What drives electricity tariffs in Switzerland? Two-stage statistical and geospatial analysis of structural differences across 1913 municipalities

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***Abstract*—We present a two-staged statistical and geospatial analysis exploring the discrepancies of household electricity tariffs across 1,913 Swiss municipalities. First, we perform a multilinear regression analysis, considering structural, socio-demographic data and energy transition indicators together with the actual regulated electricity tariffs. Secondly, a geostatistical analysis was carried to investigate upon the spatial autocorrelation of electricity tariffs with selected model variables. Outcomes show that the strong variation in electricity tariffs cannot be fully explained by the chosen socio-demographic variables or the uptake from distributed energy resources in Swiss municipalities, calling for additional research on the currently unknown influencing factors at work that shape domestic electricity tariffs in Switzerland.**

***Index Terms*—Data science, Digitalization, Electricity tariffs, Energy transition, Spatial autocorrelation**

I. INTRODUCTION

In vertically integrated electricity markets such as in Switzerland, smaller consumers have limited choice regarding electricity products. Currently, roughly 600 distribution system operators (DSO - mostly also having the retailer role) set electricity tariffs on a pass-through basis, approved by the national regulator ElCom [1]. Today, electricity tariffs vary for a average household, with roughly 4,500 kWh electricity consumption per year between 10 - 60 cents/kWh [2].

Under the absence of a rigorous, quantitative study, discrepancies in electricity tariffs are accounted to structural/geographical differences across municipalities (which indeed play a role, as shown in [3]), varying shares of self-consumption with electricity generated within DSO service areas, DSO purchasing strategies, contracts and network efficiencies [4]. Until today, the efficiency of network tariffs is assessed using ”Sunshine regulation”, which publishes the electricity tariffs on aggregated basis for different, clustered DSO categories [1]. In principle, ElCom is mandated to assess tariffs, checking for errors in cost accounting or inconsistencies across tariffs. However, this remains an ardent task given the over 8,000 electricity tariffs in Switzerland [5].

Digitalization of energy systems now allows, through increasing data volumes and digital technologies, for new analysis capabilities in energy system planning [6]. While the uptake patterns of DER in Switzerland [7] and DER's influence on distribution network expansion costs and consequently, changes in electricity tariffs, have been widely studied (e.g., [8]–[10]), no study had so far examined the interaction of DER uptake and electricity tariff cost changes across a country with multiple DSOs.

This paper aims to bridge that gap, presenting a statistical and geostatistical analysis of the relationship between Swiss electricity tariffs, DER uptake levels and structural, socio-demographic information of about 2,000 Swiss municipalities.

- A multilinear regression is presented to quantify linear relationships between the chosen explanatory variables and the response variable (tariffs) before 2023.
- In addition, in line with previous work on Portugal [11]), a spatial autocorrelation analysis of the uni- and bi-variate local Moran's I is carried to observe the aforementioned relationships spatial clustering.

In a nutshell, the objective of the paper is shedding some light into influencing factors of Swiss electricity tariffs.

II. Background on Electricity Tariffs in Switzerland

In Switzerland, access to the European wholesale electricity market is authorized only for market participants with an annual consumption of $\geq$100MWh. Hence, the majority of consumers is supplied by a regional distribution system operator (DSO), that acts within the vertically integrated Swiss electricity market. The Federal Electricity Commission (ElCom) is the responsible regulator to monitor electricity tariff evolution as set in the Federal Electricity Act (RS.734.7). Electricity distribution is organized at the lowest federal administrative level between the DSOs and the communes. On the other hand, the Swiss Federal Office for Energy (SFOE) plans and coordinates the Swiss energy strategy (Energy Strategy 2050) and energy policy developments with the different actors of the Swiss energy market.

The applied electricity tariffs consumers are made of three main components (rough percentages from 2021 in brackets): energy cost (40), network cost (50), and various taxes (10) [1]. One of the ElCom's mandates is to make sure that DSO's tariffs are not abusive. To this end, DSOs must communicate their tariffs for the following year by the month of August, and the ElCom annually gathers and publishes them [12]. As can be seen in Figure 1, the heterogeneity of households electricity tariffs across Switzerland is large.

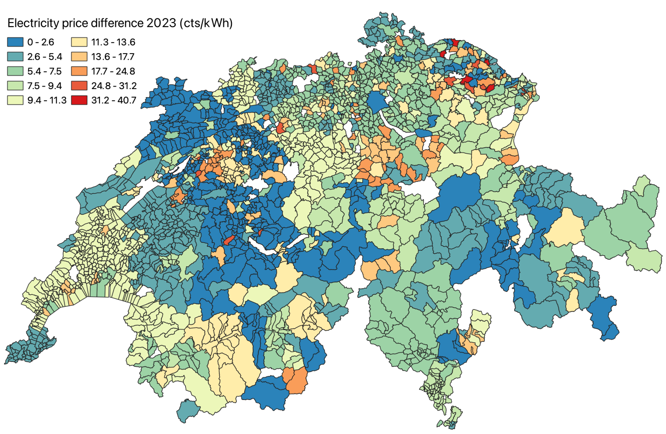

Fig. 1. Electricity price difference on average between 2013 and 2023.

Figure 2 illustrates it with a boxplot of prices from 2013 to 2023. It shows that there has been a strong increase in electricity tariffs' mean and variance for 2023 compared to the 10 last years, which is further analyszed in Section V.

III. Data

The tariffs from 2012 to 2023 were obtained from the ElCom [12]. Tariffs are given for each DSO in cts/kWh and are split by consumers categories (Households, Companies) and power level. The mean of all categories was used. The data is available and consistent over the analysed time range

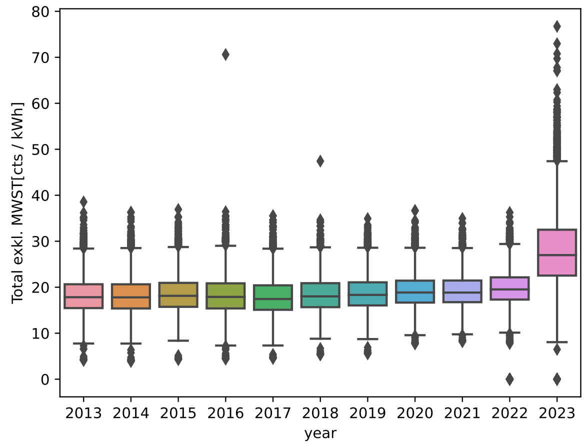

Fig. 2. Electricity tariffs variation of 2023 and the 10 years before.

for 555 DSOs out of 595 counted in 2023. Key performance indicators (KPI) on the state of the Swiss energy transition for 2021 and 2022 were extracted from the online platform Energy Reporter [13], which quarterly reports the uptake shares of the following distributed energy resources (DER) for 2,148 Swiss municipalities: electric vehicles (EV), photovoltaic modules (PV) and renewable heating systems (RHS).

Municipal population statistics were extracted from the Federal Statistical Office [14] and the Swiss national map of communes was retrieved from the Federal Office of Topology [15]. Population counts across different age groups were selected, together with population density and additional indicators such as mean income per capita.

The look-up table linking the supplied municipalities per DSO has been obtained from [12]. The resulting joined table used for analysis has consistent data for 1913 (89%) municipalities, which are related to 456 DSOs (77%). The table contains for each Swiss municipality:

- Energy-related information: Tariffs 10y-mean (2013-2022), EV share 2022, PV share 2022, RHS share 2022. Note that the response variable "Tariffs" was averaged over the 10 previous years (2013-2022) to get a higher significance.
- Socio-demographic information: Single-family home share 2022, mean income 2022, pop. age profile 2022, taxable income, population density.

In addition, we extracted three energy transition key performance indicators (KPIs) for each Swiss commune as potential explanatory variables: electric vehicle (EV) share, photovoltaic (PV) electricity consumption share, and share of heating systems operated with renewable energy sources (RHS).

IV. METHODOLOGY

A. Regression analysis

A multilinear regression aims at expressing the target variable y as the sum of an intercept α_0 and the weighted values of the input variables $\alpha_i x_i$ (1).

$$y = \alpha_0 + \Sigma_1^n \alpha_i x_i \quad (1)$$

The values are normalized before analysis. In a first attempt, we investigated upon correlation between municipal electricity tariffs and the selected energy transition and structural variables using Python [16].

Variables with negligible influence on the results were removed from the model depending on their p-value, which is the probability that a variable does not have any effect on the result. Here, a p-value below 0.05 is used as the criterion to determine whether the variable is conserved or not. The number of inhabitants was accordingly withdrawn and only two age intervals were kept: 20-39 and 60-64. An exception is made for KPI of municipal PV uptake, with a p-value of 0.3, as this could be of interest to the rest of the study.

B. Geostatistical analysis

This geostatistical analysis aims at studying the influence of geographical aspects on the electricity tariff applied by Swiss DSOs. One hypothesis we establish is that the electricity tariff is linked to the set of extracted structural information. For example, it would be straightforward to assume that tariffs are similar for structurally similar municipalities, e.g., that have a similar penetration of DER (which drive network expansion costs [8]) or population densities and income structures.

All results were derived with GeoDa v1.20.0 [17] with visualizations being post-processed in QGIS v3.14. Local spatial autocorrelations, resulting in cluster maps (Figure 6 (univariate) and Figure 7 (multivariate)) were computed with their respective Local Indicator of Spatial Association (LISA) [18]. This statistical method uses the local Moran's I to determine how a given variable varies in space relative to the variable values in the neighborhood. Formally, the statistics have the following expressions:

$$I_i = c z_i \sum_j w_{ij} z_j$$

$$I_i^B = c y_i \sum_j w_{ij} z_j$$

where:

- I_i I_i^B - local uni-/bi- variate Moran's I values.
- w_{ij} - weight between i and j.
- y_i, y_j, z_i, z_j - realizations i resp. j (normalized).
- c - a constant scaling factor.

The weights (w_{ij}) are derived using Queen contiguity (i.e. polygons sharing common edge or vertex) of order 1 (i.e. direct neighbors only). The statistical significance is obtained by comparing the results with 999 spatial random walks of the studied variables among all locations.

V. RESULTS & DISCUSSION

A. Why the high electricity tariff increases in 2023?

At first, we begin our analysis with a closer look at the strong electricity tariff increase in 2023 if compared to previous years (Figure 1). As can be seen, tariffs increased in average by roughly 40-50 percent from 2022 to 2023.

The decomposition of the 2023 tariffs shows that it is the energy fraction that explains most of the variation. The coefficient of determination R^2 almost reaches 0.9 for the energy fraction and is negative for the other fractions. This shows that the other fractions' linear models would evolve totally differently from the total fraction one. This is observed in Figure 3 as the network charges and tax fractions are very stable over the whole range of total tariffs difference variations. On the contrary, the energy fraction almost depicts the 1:1 correspondence.

In conclusion, these observations suggest that the upward drift in electricity tariffs across Switzerland from 2022 to 2023 has been primarily driven by an increasing cost of the energy component of the tariff. One likely reason may be the higher electricity prices Swiss DSOs have paid during procurement on wholesale markets or in purchasing contracts since the escalation of the gas supply shortage early 2022 in Europe.

Based on these results and potentially skewing effects on our analysis regression, electricity tariff data for year 2023 is removed from the further analysis.

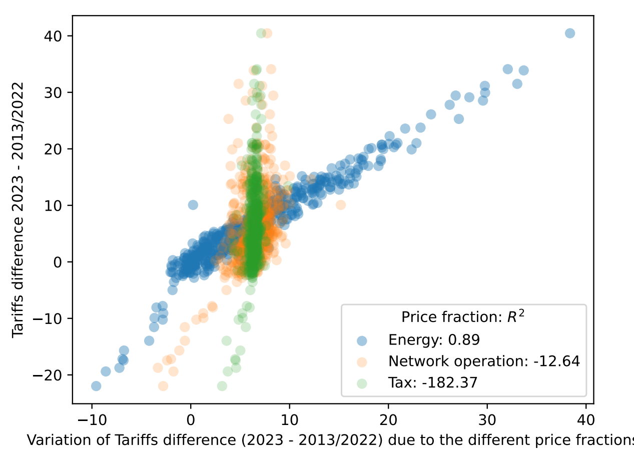

Fig. 3. The tariffs total price difference between year 2023 and the mean of the 10 precedent is compared to the difference in the energy, network operation, and tax corresponding fractions separately. The network operation and tax cost variation aren't correlated at all to the total variation, whereas the energy cost obtains a high R^2 of 0.89.

B. Multilinear Regression

1) Intercept and variable coefficients: Table I presents the retrieved regression coefficients associated with each variable in the multilinear regression analysis. It appears that almost all of the coefficients are negative, thus, suggesting that lower electricity tariffs would be associated with higher shares of the energy-related KPI and structural variables. Only the share of PV and the 60-64 years-old slice of the population has a positive coefficient, thus being positively correlated to higher electricity tariffs. Most of the p-values are significantly under the threshold of 0.005, showing that these variables have an effect on the the electricity tariffs in Swiss municipalities. The share of single family house, the population age and the share of EV are very likely to be linked to the municipal levels of electricity tariffs.

Moreover, those variables have a higher correlation coefficient, which suggests, that they may have the strongest influence on electricity tariffs in Swiss municipalities. Only the p-value of the PV ratio of 0.330 implies that this variable has no significant effect on the electricity tariff in this study.

However, all retrieved correlation factors are quite small (around 0.2), suggesting no strong effects on the diversity of electricity tariffs. The share of EV, single-family houses, and the share of the 20-39-year-old population slice seem to have the greatest effect on the variation in Swiss electricity tariffs.

Results are partially surprising, because it is often argued that the uptake of DER would increase the need for investment in electricity networks, and thus tariff levels. However, given the currently very light uptake of EV, PV in Switzerland, electricity sector decarbonzation might still no have remarkable effects on electricity tariffs.

TABLE I
COEFFICIENTS OBTAINED FROM THE MULTILINEAR REGRESSION ANALYSIS

Variable	coefficient	standard error	t	$P > \|t\|$
Intercept	7.031e-16	0.020	3.44e-14	1.000
Population density	-0.0789	0.024	-3.290	0.001
Share of single-fam. hous.	-0.2090	0.022	-9.378	< 0.001
Share of 20-39 years old	-0.2026	0.024	-8.464	< 0.001
Share of 60-64 years old	0.1283	0.022	5.949	< 0.001
Male ratio	-0.0926	0.022	-4.223	< 0.001
Taxable income per cap.	-0.0654	0.023	-2.891	0.004
Share of EV	-0.2226	0.022	-10.255	< 0.001
Share of PV	0.0205	0.021	0.974	0.330
Share of RHS	-0.1830	0.024	-7.642	< 0.001

2) Coefficient of determination: The coefficient of determination is used to estimate how well the prediction of the model fits the electricity tariff levels. It should be as close as possible to 1. In this analysis, the coefficient of determination is very low: $R^2 = 0.158$. It means that the model cannot accurately capture the realized levels of electricity tariffs in a given Swiss municipality. This is an additional hint that, statistically, the observed variety in electricity tariffs cannot be fully explained by the chosen set of variables, e.g. regionalized information on the state of the Swiss energy transition or structural differences across municipalities. In other words the strong regional variations in electricity tariffs seem not directly related to the differences both in energy transition states and the internal structure of Swiss municipalities.

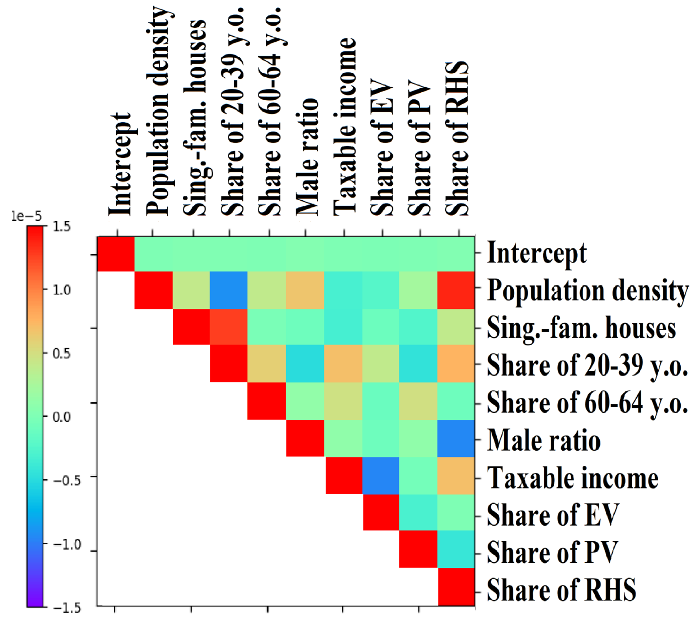

Fig. 4. Covariance matrix

3) Variance inflation factors: Variance inflation factors (VIF) quantify the multicollinearity of the variables in the regression analysis. Multicollinearity represents the correlation between multiple independent variables. If VIFs are close to five or higher, then there is multicollinearity in the input variables and the data should be adjusted accordingly, e.g. removing one of the respective variables. All of the variance inflation factors presented table II are lower than 5, consequently, the multicollinearity of these parameters is low [19].

TABLE II
VARIANCE INFLATION FACTORS (VIF)

Variable	VIF
Population density	1.375490
Share of single-family houses	1.186099
Share of 20-39 years old	1.368161
Share of 60-64 years old	1.110405
Male ratio	1.147242
Taxable income	1.222149
Share of EV	1.125044
Share of PV	1.056588
Share of RHS	1.369685

4) Covariance matrix: The covariance matrix in Figure 4 does not show a significant covariance between the input variables. Some small correlations appear between the shares of electric vehicle uptake and PV uptake, ratio of male residents and renewable heating systems, single-family houses, and the share of the 20-39-year-old population in a municipality.

5) Partial regression plots : A partial regression graph is a scatter plot of the response variable against the independent variable. It provides an indication of the nature of their relationship. Fig. 5 shows a large dispersion of the values for a given electricity tariff. Although a slight trend can be observed with renewable heating systems, single-family houses, and age categories, most of the variables seem to be spread around the average electricity tariff.

C. Geostatistical analysis

In the following, the uni- and bi- variate local Moran's I are computed for the response variable (municipal electricity tariffs) and the explanatory variable that got the highest score in section B.1) (EV share). To increase the spatial distribution significance of tariffs, the 10 years mean (from 2013 to 2022 incl.) was taken as response variable. The univariate Local Moran's I for the tariffs averaged over the 10 previous years is presented in Figure 6. A few significant high-high and low-low clusters appear. The high electricity tariff clusters in municipalities in the center west, south and at the Eastern boarder seem to coincide with the DSOs that serve these regions (as can be seen in [2]). This would be expected, as the DSOs, in case they supply several municipalities as in these cases, would charge similar electricity tariffs within the same supply region.

However, our analysis does not unveil a significant score for most of the Swiss municipalities. This means that on average over the last 10 years, tariffs were not especially high or low in any municipality if compared to their neighbors. In addition, additional research would be required to understand how similar or different electricity levels are across different groups of municipalities (mountainous regions, urban, rural). The bivariate Local Moran's I for the tariffs averaged over the 10 previous year and the EV share is presented in Figure 7.

For the EV share, clusters type are balanced in numbers. A large significant low tariffs - high EV share cluster appears in the region of Zürich. In this region, one could say that the distribution of EV share has a significant correlation to the tariffs. However, it remains open why higher adoption of EV within Zürich relates to lower electricity tariffs.

One possible explanation would be, that, inversely to our hypothesis, lower electricity tariffs could drive EV adoption, making part of the operational expenses of EV (charging electricity) lower than in other regions of Switzerland.

Overall, one observes that low-low clusters are rather localized from the center towards the Eastern part of the Switzerland, suggesting that the low share of the analysed variable in the Eastern part of the country is related to the lower tariffs in the communes of this region. On the contrary, high-high clusters appear to be rather located from the center towards the Western part of the country, suggesting that in this region's municipalities, the higher share of the analysed variable is related to the higher tariffs. Also, one observes that the region of central Switzerland, constantly got a significant cluster, suggesting that, in this region, the tariffs and the explanatory variable are rather similar.

VI. CONCLUSION

Results unveil some relationship between the municipal electricity tariffs in Switzerland and the state of the energy

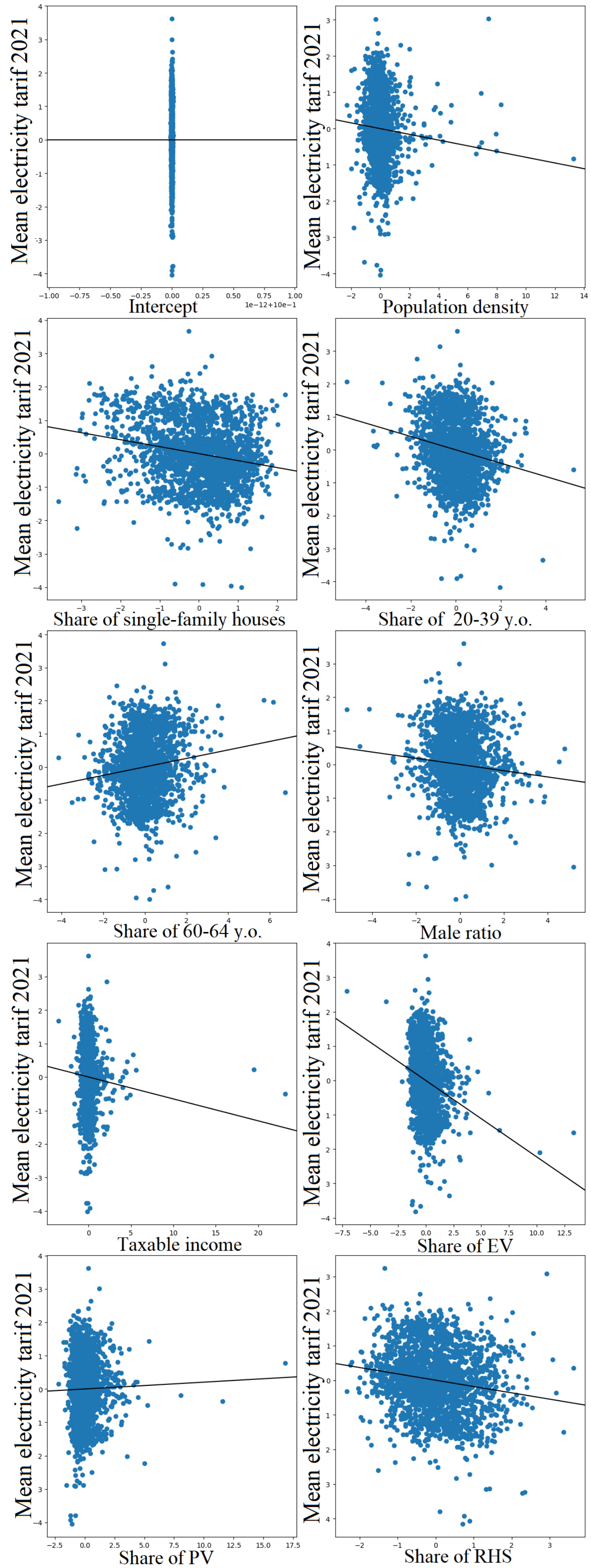

Fig. 5. Partial regression plots.

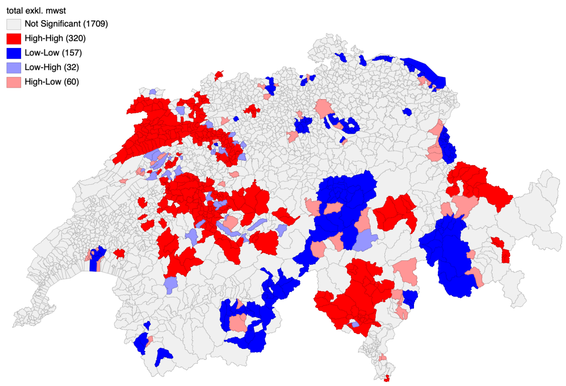

Fig. 6. LISA Tariffs 10y-mean (2013-2022). The resulting classes are: High-High:communes with high tariffs surrounded by others with a high tariff as well, Low-Low: conversely, High-Low: communes with a high tariff surrounded by others with a low tariffs, Low-High: conversely.

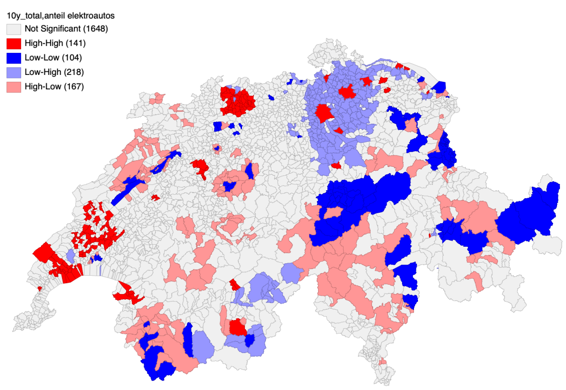

Fig. 7. BiLISA Tariffs 10y-mean (2013-2022) and EV share. The resulting classes are: High-High:municipalities with high tariffs surrounded by others with a high EV share, Low-Low: conversely, High-Low: municipalities with a high tariff surrounded by others with a low EV share, Low-High: conversely.

transition in Switzerland. However, in general, the low correlation of selected variables with the municipal levels of electricity tariffs may indicate that other, currently neglected factors are influencing electricity tariffs. Some potential factors could include the shape of bilateral procurement contracts with electricity producers, bidding/purchasing strategies of the Swiss DSOs at wholesale markets or internal pricing strategies. Since bilateral contracts with electricity producers are often fixed for a duration of several years, they are likely to be dependent on the context of the energy market during the negotiation. However, as a general tendency, tariffs were strongly increasing from 2022 to 2023 along the increase in European wholesale prices due to the sudden gas shortage that winter, suggesting that also short-term events can impact electricity tariffs in Switzerland.

While the geostatistical analysis did not uncover clear spatial clusters in which the most relevant variables of the multilinear analysis would be significantly explaining the electricity tariffs, some degree of homogeneity of electricity tariffs in regions supplied by the same DSO could be found. Overall, results suggest that for the case of Switzerland, common truths such as "the uptake of DER or dispersed settlement structures increases electricity tariffs" may not necessarily hold true throughout time and space. More research is needed to better understand the tariff-forming mechanisms in only partially opened electricity markets such as Switzerland.

VII. Acknowledgements

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of SFOE.

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