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## **Towards an Eco-City Future: A Renewable Energy Supply and Smart Mobility Symbiosis**

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**Abstract:** Taking into account that Brazil possesses 84% of its population living in cities and that transportation constitutes a significant portion of the urban cost matrix, balancing city growth, energy consumption and transportation (including maintenance and operation of the road system) represents a great challenge to be overcome. Though 65.2% of the Brazilian electricity mix is based on hydropower, the country has faced strong unfavorable hydrological conditions. This research hence had the overall objective of investigating solar energy potential to supply renewable energy for residential and public transportation end-uses. The method comprised a general analysis of the city of Londrina, in Brazil, and an indirect quantitative relational methodology of data constitution for computing energy consumption and generation potential. We followed the 'ecosystem approach' on sustainable urban development to establish present and future residential energy consumption scenarios for the studied city. Our calculations showed that, when the whole urban perimeter is occupied, installing PV arrays on 10% of the residential roof surface would produce a 75% energy surplus that, if added to PV generated by adoption of a massive local renewable energy production (MassREP) system, Londrina would be able to also supply a new, renewable electricity-powered smart mobility transportation system.

**Keywords:** Urban Metabolism, Energy Urban Planning, Solar Energy, Distributed generation, Smart Mobility.

### **Introduction**

As of 2008, over 50% of the world's population lived in urbanized areas (UN, 2014). Due to a car-dependent development culture, urban sprawl and high agglomeration of built environment, people and economic activities in one place, urban settlements represent bulk resource (energy, water, land and materials) consumers, generating immense amounts of waste, high thermal capacity material surfaces and heavy emission of pollutants to the immediate and global environments (Bai, 2007; Niemelä et al., 2011; Pincetl et al., 2012). Such negative tracks are expected to worsen as urban areas play their protagonist role in population growth forecasts and the dark path we witness today concerning the problems of pollution, resource scarcity, climate change and extreme poverty become more critical. Hence, sustainable urban planning approaches that regulate a balanced view of future developments must be increasingly consolidated.

The relationships among city growth, energy consumption and transportation represents a great challenge to be overcome in Brazil. Over 84% of the population lives in cities (IBGE, 2010), meaning that at least 168 million people use some kind of urban

transportation, private or public, individual or collective. Transportation also represents a significant portion of the urban cost matrix. Though 65.2% of the Brazilian electricity mix is based on hydropower (BEN, 2015), the country has faced strong unfavorable hydrological conditions, which restates the importance of investigating other potential renewable energy sources to sustain transitioning towards a less dependent or fossil-free society. This research hence had the overall objective of investigating solar energy potential to supply renewable energy for residential and public transportation end-uses for the city of Londrina. Such symbiosis constitutes an innovative urban energy ecosystem and an important enabler for Brazilian eco-cities in the near future.

The method comprised a general analysis of the selected city and an indirect quantitative relational methodology of data constitution for computing energy consumption and generation potential. We followed the 'ecosystem approach' on sustainable urban development to establish present and future residential energy consumption scenarios for the studied city. A top-down methodology was applied to estimate current energy consumption for each residential typology defined. Next, a bottom-up approach was applied to derive consumption for future typologies defined by the existing city zoning plan. Finally, we assessed the potential to not only counterbalance such consumption, but also to feed a new smart mobility transportation system, through adoption of a massive local renewable energy production (MassREP) system.

### ***The Ecosystem Approach***

Amid all movements and strategic views towards sustainable urban development, the 'ecosystem approach' stands out for its comprehensiveness and systemic thinking. This theoretical approach helps to frame the chaotic web of existing variables and relationships by essentially enabling partial analysis of a system without losing sight of the broader context in which it appears and by which it is influenced (van Bueren et al., 2012).

Within the ecosystem approach's scope, different 'sub-approaches' frame the built environment as an ecosystem that needs to balance its inputs, outputs, use and extraction of resources and, by doing so, enable provision of methods and tools for environmental assessment. The 'flows sub-approach', in particular, defends that city survival requires constant resource inputs and outputs flowing through it, at immense transportation and energy expense to sustain such 'metabolic' work. By seeing cities as quantifiable entities, in which the inputs and outputs of materials, resources, energy and information are measurable (van Bueren et al., 2012), concepts such as 'Urban Metabolism', 'Circular Metabolism' and 'Carrying Capacity' emerged and gained traction in the past years.

Urban Metabolism is the collection of technical and socioeconomic processes that occur in cities, and result in growth, production of energy, and waste elimination (Kennedy et al., 2007). Considered as fundamental to sustainable city development (Kennedy et al., 2012), such metabolic work enables system and technology management for reintegrating natural processes, increasing energy and resource use efficiency, and recycling waste (Newman, 1999). Shahrokni et al. (2015) further elaborated the concept of 'smart urban metabolism' (SUM), which aims at combining real-time user-generated data to offer knowledge on energy and material flows as close as possible to reality, and the use of calculation engines that can provide feedback related to sustainability indicators set by a city.

## **Smart Mobility**

Mobility efficiency within a city, region or country is closely related to the economic and social development. Transportation facilitates access to work, services, education and leisure. In large cities, it constitutes a significant portion of the urban cost matrix. In some cities, the amount spent on transportation - including maintenance and operation of the road system - is larger than the share committed with basic public services such as water, electricity and sewage supply.

The term 'smart mobility' is embedded within the 'smart city' framework, which promotes the use of information and communication technologies (ICTs) to create "*a particular form of spatial intelligence and innovation, based on sensors, embedded devices, large data sets, and real-time information and response*" (Komninos et al., 2013), that helps more efficient functioning and maintenance of urban physical infrastructure, as well as managing natural resources wisely through participatory governance, all of which supporting a strong and healthy economic and social development (Caragliu et al., 2011). In that line, 'smart mobility' refers to logistics and new transportation systems which improve urban traffic and inhabitants' local and international accessibility through ICTs (Giffinger, 2007). Smart mobility is usually associated with 'green mobility' standards, which aims at expanding public access and decreasing environmental, social and economic impact through the creation of a sustainable transport system that reduces air and acoustic pollution, greenhouse gas emissions, road congestion, accidents, and that also optimize territory consumption.

## **The Energy Issue**

Transportation is vital to the survival, well-functioning, development and, particularly, to the quality of life in cities. In Brazil, the transportation sector is the second largest energy consumer in the country (32,5%), right after industrial consumption (32.9%) (BEN, 2015). Sadly, 82% of this consumption comes from non-renewable sources.

In 2014, the total anthropogenic emissions associated with the Brazilian energy matrix reached 485.2 Mt CO<sub>2eq</sub>, from which 46% (221.9 Mt CO<sub>2eq</sub>) were transportation-driven. The current scenario could be reversed if individual mobility is decreased; alternative renewable energy sources are taken into the sector; and massive investments in comfort, safety and quality are made in public mass transportation, since it consumes 5-10 times less energy per passenger.

The Brazilian electricity matrix represents 17.2% of the total end use and is mainly consumed by the industrial (38.7%) and residential sector (24.8%). 65.2% of it comes from hydro power plants. More recently, other clean energy sources have received encouragement, such as biomass (7.4%) and wind power (2%) (BEN, 2015). However, taking into account that only 0.04% of this electricity reaches the transportation sector; the huge solar radiation available in the country; and also the recent drought periods, solar thermal energy represents an interesting alternative to be explored, especially if we consider that dry periods are associated with increased solar potential due to low interference from clouds and more intense solar radiation. Furthermore, solar energy is considered as a renewable and inexhaustible energy source. While the PV panel production indeed has its own impacts, the electricity generation process does not emit SO<sub>2</sub>, NO<sub>x</sub> and CO<sub>2</sub>: all of them greenhouse gases contributors to global warming and with harmful effects on human health.

### Our case study: Londrina

As a young city that has undergone rapid growth during its 82 years, Londrina is the fourth most economically influential city of Southern Brazil. Located 390 km from Curitiba, the state's capital, Londrina is one of the most dynamic cultural centers of the country and presents an important potential for future urban growth and development. The city has a population around 554.000 inhabitants, but also conforms a metropolitan area with over one million citizens and conurbative spatial integration with two neighboring towns. At an altitude of 608 m, the urban perimeter is set on a fertile land, containing five hydrographic basins with permanently protected areas of original bottom valley vegetation.

Londrina's urban form is characterized by two sites of high verticality, density, income and infrastructure (i.e. the city center and 'gleba palhana' neighborhood); a region of medium density, income and infrastructure in the center outskirts; a region of low density, high income and medium infrastructure in the southwest, dominated by gated communities; and vast areas of peripheral neighborhoods in the north, east and southeast with medium to high density and medium to low income and infrastructure, housing several social projects and a few irregular occupations (Figure 1a). This reveals an evident urban socio-spatial segregation, result of innumerous unplanned developments and growth.

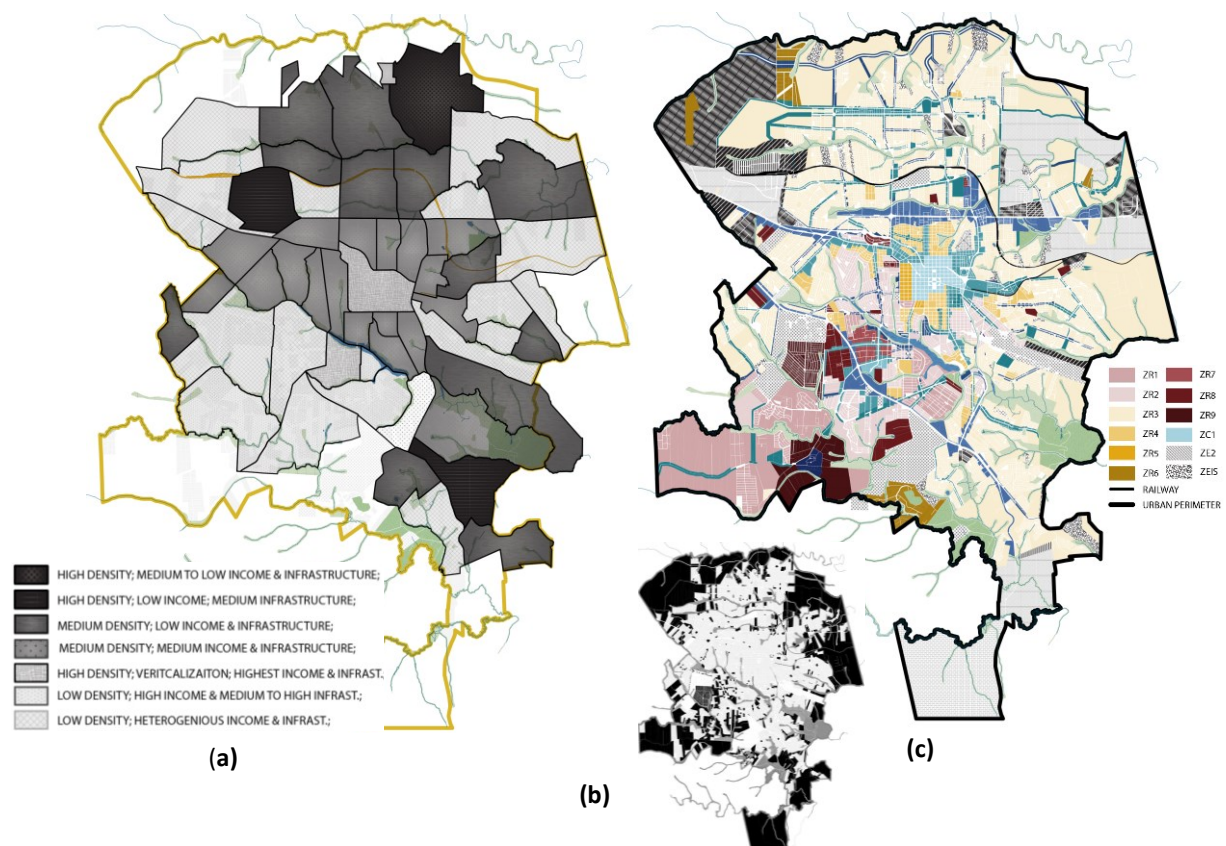


Figure 1: (a) Social, Economic and Infrastructural Synthesis Map adapted from Londrina Environmental Atlas (Barros et al., 2008); (b) Urban voids; (c) City zoning plan

Most of the services and shops are located in the central area and most industries are located in the few main roads that cross the city, consequently, so are the employment offers, the desired routes, the public transportation's passenger demand and the traffic jams in peak hours. This fact causes a considerable daily displacement due to the distance

between jobs and residences. Additionally, the city has a comparatively low mobility rate and a high number of individual vehicles per person (0.65, according with CMTU, 2013). Furthermore, the few existing terminals are concentrated in the central, northern and southern regions, leaving the west and east uncovered, which result in loaded, less comfortable lines and larger displacements.

Londrina’s energy consumption profile is basically composed by an *annual electricity consumption* of 1,356,129 MWh (in 2013), being roughly one third of it (429,974 MWh) demanded by the residential sector (COPEL, 2013); and by the *diesel consumed by public transportation*, which accumulated 27,002,508.03Km traveled in 2013 (CMTU, 2013). Considering an average consumption coefficient of 0.33 l/Km (Oliveira, 2004), therefore the annual diesel consumption by the urban buses would sum up to 8,917,444.14 liters.

## Method

A literature review addressed concepts such as the urbanization process of Brazilian cities; the ecosystem approach; eco-cities; urban metabolism; smart and green mobility; public mass transportation systems; and energy issues within urban planning. Next, an empirical research process aimed at diagnosing the current state of affairs regarding existing mobility systems, energy consumption and the new zoning plan proposed for Londrina. Surveys and interviews were carried out with official governmental municipal departments, such as: the City Hall of Londrina, IPPUL (Institute of Research and Urban Planning of Londrina) and CMTU (Transit and Urbanization Municipal Company).

Computation of the current and future residential energy consumptions, as well as of their renewable energy generation potential, was accomplished through a mixed ‘top-down’ and ‘bottom-up’ approach, combined with an ‘indirect quantitative relational methodology of data constitution’. The starting point was to create a typology table (Figure 2) based on the categorization of the 12 main residential building typologies (existing and future) extracted from the City Zoning Plan (Figura 1c).

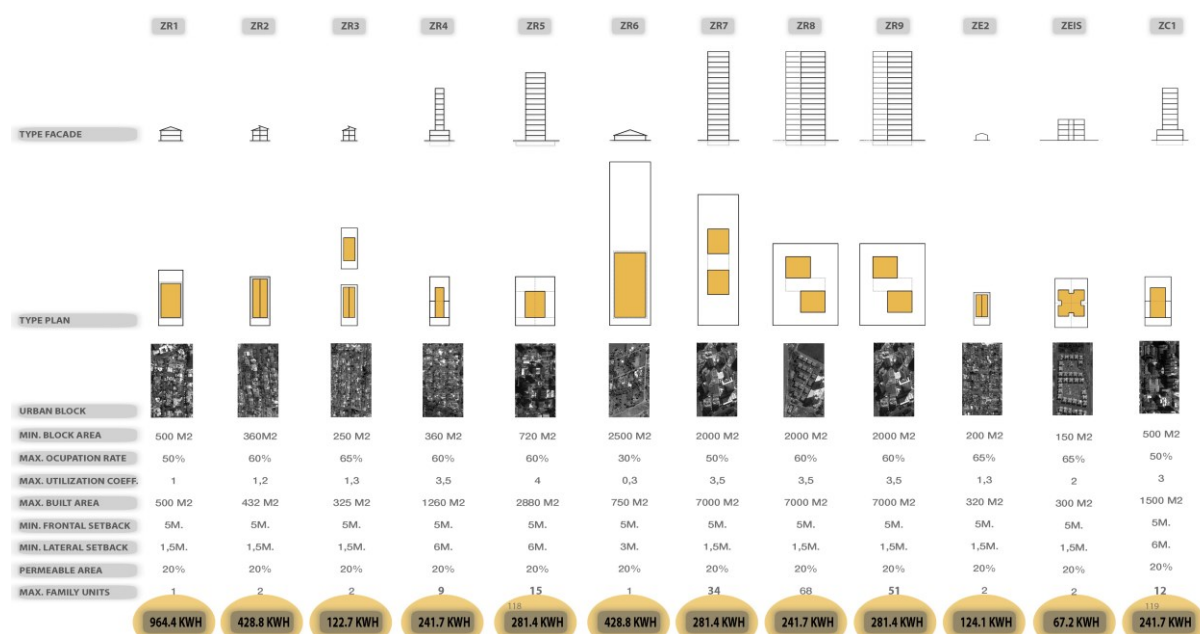


Figure 2: Typology Table with Energy Consumption by family Type

Since the currently enforced zoning legislation (Figure 1c) forecasts zone types for the complete (future) urban limits, an urban void map (Figure 1b) was created using Google Earth to distinguish areas already bearing the future zone type from those yet to be occupied. Both maps were combined over a GIS platform. The area occupied by each zone - and corresponding percentage relatively to the total urban area – allowed to finally infer the total number of families these areas could support. ‘In loco’ analysis of a number of chosen typologies coupled with information collected from the Parana Electricity Company (COPEL) directed categorization per social class, quality and quantity of electrical appliances and then divided into seven energy consumption ranges (Table 1).

Table 1. Energy Consumption Ranges

TODAY	Total Annual Consumption (MWh)	Total Number of Families per Consumption Range	Average Consumption per Family per Year (MWh)	Average Consumption per Family per Month (KWh)
Consumption Range 1 (0 - 100 KWh)	37428	46432	0.81	67.17
Consumption Range 2 (101 - 150 KWh)	62997	42326	1.49	124.03
Consumption Range 3 (151 - 215 KWh)	94898	44692	2.12	176.95
Consumption Range 4 (216 - 280 KWh)	77977	26,880	2.90	241.74
Consumption Range 5 (281 - 340 KWh)	45748	13547	3.38	281.42
Consumption Range 6 (341 - 580 KWh)	65295	12,689	5.15	428.82
Consumption Range 7 (> 581 KWh)	45631	3,943	11.57	964.39
<b>Total</b>	429974	190509	2.26	188.08

Estimation of average energy consumption of each type followed a top-down approach. From the number of household consumers, the 2013 annual energy consumption (MWh) and the percentage and number of families of each urban zone, we defined consumption ranges and estimated the average monthly consumption/family in each zone. Once we estimated the future number of families for each typology, we projected the corresponding energy consumption, considering full occupation of its urban perimeter.

Roof surface for each zone typology was calculated. The renewable energy generation potential assumed (1) that 300 Wp PV panels would be installed on 10% of the residential buildings’ roofs; and (2) a global tilted irradiation value of 5,30 KWh/m<sup>2</sup> (Pereira, 2006) and manufacturer’s data. Average energy generation capacity (KWh/month/panel) was multiplied by the maximum number of panels that each typology could hold and summed to estimate the city overall generation potential. Finally, included the massive local renewable energy production (MassREP), composed by the proposed solar farm and linear PV arrays along the two main highways that cross the city.

## Results and Discussion

Our calculations showed that, when the whole urban perimeter of Londrina is occupied by its existing and future zoning types (always considering the most densified situation), the

city would have about 688,286 family units, whose residences will consume around 1,743,926 MWh/yr.

Installation of PV arrays for distributed energy generation in 10%, in average, of the residential roof surface would produce 1.75 times the overall residential consumption. If PV generation along the *two main highways* that cross the city is added to that of a *power plant* suggested for the northwest future industrial zoning void (Figure 3a), Londrina would be able to also supply a new renewable electricity mobility system. This system could be composed by different public transportation vehicles types (e.g. regional train, light rail, tram) and be combined to walkable streets, slow mobility network and bike highways, ICTs and other solutions, connected by fifteen intermodal terminals fairly distributed throughout the city (Figure 3b).



Figure 3: Proposed (a) energy and (b) smart mobility masterplans for Londrina

## Conclusion

Londrina holds a huge potential for solar PV generation and many additional eco strategies due to the combination of economic prosperity, strict enforcement of construction regulations and favorable solar radiation potential. Energy and smart mobility masterplans were developed to express the main guidelines for distributed solar generation throughout the city, allied to an intermodal electricity-efficient public transportation system.

Socio-economic and political aspects are in the very foundation of transitioning towards eco-city models, and become more challenging in developing countries contexts. Financial and structural difficulties for installing PV systems, particularly in low income areas; safety concerns that currently hamper public transportation use and car sharing; and prioritizing green policies such as tax incentives for acquiring PV systems coupled with construction regulations to make it mandatory are some of the issues that need to be addressed for this change to happen.

## References

- Alberti, M. (2008). *Advances in urban ecology: integrating humans and ecological processes in urban ecosystems*. New York: Springer.
- Bai, X. (2007). Industrial ecology and the global impacts of cities. *Journal of Industrial Ecology*, 11(2), 1-6.

- Barros, M. et al. (2008). Atlas Digital da Região de Londrina. Londrina: Universidade Estadual de Londrina.
- BEN (2015). *Brazilian Energy Balance 2015 Year 2014*. Empresa de Pesquisa Energética – Rio de Janeiro: EPE, 2015.
- van Bueren, E., van Bohemen, H., Itard, L., & Visscher, H. (Eds.). (2012). *Sustainable Urban Environments*. Dordrecht: Springer Netherlands.
- Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart Cities in Europe. *Journal of Urban Technology*, 18(2), 65–82.
- COPEL. (2013). Parana Electricity Company.
- CMTU. (2013). Transit and Urbanization Municipal Company.
- Giffinger, R. (2007) *Smart Cities Ranking of European medium-sized cities*. Vienna University of Technology. ([www.smart-city.eu](http://www.smart-city.eu))
- IBGE. (2010). Brazilian Institute of Geography and Statistics
- IPPUL. (2014). Londrina Institute of Research and Urban Planning.
- Kennedy, C., Cuddihy, J., & Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of Industrial Ecology*, 11(2), 43–59.
- Kennedy, C., Baker, L., Dhakal, S., & Ramaswami, A. (2012). Sustainable Urban Systems. *Journal of Industrial Ecology*, 16(6), 775–779.
- Komninos, N., Pallot, M., & Schaffers, H. (2013). Special Issue on Smart Cities and the Future Internet in Europe. *Journal of the Knowledge Economy*, 4(2), 119–134.
- Newman, P. W. (1999). Sustainability and cities: extending the metabolism model. *Landscape and Urban Planning*, 44(4), 219–226.
- Niemelä, J. et al. (2011). *Urban Ecology: Patterns, Processes, and Applications*. Oxford and New York: Oxford University Press.
- Oliveira, G. (2004) *Análise do Consumo de Combustível de Ônibus Urbano*. Master thesis. COPPE/UFRJ - Rio de Janeiro, RJ, Brasil.
- Pereira, E. et al. (2006) *Atlas brasileiro de energia solar*. São José dos Campos: INPE, 2006.
- Pincetl, S., Bunje, P., & Holmes, T. (2012). An expanded urban metabolism method: Toward a systems approach for assessing urban energy processes and causes. *Landscape and Urban Planning*, 107(3), 193–202.
- Shahrokni, H., Lazarevic, D., & Brandt, N. (2015). Smart Urban Metabolism: Towards a Real-Time Understanding of the Energy and Material Flows of a City and Its Citizens. *Journal of Urban Technology*, 22(1), 65–86.