Normalizing Residential and Commercial Energy Demand for Climatic Conditions

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Overview

In a world with increased international focus on energy use, benchmarking consumption across countries can inform decision makers about their country's relative performance and opportunities for improvement. During the past decades, the energy field has been on the frontline of this exercise with energy consumption-and by association energy intensity and productivity- becoming a considerable dimension for policy-related international cross-country comparison. However, benchmarking is more meaningful when comparisons are normalized for uncontrollable factors. One of these factors is climate variation that occurs across countries.
The aim of this reseach is to provide methodologies to quantify the effect of climate conditions on energy consumption in the residential and commercial sectors as space heating and cooling incrinsgly represent the largest share of building energy consumption in most countries. We developed a time series of population weighted national climate indices which we apply to an econometric analysis to normalize commercial and residential energy consumption relative to world average climate conditions. Results have shown that for countries with extreme weather the normalized residential energy consumption for heating and cooling can change for up to 50%.

Methods

A common way to account for the effect of weather on residential and commercial energy consumption is by using the heating and cooling degree day methodology. This methodology measures the absolute value of the difference between the average daily outside temperature and a reference temperature, usually 18 deg-C (Snyder, 1985). Degrees above the reference temperature are counted as cooling degree days (CDD), and those below are designated as heating degree days (HDD).The bulk of current literature is applied at country-level. Al-Hadrami (2013), Arguez et al (2012), Büyükalaca et al (2001), Badescu et al (1999) have generated degree days respectively for Saudi Arabia, United States, Turkey and Romania. Such lack of a comprehensive and granular weather database that can be used for cross-country climate normalization of energy consumption reflected the need to generate a new one.

The degree days methodology, despite being a suitable climate accounting methodology has two main shortcomings. The first results from the usage of daily temperatures which leads to averaging of any variations in temperature. This conceals the actual need for heating or cooling services. The second relates to the fact that human perception of thermal comfort in not only affected by temperature but also by other climatic factors such as humidity and solar radiation (Franger, 1970; Considine et al, 2000). We approached these issues by incorporating weather parameters developed by the National Oceanic and Atmospheric Administration (NOAA) on a four observations sub-daily means into a set of thermal comfort indices that additionally accounts for relative humidity and solar radiation. Figure 1 below shows a series of potentially applicable thermal comfort indices available in the literature. At the current stage of the study, enhanced heating and cooling degree days were produced using the generated feel-like thermal indices derived from the Summer Simmer Index (SSI) (Pepi et al, 2000) and the Environmental Strain Index (ESI) (Moran et al, 2001) in addition to the improved plain temperature index.

A combination of gridded atmospheric satellite datasets developed by NOAA was used for the purpose of generating enhanced global temperature values as well as the SSI and ESI. The datasets include reanalysis of geo-located climate parameters temperature, humidity, solar radiation and wind on a frequency of four times a day ranging back for 1948 through 2013. These parameters were used to calculate global thermal comfort within grids determined by latitude and longitude at a resolution of 2.5° x 2.5°. Computed indices were later population weighted using Columbia University's Gridded Population of the World (GPW v.3) from 1990 to 2013 and extrapolations from UNEP/SIOUX regional datasets for the years ranging from 1960 to 1990. The population weighting procedure is an important one as to avoid over estimated energy consumption in areas with extreme weather conditions but without resident population. Resulting indices were subsequently downscaled to a resolution of 1.6° x 1.6° using statistical regressions and shaped into national boundaries using GIS geocoding. On a later stage the cooling and heating degree days for each index were calculated by taking the absolute difference between the sub-daily index value and a reference temperature being 18 deg-C or 65 deg-F. As with the case of the plain indices, yearly time series of national values of HDD and CDD from 1960 to 2013 were computed by adding local sub-daily values using GIS geocoding.

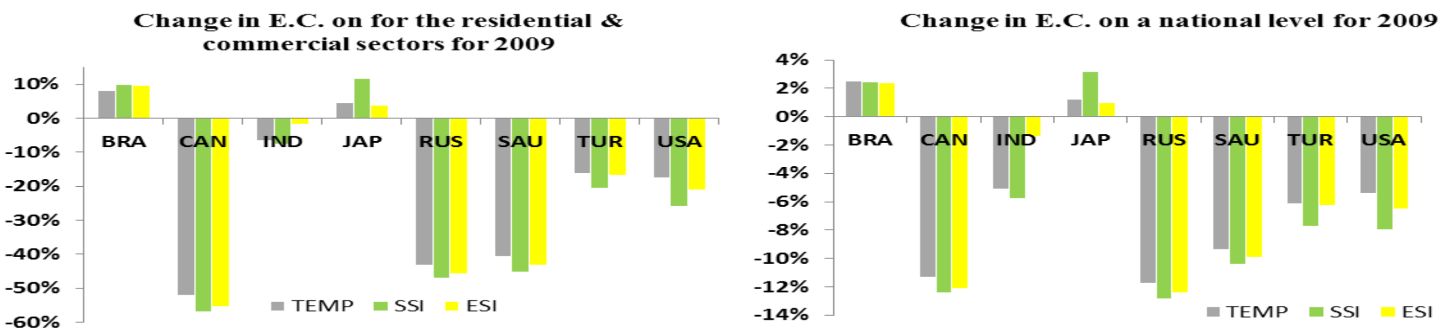
After finishing developing these datasets, a cross-sectional econometric approach was used for climate normalization of residential and commercial energy consumption.We choose ten target countries for a comprehensive representation of various climatic regions and geographical sizes. These countries include areas known for their extreme climate such as Saudi Arabia, Canada and Russia and countries with relatively moderate climes. The effect of geographical aggregation was investigated by comparing countries with similar weather but varying size such as for Japan and the USA. Using the International Energy Agency's extended energy balances (International Energy Agency, 2011) and several national sources that decompose building energy consumption, estimates of the total final energy consumed for heating and cooling in both residential and commercial buildings were generated. These were modeled as a function of GDP, population, energy price and the total degree days. The regression has been undertaken on a logarithmic level in the form of:

$$\ln(\mathrm{TFEC}) = \alpha + \beta_1.\ln(\mathrm{GDP}) + \beta_2.\ln(\mathrm{POP}) + \beta_3.\ln(\mathrm{EPI}) + \beta_4.\ln(\mathrm{TDD}) \qquad \text{(eq. 1)}$$

Where TFEC is the energy consumption for heating and cooling by the residential and commercial sectors in Mtoe, GDP, the Gross Domestic Product at constant 2005$, POP, the population in millions, EPI, the energy price index based on the weighted average of the price of electricity and natural gas for household and commercial usage. In order to avoid multicolinearity problem, a country specific total degree days was generated by summing CDD and HDD after accounting for any potential difference in thermal efficiency between the two. α is a constant that accounts for the effect of random disturbance. The above estimation was repeated three times separately modifying the degree days generated by using different thermal indices. Normalized energy consumption was later evaluated by replacing in each equation the country-specific degree days by the equivalent world average.
Normalization was undertaken on two levels, sectorial and national. Figure 3 below shows the resulting effect on the total final energy consumption for the residential and commercial sectors, along with the total primary energy supply on the national level for the year 2009.

Empirical Results

Normalization was undertaken on two levels, sectorial and national. Figure 1 below shows the resulting effect on the total final energy consumption for the residential and commercial sectors, along with the total primary energy supply on the national level for the year 2009.



<u>Figure 1:</u> Percentage change in energy consumption due to weather normalization on both sectorial and national levels.

Results show that, in general, countries with better than average climate such as Brazil and Japan see their energy consumption increase after normalization, while countries with harsher weather see their energy consumption drastically reduced. Both SSI and ESI show increases in the variation due to normalization when compared to the temperature based index albeit at a varying degree.Countries with extreme weather on both side of the spectrum behaved diversely despite having high total degree days. Canada, Russia and Saudi Arabia all translated into a high reduction in normalized energy consumption averaging respectively 55%, 47% and 40% respectively, on the sectorial level. On the other hand, India, which despite high TDD only recorded an average decrease of 8% on the same level. This can be linked to the country's reduced availability of physical capital (ACs, heaters) limiting the impact of variation of weather conditions on energy consumption. Turkey and the USA, both having moderate clims, reflected only an average reduction of 16% and 18% on a sectorial level while above average countries such as Brazil and Japan saw their energy demand increase by 8% and 7%. Since the energy consumption by residential and commercial sectors form a minimal share of the total primary energy supplied, the change in energy consumption on a national level was limited within the ranges of -12% for Russia and 3% to Japan.

Conclusion and Future Work

The preliminary work on climate normalization adds to the understanding of how weather could affects energy consumption and paves the way for potential unbiased global benchmarking within the contexts of energy intensity and energy productivity. Incorporating additional climatic factors elucidates the effects of weather on sectoral energy consumption. However,the extent of normalization is limited by the availability physical capital.
The research can benefit from further steps, namely by using other methodologies to calculate degree days such as the Heat Index, Universal Thermal Climate Index among others. We are also in the process of expanding the weather dataset to include all the world's countries dating back to 1960, and are scoping using other econometric techniques such as panel and pooled data analysis. Next steps can also include increasing the resolution of the available dataset up to 0.5 °x 0.5 °by using statistical downscaling based on topographic patterns.

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