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University of Natural Resources
and Life Sciences, Vienna

Master Thesis

Mapping the Distribution of Austrian Wastewater Treatment Plants Smaller than 500 PE

Submitted by

Dellagiacoma Fabrizio, BSc

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Supervisor:
Priv.-Doz. Dipl.-Ing. Dr.nat.techn. Günter Langergraber
Institute of Sanitary Engineering and Water Pollution Control (SIG)
Department of Water, Atmosphere and Environment (WAU)

This Master's thesis was written at the

Institute of Sanitary Engineering and Water Pollution Control

within the

Department of Water, Atmosphere and Environment

at the

University of Natural Resources and Life Sciences, Vienna

Supervised by

Priv.-Doz. Dipl.-Ing. Dr.nat.techn. Günter Langergraber

University of Natural Resources and Life Sciences, Vienna (BOKU)

Institute of Sanitary Engineering and Water Pollution Control (SIG)

Department of Water, Atmosphere and Environment (WAU)

And co-supervised by

Ing. Ph.D. Pavel Svehla

Czech University of Life Sciences, Prague

Faculty of Agrobiology, Food and Natural Resources

Department of Agri-environmental Chemistry and Plant Nutrition

Student number 01430325

Dai diamanti non nasce niente, dal letame nascono i fior'.

F. De André

I'm feel, I'm very feel.

A.Usyk

Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

City, date First name SURNAME *(manu propria)*

Vienna, 2.09.2022

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Abstract

In recent years, a dataset on Austrian WWTPs < 500 PE (personal equivalent) was established at BOKU. The present work, based on the mentioned dataset, aims at describing the distribution of WWTPs at cadastral municipality level and identifying clusters of WWTPs not complying with national regulations on nitrification. The complete workflow, including plots and graphics has been executed using Python 3.8 and is available under https://github.com/anakarpow/small_WWTPs_MSC.

WWTPs < 500 PE are essential for WW coverage in Austria because of the geomorphological barriers that do not allow a uniform centralized coverage. They are mostly located in mid to high altitudes and some clusters with higher concentrations are visible in Carinthia, Styria and Lower Austria. Of the 2'095 Austrian municipalities, about 5% (105) have most of their population covered by these design sizes. Such municipalities account for 107'330 PE and most of them are in Lower Austria (55'000 PE) and Carinthia (36'000 PE). In Carinthia 17.5% of the population relies on WWTPs < 500 PE. Lower Austria and Styria follow with about 7%. The remaining states and the national average are at about 5%. Today most of WWTPs up to 500 PE implement one of the following technologies: Activated Sludge Process (25%), Sequencing Batch Reactor (25%) or Constructed Wetlands (20%). Nonetheless, more than 6'000 WWTPs (23%) with exclusively primary treatment are still operational. Carinthia is the state in where the percentage of population relying on such infrastructure is highest (7%), whereas all the others are at about 1%. Considering that the entire population has access to some form of sanitation (WWTPs or cesspools) and that the areas where decentralized WWTPs are more common (hilly rural areas) will not be subject to considerable population growth, the number of decentralized WWTPs is likely to stagnate in the future. In this optic, the maintenance and development of existing infrastructure becomes even more important.

Kurzfassung

In den letzten Jahren wurde an der BOKU ein Datensatz zu österreichischen Kläranlagen < 500 Einwohnern (EW) erhoben. Die vorliegende Arbeit, die auf dem genannten Datensatz basiert, zielt darauf ab, die Verteilung von Kläranlagen auf Katastergemeindeebene zu beschreiben und Cluster von Kläranlagen zu identifizieren, die die nationalen Vorschriften zur Nitrifikation nicht einhalten.
Der komplette Workflow, einschließlich Plots und Grafiken, wurde mit Python 3.8 ausgeführt und ist im GitHub unter small_WWTPs_MSC verfügbar.
Kläranlagen < 500 EW sind für die Abwasserbehandlung in Österreich aufgrund der geomorphologischen Barrieren unerlässlich. Von den 2.095 österreichischen Gemeinden haben etwa 5 % (105) den größten Teil ihrer Bevölkerung mit diesen Baugrößen abgedeckt. Auf diese Gemeinden entfallen 107.330 EW, die meisten davon in Niederösterreich (55.000 EW) und Kärnten (36.000 EW). In Kärnten sind 17,5 % der Bevölkerung auf Kläranlagen < 500 EW angewiesen. Niederösterreich und die Steiermark folgen mit rund 7 %. Die übrigen Bundesländer und der Bundesdurchschnitt liegen bei etwa 5 %. Heutzutage setzen die meisten Kläranlagen mit bis zu 500 EW eine der folgenden Technologien ein: Belebtschlammverfahren (25 %), Sequenzierungs-Batch-Reaktor (25 %) oder Pflanzenkläranlagen (20 %). Dennoch sind noch mehr als 6000 Kläranlagen (23 %) mit ausschließlicher Erstbehandlung in Betrieb. Kärnten ist das Bundesland, in dem der Anteil der Bevölkerung, der auf eine solche Infrastruktur angewiesen ist, am höchsten ist (7 %), während alle anderen bei etwa 1 % liegen.
In Anbetracht der Tatsache, dass die gesamte Bevölkerung Zugang zu irgendeiner Form von Abwasserentsorgung hat, und dass die Gebiete, in denen dezentrale Kläranlagen häufiger vorkommen kein nennenswertes Bevölkerungswachstum erfahren werden, wird die Zahl der dezentralen Kläranlagen wahrscheinlich in der Zukunft stagnieren. In dieser Optik werden die Pflege und Weiterentwicklung bestehender Infrastruktur noch wichtiger.

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Definitions

BOD_5: biochemical oxygen demand in 5 days (1. AEVkA, 1996).

PE: Austrian law defines population equivalents in the first paragraph of the 1. AEVkA,1996 as “the water pollution load of 60g BOD_5 per inhabitant per day”(1. AEVkA, 1996).

Decentralized WWTPs: relatively small (≤500 PE) WWTPs that are built in areas where a centralized solution is inconvenient because of economic or technical reasons. Depending on their side they may treat single houses or small settlements. They are mostly used for treating household waste (Dopplinger, 2016; Feigl, 2018).

Small and medium WWTPs: For this work decentralized WWTPs will be further split in two categories. The term **small WWTP** is applied to the design size **up to 50 PE** and **medium WWTP** for the design size between **51 and 500 PE**.

Nitrification: microbial process by which **ammonia**, toxic to waterborne species, is sequentially **oxidized to nitrate** (US EPA, 2007). By reducing the Nitrogen content, nitrification also helps preventing eutrophication and nutrient pollution.

Primary treatment. **Physical treatment** aiming at the **removing** of 20% BOD_5 and 50% **suspended solids** (EU Council, 1992). Purely physical treatments are compost toilets and filter-sack methods. Septic tanks are considered **partially biological treatments** because they reach some degree of microbial conversion. Nonetheless they don’t satisfy Austrian WW quality standards. According to state-of-the-art treatment, mechanical methods like filtering and screening are used for supporting secondary biological treatment(Feigl, 2018).

Secondary treatment: **Biologic treatment** aimed at reaching wastewater quality higher than mere primary treatment. They take advantage of **microbial metabolism** to convert organic suspended substances into their mineral components. Usual methods are the continuous activated sludge processes (CAS) and 2 activated sludge variations: the suspended batch reactor (SBR) and the membrane bioreactor (MBR). Further treatment types are fixed bed reactors like the trickling filter (TF), the biofilter (BF) and the rotating biological contractor (RBC). Constructed wetlands (CW) have gained importance in recent years (Feigl, 2018). According to the **AAEV,1996**, each WWTP must be implemented with **biological removal of carbon and nitrification**.

For a detailed description of each primary and secondary treatment type see the detailed work of Feigl, 2016 (Feigl, 2018).

Not-state-of-the-art treatment: WWTPs implementing **only primary treatment.** They don’t respect Austrian WW regulations as they don’t reach sufficient nitrification values (1. AEVkA, 1996; AAEV, 1996). WWTPs placed in extreme geographical positions are exempted from the same nitrification standards because of logistical difficulties(3. AEVkA, 2006). Such infrastructure usually applies compost or filtration methods. For this reason, only WWTPs applying the septic tank method are considered not-state-of-the-art.

1. Introduction

In Austria about 95% of the population is connected through sewage channels to wastewater treatment plants (WWTPs) larger than 500 PE. In its most recent publication, the OWAV (2020) counts 887 WWTPs larger than 500 PE. Together with other central European countries like Germany (97%) and the Netherlands (99%), Austria leads the connection rate ranking. The lowest connection rates are to be found in Eastern countries like Rumania (51%) and Serbia (62%) (ÖWAV, 2020).The remaining 5% of the Austrian population relies on a high number of cesspools or small decentralized systems. The exact number of WWTPs smaller than 500 PE has been intensively investigated in recent years. In fact, also because of its comparatively low contribution to the total sanitation capacity, the number of WWTPs up to 500 PE has long been underestimated.

According to the European urban wastewater treatment directive (UWWTD, 91/271/EEC), only WWTPs larger than 2’000 PE need to be reported to the EU. In Austria as in most of Europe, only data for those WWTPs is collected by the central government and then forwarded to the EU. As a result, data on European WWTPs bigger than 2’000 PE is publicly accessible from the European Environmental Agency (EEA) website. On the other hand, data on smaller WWTPs is hardly available and fragmentary. In Austria federal governments are responsible for the registration of WWTPs and they recently implemented online WWTPs databases including all design sizes.

Using the online federal databases, the Institute for Sanitary Engineering and Water Pollution Control at BOKU identified a significant gap between the previously estimated and the registered number of WWTPs up to 500 PE. The institute developed the first Austrian-wide dataset, containing information on technology type, implementation year and treated volume of WWTPs up to 500 PE. This work helped shed light on the subject and was included in the most recent national report on Austrian wastewater.

Because of its mountainous character, Austria cannot solely rely on centralized WWTP infrastructure to secure sanitation for all its citizens. The connection rate to central WWTPs strongly fluctuates according to topographic characteristics. The lowest connection rate is in Waidhofen an der Ybbs (66%), at the Alps foothills and the highest in Vienna (100%), the capital city on the lowlands (ÖWAV, 2020). As a matter of fact, decentralized WWTPs are essential to ensure high sanitation levels overall the country. Cesspools are also used and allowed, as long as they are water-tight and their content is regularly carried to a WWTP. On the other hand, mostly mechanic treatments like septic tanks no longer satisfy Austrian nitrification regulations. Lendl and Muller (2016) pointed out that 20% of WWTPs up to 500 PE still apply such treatment.

Using the mentioned dataset to map the Austrian-wide distribution of small-scale wastewater system, this work aims at highlighting spatial information and represents the first spatial analysis on this subject.

2. Objectives

The first goal of this work is to analyse the dataset from a spatial perspective and describe the distribution of decentralized (< 500 PE) wastewater systems on a municipality level, the smallest administrative division in Austria. The outcome of the first goal is maps thematized by design size and percentual population coverage.

Lendl and Müller reported that 20% of WWTPs up to 500 PE don't respect biological nitrification requirements according to national law (Lendl and Muller, 2016). Building on this statement, the second research goal is to identify clusters of non-state-of-the-art infrastructure and the municipalities that mostly rely on them. The outcome of the second goal is maps showing the location of such WWTPs by design size and percentual population coverage.

Furthermore, this works specifically aims at facilitating research on the topic. To do so the original datasets will be harmonized for future research and updates. The entire source code will be published to ensure reproducibility.

In the order they will be discussed later, the specific objectives of this work are:

- To unify the existing datasets in a single database
- To describe the distribution of WWTPs at cadastral municipality level
- To identify clusters of non-state-of-the-art WWTPs and the municipalities that mostly rely on them

Structure of the thesis

In *Chapter 3* the theorical background is set, describing the legal framework and summarizing the state of knowledge on Austrian wastewater coverage. Chapter 4 discusses the workflow from raw data to the desired dataset and its analysis. In *Chapter 5,* the outcomes of the goals are presented and analysed. In *Chapter 6*, the results are interpreted and compared to literature. Finally, conclusions are drawn in *Chapter 7*.

3. Fundamentals

3.1 Legal Framework in Europe and Austria

On a European level, the Urban Wastewater Treatment Directive (UWWTD 91/271/EEC) sets minimum wastewater requirements and has been translated into Austrian national law with the 1st Wastewater Emission Ordinance (1. AEVkA, 1996). Together with the General Wastewater Emission Ordinance (AAEV, 1996) this piece of law forms the essential pillar of national wastewater regulations. Their juridical background, as for any other Austrian water related law, is set in the Water Act issued in 1959. It regulates the use, protection and quality of water resources (WRG, 1959).

In Austria WW is defined in AAEV §1 as water that, after being used for human purposes (industry, cleaning, consumption) has been so affected that its reintroduction to natural water bodies would negatively affect them (AAEV, 1996). The goal of wastewater (WW) treatment is to ensure that all pollutants are removed according to 1. AEVkA. This piece of law defines general minimum treatment requirements according to plant size. In Austria biological nitrification belongs to the state-of-the-art treatment and is required for all WWTPs larger than 50 population equivalents (PE).

Table 1 Austrian wastewater treatment requirements (1. AEVkA, 1996)

Parameters (mg/L)	51-500	501-5.000	5.001-50.000	> 50.000
BOD5	25	20	20	15
COD	90	75	75	75
TOC	30	25	25	25
NH4-N	10	5	5	5
Tot-P	-	2	1	1

As stated in the Austrian general wastewater emission ordinance minimum requirements for emission quality are only compulsory for design sizes larger than 50 PE (AAEV, 1996). Nonetheless authorities usually apply the same requirements for smaller WWTPs(Gerstorfer, 2018; Langergraber *et al.*, 2018b). Note that not all WWTPs are subject to same requirements. For example, WTTPs in isolated areas, such as mountain shelters, are subject to less stringent requirements described in the 3. AEVkA (3. AEVkA, 2006). Design guidelines are described in Ö-NORM B 2502-1 (2012) and Ö-NORM EN 12566-3 (2016) or technical plants up to 50 PE and Ö-NORM B 2505 (2009) for treatment wetlands (Langergraber *et al.*, 2018b). Once the requirements have been respected and no damage is expected for the receiving water body, a discharge permission is issued by the authorities. The permission procedure is described in WRG § 32. Permissions are granted for specific periods , like 15 years in Upper Austria (Engstler, 2020).

The Directive on the digital register of essential loadings on natural water bodiesdescribes the national database for wastewater emissions, where WWTP larger than 2'000 PE and industrial WWTPs according to 2010/75/EU and 91/271/EWG must be recorded (EMREG, 2017). This register also contains WWTPs smaller than 2000 PE and is publicly available in the Water Information System Austria (WISA) database as promulgated by WRG § 59. All 9 federal states operate their own WIS, where all WWTPs on their territory shall be listed.

The UWWTD 91/271/EEC sets out a timeline for the implementation of wastewater treatment in settlements of all sizes, where larger settlements have priority. This sparked a run for sanitation and several countries invested in WWTPs to fulfil the European goals according to timeline (European Commission, 2019; Jodar-Abellan *et al.*, 2019). In case of non-compliance member states faced monetary sanctions like Spain and Italy (European Commission, 2019). Member states must report their progress in reaching the Water Framework Directive goals every 2 years to the European commission, in accordance with 91/271/EWG. In Austria the national WISA is one of the base datasets for the biennial report to European authorities. Information about WWTPs smaller than 200 PE are issued from federal authorities to their national counterpart (Oftner and Lenz, 2020). There is no unified national database for WWTPs smaller than 2’000 PE.

3.2 Research on small WWTPs in Europe and Austria

According to 91/271/EEC Article 7 the sanitation of settlement smaller than 2’000 inhabitants had to be implemented by 2005 (EU Council, 1992). Aragon reports 2 school of thoughts in the national implementations of this Article. Some countries, like Spain, decided that small agglomerations must comply with the same requirements valid for larger ones. Other countries, like Austria, France and Finland established specific requirements(Aragón *et al.*, 2013).

To fulfil the goals and avoid sanctions, member states had to invest in the sanitation of small settlements (<2’000 PE). Furthermore, collecting reliable data on the topic became essential to report to the European commission and interest was sparked also in scientific circles. In fact, most of papers on the topic have been published in the last decade. It has to be mentioned that the compliance with Article 7 seems not to be a priority for the European Commission, as it is not mentioned in the 10th and most recent report on the implementation of the UWWTD (European Commission, 2020).

European research on the topic usually focuses on surveying the existing infrastructure (Tsagarakis *et al.*, 2000; Dubber and Gill, 2014; Istenic *et al.*, 2015; Ostoich *et al.*, 2017), the analysis of legal framework (Savonia University of Applied Sciences, 2007; Somogyi *et al.*, 2009; Aragón *et al.*, 2013) and monitoring of treatment and operation & maintenance (O&M) quality (Tsagarakis *et al.*, 2000; Istenič *et al.*, 2009; Dubber and Gill, 2014). No spatial analysis was found.

In 2013, Aragón found that less than 50% of small Spanish settlements (<2’000 inhabitants) are properly sanitized. Furthermore the research highlighted that information about sanitation of small settlements was very limited (Aragón *et al.*, 2013). Generally, the absence of a central database is evident and researchers often must cope with sparse sources. Tsagarakis surveyed WWTPs up to 10’000 PE in Greece using data from “*information given by the personnel and management of plants, available design data, and on-the- spot investigations. Additional data were acquired by post or telephone contact.”* Nonetheless this work produced interesting results, stating that less than 50% of the built infrastructure was operational at the time and highlighted an overall poor O&M (Tsagarakis *et al.*, 2000).

In fact, maybe because it has remained unaddressed for long time, the topic of small WWTPs seems to deliver relevant pieces of information. A 2011 survey in Ireland found that 2 thirds of the population rely on decentralized WWTPs. Less than 1% of the households had no treatment facility but the treatment was overall inadequate. In fact most of the on-site treatment systems consisted of a cesspool and a percolation structure (Dubber and Gill, 2014). Improper treatment has also been reported in Italy, Sweden and Finland (Somogyi *et al.*, 2009; Ostoich *et al.*, 2017).

There is little literature available on the environmental effects of decentralized WWTPs. Because of the small discharge quantities involved, negative outcomes are considered negligible especially on a basin level. The few sources available report high P concentrations in surface waters, usually at low flow conditions (Dubber and Gill, 2014). Nonetheless, the potential environmental effects of decentralized WWTPs should not be underplayed. For example, in Finland where over 2 million PE are not connected to municipal sewers, rural areas were reported to discharge 50% more Phosphorus than urban ones. This issue, caused by improper decentralized treatment may have significantly contributed to local eutrophication (Savonia University of Applied Sciences, 2007).

Similarly to the European trend, Austrian popular topics for small wastewater research are treatment technologies development (Grillitsch *et al.*, 2006) and O&M quality (Nowak *et al.*, 2015; Haslinger *et al.*, 2016). Only few published articles address the distribution of the infrastructure (Langergraber and Weissenbacher, 2017; Langergraber *et al.*, 2018b) and no exhaustive spatial analysis could be found either. Although relatively digitized, information on small WWTPs is not easy to collect because each federal state runs its own database.

The first Austrian work on the subject seems to be the 1971 paper by H. Donner where the “uncontrolled” status of small WWTPs and lack of data is strongly addressed. The author reports that only 19% of the small WWTP in the federal state of Styria had a treatment and discharge permission. Furthermore the work suggests that an inappropriate treatment consisting of cesspool and inadequate percolation, thus similar to the Irish reports of above, was extremely frequent (Donner, 1971).

In two recent articles Langergraber surveyed small WWTPs (< 500 PE), reviewing the state of knowledge on the subject, including technology trends and missing information. The work is based on research accomplished by several bachelor and master studies (Langergraber and Weissenbacher, 2017; Langergraber *et al.*, 2018b).

Dopplinger and Feigl accurately described the situation of small WWTPs in Austria and firstly identified a gap in the estimated and real number of those (Dopplinger, 2016; Feigl, 2018). Gersthofer analysed the situation in Upper Austria focusing on P removal (Gerstorfer, 2018). Although readily noted in previous works, Lendl and Muller were the first to valorise the information that about 20% of small WWTPs don’t comply with national law because not designed for the prescribed biological nitrification (Lendl and Muller, 2016). Engstler reported on the treatment performance of small WWTPs in Upper Austria (Engstler, 2020). Finally Sacken worked on sludge treatment in Upper Austria and could collect recent data on local WWTPs (Sacken, 2021).

3.3 Austrian wastewater landscape

Austria counts 8.9 million inhabitants distributed over 9 federal states. The total WWTP capacity is of 21.5 Mio. PE (ÖWAV, 2020).

The connection rate, calculated as the houses relying on municipal sewage channels is a typical measure used to describe the extent of wastewater services in a given area (ÖWAV, 2020). With 95%, Austria has one of the highest connection rates in Europe. According to EUROSTAT, the Netherlands are first with 99%, followed by Germany and Great Britain with 97%. In the last 40 years the Austrian connection rate almost doubled, following an average yearly increase of 1.2 %. The remaining 5% of the population uses private small WWTPs or cesspools (ÖWAV, 2020). In urban areas the connection rate is generally higher whereas rural areas show significantly lower values (Fig.1.)

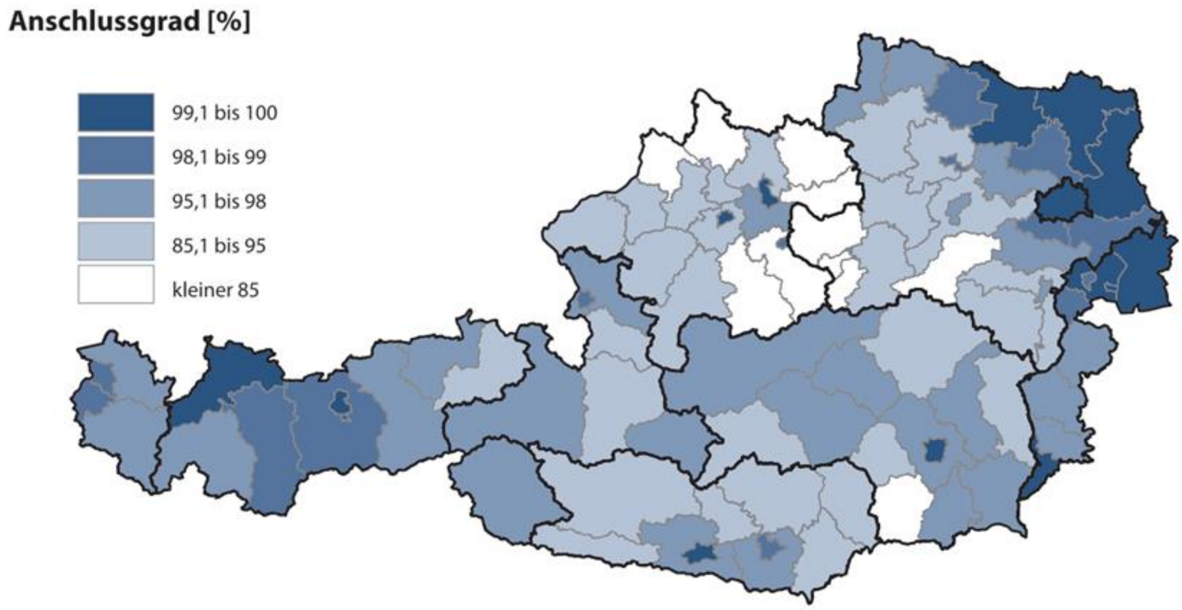

Figure 1 Connection rate (%) to municipal infrastructure by district according to ÖWAV (2020)

The Austrian wastewater review 2020 counts 17’500 WWTPs with direct discharge into water bodies. They are categorized into WWTPs under < 50 PE, WWTPs addressed by the 1. AEVkA categories and industrial WWTPs. The review cites Langergraber 2018, stating that there are 27’450 small WWTPs if exclusively mechanical WWTPs are also counted (ÖWAV, 2020).

Generally, the smaller the design size, the larger the number of plants and the smaller the contribution to total capacity. According to the 2020 Austrian Wastewater overview there were 15.554 WWTPs smaller than 50 PE, accounting for 0.7% of the total PE capacity and 1040 WWTPs between 50 and 500 PE accounting for 0.8% of total capacity.

Table 2 Austrian treatment capacity by design size according to ÖWAV (2020)

Design size (PE)	Nr. of WWTPs	% of total	Mi. PE	% of total PE
< 50	15'554	89.0	0.2	0.7
51 - 500	1'040	5.9	0.2	0.8
501 - 5'000	505	2.9	1.1	5.2
5'001 - 50'000	316	1.8	6.1	28.2
> 50'000	66	0.4	14.1	65.0
Total	17'481	100.0	21.6	100.0

Fig 2 shows the geographic distribution of the small WWTPs counted by the Austrian wastewater overview (ÖWAV, 2020). The comparison with Fig. 1 clearly shows that their number is higher where the connection rate is lower.

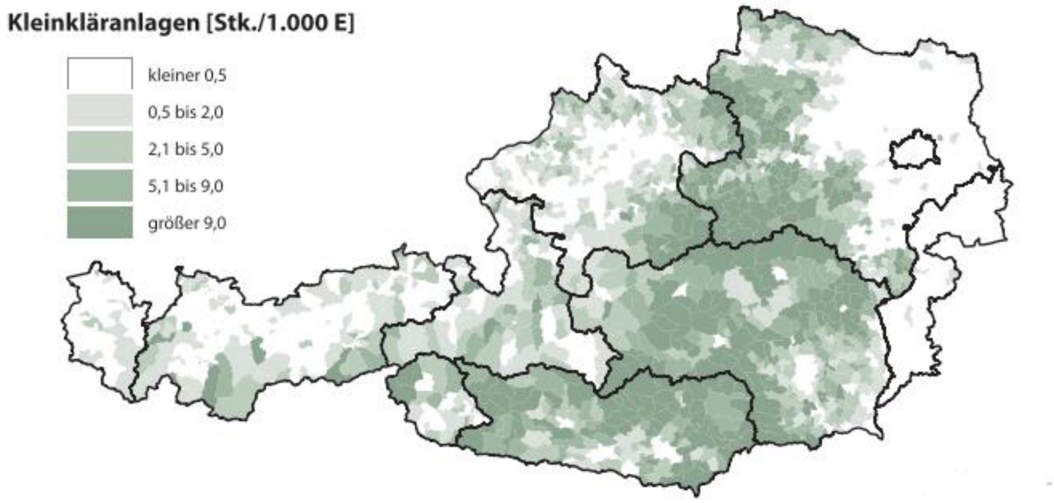

Figure 2 Distribution of WWTPs ≤ 50 PE per 1000 inhabitants by municipality according to ÖWAV (2020)

Furthermore, it is interesting to observe the projected population change for Austria (Fig.3). As usual the highest increase is foreseen in urban areas, meaning that especially centralized systems will have to cope with more users in the next years.

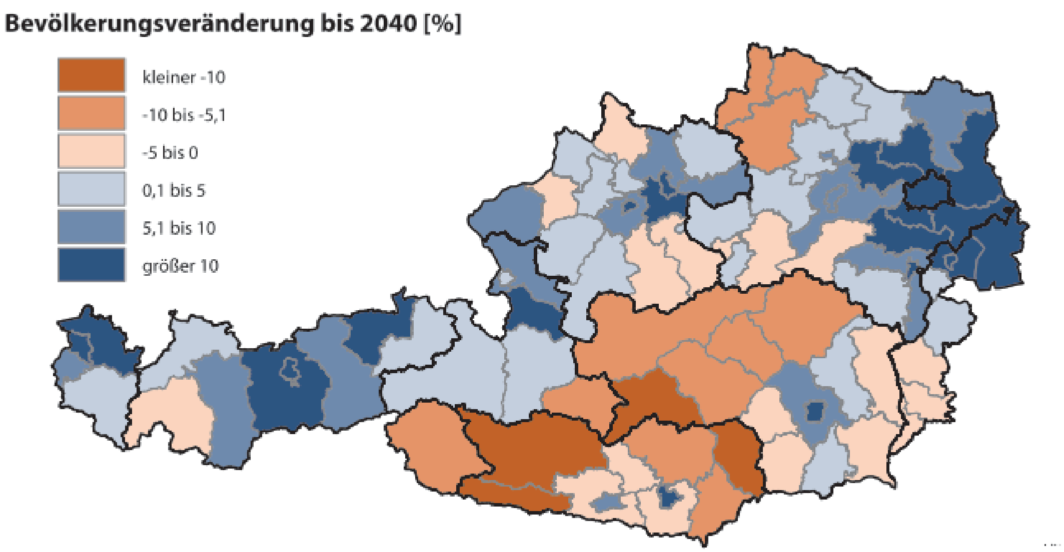

Figure 3 Population change (%) projection until 2040 according to ÖWAV (2020)

4. Materials and Methods

4.1 General methodology

The complete workflow, including plots and graphics has been executed using Python 3.8 (Fig. 4). The most used packages are pandas 1.3.3 and geopandas 0.9. For the sake of open science and ensure the reproducibility of this work, a code protocol including a complete list of packages and requirements was produced and is freely accessible online under https://github.com/anakarpow/small_WWTPs_MSC

The raw data was firstly rearranged to a unified format and compared with a control publication to check for differences in the key categories, such as amount of WWTPs, PE and technology type. The obtained database was linked to governmental geodata to obtain the spatial dataset. During this process some data was lost because of insufficient spatial reference. To monitor data losses, the spatial dataset was compared with the control publication and the obtained dataset for the same key parameters as above.

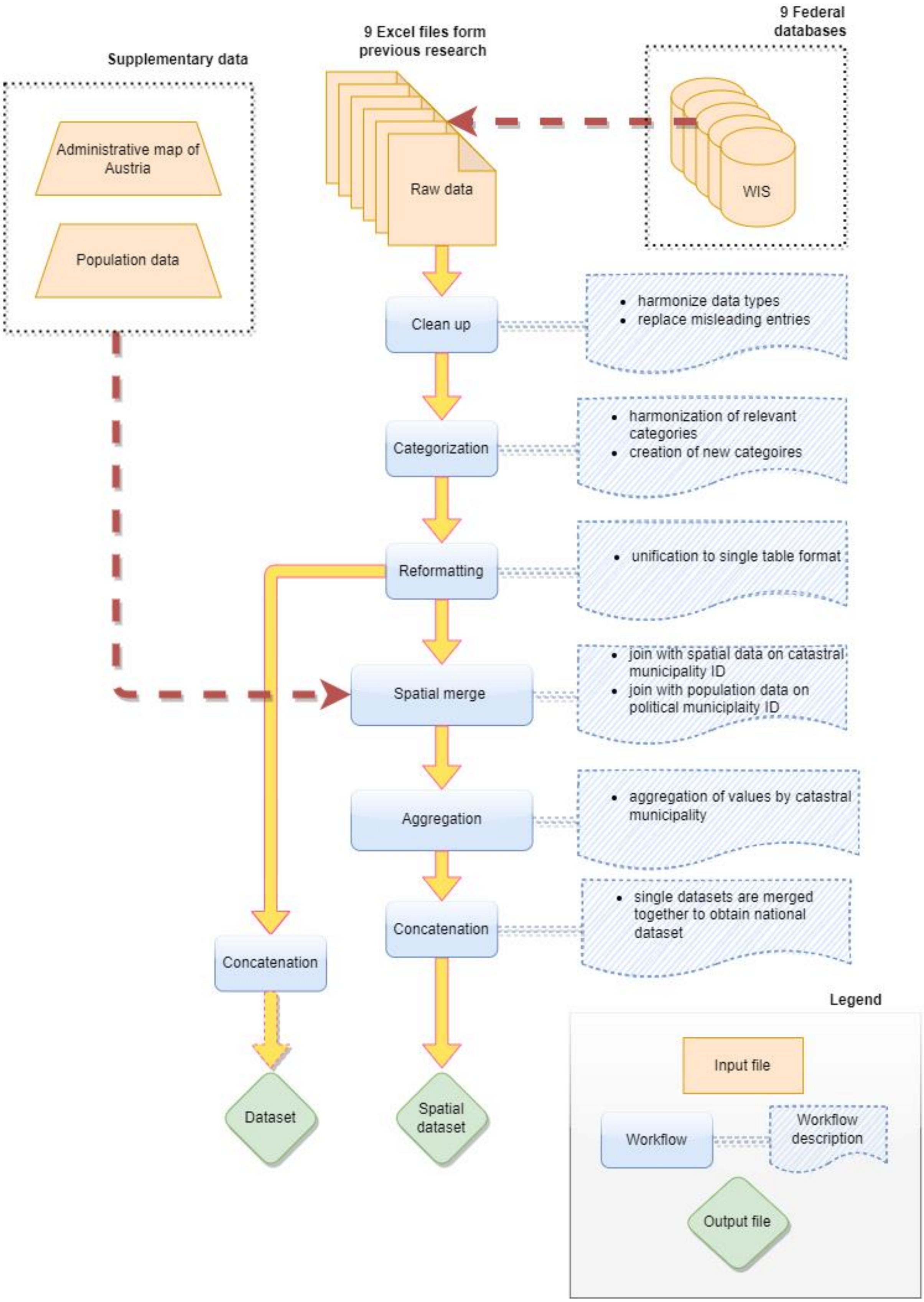

Figure 4 Data workflow

4.2 Materials

The original dataset on which this work is based contained basic technical and geographical features of Austrian WWTPs up to 500 PE. It consisted of several categories like treatment type, design size and some geographical reference. The dataset was arranged in 9 different excel files originated from different publications (Lendl and Muller, 2016; Feigl, 2018; Gerstorfer, 2018; Engstler, 2020; Sacken, 2021). Each of the files covers a federal state and was created using data from its online water-infrastructure registry (WISA). The dataset was started in 2016 and updated last time in 2021, although not in uniform way. In fact, while last data on Upper Austria has been collected in 2021, data on some federal states has never been updated since 2016.

Table 3 Years from which dataset have been available from the different federal state

2016	2018	2021
Voralberg	Carinthia	Upper Austria
Steiermark	Salzburg	
	Tyrol	
	Vienna	
	Burgenland	
	Lower Austria	

4.3 Workflow of data preparation and spatial referencing

The original files were not uniformly compiled and therefore individual processes had to be applied to perform the first three steps of the data preparation workflow: data wrangling, categorization and reformatting. In the first step, data types such as integers, floats and string had to be harmonized. Furthermore, misleading data entries, such as typos had to be disposed. This step ensures the correct functioning of further data processes. In the second step, categorization, the existing data categories were unified. For example, the technology type category has been harmonized according to Ö-NORM standards. Furthermore, new data categories have been created. The reformatting step harmonizes tabular data in a single format ensuring that further data processes will work smoothly. To make sure no data was mistakenly altered or lost, the dataset obtained from these steps has been confronted with a control publication that used the same data source. The divergence was calculated as the percentual difference between the number of WWTPs in the dataset and the number of WWTPs in the control source (Fig. 5). To obtain Fig.6, the percentual difference between the number of WWTPs by state and technology in the dataset and in the control source was calculated.

Most of the original data did not contain spatial information in form of coordinates, but only as to which municipality it belonged to. Using the identifying number of the municipality as key, the data was merged with geodata provided by the Austrian government (Statistik Austria, 2020). In this process the data that originally had no geographic reference was dropped. The resulting dataset contains only WWTPs that could be aggregated to at least their cadastral municipality. To monitor data losses in the spatial referencing process, the spatial dataset was compared to the previously obtained dataset by percentual difference as above (Fig.7)

To obtain the number of inhabitants by administrative unit, the spatial dataset has been merged with population data by *Statistik Austria*. In this case, using the cadastral municipality as linking key led to unacceptable data losses, because some cadastral municipalities have been renamed and/or assimilated with others since the collection of the original data. For this reason, all maps containing population data are projected on a political municipality level which has not been renamed or modified and allowed to maintain the integrity of the data.

After merging with the cited supplementary datasets, the data has been aggregated by cadastral municipality and concatenated to a single national dataset.

4.4 Workflow of data analysis

After gathering it in a single dataset, referencing it to spatial coordinates and checking any irregularities the data has been analysed and interpreted. To study the distribution of Austrian infrastructure the dataset has been analysed in all its dimensions: temporal, technical and spatial. Non-state-of-the-art WWTPs have been identified according to the treatment type. Exclusive mechanical treatment doesn’t comply with the actual regulation that requires a biological nitrification step(1. AEVkA, 1996). Nonetheless infrastructure in extreme geographical positions, as described by the 3. AEVkA,1993 are allowed to apply less severe treatments because of logistic difficulties. Langergraber, 2018, categorized the latter as those WWTPs that apply compost and filtration methods. This work applied the same categorization. The remaining WWTPs, applying exclusively primary treatment are considered not-state-of-the-art. The most accurate way to measure which municipalities mostly rely on such system would be to relater them to a dataset containing WWTPs of all sizes. Unfortunately, it does not exist because the design size between 500 and 5’000 PE has not been surveyed yet. For this reason the total population per administrative unit was used as proxy of PE, which is a common approach in literature (Aragón *et al.*, 2013; ÖWAV, 2020).

5. Results and discussion

5.1 Unified dataset

The unified dataset is derived from the original data and contains WWTPs up to 500 PE. Categories, like technology type, have been unified and made comparable. Each data entry contains a unique identifier, all original categories (year, technology type, PE) and the most precise geographical reference available. Most of WWTPs are tracked to their political municipality at least, whereas for other there was no further information available than federal state. In Fig.4 the obtained database is compared to a control publication (Langergraber *et al.*, 2018a).

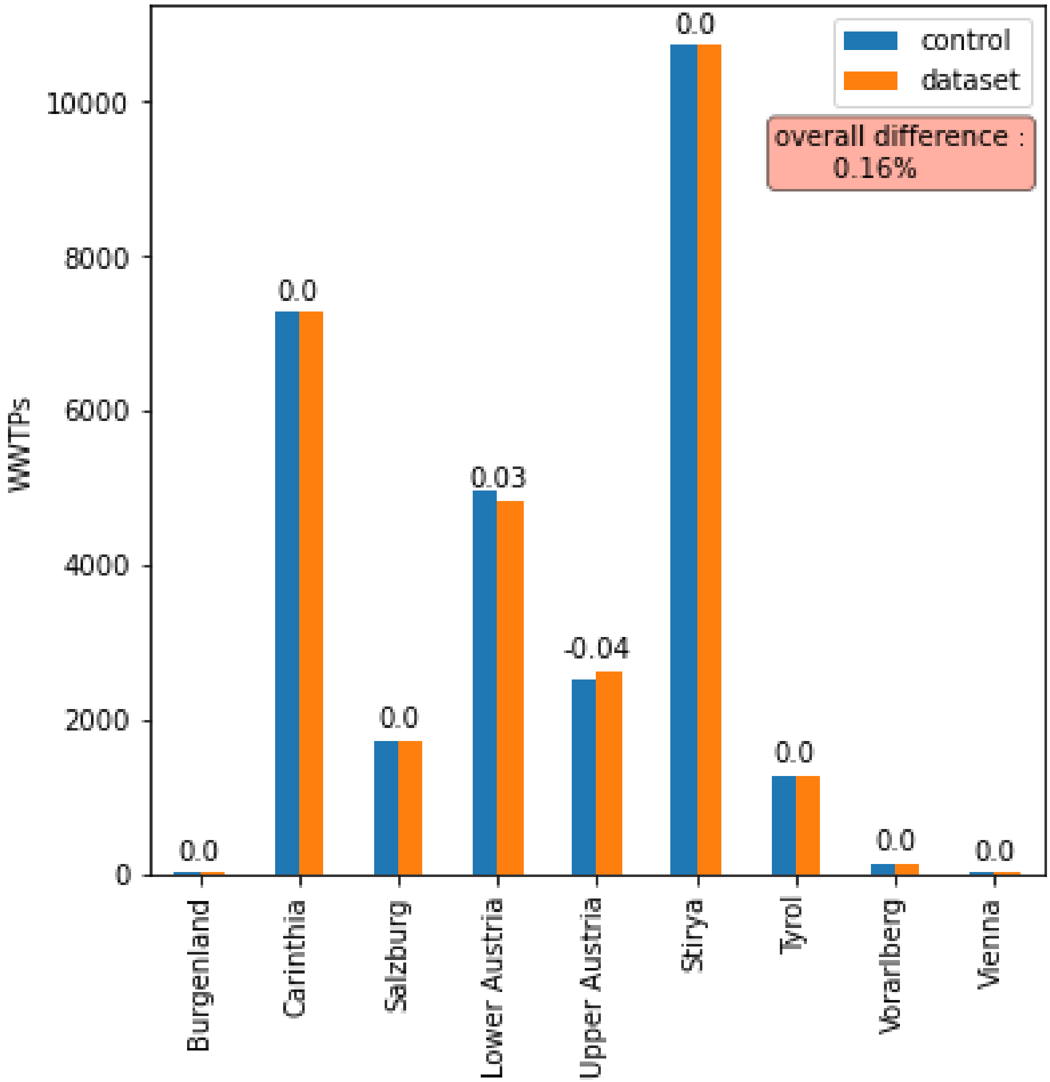

Figure 5 Percentual difference between control and own dataset

The number of tops of each bar shows the percentual difference in the number of WWTPs, where 0.0 means no difference at all. In 7 out of 9 federal states the obtained dataset is identical to its source. The control dataset of Lower Austria is 0.03% larger than the own data, probably because some WWTPs have been dismantled since then. On the other hand, the Upper Austria dataset is larger than the control source. This was expected because the own data is more recent than the control source. Due to the increased number of WWTPs in Upper Austria the own dataset is 0.16% larger than the control source. Burgenland and Vienna have such a small dataset that they are not visible at this scale.

5.2 Spatial dataset

This dataset contains only WWTPs up to 500 PEs from the unified dataset that could be linked to their cadastral municipality. This is the dataset that has been analysed to answer the main goals of this work. All following thematic maps are based on this dataset.

Fig. 6 shows the data losses due to spatial referencing, comparing the obtained dataset with the spatial data. About 95% of the PE were tracked down to their cadastral municipality. Three federal states (Vienna, Vorarlberg and Burgenland) have been excluded because they completely lacked any spatial reference.

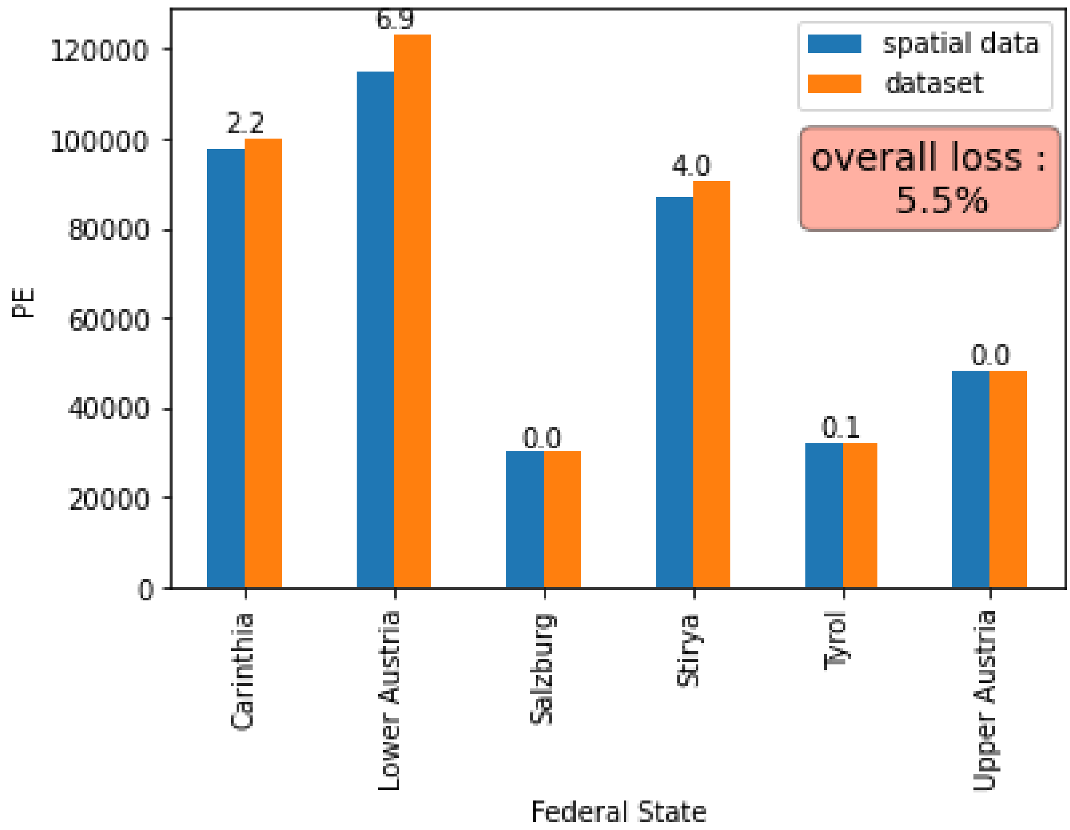

Figure 6 Data losses after the spatial aggregation

Lower Austria has the highest loss percentage. All lost entries belong to the district of Amstetten and had not further spatial reference. Generally, the data losses here are due to missing cadastral municipality reference in the original data.

5.3 Distribution of WWTPs

5.3.1 Distribution by federal state

Most of WWTPs up to 500 PE have been built between 1995 and 2015 (Fig.7). In fact, in all states the construction of WWTPs of this size has peaked in this twenty-year period. Since 2010 a pronounced degrowth is evident. As visible in Table 3, only the Upper Austria dataset has been updated since 2016. The most recent constructions for the other states (from 2016) are not included in this dataset

It is interesting to note the differences in the temporal activity of the federal states. While small WWTPs in Lower Austria were built between 2003 and 2015, Carinthia has built them before 2003. All other states have a relative homogenous distribution.

Styria has the highest number of WWTPs, followed by Carinthia and Lower Austria (Fig.8). Nonetheless Lower Austria leads with the number of PE covered, before Carinthia and Styria. Styria is the only state where small WWTPs cover more PE than medium WWTPs. Because too small to be visible at this resolution, the states of Vorarlberg, Burgenland and Vienna were excluded from Fig. 7.

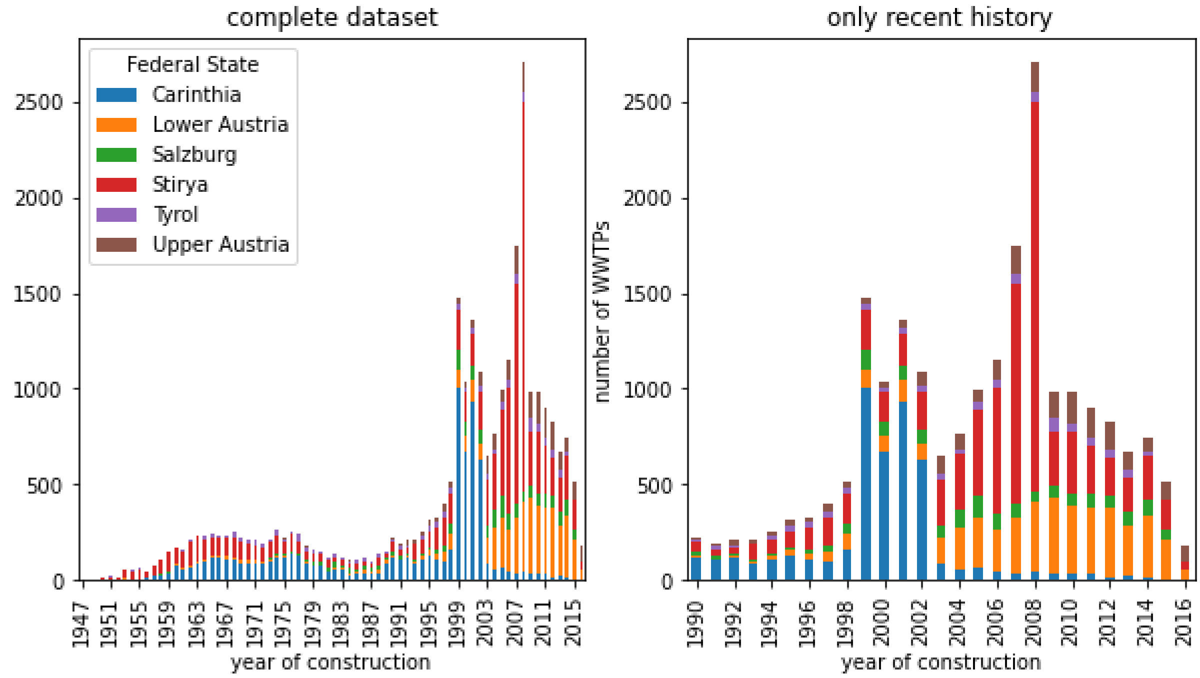

Figure 7 Temporal distribution of WWTPs up to 500 PE

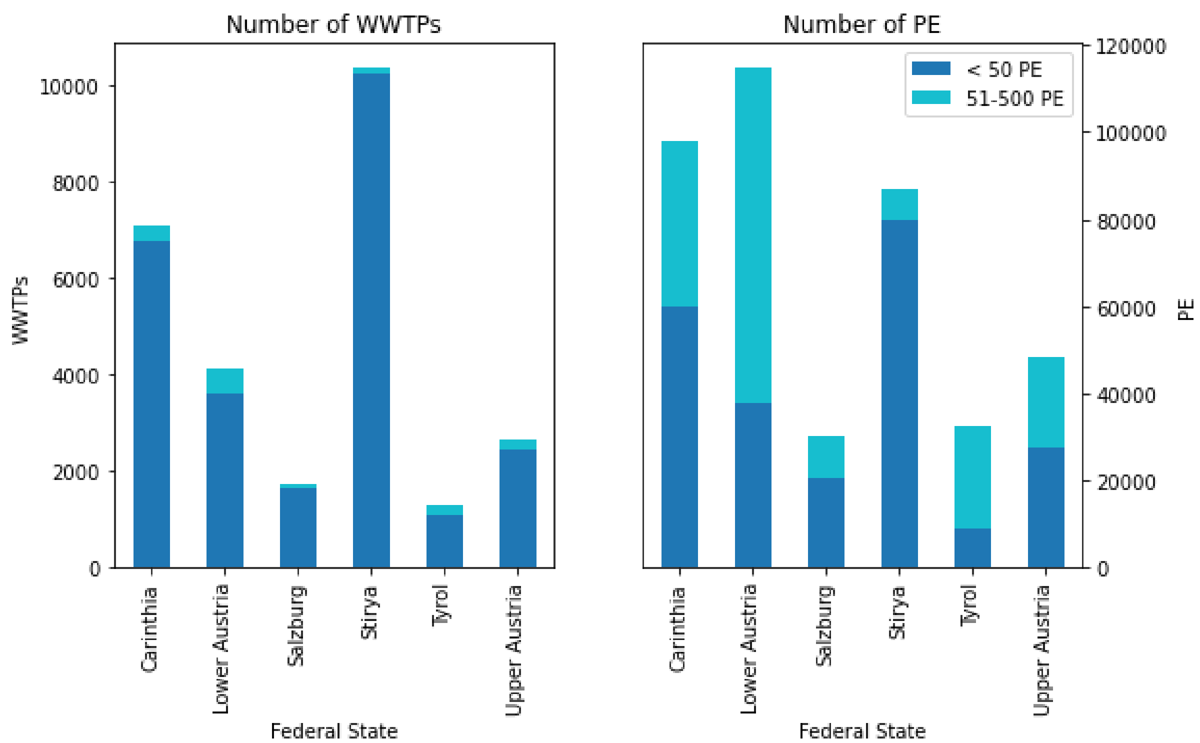

Figure 8 Distribution of WWTPs and PE by design size

In Fig.9 the design size of small and medium WWTPs in PE was plotted against the total population, to obtain a measure of how much of the population relies on them. Carinthia has by far the highest coverage with 17.5%. In Austria 2% of the population relies on WWTPs between 50 and 500 PE and 3% rely on smaller decentralized WWTPs.

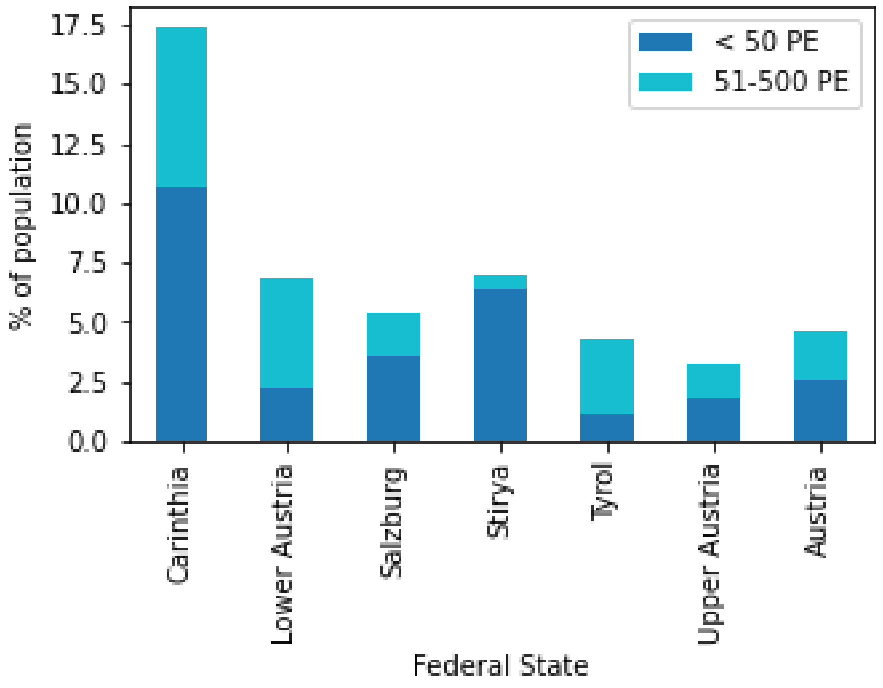

Figure 9 Percentage of population covered by WWTPs up to 500 PE

5.3.2 Distribution by treatment type

The 1991 update of the 1. AEVkA clearly marks a turning point in the development of technology types, both in their quantity and treatment diversity. Whereas before most of the infrastructure was built with exclusively primary treatment, afterwards the diversification of treatment has developed. Especially Activated Sludge Process (CAS), Sequencing Batch Reactor (SBR) and Constructed Wetlands (CW) were built after 1991 (Fig.10). The trend appears similar for both design sizes. Fixed bed systems like the semi-fixed bed (SFB), trickling filter (TF) and bio-filter (BF) play a minor role.

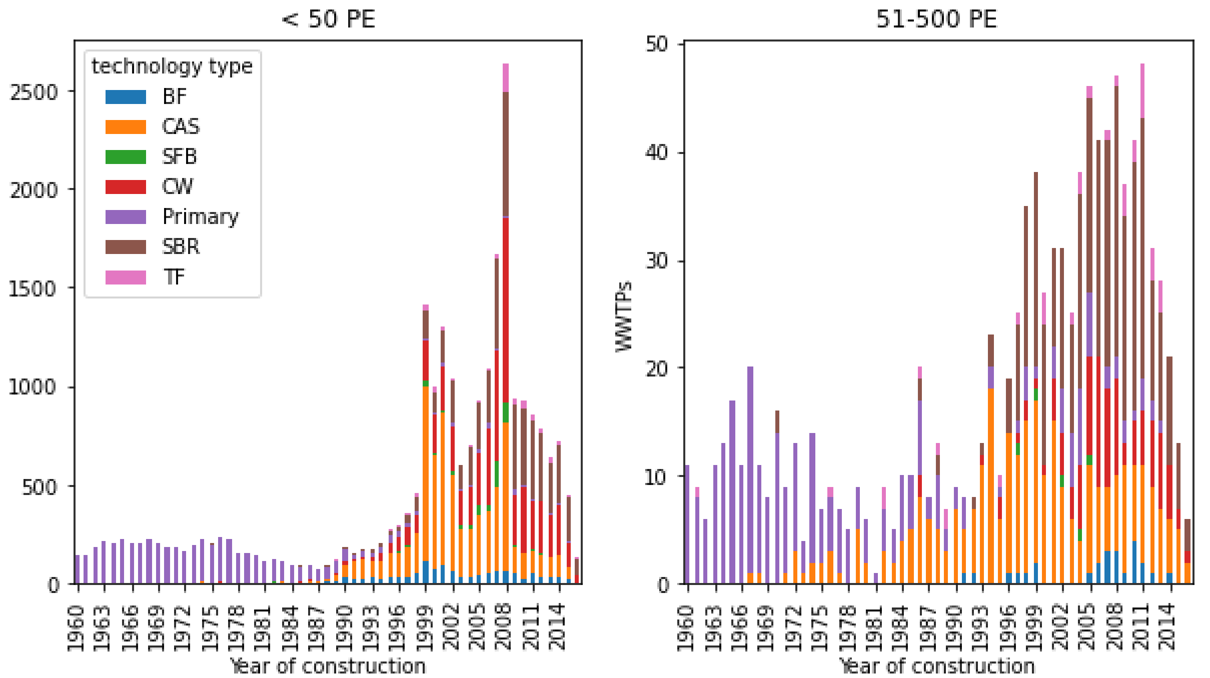

Figure 10 Temporal distribution of treatment technologies

Clearly most WWTPs with exclusively primary treatment were built before the 1991 1. AEVkA that requires biological nitrification (Fig.11). Although not respecting the legal requirements for biological nitrification, about 280 WTTPs with exclusively primary treatment have been built after 1995 anyway. The last reported implementation was in 2014.

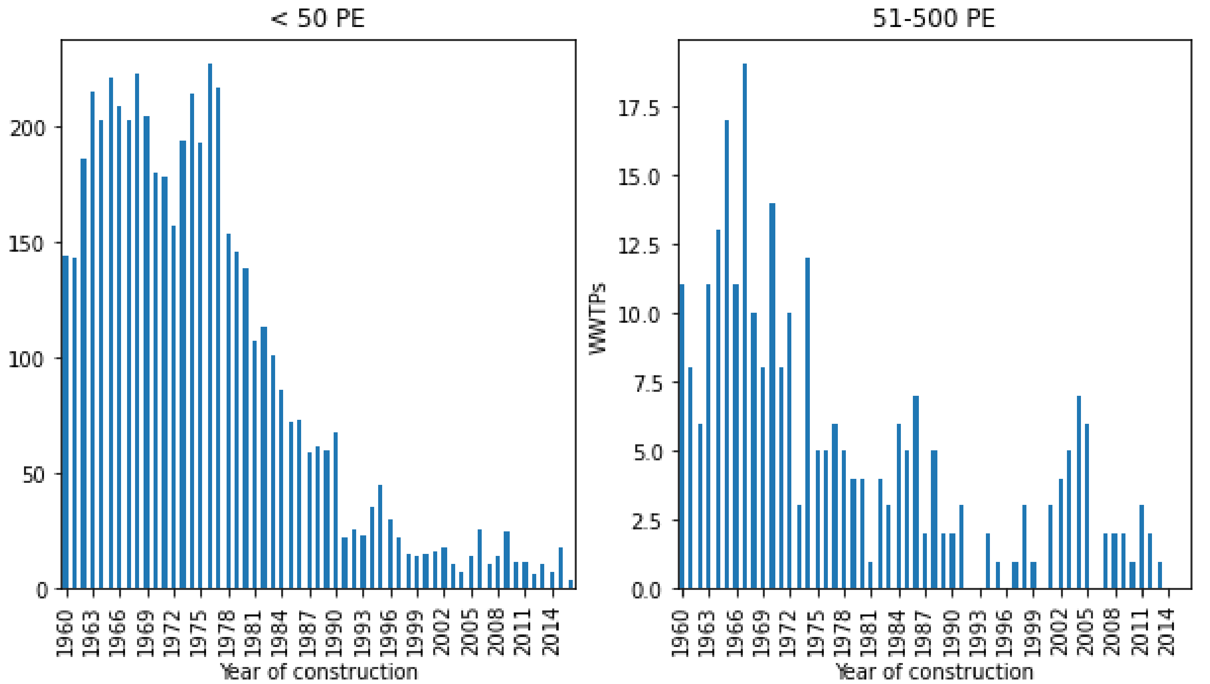

Figure 11 Construction of primary treatment only WWTP by year

Fig.12 shows the percentual PE coverage by treatment technology. Note that the categories accounting for less than 1% of the total organic pollution in both design sizes (MBR, SFB, TF, RBC) are not included to maintain readability. The technology distribution follows a similar pattern in both design sizes. SBR, CAS and primary treatment are the major components, accounting together for about 60% of all the total capacity. Constructed wetlands are more frequent in smaller design sizes. As mentioned before, the category other (minor technologies like composting) is more developed in WWTPs from 50 to 500 PE. Rotating biological contractors are rare. On the other hand, WWTPs with only primary treatment are common and account for about 20% of the PE in both design sizes. In more than 12% of the medium WWTPs the treatment type is unknown, whereas it is 1.8% for small WWTPs.

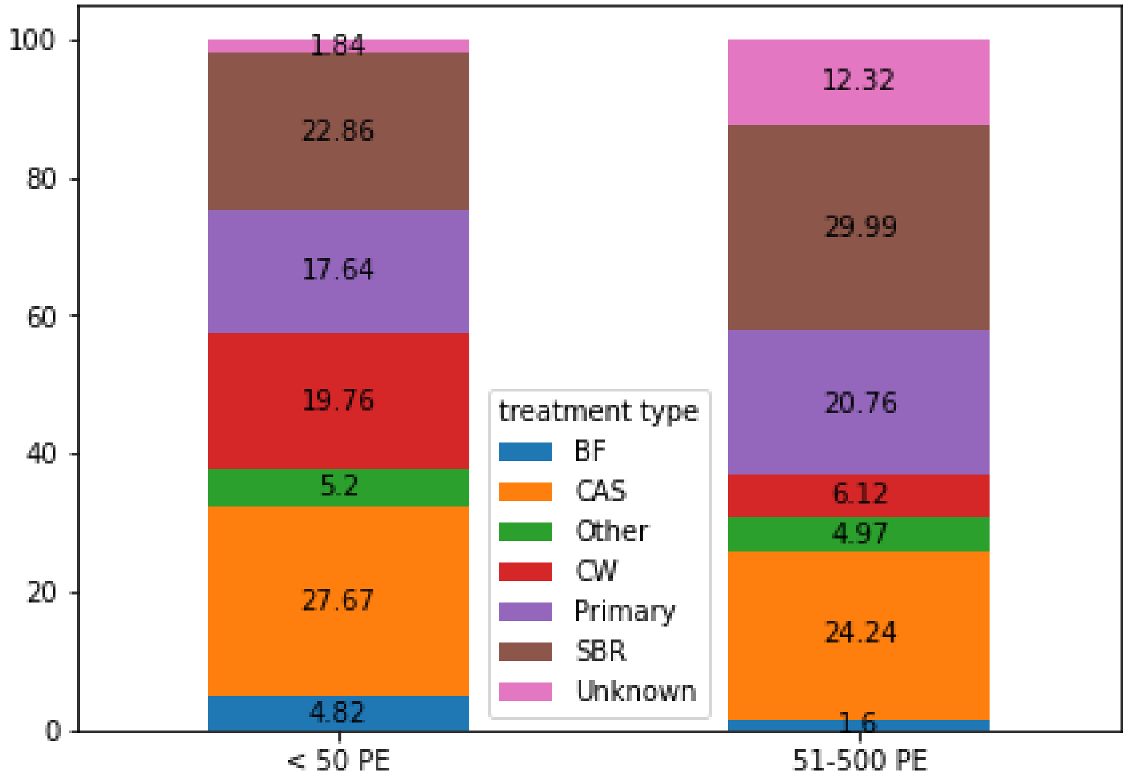

Figure 12 Percentual distribution of treatment technologies. The 'Other' category includes: MBR, SFB, TF and RBC.

5.3.3 Spatial distribution

The topographic map is based on data obtained from the Open Data Austria website at https://www.data.gv.at/katalog/dataset/4369268e-e8c0-4255-b296-01e3a174caad.

Given the mountainous character of Austria, WWTPs up to 50 PE are evenly distributed overall the country. They are mostly located in mid to high altitudes and are nearly absent in lowlands (Fig.13). Only central Upper Austria and most of Lower Austria are largely without. Those areas have high connection rates as showed by Fig. 1.

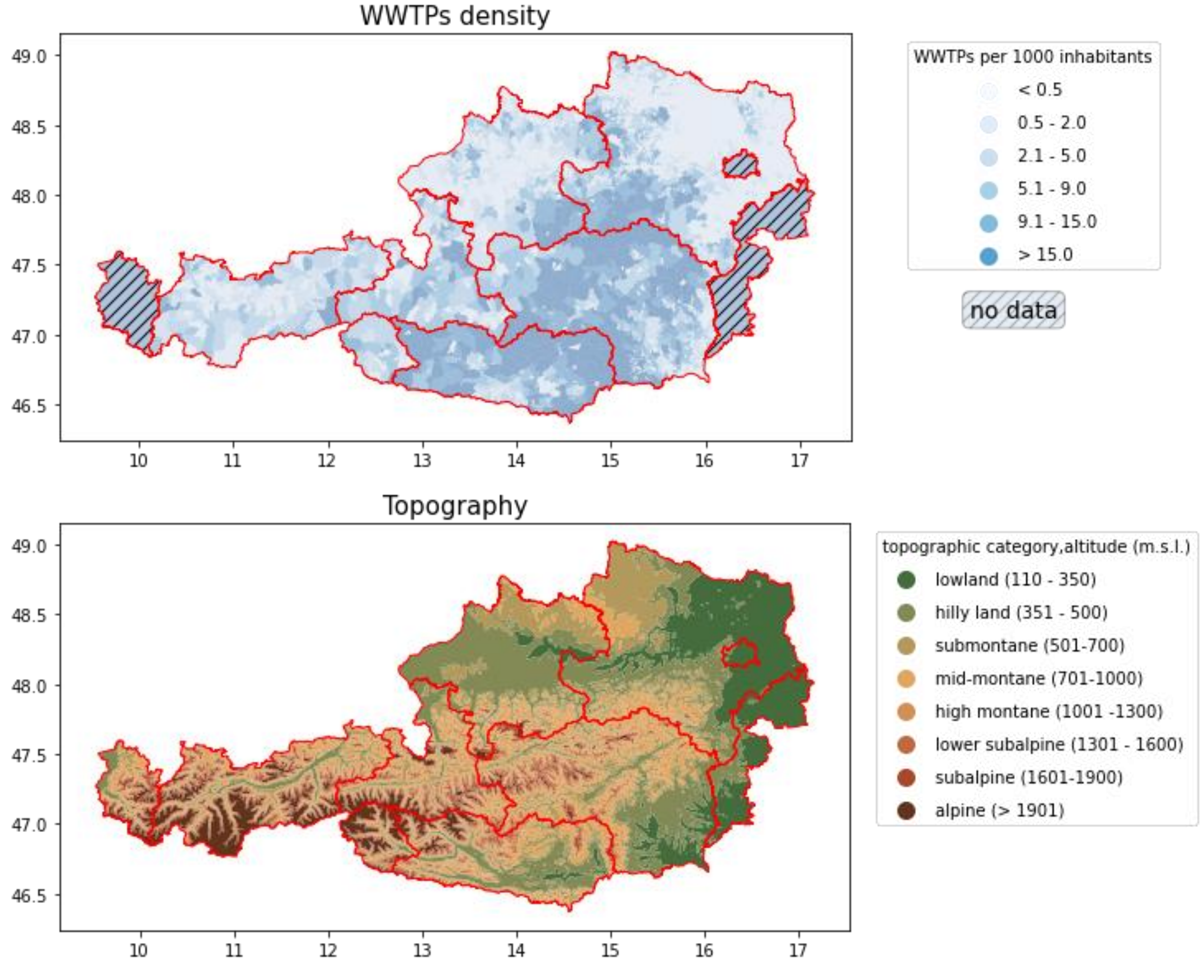

Figure 13 Topographic distribution of small WWTPs (< 50 PE)

Carinthia has most municipalities with the largest number of small WWTPs. Also, Styria and Tyrol show an elevate presence of them (Fig.14). About the three missing federal states no statement can be done yet.

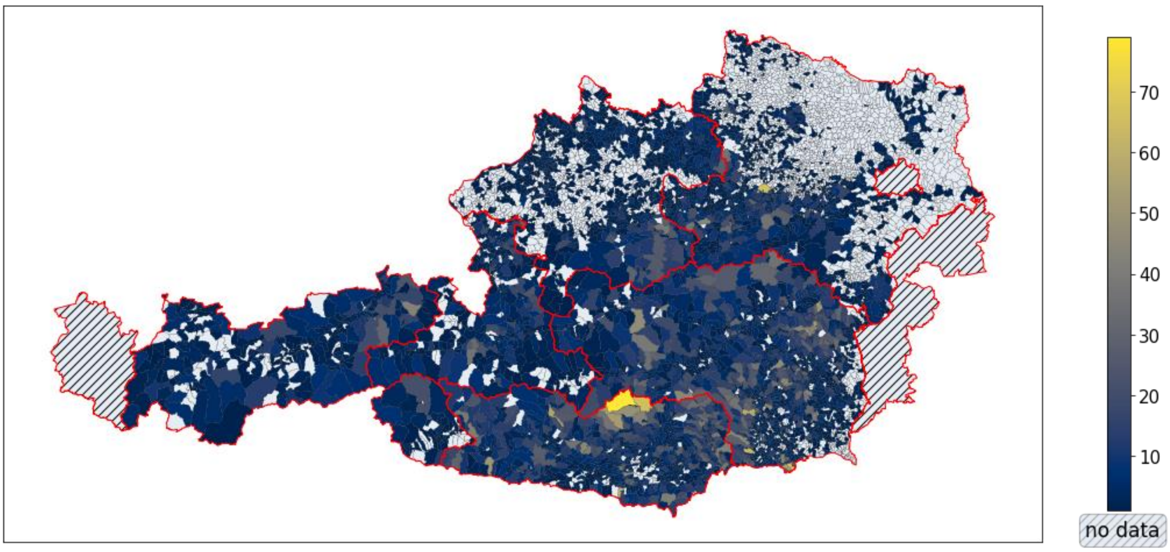

Figure 14 Number of WWTPs < 50 PE by municipality

Because most of WWTPs in the dataset are smaller than 50 PE, their distribution also defines the overall pattern. For this reason, Fig.15 only shows medium sized WWTPs (51-500 PE). Tyrol has the most WWTPs between 51 and 500 PE, followed by Carinthia. Otherwise, this design size is sparsely distributed throughout the country.

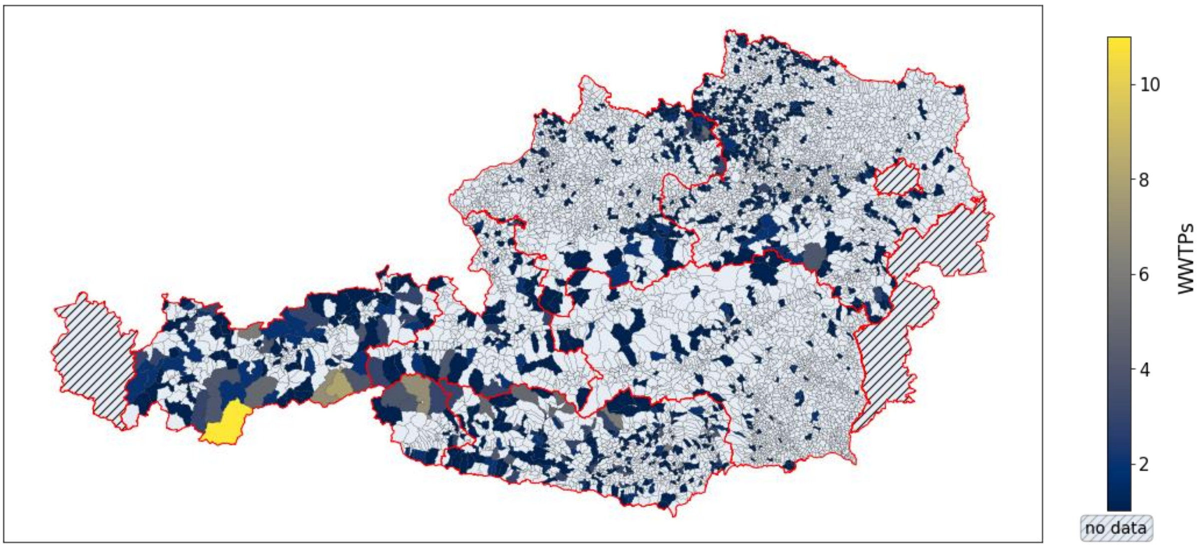

Figure 15 Number of WWTPs 51 - 500 PE by municipality

In Fig.16 the number of PE per municipality is projected. The overall distribution is identical to the WWTPs distribution in Fig.14.

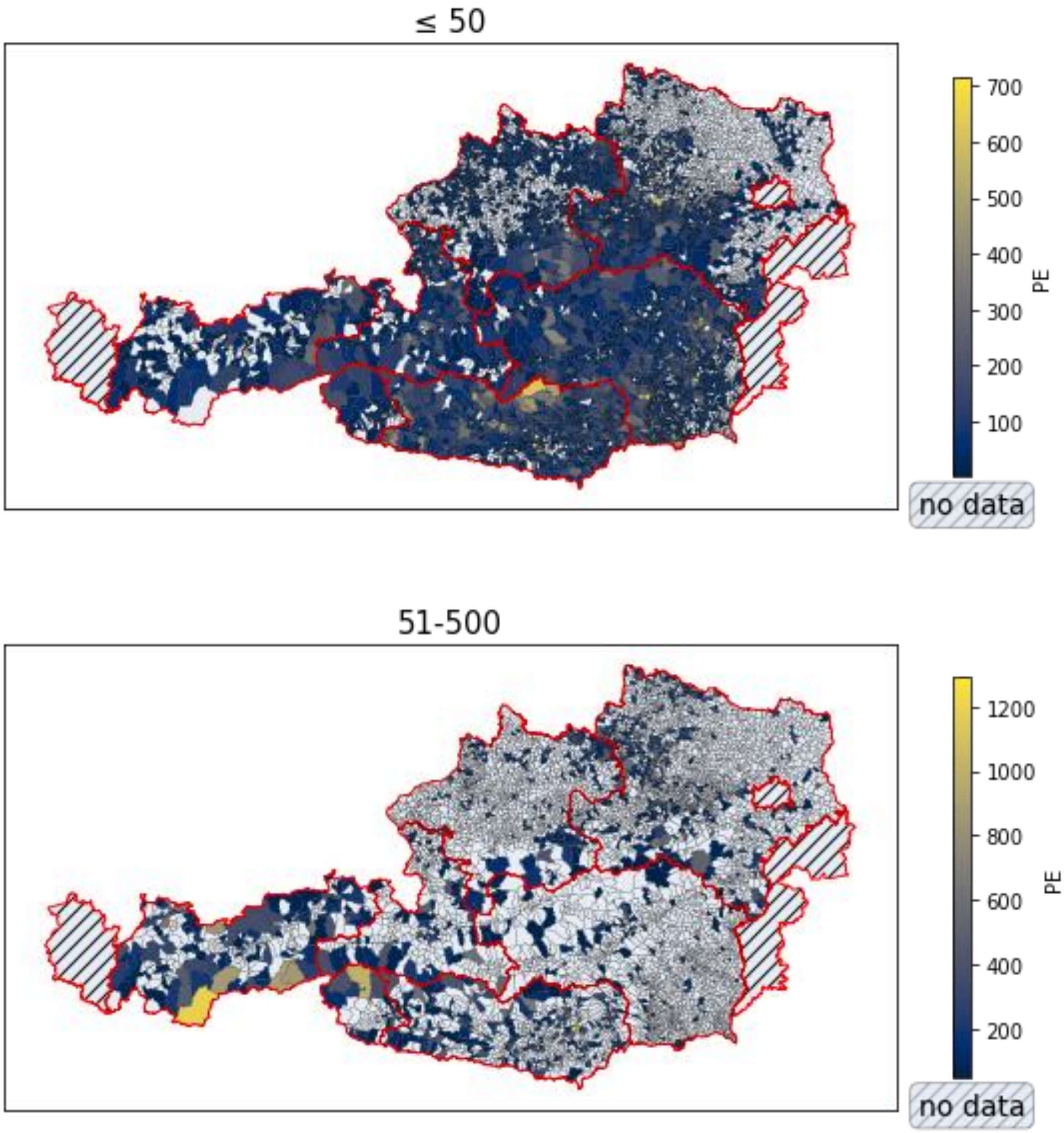

Figure 16 Cumulative design size of small WWTPs with design size ≤ 50 PE (top) and 51 – 500 PE (bottom) by municipality.

In most of the municipalities less than 10% of the population relies on WWTPs up to 500 PE (Fig.17). In Carinthia a high population coverage is common and several municipalities even have a coverage higher than 90%. A similar pattern is observed in north-western Lower Austria. These areas also contain municipalities where the entire population is covered by WWTPs of this size.

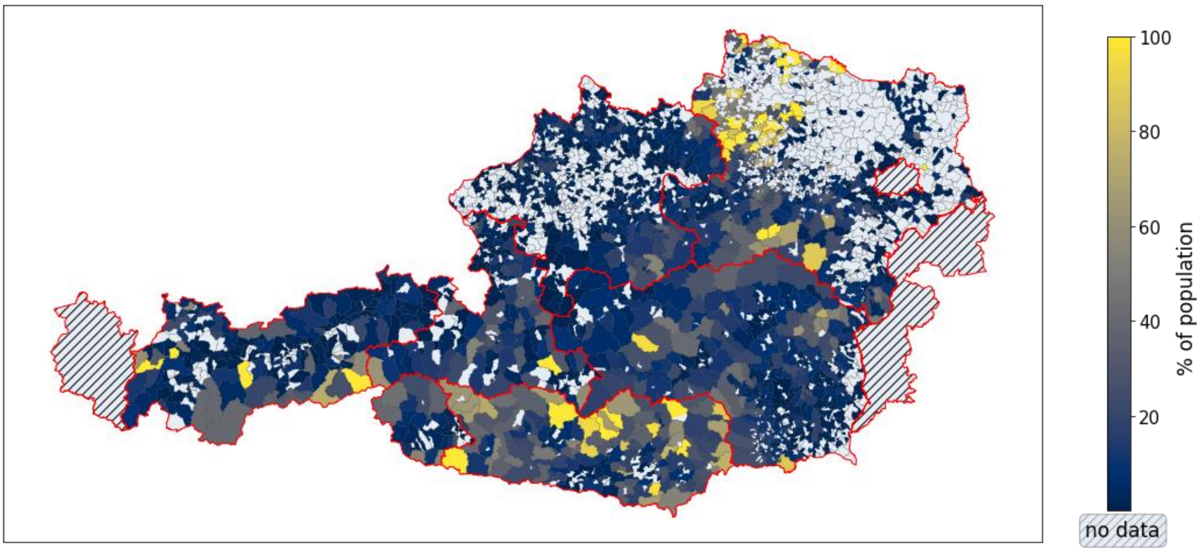

Figure 17 Percentage of population covered by WWTPs ≤ 500 PE by municipality

5.4 Distribution of non-state-of-the-art WWTPs

5.4.1 Distribution by federal state and design size

Lower Austria has the lowest percentage (6%) of non-state-of-the-art WWTPs smaller than 51 PE. all other analysed states reach at least 10%. In Tyrol every second WWTP up to 51 PE only implements mechanical/partially biologic treatment (Fig.18). Furthermore, it also has the highest percentage (5%) of non-state-of-the-art WWTPs between 51 and 500 PE. all analysed states still have WWTPs of this size with only primary treatment. Nonetheless, the percentages are overall lower than for the smaller design size. In fact, on national level 23% of the small WWTPs and 1.6% of the WWTPs between 51 and 500 PE don't' respect biological nitrification requirements.

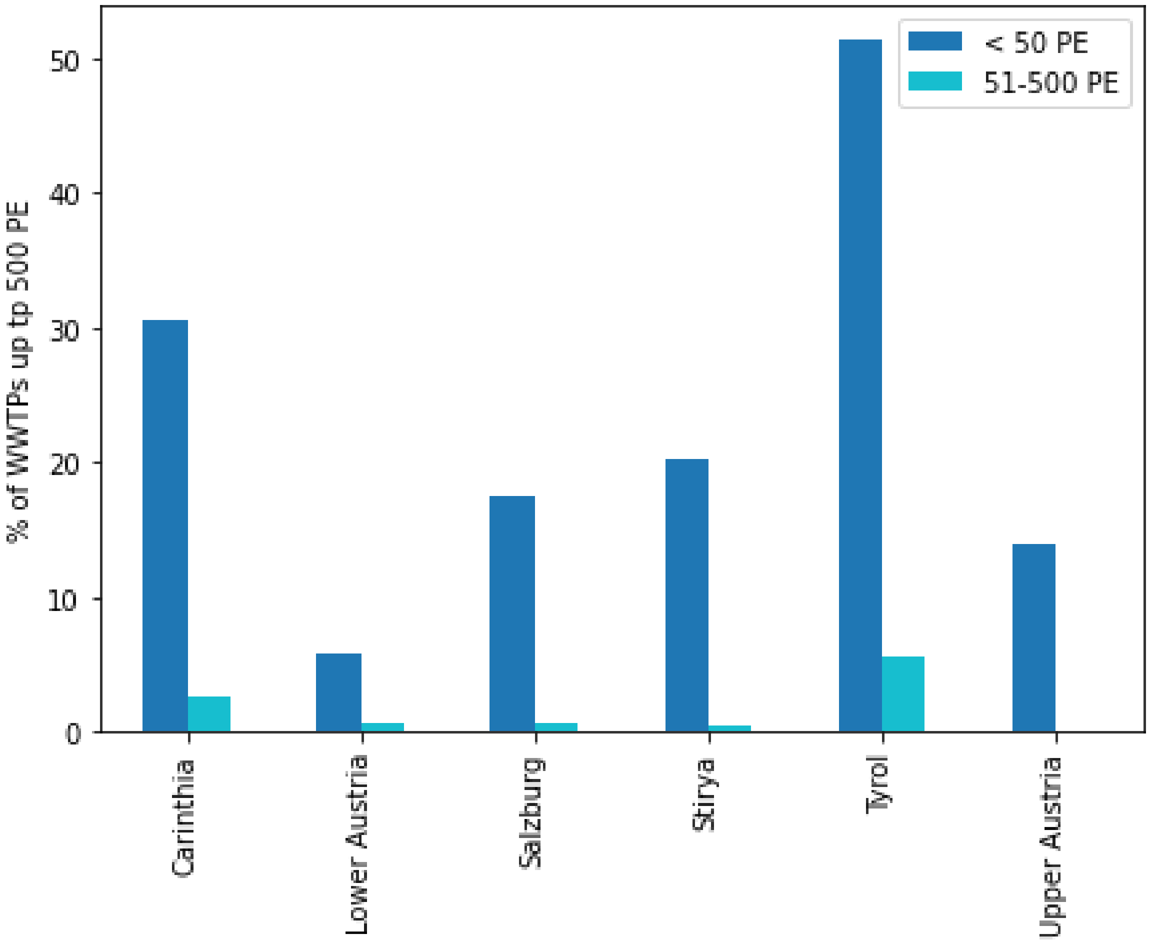

Figure 18 Percentage of population covered only by primary treatment

Fig.19 shows the occurrence of medium sized non-state-of-the-art WWTPs by federal state. The highest number is in Carinthia, where 60% of them are non-state-of-the-art. Tirol, Lower Austria, and Styria follow with about 50 WWTPs. Salzburg and Upper Austria have very few, with the latter having only one. About 35% of WWTPs up to 500 PE in Styria and Tyrol are non-state-of-the-art.

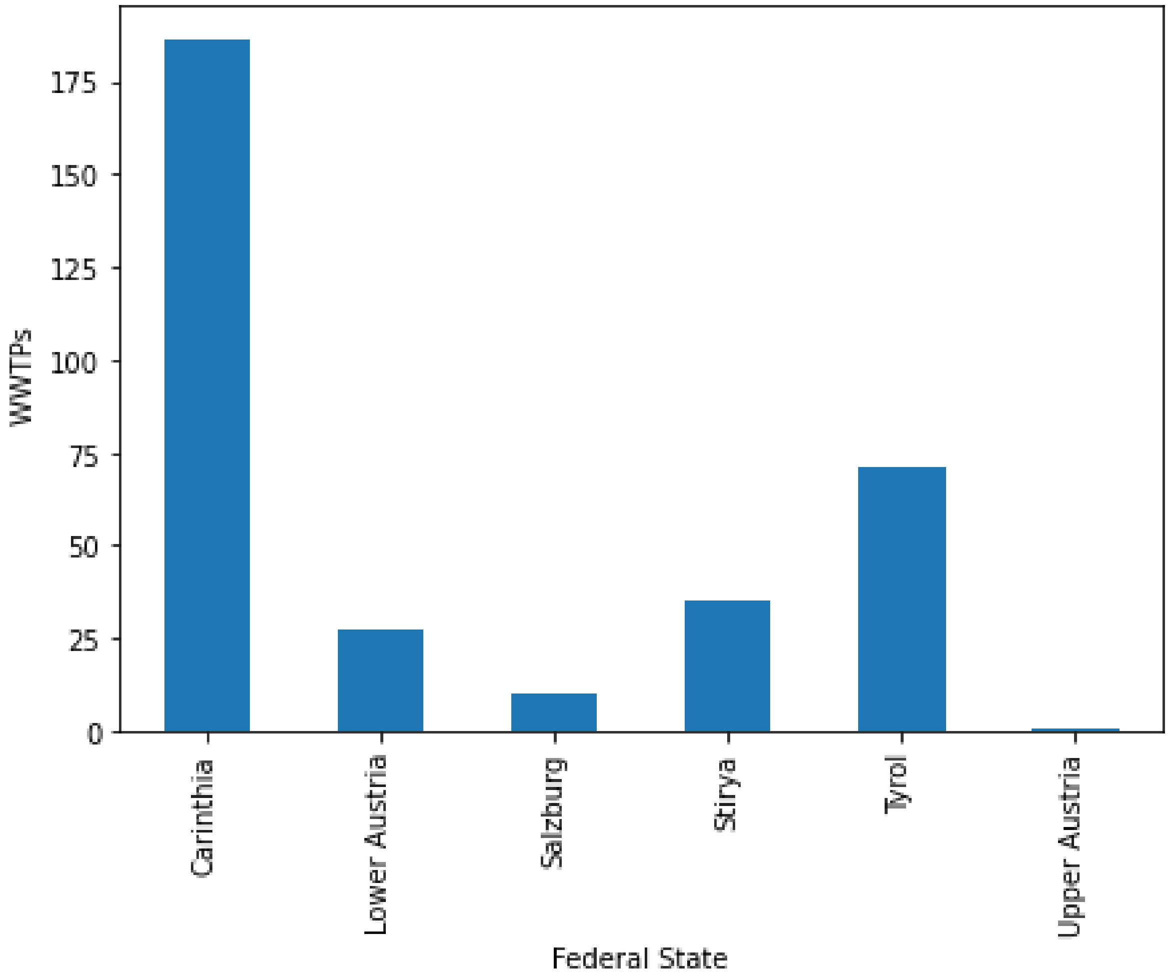

Figure 19 Number of WWTPs 51 -500 with only primary treatment

To see the amount of medium sized WWTPs with only primary treatment in relation to the whole dataset, Fig.20 shows the number of WWTPs and PE together. In Carinthia non-state-of-the-art nitrified PE are equally distributed between small and medium sized WWTPs. In lower-Austria and Tirol most of them are treated by medium sized infrastructure. The remaining states show the opposite pattern, where most of the non-state-of-the-art nitrified PE are treated by WWTP up to 50 PE.

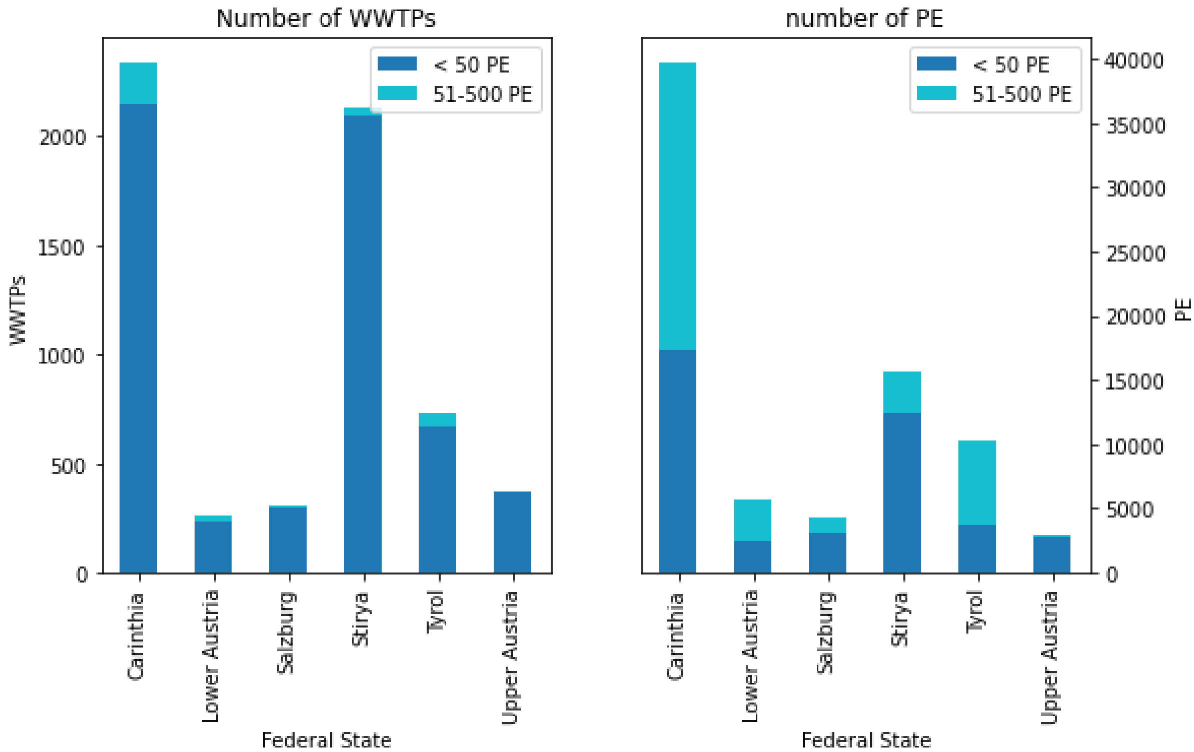

Figure 20 Distribution of WWTPs up to 500 PE with primary treatment only by federal state

Because federal states have varied sizes and number of inhabitants, to understand the distribution of non-state-of-the-art infrastructure the percentage of population covered by only primary treatment is shown in Fig.21. 7% of Carinthia's population relies on non-state-of-the-art WWTPs, by far the largest share in Austria. In fact, all other analysed states float around 1%.

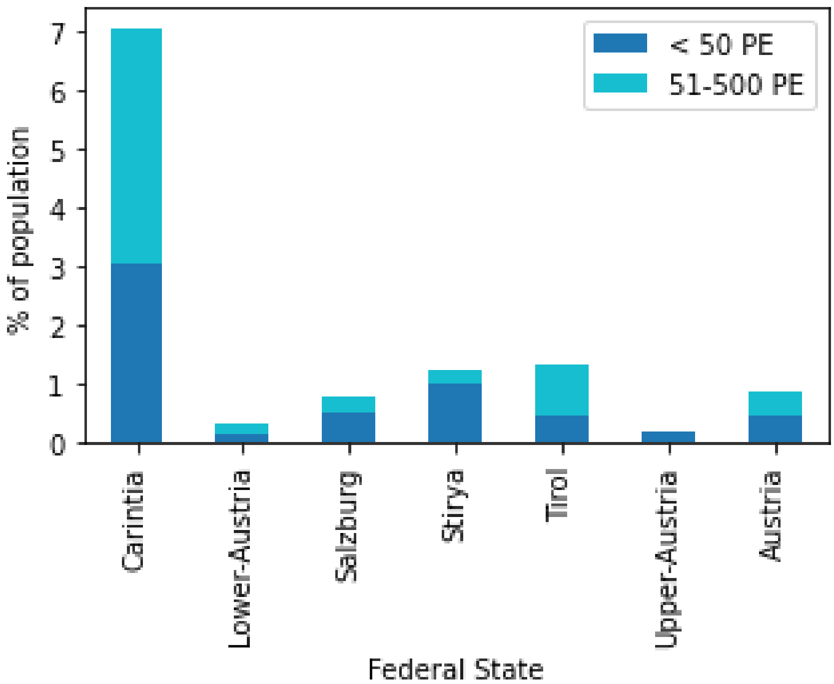

Figure 21 Percentage of population covered by primary treatment only

5.4.2 Spatial distribution

Fig.22 identifies where most of non-state-of-the-art nitrified PE are released. They are more usual in Tyrol and Carinthia. Tirol shows one municipality where the WW equivalent of about 600 PE is daily released without sufficient nitrification. Carinthia has a few very small municipalities where also about 600 PE are not treated according to nitrification standards. These are the by far the highest national values. In fact, most of others affected municipalities only have about 200 non-state-of-the-art nitrified PE.

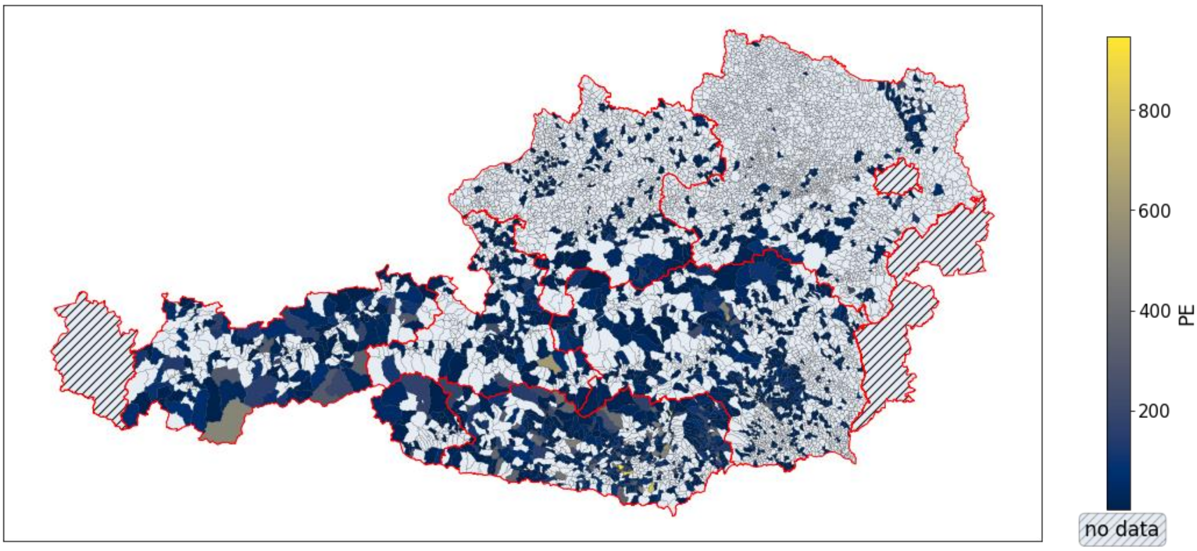

Figure 22 Distribution of PE discharged after primary treatment only

Overall, in Austria the percentage of population relying on non-state-of-the-art infrastructure is about 1%. Styria and Tyrol show some cluster-like pattern of municipalities where between 10% and 30% of the population relies on non-state-of-the-art WWTPs (Fig.23). Carinthia shows another pattern, where the municipalities with at least 10% are evenly distributed, 30% to 50% values are not uncommon and one municipality reaches 90%. Table 4 shows the top 5 municipalities per federal state relying on non-state-of-the-art treatment technologies. Carinthia and Tyrol have the highest values, whereas Upper Austria and Salzburg show low values.

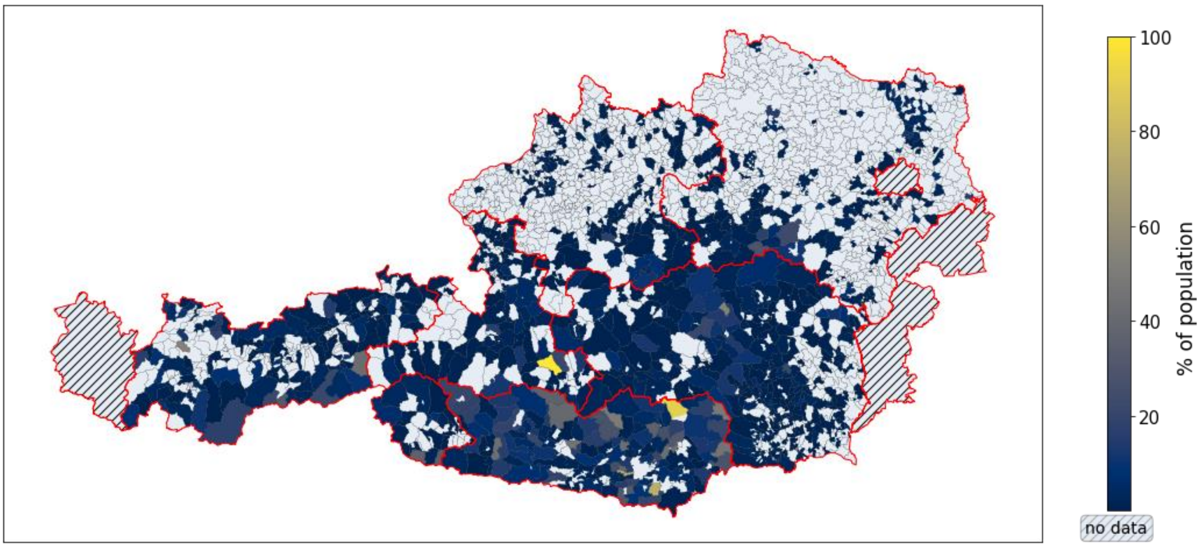

Figure 23 Percentage of population relying on not state-of-the-art WWTPs

Table 4 Top 5 municipalities relying on non-state-of-the-art treatment technologies

Federal state	Municipality	% of population	PE
Carinthia	Hüttenberg	90	1'207
	St. Margareten im Rosental	75	819
	Maria Wörth	74	1'199
	Glödnitz	50	411
	Preitenegg	49	458
Lower Austria	Mitterbach am Erlaufsee	29	140
	Türnitz	23	436
	Puchenstuben	17	51
	Rastenfeld	16	250
	Hundsheim	16	100
Upper Austria	Steinbach am Ziehberg	18	155
	Spital am Pyhrn	11	241
	Rosenau am Hengstpaß	8	53
	Vorderstoder	8	62
	Roßleithen	7	133
Salzburg	Tweng	25	623
	Weißpriach	21	67
	Mühlbach am Hochkönig	17	238
	Lessach	13	69
	Kleinarl	12	100
Stirya	Vordernberg	54	517
	Mautern in Steiermark	21	360
	Sankt Radegund bei Graz	21	449
	Trofaiach	14	1'507
	Sankt Michael in Obersteiermark	14	412
Tyrol	Pfafflar	53	56
	Gerlos	42	340
	Kartitsch	37	280
	Untertilliach	34	75
	Obernberg am Brenner	32	120

Fig. 24 shows the distribution of medium sized WWTP with only primary treatment. A clear cluster is visible in Tirol. This municipality in Tyrol has 5 medium sized WWTPs that operate only primary treatment. Further medium WWTPs with only primary treatment are sparsely distributed.

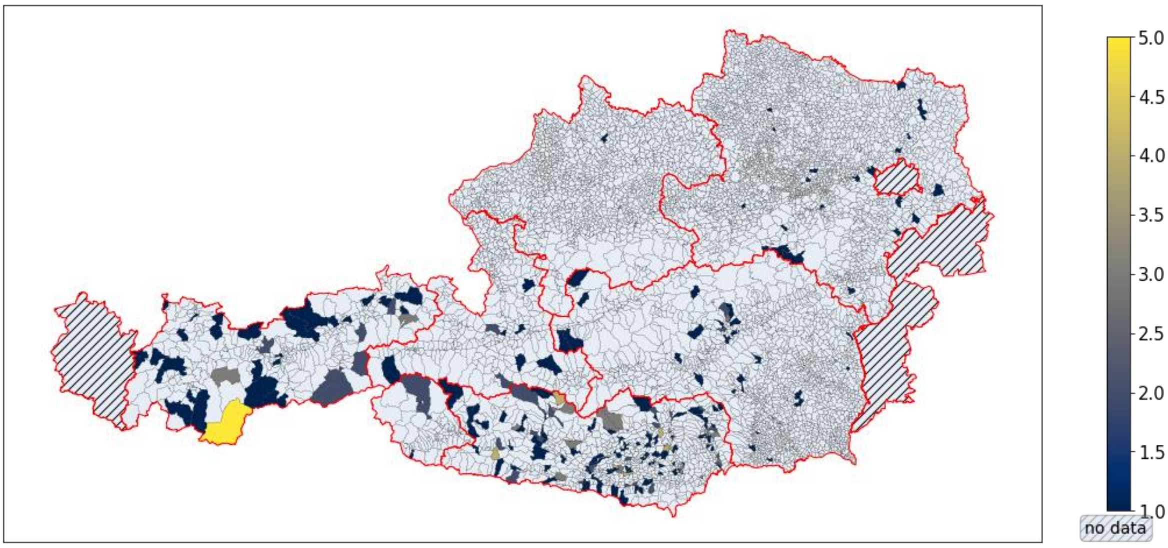

Figure 24 Distribution of not state-of-the-art WWTPs 51 - 500 PE

5.5 Detailed spatial analysis

In this section the 2 states that provided data with detailed spatial location of the small WWTPs are analysed.

The datasets of Lower Austria and Upper Austria contained coordinates for most of their WWTPs. Of the 7'615 listed WWTPs, 704 (all belonging to Lower Austrian district of Amstetten) did not have point coordinates. Of the WWTPs without point coordinates 50% use SBR treatment and 45% use CAS or CW. 6 WWTPs with only primary treatment had no point coordinates.

5.5.1 Topographical distribution

To maintain readability Fig.25 only shows the main treatment types. The remaining treatment technologies have been incorporated into the *Other* category.

Most of the WWTPs are in Lower Austria, where the mountains degrade into lowlands. Here hill land, submontane and mid-montane altitudes merge into each other, creating a complex topography. WWTPs are also frequent in mid-and-high montane areas in the northern part of the country. As expected, they are almost absent in lowlands and very high areas such as alpine environments.

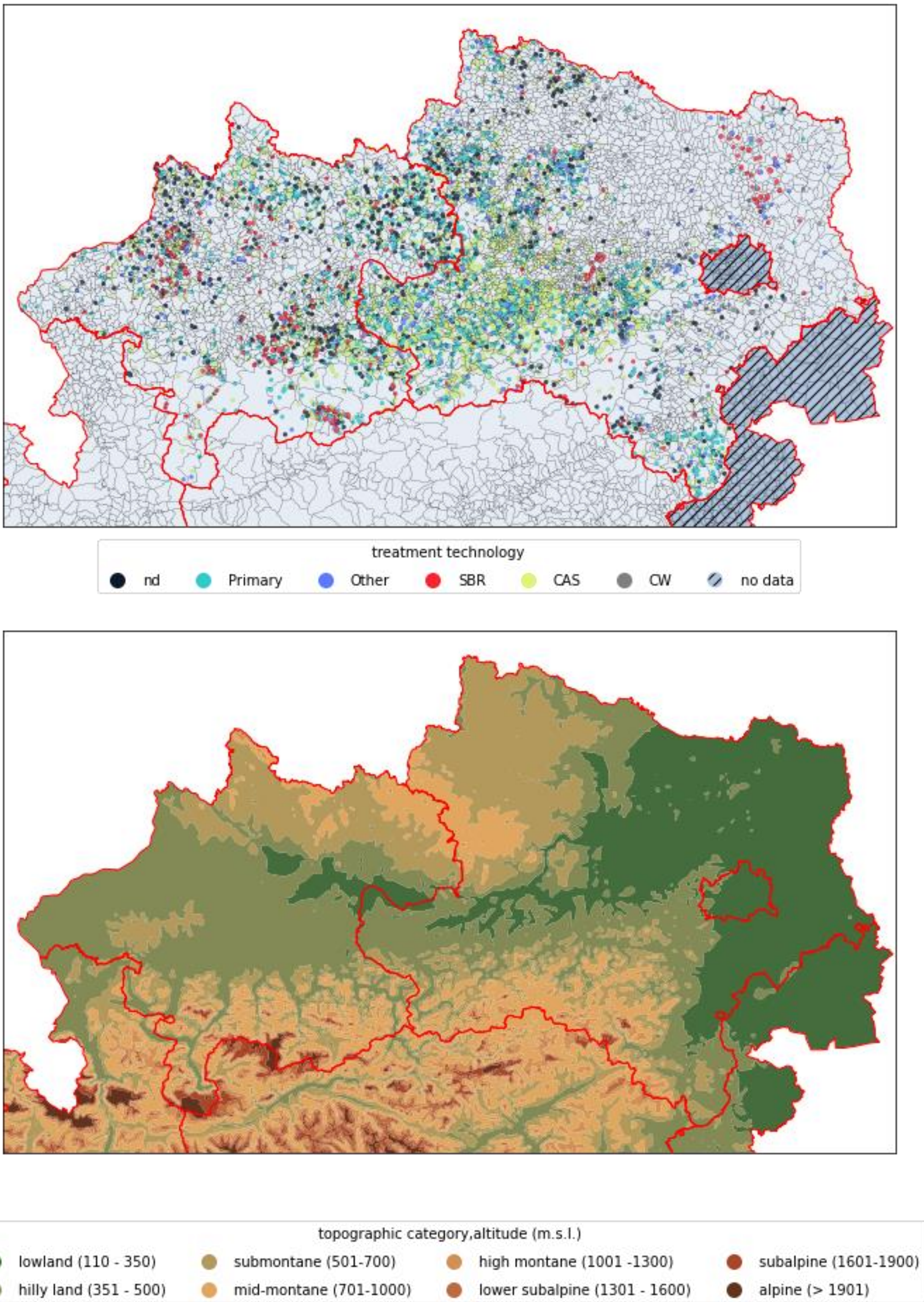

Figure 25 Topographic distribution of WWTPs < 500 PE by treatment type

5.5.2 Temporal distribution

Like the national trend, Lower and Upper Austrian WWTPs construction also has been more active in in the last 30 years (Fig.26). Most of the infrastructure was built between 1990 and 2019.

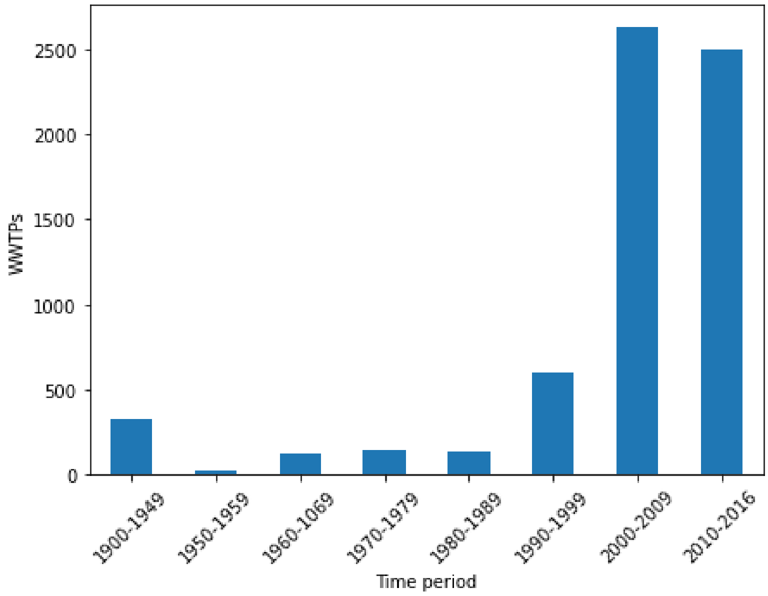

Figure 26 Temporal distribution of WWTPs < 500 PE in Lower-and-Upper Austria

Fig.27 shows the WWTPs up to 500 PE categorized by decades. The time between the beginning of the 20th century and 1950 has been categorized in a single bin, because of the low number of WWTPs built in it. The Mistelbach district (NÖ), in the north-eastern part of the country, has 95 WWTPs built before 1990, Scheibbs, Lilienfeld, Melk, St. Pölten Stadt have around 30 each. Upper Austria has more than 300 WWTPs originally built before 1950.

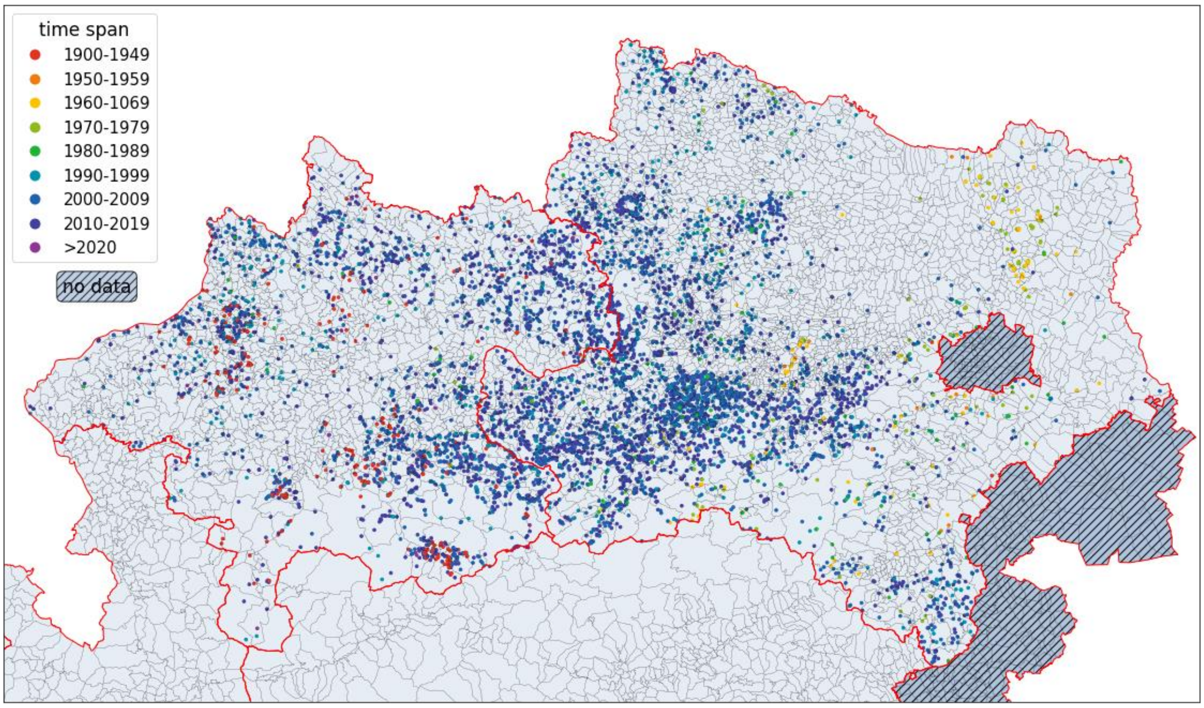

Figure 27 Administrative distribution of WWTPs < 500 PE by time periods

5.5.3 Only primary treatment

There are 328 WWTPs implementing only primary treatment in Upper Austria and Lower Austria, of which 85% are in the latter federal state. They are mostly concentrated in the Mistelbach district (40%). 4 districts in central-western Lower Austria (Scheibbs, Lilienfeld, Melk and St. Pölten Stadt) account for 50% of WWTPs with only primary treatment (Fig.28). In Upper Austria the district of Kirchdorf accounts for 43% of all the WWTPs implementing only primary treatment. The districts of Ried (17%) and Gmunden (9%) follow. All other districts float between 4 and 0.3%.

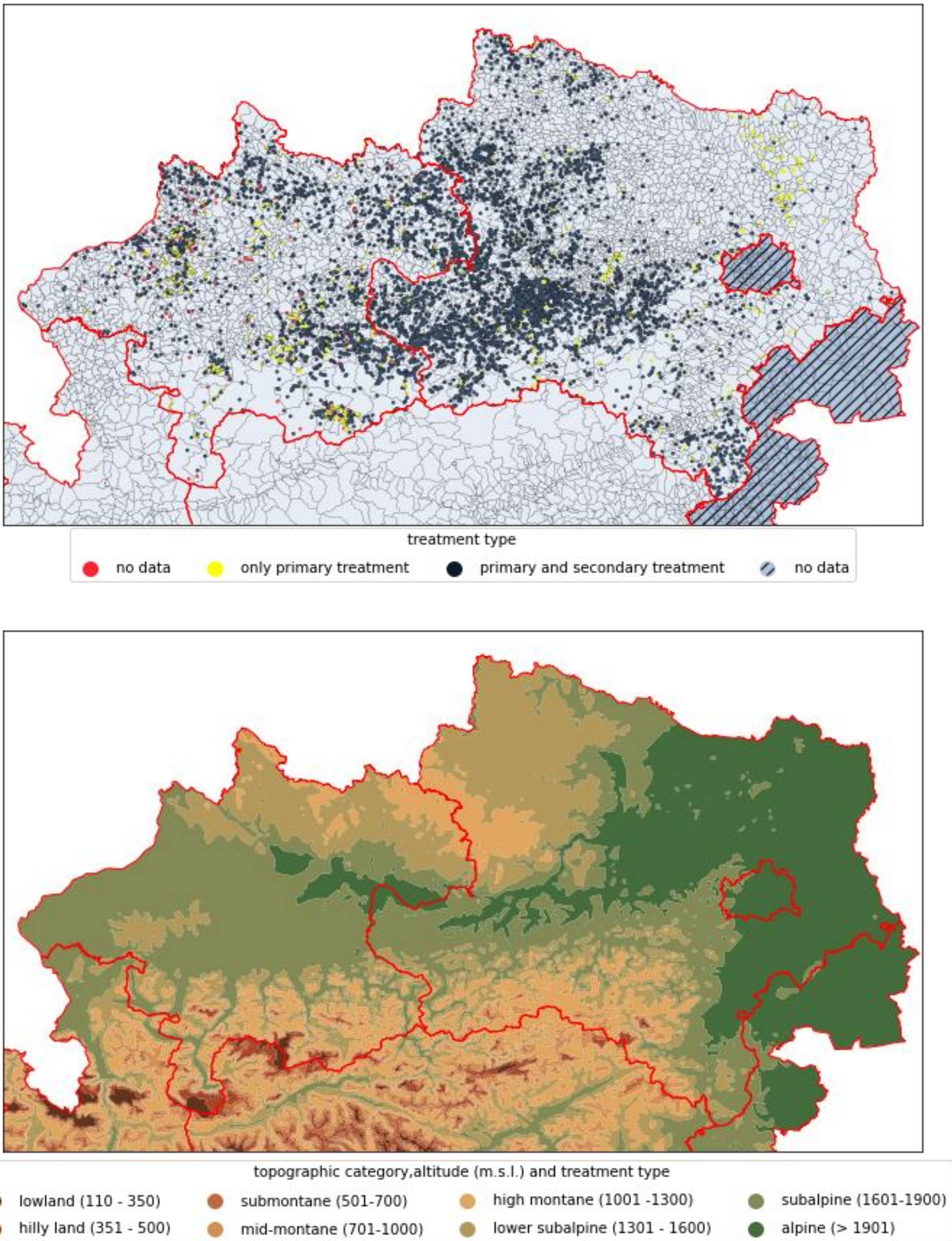

Figure 28 Topographic distribution of non-state-of-the-art WWTPs < 500 PE

6. Interpretation

6.1 Data gathering and handling

For 8 out of 9 federal states an accuracy of over 99% with the control publication was achieved, practically meaning a perfect match. Deviations may be due to errors in the present or in the control workflow but are anyway not statistically relevant. For Upper Austria, the nineth federal state, the 5% difference is assumed to be caused by the more recent version of data used in this work. In fact, the control publication has been published in 2018 whereas the Upper Austria dataset was updated in 2021. Overall, the database is considered valid and identical with the original data. The first goal is thus achieved.

After the spatial referencing about 5.5% of the original data was lost. Unfortunately, there is no way to further minimize this loss because of data incompleteness. Three states were excluded from the analysis because they completely lacked any spatial reference: Burgenland, Vienna and Vorarlberg. They have a very small number of WWTPs (0.007% of the total) and their absence did not affect the results.

6.2 Distribution of WWTPs

There are at least 27.418 small WWTPs (< 50 PE) in Austria, covering 258.514 PE. Considering the infrastructure that may have been built since the update of the dataset and interpreting Fig.4 for an approximate growth rate, the real number of small WWTPs is at about 28’500. This means that about 3% of the Austrian population rely on WWTPs smaller than 50 PE. As stated by the Austrian wastewater report 2020, the remaining 2% of the population relies on cesspools that are regularly emptied to a WWTP (ÖWAV, 2020).

Small WWTPs are evenly distributed over the hilly and highland parts of the country (Fig 13.). In fact, their high number and population coverage is a result of the mountainous characteristics of Austria. Some clusters with higher concentrations are visible in Carinthia, Styria and Lower Austria.

Table 5 Number and design size (in PE) of small WWTPs (≤ 50 PE)

State	WWTPs	PE
Burgenland	19	194
Carinthia	6'958	61'459
Lower-Austria	4'544	50'653
Salzburg	1'649	20'573
Styria	10'488	83'708
Tirol	1'096	9'436
Upper-Austria	2'522	30'880
Vienna	13	280
Vorarlberg	129	1'331
Austria total	27'418	258'514

The dataset reports 1’279 medium sized WWTPs covering 181’596 PE. They are sparsely distributed and mostly in Lower Austria, Tyrol and Carinthia.

WWTPs up to 500 PE are essential for WW coverage in Austria because of the geomorphological barriers that do not allow a uniform centralized coverage. In fact, of the 2’095 Austrian municipalities, about 5% (105) have most of their population covered by these design sizes.

Such municipalities account for 107’330 PE and most of them are in Lower Austria (55’000 PE) and Carinthia (36’000 PE). In Austria there are 1’138 and 105 municipalities with respectively less than 2’000 and 500 inhabitants. In 10% of both categories at least half of the population relies on WWTPs smaller than 500 PE.

Observing the temporal development of small and medium WWTPs, the UWWTD seems to have had a remarkable impact on it. In fact, most of the infrastructure has been built in the last 20 years. Styria has the most WWTPs of this design size (about 10’000), followed by Carinthia with 7’000 WWTPs. Although Lower Austria has about 4’000 WWTPs, they cover about 120’000 PE because many of them are medium sized. In fact, Lower Austria is first by absolute PE coverage, followed by Carinthia (100’000) and Styria (90’000) (Fig.).

Nonetheless, when it comes to population coverage in percentage, as to say how much of the state’s population is covered by such infrastructure, Carinthia is by far first with 17.5%. Lower Austria and Styria follow with about 7%. The remaining states and the national average are at about 5% (Fig. 6). When it comes to small WWTPs, Carinthia is first with 10%, followed by Styria (7%) and Salzburg (4%).

6.3 Non-state-of-the-art WWTPs

If the UWWTD signed a pivotal point for the development of small wastewater infrastructure, the 1991 update of the 1. AEVkA did so for the development of treatment technologies. The update requires all infrastructure to be able to nitrify biologically. In the early phase of Austrian WWTPs most of them only had primary treatment. Starting with the early 90s this technology dropped nearly completely and SBR, CAS and CW started to be very popular (Fig.4). Today every second WWTP up to 500 PE operates one of these three technologies (Fig. 5).

The Austrian wastewater report 2020 states that there are 27’450 small WWTPs and that about 12’000 (44%) of them have only mechanical treatment. According to the present dataset about 23% of WWTPs up to 50 PE (and up to 500 PE) have only primary treatment, as similarly stated by Langergraber et al. (2018). It is unclear from where the mentioned report gathered its data and why the results differ so much from this work. To estimate the real number of WWTPs operating only primary treatment we must consider that not all states in the dataset are fully updated (Table.3) and that some of these plants may have been renovated since the survey. Furthermore, some inconsistencies have been found in the original data.

The dataset reports about 300 WWTPs operating only primary treatment that have been built after 1991. During sample research in the respective water register, many of them where were either not found or their treatment was not exclusively primary. The inconsistency with the technology type has been tracked back to the original data and was not influenced by the method. In fact, also Dopplinger reported inconsistencies in the Upper Austria WIS regarding primary treatment only WWTPs built after 2010 (Dopplinger, 2016). It is likely that if some have been built after 1991, the real number is probably much lower. Finally, we can say that less than 23% of the WWTPs up to 500 PE operate only primary treatment and that probably the real number is between 15 and 20%.

Considering that the entire population has access to some form of sanitation (WWTPs or cesspools) and that the areas where decentralized WWTPs are more common (hilly rural areas) will not be subject of considerable population growth (Fig.3), the number of decentralized WWTPs is likely to stagnate in the future. In this optic, the maintenance and development of existing infrastructure becomes even more important.

In every analysed state at least 10% of the WWTPs up to 500 PE operate only primary treatment. Tyrol has the highest percentage (60%), followed by Carinthia (33%) and Styria (20%). When it comes to organic load, Carinthia leads with about 40’000 of non-state-of-the-art nitrified PE. More than half of them is treated by medium sized WWTPs. Carinthia is also the state in where the percentage of population relying on non-state-of-the-art infrastructure is highest (7%), whereas all the others are at about 1%.

Furthermore, the discharge of non-state-of-the-art nitrified WW is particularly concentrated in Carinthia, where 3 very small municipalities (Pörtschach am See, Hüttenberg, Reifnitz) discharge the WW equivalent of more than 800 PE/day. Tyrol also has one high discharge municipality (1'000 PE), but its area is larger and the discharge distributed over several WWTPs. Because of the high discharge and the very tiny area, the municipalities in Carinthia may be a good study area to research the effect of small non-state-of-the-art nitrified discharge on the environment.

On the other hand, the situation is particularly good in Upper Austria where only one WWTP is operating exclusively primary treatment. Interestingly most of non-state-of-the-art nitrified PE in Tirol and Lower Austria are due to medium sized WWTPs. Renovating such systems, respectively 75 and 45 WWTPs, would mean a quick and effective improvement and would get rid of most of the non-state-of-the-art infrastructure in these states. This would mean a very effective transition towards complete compliance with the 1991 1. AEVkA update. The federal state of Salzburg, having only 10 WWTPs between 50 and 500 PE that account for about 25% of non-state-of-the-art nitrified PE, would also easily find a way towards compliance.

More difficult and costly would be in the remaining states, where most of non-state-of-the-art nitrified PE are due to small sized WWTPs. Especially Styria has about 2'000 non-state-of-the-art small WWTPs, which makes it more difficult to improve quickly. Lower Austria has 500 non-state-of-the-art WWTPs. Most difficult would be in Carinthia, where a high number of both small and medium sized WWTPs equally contribute to the total non-state-of-the-art nitrified organic load.

7. Conclusion

In areas with regular or low steepness, such as the lowlands in eastern Lower Austria, building a sewage system around a big WWTP is the most efficient wastewater management strategy. On the other hand, mountains and irregular geomorphological structure increase the investment and maintenance cost of a sewage channel. For this reason, in mountainous areas like Tyrol and Vorarlberg, the sewage channel was historically built along the bottom of the valley. But in large parts of Carinthia and Styria the irregularity of terrain and settlement structures requires a decentralized WW management. In fact, these states have the most developed landscape of small WWTPs.

In Styria the development of small and medium WWTPs has historically been comparably high (Fig.4). Because of this and the massive infrastructure extension between 2003 and 2014, Styria has today the highest number of WWTPs up to 50 PE (10’000). They cover about 80’000 PE, corresponding to 7% of the population. About 2000 WWTPs still only have primary treatment, making Styria the second worse state by amount of non-state-of-the-art nitrified PE.

Carinthia has the highest number of exclusively primary treatment WWTPs (about 2’500), leading to 7% of the population relying on such systems and the wastewater equivalent of 40’000 non-state-of-the-art nitrified PE being released daily. More than half of them is treated by medium sized WWTPs. Carinthia has also been historically active in the development of its decentralized WW management but unlike Styria, the main activity point was in the early 2000s. Carinthia has about 7.000 WWTPs up to 500 PE covering 17.5% of its population. 10% of its population rely on decentralized WWTPs smaller than 50 PE.

Although it has only about 4.000 WWTPs up to 500 PE, Lower Austria has the highest PE coverage because many of them are medium-sized. In fact, of 120’000 PE about 80’000 are covered by WWTPs > 50 PE. Overall, 7.5% of the population relies on them and only 2.5% relies on smaller systems. In Lower Austria the consistent extension of decentralized systems began relatively late (early 2000) and this could explain the relatively good compliance with biological nitrification requirements. In fact, Lower Austria has the lowest percentage (10%) of WWTPs up to 500 PE operating only with primary treatment.

In Upper Austria the sanitation of small settlements has been slowly but steadily increasing. There are about 2’500 small WWTPs covering 2.5% of the population. They are mostly distributed in the south-eastern northern part of the state, whereas large parts of central Upper Austria don’t have any. Upper Austria is first by compliance with the biological nitrification update of the 1. AEVkA with about 400 small WWTPs with only primary treatment.

This work highlights a high renovation potential for several areas in Austria, as about 23% of WWTPs up to 500 PE are still running only primary treatment, releasing daily the wastewater equivalent of more than 81’000 PE.

There is very limited research on the impact of small discharges on natural water bodies. Nonetheless their effect shouldn’t be belittled. In fact, small WWTPs usually discharge in small water bodies that are more easily put out of balance. This work highlighted the areas in Austria where the discharge of not state-of-the-art nitrified PE is more concentrated. Such areas would properly serve the research and monitoring of such yet unstudied effects.

In his 1971 seminal work on Austrian WTTPs, H. Donner states observes that “*As known in expert circles, an absolute representation [of the existing small WWTPs] is nearly impossible. On the one hand because the evaluation of single discharge permissions would mean an enormous bulk of work, on the other hand because of the high number of illegal (Dunkelziffer), and thus not registered, infrastructure.”*

About 50 years later the situation has changed but Donner’s statement is still partially valid. Today we can consistently exclude the presence of a relevant number of illegal WWTPs, knowing that all Austrian population is managing its WW according to European standards (ÖWAV, 2020). Compared to Donner and his research workflow, we obviously have the advantage of computers that make it faster and easier to collect and convey information. Nonetheless, the quality of information and its accessibility are still an issue that must be considered. Because of the relatively recent start in data collection, information on the topic is relatively difficult to gather and several European countries seems to suffer from it (Tsagarakis *et al.*, 2000; Aragón *et al.*, 2013). Austria, although highly digitalized, is no exception. Information on WWTPs smaller than 2’000 PE is collected by local authorities and there is no regular dataflow between them and their national counterpart. This led to the development of 9 different online registers that are freely accessible, but don’t support research purposes. In fact, the data on which the present work is based, required years of patient collection.

8. Summary

Since, according to UWWTD 91/271/EEC, only WWTPs larger than 2'000 PE are regulated and thus need to be reported to the EU, data on smaller design sizes is usually fragmentary or inaccessible. In Austria, where each federal state manages an own database for WWTPs, the data is well prepared and accessible but not adapt for research purposes. In fact, the number of small WWTPs has long been underestimated.

In recent years the Institute of Sanitary Engineering and Pollution Control at BOKU developed an own dataset based on the WIS, allows for the first time to closely study Austrian decentralized WTTPs landscape. Contributing to its collection and elaborating on it, Dopplinger and Feigl firstly identified a significant gap between the estimated and the registered number of small WTTPs (Dopplinger, 2016; Feigl, 2018). Moreover Land and Muller, that also contributed to data collection, underlined the fact that about 20% of such WWTPs don't comply with nitrification standards (Lendl and Muller, 2016).

This work aims at exploring this dataset, collected by several bachelor and master students, from a spatial perspective. As described in chapter 2, the proposed goals are:

- To unify the existing datasets in a single dataset
- To describe the distribution of WWTPs at cadastral municipality level
- To identify clusters of non-state-of-the-art WWTPs and the municipalities that mostly rely on them

The received dataset was transferred to a single file, making it easier to analyse in the future. Additionally, the dataset was enriched with geospatial information. To ensure that this was done without compromising the original information, the result was compared with a control publication. About 5% of the WWTPs contained in the original dataset could not be linked to their spatial position due to lack of data. This includes 3 federal states that lacked any spatial reference: Burgenland, Vienna and Vorarlberg.

WWTPs up to 500 PE are essential for WW coverage in Austria because of the geomorphological barriers that do not allow a uniform centralized coverage. Of the 2'095 Austrian municipalities, about 5% (105) have most of their population covered by these design sizes. Such municipalities account for 107'330 PE and most of them are in Lower Austria (55'000 PE) and Carinthia (36'000 PE). In Austria there are 1'138 and 105 municipalities with respectively less than 2'000 and 500 inhabitants. In 10% of both categories at least half of the population relies on WWTPs smaller than 500 PE. Carinthia is the federal state that mostly relies on decentralized WWTPs. 17.5% of its population relies on WWTPs <500 PE (the national average is 5%) and 10% relies on WWTPS ≤ 50 PE (the national average is 2%).

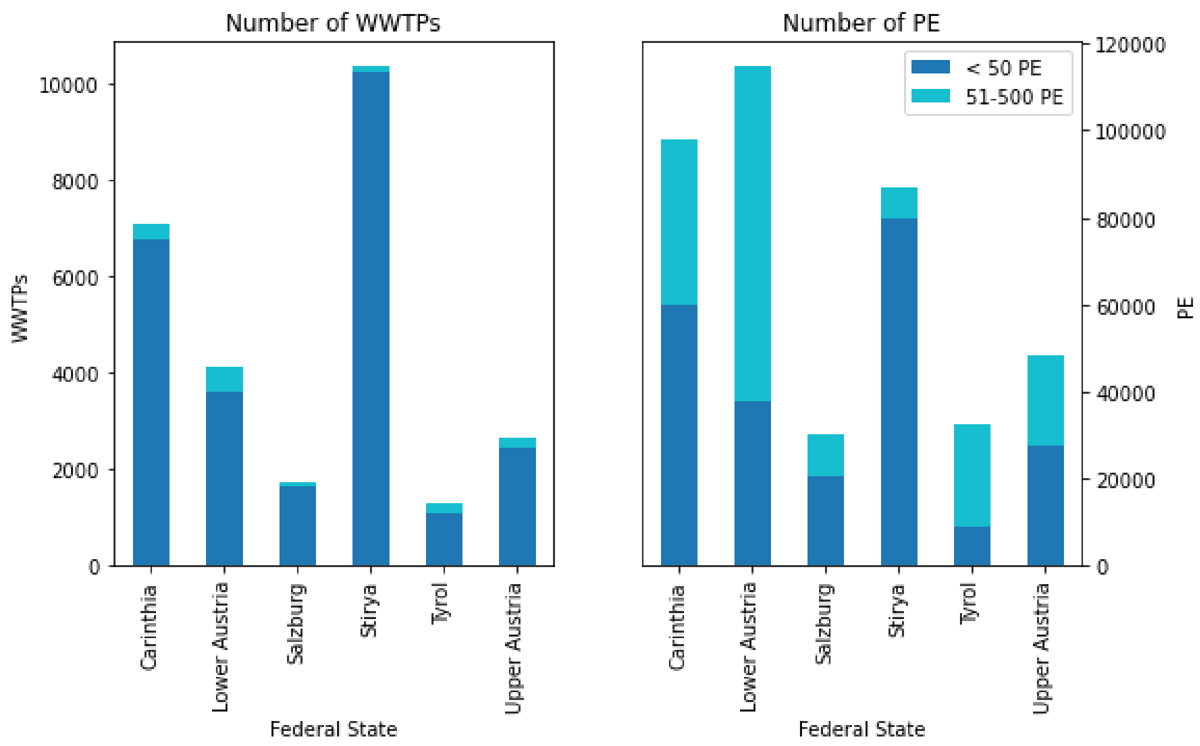

Figure 29 Distribution of WWTPs and PE by design size

In every analysed state at least 10% of the WWTPs up to 500 PE operate only primary treatment. Tyrol has the highest percentage (60%), followed by Carinthia (33%) and Styria (20%). When it comes to organic load, Carinthia leads with about 40’000 of non-state-of-the-art nitrified PE. More than half of them is treated by medium sized WWTPs. Carinthia is also the state in where the percentage of population relying on non-state-of-the-art infrastructure is highest (7%), whereas all the others are at about 1%.

Most PE covered with non-state-of-the-art WWTPs are in Tirol and Lower Austria due to a larger number of medium sized WWTPs. Renovating such systems, respectively 75 and 45 WWTPs, would mean a very effective transition towards complete compliance with the 1. AEVkA. The federal state of Salzburg, having only 10 WWTPs between 50 and 500 PE that account for about 25% of non-state-of-the-art nitrified PE, would also easily find a way towards compliance.

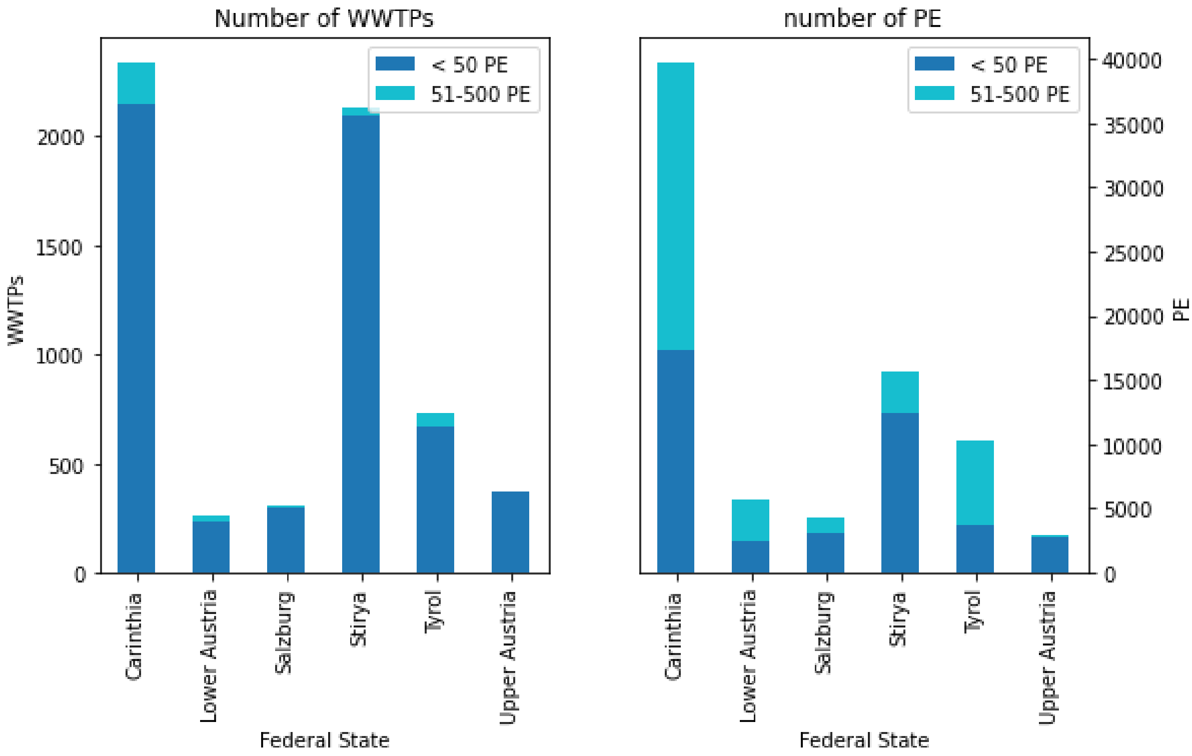

Figure 30 Distribution of WWTPs up to 500 PE with primary treatment only by federal state

The upgrade would be more difficult and costly in the remaining states, where most of non-state-of-the-art nitrified PE are due to small sized WWTPs. Especially Styria has about 2’000 non-state-of-the-art small WWTPs, which makes it more difficult to improve quickly. Lower Austria has 500 non-state-of-the-art WWTPs. Most difficult would be in Carinthia, where a high number of both small and medium sized WWTPs equally contribute to the total non-state-of-the-art nitrified organic load.

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10. Curriculum vitae

Fabrizio Dellagiacoma

Geburtsdatum: 1995

Staatsangehörigkeit: italienisch

KONTAKT

Geblergasse, 6/19
1170 Wien, Österreich
(Privatwohnsitz)

fabrizio.dellagiacoma@outlook.com

(+680) 2439486

europass

BERUFSERFAHRUNG

01/09/2021 – AKTUELL – Wien, Österreich

Data Analyst / Back-end Developer

EFS Consulting

-Planning and implementation of AWS cloud infrastructure

-Automation of data workflows

-Business Incident analisys and reporting

10/2017 – 12/2019

Sprecher und Catering Manager

Verein minimal.is.muss

-Projektmanagement & Logistik : *Planung und Durchführung von Caterings bis zu 350 Personen.*

-Führung & Personalmanagement : Zielorientierte Kooridnation von Teams (5-15 Personen)

-Raumgestaltung & Optimierung der Abläufe : Betreung und Optimierung einer professionelle Küche

Anschrift Wien, Österreich | **Website** https://docs.google.com/document/d/11wyd75CUFnsEs1NipDgXVaQ485nL1wD9Cwn7GSimxWk/edit?usp=sharing

07/2018 – 12/2019

Koch/Köchin

Deli Bluem

-Täglich vegane Küche: Menugestaltung und Zubereitung von kalten und warmen Speisen

-Planung & Durchführung: Mitgestaltung von Große Caterings bis 1400 Personen.

Anschrift Wien, Österreich

01/06/2017 – 01/08/2017

Landwirtschaftlicher Hilfsarbeiter

Bodenkultur Wien

-Ausdauer & Technik: Aufnehmen von Bodenproben mittels verschiedene technische Geräte

-Genauigkeit & Geduld : Ausführung von Messungen und optische Auslese

Anschrift Wien

01/01/2015 – AKTUELL

Wein Marktstandverkäufer

Michlits

-Selbstständige Gestaltung des Standes und Verkauf

-Kundenorientiert und freundlich arbeiten auch bei -10°

Anschrift Wien, Österreich

07/2016 – 08/2016