Energy Poverty in Switzerland? A Geospatial Analysis.

GEO 511 Master's Thesis

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Abstract

Whilst the problematic of energy poverty has become an important topic in research and policy-making in the Global North in general and in Europe especially, there exists almost no work on energy poverty in Switzerland. This exploratory work aims to perform the first spatial analysis on energy poverty in Switzerland by constructing an energy poverty vulnerability index that is composed of data of the Federal Register of Buildings and Dwellings (RBD) as well as the Swiss-SEP (socioeconomic position). Besides the implementation of the indicator on a national level, the situation regarding energy poverty vulnerability is analysed on a higher resolution for the City of Zurich. Furthermore, this work assesses the suitability and quality of the available data to analyse energy poverty in Switzerland and evaluates the implementation of energy poverty related policy measures. The spatial analysis shows that on a national level, households in rural regions have a higher risk to be affected by energy poverty than in cities. Further, households in mountainous regions are affected by a higher vulnerability of energy poverty due to colder climate. The vulnerability of Zurich appeared rather low at a coarse resolution. However, the visualization of the data on a smaller scale revealed big differences within the city boundaries, with a rather high energy poverty vulnerability index towards the outskirts of the city. The RBD and Swiss-SEP allow to perform an analysis on a neighborhood-scale on energy poverty vulnerability, but some drawbacks regarding data quality were identified. It was found that in Switzerland hardly any measures against energy poverty specifically are taken, which needs to be reconsidered. Future work to improve the indicator is proposed.

Keywords: energy poverty, energy poverty vulnerability, spatial analysis, Swiss-SEP, RBD

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Abbreviations

EGID Eidgenössischer Gebäudeidentifikator (Federal Building Identifier)

EPOV Energy Poverty Observatory

EPVI Energy Poverty Vulnerability Index

ERA Energy Reference Area

FSO Federal Statistical Office

HDD Heating Degree Days

LIHC Low-Income-High-Cost

RBD Federal Register of Buildings and Dwellings (German: GWR)

SDG Sustainable Development Goals

SEP Socioeconomic Position

SILC Statistics on Income and Living Conditions

UN United Nations

1 Introduction

1.1 Motivation

In today's world, the availability of energy is a crucial factor to humans well-being. From managing a household, transportation, production of goods, communication services, etc. there is hardly any aspect of life that does not depend on the use of energy. Studies show that, to a certain extent, the societal and economic development of a country is directly linked to the availability of energy (González-Eguino, 2015; Smil, 2004). However, people in a country could only partake in the economic growth as long as they can afford consuming energy (González-Eguino, 2015).

For a long time and due to very large fossil sources, it seemed that energy is almost abundantly available (Moe, 2010). In many countries (of the Global North) energy consumption has been growing steadily (IEA, 2023). However, rising energy prices and growing socioeconomic inequalities led to an increased occurrence of energy poverty (Halkos & Gkampoura, 2021b). In the past, energy poverty was rather associated with countries in the Global South, but the drastic development in some countries in Europe as well as in North America was the reason that the topic of energy poverty in the Global North became more important in research as well as on the political stage (Bouzarovski et al., 2012). Several countries, mainly in Europe, now keep the topic energy poverty on their political agenda. The launch of the Energy Poverty Observatory (EPOV) initiative in 2016 by the European Union (Directorate-General for Energy, 2023) clearly underlines the relevance of addressing energy poverty in Europe.

In Switzerland on the other hand, poverty has not been part of the public discourse for a long time. However, the rising inflation, a global pandemic and the energy crisis due to the war in the Ukraine have aggravated the situation for many people and the risk to be affected by poverty has increased. According to the Federal Statistical Office (FSO), 8.7% of the population were affected by income poverty in Switzerland in 2021, and around 14.6% were at risk of becoming poor (Bundesamt für Statistik, 2023c).

Regarding energy poverty, not much data and literature that addresses the situation in Switzerland can be found. One of the few exceptions is the European survey "Statistics on Income and Living Conditions" (SILC) where Switzerland collects statistics about material and social deprivation. According to the statistics of the year 2021, 5.2% of the Swiss population are considered deprived (Bundesamt für Statistik, 2023c). Among those affected people, only 0.5% stated that they “cannot keep their home adequately warm” (Bundesamt für Statistik, 2023c). Despite these fairly new statistics, the energy supply situation in Switzerland has become quite volatile in the last two years (Bundesamt für Energie, 2023). The economy is still dealing with the aftershocks of the Covid-19 pandemic, inflation is rising and with the war in the Ukraine especially energy prices increased significantly as well as the fear of an energy supply gap in winter (Bundesamt für Energie, 2023).

Although the topic of energy poverty in Switzerland has not been very prominently discussed, the Swiss energy supply faces a lot of attention in the context of the climate change debate. With the rising awareness of climate change and its consequences, Switzerland elaborated the so-called “Energiestrategie 2050” (energy strategy 2050) as a guideline to reduce its climate footprint (UVEK, 2023).

As almost one third of the total energy consumption in Switzerland falls on the households (Bundesamt für Energie, 2022) and almost 25% of Switzerland’s CO_2-emissions are produced by the housing sector, the potential in the housing sector regarding the aims of the energy strategy 2050 is substantial (Bundesamt für Umwelt, 2023). With Switzerland being a country with four distinctive seasons, the energy used for heating purposes accounts for more than 60% of the households energy consumption (Kemmler et al., 2023). Although the share of renewable heating systems is increasing, in 2021 60% of all residential buildings were still depending on fossil fuels for heating (Bundesamt für Statistik, 2023a). The still rather high dependency on fossil fuels paired with the necessary expenditures to change towards renewable systems carries the risk of being affected by energy poverty (Halkos & Gkampoura, 2021a).

1.2 Research Aims

Although the before mentioned statistics only stated a very small extent of energy deprivation or energy poverty in Switzerland, it can be assumed that the situation in Switzerland has likely not changed in a positive way since the collection of that statistic a few years ago. However, spatial research in that field does not exist.

With the detected research gap (see Section 2.6), the main goal of this thesis is to build and apply a spatial indicator of energy poverty vulnerability and to detect affected regions in Switzerland. By implementing the spatial analysis of energy poverty vulnerability in Switzerland, the following research questions want to be addressed:

- RQ1: Where in Switzerland and why are people at risk of energy poverty?
- RQ2: How do the results of the spatial analysis correspond to patterns of similar analysis in other countries?
- RQ3: Is the available data regarding its form and quality suitable for an energy poverty analysis?
- RQ4: What are possible policy measures to reduce energy poverty vulnerability in Switzerland?

2 State of the Art

This chapter consists of a literature review regarding the most recent research on energy poverty and provides background on how to build and apply a new measure of energy poverty. In Section 2.1, the dimensions of energy poverty will be outlined and in Section 2.2, the characteristics of energy poverty indicators are presented. In Section 2.3, the focus lies on the analysis of the spatial dimension of energy poverty and in Section 2.4, the conducted work on energy poverty in Switzerland is summarized. Section 2.5 provides some theoretical background on the later used methodology and finally, in Section 2.6 the research gap that is targeted with this thesis is identified.

2.1 Dimensions of Energy Poverty

According to the United Nations (UN), in 2021 around 675 millions people lacked access to the electric grid (United Nations, 2023). By proclaiming Target 7.1 of the Sustainable Development Goals (SDGs), *to ensure universal access to affordable, reliable and modern energy services by the year 2023*, the UN endeavours to combat global energy poverty (United Nations, 2023). In the growing field of energy poverty research, two main dimensions of energy poverty can be distinguished: accessibility and affordability (Maxim et al., 2016). On one hand research examines the problematic of not having access to modern energy services and the many negative consequences that come with that (González-Eguino, 2015). Studies of energy accessibility mainly focus on countries in the Global South where most of the people without access to energy services live (United Nations, 2022) and where the expansion of modern energy infrastructure is less comprehensive than in the Global North (Nussbaumer et al., 2012).

In the past decade, research activities focusing on the affordability of energy services increased strongly. Economical crisis, a global pandemic, skyrocketing energy prices due to the war in the Ukraine resulted in a rising number of people affected by energy poverty, also in countries in the Global North. As per the statistics of the European Union, almost 10% of all households are not able to heat their home adequately (Directorate-General for Energy, 2023). In Great Britain, a pioneer country regarding energy poverty research and policy, as many as about 13% of all households are considered energy poor (Department for Energy Security and Net Zero, 2023).

Being a multifaceted issue, there is not a set definition of energy poverty. Generally, it is described as the condition in which a household is unable to meet its needs up to a socially- and materially-necessitated level (Buzar, 2007). Mostly, it is referred to the dimensions of electricity and heating (Thomson et al., 2017), but energy poverty can also relate to transport (Robinson & Mattioli, 2020). And with rising temperatures due to climate change, the energy consumption regarding cooling becomes a new focus (Thomson et al., 2019). As the main drivers of energy poverty, high energy prices, low household income and lacking energy efficiency have been determined (Boardman, 1991). Adding to that, climatic conditions as well as the location of a household are also seen as contributing factors to be affected by energy poverty (Halkos & Gkampoura, 2021a). Living in particularly cold or warm climates mostly results in a higher energy consumption for heating or cooling the living place to comfortable temperatures (Rudge, 2012). Finally, Robinson et al. (2019) highlight that household vulnerability on energy poverty can stem from a varying set of factors (listed in Table 2.1) which need to be accounted for in energy poverty policy.

Table 2.1: Vulnerability factors and indicators according to Robinson et al. (2019), adapted

Vulnerability factor
Old people
Young children
Disability or limiting illness
Lone parent
Part-time employment
Retired
Looking after family/home
Provision of unpaid care
Unemployment
Elementary occupation
Ethnicity
Full-time student
Underoccupancy
Shared property
Large household size
Private renting
No central heating
Energy-efficient property
Climatic exposure

2.2 Indicators

Indicators are a valuable tool in research to effectively describe the state and extent of a phenomenon and communicate it to decision-makers (Heink & Kowarik, 2010). Therefore, they have to be clear and easy to understand (Christian, 1974). Further, indicators enable the monitoring of a specific development over time and the effect of implemented measures on the situation can be reviewed (Christian, 1974). According to Sokołowski et al. (2020) the aims of measuring energy poverty are twofold. Firstly, with the localization of the affected households, appropriate and effective support measures can be established (Sokołowski et al., 2020). And secondly, the indicator must be able to cover the most important dimensions of energy poverty (Sokołowski et al., 2020). Analogue to measuring inequality or poverty there are almost endless possibilities to measure energy poverty. Especially since the topic has been added to the political agenda of the European Union several new and often complex metrics have been proposed (Herrero, 2017).

Generally, two categories of energy poverty measures can be distinguished: *expenditure-based* and *consensual-based* indicators (Bollino & Botti, 2017; Herrero, 2017). While in the first category the focus lies on the monetary aspect and the share of the household budget that is spent on energy-related expenses, consensual-based measures on the other hand depict the subjective perception (Herrero, 2017). In the following a selection of the most popular expenditure- and consensual-based indicators is presented:

- 10%-indicator (Boardman, 1991)
  - The 10%-indicator was one of the first proposed indicator to measure energy poverty. It defines a household as energy poor when it is spending 10% or more of its budget on energy services.
- LIHC-indicator (Hills, 2011)
  - The Low-Income-High-Cost-indicator classifies a household as energy poor if its energy expenses are higher than the median of all households when at the same time its income falls below the poverty threshold after paying for its energy expenses.
- Statistics on Income and Living Conditions (EU-SILC) (Eurostat, 2024)
  - As a part of the SILC gathered by the European Union, statistics of the following three traits are collected via survey and often used in energy poverty research:

- Arrears on utility bills
- Ability to keep home adequately warm
- Dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames of floor

Initially, most of the proposed indicator treated energy poverty as a one-dimensional problematic (Siksnelyte-Butkiene et al., 2021). However, the identification of the energy poor remained difficult, as different households are classified as affected, depending on the applied indicator (Deller et al., 2021). As a consequence, more and more composite measures are developed and applied which take the multidimensionality of energy poverty into account (Herrero, 2017).

2.3 Spatial Analysis of Energy Poverty

As the methodologies to analyse energy poverty tend towards more multidimensional approaches, the spatial perspective becomes increasingly important. On one side, GIS software is used purely as a visualization tool to depict the spatial distribution of a condition, e.g., the occurrence of energy poverty (Gouveia et al., 2019; Sokołowski et al., 2019). On the other hand spatial methodologies offer a vast amount of applications that are only just being discovered in energy poverty research. For instance, clustering methods are used to identify affected areas (Chen et al., 2023) or principal component analysis is applied to analyse the spatially varying drivers of energy poverty (Robinson et al., 2019). Further, Robinson et al. (2018) especially emphasize the important role of spatial analysis on a neighborhood scale in order to localize local driving patterns of energy poverty. This is found to be crucial for the implementation of area-specific measures which reduce the gravity of energy poverty (Liddell et al., 2011).

2.4 Energy Poverty in Switzerland

For assessing the situation regarding energy poverty in Switzerland only very little information can be found. However, Suppa et al. (2019) demonstrated that vulnerable groups in Switzerland face similar problems than in other countries, where energy poverty is better investigated. Through interviews with affected people, it became clear, that vulnerable households often live in dwellings with low energy-efficiency (Suppa et al., 2019). To reduce the energy-related expenses, the households see themselves compelled to reduce their consumption of electricity or even to only partially heat their apartment

(Suppa et al., 2019). Further the participants of the study stated, that in the case of a renovation, they are rarely in the financial position to pay a higher rent (Suppa et al., 2019). As a consequence, vulnerable households are being forced to move out and can not benefit from energy-efficient housing.

Kaufmann et al. (2023) recently were able to show such displacement-patterns after renovations by analysing AHV and RBD data. In the study, the mean monthly income as well as other household characteristics such as nationality of the inhabitants or single parents, were analysed in the region of Zurich before and after renovations. It was found that after the renovations, the mean monthly income of the households was significantly higher than before (Kaufmann et al., 2023). In addition, the share of the displaced households with single parents or foreign nationality were disproportionately (Kaufmann et al., 2023), which accentuates the difficult situation for vulnerable households in Switzerland.

2.5 Measuring Energy Poverty Vulnerability

2.5.1 Energy Poverty Vulnerability Index

Gouveia et al. (2019) proposed a simple index to measure energy poverty vulnerability, which will be the base for the Swiss analysis in te context of this thesis. The approach by Gouveia et al. (2019) for measuring energy poverty vulnerability in Portugal is composed of two subindexes:

- Dwellings' energy performance gap (EPG) sub-index
- Population's ability to implement alleviation measures (AIAM) sub-index

In their analysis, the EPG is a measure for thermal discomfort as it marks the difference between the calculated energy demand of a building based on the state of the buildings thermal envelope and the real energy consumption (Gouveia et al., 2019). On the other hand the AIAM sub-index gives information about the resilience of the population to improve their situation regarding energy poverty. It is composed of the following (socio-economic) factors (Gouveia et al., 2019):

- Share of population under 4 and over 65 years of age
- Average monthly income

- Share of people who own their home
- Education level
- Unemployment rate
- Building state of conversion

Both subindexes were classified into a range from 1-20, where 1 refers to a small thermal discomfort (EPG) respectively the lowest ability to improve their situation (AIAM) and 20 to a high thermal discomfort and high ability to implement measures that lead to an improvement. After classifying the two subindexes the EPVI-index is calculated by applying the following formula:

$$EPVI = \frac{EPG + (20 - AIAM)}{2}$$

The EPVI also ranges between 1 and 20 where high values indicate a higher vulnerability to energy poverty than lower values.

2.5.2 Accumulated Temperature Differences

The length of the heating period and therefore the energy demand varies in different climatic zones and depends on the outdoor temperature (MeteoSchweiz, 2024). In energy poverty research, the "Heating Degree Days" (HDD) is often used to account for climatic differences as for example within a country (e.g. Betto et al., 2020; Gouveia et al., 2019; Liddell et al., 2011). In Switzerland the HDD are also a common measure for modelling the heating demand. However, recently it was found that the "Accumulated Temperature Differences", which are a modification of the HDD, would display the heating patterns slightly better than the HDD (Zweifel, 2015).

2.6 Research Gap

Although spatial research on energy poverty has been increasing significantly, the coverage on the topic for Switzerland remains inadequately. Previous work hints that energy poverty also might be or become an issue in Switzerland (Suppa et al., 2019), it remains unclear, to which extent in which regions people are at risk of being affected by energy poverty. This blindflight impedes taking adequate measures to curb that risk.

This thesis will contribute to reduce the identified research gaps as it will be the first spatial analysis of energy poverty vulnerability in Switzerland. Thereby, the in Section 1.2 already mentioned research questions will be answered:

- RQ1: Where in Switzerland and why are people at risk of energy poverty?
- RQ2: How do the results of the spatial analysis correspond to patterns of similar analysis in other countries?
- RQ3: Is the available data regarding its form and quality suitable for an energy poverty analysis?
- RQ4: What are possible policy measures to reduce energy poverty vulnerability in Switzerland?

3 Data

In this chapter, the data used for the analysis is described. Analogous to the methodology applied by Gouveia et al. (2019) the slightly adapted version of an energy poverty vulnerability index for Switzerland is composed of climate, building and socioeconomic data. Based on data availability, the Swiss-SEP, the Federal Register of Buildings and Dwellings, and as well as temperature data were chosen to build the energy poverty vulnerability index. For a more detailed analysis of the spatial patterns of the created index, the Urban/Rural-Topology data set was used. Subsequently, the chosen data is described in more detail.

3.1 Federal Register of Buildings and Dwellings

The first main data set of this work is the Federal Register of Buildings and Dwellings (RBD) (German: Gebäude- und Wohnungsregister (GWR)). It contains detailed information on all buildings in Switzerland (Bundesamt für Statistik, 2023b). Originally, it was built for statistical purposes and relied on the data of the Census in the year 2000. Firstly, it contained only buildings with residential use. Since then, it was updated and extended continuously and since the full revision of the ordinance of the RBD in 2017, the register also carries data about non-residential buildings (Bundesamt für Statistik, 2023b). The RBD data is reported to and compiled by the Federal Statistic Office (FSO). The municipal and cantonal building authorities are responsible for collecting the data (Bundesamt für Statistik, 2023b). The RBD is divided into several tables with different access regulations. Most information such as geographical details, building year or period, building category, specifics on the number and area of apartments or the information about the heating system is openly available. In addition, the register also contains various specifics about finished and planned renovation projects. For completely new buildings, the information of the building permit is depicted in the RBD. Normally, access to those additional information is restricted, but as part of a data utilisation agreement, the data was provided for this thesis. Table 3.1 gives an overview of the used data tables of the RBD. To check for authorisation of the data access, the data was provided in a tabular structure as .dsv-files via a password-protected area of the MADD-Platform[1] of the Federal Statistical Office. The data on the platform is continuously updated and can be downloaded at any time. The results presented in Chapter 5 were obtained with the RBD-data downloaded on 15.04.2023.

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[1] https://www.housing-stat.ch/de/madd/index.html

Table 3.1: Overview of the used RBD-data

Name of data set	**Content**	**Restrictions**
GWR_MADD_GEB-07_Data_MADD-*DATE*.dsv	detailed information about the building as a whole	openly available
GWR_MADD_WHG-07_Data_MADD-*DATE*.dsv	several information about the individual apartments in the buildings	openly available
GWR_MADD_ARB-07_Data_MADD-*DATE*.dsv	information on past, ongoing and planned renovations per building, categorized	restricted, use only with utilisation agreement

The FSO provides an extensive documentation on all the categories and information that is represented in the RBD (Bundesamt für Statistik, 2022). In the following, only the data fields used for the analysis will be described in more detail. Table 3.2 and 3.3 depict the fields of the RBD in the openly available building and apartment data set that were used in the analysis.

Table 3.2: Description of the used data fields in the building data set of the RBD (Bundesamt für Statistik (2022), adapted)

Code	**Name**
EGID	Federal building identifier
GKODE	Easting coordinate
GKODN	Northing coordinate
GKAT	Building category
GKLAS	Building class
GBAUP	Building period
GBAUJ	Building year
GABBJ	Year of demolition
GAREA	Area of building footprint
GEBF	Energy reference area
GASTW	Number of stories

Table 3.3: Description of the used data fields in the apartment data set of the RBD (Bundesamt für Statistik (2022), adapted)

Code	**Name**
EGID	Federal building identifier
WAREA	Area of apartment
WABBJ	Year of apartment demolition

In Table 3.4, the analysed fields of the building projects are listed. The data set differentiates between several types of renovations. For the purpose of this thesis only energy-related renovations were considered.

Table 3.4: Description of analysed data fields in the building projects data set of the RBD (Bundesamt für Statistik (2022), adapted)

Code	**Name**
EGID	Federal building identifier
PENSAN	Energy-related renovation
PHEIZSAN	Renovation of the heating system

3.1.1 Building Category (GKAT)

For the analysis, the building category was one of the main fields of the RBD that was used. It classifies a building depending on the extent of its residential use. Table 3.5 lists all building categories defined by the FSO and serves as an orientation for the applied methodology (Section 4.2.3).

Table 3.5: List of the existing RBD-codes for GKAT (Bundesamt für Statistik (2022), adapted)

Code	**Building Category**
1010	Temporary accommodation
1020	Buildings with exclusively residential use
1030	Other residential buildings (residential buildings with secondary use)
1040	Buildings with partial residential use
1050	Buildings without residential use
1060	Special buildings

3.1.2 Building Class (GKLAS)

In combination with the GKAT-classification, the RBD-field building class provides information on the number of apartments for each building. This information is also necessary for the energy demand modelling explained in Section 4.2.3.

Table 3.6: List of the used RBD-codes for GKLAS, (Bundesamt für Statistik (2022), adapted)

Code	**Building Class**
1110	Buildings with one apartment
1121	Buildings with two apartments
1122	Buildings with three or more apartments

3.1.3 Building Period (GBAUP)

Based on the year of construction, the FSO categorizes the buildings into 13 building periods, which are listed in Table 3.7. The age of the building will be used to determine the energy demand.

Table 3.7: List of the existing RBD-codes for GBAUP, (Bundesamt für Statistik (2022), adapted)

Code	**Building Period**
8011	Period before 1919
8012	Period from 1919 to 1945
8013	Period from 1946 to 1960
8014	Period from 1961 to 1970
8015	Period from 1971 to 1980
8016	Period from 1981 to 1985
8017	Period from 1986 to 1990
8018	Period from 1991 to 1995
8019	Period from 1996 to 2000
8020	Period from 2001 to 2005
8021	Period from 2006 to 2010
8022	Period from 2011 to 2015
8023	Period from 2016

3.2 Swiss-SEP

The second main data set used for this thesis is the Swiss-SEP. The index of Socio-Economic Position in Switzerland was initially created in 2012 for epidemiological research (Panczak et al., 2012). Since then, the index was updated twice, whereas the most recent recalculation was published in early 2023 (Panczak et al., 2023).

Based on the road network and the location of the residential buildings (deduced of the RBD), for each household, a neighborhood of 50 households was determined by using moving boundaries (Panczak et al., 2012). In the following, for each of these neighborhoods, the index was calculated considering the following factors based on the Census 2000 data and assigned to its corresponding household (Panczak et al., 2012):

- Income: Median rent per square metre
- Education: Proportion of households headed by a person with primary education or less
- Occupation of household heads: Proportion of households headed by a person in manual or unskilled occupation
- Household crowding: Mean number of persons per room

With the substitution of the comprehensive Census statistics towards a statistic that is only composed of random samples, the calculation of the Swiss-SEP had to be adapted as well (Panczak et al., 2023). Therefore, the most recent Swiss-SEP is a result of the spatial interpolation of the random sample Census data. The Swiss-SEP value ranges between 1 and 100. A higher value indicates a higher socio-economic position (Panczak et al., 2012).

Table 3.8: Overview of the used data fields of the Swiss-SEP data set

Name	**Description**
geox	Easting coordinate
geoy	Northing coordinate
ssep3	Most recent Swiss-SEP value (1-100)
ssep3_d	Decile classification of ssep3

In general, the access to the data is not public, but was provided by the Federal Statistical Office for this master's thesis. The data is structured in tabular format, the used data fields of the Swiss-SEP data set are listed in Table 3.8. As part of the data usage agreement, the Swiss-SEP data can only be visualized in aggregated form in this thesis. Figure 3.1 shows how the socioeconomic position varies in space in Switzerland.

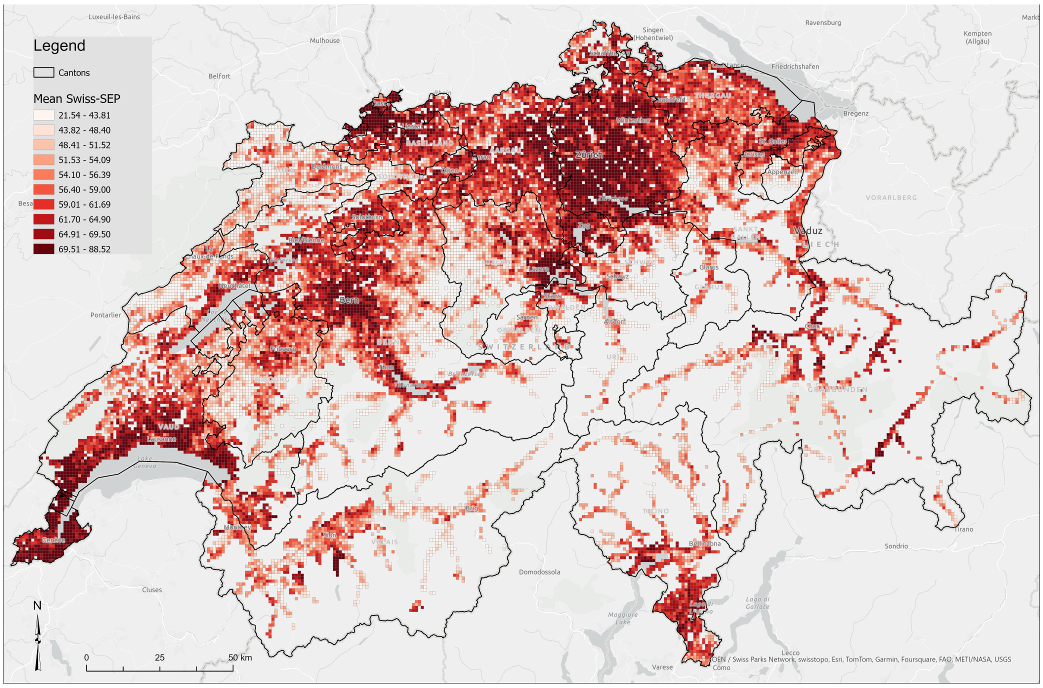


Figure 3.1: Visualization of mean Swiss-SEP, in 1km^2-raster, classified in quantiles (own Figure)

3.3 Temperature Data

As a third main data set, temperature data was used to account for climatic differences when modelling heating demand (see Section 4.2.2). For the analysis, daily mean temperature data for the years 2003-2022 was used. The raster data covers all of Switzerland and is divided into pixels of 1km^2. The data was collected by MeteoSwiss and is provided in NetCDF format (MeteoSwiss, 2021).

3.4 Urban/Rural-Typology 2012

For the analysis of the spatial patterns of the energy poverty vulnerability, the Urban/Rural-Typology 2012 was used. The FSO classifies every municipality based on density-, size- and accessibility criteria into three different categories (Bundesamt für Statistik, 2023d):

- rural (Ländlich)
- intermediate (Intermediär)
- urban (Städtisch)

The used data was lastly updated on January 1st, 2023. The correct allocation of the Typology-Classification on the other data was ensured by the FSO-Number of the municipalities which is also contained in the RBD.

4 Methods

There are many measures for energy poverty in current research (Siksnelyte-Butkiene et al., 2021). On one hand, this is due to different preconditions in the respecting countries where the research is conducted. Depending on varying preconditions such as climate, housing structures, energy market, and the organization of energy supply, energy poverty shows different forms and therefore needs to be analysed and measured differently (Siksnelyte-Butkiene et al., 2021). On the other hand, data availability on the respecting measures may also differ from country to country and thus leading to wide-ranging approaches to measure energy poverty (Kyprianou et al., 2019). As elaborated before, there is no research covering the topic of energy poverty in Switzerland that could serve as a reference for this study. Consequently, it was decided to choose one of the many existing approaches of measuring energy poverty which fits the best with the available data described in Chapter 3. For that reason, the Energy Poverty Vulnerability Index (EPVI) developed by Gouveia et al. (2019) was chosen for measuring energy poverty in the case of Switzerland.

Data (pre-)processing and the calculation of the EPVI was implemented by using R version 4.3.1 and R Studio version 2023.06.1+524. The aggregation of the point data into the grids was performed in QGIS version 3.28.9, and for the visualization of the results ArcGIS Pro version 2.9.9 was used.

4.1 Adaptation for the Swiss Analysis

After reviewing the literature and assessing the available data, it was decided to implement an adapted version of the approach by Gouveia et al. (2019) to measure energy poverty vulnerability in Switzerland. The final indicator of energy poverty vulnerability will still be a composition of socioeconomic factors and buildings energy-efficiency data. Due to missing small-scale data on effective energy consumption, only modelled energy demand will be considered in this analysis instead of the energy performance gap (EPG) as proposed by Gouveia et al. (2019).

4.2 Implementation

4.2.1 RBD Pre-Preprocessing and Swiss-SEP matching

As explained in Section 3.1, the RBD data was structured in different tables, all with the EGID as the unique identifier. In order to prepare the

RBD data to model energy demand and to match it with the corresponding Swiss-SEP information, the following pre-processing steps were necessary.

The total apartment area per building (WAREA) as well as the number of apartments per building were deduced and joined to the main building table. Then, the table with the conducted renovations per EGID was joined to the main building table as well. Before the RBD data was matched with its corresponding Swiss-SEP value, some data clean-up described in Table 4.1 was carried out.

Table 4.1: Conducted processing steps on the RBD to match the Swiss-SEP data

Step	**Explanation**	**RBD Code**
Removing data entries without coordinates	Matching the RBD with the Swiss-SEP is only possible for georeferenced data entries	Remove *GKODE/GKODN == NULL*
Removing data entries of buildings without residential use	The Swiss-SEP is based on households therefore non-residential data has to be excluded	Keep *GKAT 1020*, *1030* and *1040*
Removing data entries of the newest building period	All buildings built after the last update of the Swiss-SEP had to be excluded	Remove *GBAUP 8023* (years 2016-2023)
Removing data entries of buildings that were demolished before 2015	Ensures that the RBD matches with the most recent Swiss-SEP update	Remove *GABBJ* $\leq$ *2014*

In a first step, the main aim was to match the RBD dataset as good as possible with the Swiss-SEP data. Therefore, all buildings without residential use were excluded from the data. As described in Section 3.2 the update of the Swiss-SEP was done in 2015 and as a consequence, all the buildings that were built after 2015 were dropped as well. Further, all the data points of buildings that were demolished before the Swiss-SEP update were also not considered for this analysis. By implementing the above described pre-processing steps, the RBD-data was aligned as good as possible to the RBD-data which was used for the update of the Swiss-SEP (Panczak et al., 2023). Even though the Swiss-SEP value was initially calculated based on the RBD, the data entries only came with X- and Y-coordinates, which made the matching a bit more difficult and less accurate than if the Federal Building Identifier (EGID) would have been included in the Swiss-SEP data. Therefore, the two data sets were combined using a spatial join algorithm. With the nearest-neighbor function, every Swiss-SEP entry had its closest RBD-point assigned.

4.2.2 Accumulated Temperature Differences

Following the elaboration in Section 2.5.2, the climatological differences within the country were incorporated in the analysis by the accumulated temperature differences. Unfortunately, MeteoSwiss only publishes the Degree Days instead of the accumulated temperature differences and does this exclusively for a selected number of weather stations in Switzerland. In order to get a more comprehensive and small-scale picture on the climatological differences, it was decided to calculate the accumulated temperature differences on a nationwide level using continuous temperature data provided by MeteoSwiss (MeteoSwiss, 2021).

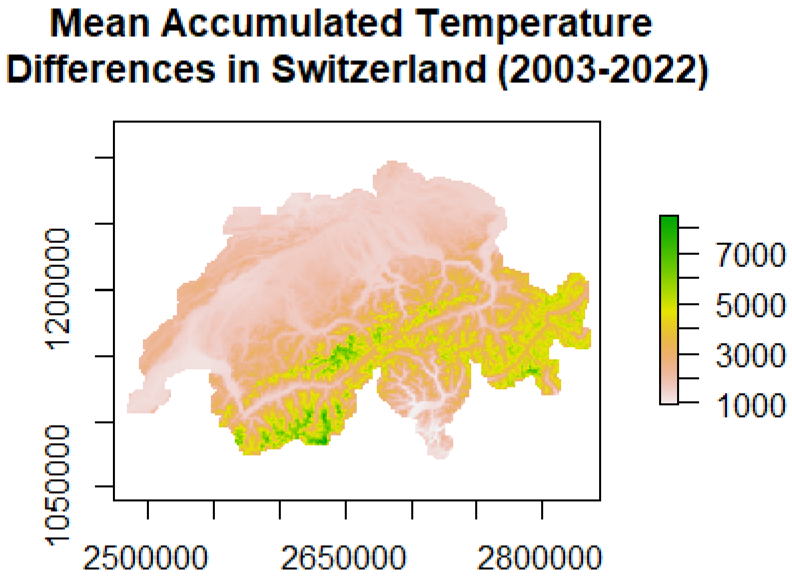


Figure 4.1: Plot of the accumulated temperature differences used for the modelling of the heating demand (own Figure)

To obtain the Accumulated Temperature Difference, only days with a mean temperature below a set base temperature, also called "heating temperature", are considered (Zweifel, 2015). The base temperature can vary, in Switzerland it is set at 12°C, which marks the outside temperature that requires heating to maintain a room temperature of 20°C (Zweifel, 2015). For all days below the base temperature, the difference between the mean outside temperature and the base temperature has been calculated and added over the course of the year. The sum of all those temperature differences constitutes then the Accumulated Temperature Difference (Zweifel, 2015). To account for yearly variation in the weather, it was decided to calculate the mean accumulated temperature difference for the last 20 years. Hence, the daily mean temperature data of 2003-2022 was used for the calculation, which is illustrated in Figure 4.1.

4.2.3 Modelling Heating Demand

Following the approach of several cantons (Amt fuer Umwelt und Energie, 2020; Departement Bau Verkehr und Umwelt, 2019; Dienststelle Umwelt und Energie, 2015), the energy demand for heating was mainly determined by the energy reference area (ERA) and the specific energy demand per m^2. The ERA of a building includes all the areas that needed to be heated for its proper use (Konferenz Kantonaler Energiefachstellen, 2013). It is slightly bigger than just the living area of an apartment, as the footprint of the walls that are inside the insulation perimeter or the staircase is included as well (Konferenz Kantonaler Energiefachstellen, 2013). For this thesis it was decided to follow the methodology of Hartmann and Jakob (2016) to determine the ERA. Although the RBD catalogue does have a specific field for the energy reference area (GEBF), the information was only available for about 8.3% of the buildings in the RBD. Therefore, the energy reference area needed to be estimated. When working with the RBD, Hartmann and Jakob (2016) suggested the following prioritisation for modelling the energy reference area, depending on the available data:

1. $EBF_{WN} = WEBF$
2. $EBF_{WN} = WAREA \times f_{WAREA-EBF}$
3. $EBF_{WN} = WAZIM \times øEBF_{WAZIM}$
4. $EBF_{WN} = WPERSHW \times øEBF_{WPERSHW}$
5. $EBF_{WN} = GANZWHG \times øEBF_{GANZWHG}$

6. $EBF_{WN} = GAREA \times GASTW \times f_{BGF-EBF}$

For this thesis, formula 2 and 6 were applied, as they were the only options that were applicable with the available data. Whenever possible, the energy reference area of a building was calculated based on the sum of all the apartment areas (WAREA) or alternatively as the area of the building footprint (GAREA) multiplied with the number of floors (GASTW).

For both calculations, the corresponding factors introduced by Hartmann and Jakob (2016) to adjust the energy reference area were applied:

- $f_{WAREA-EBF} = 1.25$ (for GKAT == 1020 when GKLAS == 1121 or GKLAS == 1122 and GKAT == 1030 and GKAT == 1040)
- $f_{WAREA-EBF} = 1.3$ (for GKAT == 1020 when GKLAS == 1110)
- $f_{BGF-EBF} = 0.9$

In addition to the ERA, the energy demand per m^2 needed to be determined. The energy demand per m^2 is dependent on the way a house was built, especially the used building and insulation materials have a big impact on the energy demand of a building (Hofmann et al., 2023). As general building codes have changed over time, the energy demand per m^2 used for modelling heating demand is conveniently categorized in the statistical building periods.

For their own energy statistics, several cantons empirically deduced reference values for the energy demand per m^2 based on real energy consumption of different buildings that were investigated regarding their energy condition (Amt fuer Umwelt und Energie, 2020; Departement Bau Verkehr und Umwelt, 2019; Dienststelle Umwelt und Energie, 2015). Based on the buildings that were analysed, the determined energy demand per m^2 values show some variation. Generally, a trend towards a higher energy efficiency in newer buildings can be observed. For this thesis the energy demand values proposed by Amt fuer Umwelt und Energie (2020) were assigned to the buildings based on the building period (GBAUP), category (GKAT) and the class (GKLAS). The “Bernese values” were chosen, as they were measured the most recently. The values are summarized in Table 4.2 and 4.3. According to Amt fuer Umwelt und Energie (2020), single-family houses with exclusive residential use (GKAT 1020 and GKLAS 1110) are characterized by a higher specific energy demand (Table 4.2). For all the other constellations (Apartment blocks (GKLAS 1121 and 1122) and buildings with partial residential use (GKAT 1030 and 1040)) slightly lower energy demand per m^2 were applied.

To determine the total energy demand per building, the assigned energy demand per m^2 and the calculated ERA were multiplied. Subsequently, the buildings were intersected with the raster layer containing the accumulated temperature difference. Then, the modelled energy demand was adjusted proportionally with the obtained accumulated temperature difference. Finally, the energy demand was normalized by the number of apartments per building.

Table 4.2: Used energy demand per m^2 for modelling energy demand for single-family houses (GKAT 1020 and GKLAS 1110), (Amt fuer Umwelt und Energie (2020), adapted)

GBAUP	**Energy Demand [kWh/m^2]**
8011	147
8012	151
8013	157
8014	156
8015	123
8016	99
8017	88
8018	79
8019	66
8020	56
8021	45
8022	34

Table 4.3: Used energy demand per m^2 for modelling energy demand for apartment blocks and buildings with not exclusively residential use (GKAT 1020, 1030 and 1040 and GKLAS 1121 and 1122), (Amt fuer Umwelt und Energie (2020), adapted)

GBAUP	**Energy Demand [kWh/m^2]**
8011	114
8012	121
8013	113
8014	104
8015	96
8016	85
8017	74
8018	68
8019	55
8020	44
8021	28
8022	28

4.2.4 Indicator Development

Similarly to Gouveia et al. (2019), the socioeconomic component and the energy component were combined to obtain the EPVI. Here the Swiss-SEP corresponds to the AIAM in Portugal. The values technically could range between 1 and 100 and were classified into deciles. For the energy part of the indicator, the modelled mean energy demand per apartment per building was also divided in deciles. Finally, the EPVI for Switzerland was calculated according the following formula:

$$\mathbf{EPVI} = \frac{\mathbf{Modelled\ energy\ demand} + (10 - \mathbf{Swiss\text{-}SEP})}{2}$$

A low EPVI corresponds to a comparatively small modelled energy demand and a high socioeconomic position. The highest energy poverty vulnerability results in a high modelled energy demand and a low socioeconomic position. Due to privacy aspects, not all data can be visualized building-specific. For this reason the data is aggregated into a grid with grid cells of 1km x 1km for the national analysis, and 100m x 100m for the City of Zurich.

5 Results

5.1 Overview

In the following, the results of the EPVI and its components will be visualized and analysed. Section 5.2 focuses on the country as a whole, while Section 5.3 presents the results for the City of Zurich.

5.2 National Scale

After the matching of residential buildings with the Swiss-SEP data, a total of 1'540'584 data entries were obtained. For the modeling of the energy demand, several data points had to be excluded due to data incompleteness. The final data set used for the visualizations counts 1'159'919 data points that were aggregated into 19'704 grid cells of 1km x 1km covering all of the residential areas in Switzerland.

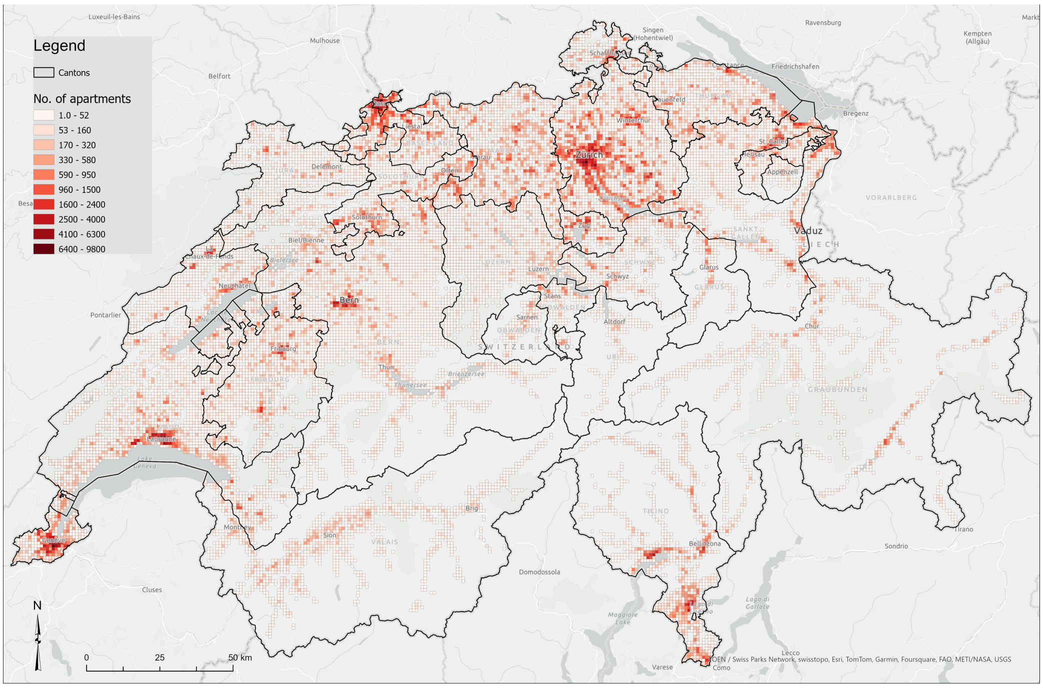


Figure 5.1: Number of dwellings per grid cell (own Figure)

Evidently, the number of analysed dwellings or households per grid cell is much higher in the cities than towards the periphery. As a consequence, the obtained results in the less densely populated area are much more prone to be influenced by outliers.

5.2.1 Energy Poverty Vulnerability Index

The mean EPVI per 1 km^2 grid cell is shown in Figure 5.2. The obtained values range from 0.5 to 9.5. The grid cells in the lowest quantile with values smaller than 3.9 mainly correspond to urban areas. Especially the City of Zurich and its surroundings, Winterthur, as well as the metropolitan area of Basel are all classified in the lowest quantile. Berne, Lucerne, and a considerable part of the canton of Zug also show very low EPVI values. In the French part of Switzerland, almost the entire Canton of Geneva as well as the regions bordering Lake Geneva also lie in the first quantile of the EPVI. And finally in Ticino, mainly the towns of Lugano and Locarno are classified in the lowest quantile too. Besides these bigger coherent areas with low EPVI, there are also some rather small-scale patterns, such as in Chur, St. Gallen, Fribourg or along the shore of Lake Neuchatel. In these cases, it is rather a matter of some single grid cells with low EPVI than a comprehensive pattern as in the listed areas above.

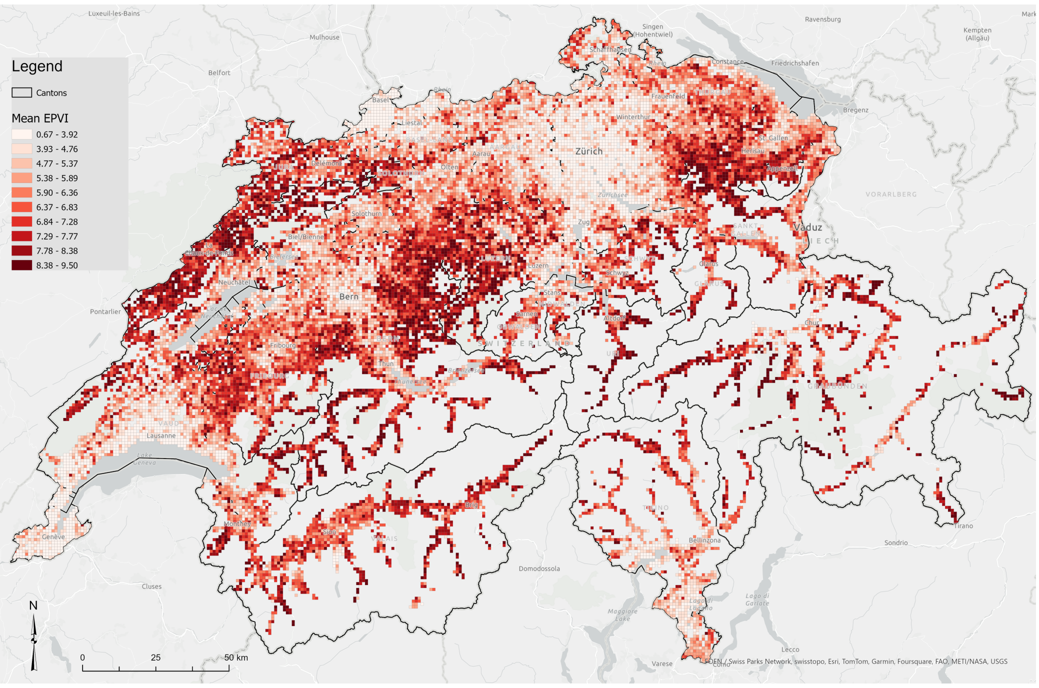


Figure 5.2: Visualization of the Mean Energy Poverty Vulnerability Index for Switzerland in 1 km^2-raster, classified in quantiles (own Figure)

On the other hand, the areas in the highest quantile (the 10% of the highest EPVI values) can be found in rather rural areas. Mainly the rural regions between Lucerne and Berne, such as Entlebuch and Emmental are classified in the highest quantile of energy poverty vulnerability. This also applies for a big part of the Eastern Alps in the Canton of St. Gallen and for the people living along the Jurassic Mountains in Western Switzerland. Further, in many Alpine Valleys, the obtained EPVI values are high as well, e.g., in the Surselva, the Goms region, or in the many valleys in the Bernese Alps as well as the Alps in Central Switzerland.

When analysing the spatial distribution of the highest and lowest 20% of the obtained EPVI in Figure 5.2 (instead of 10%), the pattern gets even clearer. The people facing the highest risk of being affected by energy poverty live in the periphery whereas the areas with the lowest vulnerability concentrate around the urban centers. This urban - rural difference is also backed up in Figure 5.3. The histogram shows the obtained EPVI values classified into the Urban/Rural-Typology by the FSO. The EPVI of the urban areas peaks between 4.0 - 5.0 whereas most of the regions classified as intermediate or rural have an EPVI of 5.0 - 8.0. Further, the energy poverty vulnerability also seems to increase with the altitude as many Alpine valleys and a big part of the Jurassic Region are classified in the two highest quantiles. However, there are some exceptions, as for example for the Upper Engadin region, the risk of being affected by energy poverty seems to be comparatively low.

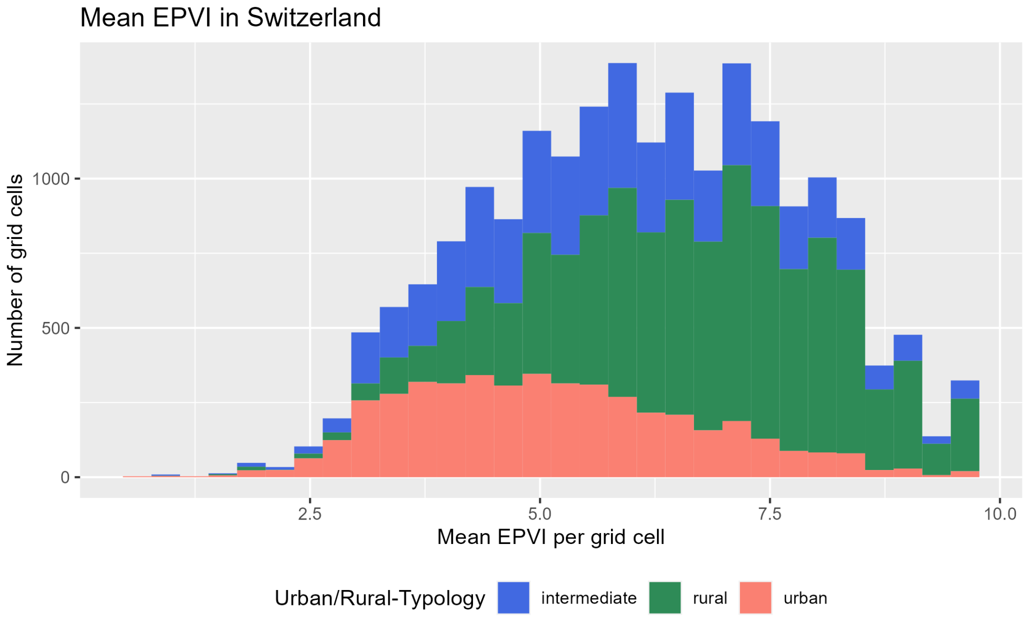


Figure 5.3: Histogram of the Mean Energy Poverty Vulnerability Index for Switzerland, categorized into the Urban/Rural-Topology (own Figure)

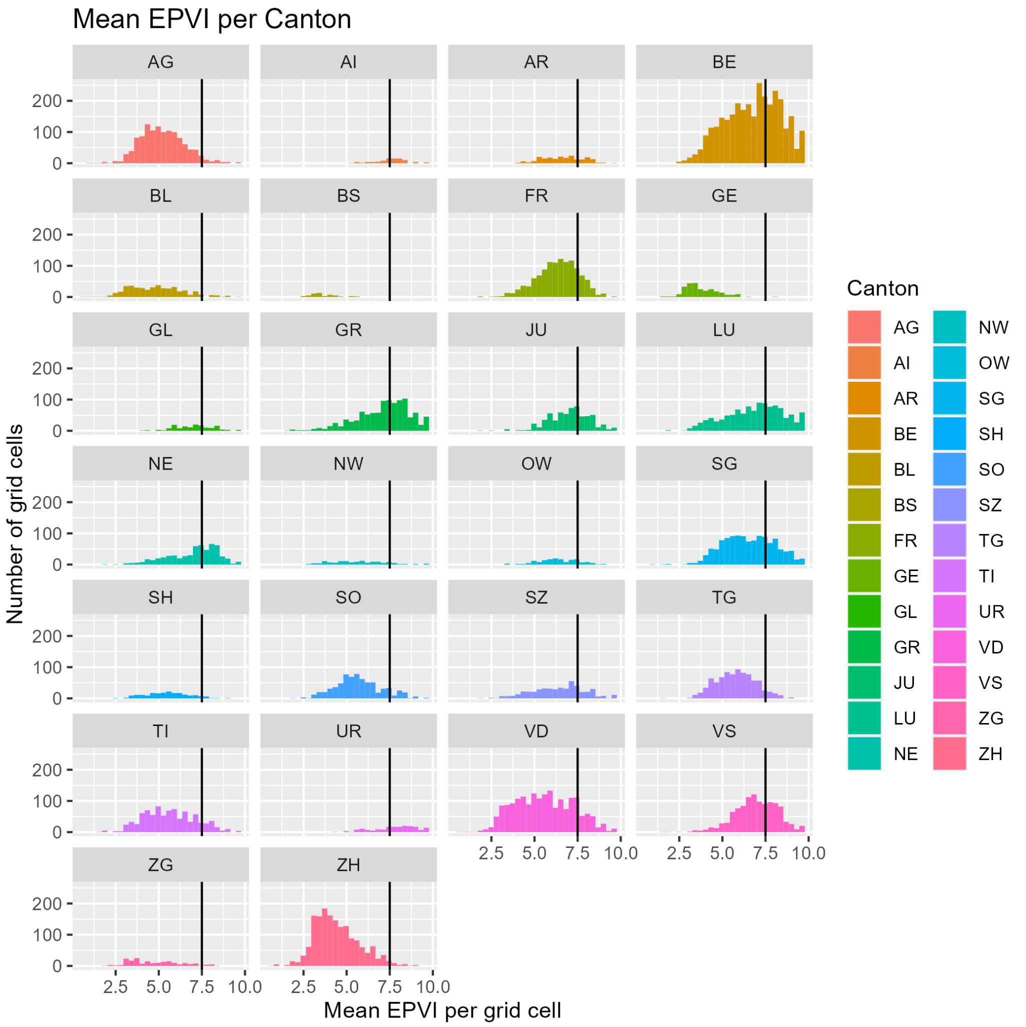


Figure 5.4: Histogram of the EPVI, visualized per Canton. The black vertical line marks a EPVI of 7.5 and therefore helps to compare the share of each canton that is confronted at a higher risk to be affected by energy poverty (own Figure)

In Figure 5.4, the histogram of the EPVI is broken down into the 26 cantons of Switzerland. Again it becomes visible that rural and mountainous cantons such as the Cantons of Berne, Graubünden, Jura, Lucerne, Neuchâtel, St. Gallen and Valais but also the less densely populated Cantons of Appenzell (Innerrhoden and Ausserrhoden) and Uri tend to have the highest energy poverty vulnerability.

5.2.2 Bivariate Visualization

The spatial visualization of the EPVI in Figure 5.2 already shows some interesting patterns, but especially for the regions with a mid-range EPVI-value, it can not be evaluated which one of the two components of the EPVI has the stronger influence on the final value. By choosing a bivariate visualization of the EPVI as it is displayed in Figure 5.5, its two components can be shown at the same time. With that representation, the spatial patterns can be analysed in more detail. Though it must be pointed out that the data in Figure 5.5 is classified into three quantiles each for both sub-indicators, whereas in Figure 5.2 the EPVI is visualized in ten quantiles.

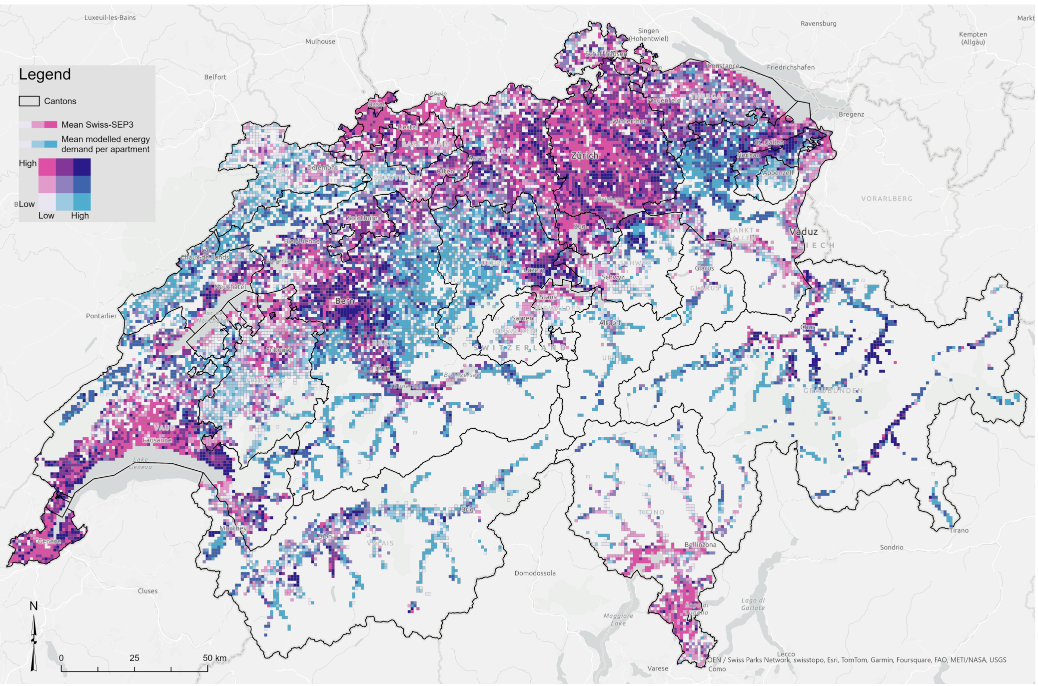


Figure 5.5: bivariate visualization of the EPVI-subindicators for Switzerland in 1 km^2-raster (own Figure)

The most vulnerable regions, here characterized by a low mean socio-economic position paired with a high modelled mean energy demand per dwelling (light-blue colored), can be found in the rural parts of the cantons of Berne and Lucerne, along the Jurassic Mountains in the cantons of Neuchatel and Jura, as well as in the mountainous part of the canton of St. Gallen. Further, many Alpine valleys such as in the Canton of Uri, the Surselva in the Canton of Graubünden or the valleys in the Eastern part of the Canton of Valais.

In contrast, most urban regions, almost the entire canton of Zurich, around Lake Geneva and the Southern part of the canton of Ticino are characterized as regions with comparatively high mean socio-economic position and a low modelled mean energy demand per dwelling (pinkish-colored). Therefore, they are classified as regions with a low vulnerability to be affected by energy poverty. It also stands out that around most urban centers areas with a high modelled energy demand in combination with a high socioeconomic position can be found (dark-blue colored). These households are expected to have elevated heating expenses. However, due to their rather high socioeconomic position it can be assumed that the energy bills do not represent a burden on their household budget.

5.2.3 Swiss-SEP

The Swiss-SEP, as it has been visualized in Figure 3.1, is the highest in and around the major cities (Zurich, Basel, Geneva, Lausanne, Berne and Lucerne) as well as in the “tax paradises” in the Canton of Zug and along the shore of Lake Geneva. But also important touristic regions such as the Engadin in Canton of Graubünden are clearly characterized by a high socioeconomic position. The difference of the socioeconomic position between urban and peripheral areas can also be seen in Figure 5.6 where Swiss-SEP is displayed in the Urban/Rural-Topology of the FSO.

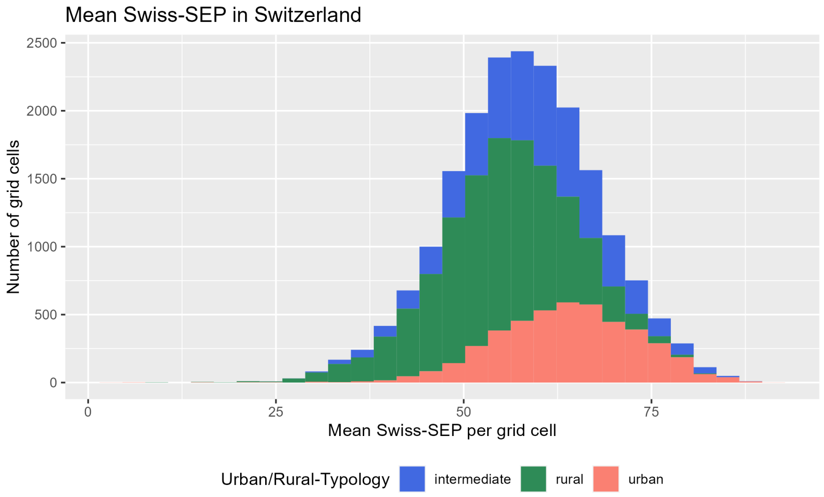


Figure 5.6: Histogram of the Swiss-SEP, categorized into the Urban/Rural-Topology (own Figure)

For lower socioeconomic-position, the share of households in intermediate and rural regions is higher. In contrast, for higher socioeconomic position (>60) the share of urban households becomes predominant.

5.2.4 Modelled Mean Energy Demand

The second sub-indicator of the EPVI is the modelled mean energy demand per dwelling. To some extent, the spatial distribution of the modelled mean energy demand was already addressed in Section 5.2.2. For a better overview, the results of the modelled mean energy demand are displayed separately in Figure 5.7. The modelled mean energy demand ranges from 2’700 kWh/a to almost 600’000 kWh/a.

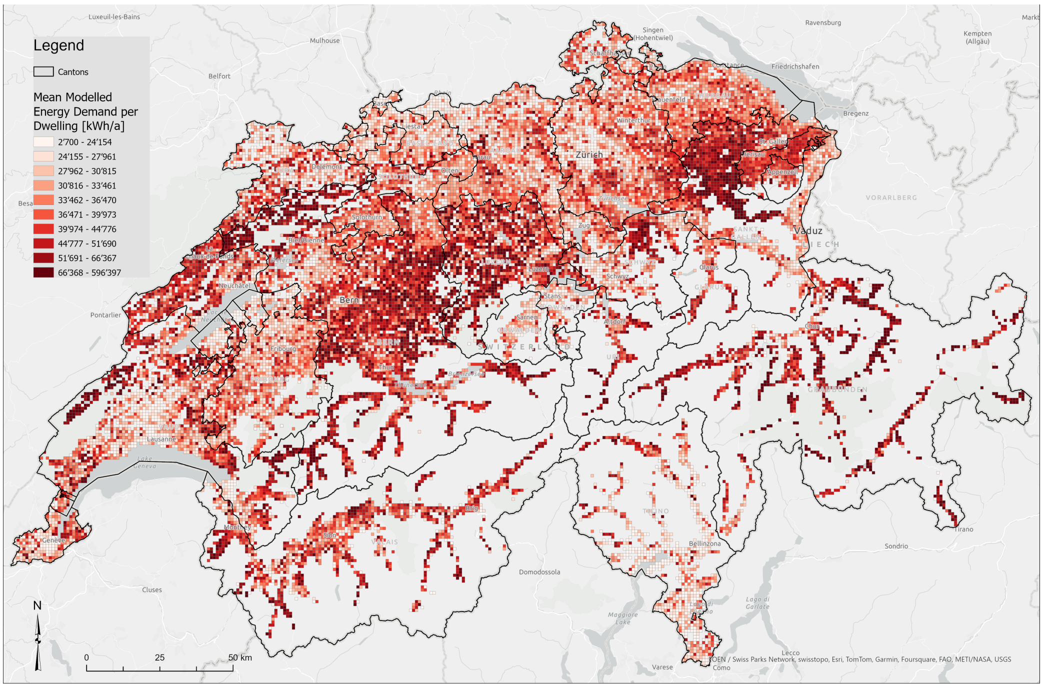


Figure 5.7: Visualization of the mean heating energy demand for Switzerland 1 km^2-raster, classified in quantiles (own Figure)

Figure 5.7 clearly shows that mainly in the Alpine valleys, the Jurassic Mountains, as well as in the Prealps of Lucerne and Berne and in the Alpstein region, the highest energy demand per dwelling is modelled. In contrast to the Swiss-SEP, the modelled mean energy demand per household can be broken down further into its separate components which are visualized in Figure 5.8 and 5.10.

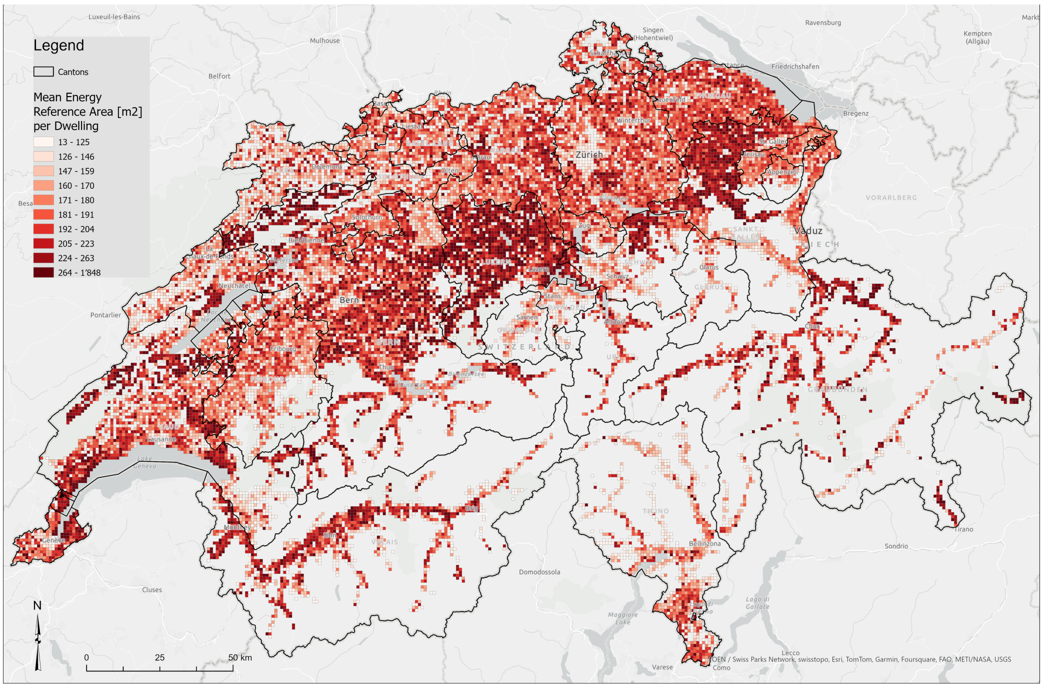


Figure 5.8: Visualization of the mean Energy Reference Area in Switzerland in a 1 km^2-raster, classified in quantiles (own Figure)

Although the Energy Reference Area is not exactly the living area of an apartment or a house, it can be seen as a proxy of the usable living area. The mean ERA varies between 13m^2 and 1'848m^2. Unlike most other spatial distributions that were presented in this work, there are only a few and rather small areas where the small mean ERA are clustered. Such clusters of small dwellings can be found in the City of Zurich, along the Jurassic mountains, the Eastern part of Canton of Waadt as well as the Northern part of Ticino. Furthermore, the cantons of Nid- and Obwalden also show relatively low ERA values. But generally, the grid cells with the lowest ERA are spread all over Switzerland.

On the other hand, the areas with a particularly high ERA show a noticeable more clustered pattern. Almost all of canton Lucerne is classified in the highest two quantiles. Further, the dwellings in Ausserschwyz, the Toggenburg region, Prättigau or the Rhone Valley as well as the Western lake side of Lake Geneva, and the Bernese Jura are comparatively spacious. As it can be seen in Figure 5.9, there are no significant overall differences in ERA between the urban, intermediate, and rural classified areas.

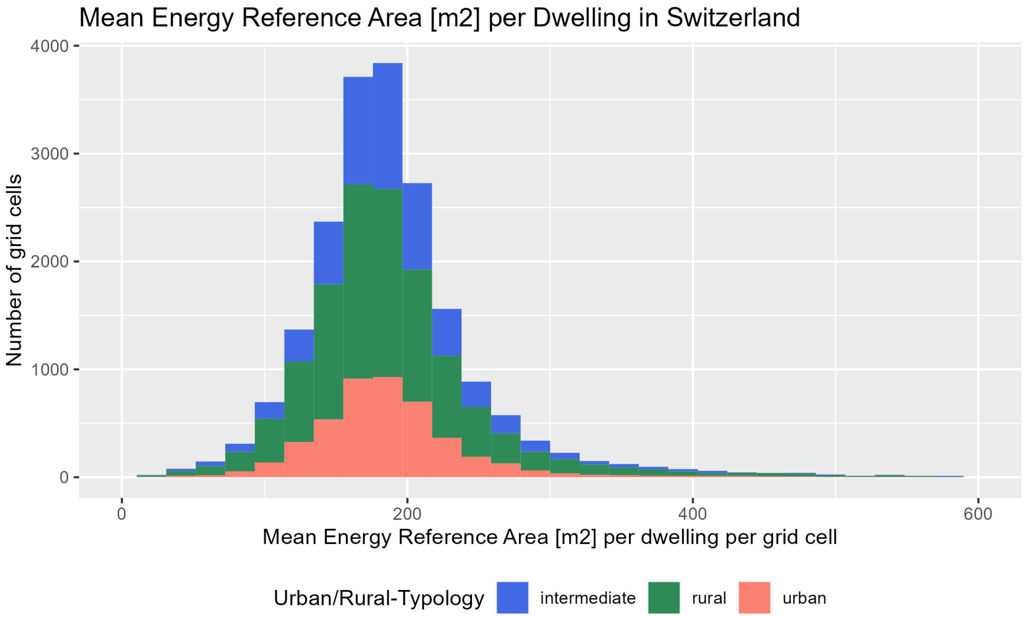


Figure 5.9: Histogram of the Mean ERA, categorized into the Urban/Rural-Topology (own Figure)

The energy demand per m^2, visualized in Figure 5.10 indicates the age and therefore the state of the building regarding its energy efficiency. The values range from 28kWh/m^2 to 157kWh/m^2, which corresponds to the assigned energy demand per m^2 values depending on the construction period of the building as described in 4.2.3. The mean energy demand per m^2 does not show very clear patterns compared with the Swiss-SEP or the ERA. The energy demand per m^2 in the canton of Ticino and Berne seem to be on a slightly higher level than the other cantons but generally, the construction periods of the buildings vary strongly in space. This is also backed up by the histogram in Figure 5.11. All three categories of the Urban/Rural-Typology show a rather similar pattern of the Mean Energy Demand per m^2.

The third component of the Energy Demand Modelling consists of the accumulated temperature differences which is visualized in Figure 5.12. The obtained values in the built-up area in Switzerland range from 127 to 563. Unsurprisingly, the accumulated temperature differences are lowest in Ticino, in the Rhein valley, along the Limmat and Reuss, in the region of Basel, as well as at the lakeside of Lake Geneva, and the Rhone valley. On the other side, the heating period is the longest in the Alpine valleys, in the Pre-Alps, and in the Jurassic Mountains.

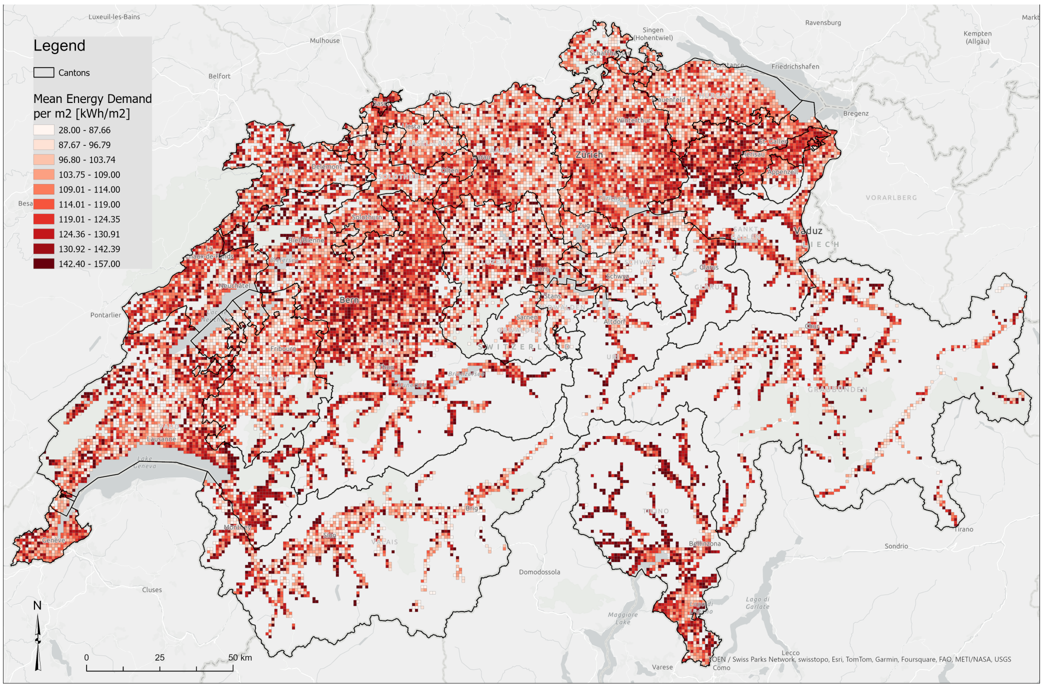


Figure 5.10: Visualization of the mean Energy Demand per m^2 for Switzerland in 1 km^2-raster, classified in quantiles (own Figure)

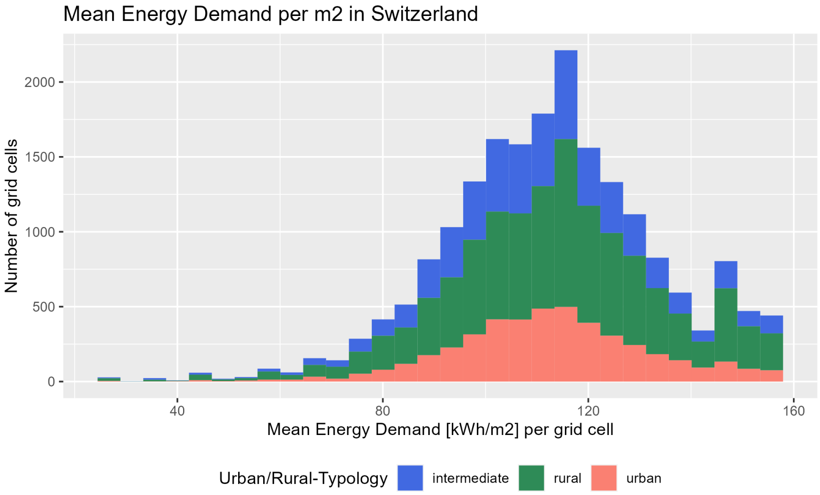


Figure 5.11: Histogram of the Energy Demand per m^2, categorized into the Urban/Rural-Topology (own Figure)

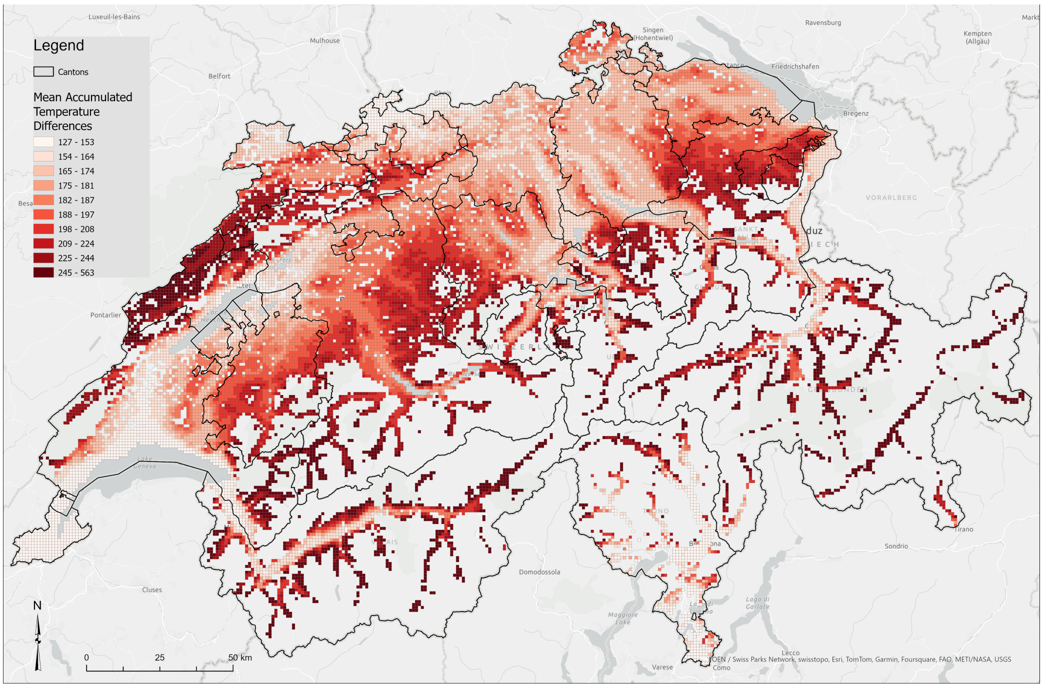


Figure 5.12: Visualization of the mean Accumulated Temperature Differences for Switzerland in 1 km^2-raster, classified in quantiles (own Figure)

5.3 City of Zurich

In the national analysis (see Figure 5.2), the EPVI in the area of the City of Zurich appears rather homogeneous. As Zurich is densely populated, the data was additionally analysed on a smaller grid for the City of Zurich. It contains 4'076 grid cells of the size of 100x100m.

5.3.1 Energy Poverty Vulnerability Index

In the Swiss context, the EPVI in Zurich is on the lower end, as the maximum index obtained per grid cell for the national analysis is 5.5. However, by refining the resolution of the grid cells, some areas with a higher vulnerability are revealed, as the maximum EPVI in the hectare grid is 8.5. Further, the higher resolution uncovers some spatial differences within the city boundaries, as it is illustrated in Figure 5.13, that are worth to be analysed.

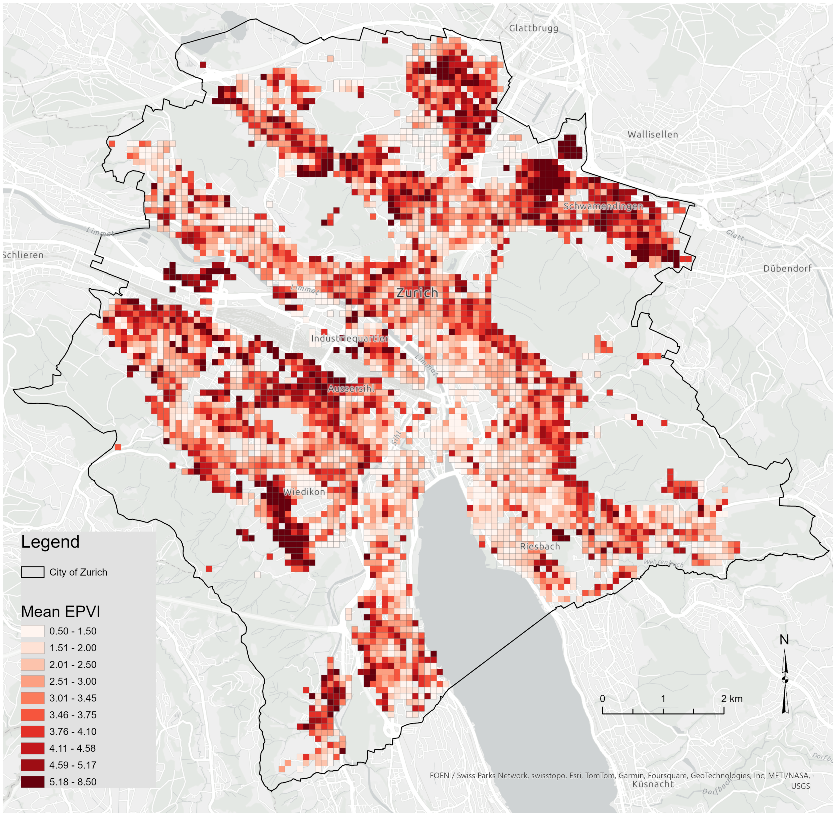


Figure 5.13: Visualization of the Energy Poverty Vulnerability Index for the City of Zurich displayed in quantiles in a hectare grid (own Figure)

In the city, the areas with the lowest vulnerability are mainly located around the lake basin as well as along the left shore of the Limmat, and the area between Oerlikon and Seebach. On the other hand, Schwamendingen, the area on the right shore of the Limmat as well as Friesenberg show the highest EPVI classification in the City of Zurich.

5.3.2 Bivariate Visualization

Again, the bivariate visualization of the modelled mean energy demand and the Swiss-SEP in Figure 5.14 allows to detect the patterns behind the EPVI-distribution.

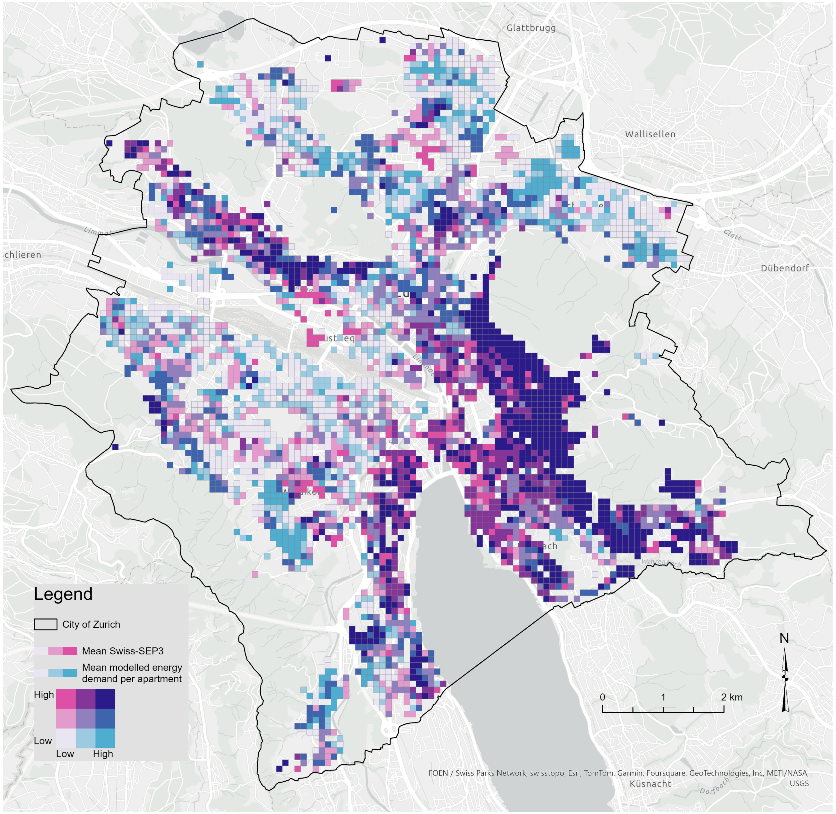


Figure 5.14: Bivariate Visualization of the EPVI-subindicators for the City of Zurich in a hectare grid (own Figure)

It becomes evident that the majority of the households on Zürichberg live in energy-intensive buildings but at the same time obtain a high socioeconomic position (dark-blue colored). The areas on the right Limmat shore and around the lake basin show a similar signal though not equally strong. Apart from Zürichberg, most areas at the city border (Schwamendingen, Seebach and towards Uetliberg) are characterized by a rather high energy demand but a comparatively low socio-economic position and are therefore at the highest risk to be affected by energy poverty.

5.3.3 Swiss-SEP

Similar to the EPVI, the Swiss-SEP shows much more variation in the hectare grid than in the large scale national analysis (see Figure 5.15). Again, Zürichberg, around the lake basin and the household on the right shore of the Limmat obtain the highest Swiss-SEP value. Although the Swiss-SEP is rather high compared to all of Switzerland, there are areas with a SEP well below 50. Generally, big parts of Schwamendingen, Seebach, and Affoltern as well as some parts on the left shore of the Limmat, such as in Aussersihl and Altstetten also show the lowest SEP.

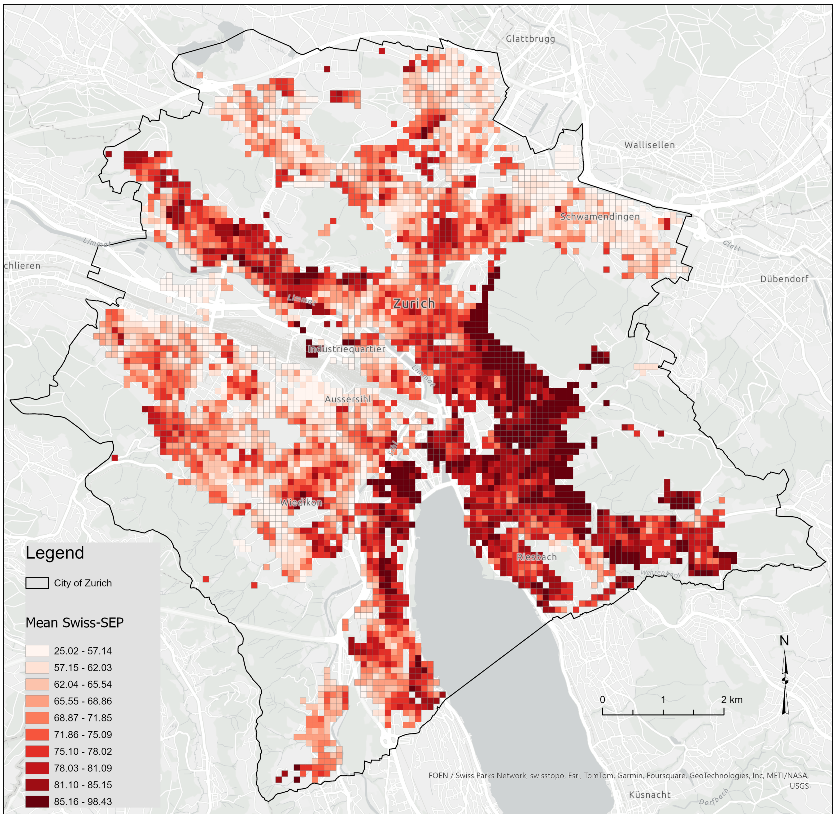


Figure 5.15: Visualization of mean Swiss-SEP, in hectare grid, classified in quantiles (own Figure)

5.3.4 Modelled Mean Energy Demand

Similar to the national analysis, the modelled mean energy demand will be decomposed into its components to better understand the obtained vulnerability patterns. The modelled mean energy demand per household varies between 2’701 kWh/a and 168’535 kWh/a as visualized in Figure 5.16. As previously explained, especially the neighborhoods at Zürichberg, along the right shore of the Limmat and the areas at the foot of Uetliberg also show high energy demand. On the other hand, the residential buildings in the city center and the left Limmat shore as well as some areas in Oerlikon and Schwamendingen are classified in the lowest quantiles regarding the modelled energy demand per dwelling.

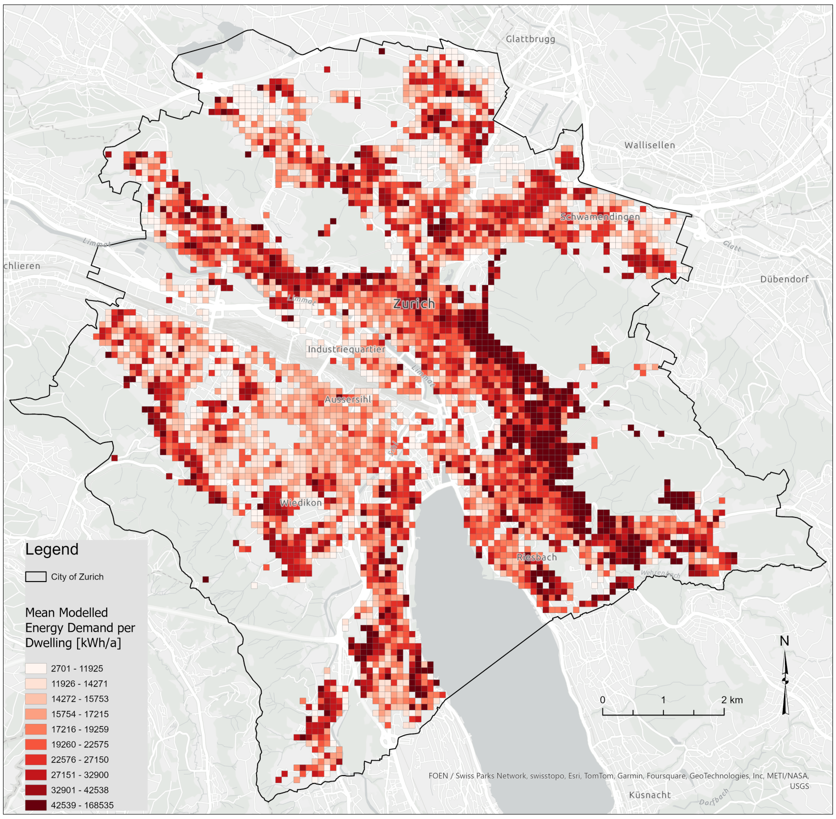


Figure 5.16: Visualization of the mean energy demand per dwelling for Switzerland in a hectare grid, classified in quantiles (own Figure)

Analogous to the results on the national level, the mean Energy Demand per m^2 lies between 28kWh/m^2 and 57kWh/m^2. The highest Energy Demand per m^2 and therefore the least energy-efficient buildings are located along the settlement boundary at Zürichberg and Uetliberg, as well as in some areas of Schwamendingen, especially in the quarter of Saatlen, as it can be seen in Figure 5.17. The lowest mean Energy Demand per m^2 can be found in Affoltern and in some parts of Oerlikon, as well as dispersed over the areas on the left shore of the Limmat.

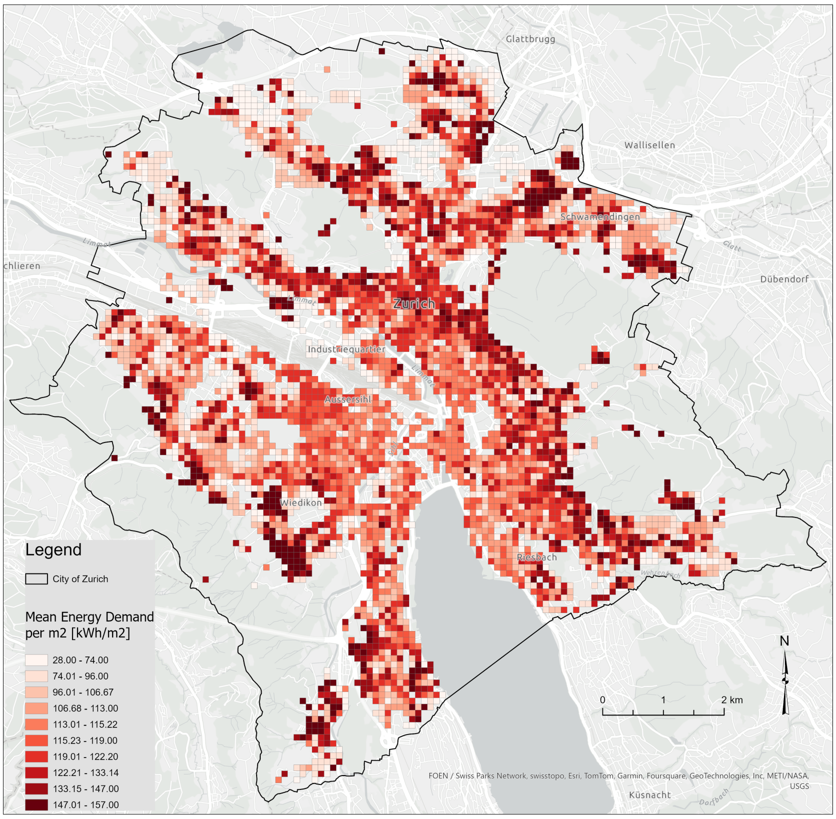
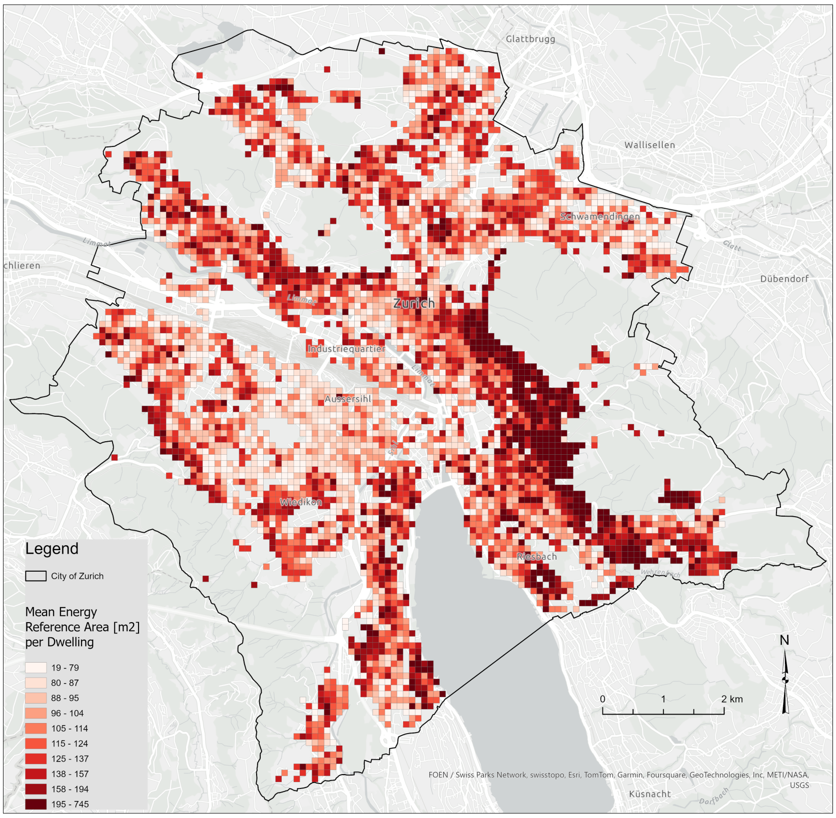


Figure 5.17: Visualization of the mean Energy Demand per m^2 in Zuerich in a hectare grid, classified in quantiles (own Figure)

For the City of Zurich, the mean ERA ranges from $19m^2$ to $745m^2$ which is a smaller range than in the national analysis. Unsurprisingly, Figure 5.18 shows that the households at Zürichberg and to some extent around the lake basin live in the biggest dwellings, whereas again in Schwamendingen as well as Altstetten and Aussersihl the mean ERA and therefore also the mean living area is much smaller.



FOEN / Swiss Parks Network, swisstopo, Esri, TomTom, Garmin, Foursquare, GeoTechnologies, Inc, METI/NASA, USGS

Figure 5.18: Visualization of the mean energy reference area in the City of Zurich in a hectare grid, classified in quantiles (own Figure)

The spatial variations for the accumulated temperature differences in the City of Zurich play a minor role compared with the national analysis, as the differences in altitude within the city borders are smaller. Additionally, the temperature data only has a resolution of 1 km^2. Therefore, the influence of the climate could not be analysed on a refined scale.

6 Discussion

With this thesis, a spatial analysis of energy poverty vulnerability was conducted. In Section 6.1, 6.2 and 6.3, the obtained results will be discussed regarding the research questions that were stated in Section 1.2 by putting them into context of the elaborated State of the Art in Section 2. In Section 6.4, the implications of this work will be discussed. Lastly, Section 6.5 presents the limitations of the chosen research design.

6.1 Occurrence and Reasons of Energy Poverty Vulnerability in Switzerland

RQ1: Where in Switzerland and why are people at risk of energy poverty?

The results of the implementation of the energy poverty vulnerability index in Switzerland shows mainly two tendencies. Firstly, rural areas are generally characterized by a higher vulnerability than urban regions. When looking at the maps in the previous chapters, it becomes evident that the main reason for that pattern lies in the socioeconomic position that tends to be higher in urban areas than in the rural regions. Adding to that, the mean energy reference area per dwelling also seems to be higher in the peripheral areas which refers on a bigger living space per dwelling than in the cities. As a consequence, the high EPVI therefore illustrates that these people with comparatively less financial means have a higher modeled energy demand which results in higher heating-related expenses. However, the analysis also showed clearly that the areas confronted with higher energy poverty vulnerability strongly depend on the level of data aggregation. On a smaller scale, notable spatial differences could be observed. In Zurich, the most vulnerable households regarding energy poverty cluster in the northern part of the city (Schwamendingen, Seebach, Affoltern) and towards the (South-)Eastern city boundary (Leimbach, Friesenberg). Interestingly, the just mentioned neighborhoods correspond fairly well with the areas pointed out by Kaufmann et al. (2023), where vulnerable households move after renovations. As a second main pattern, it can be observed that in mountainous regions, the EPVI tends to be higher than in the Swiss Plateau. The reasons for this are twofold. On one side, the longer heating period in colder climates impact the modelled energy demand. On the other hand, the socioeconomic position is rather low. Popular tourist resorts such as Davos, the Upper Engadin, Zermatt or Grindelwald are an exception in this respect, as they are characterized by higher socioeconomic positions.

RQ2: How do the results of the spatial analysis correspond to patterns of similar analysis in other countries?

Previous research has shown that especially households in peripheral areas have a higher risk to be affected by energy poverty (Mulder et al., 2023; Robinson et al., 2018; Sokołowski et al., 2020). However, it has also been found that the different conceptualisations of energy poverty indicators influence the results on which households are considered energy poor and on where the affected households are located (Deller et al., 2021; Robinson et al., 2018). The implementation of the EPVI for Switzerland yielded similar patterns compared to the EPVI by Gouveia et al. (2019). In Portugal, the higher energy poverty vulnerability in the rural areas is mainly caused by the socioeconomic preconditions as well as the harsher winter climate (Gouveia et al., 2019). Interestingly, several studies demonstrated that also the lacking energy efficiency puts rural regions at a higher risk from being affected by energy poverty than the cities (Mulder et al., 2023; Sokołowski et al., 2019). The conducted analysis could not confirm that condition for Switzerland. It has been found that in the countryside in Switzerland the building efficiency is comparable to urban areas, it is much rather the high average dwelling size in the rural areas which is the driving factor for the elevated energy demand.

Key Messages:

- Rural and mountainous areas feature the highest energy poverty vulnerability in Switzerland.
- The observed patterns are in line with the urban-rural disparities described in the literature.
- The higher risk of energy poverty in rural areas stems from a low socioeconomic position paired with generous living space.
- By reducing the data aggregation, vulnerable areas in the City of Zurich could be detected.

6.2 Data Choice and Quality

RQ3: Is the available data regarding its form and quality suitable for an energy poverty analysis?

Getting a reliable measure of energy poverty vulnerability is a complex task due to the many different preconditions that could lead to energy poverty as it is outlined in Section 2.1. As a consequence, a big variety of indicators have been proposed to depict the multidimensional nature of energy poverty. Given the fact that this work marks the first conducted spatial analysis on energy poverty for Switzerland, the choice of the data could not be built on previous, location-specific experiences. By the implementation of the EPVI, socioeconomic, building-efficiency, and climate data were combined on a neighborhood level.

Swiss-SEP:
As elaborated before, there is a broad consensus among scholars that low income and high energy costs are two main drivers of energy poverty (Hills, 2011). To locate vulnerable households that lack the financial means to consume energy carefree, the Swiss-SEP was used as one of the main data sets. One of the advantages of the Swiss-SEP data is its small-scale resolution as it contains geo-referenced information on a neighborhood level. Although the Swiss-SEP data set was provided by the FSO, the data was created and updated by researchers in the epidemiological field (Panczak et al., 2023; Panczak et al., 2012) where its validity has been proofed (Panczak et al., 2012). As the Swiss-SEP is based on Swiss Census data, the data quality is directly linked to the structure of the Census data collection. Unfortunately, the FSO changed its Census regime from a comprehensive survey to a statistic based on cantonal and communal registers, complemented by a yearly structural survey with a sample size of at least 200'000 persons (Bundesamt für Statistik, 2024b). As the Swiss-SEP depends on the results of the structural survey, the socioeconomic data had to be spatially interpolated for the newest update (Panczak et al., 2023) which might have an influence on the data quality. Another drawback mentioned by the creators of the Swiss-SEP is that they could not incorporate real income data, and therefore had to use mean rent as a proxy (Panczak et al., 2012). The integration of income data would not only improve the Swiss-SEP but also the comparability of the EPVI with other energy poverty indicators, as low income is one of the key conditions of energy poverty and not high rents.

RBD:

Besides socioeconomic and climatic factors the state of the buildings is a crucial factor when evaluating energy-efficiency and therefore the financial means that need to be spent in order to not live in thermal discomfort. By pursuing an approach that aims to analyse patterns in high-resolution on the scale of neighborhoods or even buildings, the RBD poses an appropriate data source, as it provides building-specific information in a standardised structure for all of Switzerland. The fact that many cantons use the RBD for their own residential-related energy statistics (Amt fuer Umwelt und Energie, 2020; Departement Bau Verkehr und Umwelt, 2019; Dienststelle Umwelt und Energie, 2015) as well as it has also been the data basis for analysing moving patterns after renovations (Kaufmann et al., 2023), indicates clearly that the RBD is a crucial data source for combining technical and social topics at building or even at household level.

However, it is also known that the data quality is improvable, especially for energy-related information (Kulawik & Bucher, 2013). To a certain extent, this circumstance also had an influence on the planned research design. Initially, it was planned to integrate the additional data table of the RBD containing information about renovations into the modelling of the energy demand. As carrying out renovation work on the buildings insulation improves energy-efficiency significantly, the energy demand for these buildings would be reduced. But according to the data, only for about 3'800 buildings such an energetic renovation has been reported to the RBD. That marks only about 0.3% of the buildings that were considered for the calculation of the EPVI and only covers a fraction of the 1% of the building park that is renovated every year (Boulouchos et al., 2022). Furthermore, in the same data table only 11'638 renovations of the heating system are registered. When comparing those numbers to market data the newly installed heating systems, it becomes evident that the RBD does show certain data gaps (Das Gebäudeprogramm, 2022).

Similarly, the installed heating systems should have been part of the analysis for energy poverty vulnerability. Especially the comparison between households with fossil and renewable heating systems, could have refined the energy poverty vulnerability as households depending on fossil fuels are exposed to higher price fluctuations (Bundesamt für Energie, 2022). Furthermore, the cost of future renovations of fossil heating systems could also lead to increasing rents and force vulnerable households to move (Kaufmann et al., 2023). However again, the available data of the energy carriers of the heating systems in the RBD is incomplete. For almost 15% of the residential buildings the energy carrier of the main heating system is classified as *undetermined* or *other*. Adding to that, the monitoring of the last update of the information of the *GENH1* (RBD code for the energy carrier of the main heating system) shows that as of Mid-January 2024 for more than 65% of all residential buildings in Switzerland the RBD has not been updated in the last 8 years (Bundesamt für Statistik, 2024a). Interestingly, the monitoring website (Bundesamt für Statistik, 2024a) shows tremendous differences between the individual cantons and municipalities, which is a clear indicator for a spatially varying data quality of the RBD. Further, this hints that the competence of the municipalities and cantons regarding the reporting of the data leads to spatial inconsistencies.

Key Messages:

- In general, the Swiss-SEP and the RBD are suitable data sources for analysing energy poverty as they consist of high-resolution data.
- The quality of the RBD data needs to be improved for future, more sophisticated research.
- The integration of income data in the analysis needs to be improved.

6.3 Policy Measures

RQ4: What are possible policy measures to reduce energy poverty vulnerability in Switzerland?

Probably, due to the lack of awareness on energy poverty among policymakers in Switzerland, there is only a very limited offer of subsidies in that specific field. As a reaction to the rising inflation and the energy price shock in 2022, the City of Zurich created the so-called “Energiekostenzulage” (Energy cost subsidy) in order to alleviate the financial stress of the high energy costs (Stadt Zürich, 2023). The author of this thesis is not aware of any other subsidy programs in Switzerland that aims the mitigation of energy poverty. However, such direct financial aids have been proven to be effective as they immediately lighten the burden of energy-related expenses on the household budget (Maxim et al., 2016). Therefore, the expansion of the energy cost subsidy to other affected municipalities can be useful.

In terms of energy-related funding, there exists a variety of programmes in Switzerland, though with a different focus than supporting people at risk of energy poverty. As for example with the “Gebäudeprogramm” (Buildings programme), Switzerland has a very extended subsidy system in order to reach the set goals of the previously described Energy Strategy 2050. With this program the energy-related renovations such as installing a renewable heating system or improvements in the insulation of a building are supported financially (Das Gebäudeprogramm, 2023). Such incentives are found to be very cost-effective measures in order to reduce the climate impact of the building park (Patel et al., 2021). As the incentives are primarily targeted at home owners, the people vulnerable to energy poverty can most likely not profit from financial support in that area (Suppa et al., 2019).

Generally, it is worthwhile to consider the topic from an overarching perspective. Due to the fact that the political discourse on energy poverty in Switzerland has been quasi non-existent, comprehensive measures to reduce the impact of energy poverty for the affected households are lacking. But it is equally important to elaborate a strategy that minimizes the root causes of energy poverty so that everyone can afford to meet their energy-related needs (Bouzarovski et al., 2021). The development of such a strategy requires continuing in-depth research on the topic to gain a more profound understanding on the situation of Switzerland.

Key Messages:

- In the short term, energy cost subsidies can alleviate the situation for affected households.
- In the longer term, it is proposed to develop a strategy to prevent energy poverty.
- Further research need to be conducted.

6.4 Implications

By conducting the first spatial analysis of energy poverty vulnerability in Switzerland, this work offers different potential applications. Although the national analysis showed some noticeable patterns regarding the spatial distribution of energy poverty vulnerability, it became evident that the level of data aggregation has a big impact on the visibility of energy poverty vulnerability on a neighborhood-scale. A fine-grained analysis of the EPVI, like it has been performed for the City of Zurich, allows to effectively localize vulnerable households and therefore to implement target-oriented measures

(Liddell et al., 2011). The here presented methodology can be applied to any other municipality or city in Switzerland. Knowing where vulnerable households are located can also be beneficial for the city planning authorities or housing cooperatives. When looking for new locations of social housing or when planning the spatial development of neighborhoods, the energy-related needs of the local population can be considered.

6.5 Limitations

Of course, this work comes with its own constraints mostly regarding the chosen data and methodology. When analysing energy demand for heating in Switzerland, the RBD is undoubtedly a very valuable data source that cannot be ignored. However, the data is not perfect and for many buildings important information is lacking or most probably outdated. As the data maintenance is in the competence of the municipalities and cantons, it is very likely that the data quality is varying through space which complicates the data analysis.

Another limitation refers to the age and the quality of the Swiss-SEP data. The data version used for this thesis dates from 2015 and is only an updated version of the initial SEP that is based on data from 2000. In addition to that, the collection of the Census data, which is the base of the Swiss-SEP, changed from a comprehensive data set to a random sample that was spatially interpolated to cover all of Switzerland.

Besides the limitations regarding the data, the applied methodology also had a big effect on the obtained results. The chosen energy demand per m^2 values for modelling the heating energy demand are empirical values that were obtained by the Canton of Berne, based on a sample of buildings that were analysed regarding their energy efficiency (Amt fuer Umwelt und Energie, 2020). The accuracy of those values is certainly limited, as other cantons work with other values, based on other building samples. Further, the analysis did not include any renovations that were conducted to improve the buildings energy efficiency. In addition, the installed heating systems were not considered in the analysis. Insofar, the different systems do have an influence on the final heating demand due to varying system efficiencies (Self et al., 2013).

Another aspect which also reduces the meaningfulness of the results is that energy prices and the real heating energy consumption were not a part of the conducted analysis. The integration of these two factors would certainly improve the quality of the results.

Lastly, this thesis only focused on energy poverty vulnerability for heating, but as explained earlier, energy is also consumed for transportation purposes or in the form of electricity for countless daily household applications. Therefore, the obtained results and patterns only show one part of energy poverty vulnerability and the risk to be affected by energy poverty may distributed differently when approaching the topic more holistically, or when focusing on other forms of energy poverty.

7 Conclusion

In the context of this thesis, a weighted spatially continuous indicator of energy poverty vulnerability has been implemented for Switzerland for the first time. With the Energy Poverty Vulnerability Index, the regions where the households are at the highest risk to be affected by energy poverty were detected. Based on the analysis of socioeconomic, building energy-efficiency and climate data, households in peripheral and mountainous areas in Switzerland are the most risk-prone to heating-related energy poverty. However, it was found that the obtained patterns in energy poverty vulnerability strongly depend on the scale of the data analysis. While on the national analysis on a coarser scale the City of Zurich was classified with a comparatively low energy poverty vulnerability, the small-scale analysis revealed significant differences within the boarders of the City of Zurich. As the EPVI allows to localize areas with vulnerable households it could be used to implement target-oriented measures to reduce the risk of being affected by energy poverty. Finally, data quality and availability needs to be improved to establish a more sophisticated monitoring of the situation regarding energy poverty vulnerability in Switzerland.

7.1 Future Work

With this thesis being the first spatial analysis of energy poverty vulnerability in Switzerland, it may provide a basis for follow-up studies in several different directions. A possible focus of future work could be the implementation of energy prices for heating, as that would improve the meaningfulness of the observed vulnerability patterns. Also, by including other risk factors of energy poverty such as age, lone parent, or unemployment in the analysis could help to recognize vulnerability patterns. Adding to that, the performance of a more small-scale analysis could help to better localize vulnerable households and therefore to tailor possible measures accordingly. Lastly, the analysis of other forms of energy poverty vulnerability regarding transport or consumption of electricity may add to a more integral picture of energy poverty in Switzerland.

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Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Carmen Pfoster, 31.01.2024