



# Socio-metabolic profiles of electricity consumption along the rural–urban continuum of Ecuador: Whose energy sovereignty?

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## Abstract

Integrating energy and land use planning for sustainable and resilient human settlements requires a Post-Normal science perspective where actors' views are an essential part of the quality of energy policies assessments. Through qualitative content analysis of interviews to diverse actors in Ecuador, we found two broad contrasting narratives on Energy Sovereignty: a “Hard” and a “Soft” path. By using multivariate statistical analysis of socio-demographic, land use and electricity consumption variables, we derived a typology of parishes with distinct socio-metabolic profiles along the “rural–urban” continuum of Ecuador. Four different types and eight subtypes of parishes spatially organize by processes of suburbanization, functional urban specialization and “new ruralities” or “rural multifunctionality”. Urban centers tend to specialize in service and industrial sectors while suburban and intermediate cities, remote rural areas, and dynamic towns tend to be residential and agrarian. Suburban and intermediate cities and periurban dynamic towns are mosaics of land uses and activities where the “rural” and “urban” intertwine. Looking at these results from the two narratives found, we see how centralized grids and large-scale hydropower through the “Hard” path can sustain uneven patterns of electricity consumption. Contrastingly, under the “Soft” path, distributed energy generation could provide opportunities for multiple small-scale projects of diverse renewable sources. This could help facing the heterogeneity of socio-metabolic profiles and provide enabling conditions for a small-scale and spatially distributed industrialization, instead of centralized traditional ways that reproduce uneven development.

**Keywords** Socio-metabolic profiles · Distributed energy generation · Functional urban specialization · Suburbanization · Energy sovereignty

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## 1 Introduction

In a globalized and fossil-fueled world, urbanization has become a major force on land use change and global resource extraction and consumption (Arboleda 2016; Bai et al. 2018; DeFries et al. 2010; Seto et al. 2012). Urbanization has extended beyond “core cities” to conurbations and interconnected regional urban systems of diverse human settlements along a rural–urban continuum (Baccini and Brunner 2012; Gonzalez-de-Molina and Toledo 2014). The metabolism of these complex urban regions is “the set of conversions of energy, water and material flows which are necessary for its continued existence” (Giampietro et al. 2009, 2013; Gonzalez-de-Molina and Toledo 2014; Krausmann et al. 2017).

Under climate change and peak oil, energy is a key input for urban metabolism (Bulkeley et al. 2011; Smil 2008). Energy transitions are of utmost importance to achieve sustainability and resilience of human settlements (Hussain et al. 2019; Labanca 2017; Molyneaux et al. 2016; Monstadt and Wolff 2015). Understanding spatial patterns of both physical and social factors affecting energy systems enables fruitful integration of urban, landscape and energy planning. Such integrative planning reduces consumption, improves energy efficiency, promotes renewable distributed generation, and enhances resilience (Amado et al. 2016, 2018; Cajot et al. 2017; Kostevšek et al. 2013; Wamsler et al. 2013; Zanon and Verones 2013).

The impacts of urban form, building function and infrastructure density and design on energy demand, have been extensively studied, both in the transport and residential sectors and addressing key energy carriers such as fuel, electricity and heat (Chen and Chen 2015; Evola et al. 2016; Fonseca and Schlueter 2015; Howard et al. 2012; Madlener and Sunak 2011; Rode et al. 2014; Silva et al. 2017). Spatial analyses of distributed energy generation have also mapped the potential for cities to generate energy, especially heat and electricity from solar, wind and biomass residues and urban waste (Badami et al. 2018; Chicco and Mancarella 2009; Colantoni et al. 2016; Fahmy et al. 2020; Malinauskaite et al. 2017; Manfren et al. 2011; Sechilariu and Locment 2016; Tercan et al. 2015; Thomas and Soren 2020; van den Dobbelen et al. 2011). Other studies have integrated both the study of distributed consumption and generation, under “smart city” and “microgrid” approaches (Amado et al. 2017; Avellana and Fernandez 2016; Fish and Calvert 2017; Yamamura et al. 2017).

Complementarily, a growing literature has studied the social construction of “energy landscapes” and have identified different typologies of uniform, scattered or fragmented infrastructure layouts and (un)even distribution of the access to energy carriers and end uses (Broto 2017a; Pasqualetti and Stremke 2018).

Urban energy metabolic flows are shaped by biophysical constraints and social, cultural and political relations and representations, requiring multidimensional and interdisciplinary assessments that consider multiple actors’ narratives and perspectives (Broto et al. 2012; Dijst et al. 2018; Heynen et al. 2006; Hornborg 2001; Newell and Cousins 2015; Swyngedouw 1996). Contemporary environmental problems such as energy and urban planning involve situations where facts are uncertain, values are in dispute, stakes are high and decisions are urgent (Funtowicz and Ravetz 1993). Under these circumstances, the quality of science lies in both the consistency of methodological design and its public relevance and meaning (Saltelli and Giampietro 2017). Thus, interpreting data requires considering alternative actors views and problem framings under the so-called approach of Post-normal Science (Funtowicz and Ravetz 2018).

Adopting this approach we explore the electricity metabolism along the territory of Ecuador by analyzing statistical data on energy, demography and land use and interpreting them according diverse actors' perspectives. This approach, contributes to a dialogue between discursive and planning approaches to energy policies and transitions (Bridge et al. 2018; Isoaho and Karhunmaa 2019) and emergent perspectives on “energy landscapes” and “energy geographies” that search to map and understand both the human and physical geography of energy systems (Bouzarovsky et al. 2017; Calvert 2015).

First, our methodological design contributes to the study of cities using the Multi-Scale Integrated Assessment of Social and Ecological Metabolism (MuSIASEM) methodology (Ariza-Montobbio et al. 2014; Lu et al. 2016; Wang et al. 2017). Exploring and mapping the metabolism of different types of human settlements along the rural–urban continuum of Ecuador we search for factors influencing the “energy landscape” as compared to industrialized or emergent countries (see Sect. 3 for methods and Sects. 5, 6 and 7 for quantitative results). We also contribute to the emergent applied research field on the potential for matching renewable energy consumption and generation in cities (IRENA 2016). Second, we interpret quantitative results under different discourses on the contested notion of “Energy sovereignty” understood as the right of deciding, planning and acting on energy systems, their dynamics and transitions (See Sect. 2 for Ecuador contextual information, Sect. 4 for a qualitative analysis of narratives on Energy Sovereignty and Sect. 8 for discussion and interpretation). Finally, in Sect. 9 we conclude and address policy implications of the results on whose energy sovereignty can be enforced under different scenarios and narratives.

## 2 Case study: landscapes of “energy sovereignty” in Ecuador

Ecuador is, in surface, one of the smallest countries of South America. With nearly 70 inhabitants per square kilometer, it is the most densely populated, especially considering the average population density of South America: 23 inhab/km<sup>2</sup>. Together with Guyana and Paraguay, have low proportion of population living in cities, approximately 63% compared to the continental average of 78% (INEC (Instituto Nacional de Estadística y Censos) 2011; World Bank 2019).

The most energy consuming sector in Ecuador is transport (55%), followed by industry (19%) and household (19%). Commercial and service sector (5%), building (4%) and agriculture (1%) consume a minor part (OLADE 2012). Primary energy comes 79% from oil, 9.3% from hydropower, 6.5% from natural gas, 5.2% from biomass and a negligible part from non-conventional renewable energy (OLADE 2012). The main energy carriers are biomass, LPG, oil derived fuels and electricity. Although Ecuador is an oil exporting country, the domestic capacity to refine oil is low, and more than 50% of their oil-derived fuels are imported (PETROECUADOR 2013). Oil derived fuels are used mainly for transport, but also for generating 42.1% of electricity in thermal plants. The rest of electricity is currently generated by large-scale hydropower (53%), non-conventional renewable sources (1.7%) or is imported from interconnection with Colombia and Peru (3.2%) (CONELEC 2014). Given this energy challenges, Ecuador has been proactive in implementing policies to confront their energy problems and regain control over its own energy and economic system, under a political claim for “Energy sovereignty”. During the last decade (2007–2017) the Ecuadorian Government undertook an important development plan for the “Transformation of the Productive

Matrix” while simultaneously promoting the “Transformation of the Energy Mix” (SENPLADES 2009, 2012, 2013). Both plans, inspired by a Neo-structuralist approach were oriented toward using income from natural resources for promoting, through state intervention, knowledge-based activities that could provide growing returns over time and could allow progressive abandoning on natural resource income dependence (Purcell et al. 2017). The “Transformation of the Energy Mix” plan was directed mainly to generate more than 90% of electricity with eight big hydroelectric projects and increase the oil refining capacity of the country. Through these projects, the Ecuadorian government operationalized its view on “Energy sovereignty”. According to them, it is the right of the State to control and decide about the energy system on behalf of Ecuadorian population aside from foreign companies and the interest of countries from the Global North. However, “Energy sovereignty” is a contested notion with different views and meanings about who should decide, how, and for whose benefits. “Energy sovereignty” can also be understood as the right of local communities to decide on energy issues to ensure local and peoples’ development instead of reproducing the power of the private and bureaucratic elite.

Given this relevant demographic, energy and political context, wondering about “whose energy sovereignty” is actually been enforced; we aim at identifying socio-metabolic profiles of electricity consumption in Ecuador and discuss their policy implications for “Energy Sovereignty” under different perspectives.

### 3 Research design and methods

We designed a three-step methodology. First, during 2014, we conducted 35 semi-structured interviews to diverse actors involved in energy policies in Ecuador. We dialogued with public officials (10), researchers (6), members of civil society organizations (7) and local actors affected by energy projects (12). We addressed actors with relevant roles or substantial public opinions on energy policies. We also made fieldwork in strategic sites of key energy projects such as hydroelectric and oil extraction plants. Original selection was also contrasted and refined through the snowball sampling technique, where actors are asked to refer to other key stakeholders they recommend to interview (Biernacki and Waldorf 1981; Browne 2005). Questionnaires included 20 questions approaching four main topics: (a) the general view on energy and its management; (b) the relation between energy and land use planning; (c) perspective on conflicts about energy generation; (d) democracy, participation and equity on energy planning. Qualitative content analysis of interview transcripts (Bryman 2008) and secondary information allowed us to identify core themes and subjects in controversy among different narratives on Energy Sovereignty, useful to interpret our results coherently with a Post-normal science perspective.

Second, we explored the relationships between electricity consumption and land use and socio-demographic characteristics at the lowest administrative level of Ecuador, the “parroquia” or parish. Ecuador’s administrative division is comprised of 24 provinces, 224 “cantones” or “municipalities” and 1131 “parroquias” or “parishes”. We applied to the total 1131 parishes of Ecuador a multivariate statistical analysis using a set of indicators. This allowed us to derive a typology of parroquias (parishes) with distinct socio-metabolic profiles (see Sects. 3.1 and 3.2 for details).

Third, we finally interpreted the results and their implications for energy and land use policies in Ecuador, by integrating qualitative and quantitative analyses.

### 3.1 Land use, socio-demographic and energy metabolism indicators

The first group of indicators referred to characteristics usually associated to the “rural–urban continuum” and socio-demographic factors influencing energy consumption.

We included multiple indicators of the size, population structure, land use and settlement patterns, household characteristics, and economic dynamism of parishes, as shown in Table 1. Those indicators were built from the most recent census (INEC 2011) and land use data (MAGAP-MAE 2012). We also considered poverty, incorporating the Multidimensional Poverty Index (MPI) as methodologically developed by (Alkire and Foster 2011) and adopted by the National Institute of Statistics and Censuses (INEC, for its acronym in Spanish). The MPI captures deprivations in several dimensions such as education, work, and standard of living, faced by households and individuals.

Second, to better capture the dynamics of electricity consumption we used indicators coming from the broader analytical framework of Multi-Scale Integrated Analysis of Societal and Ecological Metabolism (MuSIASEM) (Giampietro et al. 2009, 2013) (see Table 2 and Fig. 1). Such indicators were calculated by combining the land use and census data above mentioned with electricity consumption data (disaggregated at parish level and by household and economic sectors) for the years 2013 and 2016 (CONELEC 2014, 2017).

### 3.2 The MuSIASEM approach at parroquia (parish) level

The MuSIASEM methodological framework characterizes the societal metabolism of countries (Falconí-Benítez 2001; Ramos-Martin et al. 2007), local agrarian communities (Gamboa 2011; Gomiero and Giampietro 2001) or cities (Lu et al. 2016; Wang et al. 2017) through the combination of information from different dimensions (biophysical, demographic and economic) at various hierarchical scales. Following (Georgescu-Roegen 1971), this approach distinguishes between “Flow” and “Fund” variables, depending on the role they play in the production process. Flow elements, in our case, electricity consumption (Total Electricity Consumption, TEC), are inputs or outputs of the production process and are dissipated to sustain the fund elements, which are the agents that remain qualitatively unaltered and reproduced during the process, and transform input flows into output flows. In the case analyzed, funds are human activity, (i.e., human time use) and land use.

Figure 1 shows the different fund and flow elements we have considered at different hierarchical levels. Table 2 describes MuSIASEM indicators at each level, their calculation, and the purpose they serve in our analysis.

The MuSIASEM framework provides useful indicators for our purpose of understanding spatially disaggregated patterns of electricity consumption. It allows combining geographic, economic and demographic variables that can indicate the roles played by different parishes within the urban system. Intensive variables, such as ratios between flows and funds (Exosomatic Metabolic Rate (EMR) (MJ/hour of activity), TEC/THA, or the Total Electricity Consumption per hectare (TECha) (MJ/ha), TEC/TAL (see Table 2)), are useful for generating benchmarks for comparison between parishes of different sizes and roles.

**Table 1** Socio-demographic and land use indicators with their description, unit of calculation and dimension they formally represent. Source: Own elaboration

Variable name	Variable description and unit of calculation	Indicators of...
<i>Socio-demographic characteristics</i>		
Total population	Total number of inhabitants	Size
Number of households	Total number of households	Aging and population structure
Dependency ratio	Ratio between active population (15–65 years old) and the dependent part (0–15 and over 65). Expressed in percentage (%)	Economic dynamism
%Households with commuting members	Fraction of the households with some member commuting every working day. Expressed in percentage (%)	Role played in the urban system
%Households with some member commuting for studies	Fraction of the households with some member commuting every working day for studies. Expressed in percentage (%)	Daily labor mobility needs
%Households with some member commuting for work	Fraction of the households with some member commuting every working day for work. Expressed in percentage (%)	Prevalence of inequalities
Incomplete education attainment (%)	Fraction of the population which have not finished basic education. Expressed in percentage (%)	Prevalence of poverty
Multidimensional poverty index (MPI)	Simultaneous deprivations in dimensions such as education, work, and standard of living, faced by households and individuals	Size of households
Average number of people by HH	Average number of people living in the household	Access to services
Distance to > 5000 inhab. population centers	<i>Land use and settlement pattern</i> Distance to other population centers of more than 5000 inhabitants. Expressed in kilometers (km)	Daily labor mobility needs
% of population living in rural areas	Proportion of the population that lives in areas considered Rural by the INEC classification. Expressed in percentage (%)	Structure of the settlement pattern
% of population living in urban areas	Proportion of the population that lives in areas considered Urban by the INEC classification. Expressed in percentage (%)	
Population density	Density of population in total available land of the municipality. Expressed in inhabitants per square kilometer (inhab/km <sup>2</sup> )	
<i>Factors influencing household electricity consumption</i>		

**Table 1** (continued)

Variable name	Variable description and unit of calculation	Indicators of...
% of households with access to electricity	Fraction of the households with access to electricity. Expressed in percentage (%)	Factors influencing household electricity consumption
% of households that use gas (cistern) for cooking	Fraction of the households which use gas cisterns as fuel for cooking. Expressed in percentage (%)	
% of households that use electricity for cooking	Fraction of the households which use electricity for cooking. Expressed in percentage (%)	
% of households that use firewood and charcoal for cooking	Fraction of the households which use firewood and charcoal as fuel for cooking. Expressed in percentage (%)	
% of households with access to Internet	Fraction of the households with access to Internet. Expressed in percentage (%)	
% of households with computer	Fraction of the households with computer. Expressed in percentage (%)	
% of households with TV cable	Fraction of the households with TV cable. Expressed in percentage (%)	

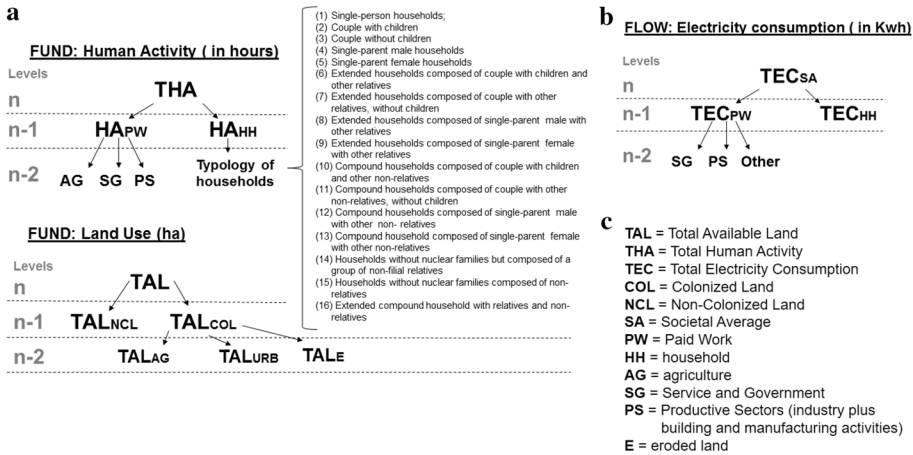
**Table 2** MuSIASEM indicators with their description, calculation and usefulness for the purpose of the analysis. Source: Own elaboration

Level	Acronym	Variable name and explanation	Unit and calculation	Usefulness for our purpose/fund or flow?
<i>Socio-demographic characteristics</i>				
<i>n</i>	THA	<b>Total Human Activity.</b> Total human time a society has available for conducting different activities.	Hours (h) (total population times 8760 h of a year)	<b>Fund</b>
<i>n</i> – 2	HAP <sub>w</sub> <sub>i</sub>	<b>Human Activity dedicated to work, paid through the market, in the given sector (“<i>w</i>”) and municipality.</b> We divide the working population in agriculture (AG), productive sector (PS) and Services and Government (S&G).	Hours (h) or share (%) (total population employed in the sector times the average daily working hours a year)	The sectoral distribution of activity indicates degrees of “rurality-urbanity”
<i>n</i> – 2	% HHType <sub>i</sub>	<b>Fraction of the population living in a given household type “<i>i</i>”.</b> We divide the household types in the sixteen categories given by Census data (INEC 2010); (see Fig. 1)	Expressed in percentage (%)	
<i>Land use</i>				
<i>n</i>	TAL	<b>Total available land:</b> Total available surface of the municipality	Expressed in hectares (ha)	<b>Fund</b>
<i>n</i> – 1	TAL <sub>NCL</sub>	<b>Non-colonized land:</b> surface covered by forests and water bodies, non-used either for agricultural or residential purposes.	Expressed in hectares (ha) or in percentage (%)	The land use pattern indicates degrees of “rurality-urbanity”
<i>n</i> – 2	TAL <sub>AG</sub>	<b>Agricultural land:</b> surface dedicated to agricultural activities	Expressed in hectares (ha) or in percentage (%)	
<i>n</i> – 2	TAL <sub>URB</sub>	<b>Surface dedicated to urban areas (out of Total Available Land)</b>	Expressed in hectares (ha) or in percentage (%)	
<i>n</i> – 2	TAL <sub>E</sub>	<b>Surface with eroded soil</b>	Expressed in hectares (ha) or in percentage (%)	
<i>Energetic metabolism indicators</i>				



**Table 2** (continued)

Level	Acronym	Variable name and explanation	Unit and calculation	Usefulness for our purposes/fund or flow?
$n$	$TEC_{SA}$ (or $TEC_t$ )	<b>Total Electricity Consumption:</b> total electricity consumed in a year in the aggregate level of the whole municipality ("Societal Average. SA") or in a given in a given socio-economic sector ("Y")	Expressed in Kwh	<b>Flow</b>
$n/n-1$	$EMR_{SA}$ (or $EMR_t$ )	<b>Exosomatic Metabolic Rate:</b> electricity consumption per hour of human time available to the municipality ("SA") or per hour allocated to a given socio-economic sector ("Y")	$TEC_{SA}/THA$ (or $TEC_t/HA_t$ ) Measured in megajoules per hour (MJ/h)	<b>Flow-Fund</b>
$n-1$	TEC per ha	<b>Total Electricity Consumption</b> in total available land: electricity consumption in household, services and industrial sectors per hectare of the total surface of the parish	$TEC_{SA}/TAL$ Measured in megajoules per hectare (MJ/ha)	Flow-Fund
$n-2$	TEC per ha_urban area	<b>Total Electricity Consumption</b> in urban area: electricity consumption in household, services and industrial sectors per hectare of urban area	$\Sigma TEC_{SA \& G.I.S. HH} / \Sigma LU_{HH}$ $_{PWPS}$ Measured in megajoules per hectare (MJ/ha)	<b>Flow-Fund</b>
$n-1$	TEC per HH	<b>Total Electricity Consumption per household:</b> total electricity consumed in a year per household	TEC/number of households (HH) (MJ/HH)	<b>Flow-Fund</b>
$n-1$	TEC per person in the HH	<b>Total Electricity Consumption per person living in the household:</b> total electricity consumed in a year per person living in a household	TEC/person in the household (MJ/person in the HH)	<b>Flow-Fund</b>



**Fig. 1** Dendograms of the different fund (a) and flow (b) elements at different hierarchical levels. We provide also the definition of acronyms (c). *Source:* Own elaboration

**Table 3** Main results of Principal Component Analysis. Values in **bold** are those factor loadings closer to or higher than 0.5 and values underlined are those closer to or higher than 0.5 but with negative values *Source:* Own elaboration

	F1: "Rural-Urban"	F2: "Suburban"	F3: "Industrial"	F4: "Electricity metabolism"
Eigenvalue	2.81	1.80	1.30	1.10
Variability explained (%)	31.25	20.07	14.44	12.29
% accumulated	31.25	51.32	65.77	78.06
%TAL_AG	-0.142	<b>0.815</b>	-0.384	-0.013
%TAL_NCL	<b>0.683</b>	-0.339	<b>0.475</b>	0.039
Average distance to > 5000 inhabitants center	<b>0.658</b>	-0.324	0.223	-0.032
%THApwag	<b>0.841</b>	0.366	-0.139	0.213
%THAps	<u>-0.570</u>	0.083	<b>0.581</b>	-0.429
2013TEC_SA (kWh)	<u>-0.571</u>	-0.131	0.155	<b>0.561</b>
2013%TECpw	-0.297	0.243	0.415	<b>0.687</b>
%Households with commuting members	-0.053	<b>0.675</b>	<b>0.514</b>	-0.271
Population density	<u>-0.665</u>	<u>-0.501</u>	-0.243	-0.120

### 3.3 Identifying and characterizing parish typologies through multivariate statistical analysis

Following previous applications of clustering procedures based on multivariate statistical analysis (Ariza-Montobbio et al. 2014; Köbrich et al. 2003) we applied Principal Component Analysis (PCA) (Abdi and Williams 2010) and Hierarchical Cluster Analysis (HCA) (Härdle and Simar 2012) to a selection of the above described indicators for a total data set of 1131 parishes.

First, we selected indicators (see Table 3 in Sect. 5) representative of the several dimensions relevant to explore relationships between profiles of electricity consumption and the rural–urban characteristics and roles within urban systems of different types of parishes. Examples are indicators related to the economic dynamism, access to services, daily mobility needs or employment attraction. For a meaningful analysis we selected indicators highly correlated with indicators of other dimensions and dismissed those highly correlated with variables representing the same dimension.

Second, principal components (or factors) derived from PCA, allowed us to identify important patterns of similarity among data. Third, HCA grouped data in different clusters according to patterns of similarity defined by PCA. This process allowed us to identify the parish types according to the emerged clusters.

Forth, further characterizing the differences between parish types we used statistical tests for variance analyses. Shapiro–Wilk normality test (Shapiro and Wilk 1965) revealed nonparametric distribution for all indicators considered. Thus, through the nonparametric test Kruskal–Wallis one-way analysis of variance by ranks (Kruskal and Wallis 1952) we compared values of all indicators (as shown in Table 1 and 2) in order to find significant differences between parish types. Fifth, and last, we calculated uni-variate and bi-variate Moran's Index of Spatial Autocorrelation (Moran 1948) in search of significant patterns of spatial distribution and autocorrelation of variables.

## 4 Energy sovereignty in Ecuador: contrasting narratives

Through qualitative content analysis of 35 interviews, we found that Ecuadorian actors' discourses gravitate between two broad ideologically contrasting views on “Energy Sovereignty”. Hajer (1995) from an argumentative approach<sup>1</sup> to the policy process, offers a method for discourse analysis. Following Hajer (1995)'s approach, we take both political proposals as “discourse coalitions” where a specific narrative or “story line<sup>2</sup>” is constructed by different actors,<sup>3</sup> which through their discourse contribute to building the coalition. The two main story-lines identified differ in three aspects: (a) the view on energy and its role in nature and society; (b) the view on the energy “mix” or “system”; (c) the view on territorial and spatial configuration and scales interrelation. The first story-line on Energy Sovereignty that we would call the “Hard path<sup>4</sup>” starts by seeing energy as a resource which can and should be appropriated from nature either as an strategic public resource (owned

<sup>1</sup> The argumentative approach considers discourse as constitutive of the realities of environmental politics. The environmental conflict is not only about which actions to be taken, but about the meaning of social-ecological problems (Hajer 1995).

<sup>2</sup> “Narratives on social reality through which elements from many different domains are combined and that provide actors with a set of symbolic references that suggest a common understanding” (Hajer 1995: 62).

<sup>3</sup> The story-lines are often feed or promoted even by actors which don't defend certain ideas, but through mentioning or even negation, consciously or not, help to consolidate different story-lines, even the rival ones. In this view, discourse coalitions differ from advocacy coalitions (Sabatier 1987). Actors rather than purely holding certain belief systems (individualist ontology) learn and change positioning through language and discourse and have different practices and discourses in different contexts (relational ontology). Language is not a mean, is part of the reality. Policy discussion goes beyond scientific “objective” discussions about “facts” to engage also with political discussions about “values”.

<sup>4</sup> We adopt the “Hard” and “Soft” path labels from previous work (Ariza-Montobbio 2013; Szarka 2007) and from the inspiration of Lovins (1977) who was one of the first authors to propose different development and transition pathways to renewable energies.

by the State) or as a commodity to be traded in markets. Society can extract energy in a responsible manner because nature is robust and can absorb environmental impacts. Raises in people's income and well-being can compensate for environmental externalities. The discussion of energy is a techno-economical one led by experts and scientists. Managing energy is oriented toward the administration of the energy mix understood as the structure of primary energy sources (oil, natural gas, hydropower, sun, wind, biomass, etc.), energy carriers (electricity, fuel and heat), and end uses (economic sectors). Finally, the "Hard path" view prefers top-down energy planning from State institutions from a Nation-state territorial perspective. Under this "homogenous" approach, the important matter is to provide the same energy services to all citizens through mass-scale centralized infrastructures.

A second contrasting story-line, the "Soft path", views energy as a foundation of life, not a resource at human disposal. Energy is a flow, not a stock where to extract revenue. Therefore, energy is a human right or a common good. Human use of energy should carefully consider fragile dynamic equilibriums of heterogeneous and diverse social-ecological systems. Taking decisions on energy issues is a social, cultural and political discussion that should be transdisciplinary and participatory. Managing the "energy system" requires debate on the structural and social organization of society, human needs and social and ecological relations. Decentralized energy sources can help reducing environmental impacts. Adapting generation and consumption to the context of diverse and heterogeneous social-ecological systems provides a clue to articulate scales from local to regional, national and global.

The "Hard path" tends to be supported and discursively reproduced by State officers or public officials and the "Soft path" by non-governmental organizations, local governments and communities affected by new and old large-scale energy projects. However, the interviewees mix perspectives of both discourses, particularly when researchers or members of political parties are interviewed (see Acosta et al. (2014) and Ariza-Montobbio (2015) for further analysis).

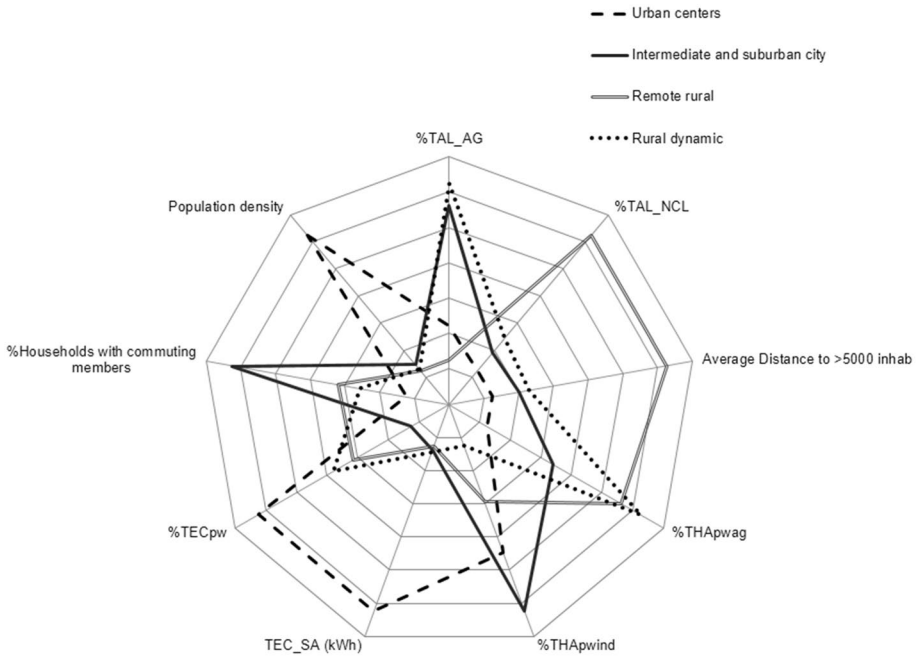
## 5 *A parish typology along the rural–urban continuum and the urban system*

Our quantitative methodological process derived a typology of parishes composed of four main types and eight subtypes, along the rural–urban continuum:

1. Urban centers,<sup>5</sup> composed of the subtypes of dense urban centers, low-density urban centers and industrial centers;
2. Intermediate and suburban cities;
3. Remote rural villages comprised of rural villages and remote villages and
4. Dynamic rural parishes comprised of dynamic rural towns and dynamic periurban towns (see Figs. 2, 3 and 4).

The typology resulted from four main principal components (factors) which explained the 78% of the variability of the sample and grouped the nine most significant indicators

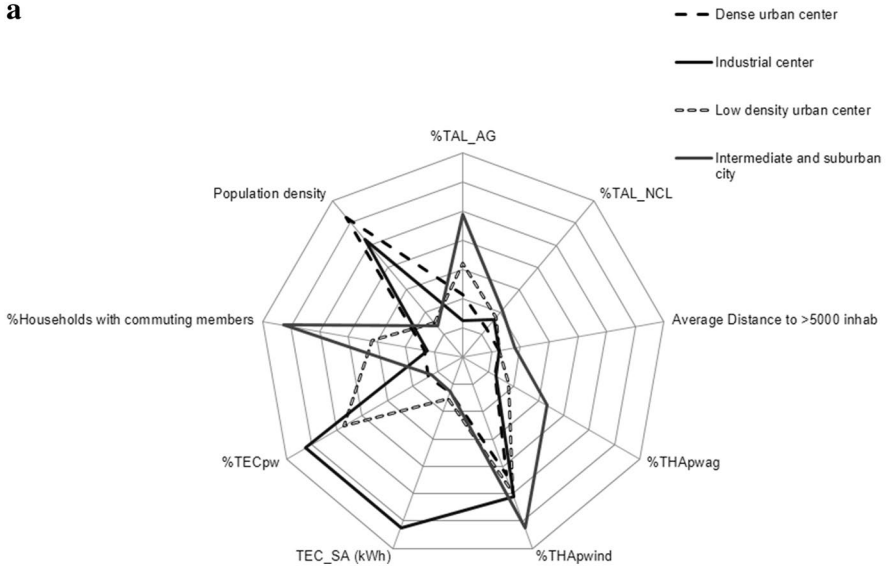
<sup>5</sup> Along the text, we use italics to highlight the names of types and subtypes of parishes as an emergent concept derived of our results to distinguish them from a general use of the same words.



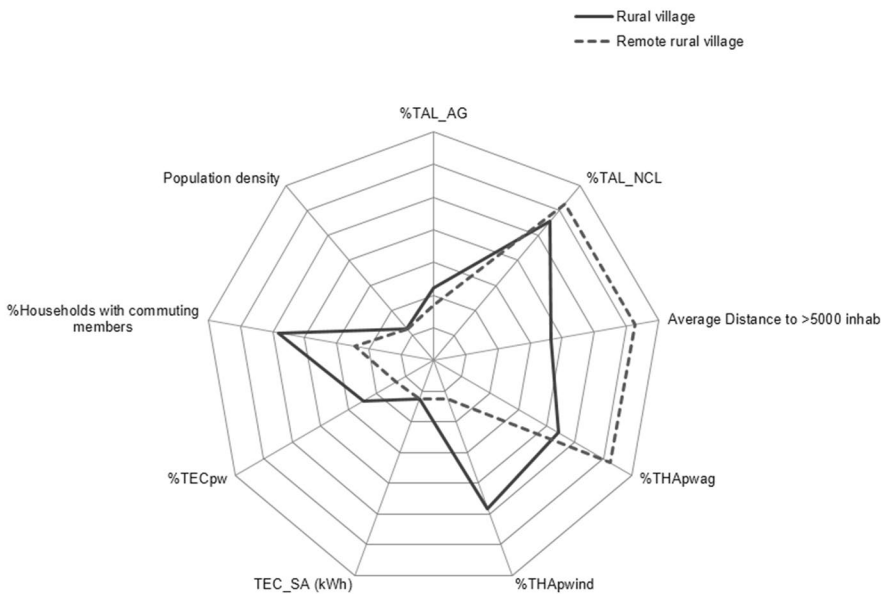
**Fig. 2** Typology profiles according to the main clustering variables. *Source:* Own elaboration

(see Table 3). Factor F1 is explained by variables related to “urban” characteristics (negative underlined variables) such as population density,  $TEC_{SA}$  or  $\%THA_{PS}$  or “rural” characteristics (positive variables in bold) such as  $\%THA_{PWag}$ ,  $\%TAL_{NCL}$  or the average distance to population centers bigger than 5000 inhabitants. This “Urban–Rural” factor explains the existence of *urban centers* and *remote rural* types. F2, with key contributing variables such as population density, percentage of households with commuting members and  $\%TAL_{AG}$  introduce the “suburban” component which explains the *intermediate and suburban city* type and the subtype of the *low-density urban centers*. Finally, factors F3 and F4 explain the emergence of the *dynamic rural* and the *industrial centers*. Those factors are grouping around variables linked to relative higher importance of the industrial sector such as  $THA_{PS}$  or  $\%TEC_{PS}$ , driving to higher  $TEC_{SA}$ . In addition,  $\%TAL_{NCL}$ ,  $\%THA_{ps}$  and  $\%Households$  with commuting members, in F3, suggest the differentiation between *dynamic rural village* and *dynamic periurban towns*. *Dynamic rural villages*, with higher proportion of their land allocated to forests and other natural ecosystems and higher proportion of population working in agriculture are located further from urban centers. Lower percentage of households with some of their members commuting back and forth suggest that *dynamic rural villages* have lower daily connections to urban centers than *dynamic periurban towns*.

**a**



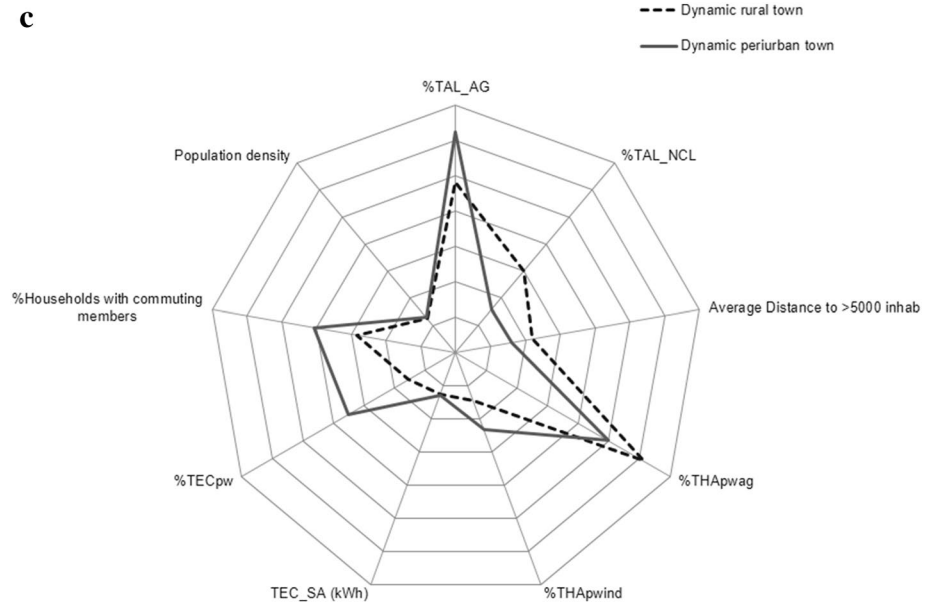
**b**



**Fig. 3** Subtypology profiles according to the main clustering variables. The three radar graph show the comparison between **a** urban and suburban subtypes; **b** remote rural subtypes; **c** rural and periurban dynamic subtypes. *Source:* Own elaboration

### 6 Suburbanization and functional urban specialization

Figures 5 and 6 show the spatial distribution of the four types and eight subtypes of parishes along the rural–urban continuum of Ecuador. The population distribution is abruptly skewed



**Fig. 3** (continued)

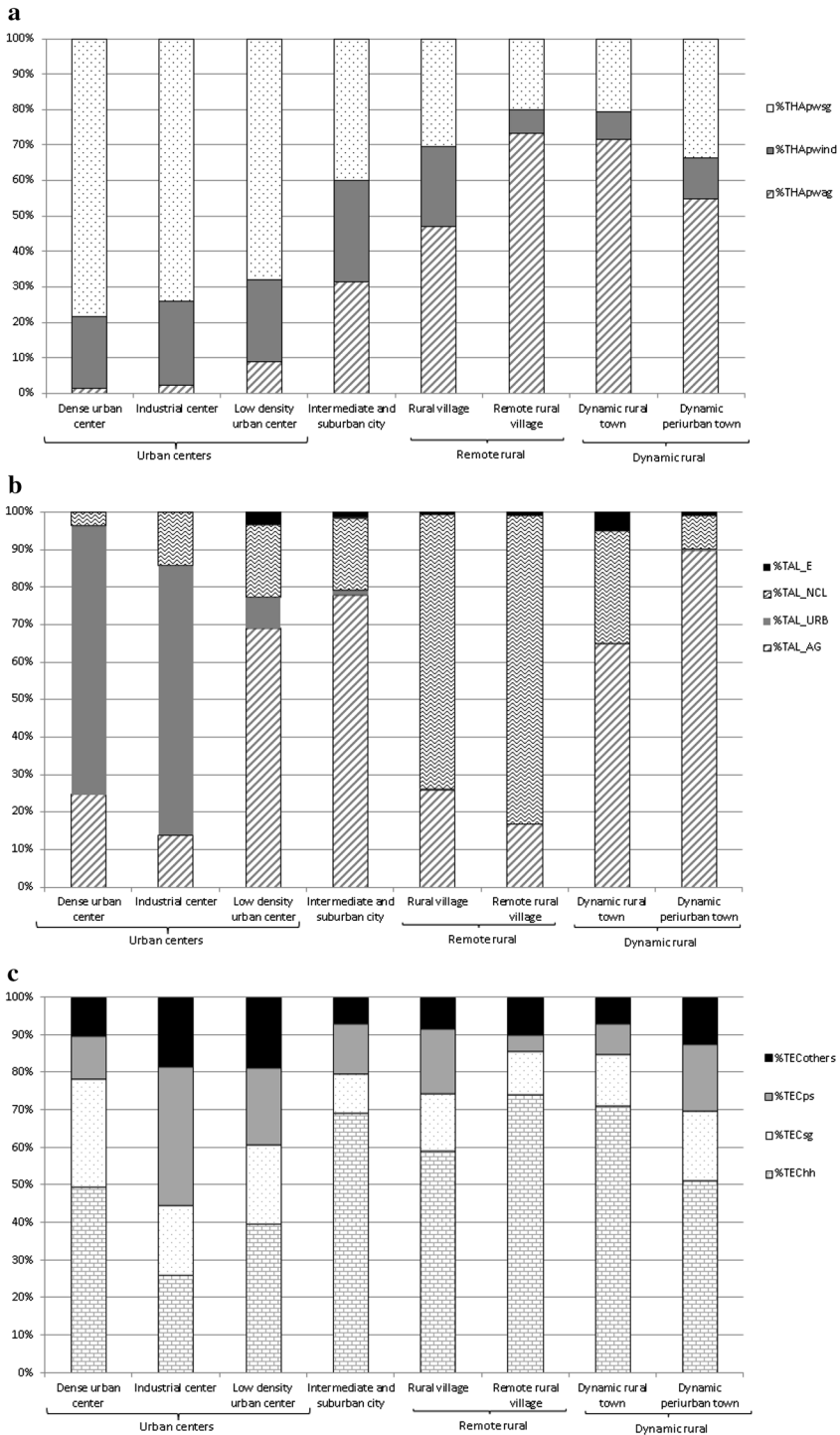
toward the *urban centers* which, occupying only the 2.4% of the territory and representing only the 10% of the total 1311 parishes, concentrate the 49.6% of the population (see Table 4).

Dense *urban centers* (5558.3 inhab/km<sup>2</sup>), surrounded by *low-density urban centers* (740.6 inhab/km<sup>2</sup>) and *intermediate and suburban cities* (249.7 inhab/km<sup>2</sup>) characterize the conurbations of Quito and Guayaquil. Particularly around Guayaquil, we also found *industrial centers*. The rest of parishes (the 72%) belong either to the category of *rural dynamic* or to *remote rural*, occupying the 93% of the Ecuadorian territory but comprising only the 36.3% of the population. The *rural dynamic* type is more prevalent in the Coastal region, particularly toward the South, and nearby urban areas, while *remote rural* is characteristic of the Amazon region, the North of the Coastal region and some parts of the interandean valleys in the Andean Region. As also shown in Figs. 5 and 6, there is a significant spatial autocorrelation of the variable parish type and subtype particularly where there are prevalence and concentration of the same type (High–High or Low–Low). Example of this pattern is grouping of *rural dynamic* in the Coastal region or *urban centers* in Quito and Guayaquil, and in conurbation areas where different types and subtypes urban, suburban and rural are, concentrically, one next to the other (High–Low, Low–High).

The skewed distribution of population and the distribution of different parish types and subtypes coincide to some extent with the distribution of the Multidimensional Poverty Index (MPI) (see Fig. 7) showing that MPI tends to be higher in *remote rural* areas and lower in *urban centers*.<sup>6</sup>

The *suburban and intermediate cities* of Ecuador occupy the double the area of urban centers due to their lower density and are home for 14% of the country's population.

<sup>6</sup> Lack of disaggregated electricity consumption and land use data at census tract limited the possibility of using census tract as the unit of analysis for the research. Analysis at finer scales could have revealed urban inequalities within parishes.



**Fig. 4** Structure of **a** human time (THA) and **b** land use funds (TAL) and **c** electricity consumption flow (TEC) variables by subtype. *Source:* Own elaboration



Considering that other 21% of Ecuadorians live in *low-density urban centers* (see Table 4) approximately 35% of the population and 6.3% of the area of Ecuador is under processes of suburbanization. The suburban parishes apart from being low-density settlements, are residential areas where there are significantly more people commuting daily for work or for studies (11% of the population) than in the *urban centers* (7% for work, 2% for studies) or the rural parishes (around 6% for both reasons) (see Table 5).

## 6.1 The paid work sector

The distribution of human activity and electricity consumption show a functional urban specialization between services oriented *urban centers*, periurban *industrial centers* and residential *intermediate and suburban cities*.

*Industrial centers* consume the 42% of electricity in industry, while dense and low-density urban parishes consume 18–22% (see Fig. 4c). The share of working time dedicated to industry tends to be higher in *suburban intermediate cities* (29%), *urban centers* (22%) and *industrial centers* (24%) as compared to 9–15% in rural areas (see Fig. 4a). Industrial activities tend to concentrate in periurban areas with lower population densities and higher electricity consumption per hectare (Fig. 8) where workers come to work from urban centers and especially residential suburban areas, which have higher shares of people commuting for work (see Table 5).

The *urban centers*, instead, tend to specialize in service and government activities consuming 25% of their electricity and dedicating 75% of their working hours on services (compared to 40% of the working time in suburban parishes and 25% in rural areas, see Fig. 4a and Table 5). The *dense urban centers* subtype consumes, in relative terms, even more electricity on services, the 38%, in comparison with other urban subtypes (industrial or low density), or periurban dynamic towns (18–20%) (see Fig. 4c).

## 6.2 The household sector

The dynamics of the household sector show also the parish typologies specialization in either residential, industrial, service or agrarian activities. While due to their bigger size, the urban centers consume in absolute terms one order of magnitude more of electricity than the intermediate and suburban cities in the household sector, and their Energy Metabolic Rate (EMR<sub>hh</sub>, MJ/h) is slightly higher, the suburban parishes consume the majority of the electricity in the household sector (73%) (see Table 6 and Fig. 9). The rural parishes have a similar share, about 67%. Although rural areas consume the majority of the electricity in the household sector due to lesser industrial and service activity, when looking at the consumption per household, in cities it is 50% higher than in suburban areas and more than the double of rural households. Although rural households are bigger than urban ones, their electricity consumption per person living in the household is much lower; nearly a third of urban households and nearly a half of suburban ones (see Table 6). Likely explanatory factors could be:

- (a) The lower percentage of households with access to electricity in rural parishes (81–86%) compared to urban ones (94–97%)
- (b) Considerably higher access in urban parishes to computer (17–43% compared to 7–9% in rural areas), Internet (5–23% compared to 2% in rural areas) and TV Cable (9–25% compared to 8% in rural areas).

**Fig. 5** **a** Ecuador's location map; **b** spatial distribution of parish types along the rural–urban continuum of Ecuador; results of Moran's Index in **c** chart and **d** map. *Source:* Own elaboration based on CONELEC (2014, 2017), INEC (2011), MAGAP-MAE (2012) and <https://hub.arcgis.com/>

However, elements of traditional rural lifestyle could be also indicators of different lifestyles and factors related also to human behavior, not only available equipment:

- (a) Higher percentages of firewood or charcoal uses for cooking in rural areas (19–28%) compared to urban ones (0.7–12%)
- (b) Lower access to natural gas for cooking in rural parishes (70–78%) compared to urban ones (86–95%).

Although is too soon to identify a solid trend, by comparing the data of electricity consumption by sectors between 2013 (Table 6) and 2016 (Table 7), the household sector has doubled its consumption in *suburban and intermediate cities*. As other references emphasize (Fichera et al. 2016; Williams 2007), the importance of the household sector as driver of resource consumption in suburban areas requires more research and public policies responding to such emergent phenomenon.

## 7 Rural–urban continuum: where the urban and the rural intertwine

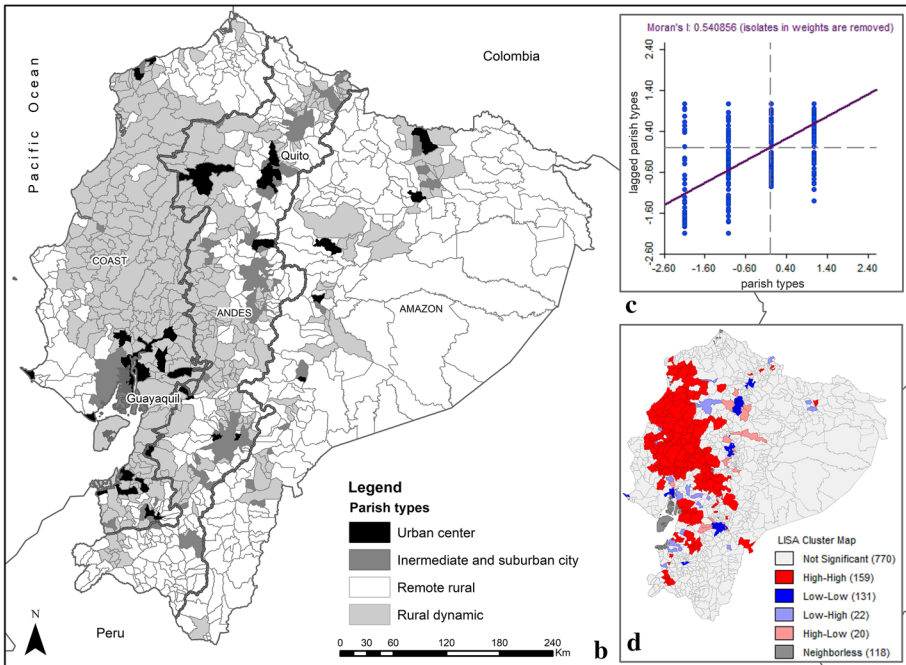
The process of suburbanization comes together with inefficient and dissipative patterns of energy consumption through functional urban specialization between residential, industrial and service/commercial oriented areas. However, in the case of Ecuador, in contrast with other studies in industrialized countries (Ariza-Montobbio et al. 2014; Lobo and Baena 2009), also comes with the concurrence of urban and rural dynamics mixing in the suburban spaces.

According to the definition of urban and rural areas used by INEC,<sup>7</sup> in the urban parishes 77–100% of the population lives in urban areas while in rural parishes, it is the 4–10%. In the periurban dynamic towns and the suburban and intermediate city, the urban population is 21–23%, while the rural is 77–79%. The suburban spaces, although they are close to big cities and heavily influenced by urban lifestyles, have a significant number of the population living in “rural” areas. Around the 31% of people's time is dedicated to agriculture, nearly equal to other activities such as industry (29%) or service (40%) (see Fig. 4a). This figure contrasts with the expectable 1–8% of working hours dedicated to agriculture in cities or the 50–70% in the rural villages. Agriculture is also an important land use in the suburban spaces (68% of the parish surface) which have a similar share than rural towns but lower than dynamic periurban towns (90%) (see Fig. 4b).

<sup>7</sup> The definition of rural and urban areas is a controversial one. However, the “Instituto Nacional de Estadísticas y Censos” (INEC), defines an “urban” area as “the urban settlements which are province capitals and *cabeceras cantonales* (main cities of a municipality, a group of parishes)” and “rural” area as “parish capitals and dispersed and peripheral population areas” (SIISE 2018).



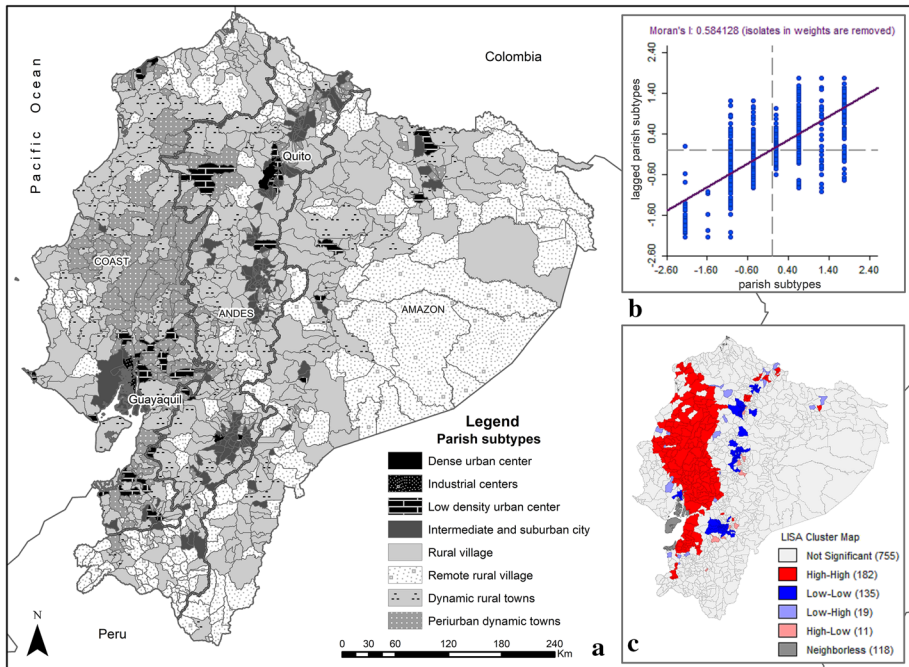
**a**



**c**

**b**

**d**



**Fig. 6** a Spatial distribution of parish subtypes along the rural–urban continuum of Ecuador; results of Moran's Index in **b** chart and **c** map. *Source:* Own elaboration based on CONELEC (2014, 2017), INEC (2011) and MAGAP-MAE (2012)

## 8 Discussion: uneven socio-metabolic profiles: Whose energy sovereignty?

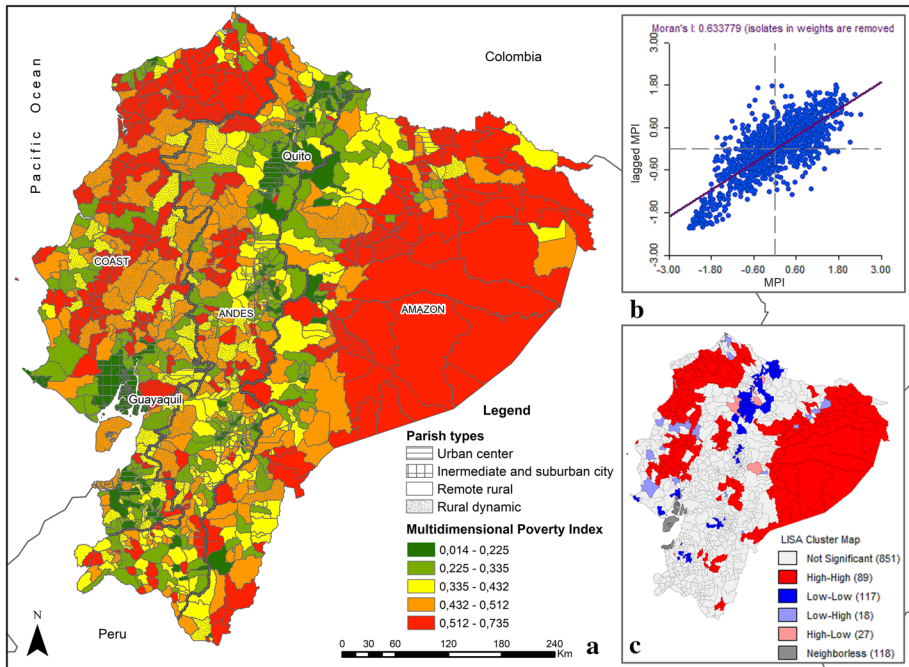
Ecuador's Constitution declares energy as a strategic sector. According to article 313, energy has such a decisive economic, social, political and environmental relevance that its development has to be oriented to the fulfillment of citizen rights and the social interest. The state has exclusive control and decision making over energy. Thus, the “Transforming the Energy Mix” and “Transforming the Productive Matrix” projects have been reclaiming the “Energy sovereignty” of the nation (Bridge et al. 2018; Fitz-Henry 2015; Purcell and Martinez 2018).

The central Government promoted big hydroelectric plants, oil refineries and induction ovens without citizens and local governments direct and active participation (Fitz-Henry 2015; Purcell et al. 2017; Purcell and Martinez 2018). This view is closer to “Energy security” than to “Energy sovereignty” because does not focus on local planning and peoples' decision making over energy (Cherp and Jewell 2014; Broto 2017b; Laldjebaev et al. 2016). Looking at our results, the government approach lies closer to the “Hard path” view rather than the “Soft path”.

Our data does not allow identifying direct spatial and regional effects of “Transforming the Energy Mix” and “Transforming the Productive Matrix” projects. However, our results show socio-metabolic profiles and electricity consumption patterns relevant to discuss how different understandings of Energy Sovereignty can approach the effects

**Table 4** Summary of main characteristics of the typology found in our research. Source: Own elaboration

Types	Subtypes	Number of parishes		Total Population		Total surface occupied		Population density	
		Absolute value	%	Absolute value	%	Absolute value	%	Average	
Urban centers	Dense urban centers	<b>119</b>	<b>10.5</b>	<b>7,181,263</b>	<b>49.6</b>	<b>606,384.1</b>	<b>2.4</b>	<b>5558.3</b>	
	Industrial center	59	5.2	2,484,385	17.2	46,440.1	0.2	8328.1	
	Low-density urban centers	4	0.4	1,675,477	11.6	28,972.2	0.1	8897.4	
Intermediate and subrurban cities		56	5.0	3,021,401	20.9	530,971.9	2.1	740.6	
		<b>194</b>	<b>17.2</b>	<b>2,027,174</b>	<b>14.0</b>	<b>1,072,146.5</b>	<b>4.2</b>	<b>249.7</b>	
Remote rural	Intermediate and subrurban cities	194	17.2	2,027,174	14.0	1,072,146.5	4.2	249.7	
		<b>436</b>	<b>38.5</b>	<b>1,735,524</b>	<b>12.0</b>	<b>16,196,532.8</b>	<b>63.6</b>	<b>66.1</b>	
Dynamic rural	Rural village	243	21.5	1,311,812	9.1	7,107,073.6	27.9	37.0	
	Remote rural village	193	17.1	423,712	2.9	9,089,459.1	35.7	14.4	
Dynamic rural town		<b>382</b>	<b>33.8</b>	<b>3,528,126</b>	<b>24.4</b>	<b>7,584,136.2</b>	<b>29.8</b>	<b>27.0</b>	
		257	22.7	1,679,795	11.6	5,129,483.1	20.1	48.4	
		125	11.1	1,848,331	12.8	2,454,653.1	9.6	102.3	
Total/average at ecuador level		<b>1131</b>	<b>100.0</b>	<b>14,472,087</b>	<b>100.0</b>	<b>25,459,199.7</b>	<b>100.0</b>	<b>577.1</b>	



**Fig. 7** **a** Spatial distribution of Multidimensional Poverty Index (MPI) along Ecuador (intervals are represented by using quartiles) and municipality types along the rural–urban continuum of Ecuador; results of Moran’s Index in **b** chart and **c** map. *Source:* Own elaboration based on INEC (2011)

of suburbanization, functional urban specialization and “new ruralities” in energy consumption.

We have found that electricity consumption unevenly distributes along the rural–urban continuum of Ecuador, expressing spatial inequalities related to skewed and centralized access to energy services and infrastructures. Four different types and eight subtypes of *parishes* have distinct socio-metabolic profiles. While *urban centers* tend to specialize in the service sector and the industrial sector in their peripheries, *suburban and intermediate cities* and *rural parishes*, either *remote* or *dynamic*, are mainly residential or agricultural areas. These results are consistent with processes of suburbanization, understood as low-density urban development which separates and segregates land uses, functions and social groups in different and unequal areas connected through roads and highways (Delgado Ramos 2019; Jordán et al. 2017; Ewing and Hamidi 2015; Roberts and Wilson 2009; Olarte 2019).

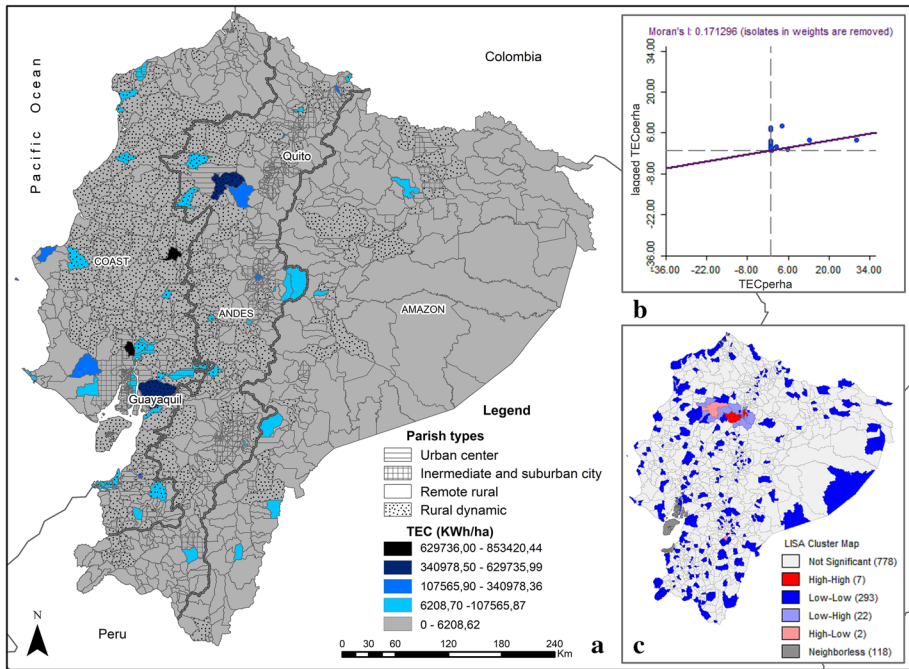
Suburbanization usually comes together with functional urban specialization where different cities and urban areas specialize in specific functions either service, industry, or residential (Duranton and Puga 2005; Lu et al. 2016; Wang et al. 2017; Jordán et al. 2017).

Suburbanization and functional urban specialization imply more energy consumption due to commuting and private transport, bigger and detached households with more rooms, appliances, higher electricity and heating demands (Ewing and Hamidi 2015; Rode et al. 2014; Silva et al. 2017). Social segregation and inequalities drive more energy consumption of the richer and less access to energy services for the poorer (Pereira and Assis 2013).

**Table 5** Results of Kruskal-Wallis test in socio-demographic variables (all variables showed a non-normal distribution under Shapiro-Wilk test

Type	1: Urban centers (n = 119)		2: Intermediate and suburban city (n = 194)		3: Remote rural village (n = 436)		4: Dynamic rural towns (n = 382)		$\chi^2$
	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.	
Total population (number of inhabitants)	<b>60,346.75<sup>C</sup></b>	113,798.83	10,449.35 <sup>B</sup>	18,776.30	3980.56 <sup>B</sup>	6685.89	9235.93 <sup>A</sup>	11,504.23	370.22
Number of households	<b>16,353.59<sup>C</sup></b>	29,950.88	2728.78 <sup>B</sup>	4907.38	993.10 <sup>B</sup>	1709.59	2366.65 <sup>A</sup>	2914.15	393.46
THA (h)	<b>5.286E+08<sup>C</sup></b>	9.969E+08	9.154E+07 <sup>B</sup>	1.645E+08	3.487E+07 <sup>B</sup>	5.857E+07	8.091E+07 <sup>A</sup>	1.008E+08	370.22
% HApw AG	4.92 <sup>A</sup>	6.88	31.30 <sup>B</sup>	20.05	58.64 <sup>C</sup>	22.00	<b>66.16<sup>D</sup></b>	16.35	508.33
% HApw PS	21.69 <sup>C</sup>	7.42	<b>28.76<sup>C</sup></b>	12.19	15.51 <sup>B</sup>	12.88	8.83 <sup>A</sup>	5.07	419.61
% HApw S&G	<b>73.38<sup>C</sup></b>	11.24	39.95 <sup>B</sup>	18.56	25.85 <sup>A</sup>	15.23	25.01 <sup>A</sup>	13.16	372.52
Dependency ratio	<b>1.79<sup>A</sup></b>	0.23	1.34 <sup>B</sup>	0.23	1.18 <sup>D</sup>	0.31	1.24 <sup>C</sup>	0.19	354.37
%Households with commuting members	2.68 <sup>A</sup>	3.17	<b>10.93<sup>C</sup></b>	6.02	5.87 <sup>B</sup>	4.39	4.83 <sup>B</sup>	2.63	268.93
%Households with some member commuting for studies	2.06 <sup>A</sup>	1.96	<b>8.45<sup>C</sup></b>	3.97	<b>6.04<sup>C</sup></b>	3.31	5.78 <sup>B</sup>	2.57	260.29
%Households with some member commuting for work	6.95 <sup>B</sup>	2.71	<b>11.12<sup>C</sup></b>	3.85	6.17 <sup>A</sup>	3.46	5.71 <sup>A</sup>	2.56	258.88
% of population living in rural areas	10.74 <sup>A</sup>	27.32	78.95 <sup>B</sup>	37.98	<b>91.88<sup>C</sup></b>	21.43	87.20 <sup>B</sup>	24.16	394.397
% of population living in urban areas	<b>89.26<sup>C</sup></b>	27.32	21.05 <sup>B</sup>	37.98	8.12 <sup>A</sup>	21.43	12.80 <sup>B</sup>	24.16	394.397
Incomplete education attainment (%)	15.76 <sup>A</sup>	5.46	28.73 <sup>B</sup>	6.52	28.28 <sup>B</sup>	6.73	<b>30.51<sup>C</sup></b>	4.60	270.754
Multidimensional poverty index (MPI)	<b>0.122<sup>A</sup></b>	0.087	0.303 <sup>B</sup>	0.120	0.420 <sup>C</sup>	0.129	0.424 <sup>C</sup>	0.114	366.99
Average number of people by HH	3.58 <sup>A</sup>	0.31	3.82 <sup>B</sup>	0.30	<b>4.11<sup>C</sup></b>	0.72	3.91 <sup>B</sup>	0.43	98.54
Distance to > 5000 inhab. population centers (km)	0.00 <sup>A</sup>	0.00	2563.73 <sup>B</sup>	4583.93	<b>16,786.21<sup>C</sup></b>	21,313.45	3564.08 <sup>B</sup>	5121.77	398.26
TAL (ha)	5095.67 <sup>A</sup>	12,232.42	5526.53 <sup>A</sup>	17,419.48	<b>37,148.01<sup>C</sup></b>	78,460.19	19,853.76 <sup>B</sup>	22,095.07	390.64
% TAL <sub>NCL</sub>	7.55 <sup>A</sup>	13.64	16.61 <sup>B</sup>	18.42	<b>75.81<sup>D</sup></b>	21.03	23.88 <sup>C</sup>	21.58	710.15
% TAL <sub>AG</sub>	31.69 <sup>A</sup>	35.23	<b>67.78<sup>B</sup></b>	31.26	21.57 <sup>A</sup>	18.70	<b>74.51<sup>B</sup></b>	22.77	534.97
% TAL <sub>URB</sub>	<b>38.69<sup>C</sup></b>	40.85	1.22 <sup>B</sup>	5.12	0.10 <sup>A</sup>	0.74	0.17 <sup>B</sup>	0.79	321.70
Population density	<b>5558.30<sup>D</sup></b>	5685.94	249.73 <sup>C</sup>	267.39	26.98 <sup>A</sup>	47.43	66.08 <sup>B</sup>	90.99	564.11

All results had 7.815 as critical value of K. a p-value < 0.0001. an alpha value of 0.05, and 3 degrees of freedom). The values highlighted in bold correspond to the typology having the maximum or minimum average values of the given indicator. Letters (<sup>A,B,C,D</sup>) indicate the significantly different groups existent along the values of the sample, which aggregate typologies according Dunn's test significant differences



**Fig. 8** a Spatial distribution of Total Energy Throughput per hectare (KWh/ha) (intervals are represented by using head/tail breaks) and municipality types along the rural-urban continuum of Ecuador; results of Moran's Index in **b** chart and **c** map. *Source:* Own elaboration based on CONELEC (2014, 2017), INEC (2011), MAGAP-MAE (2012) and Jiang (2013) method of head/tail breaks for interval representation of heavy-tailed distribution data

Analyzing nocturnal satellite images and the magnitude and intensity of luminosity from 1992 to 2012, Mejía (2020) confirms suburban sprawl and low-density urban expansion in Ecuador, emergence of new centralities, and diffusion of urban energy uses even beyond paved land. Our results help better understanding of the dynamics of Ecuador's suburban spaces. In Ecuador, like in other Latin American countries, suburbanization differs from other parts of the world in higher "social mixity" of groups, mosaics of activities and land uses and the blurring of the "urban" and the "rural" in *suburban and intermediate cities* (Salazar et al. 2011; Ávila-Sánchez 2011; Lerner and Eakin 2011; Ruiz-Rivera and Delgado-Campos 2008; Delgado Ramos 2019).

The residential is the main consuming sector in *suburban and intermediate cities*, both in absolute (TETHh) and relative terms (per hour, EMRhh). These parishes, however, consume less than the *urban centers* type (see Sect. 6, Table 6 and Fig. 8). Probably, this is so because uses and social groups, instead of mixing in a compact city center, they mix in low-density sprawl areas. Private middle-to-upper class suburbs are close to indigenous farming and working class neighborhoods, or to farming areas. Suburban areas are more heterogeneous and unequal with greater income differences between social groups, than they could be in developed countries. Lower consumption of rural and poor suburban households compensate higher consumption of affluent private middle-high class developments. As we have shown, in Ecuador, access to services such as electricity, appliances or Internet, differ substantially from urban centers to rural



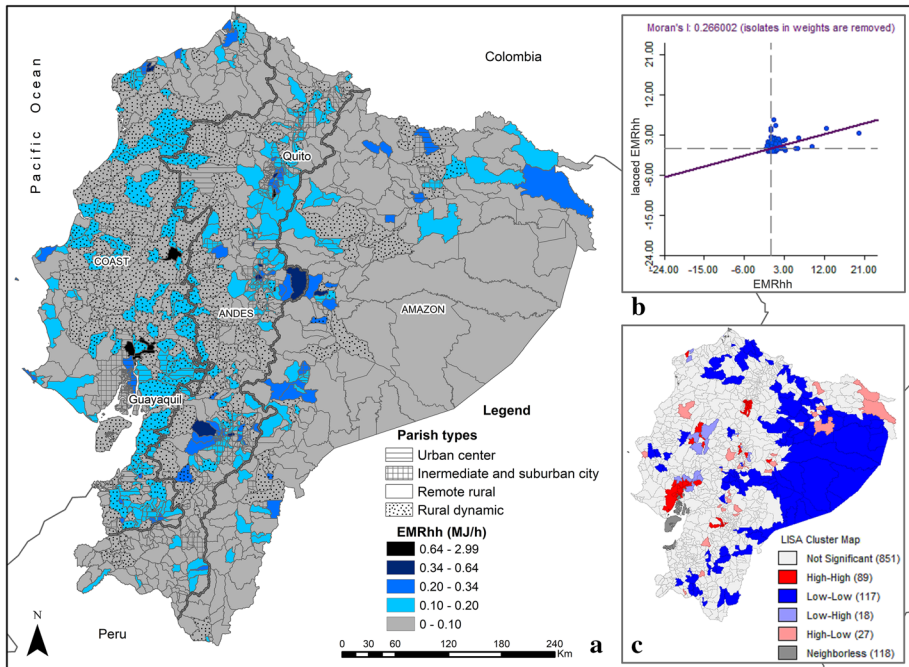
**Table 6** Results of Kruskal-Wallis test in electricity consumption variables in 2013 (all results had 7.815 as critical value of K and a p-value < 0.0001 and an alpha value of 0.05, and 3 degrees of freedom)

Variable	1: Urban centers (n = 119)		2: Intermediate and sub-urban city (n = 194)		3: Remote rural village (n = 436)		4: Dynamic rural towns (n = 382)		$\chi^2$
	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.	
TEC_SA (Kwh)	<b>7.44E+07<sup>C</sup></b>	2.84E+08	3.92E+06 <sup>B</sup>	6.55E+06	1.87E+06 <sup>A</sup>	5.46E+06	4.52E+06 <sup>B</sup>	9.05E+06	113.52
TEC_HH (Kwh)	<b>2.15E+07<sup>C</sup></b>	6.31E+07	2.20E+06 <sup>B</sup>	3.04E+06	7.40E+05 <sup>A</sup>	1.42E+06	2.12E+06 <sup>B</sup>	4.24E+06	126.51
TEC_S&G (Kwh)	<b>1.62E+07<sup>C</sup></b>	7.07E+07	4.68E+05 <sup>B</sup>	1.40E+06	2.81E+05 <sup>A</sup>	8.69E+05	8.75E+05 <sup>B</sup>	2.30E+06	116.79
TEC_PS (Kwh)	<b>2.54E+07<sup>C</sup></b>	1.39E+08	1.01E+06 <sup>B</sup>	3.79E+06	6.38E+05 <sup>A</sup>	3.91E+06	8.81E+05 <sup>A</sup>	2.77E+06	84.94
TEC_PW (Kwh)	<b>5.29E+07<sup>C</sup></b>	2.49E+08	1.73E+06 <sup>B</sup>	4.63E+06	1.13E+06 <sup>A</sup>	4.58E+06	2.40E+06 <sup>B</sup>	5.78E+06	97.483
%TEC_HH	42.06 <sup>A</sup>	21.20	<b>73.04<sup>C</sup></b>	17.97	66.94 <sup>B</sup>	23.75	66.55 <sup>B</sup>	21.11	101.56
%TEC_S&G	<b>25.57<sup>C</sup></b>	16.54	9.87 <sup>A</sup>	6.71	14.03 <sup>A</sup>	13.68	15.92 <sup>B</sup>	13.06	82.28
%TEC_PS	<b>18.12<sup>B</sup></b>	22.85	11.87 <sup>A</sup>	17.30	13.19 <sup>A</sup>	21.30	12.73 <sup>A</sup>	19.73	50.59
%TEC_PW	<b>57.94<sup>C</sup></b>	21.20	26.96 <sup>A</sup>	17.97	33.97 <sup>B</sup>	23.36	34.30 <sup>B</sup>	20.68	103.14
TEC per ha	<b>67,037.63<sup>C</sup></b>	153,086.19	<b>1449.96<sup>C</sup></b>	2958.24	162.92 <sup>A</sup>	628.50	354.57 <sup>B</sup>	879.16	76.92
TEC per ha_urban area	<b>145,338.12<sup>C</sup></b>	427,256.46	135,263.19 <sup>B</sup>	773,475.07	16,359.49 <sup>A</sup>	108,073.59	297,800.96 <sup>B</sup>	5,149,337.64	145.91
EMR_SA (MJ/h)	<b>0.24<sup>C</sup></b>	0.30	0.07 <sup>B</sup>	0.11	0.05 <sup>A</sup>	0.09	0.05 <sup>A</sup>	0.12	155.88
EMR_HH (MJ/h)	<b>0.07<sup>C</sup></b>	0.04	0.04 <sup>B</sup>	0.04	0.02 <sup>A</sup>	0.02	0.03 <sup>A</sup>	0.05	179.84
EMR_PW (MJ/h)	<b>2.81<sup>C</sup></b>	3.85	0.82 <sup>B</sup>	1.10	0.74 <sup>A</sup>	1.31	0.85 <sup>A</sup>	2.01	120.24
EMR_PS (MJ/h)	<b>2.26<sup>C</sup></b>	5.81	0.70 <sup>A</sup>	2.25	1.65 <sup>A</sup>	6.49	3.61 <sup>B</sup>	19.52	54.12
EMR_S&G (MJ/h)	<b>0.96<sup>D</sup></b>	1.76	0.23 <sup>A</sup>	0.36	0.38 <sup>B</sup>	0.63	0.59 <sup>C</sup>	1.78	82.24
Average TEC per HH (Kwh/HH)	<b>1947.07<sup>C</sup></b>	1205.10	1254.52 <sup>B</sup>	1231.50	774.95 <sup>A</sup>	577.42	843.64 <sup>A</sup>	1497.74	167.67
Average TEC per person in the HH (Kwh/person-inHH)	<b>542.50<sup>C</sup></b>	345.72	332.39 <sup>B</sup>	334.45	198.09 <sup>A</sup>	152.10	217.84 <sup>A</sup>	392.22	177.09
% of households with access to electricity	<b>97.86<sup>C</sup></b>	2.78	94.19 <sup>B</sup>	5.88	81.18 <sup>A</sup>	21.58	86.93 <sup>A</sup>	10.49	345.77
% of households that use gas (cistern) for cooking	<b>95.34<sup>D</sup></b>	3.96	86.08 <sup>C</sup>	11.55	70.44 <sup>A</sup>	23.74	78.91 <sup>B</sup>	18.28	275.42
% of households that use electricity for cooking	<b>0.89<sup>C</sup></b>	1.68	0.11 <sup>B</sup>	0.32	0.09 <sup>A</sup>	0.43	0.07 <sup>A,B</sup>	0.19	274.65
% of households that use firewood and charcoal for cooking	0.70 <sup>A</sup>	1.68	12.65 <sup>B</sup>	11.83	<b>27.75<sup>D</sup></b>	24.13	19.11 <sup>C</sup>	18.95	342.60

Table 6 (continued)

Type	1: Urban centers (n = 119)		2: Intermediate and sub-urban city (n = 194)		3: Remote rural village (n = 436)		4: Dynamic rural towns (n = 382)		$\chi^2$
	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.	
% of households with access to Internet	<b>22.69<sup>D</sup></b>	12.85	5.41 <sup>C</sup>	6.16	2.38 <sup>B</sup>	2.96	2.34 <sup>A</sup>	1.89	359.67
% of households with computer	<b>43.48<sup>C</sup></b>	16.24	17.55 <sup>B</sup>	11.97	9.04 <sup>A</sup>	8.03	7.06 <sup>A</sup>	5.52	401.25
% of households with TV cable	<b>25.06<sup>B</sup></b>	13.48	9.61 <sup>A</sup>	11.63	8.78 <sup>A</sup>	12.04	8.19 <sup>A</sup>	9.79	178.72

The values highlighted in bold correspond to the typology having the maximum average values of the given indicator. Letters (<sup>A,B,C,D</sup>) indicate the significantly different groups existent along the values of the sample, which aggregate typologies according Dunn's test significant differences



**Fig. 9** a Spatial distribution of Energy Metabolic Rate (MJ/h) at the level of household (EMR<sub>HH</sub>) (intervals are represented by using head/tail breaks) and municipality types along the rural-urban continuum of Ecuador; results of Moran's Index in **b** chart and **c** map. *Source:* Own elaboration based on (CONELEC (2014, 2017) INEC (2011), MAGAP-MAE (2012) and Jiang (2013) method of head/tail breaks for interval representation of heavy-tailed distribution data

remote and peripheral areas. However, we have observed trends of growing electricity consumption in the suburban household sector consistent with Mejía (2020) findings.

Following Hildyard et al. (2012), from a “Hard path” perspective, these differences in the density, rate and sector of consumption in electricity can be solved through centralized grids fed by big hydropower projects, as long as, access to electricity and to induction ovens is improved all along the Ecuadorian territory. Large-scale hydropower can supply industrial and strategic sectors in *industrial centers*, or in *urban centers* and supply the growing service and commercial activities and the residential sector in *suburban and intermediate cities*. It can also feed the emergent mining industry (Purcell and Martinez 2018).

However, from a “Soft path” perspective, studies on suitable places for renewable energy, such as the one conducted by Cevallos-Sierra and Ramos-Martin (2018), complemented by participatory assessments of energy needs and consumption in different parish types could build a paradigm shift toward distributed renewable energy generation (Chicco and Mancarella 2009; Manfren et al. 2011).

Identifying socio-metabolic profiles allows revealing diverse regional social-economic and environmental dynamics. This opens the door to regional and urban planning of energy policies to adapt energy generation to different rates of energy consumption and different energy carriers for different end users (Howard et al. 2012; van den Dobbelsteen et al. 2011).

**Table 7** Results of Kruskal-Wallis test in electricity consumption variables in 2016 (all results had 7.815 as critical value of K and a p-value < 0. 0001 and an alpha value of 0.05. and 3 degrees of freedom)

Type	1: Urban centers (n = 119)			2: Intermediate and suburban city (n = 194)			3: Remote rural town (n = 436)			4: Dynamic rural towns (n = 382)			$\chi^2$
	Mean	Std.dev.		Mean	Std.dev.		Mean	Std.dev.		Mean	Std.dev.		
TEC_SA (Kwh)	<b>8.27E+07<sup>C</sup></b>	2.85E+08		9.28E+06 <sup>B</sup>	3.21E+07		2.60E+06 <sup>A</sup>	7.87E+06		5.04E+06 <sup>B</sup>	8.72E+06		336.37
TEC_HH (Kwh)	<b>2.71E+07<sup>D</sup></b>	7.33E+07		4.18E+06 <sup>C</sup>	1.29E+07		9.38E+05 <sup>B</sup>	1.78E+06		2.26E+06 <sup>A</sup>	3.34E+06		365.04
TEC_S&G (Kwh)	<b>1.88E+07<sup>C</sup></b>	7.16E+07		9.66E+05 <sup>B</sup>	2.57E+06		3.98E+05 <sup>A</sup>	1.11E+06		9.88E+05 <sup>B</sup>	2.40E+06		310.11
TEC_PS (Kwh)	<b>2.44E+07<sup>C</sup></b>	1.31E+08		2.57E+06 <sup>B</sup>	1.01E+07		1.45E+06 <sup>A</sup>	7.23E+06		1.44E+06 <sup>A,B</sup>	3.76E+06		152.98
TEC_PW (Kwh)	<b>5.56E+07<sup>C</sup></b>	2.40E+08		5.10E+06 <sup>B</sup>	2.03E+07		1.70E+06 <sup>A</sup>	6.89E+06		2.80E+06 <sup>B</sup>	6.14E+06		288.02
%TEC_HH	44.35 <sup>A</sup>	20.50		<b>69.37<sup>C</sup></b>	20.67		66.39 <sup>B,C</sup>	23.02		64.87 <sup>B</sup>	20.83		102.27
%TEC_S&G	<b>24.69<sup>C</sup></b>	15.48		10.45 <sup>A</sup>	8.69		13.63 <sup>A</sup>	12.99		15.21 <sup>B</sup>	11.61		101.07
%TEC_PS	<b>16.47<sup>B</sup></b>	21.43		13.19 <sup>A,B</sup>	19.41		13.10 <sup>A</sup>	20.98		12.29 <sup>A</sup>	19.26		20.57
%TEC_PW	<b>55.65<sup>C</sup></b>	20.50		30.63 <sup>A</sup>	20.67		34.53 <sup>A,B</sup>	22.92		35.41 <sup>B</sup>	20.67		100.30

The values highlighted in bold correspond to the typology having the maximum average values of the given indicator. Letters (<sup>A,B,C,D</sup>) indicate the significantly different groups existent along the values of the sample, which aggregate typologies according Dunn's test significant differences. Note that intensive variables such as TEC per ha, EMR or TEC per household are not available given the inexistence of updated land use and demographic data at such date

Distributed multi-generation is particularly suitable for the Ecuadorian context (Dafermos et al. 2015), where the suburban and rural areas still have an important agrarian population. Agroforestry and silvopasture systems of integral agroecological farms can provide biomass for cooking stoves or biogas, generate renewable electricity (solar, wind, or biomass) and conserve soil and water, important environmental services for small-scale hydroelectric projects (Ho 2013). Urban areas, simultaneously, can contribute to renewable energy generation, especially through solar photovoltaic, waste to energy and thermal panels in rooftops (Amado et al. 2016; Barragán-Escandón 2019; Evola et al. 2016; Fichera et al. 2016; Kostevšek et al. 2013; Pereira and Assis 2013).

Until now, energy policies have taken a centralized or “Hard path” view of Energy Sovereignty. However, the uneven socio-metabolic profiles of different typologies of parishes found along the rural–urban continuum of Ecuador reveal important opportunities for a “Soft path” view. Embracing diversity of energy consumption patterns through distributed multi-generation and direct participation of local governments and communities could enforce their right to take part on energy-related decisions. Integrating energy and land use planning at the local rural–urban level could ensure a more democratic approach to Energy Sovereignty. This approach could truly help accomplishing the constitution mandate of using energy for citizen rights and social interests rather than for reproducing uneven development and the power of economic and bureaucratic elites (Bonilla et al. 2016).

## 9 Conclusions

Under a Post-Normal Science approach, we have interpreted socio-metabolic profiles of electricity consumption along the rural–urban continuum of Ecuador according different perspectives on Energy Sovereignty. Through qualitative content analysis of interviews to diverse actors in Ecuador we found two broad contrasting narratives on Energy Sovereignty: a “Hard” and a “Soft” path.

We identified a typology of four types and eight subtypes of parishes with distinct socio-metabolic profiles along the “rural–urban continuum” in Ecuador. While urban centers tend to specialize in service or industry, suburban and intermediate cities and rural villages tend to be residential. Suburban areas are also mixed and heterogeneous mosaics of “rural” and “urban” land uses, functions and social groups showing characteristics of “new ruralities” and “multifunctionality” of rural areas, where there is a blurring of rural and urban categories. Our results contribute to the understanding of the relationships between urbanization and electricity consumption patterns and indicate the need for further research on the emerging role of intermediate cities and the processes of suburbanization, functional urban specialization and “new ruralities” in Latin America. Our methodology can also be refined to study, at finer scale and through time, the evolution of energy and land use relationships, better addressing causal factors such as income effects on household energy consumption or expand the research to distributed electricity generation or other energy or material flows such as biomass, fuel, Liquefied Petroleum Gas (LPG), or food.

Current energy policies in Ecuador are closer to a “Hard path” perspective on Energy sovereignty with centralized planning and implementation of energy policies. However, our results on socio-metabolic profiles reveal spatial diversity and heterogeneity of electricity consumption patterns. Distributed multi-generation under a “Soft path” view on Energy sovereignty could help matching energy consumption and generation at the local

level enhancing local communities and governments' participation on urban and energy planning.

Integrating qualitative and quantitative methods from a multi-criteria perspective, as we attempted here seems promising for building critical informed discussions on values and facts around alternative views on energy and urban planning.

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