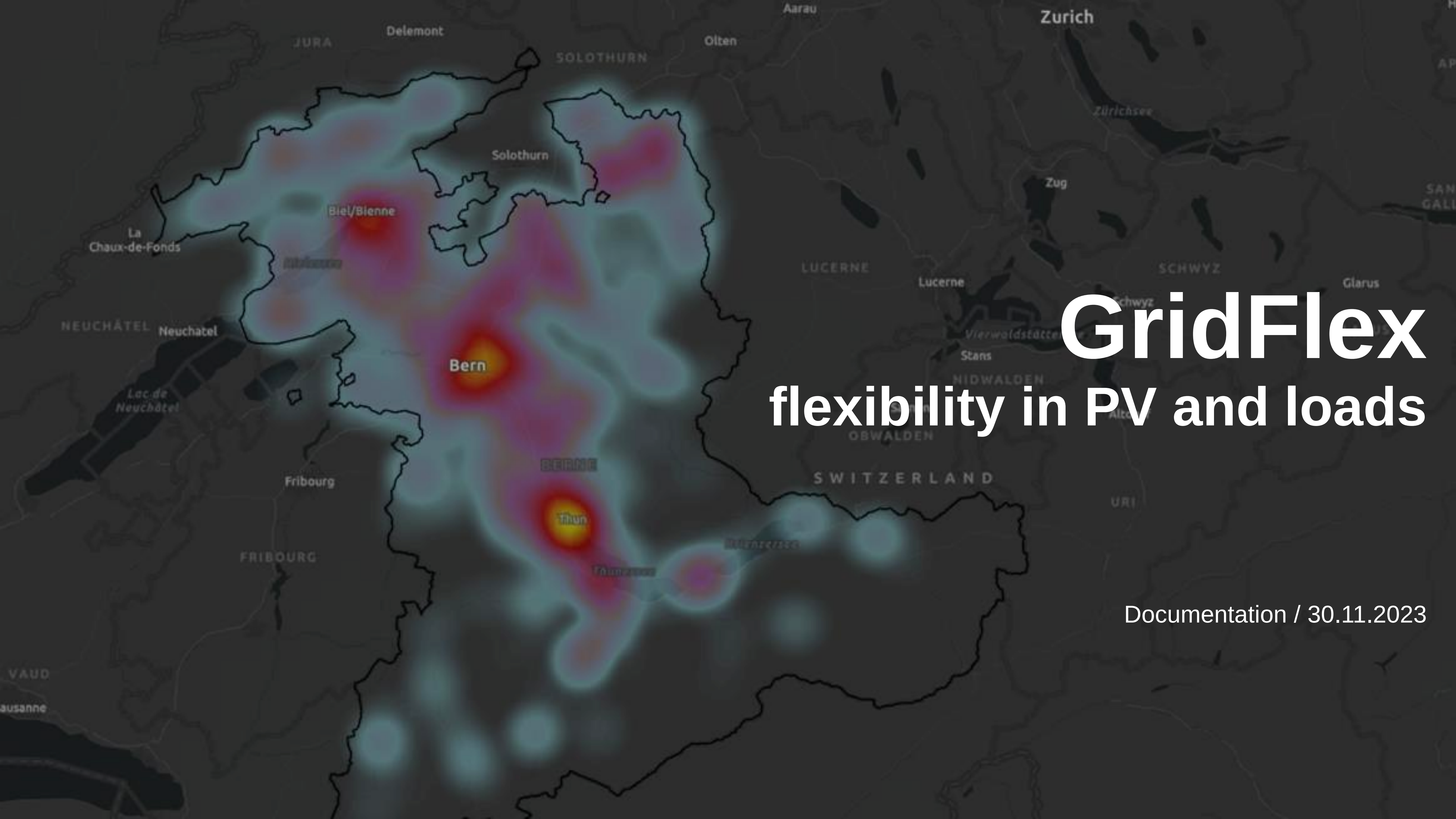


GridFlex

flexibility in PV and loads

Documentation / 30.11.2023

Final submission

Our final submission consists of two endproducts. This presentation serves as a documentation of our project. In the GitHub repository, our code is published and the outputs can be replicated or modified. README.md gives further information of the structure of the repository and how to use it. The repository can be accessed via the link below and an access request, which we will in turn approve. **Please notice, that the repository or any data of it may not be shared with third parties.**

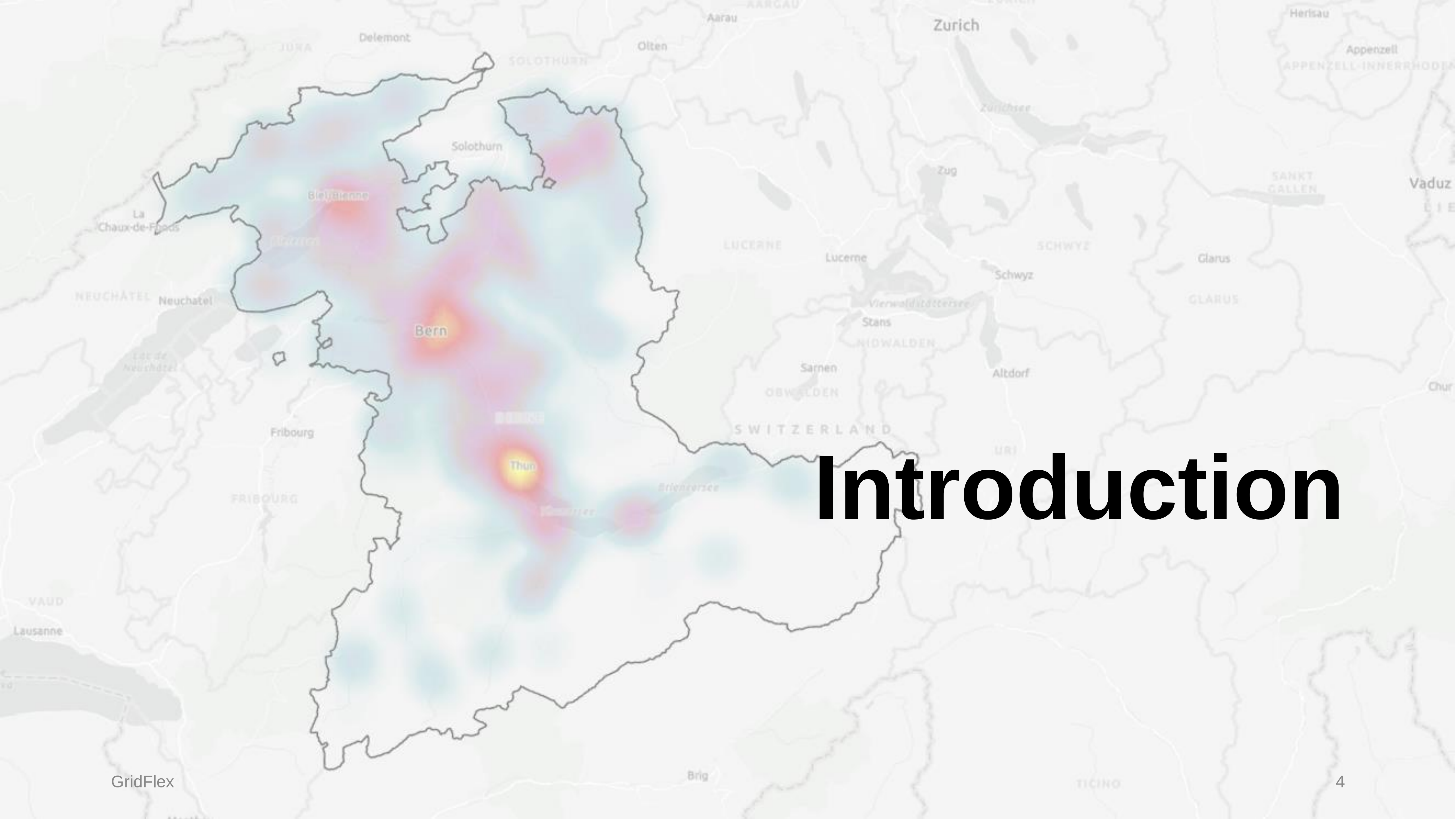
Documentation
(this presentation)

GitHub
repository

https://github.com/Boxuan1101/Gridflex_final

Content of the documentation

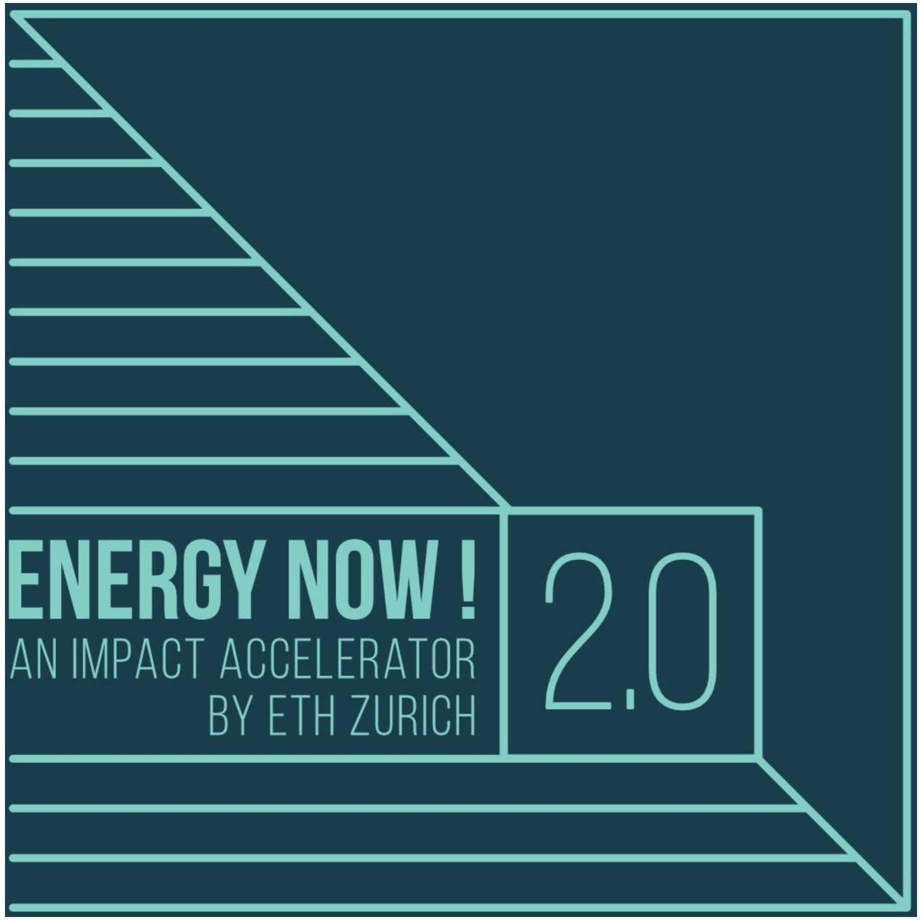
This documentation serves two purposes: One is to explain the broader context of the topic, which is the first part of the documentation. The second is to document our end product and methodology. You will find this in the second part of the documentation.



Introduction

Context of this project (1)

- This project is developed in the context of the challenge “Energy Now! 2.0”
- Energy Now! is a platform, provided by the Energy Science Center of ETH Zurich, to facilitate the dialogue between the scientific community and private and public actors.
- GridFlex participated in the challenge “Visualising flexibility for different stakeholders”.
- Our mentors were Martin Kauert and Jill Huber of BKW, Matthias Eiffert of HSLU and Raphael Wu from Swissgrid.



Context of this project (2)

The participators could choose between several challenges. GridFlex chose the challenge "Visualising flexibility for different stakeholders" from Swissgrid AG, BKW and Tiko. The description of "what" was as follows:

An approach that provides different stakeholders with the visualisation of the respective flexibility at different levels of granularity (from individual buildings to entire network areas) and across different time scales (hourly, daily, weekly, monthly).

Team members of GridFlex

Boxuan Yao

Student MSc Energy Science and Technology

Ramona Stoll

Student MSc Energy Science and Technology

Dominique Steverlynck

Student MSc Environmental Systems and Policy Analysis

Vivian Chen

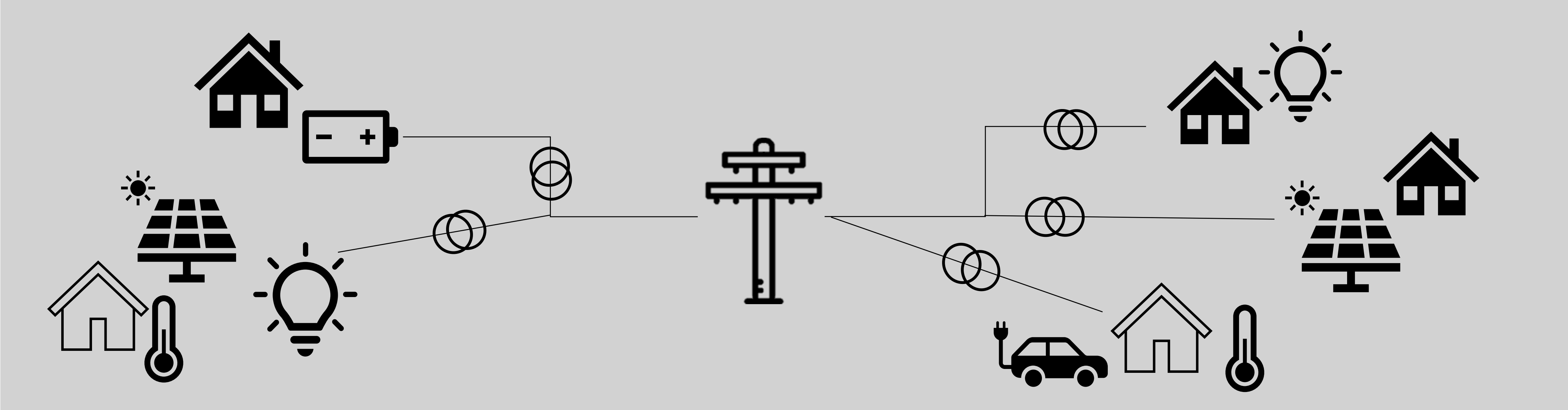
Student MSc Energy Science and Technology

Jan Heldmann

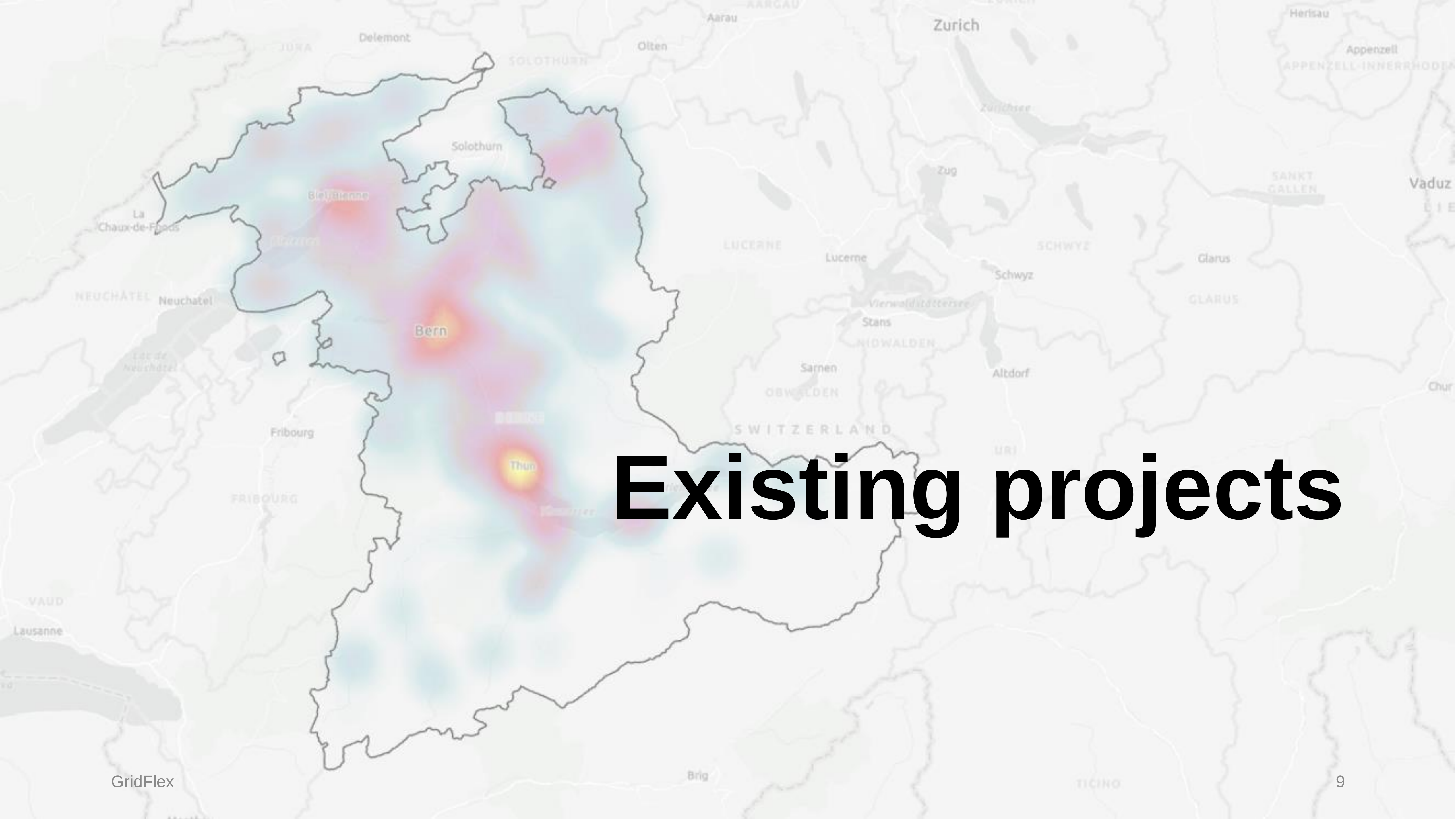
Student MSc Energy Science and Technology

Introduction to the problem: Increased stress on the grid

Increasing penetration of photovoltaic (PV) systems, coupled with the increased use of heat pumps (HP) and electric cars (EV), is placing strain on the power grid, especially on lower voltage levels. Traditional grid expansion as a solution is both costly[1] and resource-intensive. Alternative approaches focus on leveraging the flexibility inherent in both electricity consumers and generators, i.e. through load shifting (HPs and EVs) or curtailing PV.



Existing projects

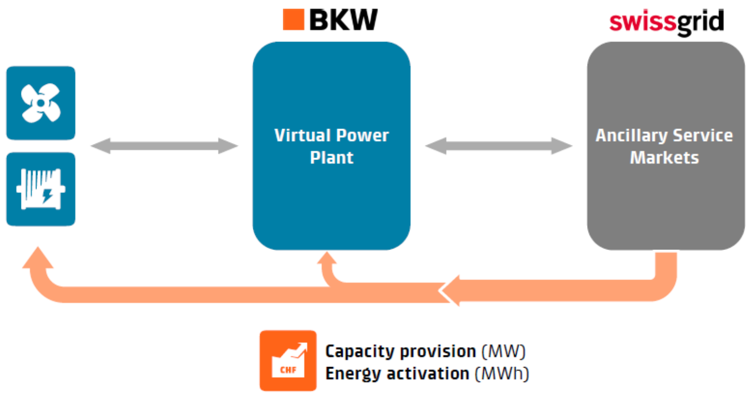


Existing projects (1)

The integration of flexibility and sector coupling is becoming increasingly important. More and more projects are being developed. In our case, we have focused on projects that primarily involve the mitigation of grid expansion:

INFRASTRUKTUR ZÜRICHSEE AG

Infra already buys flexibility directly from its customers in order to minimize network expansion[1].



BKW Energy Powerflex: One of BKW's products. Used to pool its customers' flexibility in a Virtual Power Plant and sell it to Swissgrid.

1: Infra, 2023; 2: BKW, Energy Powerflex

Existing projects (2)

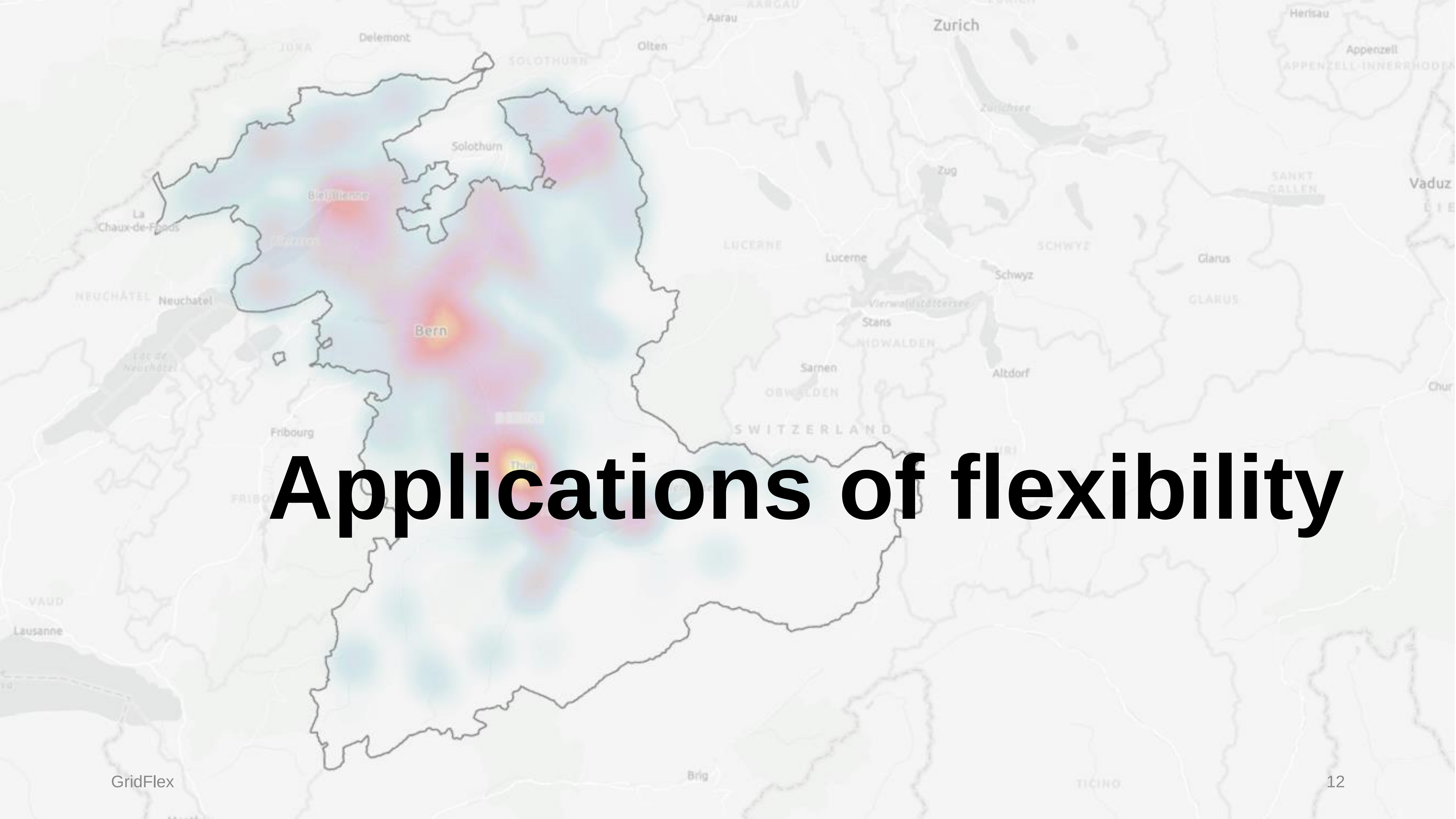
Enera: Pilot project 2018-2021 in Germany which dealt with flexibilities at household level. The flexibility options investigated allow a more efficient and, in some cases, higher utilization of grid resources than is possible with conventional grid planning approaches[1].

On the household level there are different obstacles to overcome[2]:

- User-investor dilemma:
- Low monetary incentives for potential providers of flexibility
- Installation of Smart Meter Gateway not sufficient extent
- Regulatory complexity and limits of own electricity use, tenant electricity, etc.
- Digital, bidirectional interoperability

PATHFNDR: One key aspect is to assess flexibility options across various sectors and along various spatiotemporal scales to integrate renewable energy[3]

1: netzdienliche-flexibilitatsmechanismen; 2: flexibilitatspotenziale-und-sektorkopplung; 3: sweet-pathfndr.ch



Applications of flexibility

Utilisation options for flexibility

Flexibility can be used in different ways. The SFOE focuses on three different forms. These can be combined with each other. We assume that consumers optimize for their own purposes as a first priority and the remaining flexibility can be used mainly for grid-friendly utilisation. System-oriented utilisation would also be a possibility, but is in our project not the main focus.

	Use by consumers for own purposes	Grid-friendly utilisation	System-orientated utilisation
Purpose	i.e. to avoid loss of comfort	congestion management and attenuation of the need for grid expansion	System-wide balancing of generation and consumption

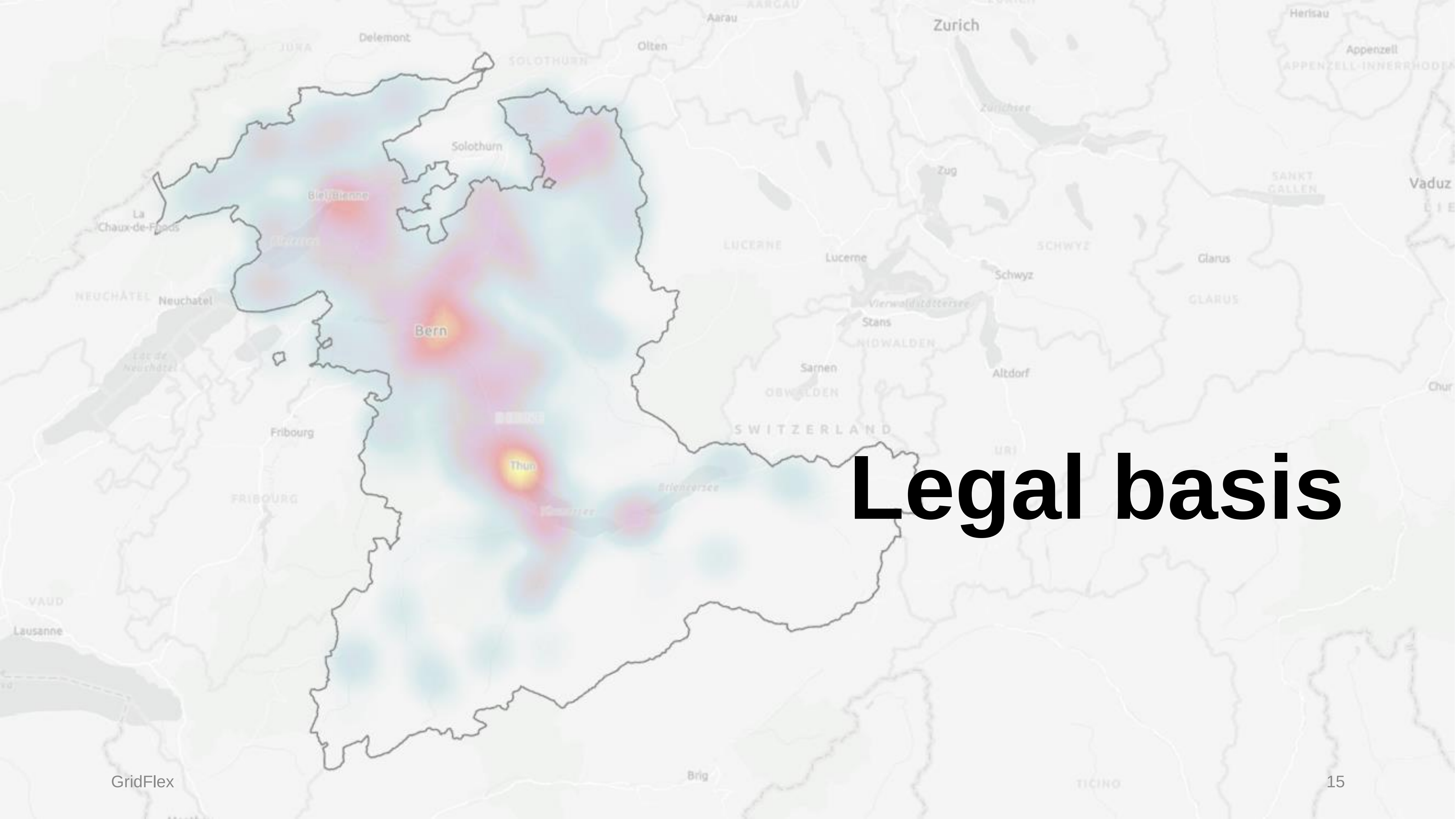
BFE, p. 103 et seq.

Applications of grid-friendly flexibility: DSM and DSR

Literature suggests different ways to think of applications in flexibility. Generally, two applications are differentiated, namely Demand Side Management (DSM) and Demand Side Response (DSR). We do not specify, whether our project accesses the flexibility through DSM or DSR or both.

Demand Side Management	Demand Side Response
DSM is defined as the direct influence on the load through the grid operator or other actors, without the endconsumer's consent in the specific case. The concepts of feed-in management (curtailment of fluctuating generation) and virtual power plants, in which decentralised generators and consumers are bundled and can be used to serve the grid or system, are relevant for our project.	DSR refers to the influencing of consumers or decentralised producers. One way to influence the behaviour might be monetary incentives, i.e. time-dependent or dynamic tariffs. The control lies with the consumer.

VSE, 2016


Aarau
Zurich
Herisau
Delemont
Olten
Appenzell
APPENZELL-INNERRHODEN
JURA
SOLOTHURN
Solothurn
Zug
SANKT GALLEN
Vaduz
Biel/Bienne
La Chaux-de-Fonds
LUCERNE
Lucerne
SCHWYZ
Schwyz
Glarus
NEUCHÂTEL
Neuchatel
GLARUS
Bern
Stans
NIDWALDEN
Sarnen
Altdorf
OBWALDEN
Chur
Fribourg
SWITZERLAND
URI
Thun
Brienzersee
FRIBOURG
VAUD
Lausanne
Brig
TICINO

Legal basis

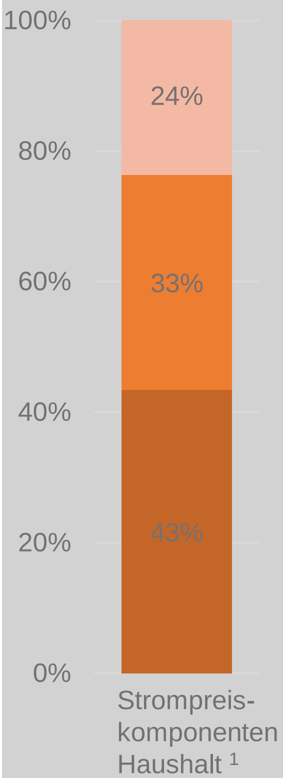
Legal basis

Regulation in the area of private energy production, tariff design and metering and control systems is relevant for our project. In terms of private energy production, we are particularly interested in whether production can be reduced. Tariff design is of interest because it allows flexibility by sending price signals to the end customer at different times. In addition, the tariff structure also governs the potential for transferring the expenses of the forthcoming grid expansion and any supplementary costs for pioneering projects. Metering systems provide the groundwork for predicting loads, while control systems are especially pertinent in the corrective application of flexibility.

Existing legal basis: StromVG

The «Electricity Supply Act» exists only in the national languages. This slide is therefore in German.

Art. 6:
Lieferpflicht und Tarifgestaltung für feste Endverbraucher



Abgabe Stufe Endverteilung und MWST: Nach Art. 6 Abs. 3 werden die Abgaben und Leistungen an Gemeinwesen veröffentlicht.

Energie: Gemäss Art. 6 Abs. 4 ist die Basis für die Tarifgestaltung eine Kostenträger-rechnung, bei der die Einspeisung nicht berücksichtigt werden darf.

Netz: Art. 6 Abs. 4 verweist auf Art. 14 und Art. 15. Das Entgelt ist je *Aus*speisepunkt zu entrichten. Das Entgelt muss dem Ziel einer effizienten Netzinfrastruktur Rechnung tragen. Als anrechenbare Kosten gelten neben den Betriebs- und Kapitalkosten auch Kosten innovativer Massnahmen für intelligente Netze.

Art. 17a:
Intelligente Messsysteme

Ein intelligentes Messsystem ist eine Messeinrichtung für Strom, die eine bidirektionale Datenübertragung unterstützt und den tatsächlichen Fluss zeitaufgelöst erfasst. Der Bundesrat kann Vorgaben zur Einführung machen. Art. 8a StromVV regelt die Details. Die alten Stromzähler müssen bis 2027 von den Netzbetreibern ersetzt werden.

Art. 17b:
Intelligente Steuer- und Regelsysteme

Intelligente Steuer- und Regelsysteme sind Einrichtungen, mit denen ferngesteuert auf den Verbrauch, die Erzeugung oder die Speicherung von Strom, namentlich zur Optimierung des Eigenverbrauchs oder zur Sicherstellung eines stabilen Netzbetriebs, Einfluss genommen werden kann. Der Einsatz bedarf der Zustimmung der Betroffenen, wobei der Bundesrat Ausnahmen vorsehen kann.

1: VSE 2018.

Existing legal basis: EnG

The «Electricity Supply Act» exists only in the national languages. This slide is therefore in German.

Art. 16:
Eigenverbrauch

Die Betreiber von Anlagen dürfen die selbst produzierte Energie am Ort der Produktion ganz oder teilweise selber verbrauchen. Sie dürfen die selbst produzierte Energie auch zum Verbrauch am Ort der Produktion ganz oder teilweise veräussern. Beides gilt als Eigenverbrauch. Der Bundesrat erlässt Bestimmungen zur Definition und Eingrenzung des Orts der Produktion.

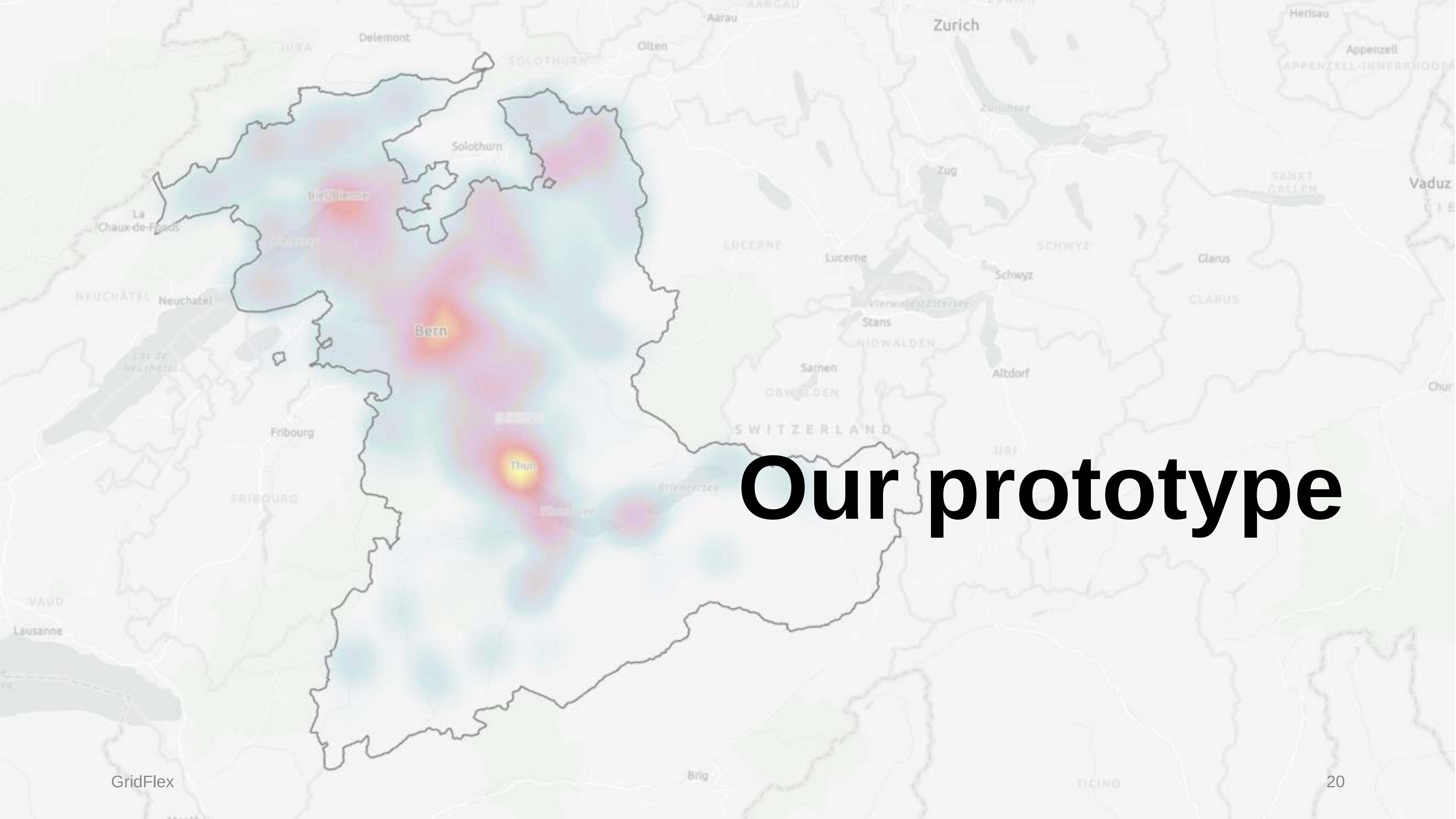
Wir vermuten, dass dieser Artikel die Basis für die Abregelung (curtailment) von beispielsweise PV-Anlagen legen könnte.

1: VSE 2018.

Parliamentary procedural requests

The Federal Act on the Secure Supply of Electricity from Renewable Energies (21.047, Federal Council) provides for a revision of the StromVG and EnG. Both the National Council and the Council of States have approved the matter. The referendum period runs until 18.01.2024. Two changes are of particular importance for our project:

Electricity market liberalisation	Grid regulation, data and metering
The complete opening of the electricity market strengthens decentralised renewable electricity production. End consumers and consumers who produce their own electricity (prosumers), producers and electricity suppliers are thus given economically important freedoms.	The utilisation and expansion of the electricity grids should become more cost-efficient. To this end, the Federal Council is creating the legal basis to enable end consumers and storage system operators to utilise their flexibility in a way that benefits the system, and it is ensuring a charging system that based on the polluter-pays principle. The Federal Council is also clarifying the responsibilities and legal freedoms of choice in metering.

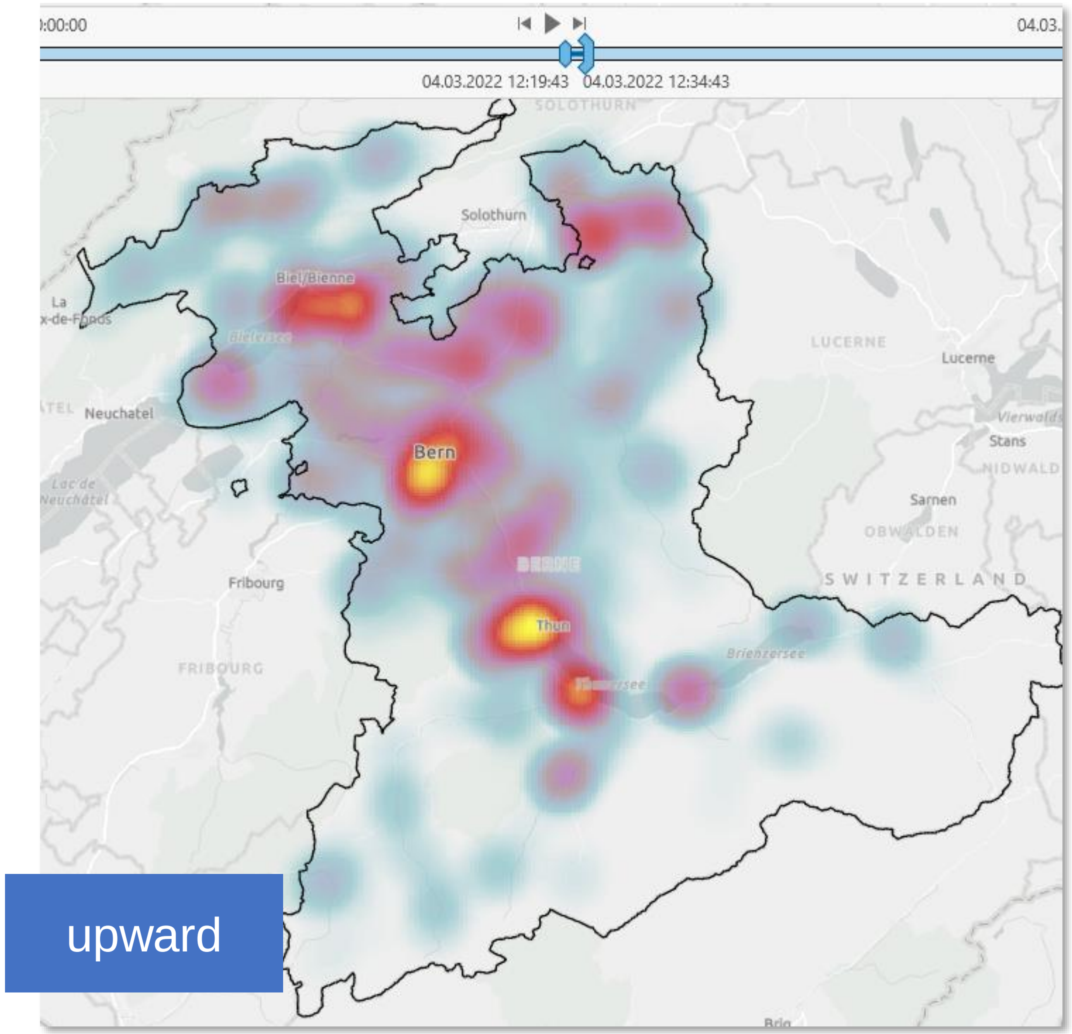


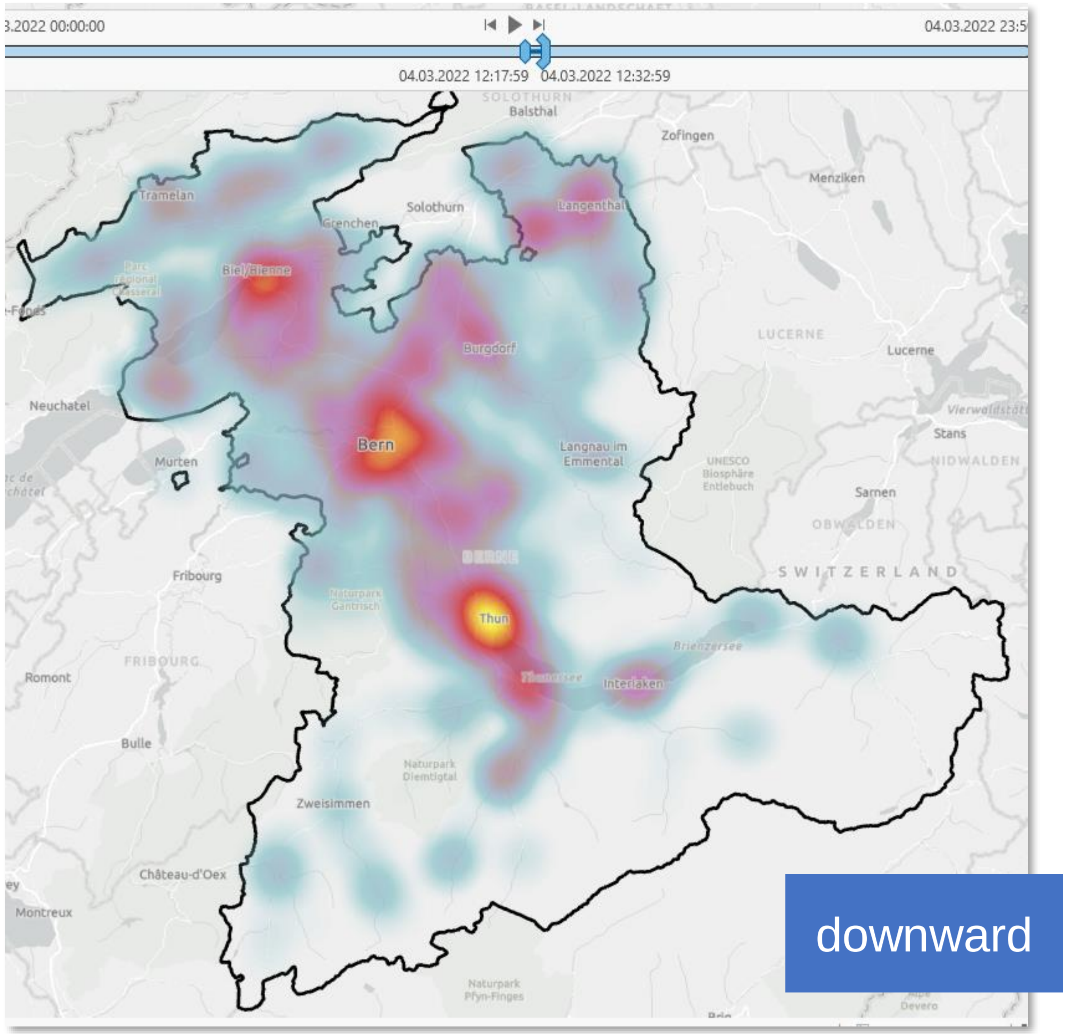
Our prototype

Prototype: Description

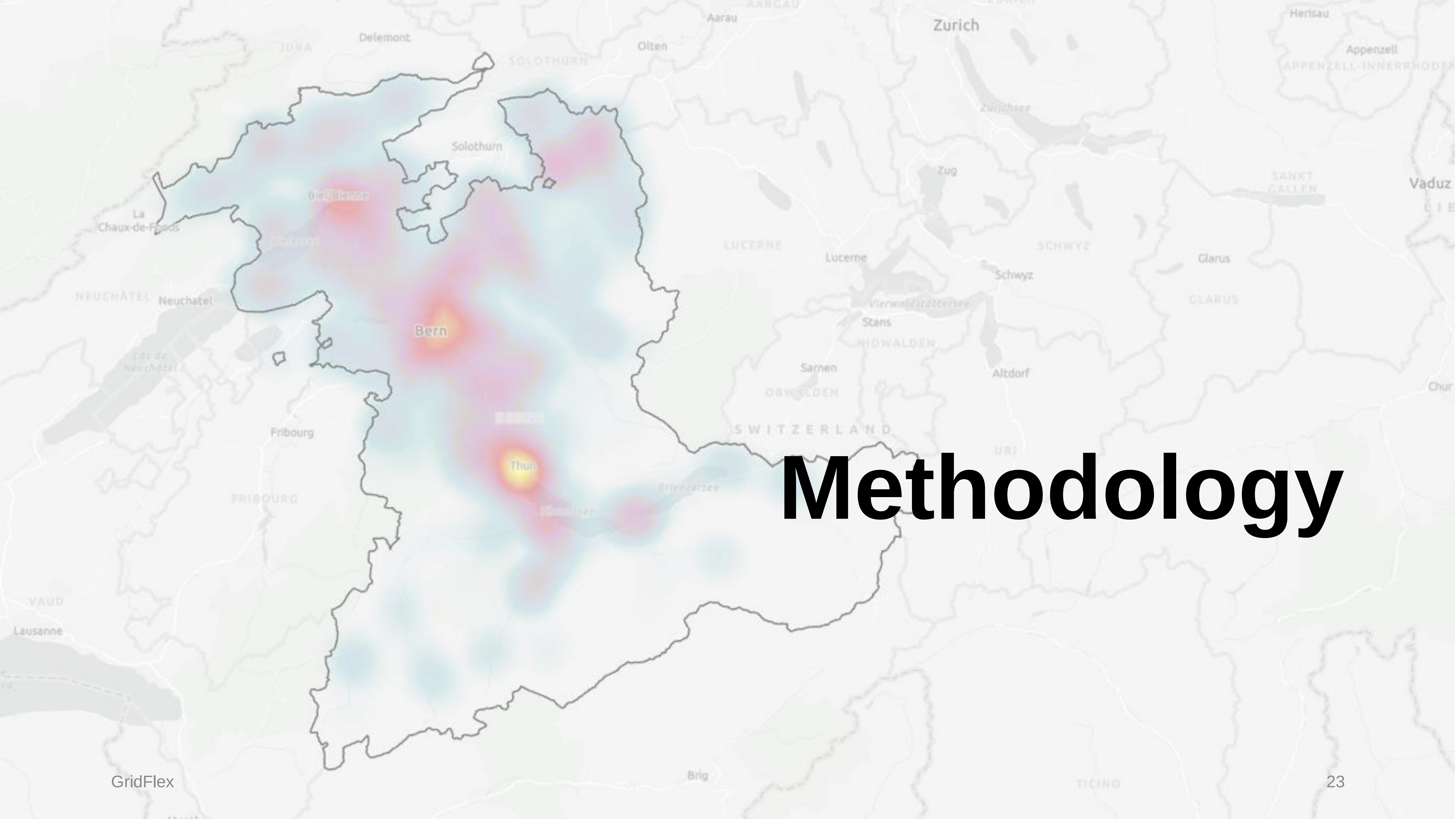
Our prototype consists of a map of the canton of Bern showing the estimated upward and downward flexibility of PV and loads of single-family homes. The prototype displays the flexibility as a heat map to show regional differences. It also takes into account the occurrence of flexibility by adding a time dimension to the map. By pressing play, the user can observe the changes in flexibility over the selected time frame.

Prototype

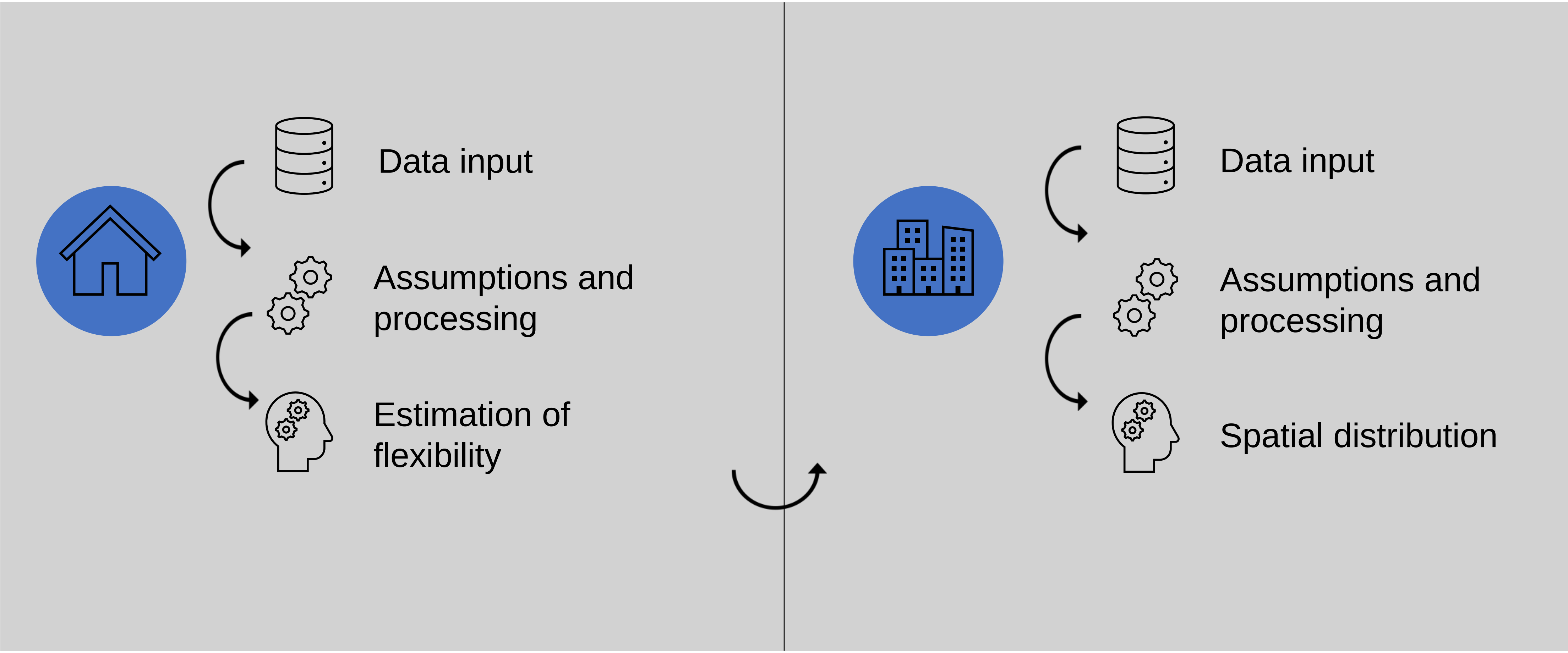

04.03.2022 12:19:43
04.03.2022 12:34:43
Solothurn
Biel/Bienne
Neuchatel
Bern
Fribourg
Thun
LUCERNE
Lucerne
Stans
Sarnen
OBWALDEN
SWITZERLAND
FRIBOURG
upward


04.03.2022 12:17:59
04.03.2022 12:32:59
Balsthal
Zofingen
Menziken
Solothurn
Grenchen
Tramelan
Langenthal
Biel/Bienne
Burgdorf
LUCERNE
Lucerne
Neuchatel
Murten
Bern
Langnau im Emmental
Stans
Sarnen
Fribourg
SWITZERLAND
Thun
Romont
FRIBOURG
Interlaken
Bulle
Zweisimmen
Château-d'Oex
Montreux
downward

Methodology



Overview of the methodology



Step 1: Modelling single house

We received our data from BKW. It consists of three different profiles of anonymized customer profiles from single family houses in 2022. The data is for one year in a 15 minutes resolution.

- Loads: Flexible are HP (3 profiles) and boiler (1 profile), inflexible is the rest of the consumption
- PV Production: 3 profiles. Value of the max. PV production in the year is assumed to be the kWp

---

- For the PV production, we assumed a curtailment 30% of the max. installed capacity. More curtailment is downward flexibility, less curtailment is upward flexibility
- We made the following assumptions for the shifting of the HP:
  - Turning off the HP is an upward flexibility→ only possible when running
  - Turning on the HP is a downward flexibility→ only possible if sufficient time has elapsed since the last cycle, otherwise the internal temperature will be too high
  - For detailed description of how the calculation are done see „Flexibility of HP: Detailed Concept"

- Upward flexibilitity from HP and PV is summed up
- Downward flexibility from HP and PV is summed up
- To avoid double counting, HP downward flexibility is only considered if it is bigger than PV down regulation

Step 2: Apply to the whole canton

For the location and the capacity of the PV instalations, we used a dataset from SFOE on the electricity production plants.

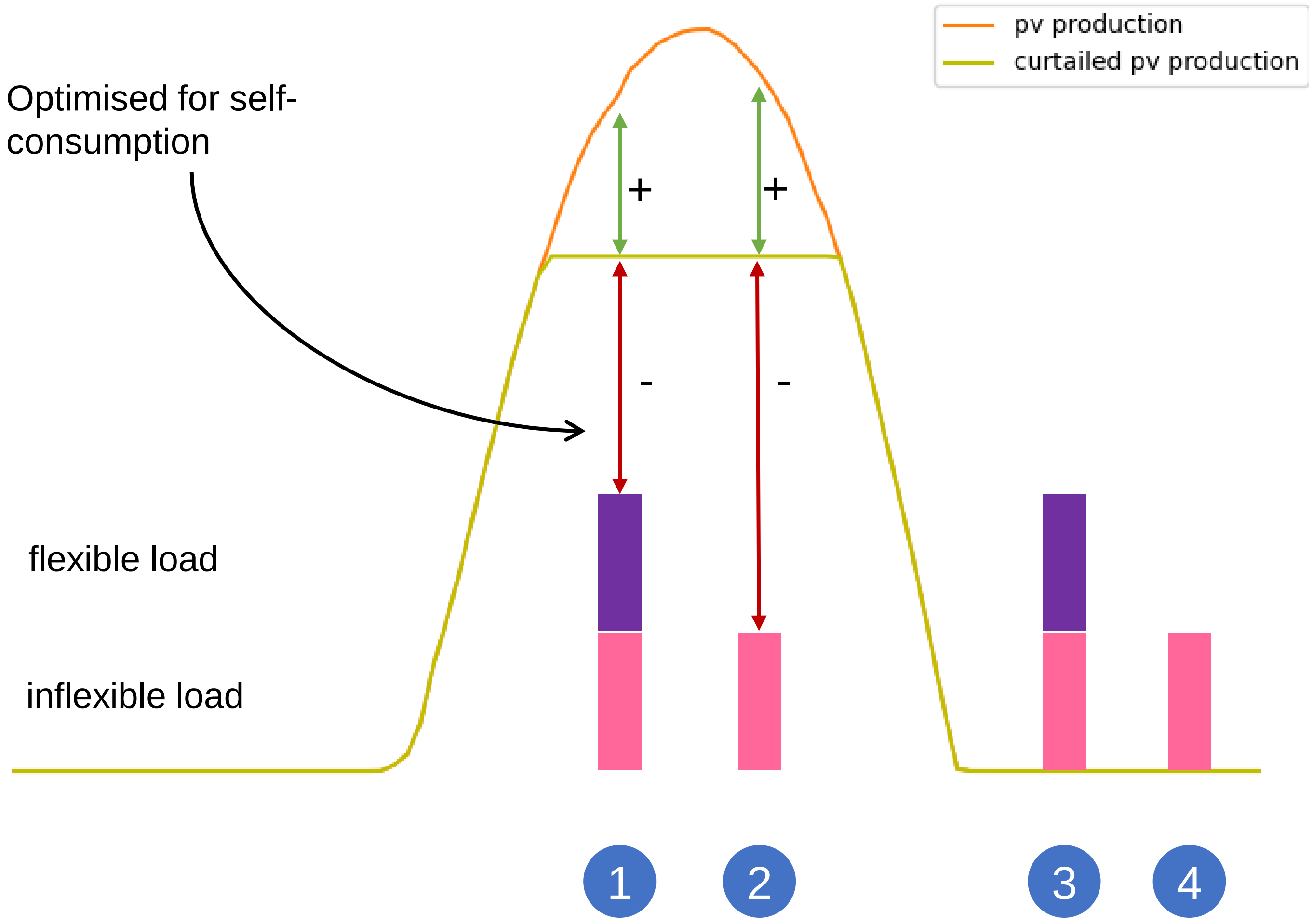
- We filtered for the subcat 2 (=PV) and in GIS selected only those plants within the canton of Bern. We filtered for all plants below 15 kWp, in order to be sure only to target single family houses.
- We then needed to assign the load profiles to the PV locations. We also wanted to create some variance, which is why we shifted the load profiles by +/- 7 days and +/- 14 days. In that way, we received a total of 3*5=15 different load profiles. The different load and production profiles are then assigned randomly to the locations of the PV plants, meaning we mix the load profiles with PV production from another house.
- To scale the PV profile, we used the installed kWp from the SFOE data.

- The upward and downward flexibility is calculated for each data point and is exported into a csv.
- The csv is imported into a GIS software and displayed as XY-data.
- The attribute «timestamp» is defined as temporal data. The points are displayed as heatmap (weight flexibility).

Scaleability of our approach

Currently, handling the data is manageable, but for future scalability, clustering can be employed. Many calculations are independent and can be divided into monthly or smaller packages, especially when dealing with data for entire regions like Switzerland. Alternatively, depending on the specific application, calculations per grid connection point could be consolidated at the respective substation. Additionally, considering the use case, a 15-minute resolution may not always be necessary.

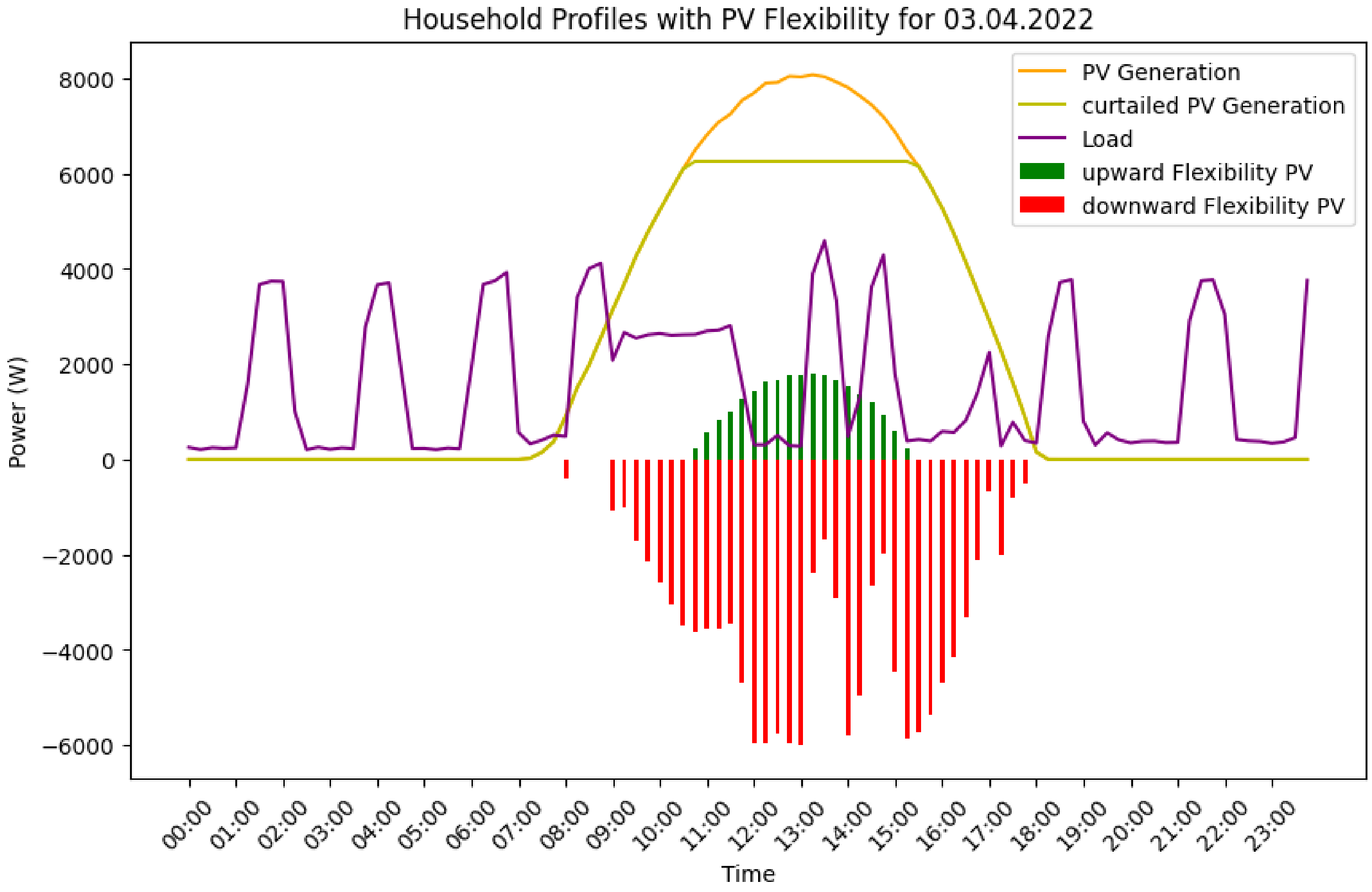
Flexibility of PV: Concept



PV upward flexibility =
PV generation – PV curtailed

PV downward flexibility =
PV curtailed – (flexible + inflexible load)

Flexibility of PV: Output



PV upward flexibility =
PV generation - PV curtailed

PV downward flexibility =
- (PV curtailed - total load)

(only if total load < curtailed PV)

Flexibility of PV: Implementation (1)

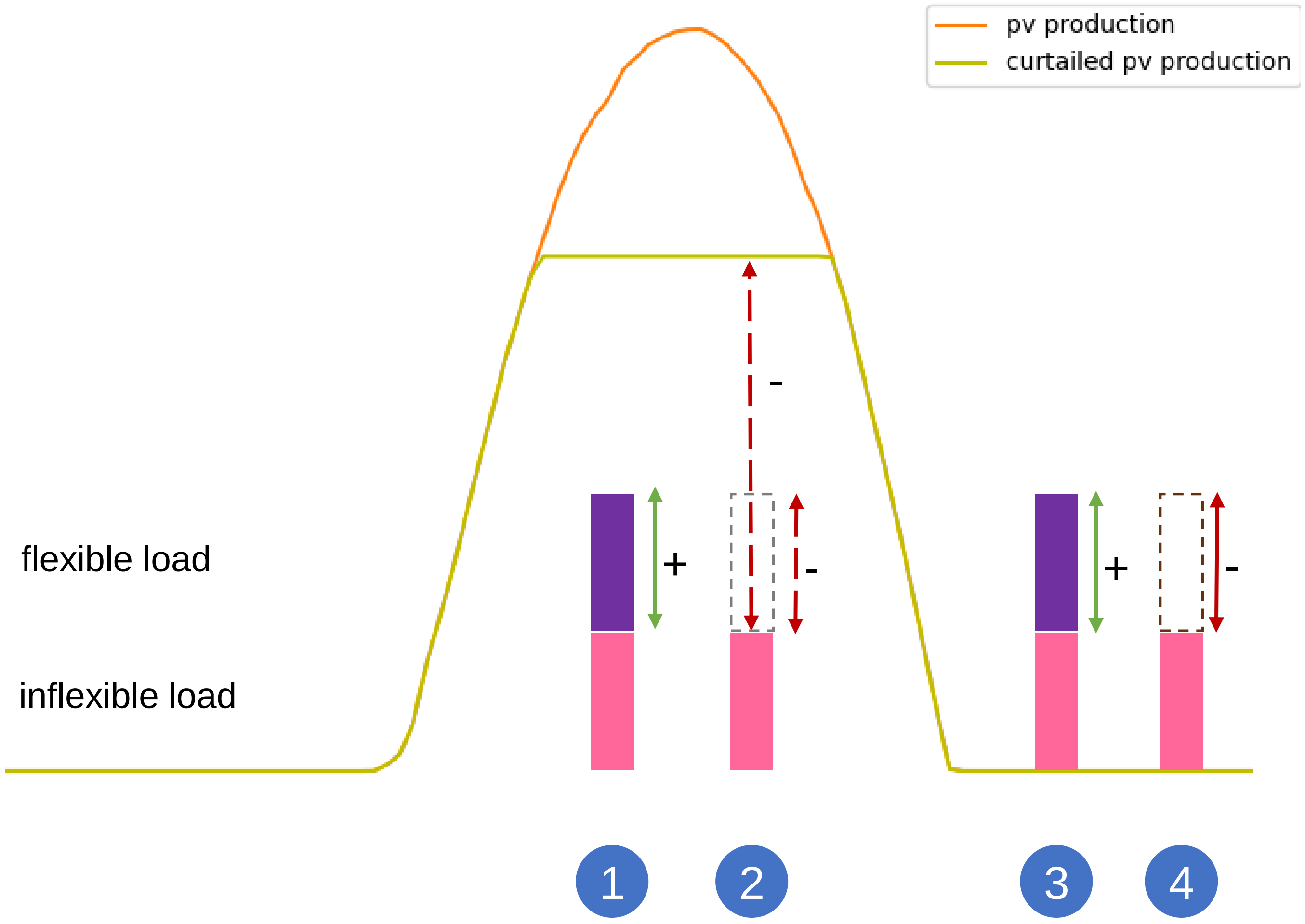
```python
def pv_flexibility(load, pv_generation, W_peak, curtailment_factor = 0):
    """
    This function calculates the flexibility provided by a prosumer from the load
    profile, the PV energy profile, the installed kW peak, and a curtailment factor
    for the PV generation at peak hours.

    Parameters:
    - load (array): Load profile of the prosumer in W.
    - pv_generation (array): PV energy production profile of the prosumer in W.
        Length must be equal to the load profile.
    - W_peak (float): Installed PV in W peak.
    - curtailment_factor (float): Factor that sets PV curtailment at peak production.
        Needs to be between 0 and 1.

    Returns:
    - upward_flexibility (array): Upward Flexibility provided by prosumer in W.
    - downward_flexibility (array): Downward Flexibility provided by prosumer in W.
    - curtailed_pv_generation (array): New PV curve which is curtailed during peak hours in W.
    """
```

Flexibility of PV: Implementation (2)

```python
    assert len(load) == len(pv_generation), "Length of 'load' must be equal to the length of 'pv_generation'"
    assert 0 <= curtailment_factor <= 1, "Curtailment Factor must be between 0 and 1"

    # Compute the curtailed pv curve
    pv_curtailed = np.minimum(pv_generation, W_peak * (1-curtailment_factor))

    # Compute upward flexibility
    upward_flexibility = np.maximum(np.minimum(pv_generation - pv_curtailed, pv_generation - load),0)

    # Compute downward flexibility according to the load profile
    down_flex_load = pv_curtailed - load

    # Compute downward flexibility
    downward_flexibility = -np.maximum(down_flex_load, np.zeros(len(load)))

    return upward_flexibility, downward_flexibility, pv_curtailed
```


Gridflex_final/Flexibility_function.py

Flexibility of HP: Concept

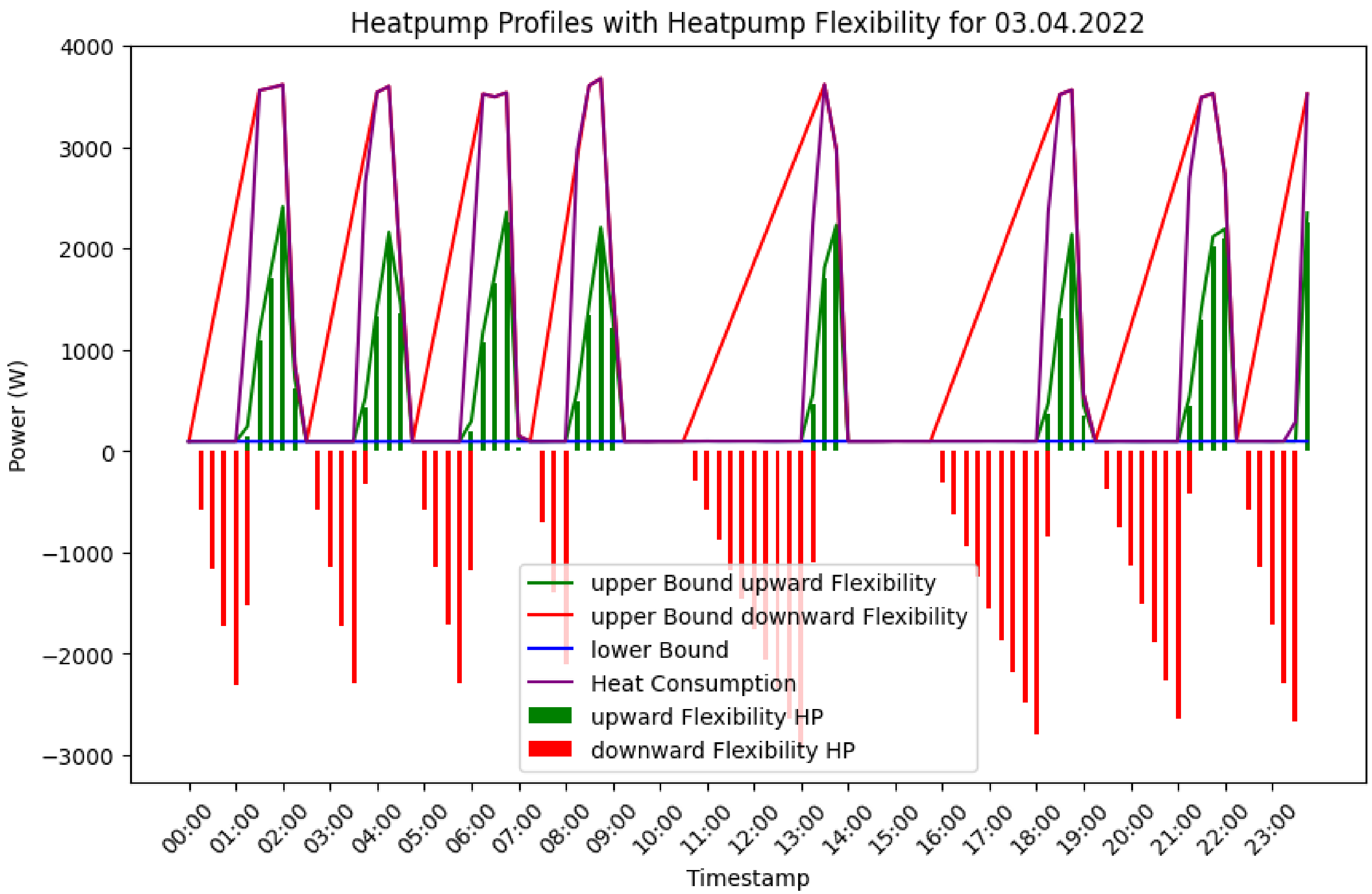


upward flexibility =
PV up + heat pump off

downward flexibility =
Max (|PV down|, |heat pump on|)

(Simplified)

Flexibility of HP: Output



HP upward flexibility = upper bound upFlex - lower bound

HP downward flexibility = - (upper bound downFlex - heat consumption)

Flexibility of HP: Detailed Concept

- **Upper Bound Downward Flexibility:** The upper bound on downward flexibility establishes a linear increasing line connecting the point where the last heating cycle ends to the beginning of the next heating cycle. If the last heating cycle ended more than three hours ago, the line starts three hours before the heating cycle.
- **Upper Bound Upward Flexibility:** The upper bound on upward flexibility is active only within a heating cycle and is defined as follows:
  - Upper Bound Upward Flexibility = a * Heat Consumption

  Here, 'a' increases over the heating cycle from 0 to 1.
- **Lower Bound:** The lower bound indicates the standby mode of the heat pump.

Flexibility of HP: Implementation

```python
def hp_flexibility(hp_profile, upper_bound_downflex, upper_bound_upflex, lower_bound):
    """
    This function computes the upward and downward flexibility provided by a heat pump.

    Parameters:
    - hp_profile (array): Array of heat pump consumption profile in W.
    - upper_boundary_upflex (array): Upper boundary needed for upward flexibility calculation.
    - upper_boundary_downflex (array): Upper boundary needed for downward flexibility calculation.
    - lower_boundary (array): Lower boundary needed for flexibility calculation.

    Returns:
    - upward_flexibility_hp (array): Upward Flexibility provided by the heat pump in W.
    - downward_flexibility_hp (array): Downward Flexibility provided by the heat pump in W.
    """
    assert len(hp_profile) == len(upper_bound_downflex) == len(lower_bound) == len(upper_bound_upflex)

    #upward_flexibility_hp = upper_bound - consumption_heat
    downward_flexibility_hp = -np.maximum((upper_bound_downflex - hp_profile),0)

    #downward_flexibility_hp = consumption_heat - lower_bound
    upward_flexibility_hp = np.maximum((upper_bound_upflex - lower_bound),0)

    return upward_flexibility_hp, downward_flexibility_hp
```

More details on the implementation of the upper and lower bound can be found in the repository.

Gridflex_final/Flexibility_function.py

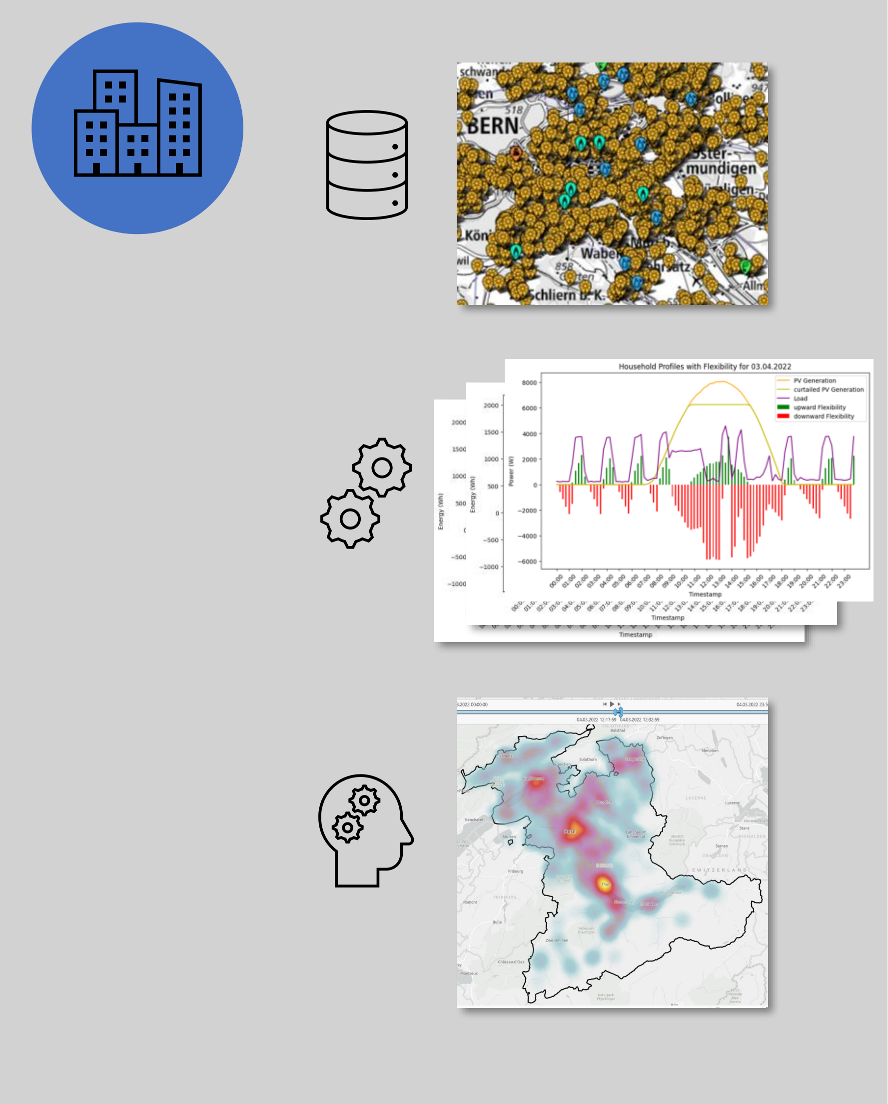
Flexibility of PV and HP: Implementation (1)

```
def flexibility(pv_profile, inflexible_load_profile, hp_profile, Wpeak, curtailment_factor = 0, heating_threshold = 100, ramp_up_timesteps = 12):
    """
    This function computes the upward and downward flexibility provided by the PV production and
    heat pump consumption of a prosumer.

    Parameters:
    - pv_profile (array): PV production profile of a prosumer for a certain time period in W.
    - inflexible_load_profile (array): Inflexible load profile of the same prosumer for the same time period as the PV in W.
    - hp_profile (array): Heat pump consumption profile of the same prosumer for the same time period as the PV in W.
    - W_peak (float): Installed PV in W peak.
    - curtailment_factor (float): Factor that sets PV curtailment at peak production. Needs to be between 0 and 1.
    - heating_threshold (float): Threshold for detecting the beginning and end of heating.
      Assumption: Heat pump considered to heat when operated above 100 W.
    - ramp_up_timesteps (int): Maximum timesteps before the heat pump is switched in, providing downward flexibility.
      Set to 12, corresponding to 3 hours in 15-minute resolution.

    Returns:
    - upward_flexibility (array): Total upward flexibility supplied by the PV and heat pump for each time step in W.
    - downward_flexibility (array): Total downward flexibility supplied by the PV and heat pump for each time step in W.
    """
    # Calculate the total load
    total_load = inflexible_load_profile + hp_profile
```

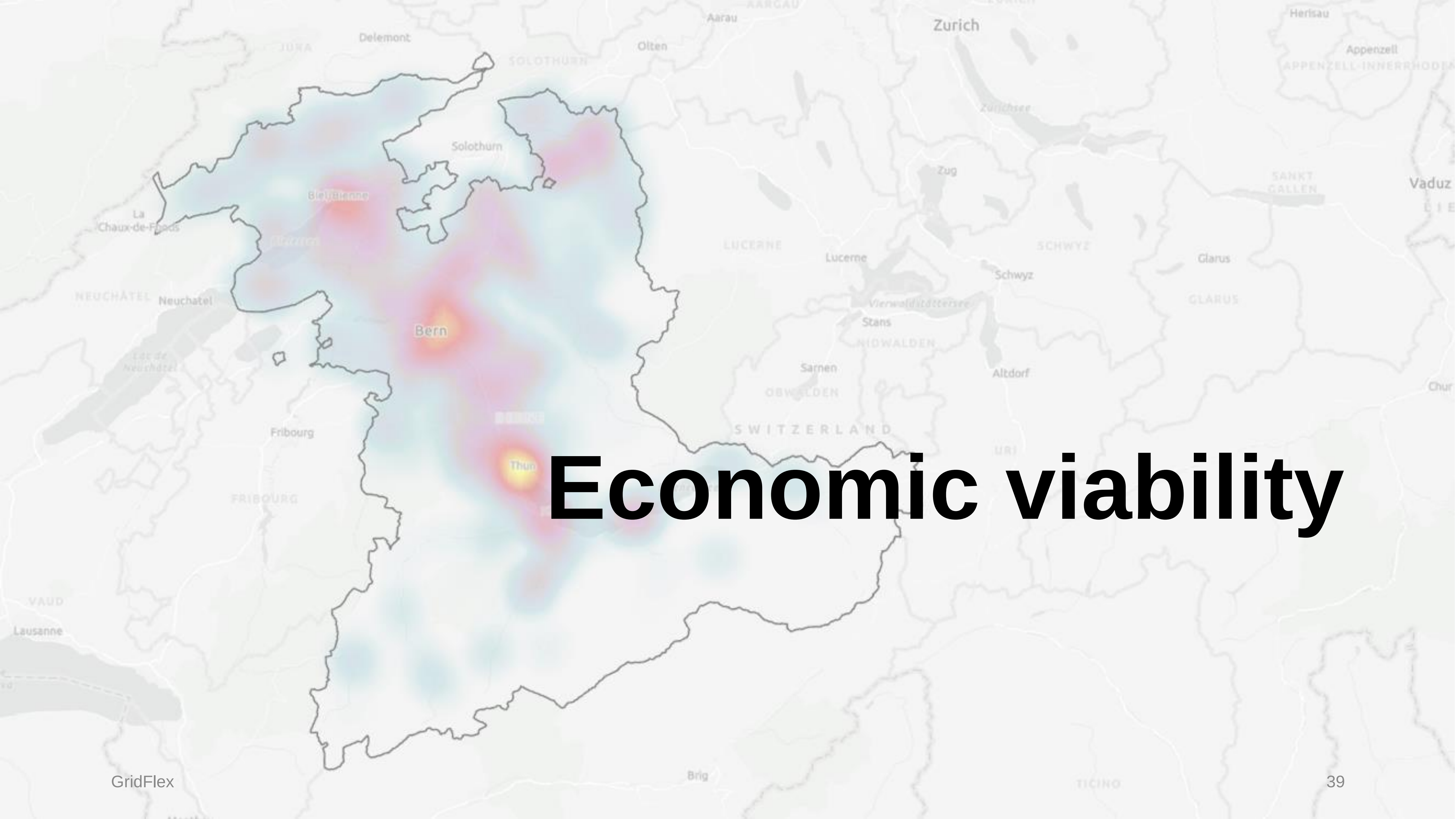
Flexibility of PV and HP: (2) Implementation

```
        # Calculate the total load
        total_load = inflexible_load_profile + hp_profile

        # Calculate heat pump flexibility
        heat_status = hp_status(hp_profile, heating_threshold)
        lower_bound = hp_lower_boundary(hp_profile, heat_status, heating_threshold)
        upper_bound_upflex = hp_upper_boundary_upflex(hp_profile, heat_status)
        local_maxima = hp_local_maxima(hp_profile, heat_status)
        upper_bound_downflex = hp_upper_boundary_downflex(hp_profile, heat_status, local_maxima, ramp_up_timesteps)
        upward_flexibility_hp, downward_flexibility_hp = hp_flexibility(hp_profile, upper_bound_downflex, upper_bound_upflex, lower_bound)

        # Calculate pv flexibility
        upward_flexibility_pv, downward_flexibility_pv, pv_curtailed = pv_flexibility(total_load, pv_profile, Wpeak, curtailment_factor)

        # Calculalate total flexibility
        upward_flexibility = upward_flexibility_pv + upward_flexibility_hp
        downward_flexibility = np.minimum(downward_flexibility_pv, downward_flexibility_hp)

        return upward_flexibility, downward_flexibility
```

Illustration: Summary



Economic viability



Economic viability

Our prototype serves as a first step in order to estimate flexibility in the area of a DSO. When the flexibility is accessed, we see three possibilities that could return the investment.

1. Mitigated expansion costs
2. Avoided balancing energy
3. Sell balancing energy

Economic viability: Mitigated expansion costs

Mitigated expansion costs 1

By making use of the flexibility, the DSO can mitigate substantial costs for expanding it's grid. To estimate the specific costs, it is important to know, whether the expansion is driven by increased demand or increased feed-in. By knowing the different components of the flexibility (PV, HP, EV, battery) for each region and timescale and in the end being able to access it, the DSO can optimize ist grid expansion costs and can thus minimize costs.

The table on the right shows the costs to expand the grid for different scenarios in comparison to the scenario ZERO Basis of the energy perspectives 2050+. It is estimated, that curtailing could reduce costs by up to 30%; grid-oriented load behaviour by up to 50%[1].

Sensitivität	Bandbreite veränderter Ausbaubedarfe über alle Verteilnetzebenen im Vgl. zu ZERO Basis
ZERO 2050	+ 20 bis + 50 %
Spitzenkappung 85%	- 0 % bis - 10 %
Spitzenkappung 70%	- 0 % bis - 30 %
Verstärktes Heimladen	+0 % bis + 40%
Verstärktes öffentliches Laden	- 0 % bis - 30 %
Marktorientiertes Lastverhalten	+ 10 % bis + 100 %
Netzorientiertes Lastverhalten	- 0 % bis - 50 %
Kombination: verstärktes Heimladen und marktorientiertes Verhalten	+ 20 % bis + 200 %
Kombination: verstärktes Heimladen und netzorientiertes Verhalten	- 0 % bis - 50 %
Kombination: netzorientiertes Verhalten und Spitzenkappung 85%	- 15 % bis - 60 %
Kombination: netzorientiertes Verhalten und Spitzenkappung 70%	- 25 % bis - 60 %
«Smarteres Netz»	- 20 % bis - 60 %

Tabelle 1.2 Veränderte Netzausbaubedarfe im Überblick über die betrachteten Sensitivitäten bezogen auf das Szenario ZERO Basis (die Prozentwerte beschreiben um wieviel Prozent die Ausbaubedarfe gegenüber denen im Szenario ZERO Basis erhöht oder verringert werden; positive Werte bedeuten demnach Mehrbedarfe, während negative Werte für geringere Bedarfe stehen)

1: BFE, 2022, p. 12

Economic viability: Avoid balancing energy

A balance group is an energy account, which can be used to process energy transactions with other balance groups in Switzerland and abroad, receive energy from power plants or deliver energy to end consumers. At any point in time at which the energy procurement and the energy release from a balance group are not in balance, the balance group procures balancing energy. Schedules and measured values are required to determine the amount of balancing energy of a balance group. Injections and withdrawals are added together, and the resulting difference is billed monthly as balancing energy between Swissgrid and the respective balance group[1].

Billing within the balance sheet group is regulated individually. Knowledge of and access to flexibility can be used for fine-tuning within the balance group in order to minimise the use of balancing energy.

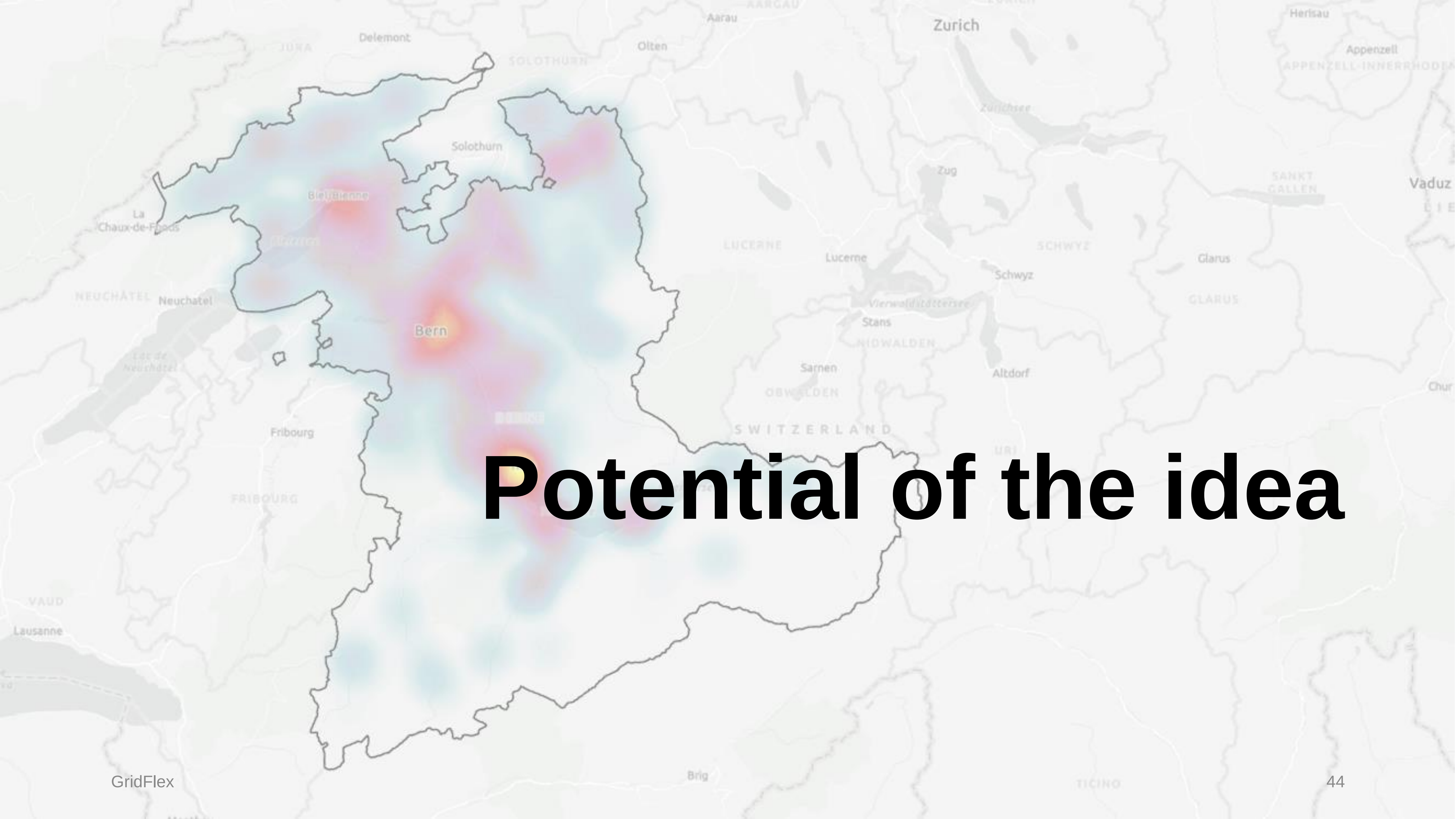
The historic prices for balancing energy can be found on the website of Swissgrid[2].

1: Swissgrid balance groups; 2: Swissgrid balance energy

Economic viability: Sell balancing energy

Aggregating flexibility, such as through a virtual power plant, presents an opportunity to commercialize it within the ancillary services market. It is crucial to acknowledge that the flexibility stemming from loads and PV production comes with inherent uncertainty. Nevertheless, with a sufficiently substantial pool and careful consideration of margins, it might be feasible to accommodate this uncertainty.

However, the existing system might not yet be adequately equipped for this approach, particularly regarding the duration of time blocks. How the market and the system develop will not least depend on the individual actors and the political framework.



Potential of the idea

Further exploration of PV

Vision

Instead of using the 3 generic PV profiles, historical irradiation values linked to the location of the PV installations could be used; also considering the orientation of the installation.

In a further step, it would be possible to switch from historical values to real-time data or even to forecast data, depending on the application.

Possible approach

Use the coordinates of the PV installation from EEA data. Use historical data from meteo swiss for the area of interest (not publicly accessible).

Use API for real time or forecast data for irradiation https://solarwebservices.ch/ (not publicly accessible)

Further exploration of heat pump

Vision

The implemented function for the estimated heat pump flexibility was only a first approach. The function could be optimized and compared to existing approaches in literature.

Instead of using the 3 generic heat pump profiles with no differentiation with respect to location or altitude, historical, real time or predicted weather data could be implemented taking into account the actual location/altitude, as the heat demand is highly dependent on the outside temperatures.

Currently, only single-family houses with PV are considered to have a heat pump. We should include all houses with heat pumps and exclude heat pump flexibility for houses with PV but no heat pump.

Possible approach

Comprehensive literature review for best practice about heat pump flexibility estimations, including temperature dependency.

Use historical, real time or forecast weather data from meteo swiss (not publicly available) to calculate the change in heat demand (function out of literature review) and combine with the coordinates of the PV installation from EEA (also GWR if the next point is considered).

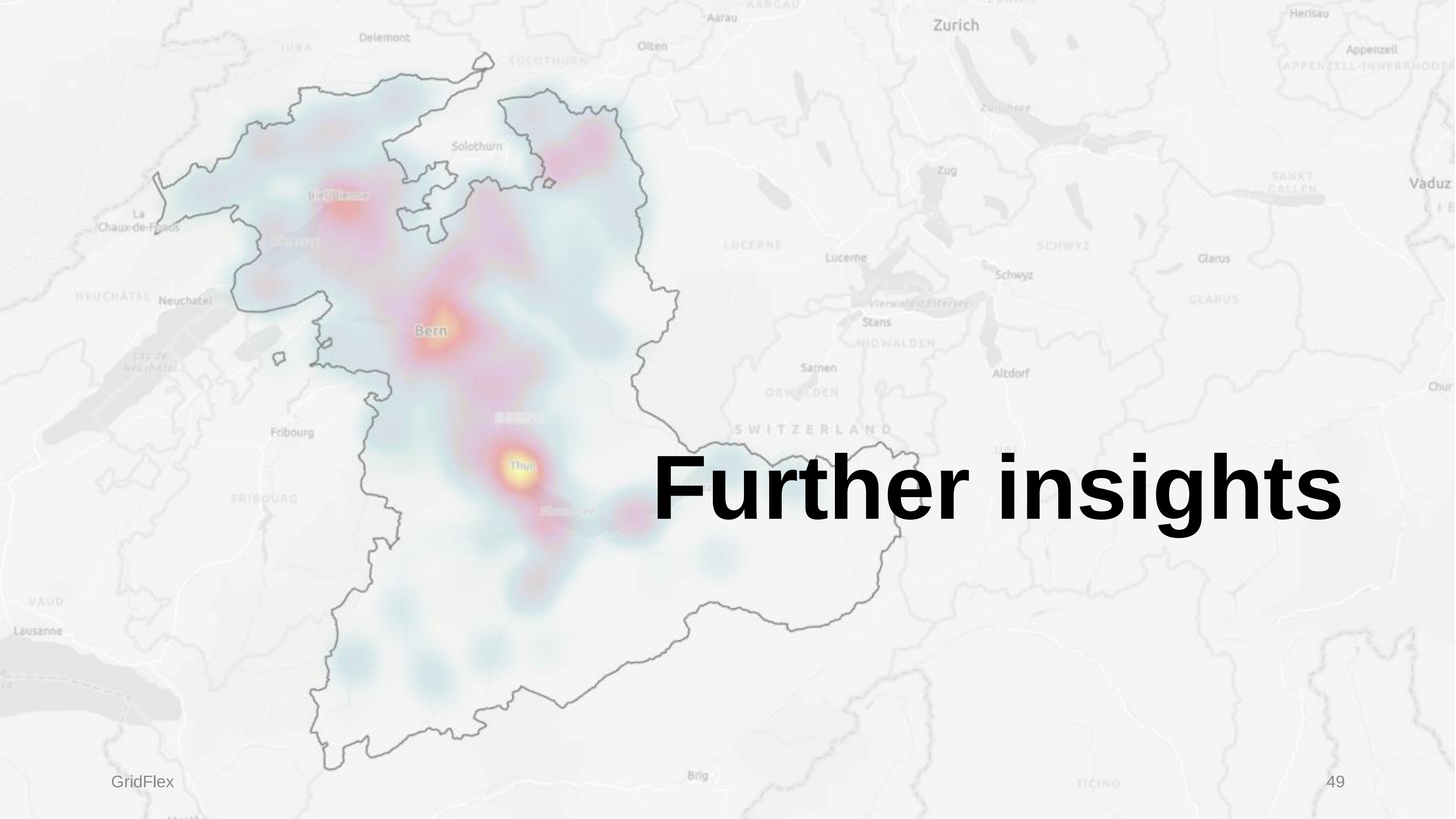
Use data from “GWR: Energie-/Wärmequelle der Heizung“ to know which buildings are having heat pumps to include those flexibilities in the spatial distribution.

Further exploration of model

Vision	Possible approach
Implement flexibility of EV	Do research about best practice for EV flexibility. Implement a function for EV flexibility calculation by using probability for charging at specific time and capacity of the battery. Use data of the share of EV in the total share of cars in Switzerland to get a % of houses with EV. Also consider location of charging (home, work, district).
Implement flexibility of BESS (battery energy storage systems)	Get proper data about the number of installed BESS in Switzerland. Use state of charge and capacity to model the flexibility.
Include different house types and not only single-family houses	Define different house categories and assign different profiles (depending on availability assumptions are needed), use GWR to assign house category profiles to different buildings and coordinates.

Further use cases

Vision	Possible approach
Location of flexibility for pooling	Analyse the spatial distribution in more detail to understand in which region the potential is bigger to pool the flexibilities.
Include EP2050+ scenarios	The penetration of PV, HP and EV will increase, and the spatial distribution has to be considered as well. Therefore, the amount of installed PV and HP as well as the share of EV could be scaled according to EP2050+. Accounting for the spatial distribution will be a big challenge in this step. Currently we don’t have convincing ideas how to assess for the fact that not every technology will spread at the same pace in all areas, and it’s the dependency on the income.
Analyse bottlenecks in the grid to mitigate grid expansion (especially interesting considering future scenarios)	To mitigate the grid expansions, the details of the power grid could be added to the GIS map in order to get a better understanding on how the usage of this flexibility can reduce the costs for grid expansion if considered and accessible.

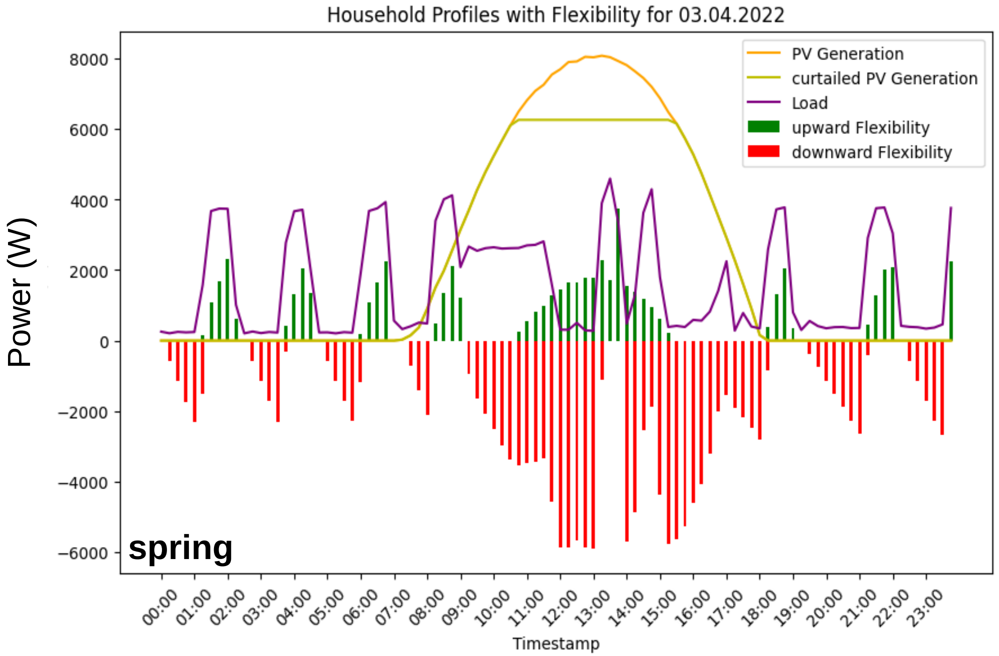


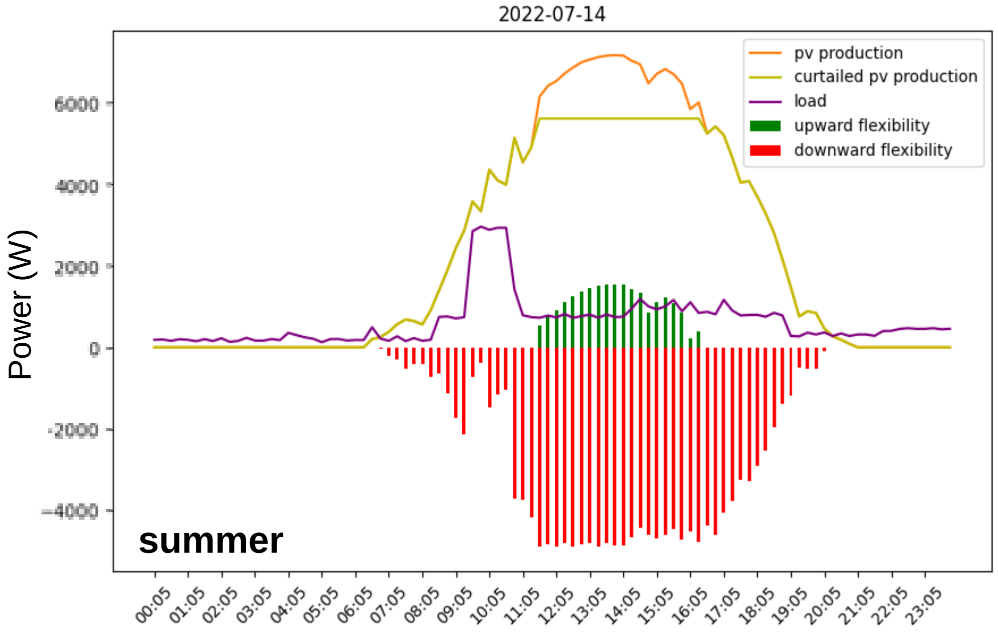
Further insights

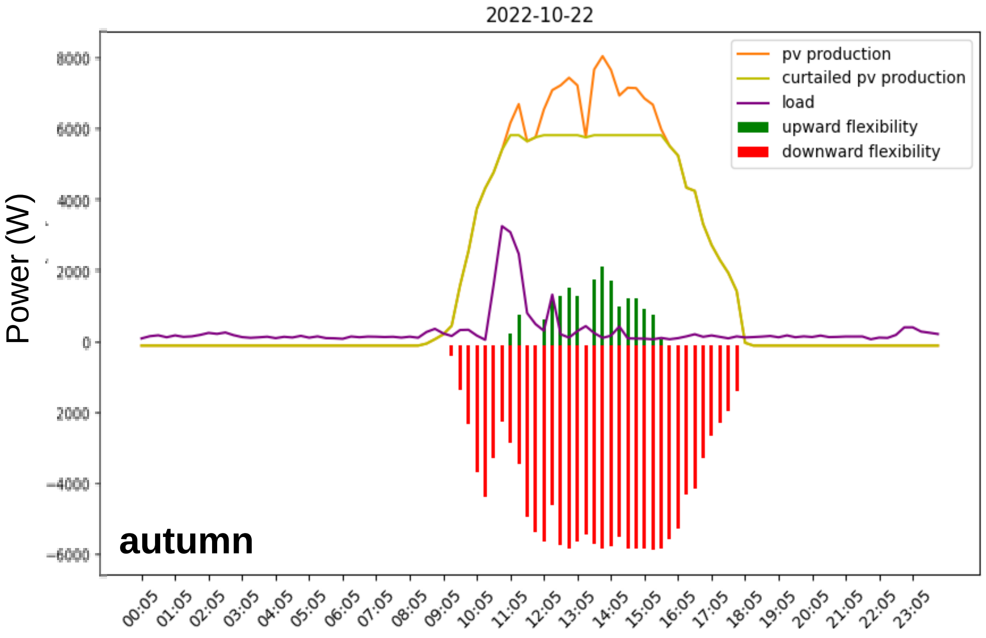
Seasonality

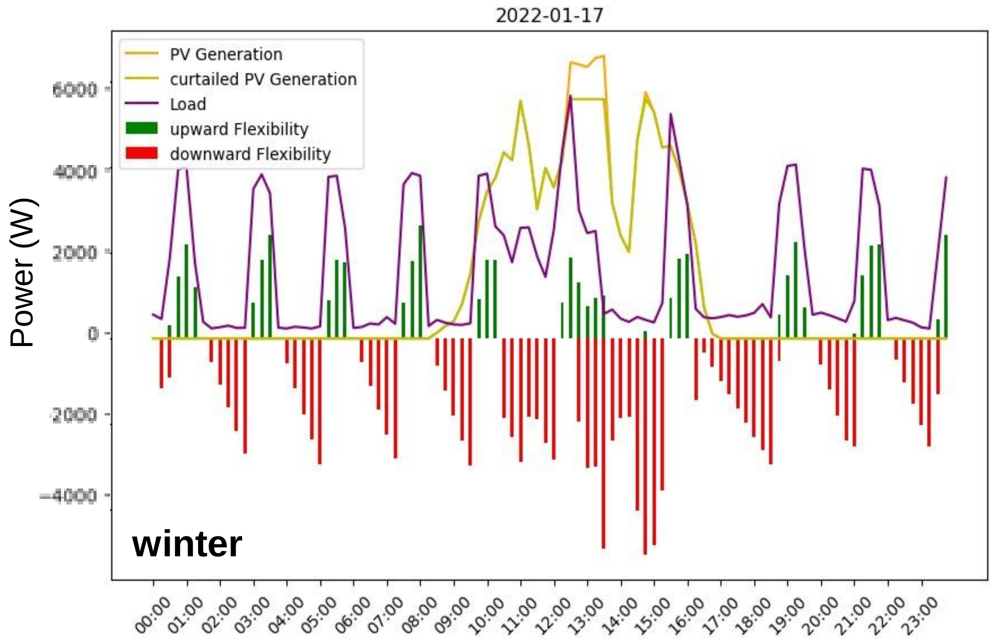
The availability and origin of flexibility varies considerably over the year. These effects would probably be even more pronounced if real irradiance and temperatures were used (increased heating at higher altitudes). The summer months are mainly characterised by PV flexibility, whereas in the winter months the combination of the two flexibilities has to be considered. This is particularly relevant when optimising for own consumption.

The following slide shows an example day for each season to illustrate the differences.

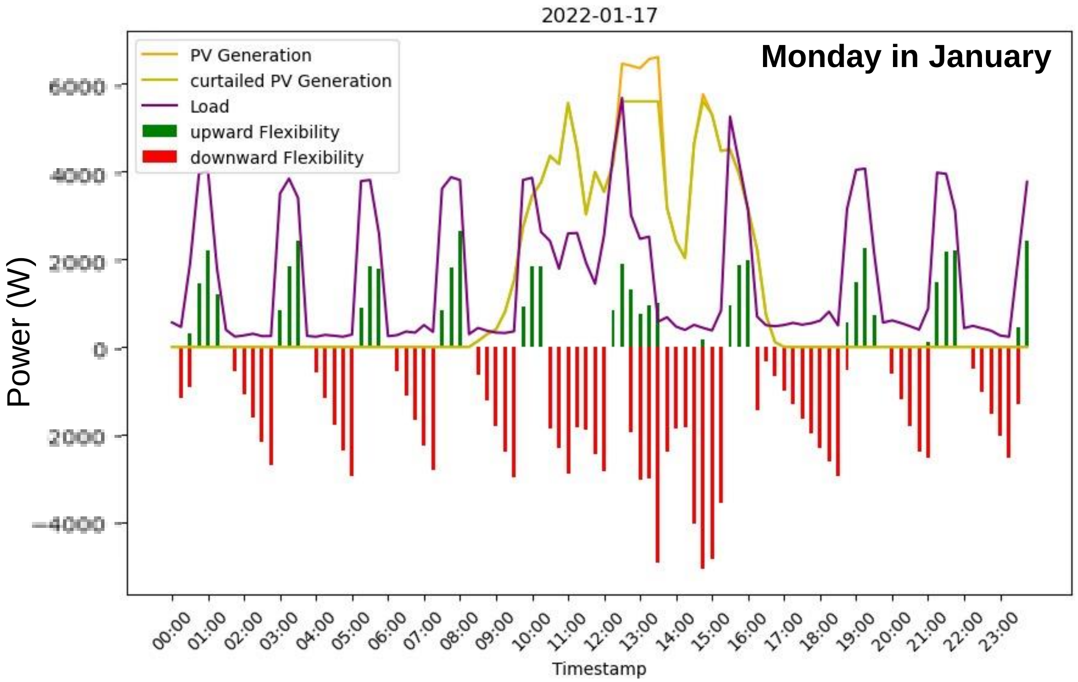

Household Profiles with Flexibility for 03.04.2022
PV Generation
curtailed PV Generation
Load
upward Flexibility
downward Flexibility
Power (W)
Timestamp
spring

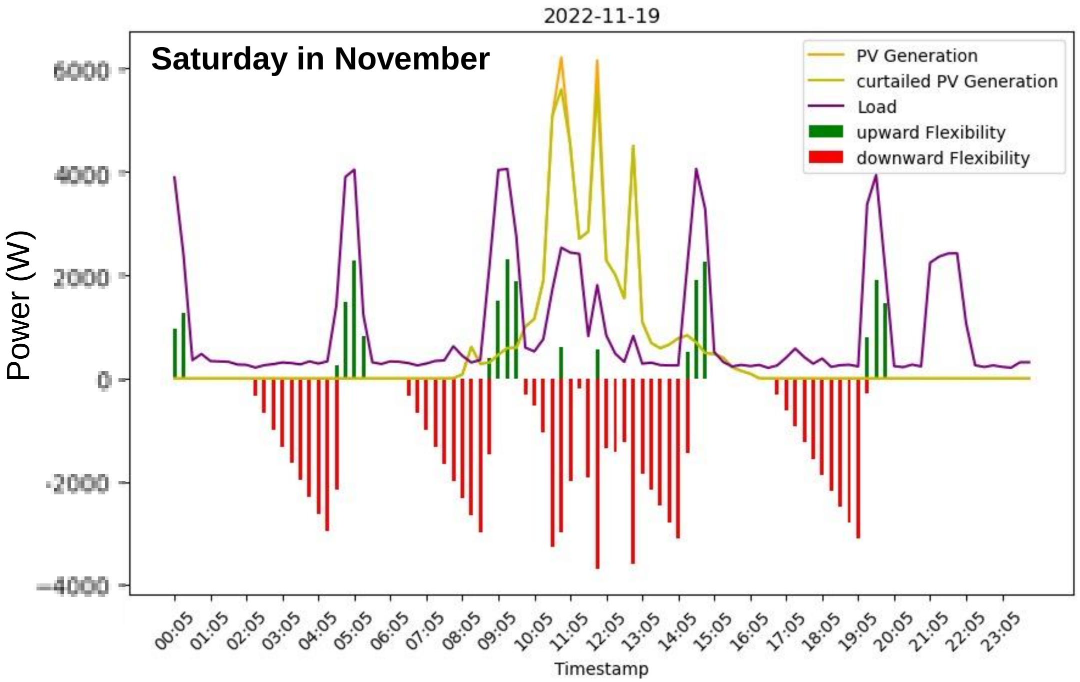

2022-07-14
pv production
curtailed pv production
load
upward flexibility
downward flexibility
Power (W)
summer


2022-10-22
pv production
curtailed pv production
load
upward flexibility
downward flexibility
Power (W)
autumn


2022-01-17
PV Generation
curtailed PV Generation
Load
upward Flexibility
downward Flexibility
Power (W)
winter

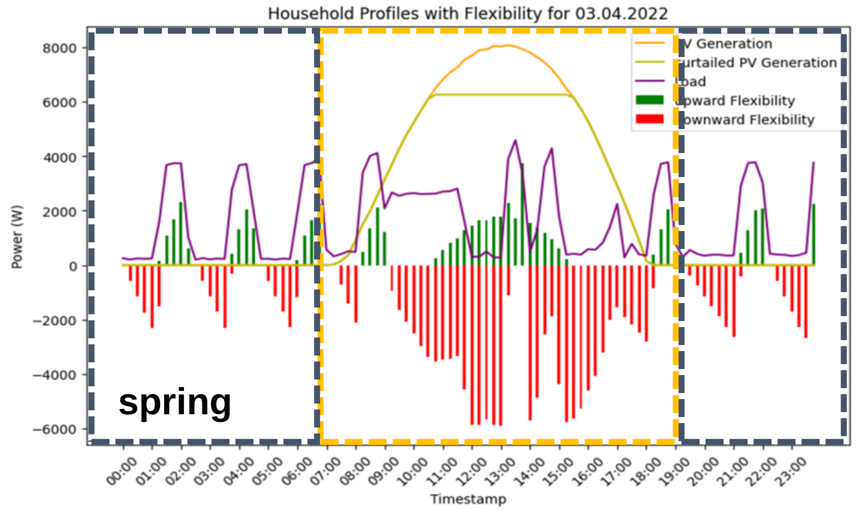
Change of flexibility in winter

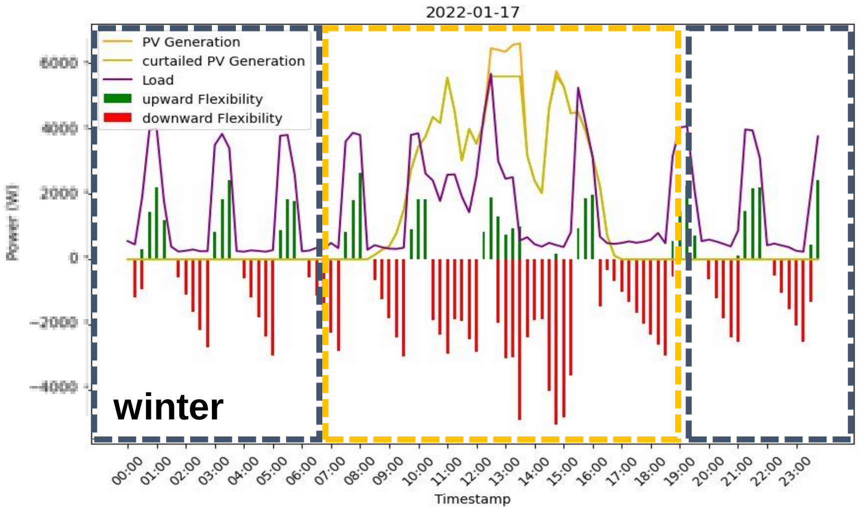




If different winter days are considered, there seems to be more flexibility on colder days, as the heat pump is in use more, but it should also be noted that the cycles cannot be postponed at will, as after a certain time the heating requirement is as great that no further postponement is possible. It should also be noted that even in winter, days with clear skies lead to PV production but due to self-consumption optimization and only little curtailment the upward flexibility is neglectable.

Day time vs. night time





Day time: On spring days, the flexibility during the day is mainly characterized by PV curtailment, since there are less heat pump cycles as less heating is needed.
On winter days, on the other hand, the flexibility of PV curtailment is minimal. During the day, the heat pump does not run as often as at night, which is why this flexibility is also somewhat lower.

Night time: In general, flexibility at night is only characterized by heat pump. In the night, outside temperatures are lower and heat demand is higher. Therefore, the flexibility is also bigger.