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Interim report dated 31 December 2022

S-DSM
Sustainable Demand Side Management for a Low Carbon Footprint operation of Buildings

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Summary

Emission-aware and flexible building operation can play a crucial role in the energy transition. On the one hand, building operation accounts for a significant portion of global energy-related emissions. On the other hand, buildings may provide the future low-carbon energy system with flexibility to achieve secure, stable, and efficient operation.

The aim of this project is to develop and practically test a building automation system that utilizes the CO2 footprint (carbon footprint, CF) of the Swiss grid electricity in a predictive manner and thus is able to avoid carbon intensive times of consumption. Subsequently, such a behavior supports a sustainable operation of buildings. Two control concepts are compared. On the one hand a concept aiming at distribution network operators (DSO), on the other hand a concept to be implemented directly at prosumers, i.e. the Building. As case studies, data sources and validation on energy systems of two buildings are accessed. Once the "K3" building complex in Wallisellen (office/commercial use), and the NEST demonstrator in Dübendorf (residential use). At both locations, the building operation is extended in such a way that the practicability of the developments can be demonstrated. Expected reductions of the CF can be assigned on the basis of measurement data of a benchmark year compared to a year of improved operation as well as simulation cases.

The S-DSM project utilizes developments of the concluded SFOE EcoDynBat Project[1], which provided code to query electrical production values of European power plants and calculated the resulting CF of the electricity grid in a one-hour resolution for past data. During the initial year of the project the temporal resolution was increased to 15 minutes and prediction capabilities were developed. Thus prediction based algorithms are able to use the CF-prediction to optimize the operation of local energy systems every 15 minutes.

Measurement data of the two implementation sites was collected in order to model the technical components in a realistic manner. The core components of the energy hubs at K3 and NEST were modelled as well as their thermal demand prediction developed. To be able to control the two sites, technical communication interfaces need to be present. For NEST this was already given at the project start. The interface for K3 was defined and implanted during the project. This interface implementation caused extensive delays in the project plan. In discussion with SFOE it was decided to prolong the project by one year, in order to facilitate enough time for a conclusive second data collection phase and analysis.

This document reports developments made in 2022 and builds up on the last yearly project report available on the aramis repository[2]. For developments made in 2021 the interested reader is referred to the 2021 report.

[1] https://www.aramis.admin.ch/Grunddaten/?ProjectID=41804
[2] https://www.aramis.admin.ch/Texte/?ProjectID=47564&Sprache=en-US

Contents

Abbreviations

CF	Carbon Footprint
DSM	Demand Side Management
DSO	Distribution System Operator
EV	Electric Vehicle
LCA	Life Cycle Analysis
MPC	Model Predictive Control(ler)
RBC	Rule Based Control(ler)
RMSE	Root Mean Squared Error
SD	Standard Deviation
SOC	State of Charge

1 Introduction

1.1 Background information and current situation

The building sector and its energy use are currently responsible for a significant share of the worldwide greenhouse gas (GHG) emissions, which raises questions on the sustainability of our current living habits. This also applies in Switzerland since ~45% of the final energy demand between 2000 and 2019 was linked to the building stock (Prognos, 2020) with an increasing electricity demand that depends on a national mix, which presents substantial variations in its carbon footprint (CF) during the year (BFE 2020, Vuarnoz & Jusselme 2018). Moreover, current energy control practices in buildings are based on rather simple rules to satisfy current energy demands without predictive considerations for future demands. For instance, domestic hot water (DHW) storage is mostly charged at night and heat pumps solely operate within normalized temperature levels. Therefore, traditional load profiles are not coordinated with local renewable energy production meaning that periods when Swiss electricity presents a low CF are not necessarily linked with higher energy uses.
Additionally, the increasing share of energy output from distributed renewable energy resources (RES) challenges the existing operation paradigm of power system, which has been designed to distribute electricity from large central power plants.
Moving energy uses in buildings at moments when the electricity presents a lower CF requires developments in the field of dynamic CF assessment and forecasting (Beloin-Saint-Pierre et al. 2020). Some solutions have been proposed to consider hourly historical CF profiles of electricity in different countries (e.g. Roux et al. 2017, Vuarnoz & Jusselme. 2018, Asdrubali et al. 2020) and show the importance of considering such variations. In additions, the electricity map web service (Electricity map. 2021) offers another option to consider actualized hourly CF values for many countries. While these solutions provide interesting insights on options for dynamic CF assessment, they sometime use outdated environmental databases, focus on marginal electricity CF instead of average electricity CF or lack clarity on how they create forecasted values for the coming days (e.g. electricity map services). Such aspects need to be described transparently to increase trust and understanding in how hourly CF values for the Swiss electricity mix can be used to manage energy demand in buildings.
To prepare power system for such challenges, exploiting the energetic flexibility from buildings may provide a cost-efficient solution. Traditionally, ripple control infrastructure is the industry standard of exploiting building energy flexibility by shifting the electrical consumption of heat pumps (HPs) and electric boilers with fixed schedules. However, it has limited functionality and may not exploit flexibility effectively. Li et al. (2021) show that building energy flexibility has been a central topic of much research on the topic of energy flexibility. Currently, there is no common definition of flexibility and field studies are very limited due to the lack of research infrastructure and the complexity of proposed methodologies. Therefore, it is necessary to investigate in real platforms and consider possible simplification for timely adoption in practice. A review on experimental predictive control studies in buildings as well as flexibility quantification and provision has been collected and published in (Cai & Heer. 2021).

1.2 Purpose & Objectives of the project

The purpose and objective of the project are unchanged compared to the last yearly report. For the year 2022 the main focus of the project was on the development of energy hub models and controllers based on the collected data. Additionally, the CO2-footprint prediction was finalized. The long-lasting interface implementation to the K3 system was also driven forward substantially.

Results of the SFOE EcoDynBat project[3] (BFE. 2020) have shown important variability in the hourly CF of the Swiss electricity mix, which means that old and new buildings could reduce their CFs significantly by shifting their electricity needs during specific periods of the day with demand-side management (DSM). This potential reduction can then be optimized with data-driven operationalization of energy flexibility.

As shown in figure 1, the aim of this project is to develop and practically test a building automation system that regards the CO_2 footprint (carbon footprint, CF) of the Swiss grid electricity and thus supports a sustainable operation of buildings. The variable CF of the Swiss electricity mix is defined by the combination of the environmental data from ecoinvent (Wernet et al. 2016) and the electricity data from the ENTSO-E transparency platform (ENTSO-E 2023), which is a central collection and publication platform for the European market.

Two control concepts shall be compared. On the one hand a concept aiming at distribution network operators (DSO), on the other hand a concept to be implemented directly at prosumers, i.e. the Building. The general development of the method is followed by a practical test in an operational building in Wallisellen (office/commercial use), and the NEST demonstrator in Dübendorf (residential use). At both locations, the building operation is extended in such a way that the practicability of the developments can be demonstrated. Expected reductions of the CF can be assigned on the basis of measurement data of a benchmark year compared to a year of improved operation as well as simulation cases.

The development of a CF forecasting algorithm, models of the infrastructure and optimization-based controllers provide the basis to minimize all of the buildings' indirect GHG emissions due to electricity imported from the grid. The investigation into available flexibility as well as simplification will provide practical tools to address challenges such as reverse power flow and increasing peak load.
Further developments of the CF assessment methodology from the EcoDynBat project will use updated values for the carbon-content of energy sources and provide a transparent method to evaluate the 15-min CF historical profile of the Swiss electricity mix since 2017. This historical profile will then be used as an input to different machine learning-based forecasting algorithms to predict the 15-min CF profile of the Swiss electricity mix for 24 to 48 hours in the future. Performance of this forecasting algorithm will be evaluated on CF profiles for the year 2021.

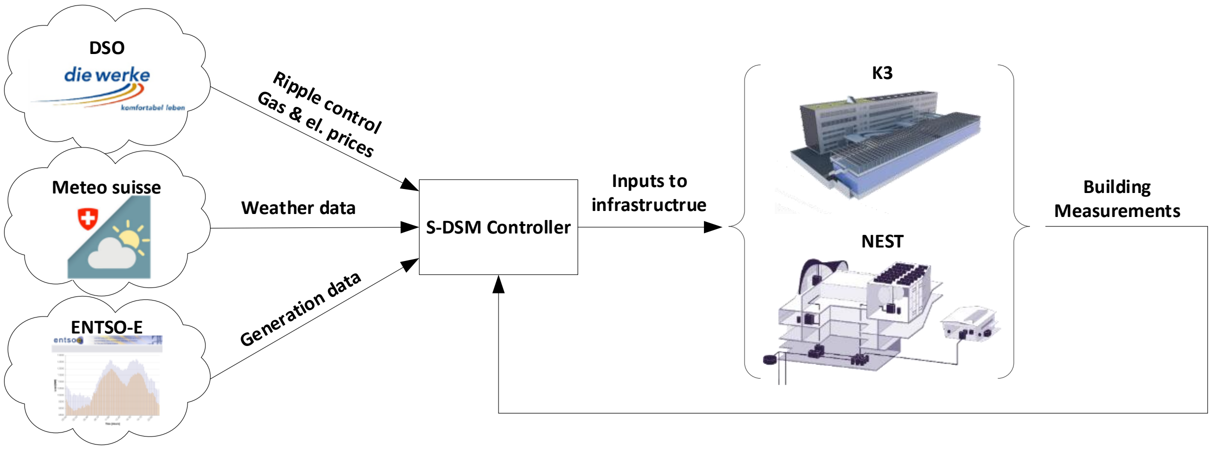

Figure 1: Project Objective

[3] https://www.aramis.admin.ch/Grunddaten/?ProjectID=41804

2 Procedures and methodology

The S-DSM project utilizes knowledge from past and parallel projects. Namely, the SFOE EcoDynBat project and an Empa funded project CAPITAL[4] feeding WP1. In this WP the EcoDynBat-Algorithm is developed further such that every 15 Minutes a CF-prediction is calculated with data fetched from several public sources.

Hardware oriented projects K3 supported by FOGA (Gaz energie. 2020) and the continuing NEST project provide access to the respective infrastructures in WP2. The main focus in terms of controllable infrastructure lies on the energy hub components of K3 and NEST, which provide the heating and cooling systems as well as electrical storages. WP1 and WP2 feed into WP4 where the DSM strategies are developed. On the modelling side the SFOE aliunid project (aliunid, 2020) and again CAPITAL reinforce the Model basis in WP3. These models serve as development environment for the novel controller and are also utilized in simulations to compare the current state of industry controller with the S-DSM controller.

The developments of WP1-WP4 are synthesized in WP5 and applied to the two implementation sites. The validation of the developments in operational conditions will allow for an in depth analysis of the developed method as well as show the practical applicability of the approach. The collected measurement results in WP5 will also allow for a comparison between the developed S-DSM controller and the state of industry benchmark controller. A visual overview over the projects structure can be seen in Figure 2.

All WPs have a strong data driven approach in that measured and/or collected real time data is evaluation during runtime in order to make statements on the CF-Intensity of electricity, inform the structure and parameters of simulation models and which actions real-life systems should take over a multi month period of time.

The descriptions of WP3 (see chapter 3.3) and WP5 (see chapter 3.5) will elaborate more on the realized demonstration sites.

Analogously, the mentioned projects also profit from synergies with the S-DSM project.

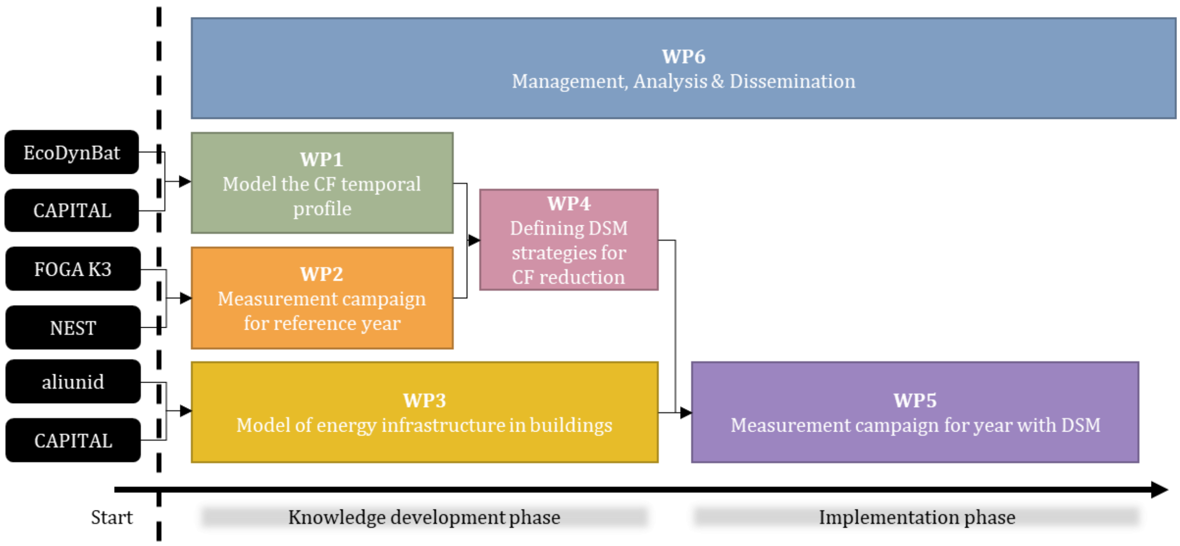

Figure 2: Project plan

[4] https://www.empa.ch/web/s313/projects1 -> Section "CAPITAL"

3 Evaluation of activities and results to date

Chapter 3 and chapter 4 are structured along the WPs of the project that can also be seen in Figure 2 and further down Figure 14.

3.1 WP1 Model the temporal profile for the Carbon Footprint (CF) of the Swiss electricity mix

The activities of WP1 have been concluded in 2021 and the necessary algorithms to assess the dynamic historical CF profile have been exchanged between the different partners of the project. As mentioned in last year's report, some information on the carbon footprint of electricity sources have been updated this year to keep the CF assessment up-to-date.

Furthermore, some partners of the project have also worked this year on the creation of a scientific publication to release the algorithms to the public. The publication will be submitted to the SoftwareX journal by the end of 2022. A detailed description of the algorithms can be found on a GitLab repository (https://gitlab.com/fledee/ecodyn/-/tree/main/) and will be open to the public when the article is accepted. This will become the reference place to find the latest version of the python algorithms and to share updates if they become necessary.

3.1.1 Task 1.1: Transfer algorithms of EcoDynBat project for hourly profile of Swiss electricity mix

The transfer of the algorithms from the EcoDynBat project to all partners of SDSM has been carried out in 2021. Version 3.8 of the ecoinvent LCA database has been used this year to include the latest available values on the CF of electricity sources.

3.1.2 Task 1.2: Create algorithms for 15-minute profile of Swiss electricity mix

This task was finished in 2021, but some slight adjustments of the algorithms have been made this year to remove some discrepancies that came from the hourly data of the ENTSO-E platform.

3.1.3 MS1: Algorithm for 15' CF footprint developed; Q2 2021

The algorithm is now stable to provide a 15' CF profile from historical data for most of the ENTSO-E statistics. We did overserve a small problem with the quality/completeness of the ENTSO-E data for the latest information (e.g. for the 4 hours that are most recent). We therefore use older data (i.e. more than 4 hours old) and its related 15' CF profile in Switzerland to forecast the short-term CF profile of the Swiss electricity mix.

3.2 WP2 Measurement campaign for the reference year

3.2.1 Task 2.1: Location NEST

The energy hub at NEST has been physically upgraded with more buffer tanks and the data of the new system configuration have been collected since November 2022[5]. The reason of this upgrade is due to the increasing number of research units (e.g. residential areas, offices, etc.) being integrated

[5] A second hardware update will be conducted in Q1 2023. Then more ground heat exchangers will be installed, leading to a higher thermal capacity from the ground available at a higher power rating.

into NEST, which increases the thermal demand. This upgrade is expected to increase the level of energy flexibility at NEST. Measurements of voltage at NEST over two years are shown in Figure 3. We can observe that the voltage was controlled within desired ranges. This analysis is used to contrast the voltage measurement collected at K3 in the previous interim report (yearly report 2021, chapter 3.2.2), where overvoltage was observed and the phenomenon was linked to the large PV installation covering the entire building. The more constant voltage profile in NEST is mainly due to smaller sizes of PVs at Empa campus and an over-sized power distribution network. Moreover, overvoltage issues can lead to undesirable PV curtailment. Thus such issues are traditionally addressed with grid reinforcement (i.e., with a larger size of cables and transformers in the network) and the existing literature suggests using demand response to mitigate the issue. Therefore, the analysis reveals operational challenges that are already happening and the outcome of this project may provide a solution to such issues.

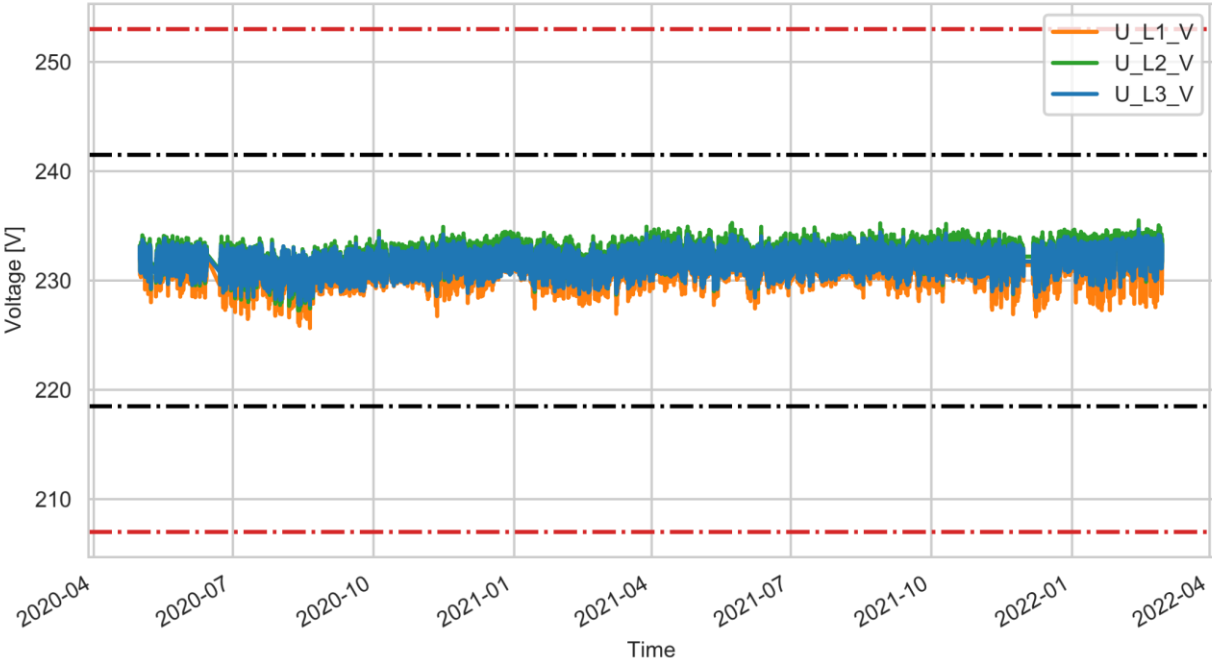

Figure 3: Voltage measurement at NEST showing each phase and specification bounds (dashed black) and critical bonds (dashed red)

.Regarding the thermal system, the controllability and actuation quality of the medium-temperature HP at NEST is analyzed in Figure 4. These two aspects directly impact the final performance of the carbon footprint aware controller. In other words, if the hardware cannot follow the set points from the controller, the experimental results will be far from expected carbon footprint reduction. The variable-speed HP at NEST is controlled via a frequency converter and it has high controllability and precision. The occasional outliers shown in the figure are due to the low-level control logic designed by the manufacturer. Such an analysis provides insights into the types of flexibility services that such kind of HP can provide.

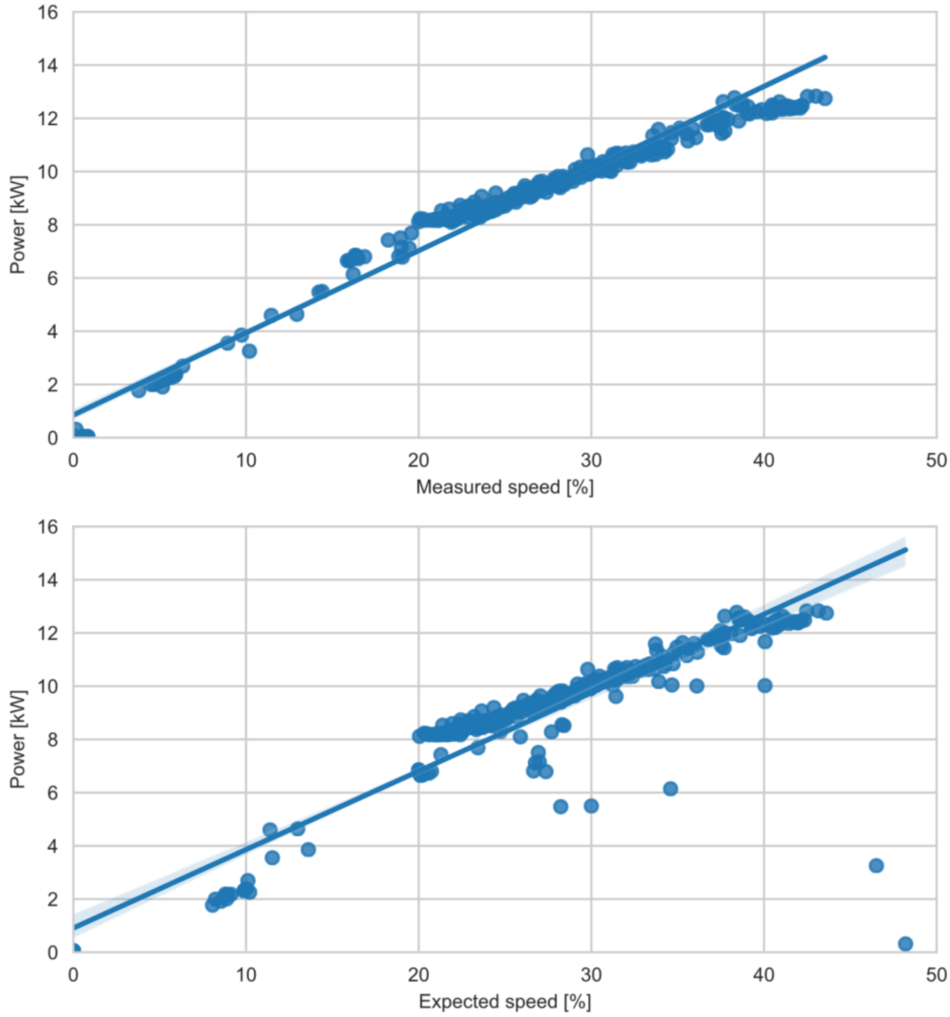

Figure 4: Controllability and actuation quality of the medium-temperature HP at NEST. Top plot: actual electrical power consumption vs measured compressor speed; bottom plot: actual electrical power consumption vs compressor speed setpoints.

SFOE expressed interest in the topic of EV charging integration. To facilitate this, measurement data from a charging station at Empa (located at the move-demonstrator; connected to the same electrical Grid as NEST, measurement and data collection done by the same systems as NEST) was retrieved and analyzed in this section. The log files from the charging station were parsed to extract information on the charging sessions. The integration of the real-time measurements was finalized in December 2022. Note that, the data presented in this section were collected before COVID, therefore giving an indication of energy flexibility in nominal operation.

We extract information such as the number of cars plugged-in, their SOCs at arrival and departure, and the maximum active power that the vehicle can absorb. Data show that EVs arrive at this charging station with a wide range of different SOCs, as Figure 6 and 7 show. As for the SOC at departure, it is more consistent; apart from a few outliers, most vehicles left with SOC at least 80%.

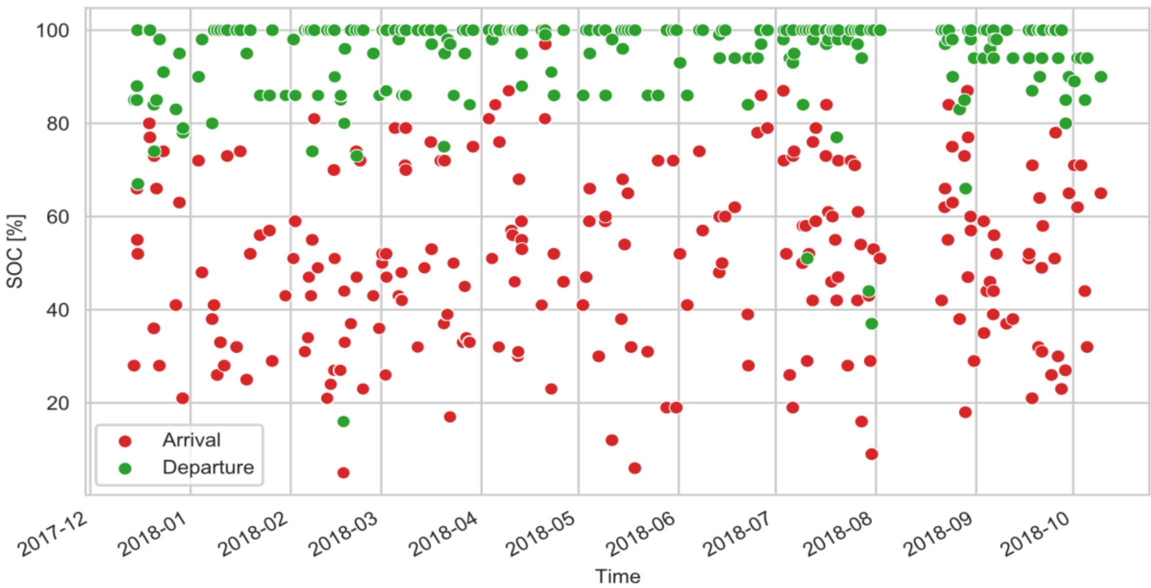

Figure 6: Scatter plot of arrival SOC and departure SOC for the charging station at move.

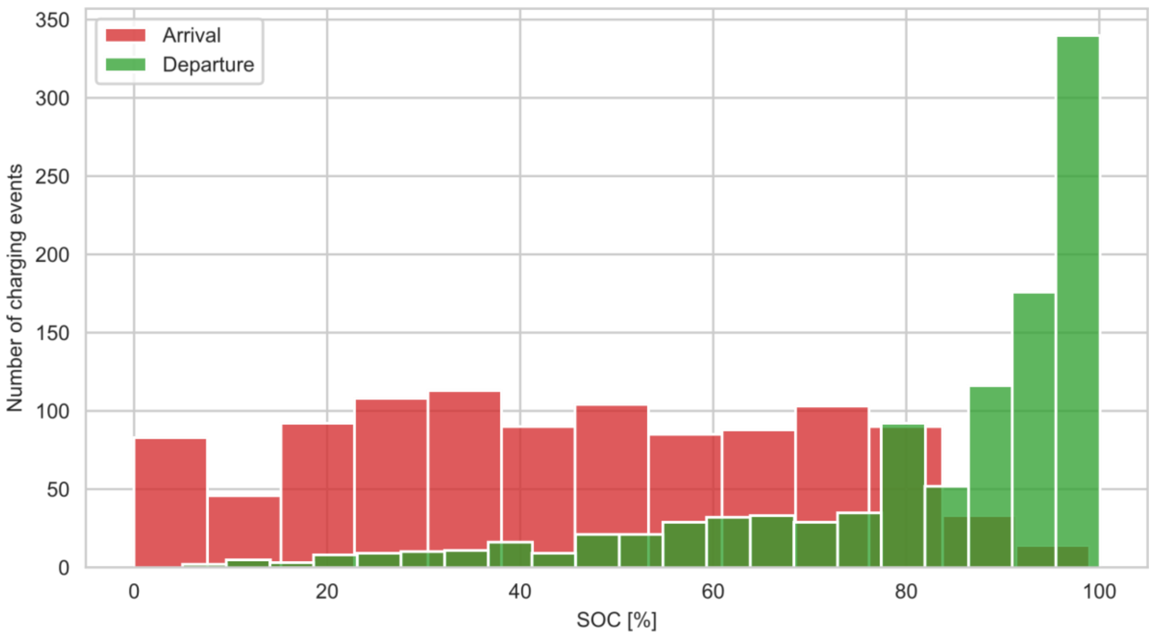

Figure 7: Histogram of arrival SOC and departure SOC at move.

The daily and weekly patterns of EV arrival and departure are summarized in Figure 8. During work days, we can observe a pattern associated to working schedules: arrival/plugged-in time concentrated in early morning and departure/unplug in the evening; during weekends, we can observe a decrease in charging events and a temporal shift in arrival and departure. Such patterns are likely a combined effect of free charging at this site, vehicles from tours/visitors and the schedules of researchers.

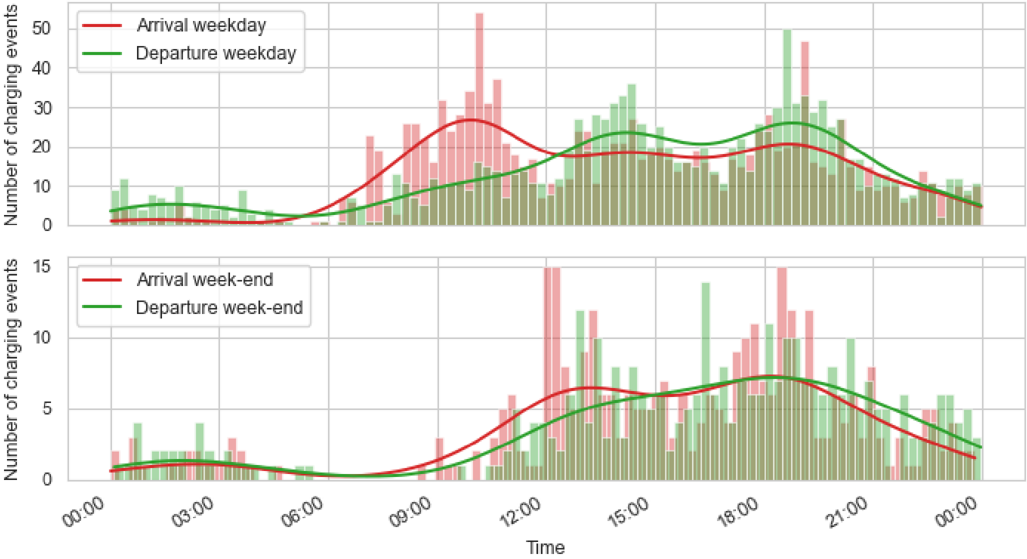

Figure 8: Histogram of the arrival and departure times. Top plot: charging patterns during weekdays. Bottom plot: charging patterns during weekends.

Figures 6 to 8 provide an overview of the amount of energy consumption of EV and inform the scale of potential impacts. However, the idle time, when an EV is available for load shifting, is needed to assess their flexibility. This is summarized in Figure 9 and we define idle time as the duration between being already at full charge and still being plugged in. We can observe that most of the time an EV is unplugged after they are charged fully. The idle duration is on average 43 minutes. This indicates limited load shifting capability and potential impacts on carbon emission reduction. For example, carbon intensity of electricity from the grid does not change dramatically within 43 minutes. Therefore, the control algorithm cannot achieve significant reduction of carbon footprint only by shifting charging schedules within such a narrow time window.

One reason for this is the limited number of chargers on site. When an EV is charged fully, the owner gets a notification and he/she may unplug the EV to make way for other colleagues. Therefore, flexibility levels are expected to increase when there are more chargers available and EVs remained plugged in for longer. Other chargers at Empa are currently under construction, and more flexibility would be expected.

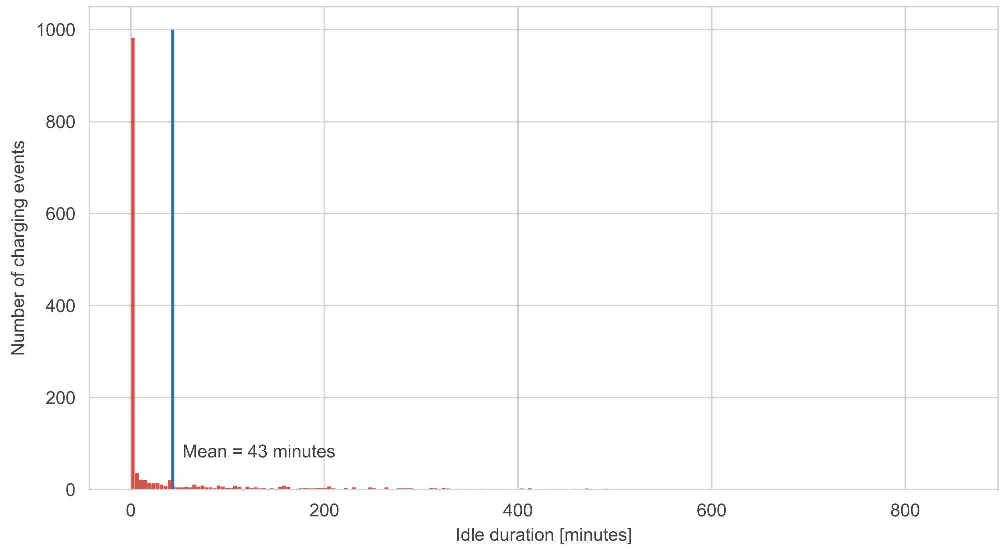

Figure 9: Histogram of the idle duration of vehicles parked at move.

3.2.2 Task 2.2: Location K3

While analyzing the thermal meter readings at K3, a poor data quality was identified. After local inspections and software updates to an M-Bus Gateway the data quality has improved. The subsequent modelling was adapted to no rely less heavily on these measurements, in order to reduce the dependency on potentially weak data. Apart from this issue. The measurement quality is within expected ranges.

Additional room temperature measurements have been collected with three standalone sensors at selected locations, as shown in Figure 5. These additional sensors are used to inform research with information such as energy saving measures if there is any. Note that room temperature measurements are in general not (remotely) available in regular buildings.

Currently, these additional sensors are being verified and will be used as supplementary info for experimental results and controller performance evaluation.

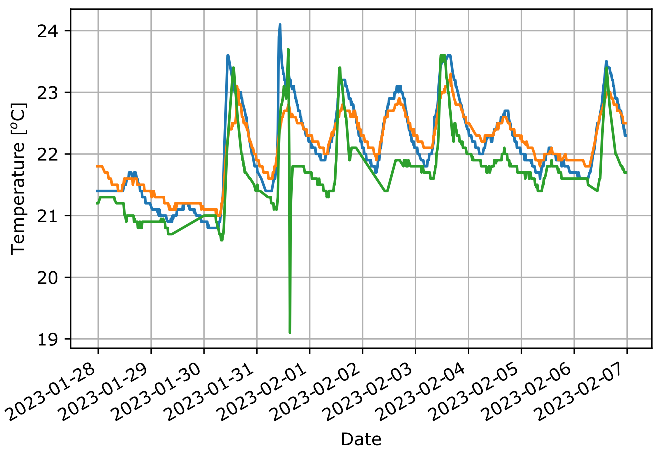

Figure 5: Measurements of three additional temperature sensors installed in selected rooms at K3.

3.3 WP3 Model of energy infrastructure in buildings

We derived models based on the collected measurement data from both sites as described in chapter 3.2. Specifically, we cover linear models of CHP and HPs, machine learning-based day-ahead forecast of cooling and heating demands and carbon intensity, and models of heat and cold storage tanks. All models are obtained with a sampling time interval of 15 minutes. We identify the model directly using historical operational data. The modelling errors are assessed and summarized with n-step ahead prediction error metrics (an example can be found in Figure 11). Such a summary of modelling errors also helps to determine the choice of horizon of the predictive controller. For example, if the model performance is very poor to predict the tank temperature 12 hours from now, then choosing a horizon of more than 12 hours for the controller cannot be justified.

3.3.1 Task 3.1 & 3.2: Model and flexibility of ehub of NEST

The energy hub at NEST has undergone upgrade and there are other energy sources in addition to the HP-based system shown in Figure 10. For example, the high-temperature network of Empa campus was used to supply heating demand of NEST when the HP cannot meet the demand. This is due to the incremental feature of NEST, in which more and more units get installed.

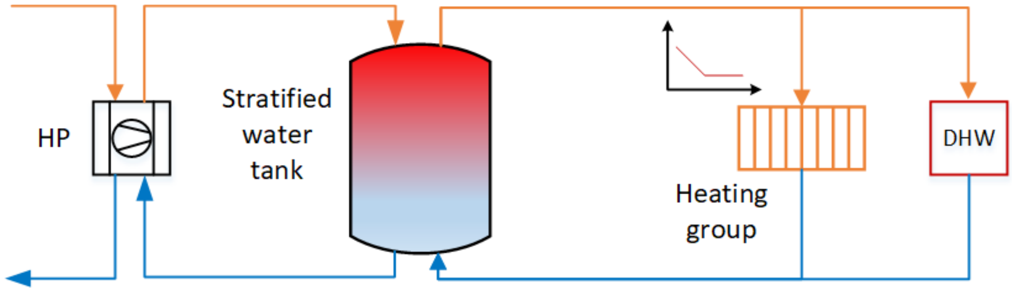

Figure 10: Simplified overview of the ehub at NEST.

The modeling performance is assessed and summarized in Figure 11 with respect to low-, medium- and high-temperature thermal distribution grid within the building. The performance is presented with respect to both multi-step ahead prediction errors and time-series views. In all cases, we can observe that prediction errors increase initially and saturates quickly. In comparison with the standard deviation (SD) of the original data, the modeling errors are relatively low.

In contrast to K3, the operating temperature range of the medium-temperature network at NEST is lower. The upper limit of temperature is lower because a high temperature prevents the usage of solar thermal and may negatively impact wooden floor. Therefore, the temperature is constrained in a fixed range, rather than following the heating curve concept, in which temperature goes up to 45 degree at K3 (note that, if CHP is used, the temperature can rise much higher).

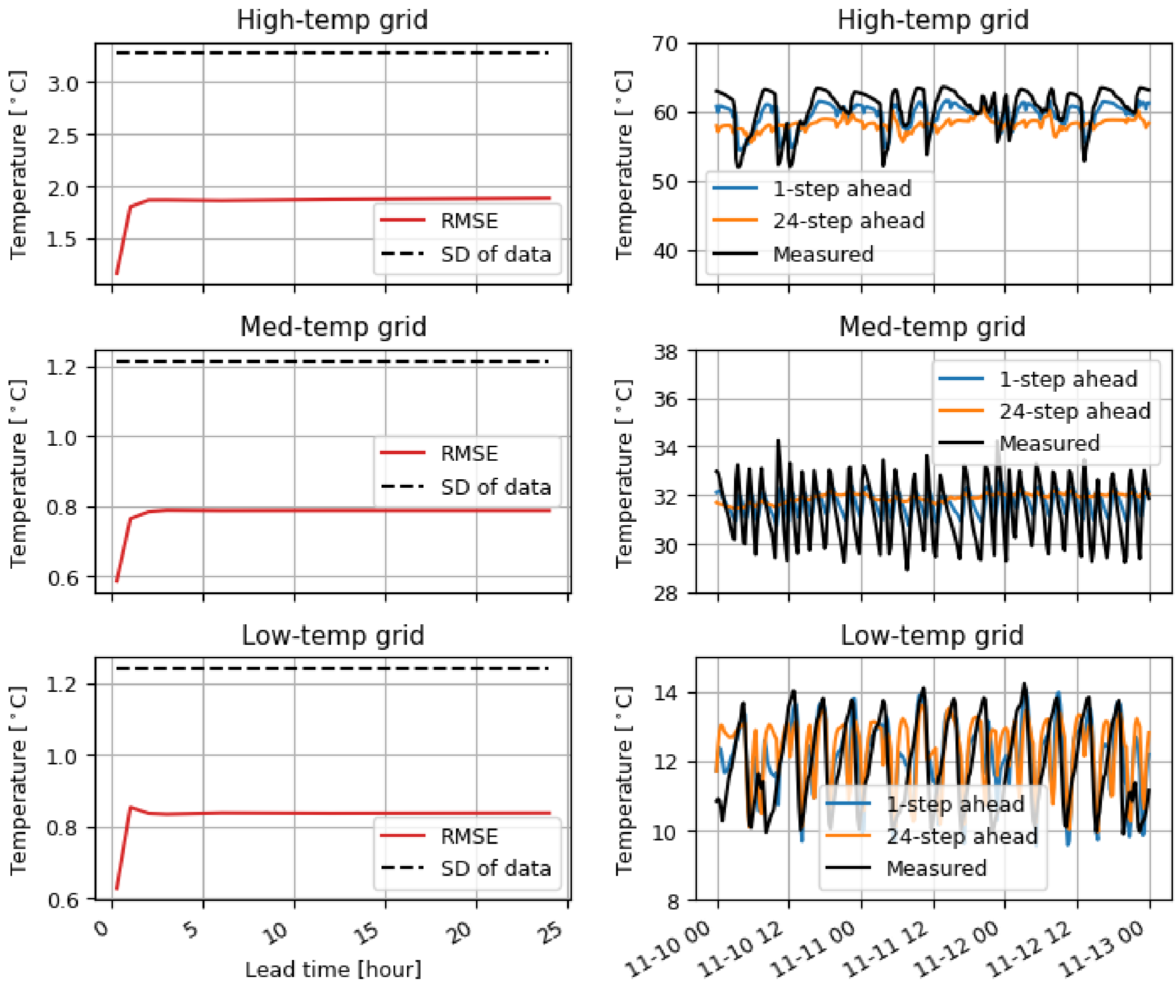

Figure 11: Assessment of modeling performance of the energy hub at NEST using root-mean-square error (RMSE[6]) as an indicator. Standard deviation (SD[7]) of temperature measurement indicates the spread of tank temperature. Left: multi-step ahead prediction error. Right: time-series view of the model performance on selected days.

Due to the upgrade of the energy hub and re-configuration of the connection with Empa campus network, operational changes were observed in the measurement data. The increased storage capacity lead to less HP operation cycles. Thus, a higher load shifting potential is expected under the developed MCP. The impacts are twofold: more buffer tanks are needed and higher capacity of the ground heat exchanger is needed.

[6] The RMSE metric is defined as: $RMSE = \sqrt{\frac{\sum_{i=1}^{N}(\widehat{x_i}-x_i)^2}{N}}$

Where $\widehat{x_i}$ denotes the estimated value, x_i is the original measurement and N is the number of samples.

[7] The SD metric is defined as: $SD = \sqrt{\frac{\sum_{i=1}^{N}(x_i-\bar{x})^2}{N}}$

Where $\bar{x}$ denotes the average value, x_i is the original measurement and N is the number of samples.

3.3.2 Task 3.3 & 3.4: Model and flexibility of ehub of K3

Apart from the previous analysis regarding flexibility to respond, the emission reduction potential is calculated for the emission-aware MPC and the results for 2021 is shown in Figure 13. The rule-based controller (RBC) was designed by a building energy management system provider to maintain a sufficient supply temperature according to a heating curve. For the cooling network, the rules were designed to ensure that the cold-water tank temperature is always below a predefined threshold. The model predictive controller (MPC) considers the data-driven model shown in the previous report and accounts for the same operational limits as the rule-based controller. More specifically, the operational limits are incorporated as constraints in the optimization problem. The results illustrate the benefits from active utilization of operation flexibility. More specifically, this is illustrated through two key performance indicators: self-consumption and carbon footprint reduction. Load duration curve (of total grid exchange) indicates a pattern change in grid interaction. There is less import from the grid and more self-consumption of PV production. The histogram of hourly emission further shows the shift of consequent hourly emission pattern.

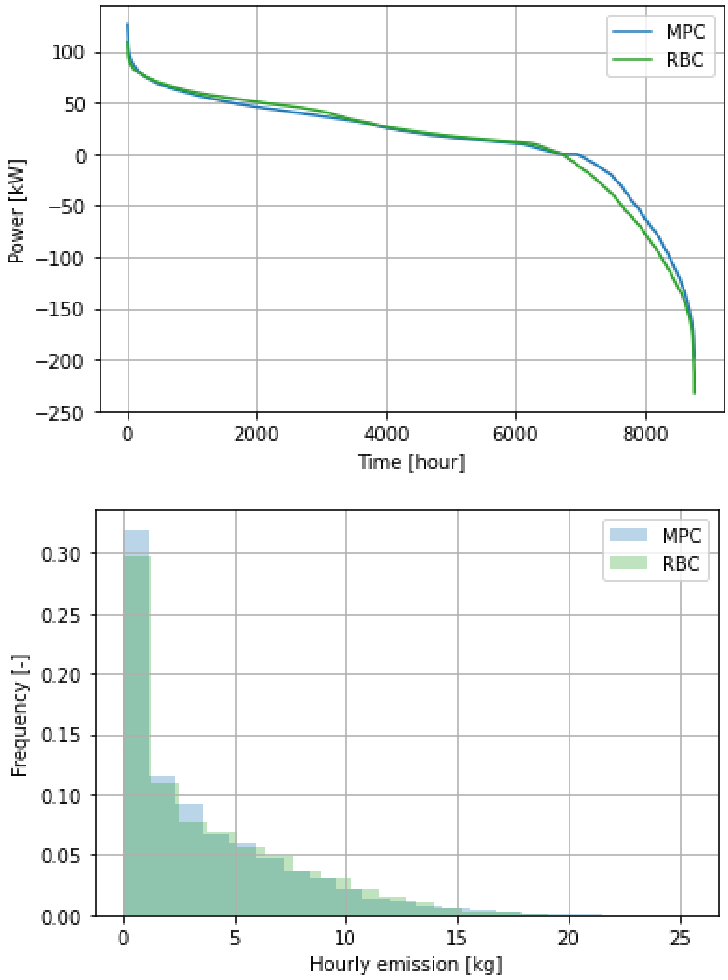

Figure 13: Example of emission-aware operation. Top: load duration curve. Bottom: histogram of hourly emission. RBC: rule-based control; MPC: model predictive control.

3.4 WP4 Definition and development of DSM approaches for CF reductions

WP4 focusses on defining and developing a DSM approach to reduce the CF of electricity uses in the NEST and K3 buildings based on potential flexibilities and when a forecasted CF profile of the Swiss electricity mix is available. Different approaches are explored to find more correspondence between the operating times of systems in buildings and the periods when the forecasted CF is lower on the Swiss grid in a given temporal scope (e.g. 24 hours ahead).

3.4.1 Task 4.1: Identification of core aspects to predict CF profile of the Swiss grid electricity

The forecasting method for the CF profile of the Swiss electricity mix that was chosen last year is still used. We will continue to monitor the predicting performance of this option until the end of the project since the electricity mixes of different European countries is evolving quickly and historical ENTSO-E data might not be as representative for the mix of the coming years. These checks will be done a few times until the end of the project since they require a substantial amount of effort and time. We will provide an update on the performance of the forecasting algorithms if we see substantial changes compared to the 15% discrepancies that we observed with the current version.

3.4.2 Task 4.2: Selection of a suitable DSM approach (prosumer, DSO)

In exchange with the project partners, different approaches were discussed. This included the proposed DSO approach, where the CF forecast would be known to the DSO only. Another discussed approach focused more on energy hub operators (i.e. the prosumers), namely by making the CF forecast known to them directly. With their superior understanding about the local system as well as the increased controllability, this approach was considered to be more suitable as service (offered by DSOs or others) to lead to a more informed decisions leading to a more sustainable operation. Thus the prosumer approach was decided to be implemented on the actual system for WP5. In parallel, while WP5 will be conducted; simulation cases with variations on the DSO approach shall be conducted. This will ideally include different levels of the state of the local system to the DSO (e.g. according to SmartGridReady levels, or flexibility envelope communications).

3.4.3 MS2: Scientific Publication on EMS method development; Q1 2022

Alternative modeling methods have been investigated and used in case study of EMS of NEST. This is in collaboration between Empa and IfA through joint master thesis supervision. The results are currently being summarized for a publication. The analysis and EMS development are being summarized for a publication. In combination with the CAPITAL project, a bottom-up flexibility quantification considering representative archetypes of Swiss buildings stocks is being investigated and will be summarized for a publication.

3.4.4 MS3: Selected EMS-Algorithm for deployment selected; Q4 2021

With the conclusion of Task 4.2 this milestone was reached.

3.5 WP5 Measurement campaign for one year with DSM

At the time of writing the interface testing at K3 is being conducted. It is foreseen that WP5 can start early 2023. Technically, this implementation delay only impacts the K3 site. However, in order to have comparable conditions, especially on weather conditions and carbon footprint profile, the campaign at NEST will start at the same time as the one at K3. Thus the WP as a whole is impacted by the delay.

3.5.1 Task 5.1: Implement EMS at NEST

The MPC combines the low, medium and high temperature networks connected by two HPs. Forecast of DHW, cooling and heating loads provide the boundary conditions of operation. Deterministic MPC considers minimizing carbon footprint as the objective. At the first stage, only HPs are controlled considering the same carbon intensity profile as K3. Potentially, HPs will be combined with battery to enlarge the available flexibility.

The interface to move charging station was integrated in December 2022 and is being verified. Preliminary analysis of the historical data has been made based on log files. Formal tests have not been carried out.

As NEST is subject to several research projects, the allocation of the involved systems to S-DSM was discussed with SFOE. Due to the delay a continuous reservation of the systems to this project can no longer be guaranteed. Thus, interruptions in the measurement campaign are expected. Nonetheless, it is foreseen that enough measurement data, with the S-DSM prosumer approach active, will be collected in order to sufficiently analyze the CF reduction potential.

3.5.2 Task 5.2: Analyze performance periodically at NEST

This task has not started yet. Upgrades of the system by introducing more buffer tanks were finalized by end of Nov. Therefore this task is shifted.

3.5.3 Task 5.3: Implement EMS at K3

The implementation of the interface between the EMS and K3 suffered a delay of 12 months is at the stage of integration test at the time of writing. The implications of this delay are discussed in Chapter 3.6.1.
The implemented communication structure is indicated in Figure 13.

The MPC combines the low, medium and high temperature networks connected by two HPs as well as the CHP unit. Forecast of uncontrolled electrical loads, DHW, cooling and heating loads provide the boundary conditions of operation. The MPC considers minimizing carbon footprint as the objective.

Characterization tests have been carried out but have not confirmed the successful implementation of the interfaces. The implementation is therefore delayed.

3.5.4 Task 5.4: Analyze performance periodically at K3

This task has not started yet.

3.5.5 Task 5.5: Comparison study and analysis

This task has not started yet.

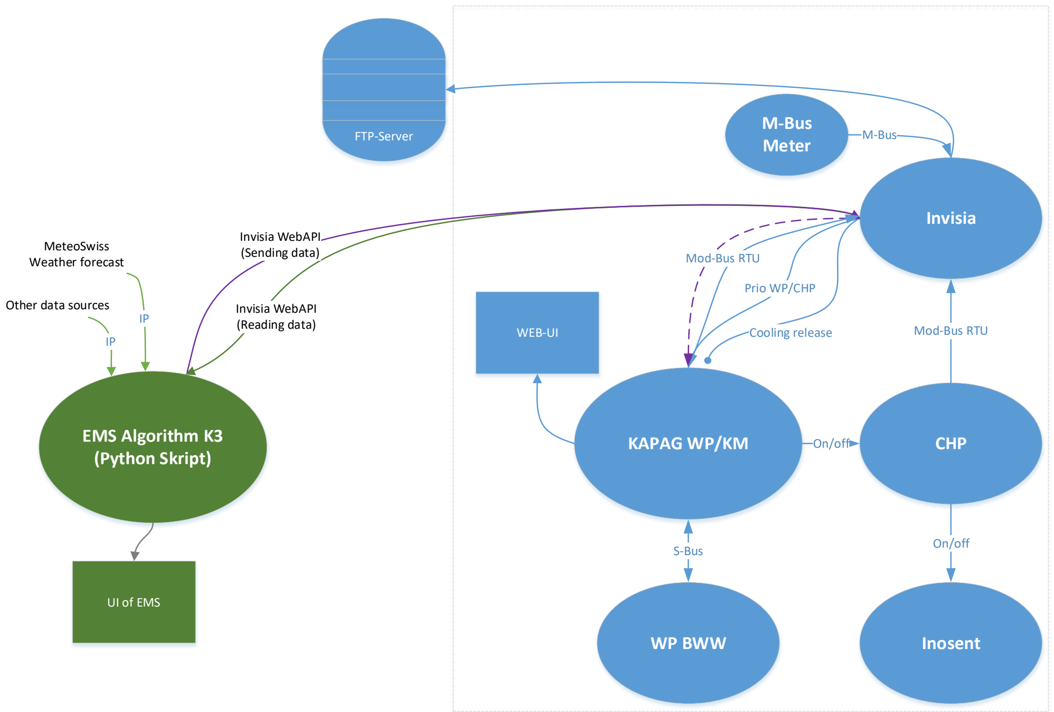

Figure 13: Communication interfaces between existing infrastructure (blue) and new EMS (green and purple). Sending data (purple) requires adaptions in current implementation on Invisias' and KAPAGs side.

3.6 WP6 Management, Evaluation and Dissemination

3.6.1 Project time line

In the first year of the project MS1 and MS2 were successfully reached. Compared to the original project timeline a delay of 12 months can be identified. This delay originated in prolonged interface definition to the K3 building. This delay results in delaying MS3 by the same amount, as well as a shortened second measurement campaign (i.e. WP5). It is expected that even with the remaining collection time enough data can be gathered for a sufficient analysis. All delays have been indicated in grey in the time plan (c.f. Figure 14).

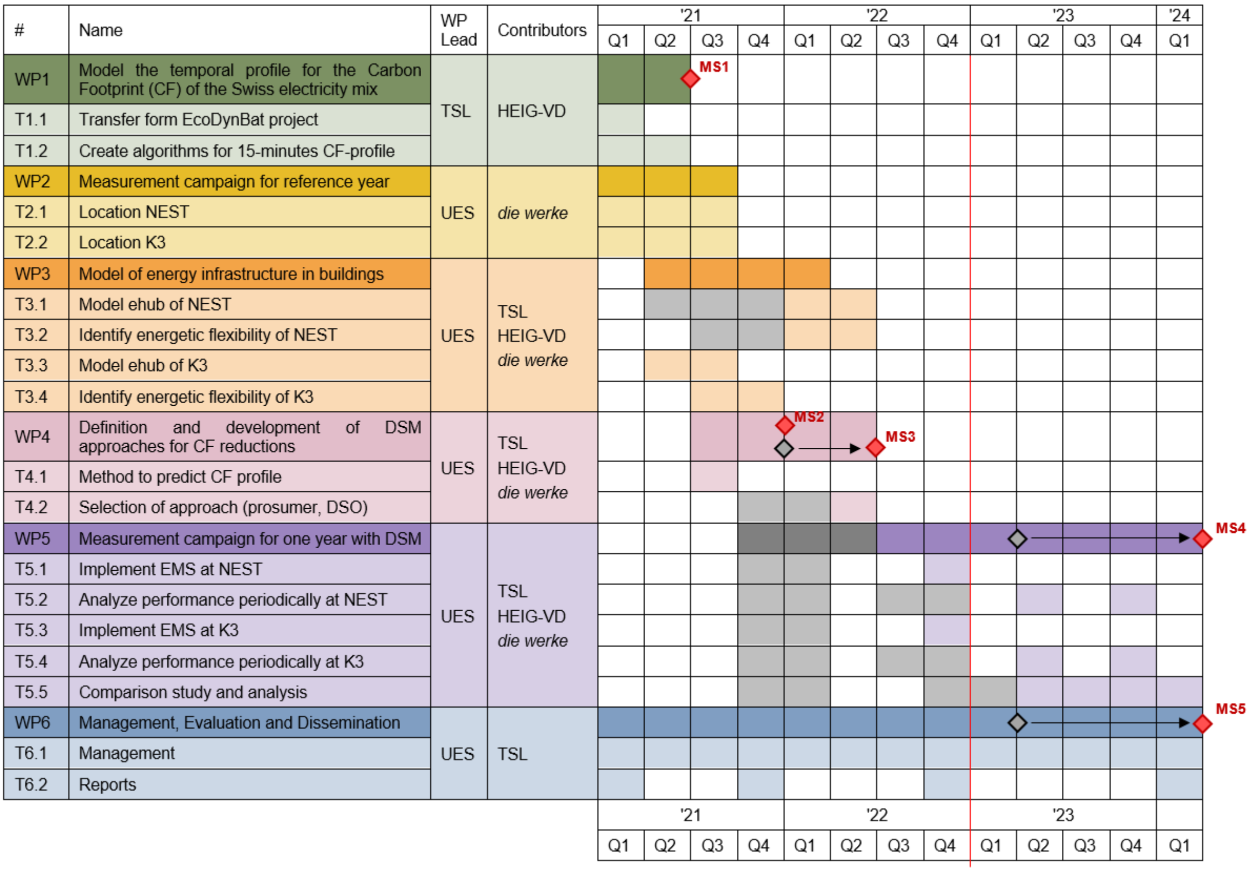

Figure 14: Project Timeline with indicated shifts of T3.1, T3.2, T4.2, WP5 and MS3.

3.6.2 Project Meetings

The collaboration between the involved groups was harmonized via by-weekly meetings, when necessary. That way an efficient handover between Work packages and share of work was facilitated.

3.6.3 Advisory board

Topic specific exchanges with members of the advisory board were held throughout the year. The project team thanks the advisory board members for their time.

4 Next steps

4.1 WP1 Model the temporal profile for the Carbon Footprint (CF) of the Swiss electricity mix

The goals of WP1 have been reached as stated in Chapter 3.1. Maintenance and updates of the algorithms will continue until the end of the project to ensure that we use the latest available information, which should increase the representativeness of the calculate CF profiles.

4.2 WP2 Measurement campaign for reference year

The activities of WP2 have been concluded as stated in the yearly report 2021.

4.3 WP3 Model of energy infrastructure in buildings

The activities of WP3 have been concluded as stated in chapter 3.3.

4.4 WP4 Definition and development of DSM approaches for CF reductions

The activities of WP4 have been concluded as stated in chapter 3.4.

4.5 WP5 Measurement campaign for one year with DSM

The measurement campaign is expected to be started early 2023. The preparations of the other WPs as well as the already conducted preparations of WP5 (see chapter 3.5), will support an efficient start of the campaign, once the communication interface has been finished commissioning.

As described, in parallel to the running campaign, simulation runs on alternative CF forecast integrations and (potentially) flexibility state communications will be conducted.

5 National and international cooperation

Intermediate results were presented in the seminar of International Energy Agency (IEA) Annex 82 working group and received feedbacks from the experts.

Tasks related to move have been investigated in collaboration with the NCCR Automation and start to collaborate with SFOE SWEET PATHFNDR.

This project is linked to a FOGA supported project concerning the analysis of energy flows in K3 and establishing the technical connectivity (bi-directional data communication) between K3 and Empa. An article in Aqua&Gas describing these activities and the link to SFOE via S-DSM is currently in preparation.

An Empa internal project called "Carbon footprint optimization of electricity in smart buildings (CAPITAL)" has been launched to be able to extend the development and analysis of CF aware building control.

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