18 | November 2020

FEEM
FONDAZIONE ENI
ENRICO MATTEI

[Brief

The Changing Spatial Distribution Of Electricity Demand In Europe: Insights For The Transition To Low-Carbon Cities

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Abstract

FEEM Policy Brief

A study developed within the FACTS (Firms and Cities Transition towards Sustainability) research program, "Projections of electricity demand in European cities using downscaled population scenarios" resulted in a Data-set of residential Electricity demand projections at the LAU level for a sample of European Countries. The study projected future residential electricity demand starting from cites population and residential land use projections. The analysis was developed from national-level energy intensity with the aim to disaggregate residential electricity at the Local Administrative Unit level for all EU member states in the year 2050. The results suggested that the amount of electricity required by cities depend mostly positively on their land-use patterns, but with an evident between- and within-country heterogeneity. This evidence poses significant challenges to the planning of future cities as it points out how the current patterns of land use will need to be properly categorized concerning future electricity requirements. Here we highlight how the development of additional downscaled datasets will help policymakers in obtaining crucial information on how to shape the future configuration of cities to reach an efficient energy transition and decarbonization.

01
Introduction

By 2050, we expect a rapid urban population growth in Europe, that could reach up to 80% of that year total population (United Nations, 2019). This means that a significant component of the GHG emissions contributing to the anthropic climate change will come from the residential sector, as they already constitute more than the 25% of the total in Europe (EEA, 2020).

The study "Projections of electricity demand in European cities using downscaled population scenarios" was developed in Fondazione Eni Enrico Mattei (FEEM) as a research initiative to assess the influence of residential land use and population growth on the future electricity demand of European cities. Indeed, the transition towards a more sustainable economy will need to assess the evolution of these variables properly.

Our research initiative is but one example of the directions that could be taken to provide policymakers with information and data that is sufficiently detailed and spatially precise to be effective for policy advice and actions below the level of the major states and regions.

Given also the different transition paths and scenarios available, like the Shared Socioeconomic Pathways (O'Neill et al., 2014), it will be important for policy makers to obtain projections and forecasts about the behaviour of the most relevant variables. These projections will follow a plurality of methods, and can provide different results, but they still contribute to inform the actions by Policy makers, that can observe and compare the different assumptions, and attempt less tentative solutions.

Most of the variables that will matter to reduce the volume of emissions and bring society towards a sustainable path, like the residential electricity consumption, will behave according to the interaction of different actors and forces and will require complex modelling to be depicted. This can limit the availability of derived and downscaled data sets, and is the reason why the development of such research efforts will be crucial to help the transition.

02
Policy problem

Policymakers can obtain projections about variables relevant to the transition mainly from two different approaches: a detailed bottom-up one that accounts for the technical characteristics and specifics of buildings, and a "Top-Down" one, that tries to infer the future behaviour of the relevant variables according to aggregate statistics (Swan and Ugursal, 2009). Both approaches present different sets of advantages and issues and can be respectively better suited for a specific type of Policy Evaluation.

The Bottom-up approach often needs precise statistics and technical information which degrees of complexity and availability makes it more difficult to build enlarged models (Van Ruijven et al., 2019). The "Top-down" approaches have the advantage of being based on aggregates data, that are usually collected by national agencies and international organizations. These data are usually of high quality, with detailed collection methodologies and reliable. Moreover, they are often free and available for the interested researcher. In our study, for instance, it was possible to project Residential Electricity demand at the National level by building a model that explained national electricity intensity by Population density and average temperatures projections. Issues might arise from Top-Down approaches when data provided by sources are not at the levels of disaggregation needed for proper policy applications. For the case of our study,

this means that keeping the analysis at the national level would provide projections to 2050 for countries, but not for underlying governance levels, such as regions and provinces.

However, for this field of investigation, policymakers would also benefit at the regional and even at the city level. First, models might evidence the presence of heterogeneities within the units of investigation (for instance, great regional disparities within a country). If policymakers at the levels below the national one would all follow the aggregate result, there could be unintended consequences; not all the cities might follow the same pattern of population and residential land-use coevolution. Policy solutions could, therefore lack proper tailoring to the actual needs of the city. Second, being able to disaggregate electricity demand projections spatially is even more important in the context of the transition to the production of renewable energy and decarbonization. Indeed, given physical endowments of renewable energy that is usually heterogeneous across territories requires a more precise matching of demand and supply to build resilient and efficient renewable energy systems (Aydin et al., 2010). Third, the lack of sufficiently disaggregated data might impede the research for some geographical regions, like developing countries (Murakami et al., 2015), or for any interrelated variables that could require them.

03
The methodology and the results

To overcome the data availability limitations that would affect policy recommendations at levels such as the city one, we explored the literature on downscaling electricity demand to obtain projections at the city level for our European Sample.

While disentangling the aggregate prediction according to some pre-determined shares based on population or national income could be a first solution, downscaling techniques permit to take advantage of the information brought by other additional variables and data. In our work, for instance, we looked at the relationship between residential electricity demand, the residential area, and the total population. This approach captures the relationship between these three variables and tries to control for the situations where, while urban population keeps on growing, the actual population of a country might decrease.

To achieve this, we extended to a multi-year setting the modelling framework of Seya et al. (2016), developed to estimate the residential electricity intensity at the municipality level in Japan, and applied it to European Municipalities (here broadly defined as Local Administrative Unit, LAU as per the 2018 unified European Commission definition). This framework seeks to understand how population growth drives urban spatial expansion and employs this information alongside downscaled population scenarios to predict future land use patterns, in order to project the electricity demand for the targeted year.

This procedure was possible due to the availability of the EEA Corine Land Cover GIS maps[1], from which we obtained Residential Land-use area at the LAU level for our sample. It was possible then to obtain the coefficients from a panel model linking the evolution of Residential Area to the one of the population. To understand how built residential areas would evolve in 2050, given the evolution of the population, we also needed a projection for the 2050 population level in every LAU. We applied a share of growth method to country population predictions from Eurostat, where we based the growth share of single LAUs on the years available in our data.

Predicting the 2050 values for residential areas by employing the coefficients from our model and the local deltas in populations, allowed us to obtain tailored predictions for every LAUs. In a second model at the country level, where we explained the electricity intensity of a given country by a model based on population density, we applied the same methodology. This was possible by employing the 2050 values for both population and residential land use, which defined the 2050 density level. Once the

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[1] https://land.copernicus.eu/pan-european/corine-land-cover

electricity intensity was obtained at the country level, it was possible to multiply it by the single municipalities land use projection, which in turn obtained the projected downscaled electricity consumption projection for the target year.
In figures 1 to 3, we can observe the results of this analysis at the European level. We can already observe that assuming a relationship between population and residential areas evolution will provide heterogenous projections, both with between and within countries. In Figure 1, we illustrate the difference in the total population from the year 2018 to 2050. In Figure 2, we can observe the same information for residential electricity, elaborated from our analysis. In Figure 3, we show the same variable as Figure 2, but zooming at the NUTS 2 region of Lombardy, Italy, to help in the perception of the disaggregation of the data. In all the Figures, white spaces correspond to missing data regarding the population of Local Administrative Units.

This model could be extended in different directions, but the current results are enough to display how the availability of disaggregated and detailed data, combined with a variety of downscaled techniques could help the policymakers to formulate more accurate actions, in this example also at the single municipality level.
We tried to condition our results also on temperatures. Residential Electricity consumption should depend on climatic variables, as most of it is related to the use of cooling and heating in winter and summer months. This relationship can take, therefore a V-shaped or a more skewed one depending on the country use of gas for heating. In our work, we considered only the average country temperatures for our panel years, but the coefficients were not significant. It appears that in this direction, more accurate variables should be considered.

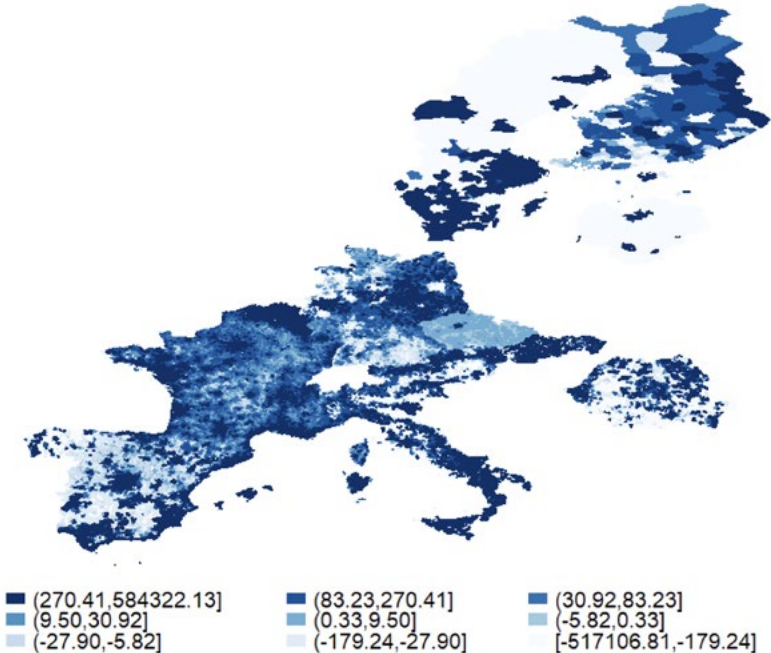**Figure 1: Absolute level of the delta (2050 to 2018) of the Total population level at the LAU level**

- (270.41,584322.13]
- (83.23,270.41]
- (30.92,83.23]
- (9.50,30.92]
- (0.33,9.50]
- (-5.82,0.33]
- (-27.90,-5.82]
- (-179.24,-27.90]
- [-517106.81,-179.24]

Figure 2: Absolute level of the delta (2050 to 2018) of the Residential Electricity level at the LAU level

(0.00,163.21]   (0.00,0.00]   (-0.02,0.00]
(-0.04,-0.02]   (-0.07,-0.04]   (-0.11,-0.07]
(-0.22,-0.11]   (-0.56,-0.22]   [-172.86,-0.56]

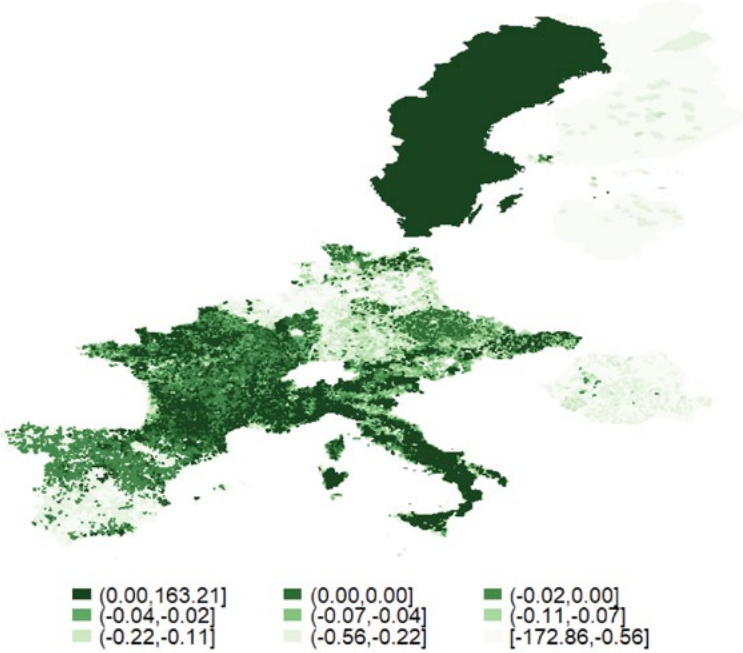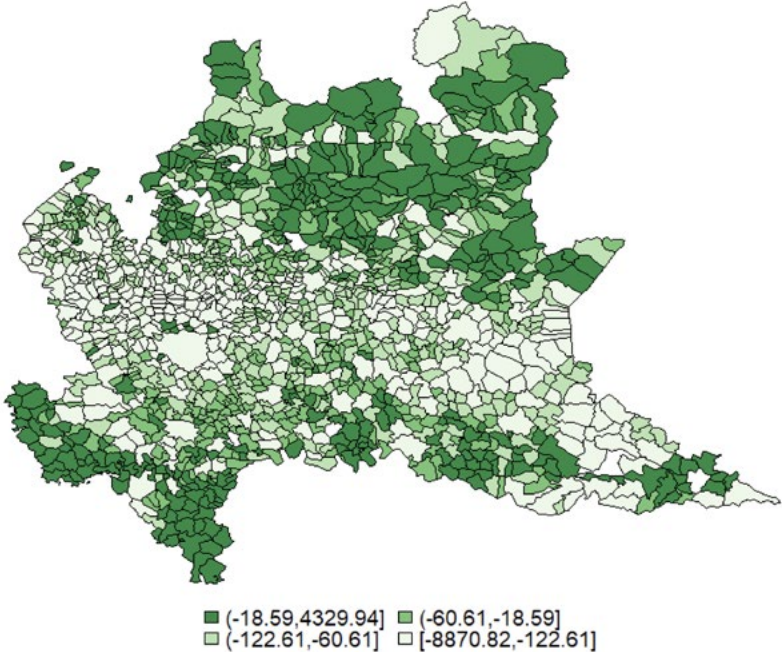**Figure 3: Deviation from the National mean of the 2050 projected Residential Electricity at the LAU level (Lombardy, Italy)**

(-18.59,4329.94]   (-60.61,-18.59]
(-122.61,-60.61]   [-8870.82,-122.61]

Conclusion

- The topic of the transition towards more sustainable energy systems will need policymakers to acquire a vast amount of data about the evolution of the most relevant variables, including Population, Economic Growth, and Energy Supply and Demand. These data come from a plurality of institutions, organizations, and models.

- Top-Down Approaches based on aggregate data and statistics often available at the Country and regional level allows many applications to project the behaviour of given variables. Sometimes, however, a more detailed level is needed to inform proper policy action. Even at this more disaggregated level, bottom-up approaches might still prove to be not available, due to technical difficulties or costs. City Council level decisions, for instance, might require a top-down approach, but it might not be feasible to obtain the relevant data.

- The literature on downscaling and other disaggregation methods allows obtaining more detailed and fine-grained datasets through sound statistical and econometrics techniques. These procedures can be applied to obtain the needed series from already available more aggregate ones.

- In our work "Projections of electricity demand in European cities using downscaled population scenarios" we applied downscaling techniques and derived a dataset for the projections of Population, residential area and residential electricity demand for Europe at the Local Administrative Unit level. There, a combination of data already provided at a geographically detailed level (LAUs population, and residential urban areas from satellite imagery), joined with downscaling techniques allowed us to obtain downscaled and detailed projections.

- The trade-off between top-down and bottom-up approaches could then be mitigated by the use of these methods, namely, to adopt predictions to guide the policy action which while coming from aggregate statistics, becomes sufficiently detailed to inform the action even at the city/municipalities level.

- These recommendations are even more helpful in the context of the energy transition, where the decoupling of demographic behaviour and land use evolution could provide information about electricity demand and its projections that while correct on average might not help in contexts with wide heterogeneity.

- Obtaining a more detailed map of residential electricity demand could help in developing a more efficient supply and demand matching for renewable energies.

- The acquisition of more detailed geographical series will help in the creation of more reliable policy advice. For instance, in our model we tested the Country average temperature effect on electricity intensity, finding no significant results. Employing additional downscaled data related to climate could provide different and more accurate results.

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