Electro What: A platform for territorial analysis of electricity consumption

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Reference


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ElectroWhat: A Platform for Territorial Analysis of Electricity Consumption

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Abstract

In the canton of Geneva, the per capita electricity consumption of private households increased by 12.1% between 2000 and 2010. The electricity efficiency program ECO21 conducted by the Services Industriels de Genève (SIG) was initiated with the goal of reducing the demand. A territorial characterization of electricity demand permits designing such programs and making ex-ante estimations of savings potentials. To extend this approach to the whole Swiss territory, a collaboration was initiated with SIG to develop the ElectroWhat platform that decomposes the yearly electricity consumption of every Swiss municipality into estimated load curves per activity and per electric appliance.

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Keywords: electricity demand; bottom-up modelling; disaggregation by usage; territorial analysis; efficiency programs

1. Introduction

According to [1] in 2013 40% of the total final energy consumed in Switzerland was used for space heating and domestic hot water production. Two thirds of this energy is made up of fossil resources generating important CO2 emissions. The use of heat pumps could increase the share of renewable heat production. Consequently the electricity demand would rise, especially in winter when PV based production is low. Today the Swiss electricity mix is mostly based on nuclear and hydro power plants. The moratorium on the construction of new nuclear power plants following the Fukushima accident will progressively phase-out nuclear electricity from the Swiss electricity mix. Hydropower
capacity is close to its maximum and the electricity demand, which had continuously been increasing until 2010, has stabilized at approximately 59 TWh/year [2]. The future vision is to combine the following: a phasing-out of nuclear production, an increase in the share of renewable heat production and the development of electric mobility. This objective represents a challenging task. Efficient use of electricity is an important driver for the transition of the electric supply, required to achieve the energy strategy 2050 goals of the Swiss Federal council. At the regional scale, Geneva achieved a decrease in the consumption of private households of 4.6% per capita between 2010 and 2015.

The design of large scale electricity efficiency programs requires a detailed knowledge of how the electricity demand of a territory breaks down into various activities and electric appliances. This is illustrated by the study of [3] that makes a detailed analysis of how electric consumption evolved in the Canton of Geneva. This study served as basis to redesign in 2009 the large scale electricity savings program ECO21 launched in 2007 by the Services Industriels de Genève (SIG). Such a study allows for example to make ex-ante estimations of savings achievable by large scale electric device replacement, as for example efficient lighting in the common parts of collective residential buildings. Expected versus real savings for two ECO21 sub-programs are compared in [4] using three different approaches.

The increasing share of renewable electric production that is often subject to temporal constraints, raises the question of how demand side management could reduce demand peaks as well as the need of storage. Active storage being expensive, a forecast of the electric load curve is useful input helping to make optimal use of the battery [5]. On the other hand indirect storage can be implemented by shifting part of the load (e.g. electric hot water boilers) to a more suitable time when renewable excess electricity is available. Local micro grids connecting producers, consumers and storage units should include efficient real time communication. A multi-scale communication protocol is defined in [6] and tested in [7] in a 0.4 kV network. The estimation of load curves by usage type is valuable input to estimate the potential of such smart grids.

There are numerous methods to simulate load curves. The review paper [8] classifies the most relevant algorithms into five groups, including both deterministic (replicating average behavior) and random models (replicating the diversity of consecutive days). Considering a larger territory including all energy service companies (ESCO) of the EOS holding group, the report [9] describes the bottom-up model behind the ElectroWhat platform. The chosen approach combines top-down deterministic statistical disaggregation in sections 2.1, 2.2 and bottom-up time of use models in section 2.3. ElectroWhat seeks to answer the question who consumes where, when and for what use at the national level.

This project is the result of a collaboration between the academic project SCCER FEEB&D [10] and the industrial partner SIG. Since this collaboration is subject to a confidentiality agreement, section 2 therefore does not give all the details behind the model. The article focus is on the outcomes and validation of the model as well as potential applications.

2. Electric demand model

The yearly demand of a municipality is split into three main sectors, each one with its own estimation algorithm as described in the following three sub-sections. The yearly consumption is split into 36 activities and 18 electric appliances such as lighting, fridges, TV, etc. A further step consists in transforming the yearly demand into estimated load curves using a library of load curve shapes.

2.1. Industry & services

For each municipality, the estimation of the yearly consumption of the industry & services sector is based on the number of working places per NOGA activity code available in the STATENT database [11]. This statistic is combined with unitary average consumption per working places and NOGA code. Considering the territory of Geneva and that of the EOSh group, these unitary consumptions are estimated using the total billed electricity per activity. For the remaining Swiss municipalities, the average unitary consumptions are calculated using a yearly national survey conducted for approximately 12’000 companies [12]. For each activity code the total yearly demand is decomposed into different appliances as for example lighting, motor power, heat, etc.
2.2. Common appliances & public lighting

The number of collective dwellings are used as explanatory variable for these two demands. This assumption is based on the fact that public lighting (including traffic lights) is linked to urban density. This approximation does not take account of specificities as for example extra urban highways and tunnels. As in the previous sub-section priority is given to unitary consumptions calibrated on local ESCO bills to take account of regional differences. For example, there are big differences between several Swiss regions in use practices of lighting in the common areas of buildings. In Geneva for example it is mandatory to have the staircase illuminated day and night. The ECO21 program promoted low consumption light fixtures with occupancy sensors that switch on only when required. In canton Vaud the common use practice is to have luminaires with a manual switch.

2.3. The residential sector

The consumption of the average household is estimated combining equipment rates, time of use and average power per main use appliance. The unexplained part is included in the appliance named “other”. The main regional difference concerns the equipment rate of electric cookers. A stock model based on sales statistics according to energy efficiency label permits to estimate the average power consumed by a specific device. Such statistics are available in the report [13].

2.4. Seasonal effects and estimation of load curves

A library of average load curve shapes per electric appliance type and activity permits to split the yearly consumption into monthly estimations. The used percentages defining these shapes are based on measured seasonal effects that are particularly pronounced for heating and lighting. Monthly demand is further broken down into daily demand for working and non-working days and finally into hourly demand. The load curve of a particular municipality is estimated by summing up the individual load curves of all activities and all electric appliances.

3. Model validation

Two kind of validations compare estimates obtained from the model with available electricity consumption statistics. Section 3.1 compares annual consumption at the national and at a number of regional levels. This enables to check the accuracy of the unitary consumptions used to estimate the yearly consumptions in the various sectors. Section 3.2 compares the estimated hourly demand with the measured one to check if the shapes of the load curve library and the weights used for aggregation replicate real demand.

3.1. Validation of annual consumptions

The annual consumptions are compared at the national, cantonal and municipality levels. At the national level, the report [14] gives yearly estimations for the main activity sectors. Some cantonal energy offices publish electricity consumption statistics on their home pages. The collaboration with SIG gives access to all electricity bills of the canton of Geneva. Comparing real and estimated electricity demand for each municipality of Geneva allows to check how accurate the estimation remains when used for smaller territorial units. Table 1 shows measured and estimated consumptions at different territorial aggregation levels for the year 2008. As can be seen in Table 1, at the national aggregated level the annual consumption has a very good match. The calibration values of the model for the canton of Geneva are based on bills issued by SIG. For this reason cantonal aggregated estimated and real consumptions are very close. For the two other examples of cantons we observe differences. For Zurich no local ESCO based calibration data is available. In this case Swiss average default values are used. Although these default values lead to an unbiased estimation at the national level, they cannot replicate in detail the variability that energy demand may have among different regions within the same activity. The same phenomena occurs when breaking demand down into smaller territorial units. For the canton of Geneva, the average
difference between real and estimated demand of a municipality is 16% with differences ranging from 0.6% (Aire-la-Ville) to 96% (Russin).

Table 1. Comparison of aggregated yearly demand estimations with other data sources

<table>
<thead>
<tr>
<th>Territory</th>
<th>Measured (TWh)</th>
<th>ElectroWhat (TWh)</th>
<th>Diff (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>National level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH</td>
<td>57.42 (i)</td>
<td>57.68</td>
<td>0.45%</td>
</tr>
<tr>
<td>Cantonal level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GE</td>
<td>2.851 (ii)</td>
<td>2.85</td>
<td>-0.004%</td>
</tr>
<tr>
<td>VD</td>
<td>3.88 (iii)</td>
<td>3.34</td>
<td>-13.92%</td>
</tr>
<tr>
<td>ZH</td>
<td>9.3 (iv)</td>
<td>9.52</td>
<td>2.37%</td>
</tr>
<tr>
<td>District level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geneva (BSF No. 6621)</td>
<td>1.26 (v)</td>
<td>1.33</td>
<td>5.56%</td>
</tr>
<tr>
<td>Russin (BSF No. 6637)</td>
<td>0.0013 (v)</td>
<td>0.0026</td>
<td>96.00%</td>
</tr>
</tbody>
</table>

(i) National demand statistics of [14] (ii) OCSTAT Table T 08.03.2.01 [15]
(iii) Canton Vaud table T08.03.01-A2017 [16] (iv) AWEL, Abteilung Energie [17]
(v) Based on SIG issued bills

3.2. Validation of load curve profiles

For each month and hour of the day, the average load is computed by taking separately the average over all working and non-working days.

Fig. 1. Real and simulated average hourly load curve from January (1) to December (12) 2008 for the canton of Geneva

Fig. 1 displays for each month (1 to 12 on the x-axis) the average daily load curve in black and the simulated one in grey. Geneva has almost no electric heating. Thus the seasonal effect is quite limited. The simulation replicates quite well the daily shape with morning (11 AM) and evening peaks (7 PM) due to cooking as well as lighting appliances in the evening. The evening peak is greater due to earlier sunset during winter. For week-ends, the overall load is less because the activity in the services and industry sector is lower, however the evening peak induced by households becomes more obvious, especially during winter.

Fig. 2 gives the same comparison for the Swiss overall load curve. The measured hourly load curve is estimated by [18] each third Wednesday for every month. It is based on a consolidation of the net production (taking account of imports and exports) of all Swiss electricity producers. An estimated loss of 12% due to transportation and
distribution was removed to reflect the final energy used by the end consumer. The main differences can be seen for June and July where the model significantly overestimates the demand.

At the Swiss level, around 10% of the space heating and domestic hot water production [1] is covered by electricity. This induces a seasonal variability with higher demand during the winter months.

4. Results and applications

GIS Maps and database: The yearly estimated consumption of each municipality split into activities and electric appliances is made available by a web service [19]. Fig. 3 gives an example of a GIS map combining yearly demand per capita, decomposition of demand into four main activity sectors and total demand for some municipalities near the city of Lausanne. A quite high heterogeneity exists among the shares consumed by sector, influencing also the per capita consumption. In the municipalities of Aclens and Mex a large part of the demand is attributable to the services and industry sector, inducing a high demand per capita compared to a residential municipality such as Bussigny. This difference of socio-economic structure influences the decomposition of demand into electric appliances and the shape of the load curve.

Web platform ElectroWhat: A prototype of web platform allows to explore the specificities of the consumption of each Swiss municipality. A report containing the main indicators is enriched with some charts illustrating the decomposition of the yearly demand into activities and electric appliances. This detailed decomposition of consumption can be downloaded in Excel format for further treatment. Fig. 3 shows how the tool visualizes hourly load curves per appliance for a selected municipality and a simulation interval.

Fig. 3. Left: Example of GIS map showing the electric demand per municipality (colour ramp) and the percentage per activity sectors (pie charts) Right: Decomposition of the estimated load curve of a non-working day into the main electric appliances
5. Conclusions

The ElectroWhat platform breaks down the total estimated electricity demand of a municipality into estimated hourly load curves per activity and electric appliances. The University of Geneva, in collaboration with its industrial partner SIG, is updating the model in view of simulating year 2015. The model, today calibrated on year 2008, replicates well the average behavior at large scale, but of course cannot replicate all local specificities. A part of the territorial variability remains unexplained as seen in Table 1. The comparison of aggregated estimated load curves with real ones shows that the model replicates the most important seasonal and intraday variations. The present simulation can be done for any geographical level for which the required input variables reflecting socio-economic activity and building stock are available. By default it was chosen to use the municipality level since it is the smallest geographical unit having all the required input easily available at the national scale.

This model also opens the perspective of making ex-ante estimations of savings that could be achieved by standard efficiency measure packages. It is also foreseen to use the model to make long term forecasts of the Swiss electric consumption for several scenarios.

Acknowledgements

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References