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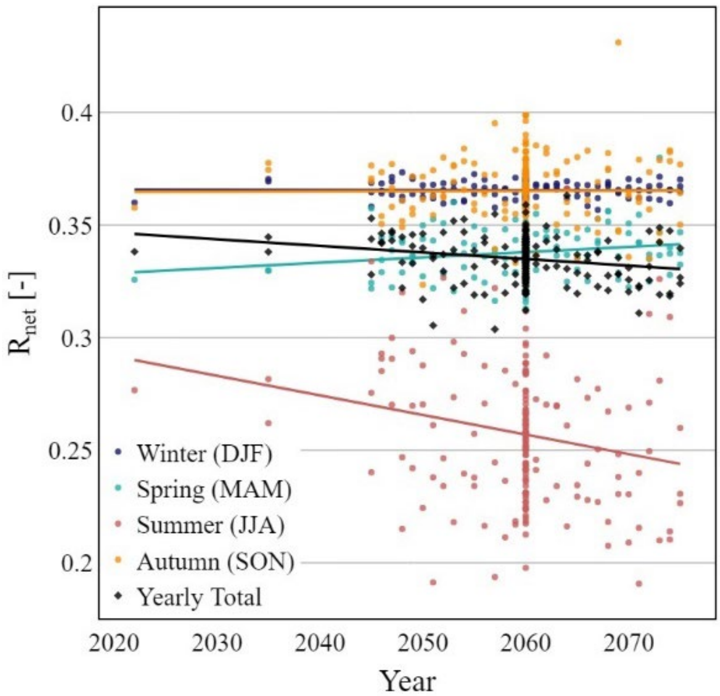
Annual Report 2022

SolResHC 2

Solar Resources for heating and cooling (Phase 2): SPF contribution to IEA PVPS Task 16 «Solar resource for high penetration and large scale applications»



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Zusammenfassung

Mit zunehmendem Anteil der Erneuerbaren Energien an der Energieversorgung weltweit nimmt die Notwendigkeit zu, Erträge solcher Anlagen vorherzusagen. Das Messen meteorologischer Daten und deren Bewertung sind eine Grundlage für eine bessere Vorhersage der Energieerträge aus solarthermischen und photovoltaischen Anlagen. In diesem Umfeld agiert der IEA PVPS Task 16.

Das SPF beteiligt sich durch Auseinandersetzung mit dem Einfluss unterschiedlicher Jahresverläufe der Einstrahlung und Temperatur auf die Vorhersagequalität.

Für Activity 2.4 werden Auswirkungen zukünftiger Wetterszenarien auf solares Heizen und Kühlen ermittelt. Es werden Simulationen für verschiedene Zukunftsszenarien durchgeführt, um die Auswirkungen der Wetterdaten auf die energetische Effizienz eines PV-Wärmepumpensystems zu ermitteln, welches den Heizwärme-, den Kühl-, Warmwasser- und Strom-Bedarf für ein Mehrfamilienhaus abdeckt. Die Systemeffizienz der verschiedenen Zukunftsszenarien wird anhand der Netzaufwandszahl bestimmt. Die Ergebnisse zeigen, dass die Netzaufwandszahl für den Standort Zürich in der Schweiz in Zukunft wahrscheinlich sinken wird, was hauptsächlich durch einen Anstieg des Kühlbedarfs im Sommer aufgrund steigender Temperaturen in Verbindung mit hoher Einstrahlung verursacht wird.

Für Activity 3.5 wird eine erste Bewertung des Einflusses einer hohen Einspeisung von PV und erneuerbaren Energien auf das Stromnetz der Schweiz durchgeführt. Die Ergebnisse zeigen Kosteneinsparungen, welche durch den Ausbau des Anteils erneuerbarer Energien (und PV) in der Schweiz erzielt werden. Darüber hinaus gab es eine Online-Teilnahme am Task-Meeting im Frühjahr sowie eine physische Teilnahme an der Tagung in Freiburg im September.

Summary

With the increasing share of renewable energies in the global energy supply, the need to predict the yields of renewable energy systems is growing. Measuring and evaluating meteorological data provides a basis for better forecasting of energy yields from solar thermal and photovoltaic systems. The IEA PVPS Task 16 operates in this environment.

The SPF participates in the analysis of the influence of different annual irradiance and temperature patterns on the prediction quality.

For Activity 2.4, some of the impacts of future weather scenarios on solar heating and cooling are evaluated. Transient simulations are carried out for different future scenarios to evaluate the impact of the weather data on the energetic efficiency of a PV heat pump system delivering heating, cooling, domestic hot water, and electricity to a multi-family residential building. The system efficiency of different future scenarios is assessed based on the grid purchase ratio. The results show that the overall grid purchase ratio is likely to decrease in the future for the location of Zurich Switzerland, which is mainly caused by an increase in cooling demand during summer due to rising temperatures that come together with high irradiation.

For Activity 3.5, a preliminary evaluation of the influence of high PV penetration and renewables on the electricity grid of Switzerland is performed. The results highlight the cost savings achieved upon expanding the share of renewables (and PV) in Switzerland.

Furthermore, there was an online participation at the task meeting in spring, as well as physically at the meeting in Freiburg in September.

Contents

Abbreviations

SFOE	Swiss Federal Office of Energy
SPF	Institute for Solar Technology
OST	Eastern Switzerland University of Applied Sciences
IEA	International Energy Agency (Paris)
PVPS	Photovoltaic Power Systems Program
SIA	Swiss Society of Engineers and Architects
PV	Photovoltaic
CSP	Concentrated Solar Power
RCP	Representative Concentration Pathway
ERA	Energy Reference Area
ST	Solar Thermal
GB	Gas Burner
ASHP	Air Source Heat Pump
DHW	Domestic Hot Water
SH	Space Heating
R_{net}	Grid purchase ratio
DJF	December, January, February
MAM	March, April, May
JJA	June, July, August
SON	September, October, November

1 Introduction

1.1 Background information and current situation

IEA PVPS Task 16 aims to reduce barriers to high market penetration of solar energy and to facilitate the planning of large scale applications. This includes the efficient processing of solar resources to predict energy contributions from photovoltaics and solar thermal technologies, and the relationship to other renewable and weather-dependent energy sources. Different subtasks highlight methods for measuring irradiance, available products, the value of prediction, or data processing procedures.

SPF is active in the following subtasks:

Subtask 2 – Enhancement data and bankable products (Subtask lead: Philippe Blanc, MINES ParisTech, FRA):

Activity 2.4 – Long-term inter-annual variability (Activity lead: Kristian Nielsen, DMI, DNK)

Subtask 3 – Evaluation of current and emerging solar forecasting techniques (Subtask lead: Elke Lorenz, Fraunhofer ISE, DEU)

Activity 3.5 – Firm power generation (Activity lead: Richard Perez, SUNY, USA)

1.2 Purpose of the project

As the share of renewable energy generation in the energy mix increases, new system mechanisms must be implemented to use the generated energy efficiently and to substitute energy generation from conventional power plants. This includes new storage technologies, intelligent energy management systems as well as accurate predictions of climatic conditions and the resulting outputs and energy yields of solar energy generation. If any of these building blocks are insufficiently developed, market expansion will stall. This project aims to analyze solar sources with sufficient accuracy and to further develop and use forecasting tools in a meaningful way, thus smoothing the way for further expansion of solar power generation.

For activity 2.4, multi-year weather data sets are investigated. Among other things, artificially generated as well as measured data sets are compared. Investigations of uncertainty and different methodologies are core topics. With the extension of Task 16 comes an additional focus on RCP (Representative Concentration Pathway) scenarios and climate change.

Furthermore, simulations regarding the influence of solar resources in the evaluation within the EU project NEWCLINE – which investigates concentrated solar power plants with salt storages – are planned.

Activity 3.5 focuses on the transition from volatile to firm solar power production. In addition to various technical aspects, the economic hurdles and opportunities will also be assessed.

1.3 Objectives

In activity 2.4 SPF contributions focus on solar energy applications (thermal or PV & heat pump) for heating and cooling. The following questions will be investigated:

- The Influence of artificially generated weather data on the simulated system performance compared to measured weather data.
- Differences between simulations with single "Test Reference Year" weather data sets compared to multi-year simulations with measured data.
- Influence of different future scenarios (changes of irradiance intensity and distribution) on different application areas. The radiation development of the past shall be included. In particular, the influence on the selection of different storage types (hourly to seasonal) will be investigated.

Within activity 3.5 SPF aims to investigate correlations between solar resources and other renewable energy resources such as wind or water in the period of days, weeks, or seasons and to find conclusions for the evaluation of the market value of solar energy in future energy systems with a high share of renewable energies.

2 Procedures and methodology

2.1 Activity 2.4: Methodology of Future Weather Data Evaluation for Solar Heating and Cooling

Disclaimer: The Content of this section (2.1) was presented at the WCPEC-8 conference in September in Milan[1].

Based on the Literature Review presented in the last yearly report, simulations were conducted with future weather data for a multifamily building with a PV-powered air source heat pump for heating and cooling.

2.1.1 Future Weather Data Sets

For the analysis within activity 2.4, the following sources were chosen for the location of Zurich (SMA):

CH2018 Climate Scenarios [2]:

These scenarios contain 68 different datasets for regional and global climate models. They contain the three RCP scenarios 2.6, 4.5 and 8.5, and are available in daily resolution for the years 1980-2100.

Climate Scenarios Indoor Climate (IC) [3]:

These datasets are based on the CH2018 Scenarios and are intended to be used for building design. They contain design reference years (DRY), that represent a normal year as well as extreme years, labeled *1 in 10 hot summers* (1in10). The dataset includes a total of 6 subsets, consisting of each a DRY and a 1in10 set for the RCP8.5 scenario in both 2035 and 2060 as well as for the RCP2.6 scenario in 2060.

Meteonorm (MN) [4]:

A tool to get weather data for every location in the world. It contains datasets of the past, average datasets of the present, as well as datasets including future scenarios.

From these sources, the following five sets were chosen for the location of Zurich (weather station Fluntern/SMA) in Switzerland:

- The year 2060 was selected for all 68 CH2018 scenarios. This set is named **60S** in the following.
- For all 68 scenarios from the CH2018 set, the average irradiance over 30 years, i.e. from 2045 to 2075 was evaluated and compared. Three of the RCP8.5 scenarios were then selected: the one with the lowest average irradiance, the one with the highest average irradiance and the one where the average irradiance is closest to the IC DRY RCP8.5 2060 data. Those three sets of 30 years are referenced in the following as **30Y**.
- All *Climate Scenarios Indoor Climate* together make up the **IC** dataset.
- Based on the IC DRY RCP8.5 2060 dataset, the irradiance was artificially altered by multiplying the whole timeseries with a constant between 0.9 and 1.1 in order to get the influence of only the irradiance, independent of the temperature. This parametrically changed dataset is called **PAR**.
- From Meteonorm, a reference dataset for current weather, as well as the three RCP scenarios 2.6, 4.5 and 8.5 for the year 2060 were selected for the **MN** dataset.

An overview of the evaluated weather datasets is given in the following Table 1:

Table 1: Weather dataset overview.

Shortname	Source	Scenarios	Years	Set Size
60Y	CH2018 Climate Scenarios	RCP2.6 RCP4.5 RCP8.5	2060	68
30S	CH2018 Climate Scenarios	RCP8.5	2045-2075	90
IC	Climate Scenarios Indoor Climate	RCP2.6 RCP4.5 RCP8.5	2035 2060	6
PAR	IC RCP8.5 2060	-	2060	13
MN	Meteonorm	Reference RCP2.6 RCP4.5 RCP8.5	Presence 2060	4

When analyzing the data on a seasonal level, the seasons are defined as follows:

- Winter: December, January, February (DJF)
- Spring: March, April, May (MAM)
- Summer: June, July, August (JJA)
- Autumn: September, October, November (SON)

2.1.1.1 *Weather Data Processing*

Weather data from the CH2018 scenarios is only available in a daily resolution. As the dynamic simulations need at least an hourly resolution for the input data, the data was resampled to hourly using Meteonorm.

2.1.2 Simulation Methodology

Dynamic simulations are carried out with the open source module pytrnsys [5] that uses the commercial software TRNSYS 18 [6]. The simulations are done in order to assess the influence of the different weather data files on the efficiency of a multi-family residential building with PV and an air source heat pump.

2.1.2.1 Simulation Environment

The simulated system contains the following components:

- Multi-family building
- PV panels
- Air source heat pump (ASHP)
- Two sensible heat storages, one for space heating/cooling and one for domestic hot water
- Control system

An overview of the system is given in Figure 1.

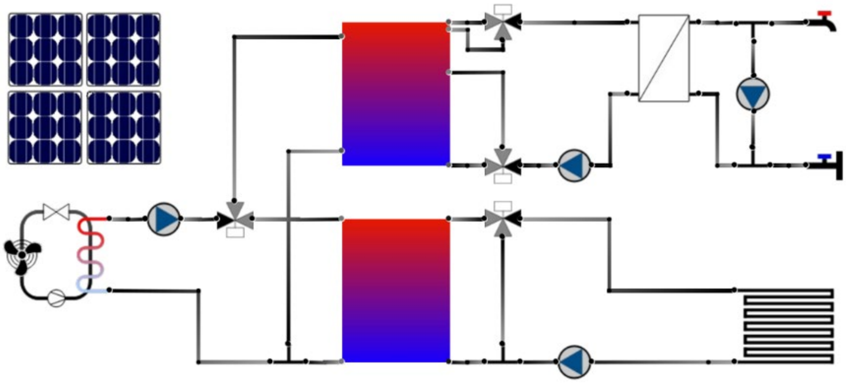

Figure 1: Photovoltaic system with air source heat pump (PV-ASHP)

The multifamily building [7] has six apartments and a reference total yearly heat demand of 60.8 MWh/a for the MN reference weather file. The domestic hot water (DHW) demand is constant for all simulations and equals 17.2 MWh/a. The space heating (SH) demand changes depending on the weather file. For the reference MN case it equals 43.6 MWh/a, the corresponding cooling (SC) demand equals 5.8 MWh/a.

The household (HH) electricity demand is constant at 16.2 MWh/a. The PV field is sized to 12.2 kWp which corresponds to 10 Wp per m^2 energy reference area as suggested by the joint model cantonal provisions in the energy sector (MukEn [8]). The PV panels are 190 Wp monocrystalline modules. They are oriented towards south with an inclination of 15°. A 20 kW reversible air source heat pump was used for both heating and cooling. The DHW and SH storages have a sizes of 2 m^3 and 1 m^3, respectively.

2.1.3 Key Performance Indicator

In order to compare the different systems and weather files, the grid purchase ratio (R_{net}) was chosen as key performance indicator. The R_{net} expresses the ratio of the electricity taken from the grid ($E_{grid\ purchase}$) to the total amount of energy used by the system (E_{use}) including heating, domestic hot water, cooling and electricity demands. Thus, the aim is to achieve a low R_{net}.

$$R_{net} = \frac{E_{grid\ purchase}}{E_{use}} \qquad \textit{Eq. 1}$$

Where:

$$E_{use} = E_{HH} + Q_{DHW} + Q_{SH} + Q_{SC} \qquad \textit{Eq. 2}$$

E_{HH}: *Household electricity*
Q_{DHW}: *Heat demand for domestic hot water*
Q_{SH}: *Heat demand for space heating*
Q_{SC}: *Space cooling demand*

2.2 Activity 2.4: Methodology of Concentrated Solar Power Evaluations

The work in the EU project NEWCLINE, which aims to assess new thermocline concepts for thermal energy storages with concentrated solar power, is ongoing. Within the SolResHC project, it is planned to use some of the simulations developed within the NEWCLINE project in order to evaluate the dependence of the system on weather data. Specifically, it is planned to simulate a parabolic trough concentrated solar power plant with a multi-year weather data set provided by the photovoltaic geographical information system PVGIS [9]. With this, the inter-annual variability can be assessed. Furthermore, future weather data from Meteonorm will be used to evaluate how the performance of a CSP plant may change in the future.

2.3 Activity 3.5: Methodology

Based on the literature review presented in the last yearly report, oemof [10] was chosen as the tool for analysing the influence of high PV penetration on the electricity price.

Remund et al. [11] examined several high renewable share scenarios where most of the energy demand in Switzerland was covered by PV and hydro while totally phasing out the nuclear power. Such scenarios yield a power production cost between 6-8 cents per kWh. Moreover, the cost was found to increase only marginally when scenarios with a very low (or no) share of imported electricity were considered.

An open-source tool based on oemof, deflex [12], was presented in the last yearly report. Deflex is a modelling and optimization framework for multi-sectoral energy systems, which can be used to model the electricity market of Switzerland. In addition to the modelling framework, it is essential to gather the production profiles of PV, wind and other volatile renewable power plants as well as imports and exports for carrying out simulations. PowerCheck [13] was selected to investigate different energy scenarios in Switzerland and thereafter, the simulations were setup in deflex.

2.3.1 Scenario Definition

The scenarios for the analysis within activity 3.5 were defined using PowerCheck. PowerCheck is a web-based tool developed by IET (Institute for Energy Technology), OST Rapperswil to calculate different electricity production scenarios within Switzerland. The tool includes predefined scenarios for the years 2017-2019 and the SFOE Zero Basis Year 2050 (from the SFOE Energy Perspectives 2050+) with details of the power plants including available types (nuclear, PV, wind, thermal etc.) and capacities, time series production profiles of the renewable power plants, imports, exports and the electricity demand. The scenarios can be modified by varying the available capacities of different power plants and storages to perform a sensitivity analysis. The following scenarios were analysed in the simulations:

- *Scenario 1* – This scenario includes real data from the predefined scenario of the year 2019 including exports and imports from PowerCheck. The installed PV capacity is 2.26 GW and the total share of production from renewable sources is 65%. About 60% of the electricity produced from the renewable sources comes from hydro and PV. This scenario represents the present situation in Switzerland.
- *Scenario 2* – In this scenario, the PV capacity is increased to 20 GW, while the rest of the system configuration is the same as scenario 1. The shares of nuclear and thermal power are expected to reduce in this case owing to the increase in the available PV electricity.
- *Scenario 3* – Here, a future scenario following the SFOE energy perspectives 2050+ (SFOE Zero Basis Year 2050) is considered. This scenario depicts a very high renewable share where nuclear power is completely phased out and the imports are allowed only during winters.

Table 2 gives a detailed description of the scenarios considered within the analysis.

Table 2: Scenario description.

Scenario	Year	PV [GW]	Wind [GW]	River [GW]	Nuclear [GW]	Dam [GW]	Pump storage [GW]	Thermal [GW]	Import [GWh]	Export [GWh]
1	2019	2.26	0.075	3.47	3.31	8850	200	0.665	5451	11,711
2	2019	20	0.075	3.47	3.31	8850	200	0.665	5451	11,711
3	2050	37.5	2.2	3.63	0	10,000	200	0.35	9000	0

2.3.2 Simulation Environment

Simulations were carried out with the open-source tool deflex, which is based on the open-source framework oemof. The economic potential of higher PV penetration and higher share of renewables in the electricity production sector of Switzerland was assessed. In deflex, the components of an energy model are divided into the following:

- Commodity sources
- Electricity demand series
- Power plants
- Renewable/volatile plants
- Volatile plant production series
- Storages

A deflex scenario is modelled using an excel file, where each of the abovementioned components is defined, including their parameters such as costs, capacities, efficiencies, annual production limits (if any). As a general rule, each commodity source should be connected to at least one power plant. All the power plants (including renewable plants) feed into the electricity bus, storage can be charged from and discharged into the electricity bus, while the electricity demand is connected as a sink to the electricity bus. The connections between different components in deflex are depicted in Figure 2.

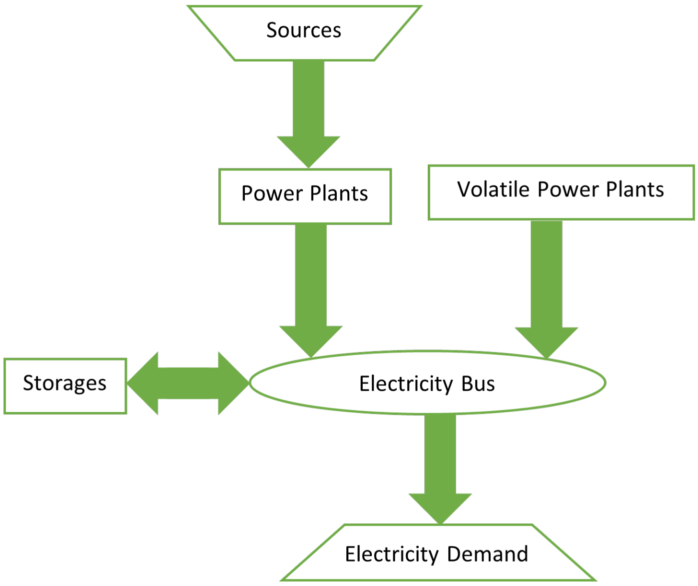

Figure 2: Schematic representation of the deflex modelling environment

The scenarios described in Table 2 were setup into the deflex input environment. PV, river and wind power plants were modelled as volatile power plants, each having a fixed normalized time series production (defined in MWh per MW of the capacity installed). Nuclear and thermal plants were modelled as power plants by defining the associated fuel costs, plant capacities, efficiencies and annual production limits (if any). As shown in Figure 2, both power plants and volatile power plants are directly connected to a common electricity bus in deflex, this poses a challenge when modelling dams and pump storage hydro power plants. Ideally, the output from turbines should be limited by the available storage capacity, which marks the usable energy from the reservoirs, and then connected to the electricity bus. However, such a configuration cannot be mapped into the framework of deflex. Dams and pump storage hydro power plants were therefore setup as dummy power plants constrained by a limited annual production. The annual production limits of dams and pump storage hydro power plants were taken from the respective PowerCheck scenarios.

The electricity imports were modelled as volatile power plants with a fixed time-series, while the electricity exports were defined as an additional electricity demand series. As a result, costs could not be associated with electricity imports and exports in the deflex environment. However, these costs do not impact the optimization results since both imports and exports are fixed time-series in the model. As mentioned before, the hourly profiles for electricity demand, import, export and production from renewable sources are obtained from PowerCheck.

2.3.3 Variation of PV Capacity

In order to assess the influence of high PV penetration on the electricity grid of Switzerland, the installed PV in the present scenario (scenario 1 described in Table 2) was varied from 2.26 GW (actual case) to 50 GW. The cases with different installed PV capacities, namely 2.26 GW, 10 GW, 15 GW, 20 GW, 25

GW, 30 GW, 35 GW, 40 GW, 45 GW and 50 GW, were simulated with deflex to evaluate the optimum operation.

2.3.4 Cost Calculations

The Levelized Cost of Energy (LCOE) of the produced PV power was calculated for each case as follows:

$$LCOE = \frac{I_{PV} \cdot CRF}{E_{a,PV}} \qquad \textit{Eq. 3}$$

where:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad \textit{Eq. 4}$$

I_{PV}: *Total base investment cost of the PV system*
CRF: *Capital recovery factor*
$E_{a,PV}$: *Annual energy produced by PV*
i: *discount rate in percent*
n: *lifetime in years*

A discount rate of 3% and lifetime of 25 years were assumed within the calculations. The investment cost of PV system was assumed as CHF 860 per MWh of capacity installed [11].
The cost assumptions of fuels for thermal and nuclear power plants are given in Table 3.

Table 3: Cost assumptions for fuels.

Fuel	Cost [CHF/MWh]	Source
Natural gas	30	[11]
Biogas	32	[14]
Wood	35	[14]
Nuclear	10	[14]

3 Activities and results

3.1 Activity 2.4: Activities and results

Disclaimer: The Content of this section (3.1) was presented at the WCPEC-8 conference in September in Milan[1].

First some general evaluations of the weather datasets are given in subsection 3.1.1. Then, the simulation results are presented in subsection 3.1.2. All evaluations are done for the location Zurich-SMA.

3.1.1 Weather Data Analysis

To see the overall development of the different CH2018 climate models and pathways over time, the yearly average global horizontal irradiance and ambient temperature of all 68 scenarios are given in Figure 4 with a corresponding linear fit. The lines are smoothed with a five-year gaussian filter. For the irradiance, a slight general decrease over time can be seen, though with the large variance, a general increase in irradiance is also possible. For the temperature, on the other hand, it is more clear: all scenarios show a significant increase in temperature.

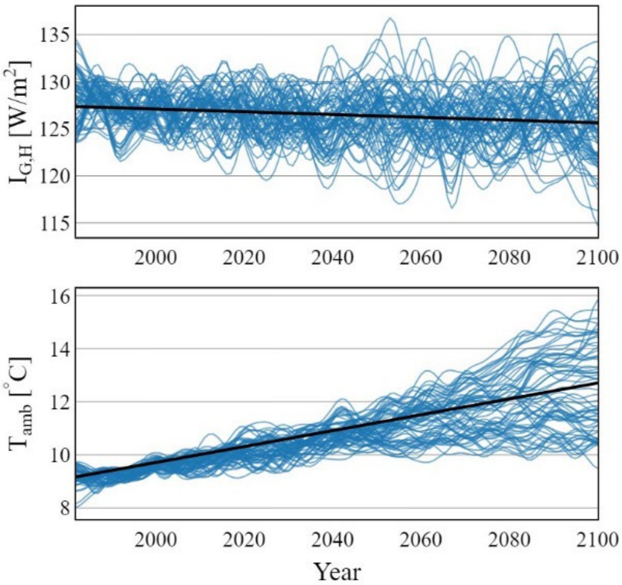

Figure 3: Global horizontal irradiance (top) and ambient temperature (bottom) development for all different scenarios in Zurich SMA. Blue lines are smoothed with a five-year gaussian filter, the black line shows a linear fit of the data.

The yearly averages of the different RCP scenario from the CH2018 data are depicted using a 20-year gaussian smoother in Figure 5. On the top, it can be seen that the slight decrease in irradiance is stronger for the more extreme scenarios (RCP8.5) but still quite small with a change of less than 2 W/m^2 over 120 years. The ambient temperature changes (bottom) are more relevant. For the RCP2.6, 4.5 and 8.5 scenarios, an increase of 1 °C, 1.9 °C and 3.8 °C can be seen, respectively.

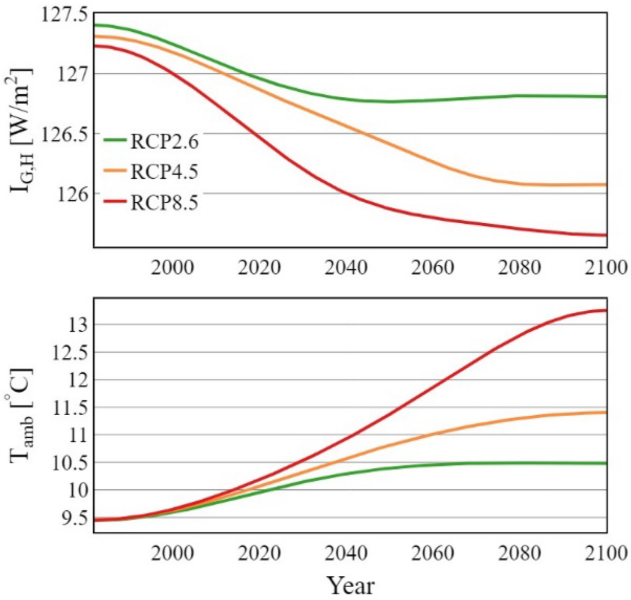

Figure 4: Average global horizontal irradiance (top) and outside temperature (bottom) development for the three evaluated RCP scenarios, smoothed with a 20-year gaussian filter.

A seasonal comparison of the different data sources are given in Figures 6 and 7 for the RCP8.5 scenario. The lines show the seasonal development of the CH2018 scenario, whereas the icons represent the MN and the IC datasets for the year 2060. In Figure 6, which shows the global horizontal irradiance development, it can be seen that the irradiance is slightly decreasing for winter and spring, whereas in summer there is a slight increasing trend. A comparison with the other datasets show that the MN data has generally larger irradiance values, whereas the IC data corresponds better to the CH2018 development, though slightly on the low side.

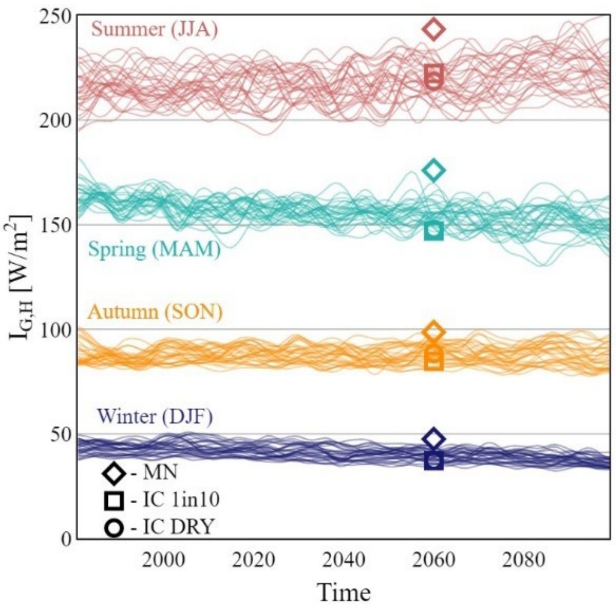

Figure 5: Seasonal global horizontal irradiance development over time for all RCP8.5 datasets, lines represent the values from the CH2018 scenarios and are smoothed with a five-year gaussian filter.

The temperature development, shown in Figure 7, shows an increase for all seasons. The MN, as well as the IC datasets correspond well to the projections, except during summer, where the MN dataset and the IC 1in10 are significantly above the average projection from the CH2018 scenarios. For the IC 1in10, this is expected, as it shows an extreme scenario. For the MN case, the different data on which it is based on can be taken as explanation.

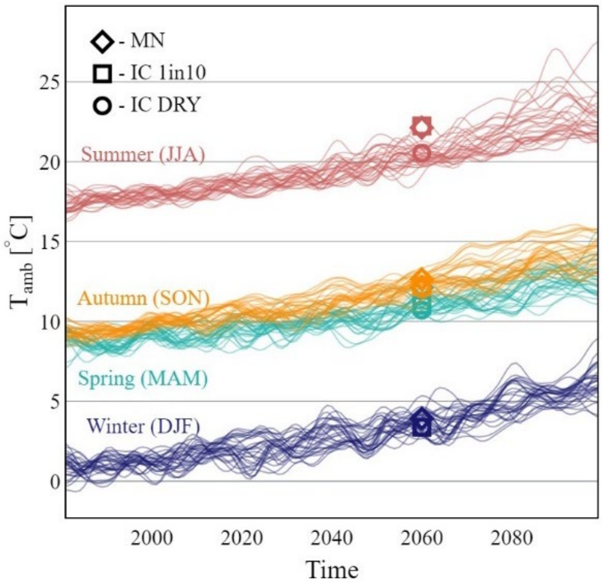

Figure 6: Temperature developement over time for all RCP8.5 datasets, lines represent the values from the CH2018 scenarios and are smoothed with a five-year gaussian filter.

3.1.2 System Simulations

The grid purchase ratio of all simulation results are shown in Figure 8, sorted by dataset and RCP scenario. The higher RCP scenarios tend to lead to smaller R_{net} values, reducing thus the need of purchasing electricity from the grid. Furthermore, it can be seen that the CH2018 scenarios (60S and 30Y) lead to a large variety in grid purchase ratio (from 0.303 to 0.363, which corresponds to a difference of about 20%). This variability is a lot larger than the variability from the different scenarios within one dataset (IC or MN) or when parametrically changing only the irradiance of a dataset (PAR). For the MN dataset, which contains also the reference in blue, a difference of up to 6% in R_{net} is caused by climate change in the year 2060.

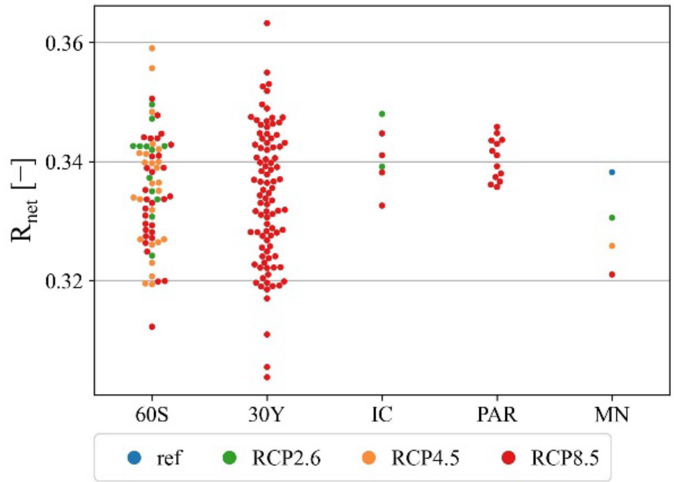

Figure 7: Swarmplot of the resulting grid purchase ratios for the analyzed datasets.

The dependence of the grid purchase ratio on ambient temperature and global horizontal irradiance is given in the scatterplot in Figure 9. Clearly R_{net} is decreasing both with increasing temperature and irradiance.

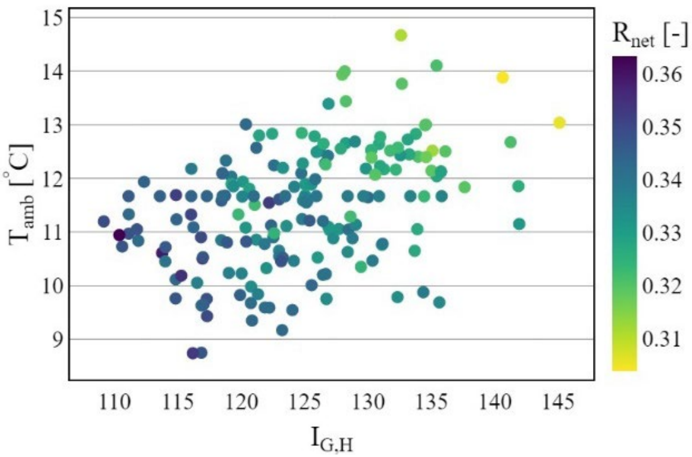

Figure 8: Scatterplot of all simulation results, grid purchase ratio as a function of ambient temperature and global horizontal irradiance.

To further analyze this dependency, the individual correlations are shown for each season in Figures 10 and 11.

The dependence on irradiance is depicted in Figure 10 where it can be observed that R_{net} decreases with increasing $I_{G,H}$. This can be explained by an increase in PV production. The r-value of the corresponding linear fits is highest in summer (-0.86), followed by winter (-0.71), autumn (-0.53) and spring (-0.41).

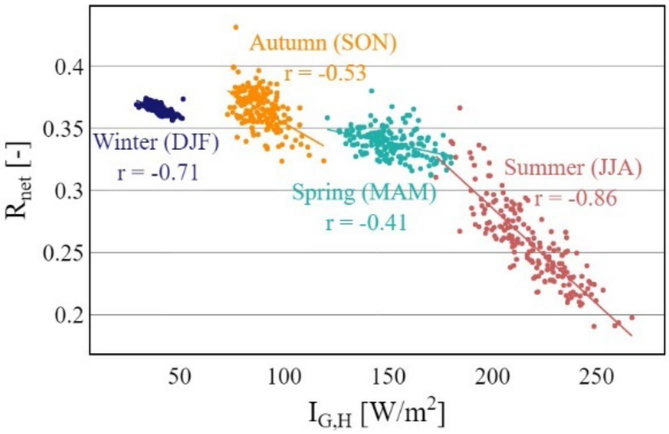

Figure 9: Seasonal dependence of grid purchase ratio on global horizontal irradiance.

The ambient temperature dependence is shown in Figure 11. Only in summer, a clear correlation between R_{net} and T_{amb} (r-value of -0.94) is observed. There is a small positive correlation in spring (r = 0.26), but for autumn and winter, there appears to be no significant correlation (r-values -0.09 and -0.07, respectively).

During summer, when there is cooling needed, higher irradiance comes with higher temperatures. Therefore, the demand for cooling increases in times when there is a lot of irradiance available for PV electricity production. The high correlation between R_{net} and $I_{G,H}$ in winter is best explained by the general low total irradiance in winter. Most irradiation in winter can be used by the system, as the demand is comparably high. The low dependence on temperature in autumn, winter and spring can be explained with temperatures not strongly correlating with irradiance: e.g. a sunny and clear day in winter may come with very cold temperatures, whereas a clouded day without much irradiance may be significantly warmer.

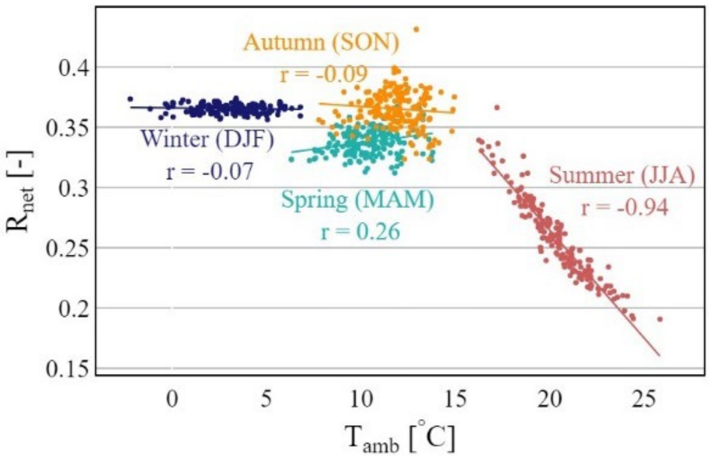

Figure 10: Seasonal dependence of grid purchase ratio on ambient temperature.

Finally, the development of R_{net} over time is depicted in Figure 12 as a function of the season. It can be seen, that R_{net} is decreasing overall and particularly in summer. There is no significant change in autumn and winter and in spring a slight increase can be seen. The decrease of R_{net} in summer can be explained mainly by the increasing temperature, as discussed before. Vice versa, the increasing R_{net} in spring is likely due to the increasing temperature and decreasing irradiation. The overall decrease R_{net} is thus driven by the summer period.

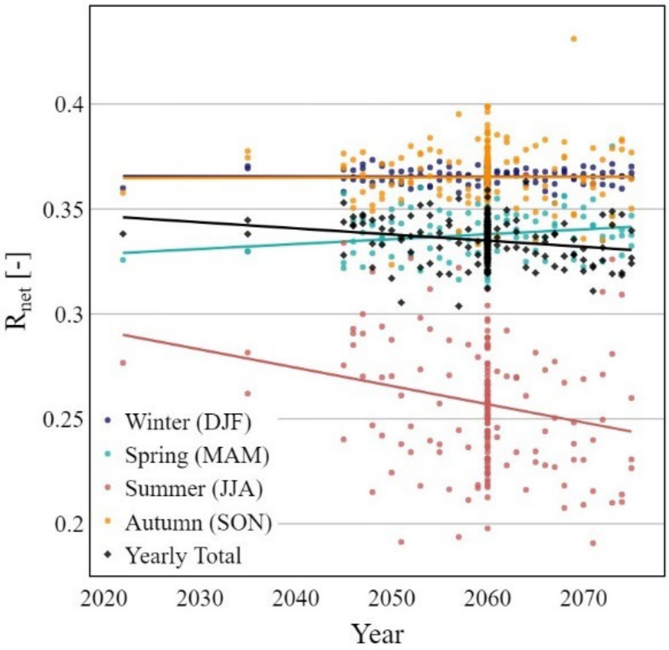

Figure 11: Seasonal dependence of grid purchase ratio on simulation year.

3.2 Activity 3.5: Activities and results

The monthly electricity consumption and optimal electricity production profiles evaluated for scenario 1 (present situation as described in Table 2) are shown in Figure 1. As shown, the electricity demand (including exports) is covered majorly with hydro power. The remaining demand is met with PV, river, wind, thermal and nuclear power. Nuclear power plants are preferred over thermal plants for cost-effective operation due to lower fuel costs and higher conversion efficiency. Thermal power plants include waste incineration plants as well as combined heat and power plants (both large-scale and small-scale) which are mainly operated for heating. This is not a future-oriented combination of energy sources, while wood, biogas and sewage gas enable a closed carbon cycle, natural gas must be replaced. In this category, the energy sources are 16% natural gas, 10% biogas, sewage gas and 7% wood. The annual share of renewables in optimal operation of scenario 1 (excluding exports) is found to be 75%, out of which 53% is from dams and pump storages, 41% from river, 5% is from PV while the remaining 1% comes from wind power. Moreover, about 9.5% of the annual electricity demand is covered by imports. In the future, an increase in the share of domestically produced renewable energy is expected to reduce this dependence on electricity imports.

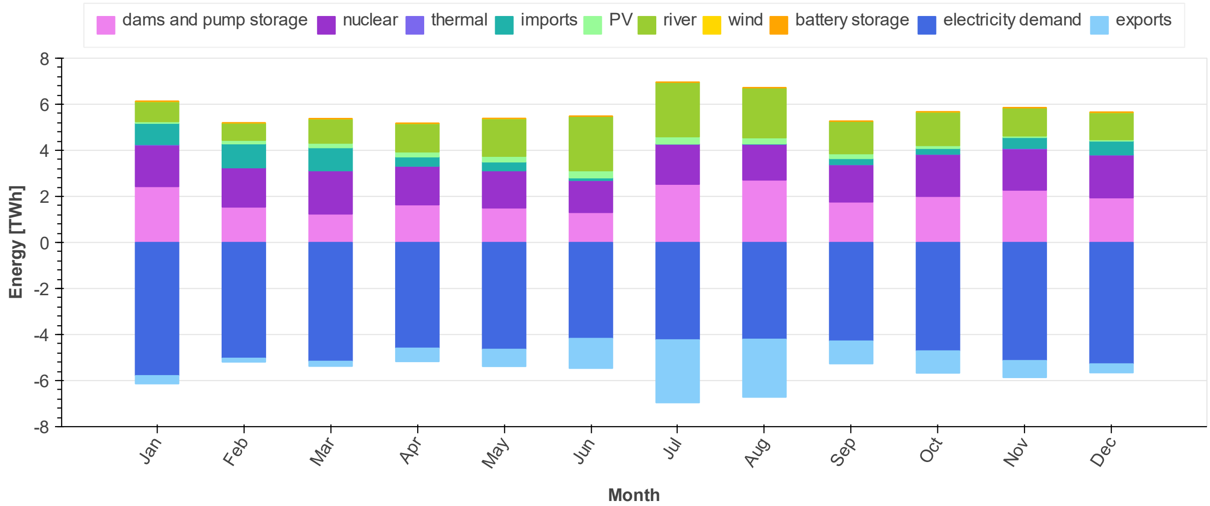

Figure 12: Monthly variation of electricity consumption and production for scenario 1.

Moreover, when looking at the hourly profiles, it was found that the production from nuclear power plants is rather volatile, which is unrealistic. During optimization, the renewable power plants (PV, wind, river, dams and pump storages) are used as much as possible (since their operation does not incur a cost) without exceeding the limits introduced by the plant capacity and permissible annual production (if any). Out of these, PV, wind and river productions are defined by fixed time series, while the production from dams/pump storages is chosen by the optimizer (within the constraints defined). And then, the remaining electricity demand (including exports) will be covered by nuclear and thermal plants, both of which add an operation cost within the optimization. Nuclear power, being cheaper, becomes the first choice for the optimizer and therefore, such volatile operation of nuclear plants is observed. This issue could not be addressed in the deflex optimization environment, but will be addressed in the future.

The impact of the installed PV capacity on the total operation cost is shown in Figure 14 . The operation cost constitutes the cost of generating electricity from thermal and/or nuclear power plants, since the rest of the electricity comes from renewables which essentially benefits from free operation. The share of non-solar renewable sources, namely wind, river and hydro power plants, are considered to be constant while varying the installed PV power plant's capacity.

The operation cost is found to decrease by 60% as the installed PV capacity increases from 2.26 GW to 50 GW. These savings correspond to the increase in the share of PV power from 2.2 TWh to 48.7 TWh. Furthermore, the LCOE of PV power was found to reduce slightly from 6.5 cents per kWh to 5 cents per kWh.

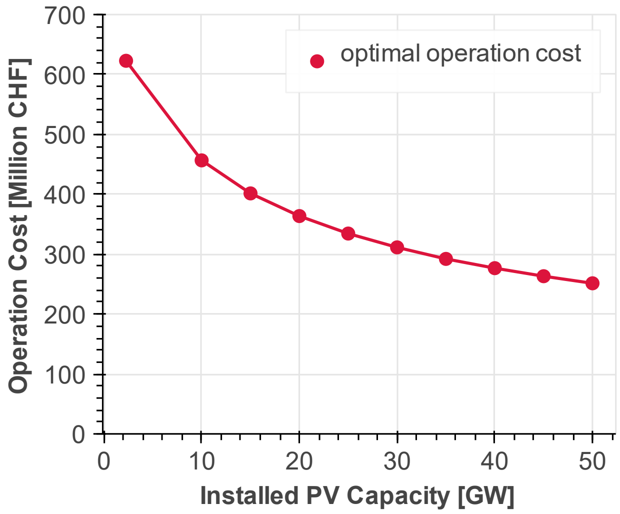

Figure 13: Variation of the operation cost with the capacity of installed PV.

To further analyse the influence of high PV penetration and share of renewables on the electricity grid of Switzerland, a comparison between the three scenarios described in section 2.3.1 is shown in Figure 15. For each of the considered scenarios, a case without any electricity imports is also assessed. The red dashed line represents the actual operation cost calculated from the production time-series in PowerCheck, while the bars depict the optimized operation costs of the scenarios where the production from non-renewables (thermal and nuclear power) is optimized.

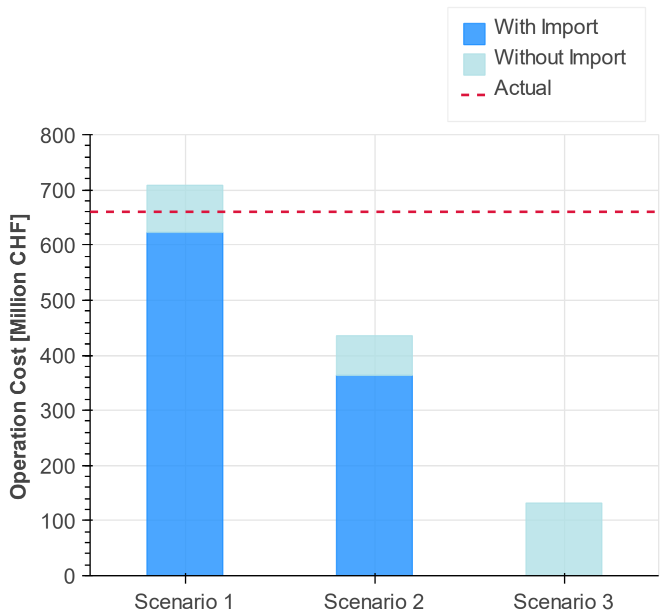

Figure 14: Comparison of the operation costs between the considered scenarios.

The actual operation cost (red dashed line) is shown for scenario 1, which represents the present situation with a relatively lower share of renewables. The optimized operation led to cost savings of 37.2 million CHF in scenario 1. However, in the absence of imports the total operation cost increases by 48.2 million CHF. The operation cost reduces significantly when PV capacity is increased to 20 GW (scenario 2). Scenario 3 with a very high renewable share (SFOE Energy Perspectives 2050+) has the lowest operation costs. The operation costs are evaluated to be 131.8 million CHF without electricity imports, whereas in the presence of electricity imports (restricted to winters only), the operation costs vanish completely. If the permissible imports are reduced to 10% then the annual operation costs are found to be 4.01 million CHF.

3.3 Activity 2.4: Evaluation of results to date

Disclaimer: The Content of this section (3.3) was presented at the WCPEC-8 conference in September in Milan[1].

Dynamic simulations in TRNSYS were used to assess the influence of different future weather data files on a PV driven air source heat pump system for domestic hot water, space heating, and cooling, of a multifamily building in Zurich, Switzerland.

The results show increasing temperatures for all seasons and RCP scenarios, while the irradiation is likely to decrease in winter and spring and increase in summer. With these climatic changes, the grid purchase ratio can be expected to decrease overall and during summer, while there may be a small increase in spring.

3.4 Activity 3.5: Evaluation of results to date

Simulations were carried out in deflex to evaluate the impact of high share of renewables on the electricity market in Switzerland. The simulations were setup using the time-series profiles from PowerCheck.

The results demonstrate increasing cost-benefits as the installed PV capacity increases. Moreover, in the future scenario based on SFOE energy perspectives 2050+ with massive shares of renewables, considerably higher savings and reduction in dependence on imports are achieved.

A few limitations, such as lack of flexibility in modelling hydro power plants, inability to associate costs with energy imports/exports and no scope for investment optimization were observed while using deflex.

4 Next steps

4.1 Next steps activity 2.4

Upcoming evaluations for the project regarding activity 2.4 will include the following points:

- Storage simulations (short- and long-term)
- Cost evaluation
- Evaluations regarding the CSP simulations from the Newcline project

4.2 Next steps activity 3.5

The following points will be addressed in the upcoming studies within activity 3.5:

- The analysis will be continued with the optihood framework which was developed within the projects OptimEase and SolHOOD. Optihood shall allow selection of both optimal capacities and optimal operation of the power plants, flexibility in modelling power plants (for example hydro plants can be modelled in combination with a storage) and the possibility to optimize imports and exports.
- A more in-depth analysis including an evaluation of curtailing PV production and the influence of the market system is planned.

5 National and international cooperation

5.1 Conferences, Synergies and Networking

In September, Jeremias Schmidli participated at the task meeting in Freiburg and held a presentation about the work done for activity 2.4 on future weather data analysis for solar heating and cooling.

Furthermore, there was an online participation at the meeting in spring 2022.

There were various interactions with different projects regarding activity 2.4:

The EU-project **Plural** (Plug-and-Use renovation of facades with adaptable lightweight systems) evaluates prefabricated façade modules for building renovation. Within Plural simulations are executed for various locations. The knowledge about energy system simulations in general and about solar resources in particular can be used in both projects.

In the EU-project **Sophia** (Sustainable off-grid solutions for pharmacies and hospitals in Africa), off-grid containerized solutions for hospitals using natural refrigerants, solar thermal and photovoltaic are developed. SPF takes part in different aspects of the project, among others the assessment of the solar resources and simulations of the systems. For this, there are collaborations with other institutes about solar resources and system simulations.

In the SFOE-project **KliKo** (Analysis and optimization of today used methods for weather normalization of building energy measurement data) different statistical evaluations are done with the aim to improve weather normalization of building energy data. These statistical evaluations can also be utilized for activity 2.4.

The EU-project **NEWCLINE** (Advanced thermocline concepts for thermal energy storage for CSP) aims to assess new thermocline concepts for thermal energy storages with concentrated solar power. SPF is involved in the system simulations. When the corresponding simulations are ready, the influence of inter-annual variability and future weather data are assessed for a parabolic trough concentrated solar power plant.

Regarding activity 3.5, there are interactions with the projects **OptimEase** (environmental and economic optimization of building clusters) and **SolHOOD** (optimal design and operation of solar neighborhoods) where an open-source modelling framework optihood is developed for optimizing groups of buildings. This modelling framework is based on oemof and will be used for future assessments within activity 3.5.

Furthermore, there were contacts and discussions with Jan Remund (Meteonorm) and Kristian Nielsen (Danish Meteorological Institute) about future weather data and Uwe Krien (University of Bremen) about the simulation tool oemof.

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