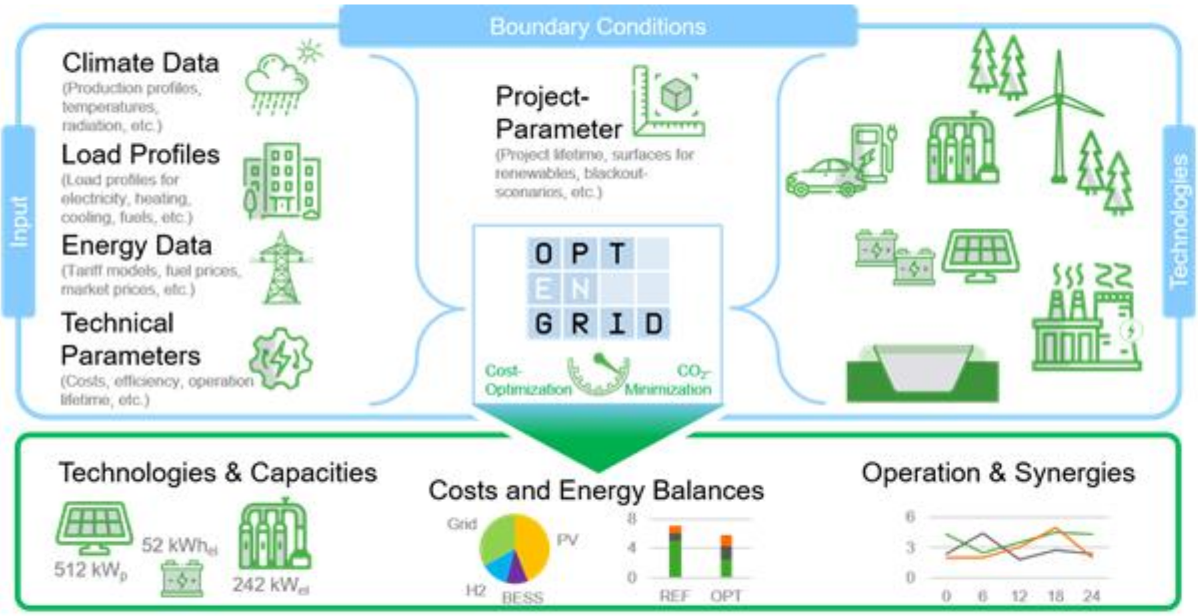
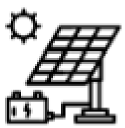
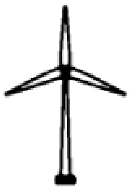
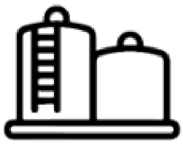
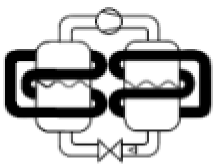


Figure 12: Concept of the mixed integer linear programming optimization OptEnGrid

3.2.3 Identifying use cases for implementing renewable energy sources, storage systems and energy saving strategies

The MILP-based planning process include a variety of RES and storage technologies, as well as optimal operation using flexibilities. With the REC approach, technologies were designed at an individual metering point or located centrally in a fictive energy station generating and supplying electricity to metering points of a skiing area and local stakeholders. The war in the Ukraine caused a completely changed situation due to exploding energy prices and rising technology costs. Due to the dynamic situation during the project, the focus of consideration depends on point of time in the project, see following use cases. The following use cases are structed by the main renewable energy source or storage technology, often diverse technologies were considered in a use case.

 Solar	Four of nine skiing areas have less potential either for hydro power or wind turbines to cover high electricity loads. The integration of photovoltaic systems (PV) and electric storages (ES) offers a universal solution for decarbonization, increased system efficiency and local energy generation. Since a variety of barriers block on-site integrations, decentral energy station with PV and ES provide electricity for a REC consisting of a skiing area and diverse local businesses. In order to take economic influences into account, diverse effects were considered, e.g. CO_2 taxes, increasing energy prices or technology costs, snow-covering, PV area availability.
 Hydropower	Three skiing areas own a hydropower plant, whereby one of these plants had to revitalise and the other. All plants are evaluated in a REC approach to transfer electricity from the non-mobile plant to various consumers (lifts, pump stations, etc.) scattered throughout the skiing area. Since REC were enabled at the time of the evaluation, one ski area addresses the formation, participants mix and tariff models of a REC in detail and interested households, hotels, companies and local government buildings were involved. The second and third hydropower plant focused the optimal energy design - with storage systems – especially hydrogen -– and PV due to sessional gaps

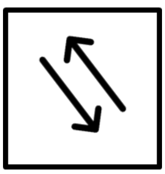
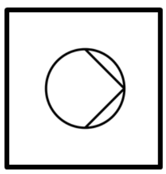
	between electricity generation and consumption. Therefore, these plants are embedded into the hydrogen use case.
 Wind	A possible location for wind turbines were found during the project based on wind measurement data, existing infrastructure and geopolitical conditions. Similar to the hydropower plants, a REC approach was considered to transfer electricity to other metering points, due to low consumption of the metering point connected by the wind turbines. Since the evaluation began in parallel with the conflict in Eastern Europe, increased energy costs and technology costs as well as CO_2 taxes were factored into the analysis. Furthermore, energy storages were involved to match the highly volatile generation and daily-dominated consumption in the REC.
 Hydrogen	Diesel-consumption by snow groomer or mobility in general was one of the most challenging issues in the energy design and planning. Different approaches were considered (hydrogen, biofuels, Fischer-Tropsch-synthesis, electrification, etc.). Finally, an initialization of a hydrogen station in the region Pinzgau was considered, in which a bus pool switch to hydrogen-driven busses and hydrogen is generated on-site using a REC approach, renewable technologies on-site, flexibilities by volatile energy market and grid-friendly services.
 Thermal Systems	A small-scaled district heating system offers the consideration of sector-coupled energy generation as well as electric and thermal flexibilities by combined heat or power (CHP) plants, heat pumps and storages but also condensing heat boiler. The considered CHP used biomass or natural gas to save energy costs, increase system efficiency and avoid CO_2 emissions.

3.3 Energy costs optimization and development of a framework to integrate additional renewable energy

The developed system uses interfaces to related SCADA systems of energy suppliers and skiing area operators for the provision of flexibility.

3.3.1 Flexibility potentials:

First of all, flexibility potentials and possibilities of optimization have to be clear, that, when suitable, the developed technology can be utilized. Therefore it is necessary to understand, which assets have technical availability (no theoretical availability). In various workshops, the project team has identified the following flexibilities:

	 **Lifts and cable cars**	 **Snowmakers**	 **Pumps and compressors**	 **Buildings and hospitality s.**

Flexibility provision	Very limited	limited	possible	partially
Information provision	profile and consumption for monitoring	profile and operation mode for monitoring Information for energy supply company (start of “base snow making”)	profile and consumption for monitoring	profile and consumption for monitoring

Table 1: identified groups of flexibilities

In cooperation with energy trading experts from Salzburg AG, several workshops with the skiing resorts were held to identify scenarios for a technical feasible usage of flexibilities. Asset topologies and detailed maps have been establishes to gain knowledge of the situation in each skiing area. The following tasks have been conduced:

Identifying all assets, like:

- pumps& pumping station (power, elevation,..)
- water reservoirs (size, elevation)
- mixed air compressors and fountain pumps (power, period of usage, restrictions)
- used infrastructure (like pipes or water extraction points)

Identifying operation specifications, like:

- time frames for pumping times
- public authorities orders (for example restrictions on water extraction)
- personal needed or is full automated operation possible?
- technical requirements (restrictions due to icing,..)
- restrictions from the skiing resorts, mainly technically indicated
- touristic requirements (for example full water reservoir in month xy)

Run live Demonstrators to test SCADA and possible VPP automation

Calculate flexibilities in form of:

- the possible flexible usage of assets, taking into account limits and operational
- results in MWh per year and MW

Calculate economic benefits in the energy market, this means:

- identify baseline scenario
- calculating savings when shifting flexibilities in different markets, taking into account all restrictions and boundaries

3.3.2 Energy markets

The electricity market is one of the most important energy markets. Due to the circumstance that electricity cannot be stored in the power grid, the power companies must sell the energy in hours when there is more generation than consumption and must buy energy when there is less generation than consumption. It is an interaction between consumption forecasts and production forecasts. There are different possibilities to equalize the electricity need. The electricity market is separated in different time frames.

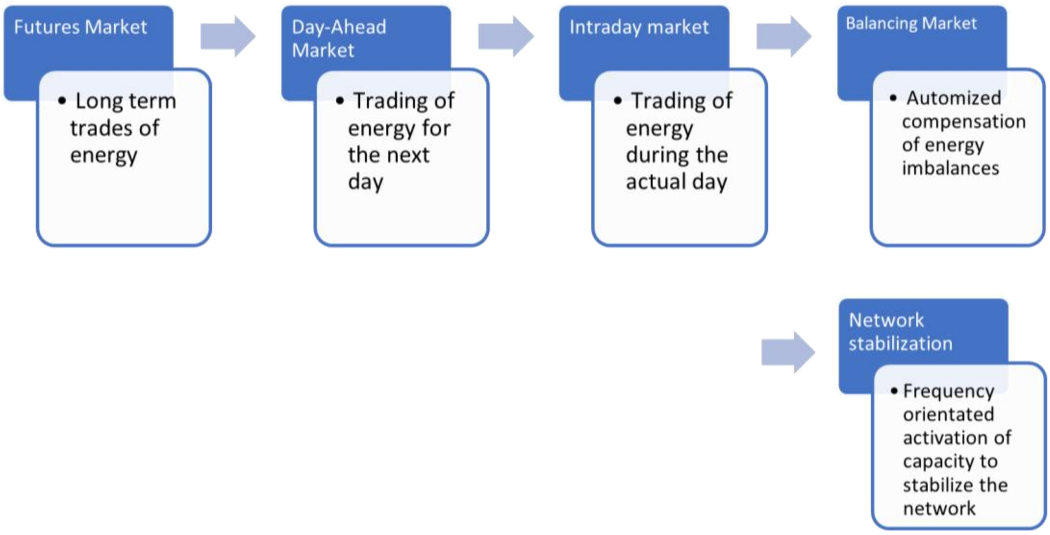


Figure 13: Energy markets

The long-term market is called futures market, where you can buy or sell energy with a fixed price in the future. Here you can buy e.g. a full year volume with a fixed power. The second one is the day-ahead market where you buy or sell energy for the next day in quarter-hour or hour resolution. Due to demand and supply every quarter-hour or hour results in a different price. The prices are usually lower at night and higher in the morning and evening where more energy is needed. The next short-term one is the intraday market. You can trade energy in quarter-hour resolution till five minutes before the delivery quarter-hour. With the trading on the three markets, you are trying to equalize your difference between production and consumption to zero. Every quarter-hour where your balance is not zero goes to the balancing market. The balancing market is fully automized. If you produce more than you consume, you are delivering balancing power. In the other direction you consume balancing power. Further there is the market for the network stabilization. The balancing market is separated in three spares, the Frequency Containment Reserve (FCR), Automatic Frequency Restoration Reserve (aFRR) and Manual Frequency Restoration Reserve (mFRR). The aFRR and mFRR are separated in positive and negative direction and in a power- and energy auction. At the five markets, you can participate at auctions with your flexibilities. The units must be flexible enough to fulfill the activation time requirements for these markets. For participation, you have to offer at least 1 MW of power. For smaller power plants it is possible to aggregate some different assets to reach the 1 MW hurdle.

3.3.3 Identified product chances within the markets

Considering the different market types there are some chances for production and consumption units of skiing resorts.

1. Spot market chance
   Due to price forecast and the flexible use of the assets, the production or consumption of the unit can be optimized. The hourly price forecast for the next day tells the high- or low-priced hours. For production units, it is optimal to produce the energy at high priced times. For consumption units it is best to consume energy at low priced hours. The main task is to predict the prices for the next day. In addition, the correct use of the units is important. You must fulfil limitations of the units like the minimum running hours or the starting or ending times of the operation. Altogether it is a complex task to get the optimum.

2. Intraday market chance
   Very similar to the spot market, the different units can be used for intraday optimization. If the units are flexible enough to interact with the short-term market. It must be possible to shift the operation hours throughout the day. The operation for every day is set with the spot market schedule. So, if you have bought energy at the spot market, which is more worth on the intraday market, you can sell the energy at the intraday market. The sold energy can be bought at a later time the day so you can run e.g. your pump to fulfil the needed operation at this day. The most difficult part is the price prediction.

3. Balancing market chance
   If there is a deviation between your production and consumption of energy and you cannot equalize it with trades at the intraday market, the deviation is equalized over the balancing market. It is important to know the position of the control area. On the one hand, if you produce too much energy and the control area is short, everyone else is in need for your over-produced energy. On the other hand, if you consume too much and the control area is long, you can get cheap balancing energy. Altogether you must know the state of the control area, and whether your deviation between production and consumption is long or short. If you know these facts, you can e.g. turn off or turn on pumps when the balancing energy is available. But it's very difficult to predict the position of the control area.

4. Network stabilization market chance
   A flexible usable unit can take part for network stabilization. Like said before, the minimum power must be 1 MW. If the unit has less power, it is possible to accumulate the unit in a virtual power plant. The market pays for a capacity price for the provision of the power and an energy price for the activation of the power, that means the energy (power multiplied with time) is compensated with the energy price. Due to the merit-order-list, it is possible to control your retrievals. If you want to be retrieved with much energy you try to settle down your bids at the beginning of the merit-order-list. E.g. for pumps it can be possible to pump water with the energy of the retrievals with prices where you get a payment. But it's very uncertain to tell when there are retrievals.

3.3.4 Utilization of the water reservoirs Asitz I and Asitz II for pumped storage of electrical energy

The Leogang ski area has 2 large water reservoirs (Asitz I and Asitz II) with a volume of approx. 75,000 m³ each with a surface area of approx. 1 ha each. The two water reservoirs are connected by a pressure line, which has so far been used to fill the upper of the two ponds. An altitude difference of 493.80 m must be overcome. The reservoirs must always remain filled during the summer months and are used for tourism during the day. Energy use is thus limited to around 12 hours a day between 22:00 and 10:00. In order to only minimally affect the water level, a maximum of 10 cm should be lowered, which corresponds to an amount of around 1,000 m³.

Within the project it was calculated, if it would be reasonable to update the infrastructure to a pump storage utility.

3.3.5 Utilization of pumpe Dießbach for local energy balancing

The energy consumption of the ski resorts is seasonally different. The consumption in the summer months is low but otherwise high in the winter. Some ski resorts produce their own energy with water and photovoltaic power plants. The generation of the power plants is opposite to the consumption. The power plants produce less in the winter month due to lower sun radiation or lower water availability. The idea to store the overproduced energy in the summer month and use it when the consumption is higher than the generation, was born. For the storage, the local power plant Dießbach[5] with its flexible

[5] https://www.salzburg-ag.at/ueber-die-salzburg-ag/unternehmen/erzeugung/erzeugungsanlagen/wasserkraftwerk-diessbach.html

matrixpump and two pelton turbines could be used. At times, where the generation is higher than the consumption, the overproduced energy would be used by the pumps to store the water in the Dießbachsee. At times when the consumption of the ski resorts is higher than the generation, the stored water would be turbined and the energy output could be used by the ski resorts. Only the amount of water that was pumped with the used energy would be used for power generation. The figure below shows the energy flow from ski resort to Dießbach and back.

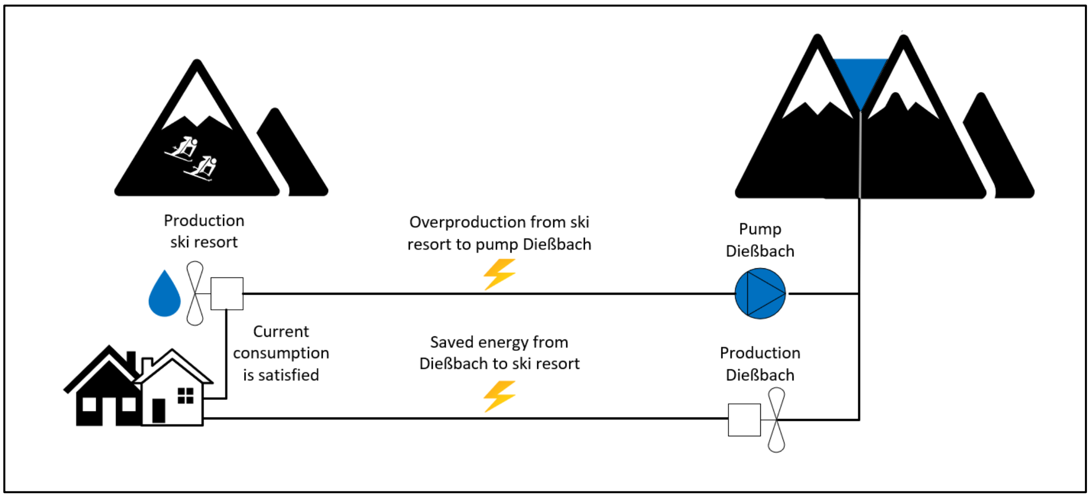


Figure 14: Energy flow ski resort - Dießbach

The basic assumption is that the ski resort produces energy with a photovoltaic powerplant of 150 kWp and a water powerplant of 1,2 MW. The maximum consumption comes up to about 15 MW when the lift and snow making assets are running. The generation profiles are usual for photovoltaic- and water production and the consumption profile is usual for the ski resort. The annual consumption then is about 10.000 MWh and the annual generation is about 6.700 MWh. The figure below shows the annual production and consumption per month for the year 2021.

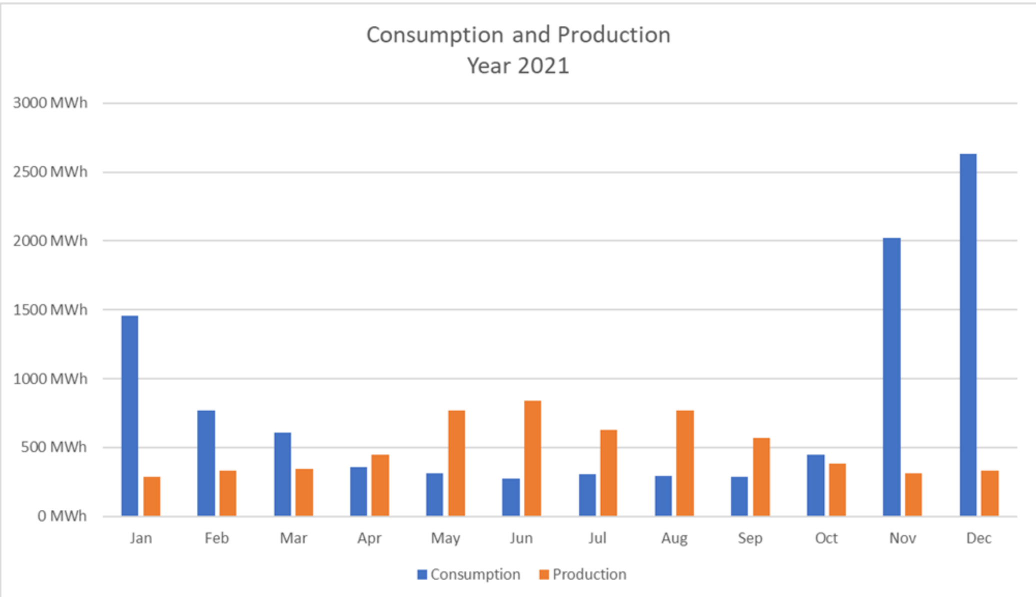


Figure 15: annual production and consumption per month for the year 2021 Dießbach

Results will be shown in chapter 4

3.3.6 Software

The system is designed to steer flexible technical units in skiing area assigned to an use case fully automated according to schedules created by the AIT optimizer and approved by Salzburg AG, but supporting manual operation when the systems require it. Figure 16 shows the model for data exchange and optimized deployment control between technical units in skiing areas, IoT-platform, optimizer and related systems from Salzburg AG and the DSO Salzburg Netz to control and optimize electricity consumption within the skiing area. Aim is to achieve the highest possible degree of energy efficiency and to provide flexibility for managing and minimizing peak-demands and utilizing flexibility for electricity markets and distribution system grid operator.

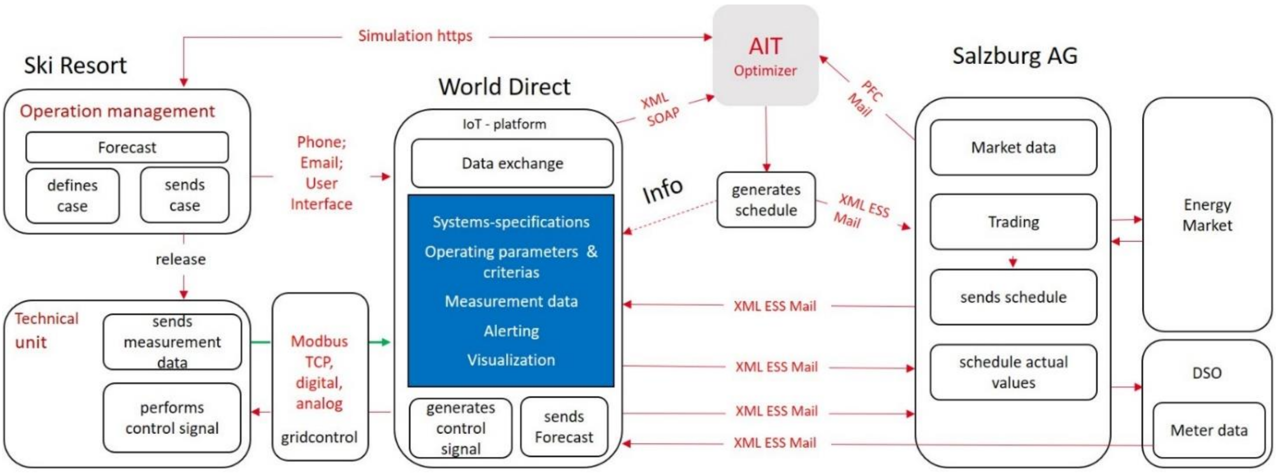


Figure 16: VPP - model of data exchange & optimized deployment control between skiing area, IoT-platform, optimizer, SCADA system, energy market and grid

The applications on the central IoT platform ensure the exchange of steering commands, measurement data, alarms and information between the connected units. The applications interpret the received values and react according to the program logic.

3.3.7 Connection, monitoring and steering of technical units

Where available and accessible, already installed/embedded monitoring functionalities have been used. The producers of the technical units have been contacted to see if the systems are equipped with monitoring functionality already and if so which interfaces are available which can be used to collect provided data. Most assets that are subject to be monitored and steered have been equipped with gridcontrol devices from World Direct. The device enables the communication between technical units and the central platform. It monitors the data from the technical units, processes and transmits setpoints and control commands. Digital and analogue inputs and outputs are available to cover the most common interfaces and standards. One gridcontrol device can address several technical units.
Instead of the physical controller some technical units provide a software solution that functions as a controller. Such systems can be connected via VPN (Virtual private network).
It is necessary to define together with skiing area and individual manufacturers of the technical units how systems can be steered and which safety aspects need to be taken into consideration to ensure that no damage occurs to systems or associated infrastructure. An intensive exchange of information with the manufacturers, supplier of controller systems or manufacturer of snowmakers and pumping stations was necessary. Interfaces to the systems of all major manufactures and system suppliers in ski areas are established. Not all technical units and related systems can be steered fully automated because some technical systems require the presence of the operators and a manual start and stop of the individual components. For ropeway systems and lifts, there are legal restrictions which don’t allow external control systems to access the lift controller. These systems therefore have no potential for fully automated steering by a VPP. The optimizer can only generate operating recommendations for these systems which are transmitted to the operator. For optimal results and for short-term reactions to changed

conditions an extensive and continuous data exchange between the optimizer, related systems from Salzburg AG and the IoT platform is essential.

Although the infrastructure and requirements of individual skiing area vary greatly, the experience and technologies developed in the project provide a valuable basis for transferring and applying them to other skiing areas.

3.4 Grid friendly operation

3.4.1 Introduction

The task was on the one hand, to define the framework conditions that result from the distribution network and to make them available to the other work packages as input parameters. This is done by the aim of developing an algorithm that optimizes both local (ski areas) and global (energy market) objectives and considers the framework conditions set by the network. On the other hand, the objective was to use the existing flexibilities to specifically support distribution network operations. Measured consumption time series form the basis for the work in WP5.

3.4.2 Grid costs

In normal operating conditions, the power grid is designed in such a way that the thermal and voltage limits are always met. This applies in particular to those times with the highest utilization. In Figure 17 the annual load profile of a medium voltage feeder can be seen. The measurement is taken at the primary substation and therefore shows the total load of the supplied area. The Y-axis shows the total active power consumption in normalized values. The blue line shows the 365 daily average values of the active power. The Gray area is built by the daily minimum and maximum values. The red envelope marks the maximum power value which occurs during the corresponding calendar month.

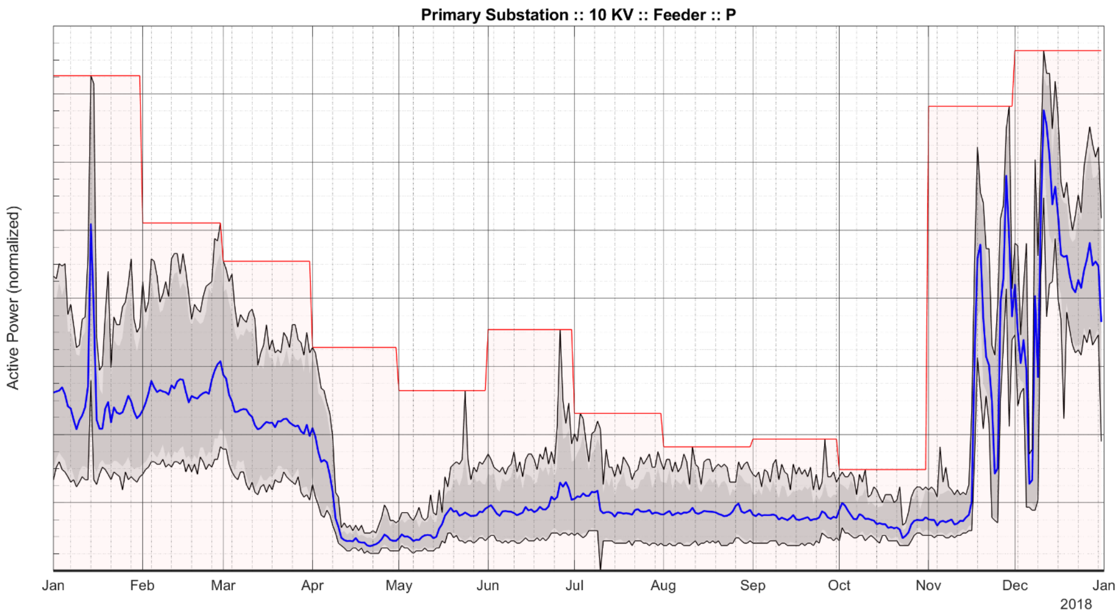


Figure 17: load profile of a medium voltage line in a skiing area

Figure 17 shows that the supplied area (in this case mostly a skiing area) has a seasonal behaviour. During the summer months the load is comparatively low. In the months January to April the winter season can be seen. The daily mean value is higher than in summer months. The range between daily minimum and maximum value is comparatively high. In contrary especially at the end of November / start of December high peak values can be seen. In this period also the daily mean value (blue curve) is comparatively high and very volatile. This effect can be explained by the artificial snow making process which can only take place at special days when the weather conditions are appropriate. The distribution system operator has to make sure, that especially these peak values can be supplied. If the network can cope with these peak values, then all other times of the year are no problem. The actual costs for the network operator are mainly determined by the one single maximum power demand during the year.

In contrary Figure 18 shows the normalized load profile of an industry company. Here it can be seen that this metering point has a higher utilization. The monthly maximum values are relatively constant over the year. For this meter more than 90% of the occurring peak power are charged (ratio of monthly average peak value to absolute maximum value). The profile also exhibits a typical weekly drop off on weekends.

Load Profile	Peak Power	Billing Power	Energy Demand	full load hours
snow making LV (NE6)	100 kW	23 kW	24 MWh/a	240 h/a
snow making MV (NE5)	1000 kW	230 kW	240 MWh/a	240 h/a
industry LV (NE6)	100 kW	92 kW	315 MWh/a	3150 h/a
industry MV (NE5)	1000 kW	920 kW	3150 MWh/a	3150 h/a

Table 2: load profiles and power demand

In Table 2 the data of the four load profiles are shown. The peak power is given by the normalization to 100 kW and 1000 kW, respectively. Loads with a peak power demand of 100 kW are typically connected in the low voltage (LV) grid, while power values of 1000 kW are typically connected in the medium voltage (MV) grid. The power value which is relevant for the billing is derived from the twelve monthly maximum values. For, the industry profile about 92% of the actual peak power demand are billed. In contrary for the snow making process about 23% of the actual peak power demand are billed.

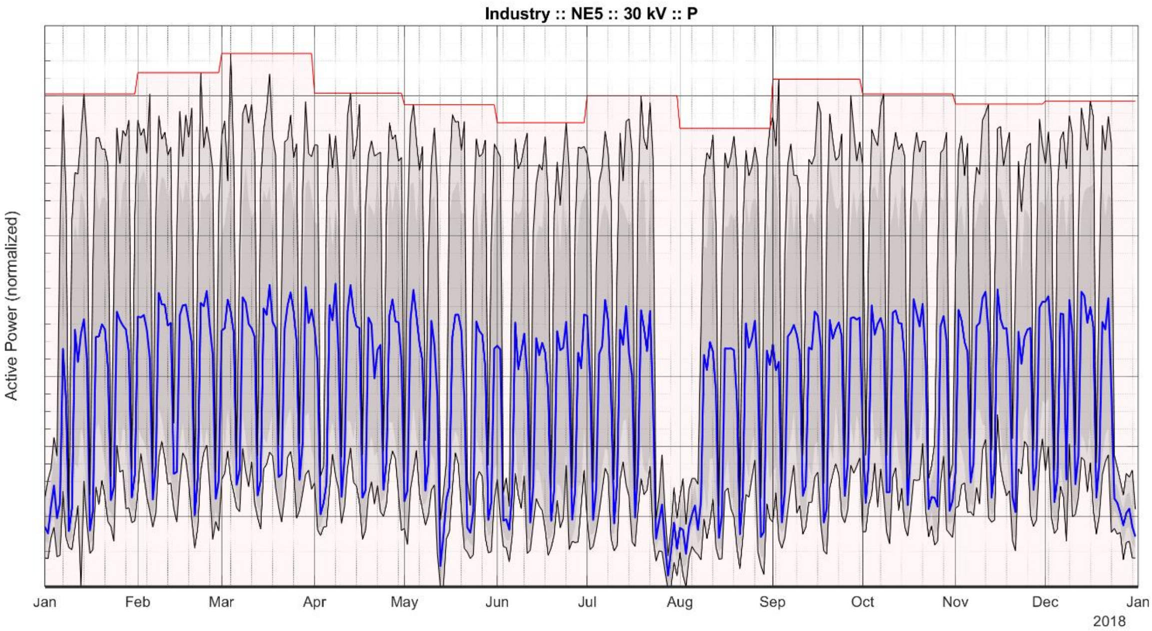


Figure 18: load profile of an industrial company

These two typical load profiles form the basis for the following evaluation. The load profiles “snow making” and “industry” are now normalized to a peak power value of 100 kW (low voltage grid connection) and a second time to a peak power value of 1000 kW (medium voltage grid connection) to compare network utilization and grid costs.

Table 3 shows the total annual costs for the grid connection of the four load profiles. These total costs are then divided by the total energy demand to get the “specific energy cost” which is shown in the third column. The annual costs are also divided by the peak power, which is shown in the last column as “specific power costs”.

Load Profile	annual costs	specific energy cost	specific power costs
snow making LV (NE6)	3 T€	118 €/MWh	28 €/kW
snow making MV (NE5)	31 T€	129 €/MWh	31 €/kW
industry LV (NE6)	17 T€	54 €/MWh	169 €/kW
industry MV (NE5)	145 T€	46 €/MWh	145 €/kW

Table 3: total costs related to the energy demand and power demand

In Table 3 there is a rather small difference between the specific costs for a low voltage (NE6) and a medium voltage (NE5) connection. This is true for the snow making profile as well as for the industry profile. The specific costs (network and taxes) are also nearly the same. The higher annual flat rate part for a medium voltage connection (NE5) is compensated by the lower energy and power tariffs. Due to the circumstances that the snow making process has a comparably low energy demand and high power demand, the specific costs differ from the industry load profile.

3.4.3 Flexibility provision for the distribution system grid operator

Under the current regulation there is no direct possibility to sell flexibility to the distribution system operators (DSO). The EU directive 2019/944 ("clean energy package") describes that the distribution system operator should also take medium- and short-term flexibility provision into account, when creating the network development plan. So far (as of July 2022) no national law exists, so that the DSO could take use of these flexibilities. The power-component of the grid tariffs acts as an incentive for customers to use the power grid steadily. In most situations this is also the desired operation mode from the perspective of the network operator and therefore "grid friendly". In some situations, it could be beneficial for the network, when customers use their flexibility to achieve a local power balance between local generation and consumption. Within the current regulation every customer request for generation feed is answered with the point in the grid, where the generation power can be fed in without restrictions. Especially for bigger units this point, where the full power is continuously possible, can be far away from the generation unit. Therefore, an alternative connection point nearby is offered by the DSO where restrictions can occur. This offer is typically chosen by customers to avoid long private feed-in power lines. The grid operator in return has the right to curtail the feed-in power in certain network cases with a very high network load.
Exactly in these situations with a (DSO related) curtailment of generation power, the flexible loads can be used. The task for such flexible loads is, to increase their load in order to balance the net generation of the power plants. Therefore, possible network congestions can be solved, and it's not needed to curtail the generation by the DSO. This only works when the flexible load is in the same area as the affected power plant. In this use case the trigger is the network congestion of the DSO, which would lead to a power curtailment of the generation units. By using flexible loads, this curtailment can be avoided. So therefore, there is no cashflow from the DSO to the market participants, which is not possible under the current regulation. Instead, the use case is built between the power plant and the flexible loads. With the help of the flexible loads, the power plant can feed in the full energy which would be lost otherwise. Therefore, the cash flow for the use of flexibility must take place between these two market participants.

3.4.4 "Grid friendly" charging of EV (electric vehicle)

The IoT-platform is primary designed to steer flexible technical units in skiing areas assigned to an use case fully automated according to schedules created by the AIT optimizer and approved by Salzburg AG. Although no skiing area involved in the project currently has a major EV fleet or major charging infrastructure for customers and visitors, the opportunity to use flexible charging of EVs to reduce load peaks was considered in the development of the IoT-platform. The system was tested with 12 charging stations (Type KEBA P30 series) connected to different metering points. In workshops with ski resort operators, expansion plans of their EV charging infrastructure were discussed. Result was that the focus will be on the expansion of alternating current (AC) charging infrastructure with an adjustable charging power between 1.4 and 7.4 kW single-phase and 4.1 to 22 kW three-phase and not on direct current (DC) fast charging > 22 kW charging power, as operators in skiing areas expect visitors to stay longer on their location during a visit. This opens opportunities for load-dependent charge control.

Figure 19 shows the data exchange between AC charging stations and IoT-platform, and prepared interfaces to related systems of Salzburg AG and AIT optimizer, to control and optimize EV charging in skiing areas. Aim is to utilize flexibility for managing and minimizing peak demands and provide flexibility for the DSO in the future.

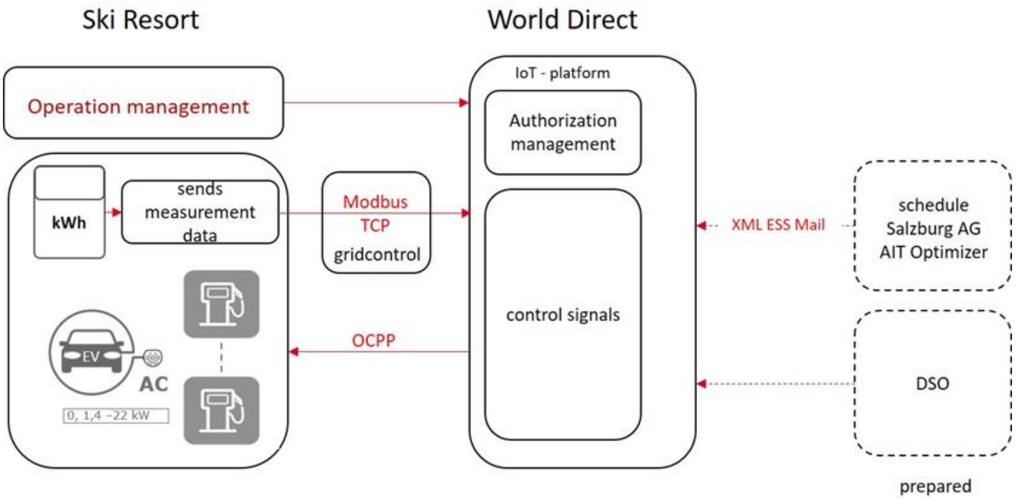


Figure 19: VPP - Model of full automated steering of AC EV charging stations

The charging stations are connected to and controlled by the World Direct IoT-platform via the OPEN CHARGE POINT PROTOCOL (OCCP) version 1.6. Communication between the charging stations and the IoT platform takes place via mobile communication network, for which the charging stations are equipped with SIM cards. OCPP is used because it is manufacturer independent and provides all the required functionalities, so that user authentication, prioritization of charging processes, monitoring and power reductions based on optimization results can be implemented.
In the event of a failure of the communication network, corresponding fallback functionalities have been developed so that the charging power of the charging stations does not lead to an overload of the network connection point in any case, but the charging of the vehicles can still be guaranteed.
The power meters of the locations are connected via gridcontrol device from World Direct using Modbus TCP and read out cyclically. The measured values are transferred to the IoT platform and compared with the threshold value defined by the ski resort operator. The charging stations connected via OCCP can thus react to load changes of the location by means of the IoT platform whereby an optimal charging performance can be realized without overloading the grid connection point. Depending on the requirements charging processes can be paused (charging power 0 kW) or the charging power can be steered between 1.4 and 22 kW depending on the EV. Individual charging processes can be prioritized depending on the charging ID (Identification).Charging stations at locations can be assigned to different metering points and combined into groups across sites. The charging power of charging stations and groups can be controlled according to defined rules.
Load management rules and schedules can be defined for locations and groups. The IoT platform is prepared to consider future requirements from the DSO and schedules specified by the energy supplier or an optimizer. This enables to control charging processes at times of high energy demand, high prices or high CO2 shares in power generation. For the case that in the future caused by a strong increase of e-mobility peak demands arise which the grid cannot cover an influence by the DSO of charging processes in certain groups is made possible. The integration of large-scale renewable energy sources and charging infrastructure for EVs in skiing areas is expected. These systems will play an important role for matching supply and demand in the power grid. The developed IoT platform is prepared to enable the potential flexibilities.

3.5 Optimization – overall system

3.5.1 Introduction

A part of the project was to optimize the operation of flexibilities in the ski resorts. Flexibilities are devices/processes, for example, the refilling of a water reservoir, which are flexible in terms of operating times, point of operation etc. This operation flexibility can be used in manifold ways: to reduce the CO_2-footprint, decrease the energy, or to support the electrical grid. The strategy how to operate the devices/processes in an optimized way, is obtained by solving a mathematical optimization problem. In this optimization problem, all relevant aspects which have to be considered are formulated in a mathematical model. With that model a solver minimizes a cost function which can be, for example, the reduction of costs of energy. The result is a schedule how to optimally operate the flexibilities.

3.5.2 Optimization problem

The optimization problems are built by using pre-defined components. An example is given in Figure 20 for the operation of a fountain pump together with a battery where their peak load and the CO_2-footprint of the consumed energy should be reduced. The fountain pump has pre-defined constraints e.g., it should be operated 16 hours per day. The optimizer schedules the operation of the fountain pump and the battery in such a way that both the peak power and the CO_2-footprint are minimized by shifting the 16 operation hours per day to ideal times.

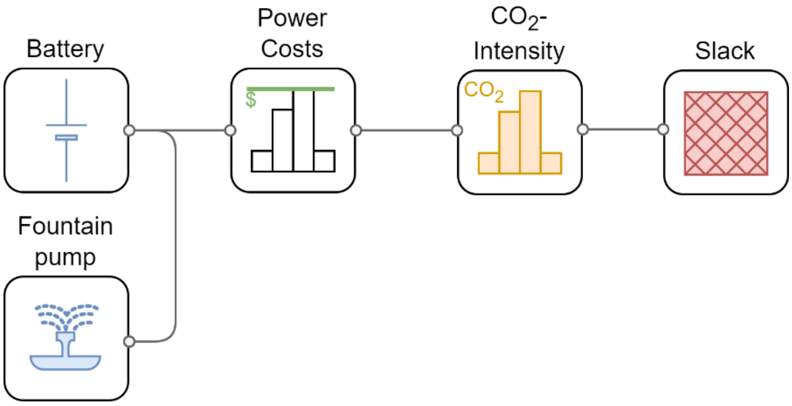


Figure 20: Example of an optimization problem

The optimization problem is modeled as a mixed integer linear program (MILP) by using the programming language Python and the modeling language Pyomo. As solver the coin-or branch and cut (CBC) solver is used.

3.5.3 Optimizer as part of the hybrid VPP

The optimizer has been developed to interact directly with the skiing area, the energy supply company and the IoT platform and is a core part of the hybrid VPP. Besides the optimizer, a database is deployed which buffers and stores all data needed for an optimization run.

Figure 21 shows the main interactions of the optimizer with the other parts of the VPP. Before the optimization of technical units in a skiing area, the skiing area needs to parametrize a demonstration use-case. This includes, among others, the time horizon of the optimization, parameters of the devices (e.g. active power consumption and lead times), and other constraints like the operating hours of the resort. After that, an optimization is performed at each day of the optimization time horizon.

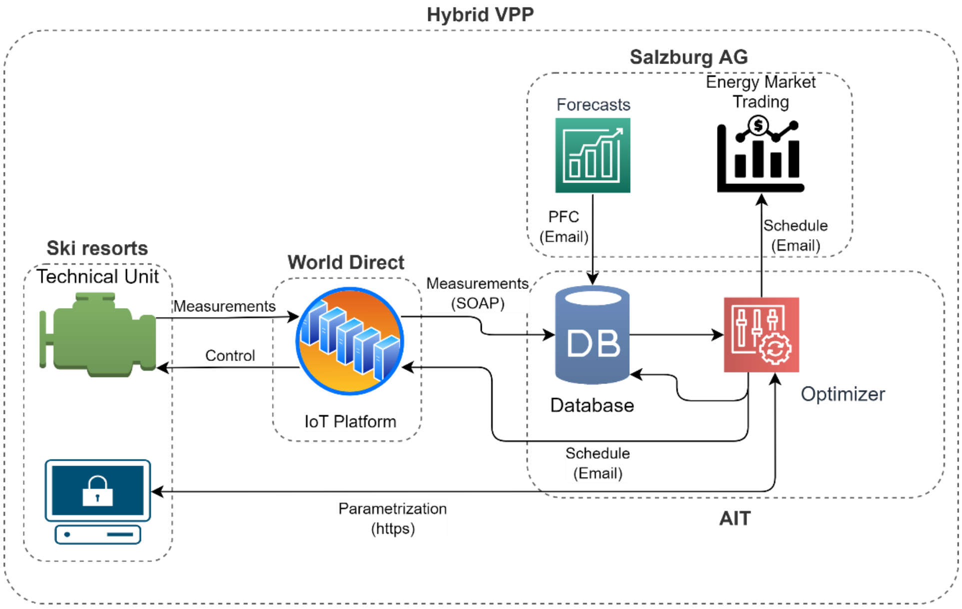


Figure 21: Interaction of the optimizer with the other parts of the hybrid VPP

The IoT platform has a dedicated SOAP (Simple Object Access Protocol) interface for accessing measurement data used by the optimizer to know the current state of the technical units. The resolution of the measurement data is 30 s. On every working day Salzburg AG sends price predictions via email to the optimizer. All the previously mentioned data is buffered locally in a dedicated database. Then, the optimizer runs the optimization for the remaining time of the specified optimization horizon. In case of refilling a water reservoir, this means the final date until when it must be filled. The result of such an optimization is a schedule containing information on how the optimized devices should be operated. The schedule is only fixed for the next day; however, the optimization is retriggered at every day for the remaining optimization horizon. By doing so, the optimizer can better consider forecast deviations and small differences between the modelled devices and the physical devices. This is done with model predictive control (MPC).
The fixed schedule for the next day is send to the IoT platform and Salzburg AG in an XML-ESS format. Salzburg AG uses this schedule for trading the energy at energy markets. The IoT platform controls the devices in the skiing area accordingly to the schedule.

3.5.4 Scenario evaluation

Within the project, algorithms are developed to optimize investment decisions for renewable technologies (OptEnGrid), and to best utilize the operation of technical units in the ski resorts (ENDOPT).
For simulations and analysis tasks the so-called “simulation framework” is implemented. The goal of the simulation framework is to evaluate and validate implemented use-cases, and to analyze future scenarios. Many of the use-cases implemented in this project use one of the optimization frameworks mentioned before: OptEnGrid and ENDOPT. Thus, these optimization frameworks can be embedded into the workflow of the simulation framework. Furthermore, custom profiles can be analyzed with the simulation framework because some use-cases are not based on optimization models. Another important part of the framework is electrical network simulations. It should be analyzed how the optimization and control of technical units in the ski resorts, the installation of renewable technologies, and future scenarios impact the safe operation of the electrical grid. Therefore, the simulation framework can utilize a network simulation software. Another task of the simulation framework is to compare the results of the simulations with data obtained from the field. The algorithms implemented in this project should be tested under varying conditions and thus with varying parameters. In order to perform these tests, the simulation framework can use input data coming from different sources, for instance, measurements from the field, forecasts, and historic data. To fulfill these requirements the simulation framework is organized in a modular fashion as shown in Figure 22. This allows to flexibly configure the interaction between the modules and software applications used by the simulation framework.

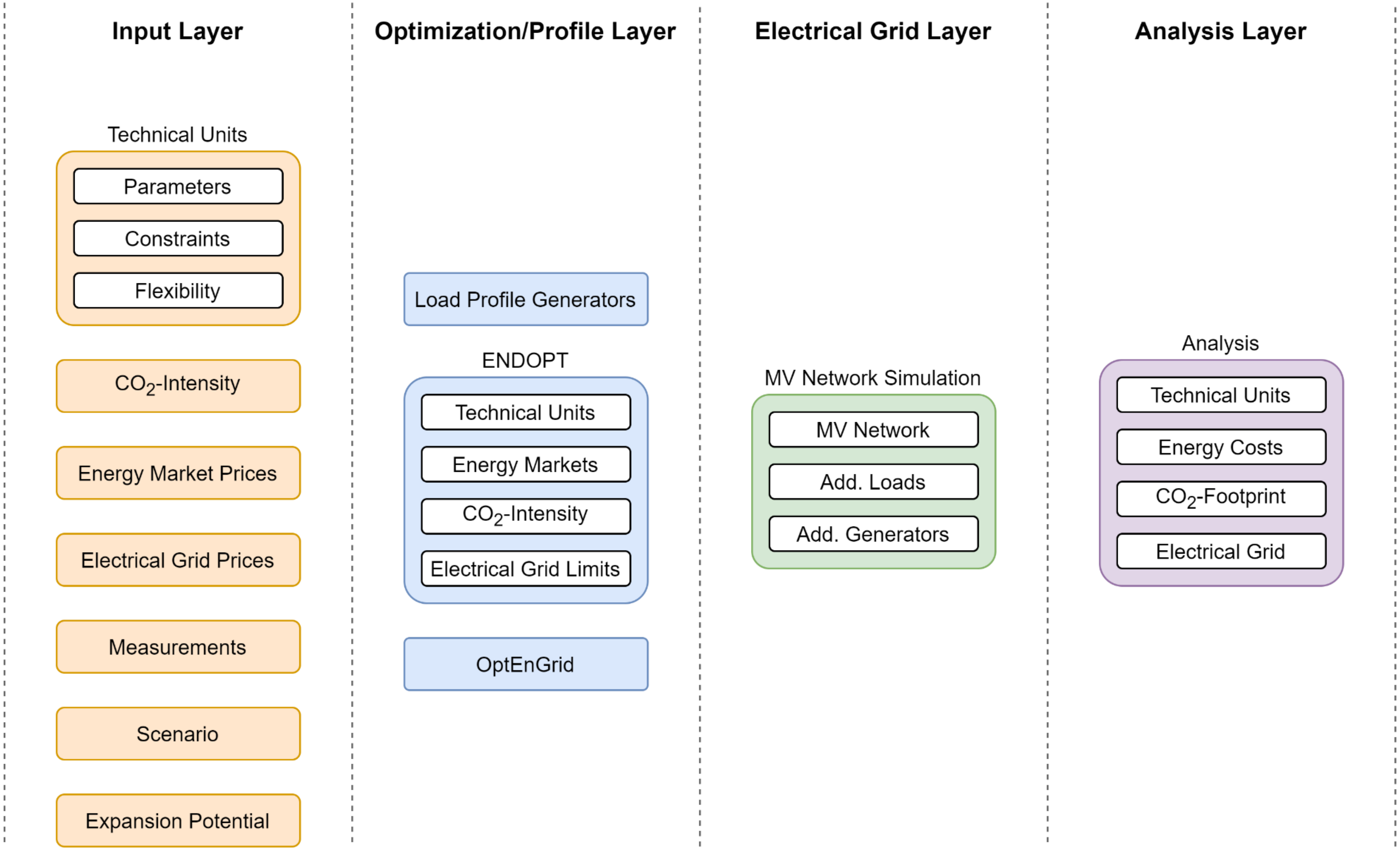


Figure 22: Concept of the simulation framework

The modules used by the simulation framework can be divided into four layers each responsible for a different type of task. These layers and their functionalities are:

- *Input Layer:* The input layer provides data which is needed for the calculations made by the simulation framework. For example, this data can be historic data, forecasts, and parameters for the configuration of the scenario. This data is provided in various formats depending on the modules used. For instance, historic loads profiles are provided in a tabular format (csv) and the CO2-intensity can be either provided in a database or in a tabular format as well.
- *Optimization/Profile Layer:* One part of the optimization/profile layer is the optimization. This can either be the optimal utilization of flexibilities in the ski resorts or the optimization of investments into renewable technologies. In both cases, load profiles are generated which contain the results of the optimization run(s). These results can be further used, for instance, to analyze the impact of the resulting profiles on the electrical grid or to investigate the CO2-equivalent of the consumed energy. In some of the scenarios, optimization is not needed but a load profile generator can be used instead. Such a scenario can be, for example, to analyze the impact of reducing the time for basic snowmaking on the electrical grid.
- *Electrical Grid Layer:* The third layer of the simulation framework is the electrical grid layer. Its main task is to analyze the impact of scenarios on the Medium Voltage (MV) electrical network. At its core, the MV network simulation uses the network simulation application PowerFactory®. Interfaces have been implemented to ease the interaction with this application and to provide convenience functions. This interface allows the provision of custom load profiles which in turn is used to apply the profiles of optimized flexibilities or from future technologies.
- *Analysis Layer:* Depending on the scenario only parts of the modules from the other layers need to be used. Nevertheless, the results and intermediate results must be analyzed to investigate the impact of the scenarios, for instance, how much the optimized refiling process of a water reservoir reduced the CO2-footprint of the electrical energy consumed. Thus, the simulation framework has its own layer – the analysis layer – to calculate and compare these metrics.

3.6 Regulatory assessment, cost-benefit evaluation and business opportunities

The development of business models accompanying the technological implementation in the project was performed in three phases. The first phase assessing the conditions and identifying promising use cases provided a basis for the second phase: the cost-benefit analysis. In a third step, the results have been compiled and concrete business opportunities outlined.

The regulatory assessment that has been conducted in the investigation of the overall framework for current and future business cases included a detailed review of pricing schemes. It included a detailed outline of regulated tariffs and levies. Demonstration sites in the project are located in the Austrian Federal States of Salzburg and Tyrol. This also defined the scope of the assessment since not all tariffs and levies are regulated on national level. This allowed us to get a clear picture of the rules and regulations applicable to a particular demo site or to a particular activity (i.e. consumption and feed-in).

The results of this assessment summarized the cost positions to a large extent (energy price is subject to an individual contract and thus to be treated as restricted information). Although some changes are expected in the future development of tariffs and levies, the current scheme will still be largely applicable after the project implementation. To complete the picture with the benefits that the implementation might bring, different revenue possibilities for the involved actors have been investigated. The variety of possibilities include aggregated bidding on electricity markets, reduction of imbalance costs, revenues from offering ancillary services, demand response and energy sharing.

The gap analysis was based on the needs of the involved stakeholders and yet untapped possibilities of their assets within the given implementation framework. Energy efficiency potentials in the ski resorts are already utilized to a large extent since energy consumption of ski resorts' assets is very high and so the operators are particularly cognizant of this issue. The expected rise in energy demand in the future should be covered by local renewable energy sources. Ski resorts plan to invest in renewable energy sources (RES). There is, however, a need to optimize local generation and demand in order to avoid network extensions and reduce costs in the long term. Several assets show promising flexibility potential and ski resorts aim to utilize it. Cooperation is seen as key. Ski resorts intend to share the procurement of energy and develop integrated energy concepts going beyond their own enterprise. New business models should be integrative and involve the ski resorts, grid operator and retailer.

Marketing of flexibilities represents a current gap. Certain types of assets can provide flexibility in operation. Major potential among ski operators is seen in water pumps, air compressors, and buildings on the mountaintop which have electric heating. Some potential can also be provided by snowmakers. Lifts and cable cars are strongly regulated and offer low flexibility potential. Hydropower facilities close to a project demo site show a potential to be offered on market for the manual frequency restoration reserve in an aggregated pool of the retailer. Ski resorts can further provide information about the (expected or historic) electricity consumption of their facilities to the retailer in order to optimize the procurement on wholesale markets. This can lead to lower energy price where the reduction can be forwarded to ski resort operators and/or lower carbon emissions.

Subsequently, a modified version of a cost-benefit analysis has been applied. The method used quantitatively focused solely on the economic parameters. For that reason, it is referred to as a profitability analysis rather than a CBA. Fitting key performance indicators for the profitability analyses of the individual use cases have been selected: benefit-cost ratio, net present value, payback period and, for the information exchange use case in particular, the value of the transmission of information and forecast. In addition, the stakeholders' perspectives and influencing factors other than financial indicators were discussed qualitatively, as to give a more complete picture of the presented profitability analyses.

The profitability analysis was carried out by calculating the possible profits (or losses) of their implementation compared to a baseline. The baseline is either a status-quo scenario, comprised of the current business-as-usual, or a specially defined basic scenario if the current situation is unknown, not easily ascertainable, or difficult to quantify. The KPI that is used to assess the profit/loss of each use case is the. By comparing the NPV of the use cases to the NPV of the respective baseline, the achievable savings are assessed.

The first use case aims at improving the current state of the art concerning the basic snowing periods in the ski resorts, namely that the basic snowing is often started on a very short notice. As a consequence, there are load deviations from the schedule, which have to be balanced with imbalance settlement. This is both expensive and strenuous on the grid. For that reason, the use case comprises communicating the anticipated deviation from the schedule due to the start of basic snowing to the energy supplier, who can then purchase the deviations on the day-ahead market. A part of the resulting cost savings could then be transferred back to the ski resort operators.

The second use case builds upon the same problem as the first use case, namely that there are load deviations from the schedule due to the start of basic snowing, which have to be balanced with imbalance settlement. In this use case, however, the deviations in energy are traded on the intraday market. Once again, the cost savings due to the implementation of the use case could partly be transferred to the ski resorts.

The third use case is related to the operation of selected flexible components within the ski resorts, namely water reservoir pumps and mixed air compressors. Using a mixed-integer linear program (MILP) optimization framework, the optimal times of their operation to achieve:

(i) minimum day-ahead energy prices,
(ii) minimum CO_2 emissions, and

(iii) minimum monthly peak power as well as minimum day-ahead energy prices

were investigated. The resulting savings in energy costs benefit the energy supplier and the savings in peak charges benefit ski resort operators, so the total savings are shared among them. In addition, the grid is relieved when optimizing for low peak loads and the CO_2 emission savings support the decarbonization goals of the ski resort operators and on a larger scale.

The fourth use case is only considered qualitatively, because practical barriers of its implementation were identified under the current circumstances. The use case comprises optimizing the operation of the aforementioned flexible components within the ski resort for the lowest day-ahead prices and providing balancing energy with the still unused flexibility, thereby yielding additional revenue.

The Business Model Canvas method, introduced by Alexander Osterwalder and Yves Pigneur in 2005, was used for visualizing existing business models and developing new ones. Through the publication of Osterwalder and Pigneur's book Business Model Generation in 2010 (Osterwalder and Pigneur, 2010), the BMC approach became widely known and applied.

Visually and content-wise, the business modelling approach is centered around the value proposition, which ensures that the other components are built upon and focused around it as well. This is one of the method's main advantages. Another benefit of the BMC is, that due to its compact design, identifying correlations between its elements is facilitated. In addition, a business model becomes more palpable by displaying it through the BMC, because of the compartmentalization into the nine components. Moreover, collaboration on the BMC is easy and productive since simultaneous work on the different elements is possible, for example by using post-it notes. Through that, a common understanding of the business model within a team is furthermore fostered. (Osterwalder and Pigneur, 2010)

3.7 Definition of new energy products and services

The focus of the work lies in a rapid learning process instead of trial and error by strongly integrating all partners, especially the ski resorts into the process. The underlying process is visualized in Figure 23.

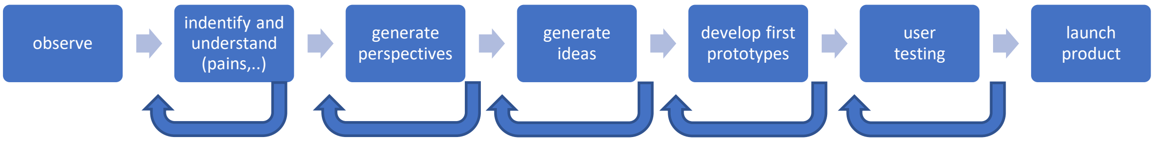


Figure 23: Iterative and customer centric approaches (source: own chart)

In this project, the aims and tasks of investigating flexibilization, pathways for more renewable energy or the tasks for the further development of algorithms have been set very clear. So, there was no need to go into a conceptual agile idea generation process. Following the living lab approach in CE4T, the users (= customers) have the role of co-creators in a laboratory setting. Following this approach, various testing environments and interviews have been set up. In the course of the project his approach proved to be advantageous for both, the overall strategy and for product development (see chapter 3.8).

The aim of the project CE4T is to promote the decarbonization of the Austrian winter tourism industry by investigating the technically and economic feasible approaches. The project team has identified the following main chances:

Key issue	Possible service	WHO? Beneficiary (involved partners)	Addressed pain points	Possible offer / service	Product testing
reducing energy consumption	energy monitoring dashboard	Ski resort operator + (Energy supply company & technology provider)	without expensive energy management tools in place, there is no knowledge of their energy consumption	Energy supply company offers basic version for free to strengthen customer loyalty	Develop minimal viable product (MVP), with user centric testing (interviews); when OK further development
using flexibilities for energy procurement optimization	Ski resort operators offer flexibilities to energy supply companies	Energy supply company + (Ski resort operator & technology provider)	High energy costs in the markets combined with pressure from ski resort operator to lower costs when energy flexibility is traded	Energy supply company offers a service to use flexibility for energy procurement optimization. When costs savings can be achieved, they will be pass through to the customer	Identifying and discussion -> afterwards calculation of possible revenues & costs testing with interviews
using information to optimize energy procurement	Ski resort operators gives actual and short time information when starting energy intense processes	Energy supply company + (Ski reset operator & technology provider)	High energy costs in the markets combined with pressure from ski resort operators to lower costs when energy flexibility is traded	Energy supply company offers a service to use just in time information for energy procurement optimization. When costs savings can be achieved, they will be pass through to the customer	Identifying and discussion, afterwards calculation of possible revenues & costs testing with interviews
additional renewable based electricity generation	Energy supply company offer services for the establishment of local energy communities	Energy supply company + (Ski reset operator & research company)	High dependency / low self-sufficiency	Energy supply company offers a consulting service for customers concerning energy communities	MVP of tool, testing & interviews
highly flexible storage options	Ski ressort operators convert pumping stations to small hydro pump storage power plants	Ski resort + (Energy supply company & technology provider)	Existing water reservoir and pump station infrastructure – only used for snow making	Balancing energy for the VPP of the Energy supply company	Research, theoretical approach, discussion on economic reasonability
Extension of renewable energy sources in ski resorts	Energy supply company offers consulting and implementation services for new renewable energy sources	Ski resort + (Energy supply company & technology provider & research company)	Setup additional renewable energy sources (PV, wind, Storage, H2, …) in ski resorts to locally produce energy	Consulting and implementation services by the energy supply company	Calculation of theoretical business and investment cases, Discussion of feasibility

Figure 24: main product chances

Chapter 4 summarizes key findings of the assessment of revenue and price possibilities in the filed of new energy products and services.

3.8 Living lab, stakeholder engagement and KPI development

3.8.1 Introduction

The purpose of the living lab was to guarantee a close stakeholder involvement and engagement throughout the entire project. The living lab was a co-creative learning process between researchers, energy & technology providers and cable car operators to anticipate and discuss sustainable practices. In several feedback loops methods, KPIs and models were tested for their practical use and co-creatively developed.

3.8.2 Methodology for monitoring and evaluation

For ensuring a proper impact assessment of interventions carried out within the project, a methodology for monitoring and evaluation was set up.
The overall assessment of the project was performed from different perspectives to acquire a comprehensive picture of the impact of the implementation. The different assessment fields included:

- Performance assessment: The assessment included the energy consumption and generation of the assets in the ski resorts as well as the grid. This assessment built a basis for the evaluation of carbon emissions and for the regional impact assessment.
- Assessment of the impact on carbon emissions. An evaluation of the carbon emissions of skiing resorts was conducted (results see chapter 2.2.2 CO2 emissions in skiing areas)Assessment of flexibilities, trading, costs and revenues: The assessment focused on economic and business related evaluation of the implementation.
- User involvement and communication assessment: The assessment focused on the interaction and involvement of users with the implemented systems.
- Regional impact assessment: This assessment included a larger geographic area. It scaled up the results to the whole region of Pinzgau. Furthermore, it included the assessment of descriptive variables that was used to bring the results into relations used in the winter tourism industry.

Right from the start, the motivation of the cable car operators for participating in the project was to improve their energy efficiency and to present themselves as part of a sustainable tourism region. Although each skiing area has its own framework conditions and is in some competition with the other, the true competition takes place between different skiing regions. As the regional scale is important, the regional KPIs and the regional impact assessment was an essential component for the cable car operators. It required specific analysis between the micro level of each ski resort and the macro level of the NEFI projects (see Figure 25).

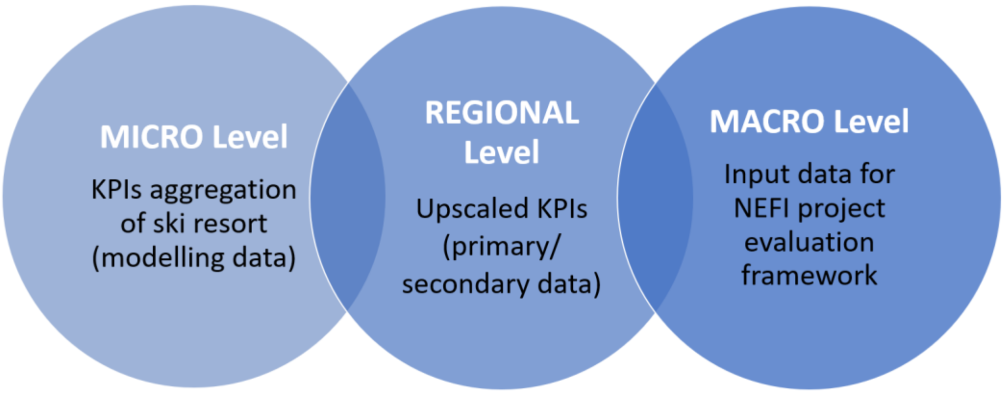


Figure 25: Level of KPI generation

In order to derive regional KPIs, economic data is necessary in addition to demographic data. For this purpose, the project-relevant information of each municipality located in the project area was collected (Statistics Austria, "A look at the municipality"[6]). In parallel, the cable car operators were asked to provide specific data for the seasons (if applicable) under consideration (Winter 2017/2018; Summer 2018; Winter 2018/2019; Year 2018; Summer 2019; Winter 2019/2020; Total 2019; Summer 2020; Total 2020). The information requested can be found in Table 4.

Category	Unit	Category	Unit
Daily visitors	# per year resp. season	Bed occupancy rate	% if applicable/ available with spatial reference to communities or region)
Area of the ski resort (total; ski piste; lift and lift facilities; other)	in m^2	Employees (administration, lift operation, snow making)	# per year resp. season
Energy demand	MWh per year resp season	Heating demand (lift operation incl. administration; gastronomy)	MWh per year resp. season
Energy demand	MWh per year resp season	CO_2 emissions (if known)	kg_{eq} or t_{eq} per year resp season
Snowed area	km^2 per year resp. season	Natural snowfall	cm per year resp. season
Amount of snow produced (snowmaking)	m^3 per year resp. season	Snowmaking equipment / snow cannons / etc	# per year resp. season
Start & end date of snowmaking	Dates	Basic snowmaking period	Dates
Additional snowmaking period(s)	Dates	Capacity of all mixed air compressors & fountain pumps in the ski area.	in kWh
Period of activation of mixed air compressors + fountain pumps	Dates	Volume of storage ponds and Reservoir target volume	in m^3
Period and approximate volume of pumping	Dates, m^3	Ski buses (used total; own and rented buses)	# per year resp. season
Ski buses (type of fuel or energy used))	type	Ski buses (driven km)	km per year resp. season
Ski buses (lines)	# of lines	Ski buses (mean utilization)	mean # per day or %
Ski buses (total utilization)	# of people transported per day in season/year	Parking lot size of the ski resort	# of parking spaces
Utilization of parking places	average/highest utilization (#) per day in season/year	e-fueling stations (total; in own parking area; in municipal area)	# per year resp. season
Passenger transportation (total; different types of lifts e.g., cable car, T-bar,…)	# per year resp. season	Operating days (total; different types of lifts e.g., cable car, T-bar,…)	# of days per year resp. season

Table 4: Data requested from the cable car operators

Based on the data and on further discussion about relevant KPIs for the skiing resorts, the requirements for the overall visualization were defined in workshops with Salzburg AG and ski resort operators. In a first step a dashboard structure and concept was created. This was evaluated with the other partners before starting the software development. In the first concept a view of energy costs and related KPIs (Key Performance Indicators) was considered. But the feedback of the ski resort operators made clear that this

[6] https://www.statistik.at/blickgem/gemList.do?bdl=5; last accessed, 20th of June 2022)

requirement was not able to provide them with additional information, since the costs are already available and analyzed in other systems. However, for further data consolidation and data analysis, the ski resort operators needed an option for data download (CSV format). Therefore, this key requirement was implemented as an additional feature in the dashboard.
The development of the dashboard was done in two steps. To gain experience, a first version was launched focusing on the display of measurement data and an input interface for the use of energy intensive processes. This allowed collection of data and experience over a sufficient time period (whole winter season 2021/22). In a second step the experiences were evaluated and additional requirements defined. These were then implemented in version 2. Figure 26 shows the basic dashboard structure with the available data sources.

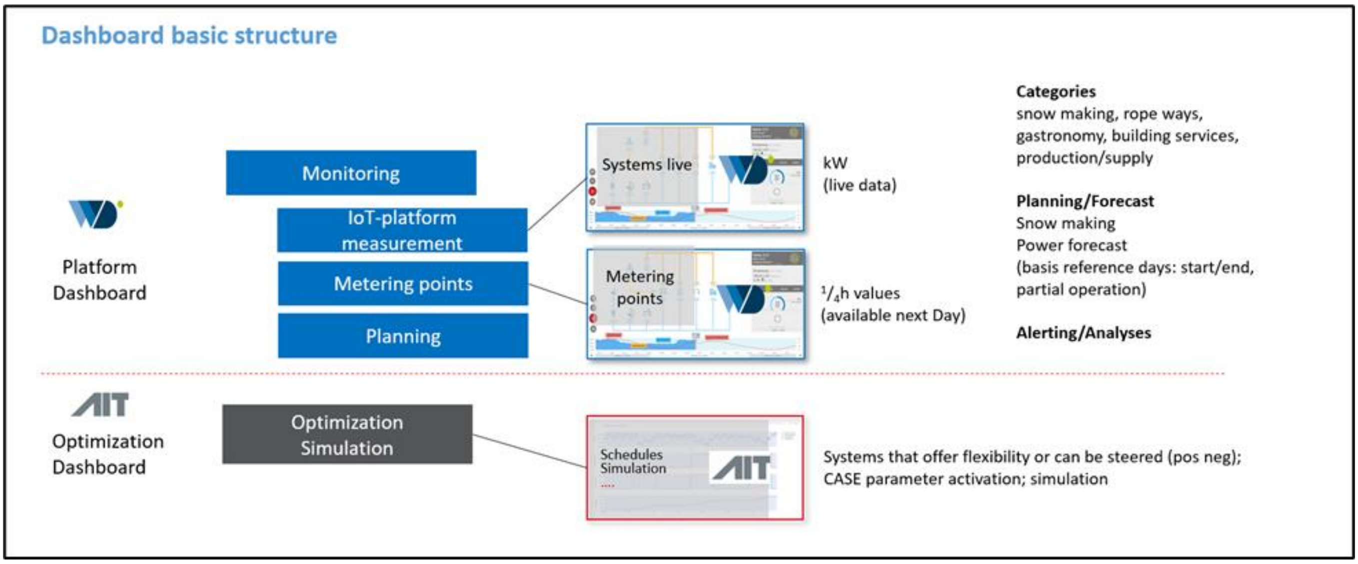


Figure 26: Dashboard structure and available data sources

Finally, as a last feedback loop, a user survey was made after the implementation where the following questions were asked:

How will the data be used in the future?

- For observations and subsequently implementation of optimization processes.
- First of all to get an overview of when and where energy is consumed, to optimize processes afterwards.
- For information and evaluation
- Monitoring of energy use; planning of snowmaking and revision operations

Which information has the greatest benefit?

- Peak power
- Consumption data and peak demand data
- Quarter hourly values; energy consumption that we can assign to a specific period of time and not only related to the month
- Consumption figures
- Data history; clear representation of the energy consumption

3.8.3 Stakeholder involvement and engagement

To develop solutions in line with the stakeholders´ needs, the project supported an intensive stakeholder process embedded into a living lab for co-creating technological solutions. Stakeholders included end-users such as cable car operators as well as grid operators and regional stakeholders. To promote participation and cooperation from all relevant stakeholders it is crucial to build trust among the parties

and understand drivers, needs and framework conditions of each stakeholder group. Thus, a living lab was set up as a frame for continuous collaboration and exchange.
The living lab approach included the evaluation, co-creation, continuous discussion of interim and final results as well as replicability and knowledge transfer. It provided an interface to the stakeholders and was strongly interlinked with the development of KPIs and tools. Additionally, it facilitated the analysis and assessment of costs and benefits of the solutions provided in the project.

During the entire CE4T living lab process, different participation methods such as stakeholder-workshops with impulse presentations, questionnaires, world café, marketplace, brain walk etc. were applied. In the second part of the project, due to the Corona-pandemic, the workshops were conducted mostly online. The timeline with the different steps is illustrated in the following Figure 27.

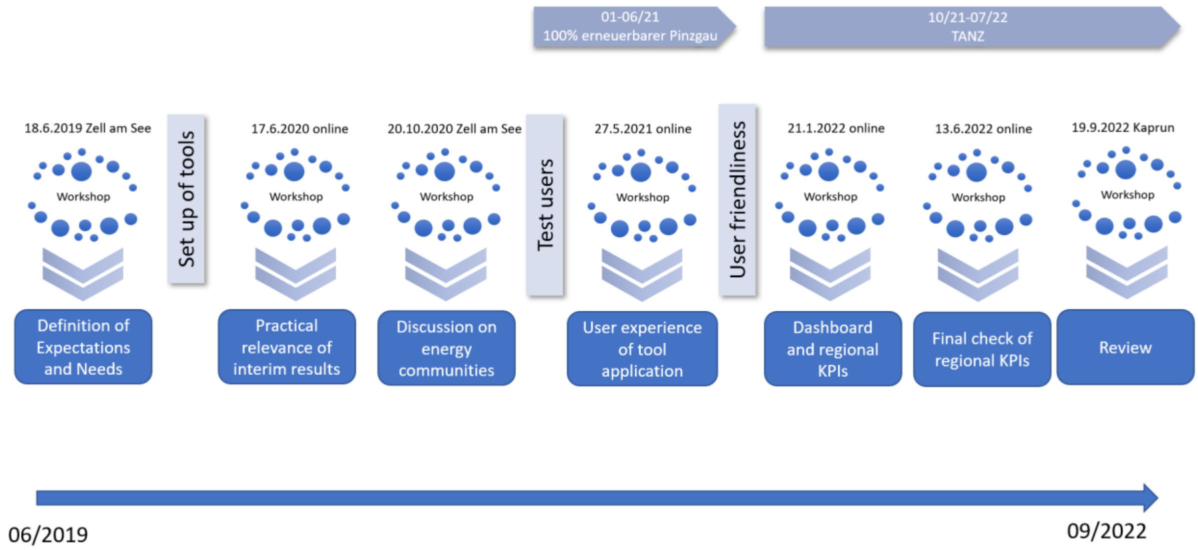


Figure 27: Timeline of the CE4T living lab process.

The living lab places the stakeholder group of the cable car operators at the centre of its focus. Cable car operators from the participating ski regions have been involved into the process (see Figure 2)

The approach in the initial phase of the project included two interactive workshops. The main aim of these workshops was to launch the co-creating living lab process and engage the involved stakeholders.
A Design Sprint organised on the 20th of May 2019 had the focus of applied technology. The idea-finding process enabled the identification of an initial set of business model innovations for the involved technology partners. The aim of the workshop was to get an overall picture of possible technological setups in the operational phase and use it as a basis for the definition of scope among technology providers as well as for the refinement of the approach in the design and planning phase.
Following this, a Living Lab was organised in Zell am See on the 18th of June 2019. The main aim of this process was the active co-creation of technological solutions, by involving the user-side (Figure 28). This first workshop supported the pre-implementation phase. Hence, main topics included expectations, challenges, future developments, roles and impacts of the implementation in the region.

Figure 28: Workshop at IONICA at 18th of June 2019.
Positioning of participants from left to right: Tara Esterl (AIT), Tarek Ayoub (World-Direct), Hannes Passegger (Faradis), Thomas Kienberger (MUL), Martin Reinthaler (AIT), Tanja Tötzer (AIT), Gerhard Enzinger(cable car operator), Rudolf Göstl (cable car operator), Siegfried Rasser (cable car operator), Michael Brüggl (cable car operator), Stefan Reisinger (cable car operator), (photographer of the Ionica), Herbert Gensbichler (cable car operator), Johann Schmidhuber (SAG), Julian Feichtinger (SAG), Stefanie Kritzer (SAG).

In the second year, the ski resort operators were intensively involved through site visits, technical meetings and two workshops. Customer relations with ski resort operators were strengthened and research was aligned with the needs of the users. The interim results were presented and discussed in-depth and their daily routines concerning artificial snow management, slope preparation and cable car operation were considered and integrated into the simulations and tools.
The workshop with the external regional stakeholders was a first step for disseminating the (interim) results and enhancing the visibility of the project in the region. Furthermore, the cooperation with regional partners could be strengthened. As a follow-up of the workshops, a joint "Klima- und Energiemodellregion" (KEM) flagship proposal with the KEM Oberpinzgau and KEM Saalachtal was submitted.
Additionally, multiple bilateral exchanges took place, where the focus was placed on the role of individual ski resorts in this project. The workshops were split into three parts: planning of investments into new renewable energy resources, flexibilities for optimization, and devices which should be monitored and controlled. A prerequisite for the investment planning into new devices is to put together a list of the current technologies used in the ski resort. Furthermore, the new technologies which should be considered in the planning, including their constraints (e.g., area available for PV), need to be defined. The second focus was on assets in the resort that provide flexibility in their energy demand in order to reduce peaks loads (hereafter titled "flexibility"). This flexibility is usable by the "optimiser" developed in this project (see Deliverable 3.3) to increase energy efficiency, reduce load peaks, trading on energy markets etc. An important point is the operational and technical constraints to be considered, such that the optimization does not interfere with the operation of the ski resort. To use flexibilities, additional equipment must be installed to provide measurements and control for the assets. Moreover, the monitoring gives the operators of the ski resorts insights into their electric systems.
In the third project year, two workshops were held at the IONICA Congress 2020 in Zell am See. One Living Lab workshop with ski resort operators took place on October 20th, 2020,the other one together with regional stakeholders in October 2020. Customer relations with ski resort operators were strengthened and research was aligned with the needs of the users. A special focus was placed on the topic of renewable energy communities (Erneuerbare-Energie-Gemeinschaften). Impulse presentations were given online, followed by exchanges on potentials and barriers for establishing renewable energy communities in skiing resorts.

Figure 29: Living Lab workshop with ski resort operators took place during IONICA 2020
(from left to right): Stefanie Kritzer (SAG), Roland Steiner (SAG), Herbert Gensbichler (BBSH, Hinterglemm), Johann Schmidhuber (SAG) Günther Brennsteiner (Kaprun), Michael Brüggl (Schmitten), Hannes Passegger (Faradis), Branislav Iglar (AIT)

The workshop with the external regional stakeholders aimed at disseminating the (interim-)results of CE4T and enhancing the visibility of the project in the region. Furthermore, the topic of renewable energy communities was discussed in a broader context.

A fourth workshop was conducted online on May 27th, 2021. In this workshop the monitoring dashboard and the demonstrators were presented and BEST goes into an in-depth discussion on the establishment energy communities (SAG).

Due to Covid-19 restrictions, the fifth workshop on the topics "Dashboard" and "Regional KPIs" (Figure 30) was held virtually on January 21st 2022. The central questions for both topics were:

- which numbers/indicators should one present externally (in terms of regional KPIs)?
- which should only be developed or available for internal operations or the dashboard?

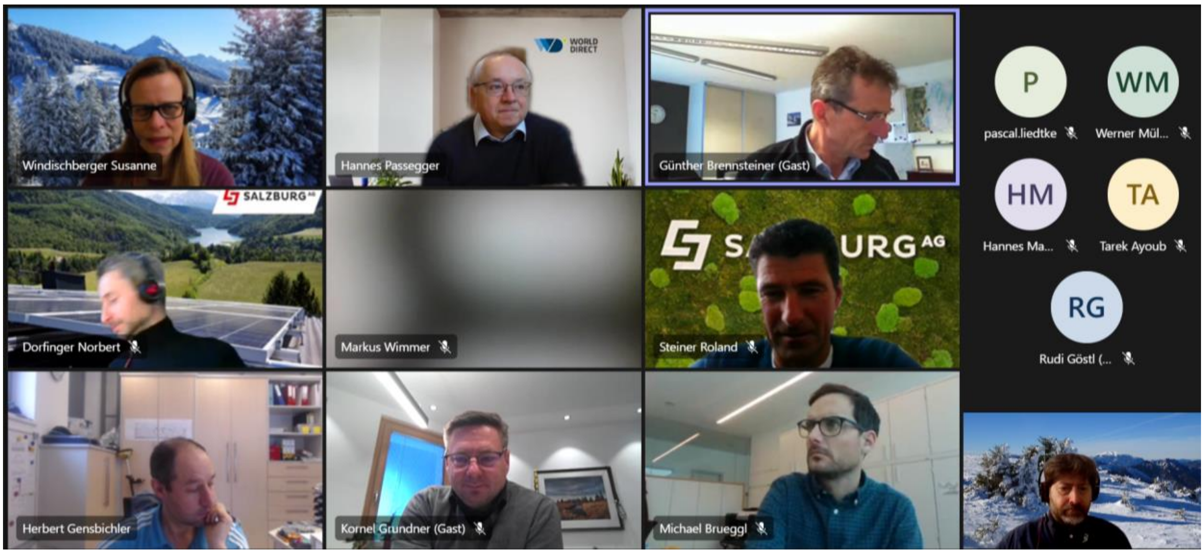


Figure 30: Virtual workshop on the Dashboard and regional key performance indicators

The topics of the last workshop (June 13th, 2022) as in the previous workshop, revolved around indicators for internal use and for external presentation.

3.9 Transferability to the energy-intensive industry

The results and findings from the operational optimization of the processes considered in the skiing areas were investigated with regard to their transferability to the energy-intensive industry. For this purpose, the chosen approach is divided into two main tasks:

- Comparison of processes considered in the skiing areas with processes generally being used in other sectors of energy-intensive and extensive industry
- Comparison and benchmarking of approaches, methods and algorithms for operation-optimization

For the process comparison, the first step was to identify the energy-intensive sectors and their processes. Next, appropriate key performance indicators (KPIs), such as typical nominal power, operating mode and flow rate, were developed. The developed KPIs were divided into three categories:

- Energetic KPIs (e.g. Energy consumption – thermal, electrical, typical nominal power)
- KPIs for the characterization of the operation (e.g. operating mode, operating duration, on/off time)
- Process specifies KPIs (e.g. flow rate, storage capacity)

In addition to the characterization, the developed KPIs can be used to identify and describe the flexibility potential of the processes as well as the determination of possible algorithms for operational optimization. Besides the determination of the KPIs as well as the flexibility potentials of the processes in the energy-intensive industry, further parameters for the process comparison were identified based on the analyzed and optimized processes of the skiing areas. These parameters include:

- Load shifting potential (process can be turned on or off under certain secondary conditions)
- Peak shaving potential (partial load operation possible, load shedding possible)
- Storage capacity available
- Dependence on other processes (process chain) low

After determining the KPIs and flexibility potentials for the identified processes, similar processes to those considered in the skiing area were identified, taking the parameters into account.
In order to transfer the chosen approaches, algorithms and methods for optimizing selected processes in the skiing area to the energy-intensive industry, the identified processes and their KPIs were analyzed in detail in terms of flexibilities. With regard to flexibility, the main focus was placed on load shifting, as the processes considered in the skiing area can be shifted in time. An analysis of the applicability of the chosen approaches, algorithm or method was carried out for each process. For this purpose, mathematical models are created to describe selected industrial processes (processes that have similarities in terms of characteristics and flexibility). Based on the mathematical models, the necessary parameters for the optimization as well as the necessary constraints were determined. The models and the parameters of the selected processes can be compared with those of the processes considered in the skiing areas. In addition to determining the suitability of transfer, possible adaptations to the application were identified.

4 Results and conclusions

4.1 Results: prototype of a highly automated monitoring and energy management system for skiing area

With the VPP platform a completely new solution was developed which is not available in the market in a similar way. It can optimize the operation of individual technical units and processes and based on that, it enables energy management for entire skiing regions too, involving all stakeholders in an integrated manner. The developed CE4T Hybrid VPP platform, including the optimization algorithm developed by AIT, allows to reduce energy costs through the best possible use of the available flexibilities, more accurate measurement and forecasting data. In addition, it opens the way to increase the efficiency of the entire system and increase the share of renewable energies, resulting in a CO-2 emission reduction. The system will significantly support skiing areas in

- Monitoring of energy use in the whole skiing area
- Optimizing of processes
- Observation and evaluation of optimization processes
- Planning of snowmaking and operation

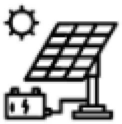
It provides Salzburg AG with additional information directly from ski resort operators. The information gained is used in various areas related to energy trading. It was decided that the dashboard will be offered to other skiing areas in the supply area of Salzburg AG after the CE4T project. In the project the major manufactures and system suppliers for skiing areas were well involved and interfaces to their systems are established and tested. The technical possibilities of the systems in skiing areas have been opened, but limitations often lie in the disposition and operating conditions as well as in regulatory requirements. The experience gained can be considered in the construction of future systems, enabling a better support for the energy system. The developed technologies can utilize as good foundation for providing further optimizations in the future and integrating renewable energies more efficiently.

It was decided to keep up using the monitoring dashboard after the end of the project. This was the result of a overwhelming approval from the participating ski resort operators:

The development of the platform and gained experience were only possible due to the conditions offered by a research project of this scope.

4.2 Results on identifying possibilities of additional renewable energy resources

The described use cases were evaluated by the planning process using the MILP-optimization program *OptEnGrid* by BEST GmbH. Following, the use cases are presented by energy cost and emissions savings in relation to the current or future state without implementing renewable technologies or regional energy communities (REC) to increasing self-sufficiency or system efficiency. These scenarios are always defined as reference cases (REF) and serve as comparison in benefit-analyses. Optimization cases are allowed to implement renewable energy sources, storage technologies or REC and focus on either reducing energy costs or emissions.



For the solar use case, twelve scenarios were made for each skiing area in form of parameter analyses to identify diverse influences. For this reason, the process of the schemata below was used for four skiing area without another renewable technology potential e.g. wind turbines or hydropower plants. The considered effects include CO_2 taxes, increasing energy prices (or constant like 2018), limited areas for PV, risen investment costs for PV and snow covering in certain periods.

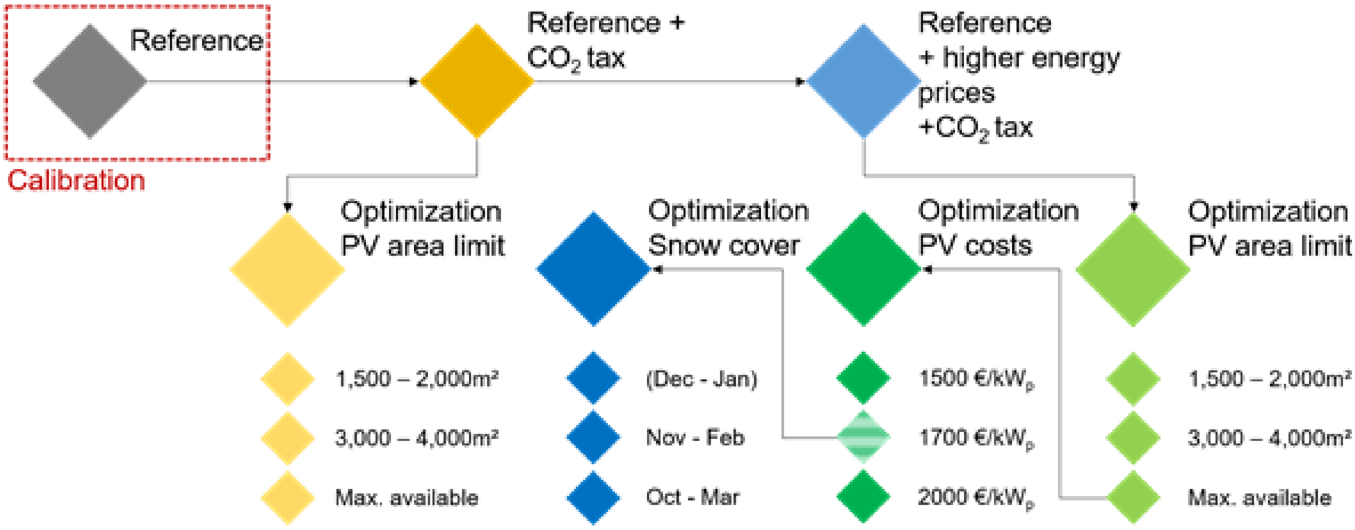


Figure 31: Scheme of the calculated solar reference and optimization use cases

Figure 31 represent the benefit analyses of two skiing areas with several differences including higher energy demand in general (bubble size), summer and winter demand and base load. The scenarios involve not only the skiing area but also of participating REC members which account for roughly 25% of the consumption. The considered effects demonstrate restrictions especially by snow covered PV panels, low energy prices (yellow) and limited PV areas. Higher investment costs influence the results less. In general, the benefits analyses diverge between the skiing areas but also demonstrate similar developments in the scenarios and parameter studies. Because of the modular system (PV and electric storages), solar use case offers the most scalable implementation of renewable technologies.

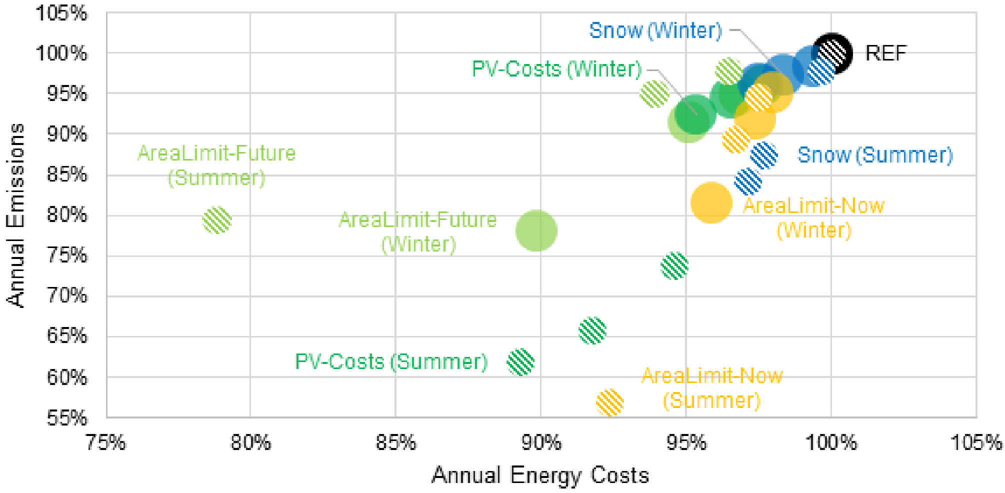
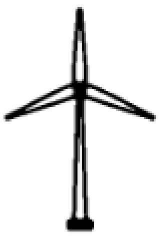


Figure 32 Relative costs and CO2 emissions of solar use cases based on two different skiing areas



This use cases address the implementation of maximum three wind turbines near a lift station on the mountain. The wind turbines can generate electricity for on-site demand or demands of a REC as well as sale to the market. Three reference cases show the current or future state. The first reference case considers no wind turbines and prices of 2018 (REF-NoWind), the other cases demonstrate already an implementation including rising electricity prices or not (REF-Wind in brown & REF-Wind-Future in striped black). In this context, price stability is already created by the wind turbines when comparing REC-NoWind and REC-Wind-Future. Refered to the implemented wind turbines in a REC, the optimal technology mix including PV and electric storages were identified by the MILP-optimized planning process focussing cost or CO_2 reduction. Resulting, the combination of wind turbines electric storage shows high profitability and increasing sustainability. Based on higher energy prices, high savings were evaluated by cost optimization with further renewable energy sources and wind turbines (striped lila scenario). To set the perspective in more detail, debit rates (DR) of 50 or 80% were involved based on REF-Wind-Future in form of full feed-in plants (FFI) or connected to a REC. Generally, the savings reduce enormous in comparison to the parameter study of designing the optimal technology mix. Nevertheless, the consideration of a REC demonstrates higher economic and ecological benefits due to constant feed-in tariffs of 100 € per MWh.

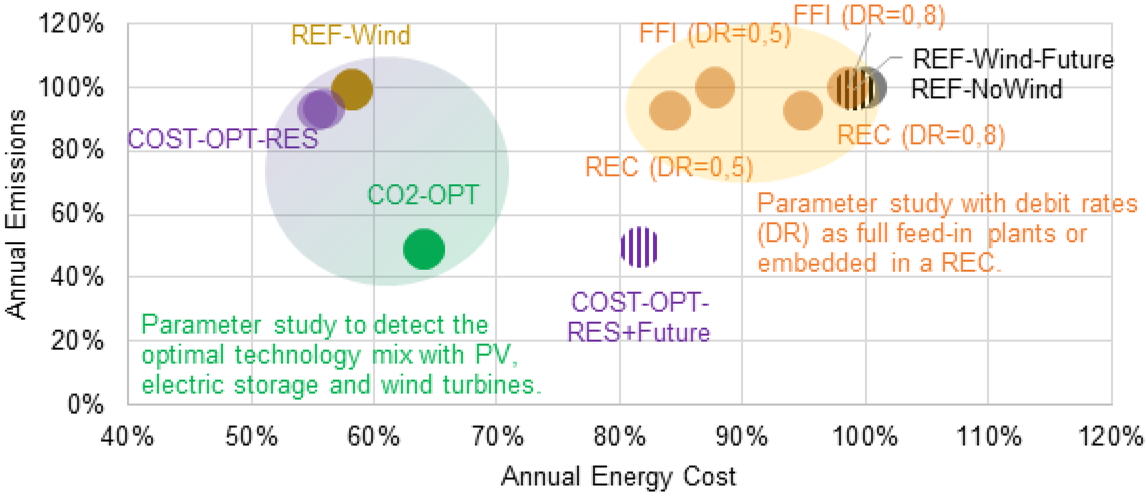
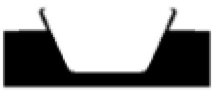


Figure 33 Relative costs and CO2 emissions of wind use cases



In the project, three existing hydropower plants (HPP) were detected, whereby one needs to be revitalised and another generate only electricity only during summer months controlled by an energy supply company. The revitalisation project would create enormous investment costs those rentability should be improved through innovative approaches. For this reason, the use case of HPP focusses on establishing a renewable energy community (REC), finding participants, evaluating the optimal consortium and ownership approach, testing different feed-in tariffs, changing transmissions & distribution tariffs and involving licence costs for accounting and real-time optimization programs. The diagram below demonstrates two different perspectives for the revitalized HPP. The lila bubbles include the skiing area as participant of the REC and show bigger bubble size based on higher electricity demand. In that approach, the HPP belongs to all REC-participants. In the second approach, the skiing area is no participant in the REC but own the HPP and supply electricity to REC participants, what increase economic and ecological benefits. Nevertheless, the savings create not more than 7 % due to high investment costs and summer-dominant generation profile. Furthermore, the sustainability increases only for participants of the REC, not for the skiing area.

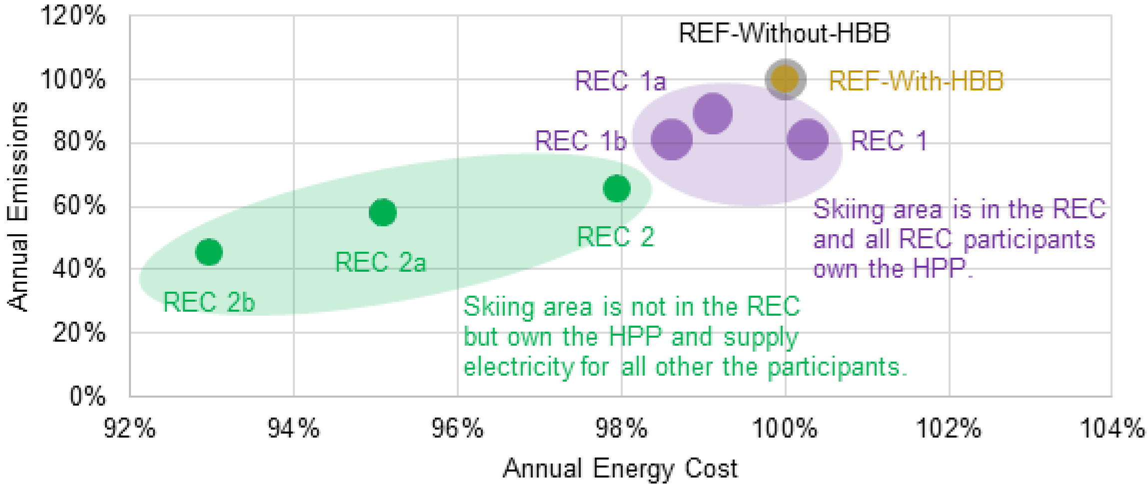


Figure 34: Relative costs and CO2 emissions of hydropower use case

The electricity demand of skiing areas is the most dominant sector, nevertheless a thermal use case were included to prove sector-coppling. Minimum two skiing area has at least more than one building which is connected to a (small-scaled) district heating system. Therefore, an use case consider three buildings in the valley of a skiing area, whereby the utility grid cover currently all electric demands and a condensing heating boiler using natural gas supply heat for the buildings (REF). Because of sharp uphill slope to the south-side, decentral PV panels have inefficient location, but CHP systems could generate both heat and electricity. For this reason, two fuel types for CHP were evaluated: natural gas due to the existing connection and biomass -– precisely wood chips. For the CHP driven by natural gas, three different models were evaluated but all systems demonstrate economic disadvantages based on low electricity prices (generally high electricity demand of the skiing area), comparable high natural gas prices (less demand) and low feed-in tariffs for these CHP. Based on the CO_2 modelling of national electricity grid and specific emission of natural gas, the emitted emissions of the system would rise too. These problems could be solved by wood chip driven CHP because of funded feed-in tariffs (170 to 210 €/MWh), low-priced fuels (40 €/MWh) and specific emissions of wood chips (23 g_{CO2}/kWh) based on sustainable value chain. Even with enormous investment costs (roughly the triple of natural gas CHP), maintenance costs and increasing heat demand due to drying wood chips, the most economic scenario demonstrate lower energy costs than the reference case in parallel to 65% of CO_2 savings. Among the downside, more space must be required to store and dry wood chips. The third scenario addresses the low electricity prices and implement an air-sourced heat pump to cover (most) heating loads, supported by power-to-heat elements for too-cold winter days. These cheap technologies (related to CHP) are modular for other skiing areas and results into energy costs and CO_2 savings. Unfortunately, the flow temperature of the district heating system must be reduced to 65 or 70°C, otherwise a realistic and economic operation is not possible. This includes renovating buildings as well as switching to surface heating systems, but studies show that these measures can amortize even in 0.3 to 18 years. Finally, the considered system benefits at most from last use case in term of sustainability and profitability.

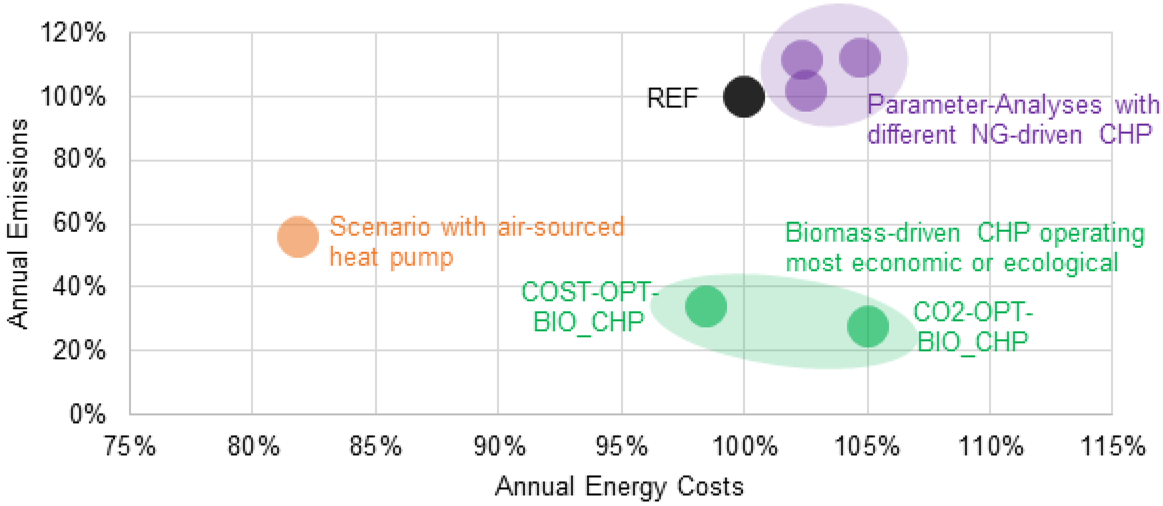
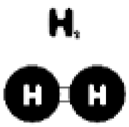


Figure 35: Relative costs and CO2 emissions of thermal technology use cases



Hydrogen is expected to play a major role in seasonal storage. Especially due to the winter-dominant load profile of skiing areas and the summer-dominant generation of renewable energy sources (RES -– in that case photovoltaic or hydropower), hydrogen is considered as an approach for energy design. The use case consider hydrogen either as storage system and/or as fuel for local bus transfer. The MILP optimization evaluate the optimal technology mix including RES, polymer electrolyte membrane (PEM) electrolyser, pressurized storage tanks and fuel cell as well as the optimal electricity transmission by a REC. Furthermore, one scenario considers also grid-friendly operation (GFO) of a PEM-electrolyser during the basic snow production.

The first use case addresses the initial hydrogen station to decarbonise 20 busses for local passenger transport in the Austrian region of Pinzgau which involve hydrogen and electricity demand of 16.8 GWh or 16.1 GWh of diesel (big bubble size in diagram below). Thus, two reference cases were calculated using diesel- or hydrogen-driven busses. Both reference cases include also investment and operation costs of busses, but also further infrastructure (e.g. for decentral hydrogen storages) and distribution costs (for trucks and salaries). The required energy for PEM-electrolyser is supplied only by volatile electricity markets without RES or REC-approach in the reference case. Focussing a cost reduction by designing optimal technology mix and evaluating an ideal energy flow by a REC, the local busses transport could benefit economically from a hydrogen station since the diesel reference case consider fuel prices of 1.5 € per liter. But the MILP optimization designed few renewable technologies, because of high energy losses by generating hydrogen, low prices by volatile energy markets and comparable high generation costs. Based on the low RES-integration and the modelled CO_2 of national electricity grid, no CO_2 savings were identified by the MILP optimization. If the energy costs were allowed to increase by 25% or 50% and CO_2 reduction were focussed, the MILP optimization designed huge PV areas which reduce highly the CO_2 emissions. With a plus of 50% of the energy costs, grid-friendly operation (GFO) did not increase significantly energy costs and emissions.

The second use case dealt with hydrogen technologies as sessional storage or electric storages using saltwater. The technologies or storages were supplied by electricity from a hydropower plant and cover loads of a small skiing area with 1.8 GWh_{el} (small striped bubble in the diagram below). Similar to last use case, the reference scenario sells all generated electricity by the hydropower plant, cover all loads by the utility grid and no REC and further RES were considered. The MILP optimization calculate clearly benefits only by enabling a REC approach and focusing on cost reduction. Further RES were also implemented but only photovoltaic systems and no hydrogen or other storage systems. Electric storages were only designed, when the optimization target change to CO_2 reduction, 10% cost increase are allowed and PV is neglected (scenario ES). The same approach was used for hydrogen technologies but with a maximum cost increase of 50% (H2). Both scenarios show low benefits, as profitability is not given at all and CO_2 reductions are better achieved by using PV – inclusive cost reduction. Only with the combination of further PV to the hydropower plant and hydrogen technologies, significant CO_2 reductions can be reached (H2 + PV).

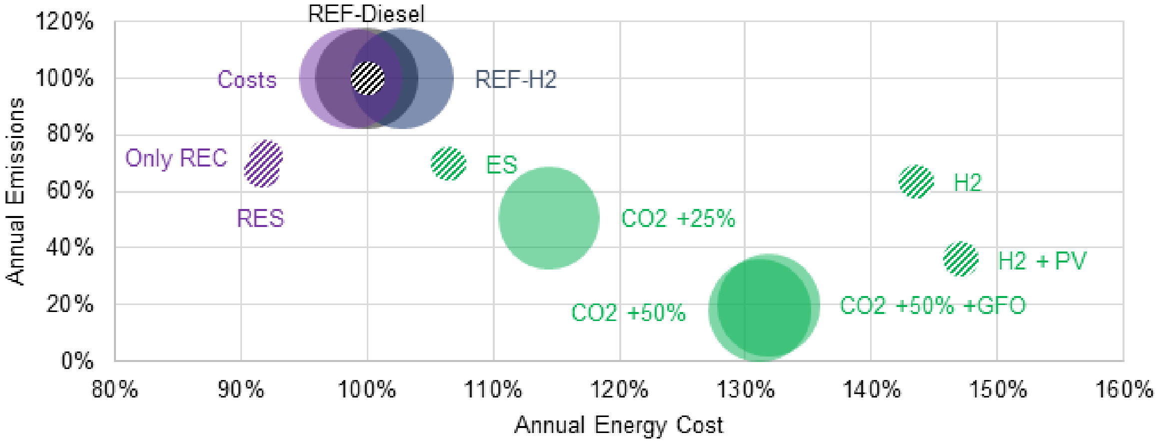


Figure 36: Relative costs and CO2 emissions of hydrogen use cases

Figure 37 gives an overview of results in the benefit analysis based on energy cost and emission savings for all skiing areas and use cases. The size of the bubbles correlate with the considered energy demand of the particular use case. A variety of renewable energy sources were considered with the optimization target reducing energy costs or CO_2 emissions. Furthermore, the time of the calculation affect the results too, because solar, wind and hydrogen use cases consider increasing energy prices due to international conflicts. In general, some beneficial aspects but also barriers to the integration of renewables can be mentioned. Renewable energy communities (REC) have a high relevance for skiing areas, due to their high number of metering points with seasonal differences in operation (e.g. pumping stations, snowmaking systems or lifts). Some use cases or technologies show a very broad saving potential, but wind power show beneficial aspects based on the similarity of generation and consumption, even though geographic and logistic aspects restrict enormously the implementation. Thus, innovative concepts of wind power must be further observed, for instant kite systems or electrostatic wind energy converter (EWICON). Generally, barriers for renewable energy design can be prioritized in space requirement, low-priced energy for skiing areas, geographical or climatic conditions and regulatory aspects. One of the big hurdles is mobility, as snow groomers have to satisfy high climatic and technical requirements (slopes and -30°C ambient temperature). The implementation of an H_2 station would be a first step, but more research is needed for this application and the energy design has to cooperated in a long-term strategy with several policy.

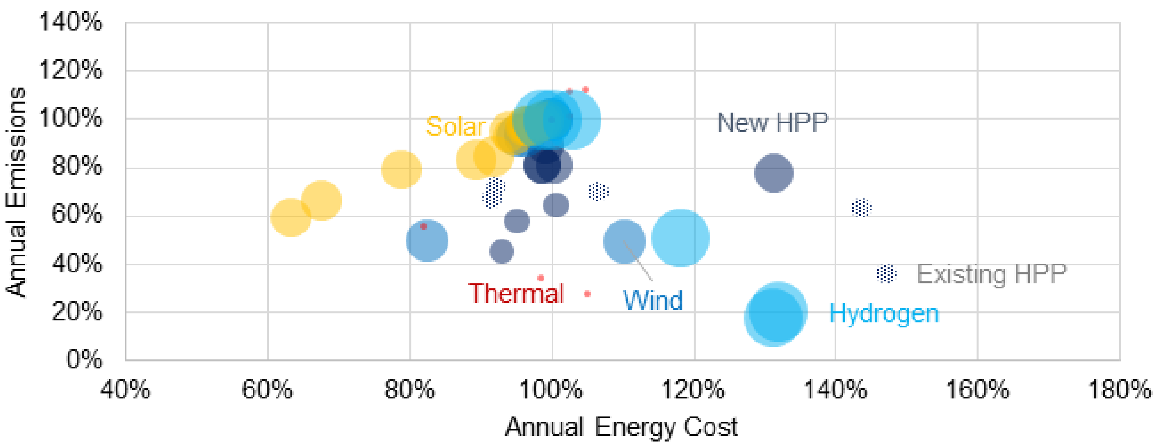


Figure 37: Overview of several use cases based on relative energy costs and CO2 emissions

4.3 Results on energy costs optimization and development of a framework to integrate

4.3.1 Market chances of the ski resorts – using flexibilities

Mostly the flexible units of the ski resorts are pumps and mixed air compressors. The pumps take the lions part of the flexible power. Nevertheless, there are some more restrictions for the pumps than for the compressors which must be satisfied. Restrictions are for example maximum pumped water, minimum running time, on- and off-switching time. Mostly there must be a worker on site for switching on or switching off the pumps. Compressors are automated to start and end their schedule.

Existing flexibilities	Flexibility potential	Possibility of offering other services		
		Day-ahead and Intraday market	Balancing market (aFRR/mFRR)	Demand response and Redispatch
Cable cars and ski lifts	**low**			
Snowmakers and pumps:	**Medium to high**	Minimization of day-ahead and intraday costs (purchase and sale) by using existing flexibilities	Possible, check necessary (reaction times,..)	Possible future applications
- for basic snowmaking	low			
- for renewal of snow cover	low			
- for water reservoir filling	high			
- mixed-air compressors	high			
Buildings	medium	Not further investigated (too low potential)		
Power generation facilities (hydro power plant)	medium	Not further investigated (too low potential)		

Table 5: results on the elaboration of flexibility potentials in the skiing resorts

Over all the investigated ski resorts (all partners except Saalbach) we estimated 10 flexible units with market chances. This was done by several workshops for each skiing area and map based research an the existing assets, their elevation, the pipe systems or their size.

Some interesting aspects and KPI's have been identified. Mostly, flexible pumping of water reservoirs offers the biggest possibilities (Table 6):

	Power [kW]	Flexible energy [kWh]
water reservoirs and pumping	5.926	2.462.248
Mixed air compressors & fountain pumps	829	213.278

Table 6: CE4T flexibilities

One of the main skiing areas (one of those which have a lot of water shifting potential) has a flexibility of approx. 12% if it's total electricity consumption. This is about 64% of the annual total pumping energy demand!

4.3.1.1 Spot market

Usually, an optimization for the spot market is calculated as followed. For a defined time horizon, a price forward curve (PFC) is calculated. This is the price forecast for the market prices. Related to the PFC, the optimal operation is calculated with the different asset parameters e.g., starting time every day. With this calculation the optimal operation related to the PFC is set up.

To determine possible use cases for the spot market, possible flexible units and their scenarios have been considered. The result was that there are scenarios of reservoir fillings, that can be executed considering the market prices of the spot market. First of all, it seemed intelligent only to use the pumps when the prices are low. But under closer inspection, there are some important limitations for the operation of the pumps, like the minimal running time. Altogether it was not possible just to operate at low price hours of every day. The seasonal operation of the pumps for filling the reservoir was strictly bounded to some weeks or months of the year. With the knowledge of the needed water amount to fill the reservoir and other parameters, the energy need for filling could be calculated and so the amount of pumping hours. Considering the seasonal operation time and the amount of pumping hours, it fitted perfectly to shift the operation to the weekends, where the prices are usually lower than on weekdays. With this shift, the minimal operation hours could be satisfied, and the start and stops are not overwhelming high on the one hand to spare the pumps and on the other hand to minimize additional personnel costs.

With this definition, the optimal schedule for operation of the pumps was set to the weekends.

The calculation was made with prices from the three years 2019 to 2021. For these years the spot prices were used, so the saving potential could be calculated exactly and wasn't depending on forecast instabilities. Next step was to set a baseline to which the optimal schedule would be compared. The comparison of the optimal schedule to the baseline would be the profit. The challenge was how to define the baseline. The baseline was defined as followed. It was assumed, that the ski resorts only start their pumps once and then let them operate for the needed hours to fill the reservoirs. The starting time could be flexible but must be in the seasonal time range. So, the ski resorts could start the pumps on the first day and let them run for example 12 days or they could start at the middle of the seasonal time range and then let them run for 12 days. Every 12-day run of the pumps gives back the same amount of energy but due to the different spot prices, variable costs. The average of the different operations builds the baseline.

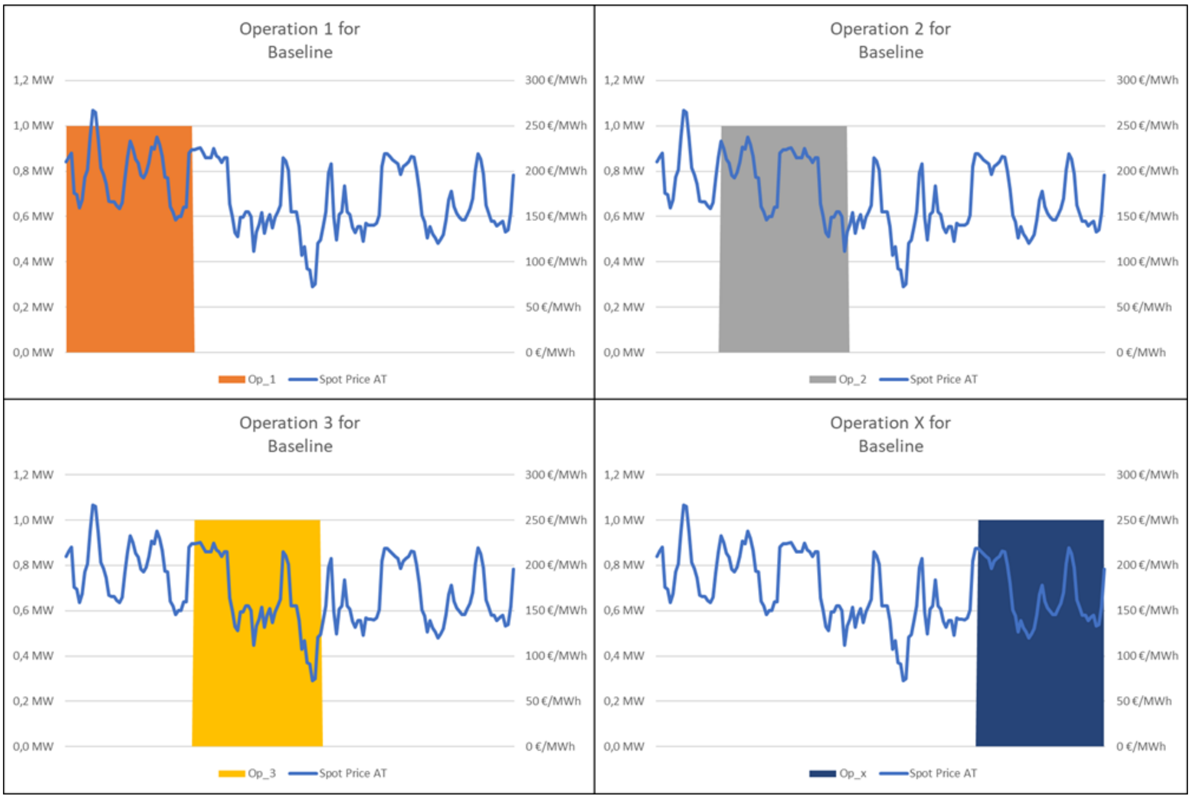


Figure 38: Baseline visualization

Each operation for the baseline calculation costs an amount of money. For example, Operation 1 costs 25.400 €, Operation 2 costs 19400 €, Operation 3 costs 15800 € and the last Operation x costs 18300 €. The average of all operations would be the costs for the baseline. The example shows the very strong dependency on the starting time of the costs.
The cost for the operation of the pumps at the weekends is calculated similar. The energy amount of the operation at the weekends is the same as it was used for the baseline it is only separated in more starts and stops.

Figure 39: Weekend operation of the pumps

The difference between the cost of the baseline and the cost of the operation when the pumps run at the weekends are the saving potentials.
Some of the ski resorts use mixed air compressors in their water reservoirs. These should operate at least for some hours a day during a seasonal time range. For these scenarios, the average low-priced hours of the days in the time range where found. The baseline for these scenarios is calculated differently but simpler. The baseline is set to the spot base of the operation time range. The used energy in the time range for the mixed air compressors multiplied with the spot base of the time range gives back the costs of the operation. The costs of the daily operation at the low-priced hours multiplied with the energy gives the optimized costs. The saving potential is the difference between these two costs.

An overview of the saving potentials of the different scenarios gives the figure below.

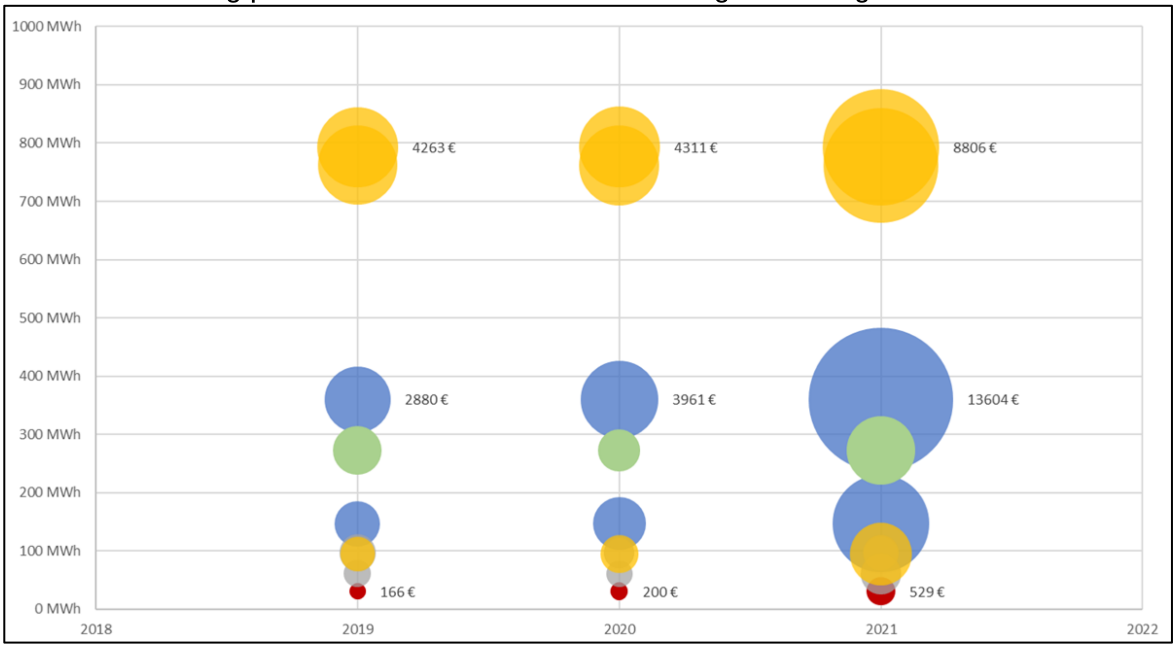


Figure 40: Saving potentials of the scenarios

The figure shows the saving potentials of the scenarios in the three years 2019-2021. Every dot is a scenario. The higher the dot is on the y-axis the more energy is used in the scenario. The bigger the dot, the higher is the saving potential. It shows that it is likely that the saving potential is higher when the use of energy is high.

4.3.1.2 Intraday market

Due to the circumstance, that the most assets are not flexible enough and operation starts and stops are only possible if there is personnel present, the assets cannot be used for the intraday market. The short-term products of the intraday market need a flexible and mostly automated asset environment.
It could be possible for the smaller mixed air compressors, but due to the very small amount of energy usage, this market was not considered.

4.3.1.3 Balancing market

The initial position is the same as the intraday market. For a balancing market chance, the assets must react very fast and mostly automated. The balancing market chance was not considered either.

4.3.1.4 Network stabilization markets

It is possible for the pumps to take part at the network stabilization markets. For the FCR, the pumps must run at an operation point where they can reduce or raise their consumption. This operation point is mostly not the optimal operation state for the pump. For the aFRR there are two possibilities available. The first is to run the pump at the optimal operation point and offer positive secondary capacity. If there is a retrieval, the pumps reduce their operation point, so that they obtain less power from the network. The other possibility is to run the pump at a lower operation point and offer negative secondary capacity.

So, if there is a retrieval, the pumps raise their operation point. For the mFRR it is very similar to the aFRR. The particularity of the tertiary market is, that there are very few retrievals.
For the participation at the network stabilization markets, the offered power must be at least 1 MW. Most pumps are smaller than this limit or the reduction potential from optimal operation point to minimum operation point, so that the pumps must not be shut down, is fewer than the limit. Due to that, the pumps must be included to a virtual power plant where the offered power can be accumulated and the different units can provide reserves for each other.

In conclusion, the predestined markets are the positive secondary and the positive tertiary markets. Unfortunately, the actual version of the Salzburg AG VPP does not provide all settings to include the pumps. But this option can be implemented in the future.

4.3.2 Results on use case "utilization of the water reservoirs for pumped storage of electrical energy" – show case Asitz I and Asitz II

The existing pumps allow a maximum flow rate of 35 l/s. This requires an electrical power of 315 kW. The applied pressure while operating is 57 bar. With pump/turbine operation of 6 h/d each, around 756 m³ can be pumped/turbined, corresponding to a level change of 7.56 cm. Based on the geodetic height of 493.8 m, a theoretical pressure of 50.34 bar should be sufficient. This results in a pressure loss of 6.66 bar across the pressure line. A rough estimate of the pressure loss based on pressure loss tables results in a pressure loss of 4.72 bar and is thus in a similar order of magnitude. The difference can be explained by deviations in the assumed pipe lengths or by changed friction coefficients due to material aging. The largest contribution to the pressure loss is made by the pipe sections that are designed in DN 150. The specific pressure loss in these sections is more than four times higher than in the DN 200 sections and almost fourteen times higher than in the DN 250 sections. The pressure loss could be significantly reduced by reducing the flow rate. From the ratio of the theoretical capacity of 169.55 kW plus the power loss to overcome the pressure drop (22.44 kW) and the actual pump capacity of 315 kW, the pump efficiency is 0.61. The possible turbine capacity results from the theoretical capacity of 169.55 kW minus the power loss of 22.44 kW to 132 kW.

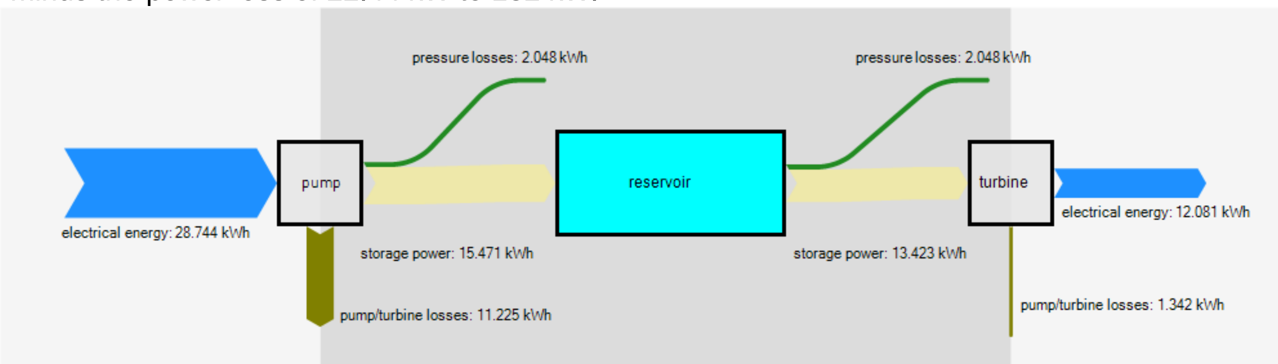


Figure 41: Sankey diagram showing energy flows (updating Asitz 1 and Asitz 2 to a pump storage system)

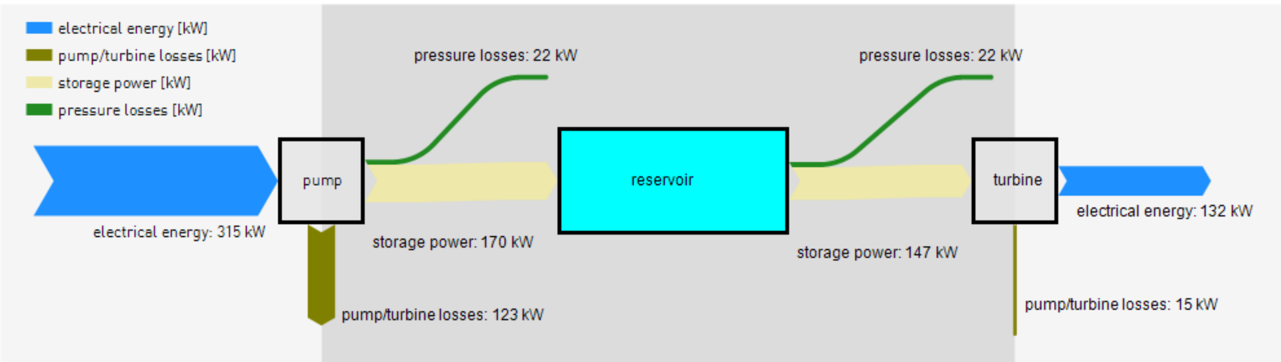


Figure 42: Sankey diagram showing power flows (updating Asitz 1 and Asitz 2 to a pump storage system)

The heat introduced by the pumping operations (pipe losses, pumping losses) increases the temperature of the pumped water by about 1 °C. For 250 operating days of the pumped storage, this raises the temperature of the storage ponds by 1.34 °C. The losses in the turbine were neglected and should be compensated by the increased heat release to the environment. The investment costs for the turbine plant are assumed to be 1,000 €/kW based on the diploma thesis of DI Günther Mimm[7].

With a possible output of 132 kW, investment costs of €132,391 are therefore estimated. To achieve a revenue a factor of 2.4 in the electricity price between pump and turbine operation is necessary.

According to the evaluation of Salzburg AG, there are days on which such a price difference occurs, but only in individual hours. In the average of the years 2019-2021 the factor between cheapest and most expensive hour of the day is 1.8. On average, price differences with a factor of more than 2.4 between pumping and turbine operation occur only on 25% of the days in the year and then only 1 hour can be pumped or turbined. Furthermore, this operation can only work if the boundary condition of only working between 22:00 and 10:00 can be removed. Under these conditions, a revenue of approx. 450 € would have been generated on average for the years 2019 - 2021. Due to the high pressure and especially pumping losses, about 2.4 times more energy is needed for the pumping process than can be gained by the turbines. Thus, only 40 % of the stored energy can be released again, making it a very inefficient storage solution from an energy point of view. In order to optimize this, the pipe cross-sections would in any case have to be increased to DN 200 and the pump efficiency would have to be significantly improved, which would entail considerable investment costs. It should be noted that this would also make storage pond filling more energy efficient. The economic efficiency is also not given due to the necessary high factor in the prices.

One possibility for using the pumping capacity in the power grid, would be to provide negative control energy, i.e. the consumption of surplus electricity. This would require minor investments in the pumping plant and it would have to be included in a virtual power plant.

4.3.3 Utilization of “KW Dießbach” for local energy balancing

The calculation was made for the last three years 2019 – 2021.
The efficiency of the matrixpump is 70 % for pumping the water. The turbines efficiency is at 85%. Additional costs for using the grid are added. Those are for network level 5 11,51 €/MWh and for the pump storage 2,8 €/MWh.

The results are shown for the year 2021. 2021 was an outstanding year for the energy prices. The prices rose very strongly from September to December.
In 2021 the saldo of the production was 2375 MWh. This energy could be stored in the Dießbachsee. After pumping and turbining, the energy output due to efficiency was 1411 MWh which could be used by the ski resort. The lost energy due to efficiency is 41 % of the produced energy. Additional costs would be 43.500 € for using the grid level 5 and 10.600 € for the pump storage.
Although the losses are high, there would be a positive output for storing the energy. The profit for 2021 was 36.000 €. But this was only possible because of the energy prices which were low during the summer month and high during the winter month where the stored energy was re-used.
The other two years 2020 and 2019 can show this very well in the result. For 2020 the profit was -66.200 € and for 2019 the profit was -87.000 €. For both years there was no advantage to store the energy in the Dießbachsee.

The results of the calculations show that it is economically unviable to use the pump Dießbach for local energy balancing. Reasons are, that the pump is not designed for this scenario. The total efficiency is low. The loss of energy is high and additional costs must be paid.

[7] Vgl. Mimm (2018): „Kunstschneeanlagen als Stromspeicher, Sekundärnutzung von Beschneiungsseen als hydraulische Energiespeicher in Österreich“, Diplomarbeit TU Graz, 2018

4.4 Results on grid friendly operation and demand side management

Customers with an annual consumption of more than 100MWh and more than 50kW are equipped with a load profile meter. These customers have a network tariff part, which takes the peak power into account. Typically, the peak power of customers occurs at the same time as the maximal network load. Therefore, a grid friendly behavior is automatically achieved when customers try to reduce their peak load with their flexibilities.

A second use case for flexibilities can occur, when there are network congestions for power plants. With the use of flexible loads, the local congestions can be avoided, and no loss of power occurs. Currently network congestions for power plants occur seldom and typically affect less than 1% of the generated energy. Therefore, in most cases the investment and operation costs of flexibilities won't be covered by the use case between the flexibility provider and the power plant operator.
Data analysis and monitoring results showed that the primary snowmaking systems in skiing areas offer little flexibility. They are only in operation for short periods and in case the weather conditions at the beginning of the skiing season make snowmaking possible. At the start of the winter season a full capacity operation for a few days is required to ensure good snow conditions for the rest of the entire winter season, providing the basis for economic success. Hence, in that period no flexibility of the snow making process is given. Analyses and results from monitoring showed too, that during this period the highest load peaks and network loads occur. For the DSO are precisely these peaks decisive for the network expansion.

To be prepared for the future and to be able to react to changing conditions on the market or in the regulation, the IoT platform and interfaces are designed in a way that if the current regulation situation changes and optimizing of flexibilities for the DSO with technical units in skiing areas would make sense, this use case can be implemented. Same if systems in skiing areas are installed which can be used to generated flexibilities to be used for ancillary services, the IoT platform is prepared for this scenario.

The overall visualization of the Hybrid VPP platform includes a monitoring dashboard with alerting functions for the individual ski resort operators as well for energy supplier Salzburg AG.
The CE4T Monitoring dashboard support ski resort operators to identify and analyze load peaks. Since most ski resorts have many metering points the dashboard gives operators an excellent overview of the energy states and peak demands in the entire resort. This supports them in identifying and analyzing peak loads in order to be able to reduce them in the future. Feedback from ski resort operators showed, that the new information gained through the dashboard is very valuable for optimizing processes and reducing peak loads.
Since peak loads cause costs, ski resort operators are very interested in keeping them as low as possible. This consequently leads to a grid friendly behavior.

4.5 Results on optimization - overall system & scenario evaluation

In the project, four different demonstrators were performed, where the optimization and control of flexibilities and the ideal operation of a ski-lift were field tested. This section describes the demonstration setup and the results and conclusion obtained from them.

4.5.1 Ski lift

Ski lifts are considered to play an essential part of the energy demand of ski resorts. One particular source of flexibility provided by ski lifts is the variability of the operating velocity of the ski lift. The ski lift operators are able to adapt the velocity and thus the energy depending on the queue of guests waiting at the entries of the lift. Unfortunately, the associated flexibility potential is rather low. For example, reducing the speed of the ski lift in times when the electrical grid has a high CO_2-intensity is infeasible. This would yield an increase in guests waiting at the lift. Afterwards a rebound effect occurs because the velocity has to be increased in order to increase the number of transported guests to reduce the number of waiting guests.

However, a degree a freedom is the number of lift cabins outside the peak season. The main question is *"What saves more energy: operating the ski lift with more cabins and a slower speed or with less cabins but instead with a higher velocity?".* Since the full capacity of the lifts is usually not needed in the off-season this energy saving approach is mainly applicable for this season.

To analyse the dependency of the energy demand on the velocity and the number of cabins, a demonstrator was set up in Summer 2022. From July 18th to July 20th a lift was operated with 40 cabins and a velocity of 4.5 m/s whereas it was operated with 45 cabins and 4.0 m/s from July 21st to July 24th.

The demonstrator showed that on average, *4.6 % energy can be saved* in the off-season when operating the analyzed ski lift with the slower speed of 4.0 m/s but with 45 cabins instead of 4.5 m/s and 40 cabins.

4.5.2 Mixed-air compressors and fountain pumps

Mixed-air compressors and fountain pumps are installed in the water reservoirs of the ski resorts. Mixed-air compressors pump compressed air through pipes, which are laid on the ground of the water reservoirs. These pipes have holes that allow the compressed air to escape at the bottom of the reservoir. Then, air bubbles ascent from the bottom to the surface of the lake. Mixed-air compressors have the following intended usages:

- The water reservoirs must not freeze during the winter. When the ascending air bubbles hit the surface, they burst and thereby help prevent the freezing of the lakes.
- In autumn before the beginning of the basic snow making, the mixed-air compressors can be used to cool down the water reservoirs. Depending on the water temperature, the snow cannons operate with different energy efficiencies and consume different amounts of water. The surface water layers of the lakes are more exposed to temperature changes than the lower layers (Denfeld, Klaus, Laudon, Sponseller, & Karlsson, 2018). When the ambient temperatures drop, the air bubbles created with the mixed-air compressors help circulating the water layers in the reservoir. The circulating of the water layers with different temperatures increase the cooling process of the reservoirs.
- Another use-case of these compressors is the algae control. During summer, in some water reservoirs the mixed-air compressors are used to reduce the algal formation. Usually, algae are not a problem in reservoirs at higher altitudes.

Additionally, in some water reservoirs pumps are installed that set water under pressure. These pipes end vertically near the surface of the reservoirs. The pressurized water creates jets of water when leaving the pipes. These water fountains have the following usage:
Similar to the air bubbles from the mixed-air compressors, the water fountains are used to prevent the freezing of the surface in winter times. The water fountains are located so that the water hits the water's surface. Thereby, the impact of the water drops from the fountain on the reservoir's surface hinder the freezing of the water reservoir.

The optimization of mixed-air compressors and fountain pumps was demonstrated in a cross-ski regional demonstrator with two participating ski-resorts. Most of the time, the demonstrator was operated in open loop. This means, that the optimizer was optimizing the operation of the devices for the entire horizon in day-ahead, price forecasts were sent daily from Salzburg AG to the optimizer module of the hybrid virtual power plant (hybrid VPP), and the resulting forecasts were sent from the optimizer to the IoT-platform of World Direct. However, the schedules were not applied to the devices and were not used for trading outside the normal operation times of the devices. For test periods the demonstrator was also successfully operated in closed-loop where the operation was optimized, and the resulting schedule was applied by the IoT-platform.

During the entire testing period of over one year the hybrid VPP operated without problems or failures. This was only possible due to the extensive testing which was done in advance

4.5.3 Refilling of water reservoirs

In the project two demonstrators for the refilling of water reservoirs were shown. In the first demonstrator a water reservoir was entirely emptied for maintenance work in advance. Then, in a time frame of approximately four weeks in summer, the water reservoir had to be refilled again. For the refilling process, the optimizer chose the best time spans for refilling based on the price forecasts of the day-ahead market. The entire process was conducted in a semi-automatized way. Once every week the optimizer was run for generating the pumping schedule for the entire next week. The resulting schedule for the next week was validated by the ski resort operators. Afterwards, it was sent to Salzburg AG for trading. The ski resort operators operated the pumps for the refilling accordingly to the schedule. Thus, it was crucial to take the working time of the ski resort operators into account because only during these times the pumps could be turned on/off.

In the second demonstrator two coupled water reservoirs had to be refilled. Both involved pump stations have different water flows. Therefore, their optimization models cannot be aggregated because when sending the same schedule to both pumps, the water reservoir with the pumps with the higher flow rate would receive more water than the other water reservoir. Furthermore, during the time of the demonstrator the surface of the lower water reservoir was frozen. As a consequence, the water level of the reservoir was not allowed to lower too much because this would break the artificial reservoir. Therefore, in the optimization a constraint had to be added to limit the change in the water level. Furthermore, the two pumping stations are operated differently. One can be fully controlled autonomously from the hybrid VPP, whereas the other pump station must be controlled semi-automatically by informing the ski resort operators in advance about the planned schedule.

4.6 Results on regulatory assessment, cost-benefit evaluation and business opportunities

4.6.1 Results on cost-benefit evaluation

The use cases investigated as part of the cost-benefit evaluation aim at improving a selection of challenging aspects within ski resorts. More specifically, issues such as high imbalance settlement costs due to the spontaneous start of the basic snowing and the inefficient operation of flexible components leading to their cost- and carbon-intensive operation and high peak loads are considered. In the following, the solutions to these challenges proposed by the examined use cases, namely the information exchange use case, the intraday use case and the flexibility operation optimization use case, will be summarized.

The information exchange use case makes use of the day-ahead (DA) market to procure energy for the basic snowmaking in order to avoid the use of imbalance settlement energy. To do that, information exchange on the start of basic snowing is necessary between the ski resort operators and the energy supplier. For that, information and communication (ICT) infrastructure in the form of a Hybrid VPP platform with visualization provided by a technology provider is used. Consequently, the costs in this use case are the expenditures for the Hybrid VPP platform and the benefits are the savings in imbalance settlement costs. The analyses have shown that the profitability of the use case depends on the average annual benefits per ski resort and the number of ski resorts that use the ICT infrastructure, since they share its costs. While the costs are fixed, the results of the analyses illustrate that the attainable benefits per ski resort fluctuate on a year-by-year basis. It can be concluded from these results that for the economic viability of the use case the maximum number of ski resorts possible should use the ICT infrastructure. In this way, the effect of fluctuations in the benefits on the profitability of the use case can be intercepted. Moreover, a part of the benefits reaped by the energy supplier should be passed on to the ski resort operators as a remuneration in order to incentivize their participation. Under consideration of these points, a viable business case for the ski resort operators can be constructed from the use case.

Furthermore, the installation of additional live monitoring ICT infrastructure is possible, which represents a business case for the technology provider. The profitability of installing the live monitoring ICT infrastructure for the ski resort operators is determined by its application. For instance, it can be used to live monitor loads in the ski resorts and modify their operation to save on peak charges. The benefits for the ski resort operators are thus the peak charges they can save. This again depends on how well the loads can be monitored, for which controllers are necessary. Since the latter are a cost factor, a detailed assessment of the dependency of the amount of peak charge savings on the number of controllers should be made in order to ensure profitability for the ski resort operators. Moreover, like in the information exchange use case, the cost for the ICT infrastructure is shared among the participating ski resorts. This dependency may make the business case less attractive for the individual ski resort operators and therefore, needs to be carefully considered by the technology provider before its implementation.

Like the information exchange use case, the intraday (ID) optimization use case aims at avoiding the use of imbalance settlement energy. However, the ID market is used to procure energy in this case. To do that, models are needed to make predictions on the volume-weighted average prices for different hours on the ID market and to optimize the trading strategy. Should an order not be executed, meaning the energy cannot be procured on the ID market, imbalance settlement is still used. As a result, the costs of this use case consist of license costs for the use of the model and the benefits consist of the profits made on the ID market as well as savings compared to the use of imbalance settlement energy. Since the rollout of this use case has not been executed yet, the negotiated costs for the use of the model are uncertain. Moreover, the attainable benefits can fluctuate based on the trading strategy. The conducted analyses have shown that the effects of these aspects on the profitability of the use case can be intercepted or ameliorated if many ski resorts participate in it. As in the information exchange use case, an economically viable business case can be built for the energy supplier if the outcomes of the aforementioned analyses are considered.

The flexibility operation optimization use case is comprised of several aspects concerning the optimized operation of selected flexible components within ski resorts, namely water reservoir pumps and mixed-air compressors. The first aspect, i.e., objective of the optimization, is minimum DA energy costs, the second one is minimum DA energy costs and minimum peak charges, and the third one is minimum CO_2 emissions. The benefits of this use case are therefore either cost or CO_2 emission savings. The savings in DA energy costs profit the energy supplier and like in the information exchange use case, a part of them is passed on to the ski resort operators as a remuneration for their participation. Moreover, the savings in peak charges are directly reaped by the ski resort operators and the CO_2 emission savings benefit their green tourism strategy. The conducted analyses have revealed the following aspects, which should be considered to ensure the profitability of the use case for all involved stakeholders: First of all, the more time flexible a given component, the better the results of the optimization concerning the objectives, i.e., the greater the savings in costs or CO_2 emissions. For that reason, it is most beneficial to focus the optimization on the most flexible components within the ski resorts. Secondly, the results of the optimization have shown that it is difficult to achieve simultaneous cost and CO_2 emission savings, because the times when the DA energy is cheapest are often when there is energy from the most CO_2-intensive electricity sources in the electricity mix and vice versa. However, simultaneous CO_2 emission and cost savings can be achieved by combining both objectives in the optimization. Thereby, a more economic as well as more sustainable operation of the flexibilities can be realized. Lastly, the results of the analyses show that the savings in DA energy costs yielded by the optimization can be nullified by the peak charges if they are not included as an optimization objective as well. For that reason, it is essential to combine both objectives in the optimization to ensure profitability for the energy supplier as well as the ski resort operators. In conclusion, if all of the aforementioned aspects are considered, this use case encompasses the possibility to construct a successful business case for the energy supplier, while simultaneously bringing economic benefit to the ski resort operators and contributing to their green tourism strategy.

It can be concluded that for each of the investigated challenges in the ski resorts, an amelioration can be achieved through the examined use cases. Moreover, viable business cases for different stakeholders can be built based on them. It can be surmised that the real-world implementation of the presented use cases and business cases is recommendable if all relevant aspects of the presented investigations are carefully considered.

4.7 Results on identifying new energy services and products

The following chapter summarizes key findings of the assessment of revenue and price possibilities with corresponding customer feedback to the mentioned approaches in chapter 3.7.

4.7.1 energy monitoring dashboard

For the energy monitoring dashboard, the following results can be summarized:

- Revenues: basic service should have no price, customer loyalty is the aim
- Costs: continuation of the developed MVP of the monitoring dashboard (described in Del. 2.1, chapter 2.1) will lead to approx. 10.000 EUR p.a. for the existing ski resorts (fix price for hosting and service costs + variable costs depending on the numbers of metering points);
- Benefit: customer loyalty.

A cost revenue estimation for the energy monitoring dashboard is provided in Figure 43: costs vs. revenues DashboardFigure 43:

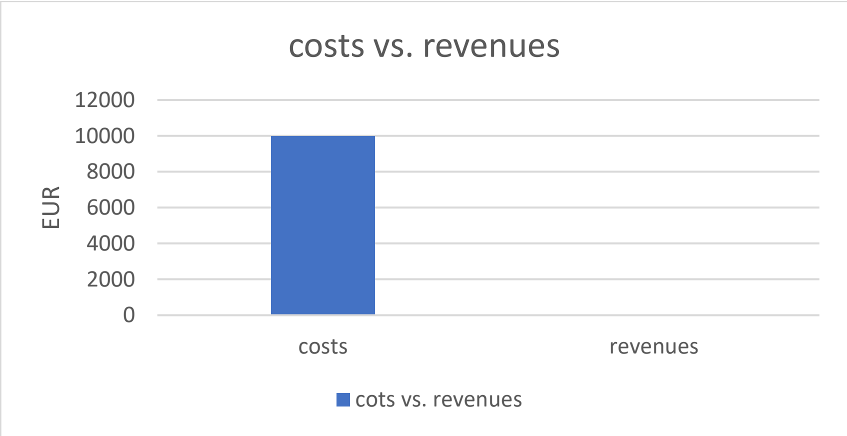


Figure 43: costs vs. revenues Dashboard

User Feedback was picked up via interviews and questionnaires - for example the quote for recommendation to other colleagues (see Figure 44)

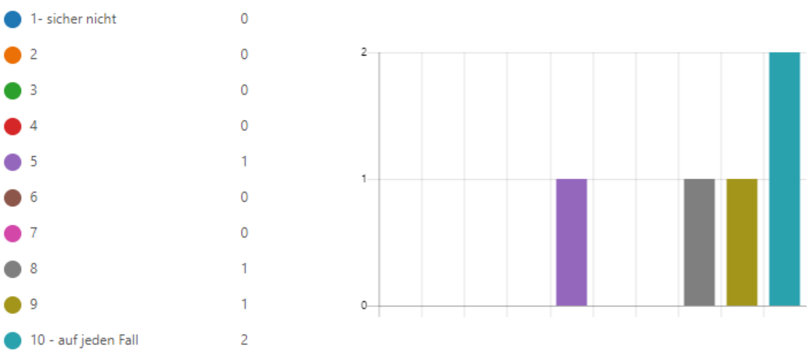


Figure 44: Recommendation Quote

4.7.2 Ski resort operators offer flexibilities to energy supply companies

In sum the flexible usable power for all skiing areas is about 6,7 MW and 2,7 GWh energy use per year. One skiing areas has a flexibility of approx. 12% if it's total electricity consumption (this is about 64% of it's total pumping energy demand).[8] As shown in chapter 4.3.1.1, the calculated saving potential (value

[8] At this point it is important that the flexible power of 6,7 MW is not available for the full year. Some pumps are only available during spring, others only in autumn.

2021, with high energy prices) is approx. 17 EUR/MWh on the energy markets (high price scenario). The years 2019 and 2020 would have been significantly lower. The higher the prices, the higher the possible savings.

Remark: This calculation has been performed by Salzburg AG. A further approach performed by AIT is explained in chapter 4.9.

Partner World Direct has made an offer to operate the flexibilities automatically. Therefore, a VPP has to be ordered. Costs are depending on the number of controllers and assets, which should be connected (see Figure 45).

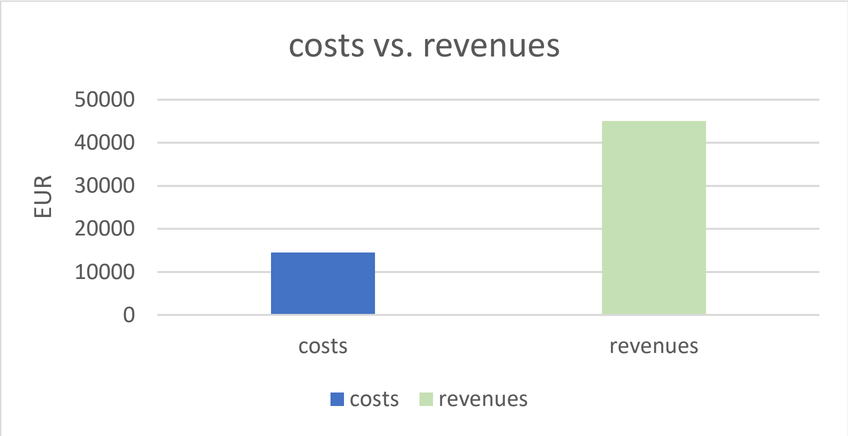


Figure 45: Costs vs. revenues: flexibilities (only energy market, no balancing market)

Due to the fact, that Salzburg AG is running an other VPP product it was agreed, to further use the flexibilities in a very efficient and simple way (arranged and coordinated periods during the year -> arrangement between skiing resort and Salzburg AG).

4.7.3 Ski resort operators give actual and short time information when starting energy intense processes

AIT has identified, that more precise and detailed information about the start and end times of the basic snowmaking periods could lead to cost savings for the energy supply company. The more precise and detailed the dates and times of basic snowmaking are reported, the more energy deviation can be bought or sold on the day-ahead market. Overall, it was found that relative savings of 168 % in 2017 and 56 % in 2018 can be achieved through the information exchange use case. Per year and skiing resorts, those are average savings of 2060 € in 2017 and 1400 € in 2018.

4.7.4 Energy supply company offer services for the establishment of local energy communities

BEST research could offer the tool on the base of hourly rates directly to skiing resorts, but prefers a license-based model that sets the energy supplier in between. This would mean, that at least one person of the energy supply companies should become an expert using that tool. Visualization would be done similar to the Dashboard via Grafana.

4.8 Results on living lab, stakeholder engagement and KPI development

In the last third of the project, feedback of the cable car operators on the usability of project results were collected. They have been asked, if the interim results and the development of the project meet their expectations and what could be improved in the last stage of the project. The following figures show the results from the workshop on May 27th 2021.

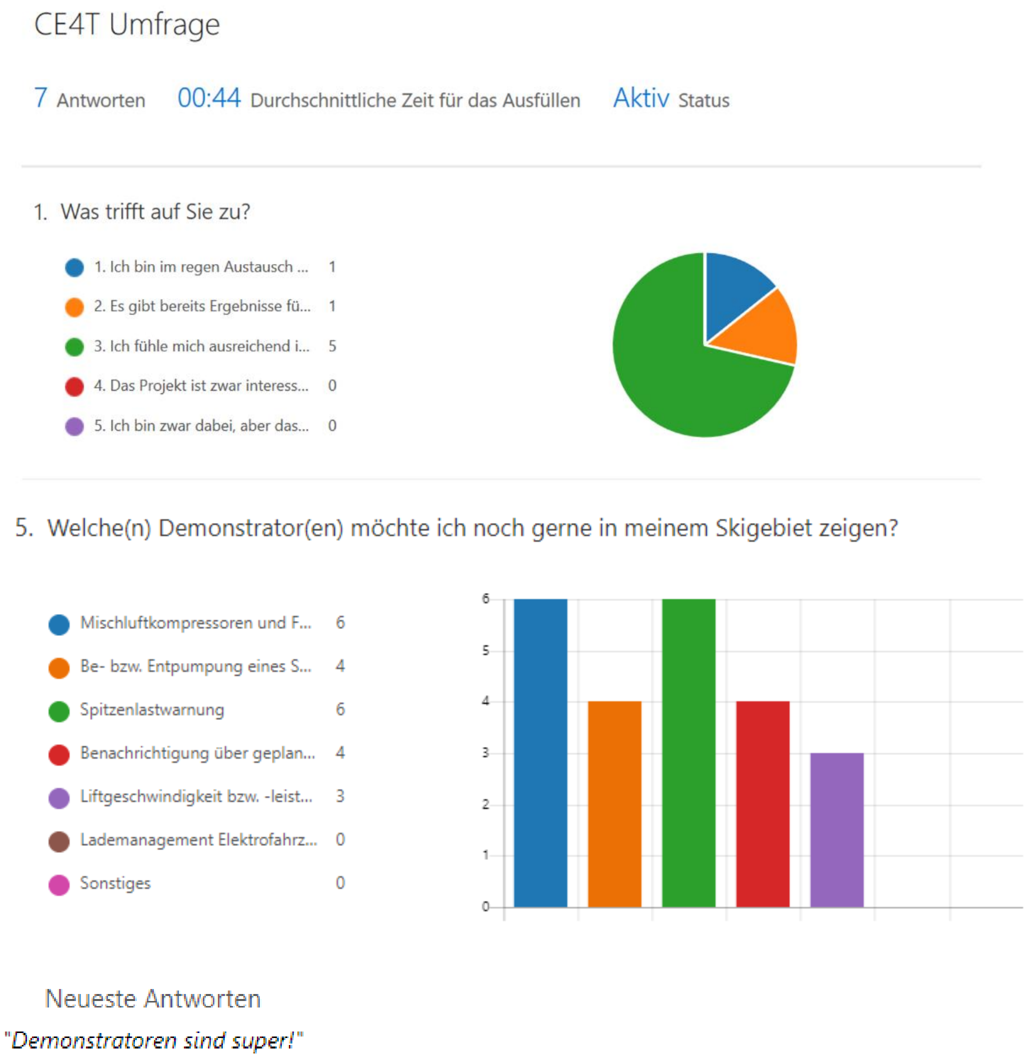


Figure 46: Some user feedback

The positive answers proved that the involvement of the cable car operators was fruitful and that it increases the likelihood of the technology and demonstrators being continued after the end of the project.

In the workshop on January 21st 2022, the CO_2-intensity based on the Austrian electricity mix, the energy costs (as an indicator for the current purchase price via the price on the day-ahead market) and a representation for the avoidance of power peaks were discussed as indicators for the dashboard. As a prelude to the discussion, the purpose and characteristics of Key Performance Indicators were discussed again and different example indicators were presented, such as the ratio of natural snowfall to artificial snow production, the comparison between energy demand and energy production as well as share of the population working in the tourism sector compared to the total employment (related to the municipalities). Reference was also made to the Interreg Alpine Space project “Smart Altitude”: Its participating ski resorts (Krvavec, Madonna di Campiglio, Les Orres, Verbier) and the KPI catalogue elaborated during its project duration. All data processed in the Smart Altitude project were aggregated into KPIs and published only in this form (KPIs) in the deliverables, which could also be used as an example for CE4T. During the workshop, two main topics of interest emerged. These were energy management (energy balance, ISO certification, thermal refurbishment, forms of energy used and applicable, etc.) and a strong focus on CO_2-emissions.

In the last workshop on June 13th, 2022 specific indicators were presented based on the data and information provided by the cable car operators. Afterwards, they were asked to fill out the online questionnaire with the following questions:

1. Are or would KPIs be important for your company? (Answer options from 1 = “very important” to 5 = “unimportant”).
2. Do you already use KPIs in your company for operations and/or decision-making? (Answer options from 1 = “never” to 5 = “very often”).
3. Which KPIs would you need or be interested in? (Multiple answers possible). (Reply options: a.) Energy consumption i.A.; b.) Fuel consumption; c.) Emissions (CO_2, etc.); d.) Snowmaking demand/water consumption; e.) Energy-water-wastewater nexus; f.) Amount of snow produced vs. water consumption vs. energy consumption; g.) Other (please specify).
4. Which of the specific KPIs listed would be of interest to you? (Multiple answers possible) (Reply options: a. Slope alignment and fuel consumption of slope grooming equipment (total or for each slope).; b. Slope inclination and fuel consumption of the slope grooming equipment (total or for each slope).; c. CO_2 emissions for the slopes (taking into account slope equipment, lift operation, slope characteristics).; d. CO_2 emissions per skier for slope/lift system or for the entire operation; e. Height and area distribution of the slopes or lifts; f. Other (please specify).
5. Which KPIs would you suggest? (Multiple answers possible).

In summary, the majority found KPIs important for their business, but they are not always used for operations or decision making. Furthermore, energy emissions and snowmaking related KPIs were named as important. The correlation of emissions to slopes or ski days would also be of high interest. Specifically mentioned was the relationship between energy consumption and Vertical Transport Meter (VTM), taking into account the actual skier frequencies. The discussion was supported using a Jamboard. During the discussion on energy consumption and use, it was repeatedly pointed out that the arrival and departure of guests represents the highest share of the total energy demand. The vacation behaviour of guests (length of stay, origin of guests) was also addressed, which is only partially within the influence of the ski resorts. The workshop participants see the greatest challenge in the fact that previous attempts to replace the fuel currently used, especially for grooming equipment, with other more climate-friendly fuels in the short term have not been very successful (hydrogen, electrification); further ideas go in the direction of synthetic fuels such as GTL (gas-to-liquids, synthetic diesel) or HVO (hydrogenated vegetable oils) also for skier shuttle buses. Important indicators are energy and snow making, whereby the consideration of energy turnover/consumption by metering points or even more precisely would be desirable, whereby a problem of the comparability of the metering points would have to be considered here. Energy demand per skier day (also in combination with relative altitude meters) was mentioned as a good external indicator. For internal indicators, it makes sense to break down by type of slope, differentiating between energy for snowmaking and for slope preparation. The indicators should not be created to compare the ski resorts, which have different prerequisites, but to establish a baseline with which the performance of each individual ski resort can be evaluated. The discussion described moved seamlessly into the discussion of the necessary indicators in the dashboard.
The visualisation of total energy costs within the dashboard does not seem so relevant to the participants and should be avoided altogether. Since the trade association will create a CO_2 calculator, there is therefore no need for the presentation of emissions in the medium term. The breakdown of energy costs is already well provided by energy supplier for each metering point per calendar quarter. The dashboard could rather show the cumulated energy consumption and on daily basis; daily consumption and the possibility to extract time series are very relevant. The question of "the" dashboard user has also been raised, although the typical user does not exist due to the very heterogeneous user group. An even stronger interlinking of different data sources (energy suppliers, cable car operators, etc.) would be desirable for the future.

It proved to be essential that data collection and analysis as well as the development of services and tools needed to be closely coordinated with the cable car operators as future users and implementers. An own project task was dedicated to the living lab approach which helped to steer the user involvement process throughout the entire project. Additionally, the applicability of new technologies and tools could be tested in real settings, which also allowed to link the simulations to real world conditions and needs in the skiing areas. These findings are in line with learning from other living lab processes such as SINTEG, which made clear that a successful living lab has to provide a portfolio of innovation from the design, over validation, scalability and transferability to the established solution.

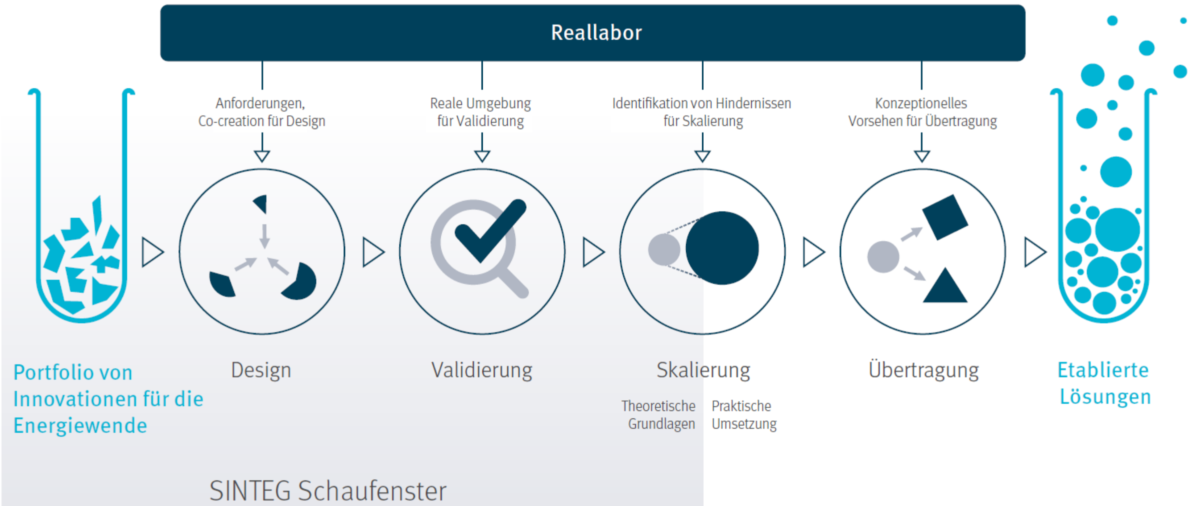


Figure 47: Role of the living lab in the different development stages in the SINTEG-show cases © IFOK; Quelle: Widl et al. 2022[9]

Similar to the SINTEG show cases, CE4T reached the first 3 steps – design, validation and a theoretical basis for scalability: Use the real environment as comprehensively as possible: In order to be able to use the real environment comprehensively, it is first necessary to clarify which areas can be tried out in the real context, which areas require an active design of environmental parameters up to the simulation, and which areas can be transferred from the simulation to the real context in the course of the project. In CE4T it could be shown that there is a lot of technological potential. However, this is not practical when tested "in the field" or requires more comprehensive, namely also organisational solutions. Especially in the tourism sector, the acceptance of organisational and technological innovations is an essential factor in turning a theoretical potential into a real potential. The intensive exchange with the cable car operators and their integration as equal partners was therefore essential in order to develop practical solutions.
- Targeted use of analysis and simulation tools: In order to quantify the potential of typical regional solutions and to fully exploit the possibilities for scalability and transferability, appropriate analysis and simulation tools are required. The simulations were able to support the quantification of the potentials of flexibilisation measures and to run different scenarios. It turned out to be essential that both the tools and the simulation results were repeatedly discussed with the users, the cable car operators, and further developed according to their feedback. This is the only way to ensure that relationships and potentials are realistically depicted and that the tools continue to be used by the users after the end of the project. Furthermore, the methodology developed can also be transferred to other regions or applied under different framework conditions. Thus, future scenarios with, for example, higher energy prices can be simulated and presented. This helps to scale the findings from the real tests and to raise them to a generic level or to transfer them to future framework conditions.
- Focus on regional anchoring and establish systematic interfaces between large consumers, energy suppliers and grid operators: The cable car operators are the regional key players for energy-intensive winter tourism in the region. Even if the cable car operation per se does not cause the largest energy consumption and CO_2-emissions in the region, the related activities such as slope equipment, feeder traffic, arrival and departure traffic and heat demand in the hotel industry do. Through its intensive involvement of regional actors, the CE4T project has given a massive impulse towards the energy transition in the region. The project "100% renewable Pinzgau" and the exploratory study "TANZ - Tourism as an opportunity for the energy transition" followed during the project term. It has strengthened cooperation and the basis for discussion between the major consumers, cable car operators, energy

[9] https://www.sinteg.de/fileadmin/media/Ergebnisberichte/SF4_Reallabore/20220502-SINTEG-SyF4_bf.pdf

supplier Salzburg AG and the grid operator Salzburg Netz GmbH, as well as the research institutions and technology providers. Last but not least, the exchange and learning between the individual cable car operators in the region was supported.

4.9 Results on optimization - overall system & scenario evaluation

4.9.1 CO2 vs. energy costs

The optimizer cannot only optimize for a single objective but can solve multiple objectives together. Such a multi objective optimization can be, for example, the reduction of the CO_2-footprint of consumed energy and the minimization of costs from buying energy on the day-ahead market. However, there is in general no single solution which has both the minimum costs and the minimum CO_2-footprint. Therefore, a trade-off must be made.

The following scenario investigates the solution space of the trade-off for the refilling of a water reservoir. In this scenario the energy costs of the day-ahead market are compared with the CO_2-footprint of the consumed energy[10]. The demonstrator showed that on average, *4.6 % energy can be saved* in the off-season when operating the analyzed ski lift with the slower speed of 4.0 m/s but with 45 cabins instead of 4.5 m/s and 40 cabins. shows the results for 2000 different scenarios including 100 different baselines. In the baselines, it is assumed that the water reservoir is continuously filled until it is full. Each baseline assumes that the beginning of the refilling start at a different time. On the x-axis, the energy cost savings on the day-ahead market are plotted and on the y-axis the CO_2-savings. For the calculation of the savings the optimized schedules are compared with the baseline schedules. Each blue data point represents the result of one optimization/baseline comparison. The yellow regions mark regions where the CO2-savings or the energy cost savings are negative and thus, the optimization performs worse in one of the metrics than the baseline. However, in this scenario most data points have positive CO_2 and energy cost savings and perform, therefore, better than the baselines.

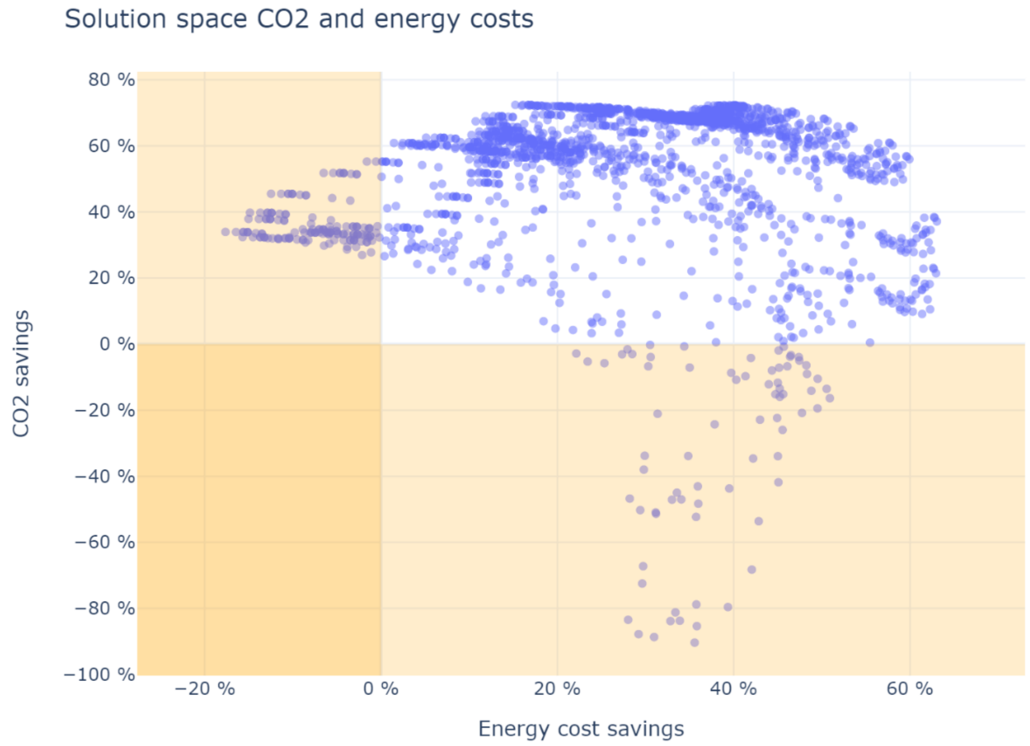


Figure 48: Solution space for the optimized refilling of a water reservoir with 100 baselines

[10] For the CO_2-footprint the CO2-intensity of the energy in the entire Austrian grid including imports from and exports to neighbouring countries.

The trade-off can be represented as a pareto-front. For each point in the pareto-front, no point exists which has better CO_2-savings and energy cost savings. This pareto-front is shown as a red line in Figure 49 for a single baseline. For example, a solution exists (right most point of the line) with 51,03 % energy cost and 6,88 % CO2-savings. The next point above has 46,9 % energy cost and 34,74 % CO2-savings. This means by reducing the energy cost savings by $51{,}03\ \% - 46{,}89\ \% = 4{,}14\ \%$, CO2-savings can be increased by $34{,}74\ \% - 6{,}88\ \% = 27{,}86\ \%$. Thus, by reducing the energy cost savings only slightly, significant CO2-savings can be achieved. The slope of the pareto-front decreases when the CO_2-savings should be further increased which means that it gets more expensive to reduce the CO_2-savings to the same amount. For example, increasing the CO_2-savings from 34,74 % to 58,08 % (increasing of 23,34 % CO_2-savings), reduces the costs savings from 46,89 % to 19,75 % (decrease of 27.14 % energy cost savings).

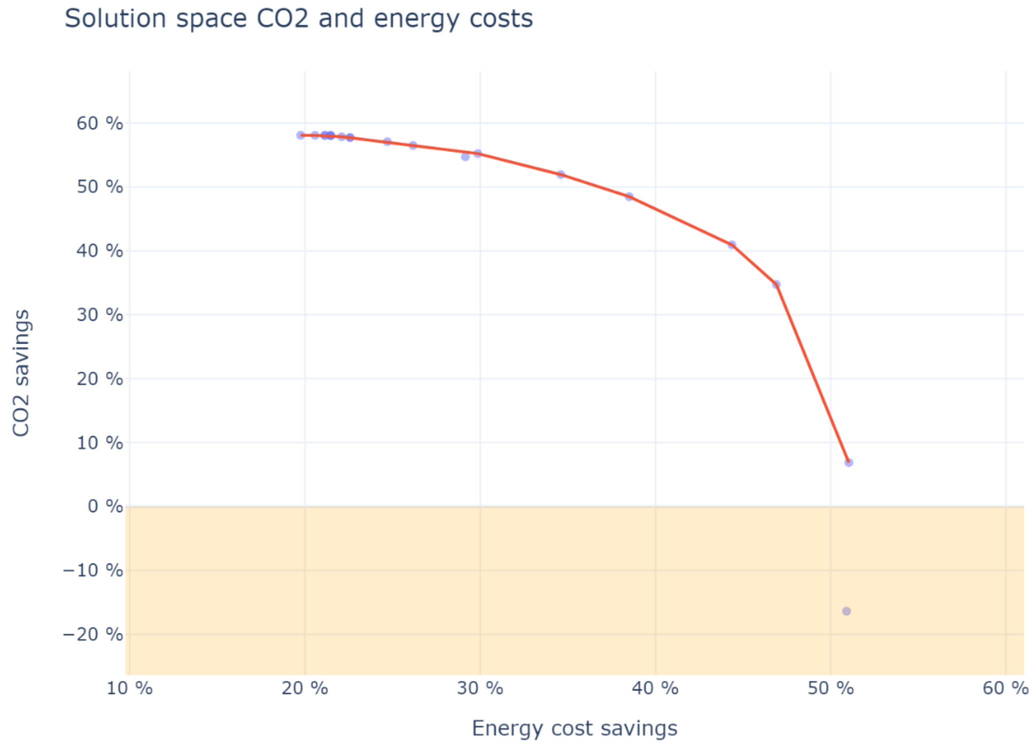


Figure 49: Solution space for the optimized refilling of a water reservoir with a single baseline

4.9.2 Aggregated power peak

In the next scenario, the resulting power peaks are analysed when many devices are optimized towards an energy market. Then, it is investigated how much those peaks can be reduced when the optimizers target is the minimization of the aggregated power demand of all optimized devices.
For the scenario 60 devices are optimized. In Figure 50 the aggregated active power demand is shown, when these 60 devices are optimized for reducing the costs on the day-ahead market. It can be seen as a result from the optimization, that the morning peak (6 – 9 a.m.) and the afternoon peak (5 – 9 p.m.) is avoided. In those hours an increased energy demand exists which increases the energy market prices. As a result, the optimizer shifts most of the load demand into the night hours when the prices are cheapest. This power demand results in high coincidences which can lead to power peaks.

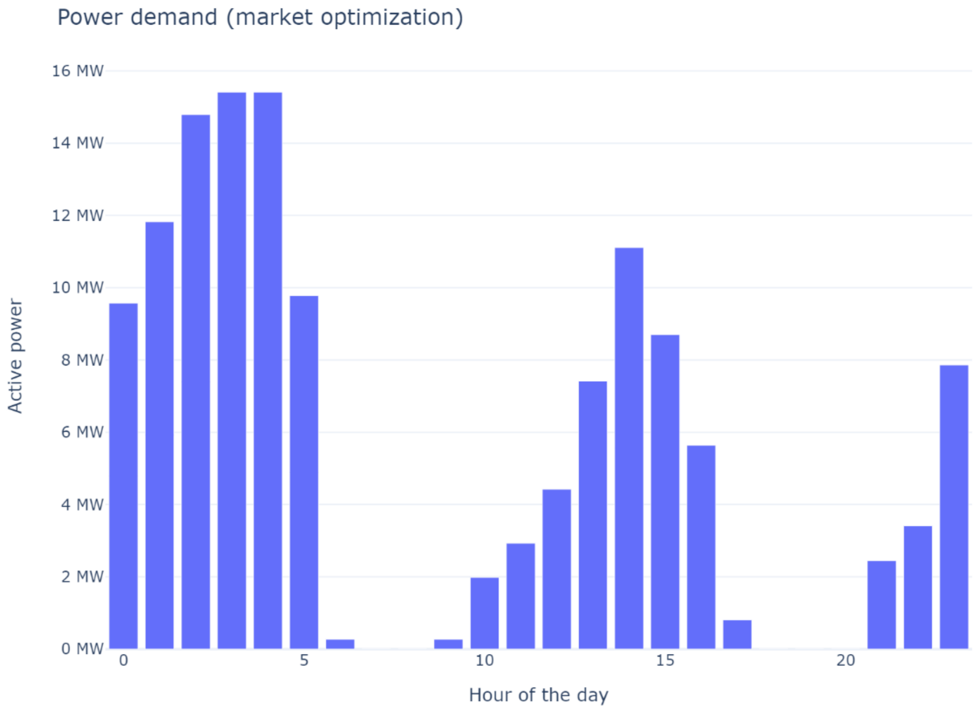


Figure 50: Power demand when optimizing 60 mixed-air compressors and fountain pumps on the day-ahead market

In the following, the goal of the optimization problem is to minimize the maximum aggregated active power demand of all devices. In Figure 51 the comparison of the power peaks is shown when scaling the number of devices from 1 to 60. On the x-axis, the number of devices is plotted. In the upper plot, the total power peak is shown when minimizing the costs for purchasing energy from the day-ahead market (blue) and when minimizing the aggregated power peak of the mixed-air compressors/fountain pumps.

In the lower plot the reduction of the power peak is shown when minimizing the peak in comparison to the optimization on the day-ahead market. The reduction varies between 21,04 % for 5 devices and 51,70 % for 15 devices.

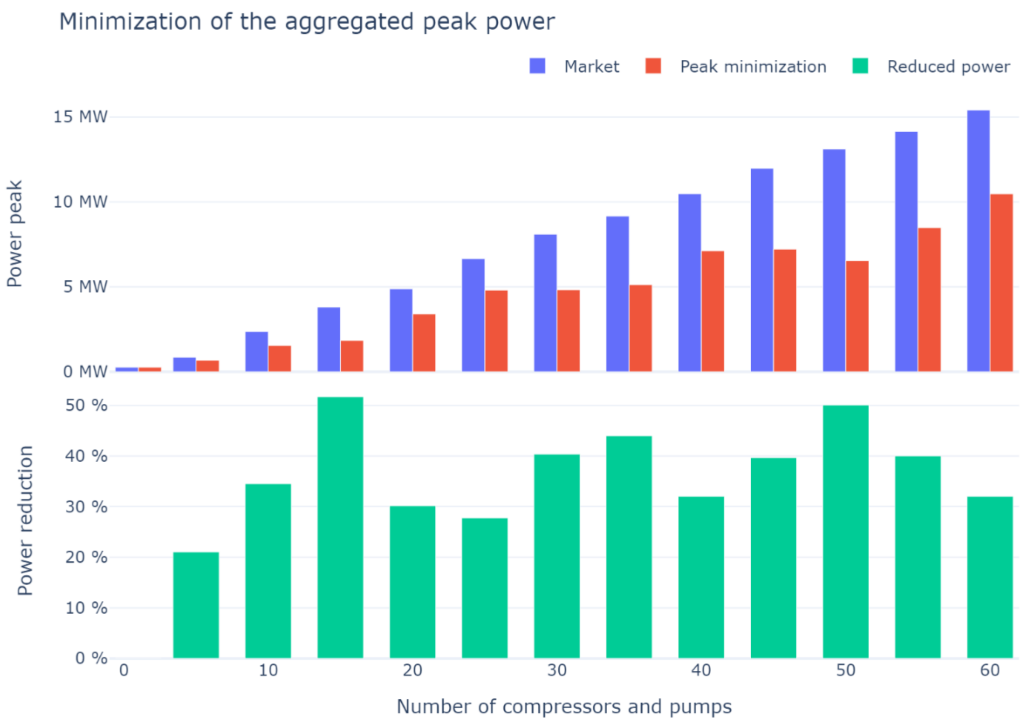


Figure 51: Comparison of the power peak when optimizing for the minimization of costs on the day-ahead market (blue) and when minimizing the aggregated power peak (red). In green is the power reduction shown when minimizing the power peak in comparison to the minimization of energy costs.

4.10 Results on the transferability to the energy-intensive industry

The comparison of the processes as well as the approaches, algorithms and methods for the processes considered in the skiing area to the energy-intensive industry shows that only a few processes in the energy-intensive industry have sufficient similarities for a direct transfer.

4.10.1 Comparison of processes

Table 7 shows selected results of the process comparison, which was carried out on the basis of the determined KPIs and flexibility potentials for the identified processes as well as taking into account the other identified parameters. The results show that there are similarities between the industrial processes and those in the skiing areas. However, due to the dependencies between the processes, the similarities are not sufficient to be classified as similar.

Sector	Process	Description
Iron & Steel	Electric Arc Furnace	• Discontinuous • High process dependency • Short-term compensation of load • Change of operation effects the whole process chain
Iron & Steel	Dedusting	• Discontinuous • High process dependency prevents load shifting
Iron & Steel	Recoil plant	• Discontinuous • Low process dependency • Mostly high utilization of the process à Load shifting potential low

Cement production	Raw Mill	• Discontinuous • Low process dependency due to storages & cement production • Storage for input and output material available • Load shifting possible
Cement production	Rotary Kiln	• Continuous • High process dependency • Change of operation effects the whole process chain
Lime production	Material Mill	• Discontinuous • Low process dependency due to storages • Load shifting possible
Refractory production	Material Mill	• Discontinuous • Low process dependency • Load shifting possible
Chlorine production	Electrolyzer	• High process dependency • Continuous operation (electrolyzer designed for full load operation) • Short-term compensation of load

Table 7: Results of the process comparison for selected processes

Some processes in the energy-intensive industry showed high flexibilities in the initial analysis. However, the detailed analysis indicates that most processes have high process dependencies. Although some processes are batch operated, they are still integrated into the process chain in such a way that turning the process on and off can rarely be used as flexibility. In practice, load shifting is usually only possible in the minute range. Continuous processes are usually designed for full-load operation, so that also for these processes' flexibility is only available in the minute range. In addition to the high dependency between the processes within a process chain in the energy-intensive industry, various secondary conditions (which primarily influence the quality of the product) and operation at the optimum operating point also play a significant role. The optimum operating point is usually not the optimum in terms of energy or costs, but is defined as the operating point at which the required quality of the intermediate or final product is achieved. Only minor changes in the process can lead to significant changes in product quality. This means, for example, that small fluctuations in temperature and oxygen in a rotary kiln can already have a considerable influence on the product quality of the clinker.

4.10.2 Comparison of approaches, methods and algorithms for operation optimization

The described process dependencies between the processes themselves, as well as the requirements for quality and the associated optimal operating point of processes, make the creation of mathematical models for operational optimization extremely complex. Since the two optimized and demonstrated processes were two independent processes; care was taken to identify such processes in the energy-intensive industry as well. Therefore, the transfer of the applied approaches, algorithms and methods to a raw mill in a cement plant was analyzed.

The design of the raw mill and its operation is in most cases closely based on the rotary kiln in the mill. The capacity of the raw mill is designed to be slightly larger than necessary for the continuous operation of the rotary kiln in order to ensure the availability of raw meal in any case (e.g. due to mill breakdowns and maintenance). For reasons of emissions and efficiency, the raw mill operation is usually carried out in combined operation with the clinker production. In practice, the combined operating times are usually more than 80 % of the operating time (corresponds to around 7000 full load hours per year). Direct operating times without operation of the raw mill are used for maintenance and repair work of the raw mill. (Arnold, K.)

As the comparison show, the chosen method can be applied to processes with similar characterization (like those considered in the skiing areas) and low process dependence. The mathematical model required for the optimization had to be newly created for the selected process (raw mill). The raw mill was not directly modeled. The focus was on the minimum quantity to be produced per day. This means that the number of hours the raw mill must be operated (full load) to produce the required minimum quantity is given. Since the operation of the raw mill is designed for the cement production schedule (rotary kiln). Deviations from the production plan are due to maintenance or, for example, technical breakdowns and problems with the delivery / extraction of the raw material. In order to avoid an impact on the cement production in case of technical failures, storage facilities are available. An extension of the model would be the consideration of storage facilities (e.g. silo, storage facility), which are available before and after the mill. Through these storages, the quantity to be produced per day acts as a variable parameter in the mathematical model.

However, due to the similarity of the parameters required for the optimization, some relationships could be adopted. Although the raw mill in a cement plant looked very promising in terms of utilization of flexibility, the results of the optimization show only a minor cost saving at a high annual utilization (7000 full load hours per year). At low utilization rates (2920 full load hours per year), the results even show an increase in costs, which can be attributed to the additional operating time required for the turn-on and turn-off processes. The duration of the turn-on and turn-off time depends on the mill type, size and product. In the simulations, one hour was calculated for each turn-on and turn-off process. This means that for each turn-on and turn-off process an additional working time of the mill of one hour is added. Regarding CO_2 emissions, there is no reduction in emissions in any scenario. For practical application, an additional constraint is added to the optimization algorithm. This constraint allows the operation after an optimization only if a cost reduction is possible for this day (24 hours), otherwise the mill is operated according to the schedule, the same applies to the CO_2 emissions savings. On individual days, higher cost savings or a reduction (also in CO_2 emissions) is possible, but in order to test this in practice, it is necessary to add further constraints to the mathematical model and the optimization approach. These include, for example:

- Real load profile of a raw mill (schedule) incl. planned downtimes
- Consideration of the power peak when starting up the raw mill
- Actual time required for turn-on and turn-off of the raw mill depending on type, size and product

5 Outlook and recommendations

This report shows precise and practical results for technical feasible flexibilities and market revenues. As outlined, some but not all developed tools in CE4T will lead to further usage.

The technologies and solutions developed in CE4T can be transferred to other tourism regions in and outside of Austria as well as to other energy-intensive industrial branches, where the interrelations between big energy consumers (such as industrial companies), grid operators and energy provider shall be optimized (especially technology development).

5.1 Recommendations for skiing area operators and regional stakeholders

- In future, skiing resorts should prepare for pump storage application when building new infrastructure. With manageable efforts (bigger pipes to reduce friction losses,..) this will help to balance the overall energy system.

  As shown in use case water reservoir Asitz 1 and Asitz 2 (a common use case), a later update of pumping stations to a pump storage plant is often not economically reasonable.

- When constructing new technical units in ski resorts (for example lifts, snowmaking systems, pumps, mixed air compressors, ...), it is important that the corresponding technical interfaces are provided right from the start and implemented as standard in these systems. Attention must be paid to whether the interface is used for monitoring or also for controlling the units via an automated control system. It is essential that the corresponding signals are made available for each use case in advance during the building of the unit. This saves time and money in comparison in implementing the interfaces at a later time. The consortium recommends the implementation of Modbus TCP or RTU interfaces[11].

- Skiing resorts can use existing flexibility for reducing energy procurement costs (in this project up to 17 EUR/MWh). Relevant cost savings could be pass through (from the energy supply companies), if the energy supply company is using the flexibility for energy market optimization.

- Beside the technical prerequisites, the organizational overhead for integrating technical units is relevant. There are several organizational steps involved for integrating various units. Third party contacts in charge of the unit control systems must be contacted at an early stage so that interfaces can be implemented efficiently.

- The energy demands of ski resorts have extreme characteristics. For example: building a ski lift offers space for a 30 kWp PV system, but the lift performs with 500 kW. Often the lift operates mainly in winter with low solar output and is shut down in the summer.

- Regional energy communities (REC) are a possible instrument for skiing areas with large number of metering points scattered throughout the area. Thus, generated electricity can be allocated from one metering point to another and can strengthen the economic relations of the skiing area with local households, hotels, governments, etc. which lead to higher acceptance in the regional population.

[11] In the field of automation interfaces, Modbus has in many cases become the quasi-standard in continental Europe. Interfaces and signal lists can be provided by the consortium for future implementation. Next to Modbus Interfaces also other Interface Types like data via XML-Files or analogue and digital I/Os were used within the project

- For mobility and diesel-powered snow groomers, different drive solutions were considered including biofuel (bioethanol, biodiesel), electrification, Fisch-Tropsch process and hydrogen. Unfortunately, these concepts indicate technological barriers which need more research. Hydrogen-driven busses are already available on the market and local hydrogen production can be implemented.

5.2 Recommendations for energy supply companies

- At the first view, regional energy communities (REC) seems to reduce the relationship between skiing areas and those energy supply companies, but it offers new potentials. On the one hand, the bureaucratic effort for ski area is very high and far from their main competence. On the other hand, energy supply companies can provide services and infrastructure.

- A energy dashboard will improve customer loyalty (with live-data as additional service). There is a customer pain, need and a market! Business portals can offer such services.

- More knowledge oft the existing customer pool concerning flexibilities leads to optimization potential and possible cost savings. For skiing resorts, the project hast worked out detailed KPI's (like the mentioned 17 EUR/MWh of flexible power). Salzburg AG will pursue talking with the involved (as well as new) ski resort operators to optimize flexibilities within different markets.

- Using flexibilities in skiing resorts for the balancing energy market is very complicated (for the investigated skiing resorts it was no suitable solution found).

5.3 Recommendations for technology development companies

- Concepts and products for environmentally friendly, scalable and flexible renewable energy sources and storages have to be further developed which leads to mentionable market chances.

- The consortium recommends the implementation of Modbus TCP or RTU interfaces for flexibility usage.

- The technologies and solutions developed in CE4T can be transferred to other tourism regions in and outside of Austria as well as to other energy-intensive industrial branches.

5.4 Recommendations in the field of electricity market regulation / DSO topics / legal

- Within the current regulation, there is a cost part for the monthly power peak at the meter. If a flexibility provider runs within the already occurred monthly power peak, no additional costs are charged. But if the flexibility provision creates a higher monthly peak value, this power consumption must be paid in the network tariffs. This topic should be addressed, so that if customers use their flexibility in a "grid friendly way", these customers are not charged a higher peak power fee for that.

- In contrary to an industrial company with one site and therefore typically one metering point, skiing area typically have more than one metering point at various locations. Therefore, the flexibility provision must be made at every single metering point. If a global flexibility provision for the whole skiing area is desired, then the regulatory framework must be adopted, so that also the flexibility provisioning is metered as a sum for all of the metering points.

- Skiing resorts see disadvantages compared to other industries due to scattered infrastructure & metering points. Salzburg Netz GmbH has not completely agreed with the declaimed arguments but will discuss the topic of virtual metering points within "Österreichs Energie".

6 Bibliography

Mimm G.: „*Kunstschneeanlagen als Stromspeicher, Sekundärnutzung von Beschneiungsseen als hydraulische Energiespeicher in Österreich*", Diplomarbeit TU Graz, 2018

Arnold, K., et.al.: *Flexibilitätsoptionen in der Grundstoffindustrie. Methodik, Potenziale, Hemmnisse. 1. Auflage. Edited by Florian Ausfelder, Antje Seitz, Serafin von Roon. Frankfurt am Main: DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V., 2018*

7 Project Partners

- Salzburg AG für Energie, Verkehr und Telekommunikation (Projektleitung)
- AIT Austrian Institute of Technology GmbH
- Montanuniversität Leoben – Lehrstuhl für Energieverbundtechnik
- BBSH Bergbahnen Saalbach-Hinterglemm GmbH
- Leoganger Bergbahnen GmbH
- Bergbahnen Fieberbrunn GmbH
- Rauriser Hochalmbahnen AG
- Saalbacher Bergbahnen GmbH
- Hinterglemmer Bergbahnen GmbH
- Oberpinzgauer Fremdenverkehrsförderungs- und Bergbahnen – AG
- Faradis GmbH
- Schmittenhöhebahn AG
- Gletscherbahnen Kaprun AG
- World-Direct eBusiness solutions GmbH
- sattler energie consulting GmbH
- BEST – Bioenergy and Sustainable Technologies GmbH