Mapping Energy Vulnerability[1]

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Abstract

In a context of a growing urban population, energy supply and vulnerability are of paramount importance. Although many authors address this matter, we seldom find proposals to express concretely this concept in a way that it can be applied to certain urban realities. This study aims to fill this gap in creating different classes of energy vulnerability that can be mapped and, consequently, used to support energy management. After discussing the concept and its indicators according to different authors, we frame four classes of vulnerability to be applied to the city of São Paulo. Then, we present a first approach of a vulnerability map, pointing to some pendent issues yet to be solved. Then, we will draw some partial conclusions.

Key words: energy, vulnerability, urban, mapping

Introduction

Considering that around 54 % of world population live in cities[6], energy supply is essential to guarantee all human activities. Hence, discussing energy vulnerability is a momentous issue. Many authors studied the concept of energy vulnerability proposing different indicators to assess it, as we will show in the next section. However, few tried to apply the concept to an empirical urban reality. It is the case of Maliszewski and Perrings (2012) that mapped central Phoenix (USA) although he focused the concept of resilience (as the speed of return to equilibrium following perturbation), not vulnerability itself. Furthermore, the wide diversity of cities requires us to choose different indicators of energy vulnerability. In an immense metropolis of a developing country, in the likes of São Paulo with more than 21 million inhabitants, some indicators may be more relevant than others. This being said, this study aims to fill a gap concerning the application of energy vulnerability concept in São Paulo where there is a permanent pressing energy demand. After discussing the concept and its indicators according to different authors, we will frame four classes of vulnerability to be applied to

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the city of São Paulo. Then, we will present a first approach map, which is a methodological essay rather than a definitive product. At the end, we will draw some partial conclusions.

Conceptual background

Vulnerability related to energy supply is a concept largely used and embraces such a wealth of ideas. However, it remains as a theoretical variable and, despite being widely used in colloquial language as pointed out by Gallopín (2006), is conceptualized in very different ways by scholars from distinct areas and even within the same area (FÜSSEL, 2007). Gallopin (2006) affirms that "this plurality of definitions is possibly functional to the needs of the different disciplinary fields, as well as being a reflection of the different intellectual traditions (apud Adger, 2006; Janssen et al., 2006)…" (p.293). Kruyt (2009), Gruble et al. in GEA (2012) and Gnansounou (2008) related it to security of energy supply in a way that the more secure, the less vulnerable is a system or an area. According to Adguer (2006) "the concept of vulnerability has been a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems, and for guiding normative analysis".

By approaching systems weakness by vulnerability analysis, one can know the factors that have influence in system behavior. This importance is highlighted in studies involving interconnected systems, where the impact due to the interaction of which one is not evident. Regarding couple human-environment systems, Turner et al. (2003) say that vulnerability is one of the key elements of the dialogue between science and decision making (*apud* National Research Council, 1999; Burby, 1998; Kasperson, 1999; International Federation of Red Cross and Red Crescent, 1999). This knowledge is very important, as Adguer (2006) points out for example, for guiding normative analysis of actions to enhance well-being through reduction of risk.

A few authors discuss and specify what could be used as indicators of vulnerability, i.e., what could be used as indicators, or empirical variables in the analysis of vulnerability. It is the case of Artigues (2008), who discusses vulnerability indicators to undertake a comparative analysis between European countries.

The first indicator is **diversity** of a system in a way that the more diverse the less vulnerable a system is. Nonetheless, the assurance of energy supply does not account only for the diversity of sources, but also for an equitable use of this diversity. In other words, the more diversely supplied is an area, the less vulnerable it would be. Yet, diversity is useless if not all different sources are used equally to some extent. For example, if natural gas is available but not significantly used it does not help to diminish energy vulnerability. Consequently, an equitable use of different energy sources would be a condition to diversity helps to diminish vulnerability. In the São Paulo context, for instance, natural gas is available in most areas, but it is underused in a way that electrical energy keeps highly predominant.

The second indicator of vulnerability is **sustainability**, referring to the energy production and factors that may disturb it, as political instability and exhaustibility of sources. On the one hand, electricity, for instance, is more secure and stable in production, once it may come from several sources, but more vulnerable in distribution, as it involves a technically more complex grid and it is normally more exposed to external influences. On the other hand, natural gas may be more vulnerable in the production, once is exhaustible and more affected to political issues (considering the Brazilian context where most gas is imported from Bolivia), but more secure in distribution. An evidence to that is the fact of electrical supply is more likely to outages than natural gas supply, although the production of the first is more durable when the vast majority of electricity is generated in hydroelectric power stations, as in Brazil.

Turner et al. (2003) define vulnerability as "the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress / stressor" (p.8.074). This author links vulnerability with resilience concept, which is the capacity of recovering after being harmed by a perturbation. The more resilient is a system, the less vulnerable it is. Moreover, it is necessary to consider vulnerability in the totality of the system. In São Paulo, for instance, electricity system is less vulnerable in the production phase, once electricity comes mostly from hydroelectric that works indefinitely and safely, while distribution by overheaded grid is more vulnerable.

Not only the exposure, but also the sensitivity to hazards is also important to define vulnerability. Sensitivity is defined by "the degree to which the system is modified or affected by an internal or external disturbance" (GALLOPIN, 2005, p.295). In this sense, it is vital to consider the context in which the system is in order to evaluate its vulnerability. For instance: it is clear that the electrical grid is much more vulnerable than gas grid, because it is aerial in most cases, which means it is more exposed to perturbations. However, it is not necessarily more sensitive. The context could be a safe one, free from any kind of perturbations (heavy rains and winds, falling trees, etc). In the context of São Paulo, electrical grid is vulnerable not only because it is aerial and, being so, more exposed to hazards, but also because hazards indeed exist, rising sensitivity. Furthermore, vulnerability rises due to inefficient maintenance of electrical grid and green cover (trimming trees services). Metaphorically, a person who is prone to get diseases would be more sensitive if surroundings are infected, and less sensitive if they in a sterile neighbourhood.

Authors always link vulnerability to something that can disturb the system, which is called perturbation, hazard, harm, disturbance to name a few (Turner et al, 2003; Artigues, 2008;Gallopin, 2006). Still, here we are not distinguishing these terms and we are considering them in a general way as perturbations. Turner (op cit) goes a little further asserting that we have two kinds of perturbations: external and internal ones. A fault in the system would be an inside or internal perturbation, whilst a falling tree or a strong window would be an external or outside perturbation. Sources of stress could foment external or internal perturbation. For example, an internal perturbation could be caused by stress of the infrastructure getting obsolete at the same time that has to support more demand and pressure. On the other hand, an external perturbation could be fomented by a stress consisting in lack of prevention of falling trees due to faulty maintenance services.

Again, in this study we are not considering external or internal perturbation. Better still, we are considering that all perturbations are internal and should be treated accordingly. We justify this choice: being sensitive to perturbations (even caused by external facts) reveal the inability of the system of coping with them properly. Therefore, responsibility to higher or lower vulnerability is always an internal issue.

Framing vulnerability classes for São Paulo

Based on conceptual literature discussed above, we decided to establish four classes of vulnerability: *very high*, *high*, *medium* and *low*. All classes resulted from the integration of four indicators, such as: percentage of electricity contribution (in total energy supply); type of grid (overhead or undergrounded); distance of priority areas (such as hospitals and prisons) and number of trees per hectare. For the first indicator, we considered that the higher percentage of electricity in total energy supply, the more vulnerable is the area. Without an alternative source, there is a higher risk of being completely without energy in case of outage. As we mentioned before, literature considers that the vulnerability diminishes when there is more than one energy source, and moreover, when these sources are equally used. As a consequence, areas with only electricity or a very high contribution of electricity are considered more vulnerable, not because the electricity itself, but because population would be relying on just one source. For the second indicator, it is generally accepted that overhead grid is more vulnerable than undergrounded grid, once the first are more likely to suffer outages caused by perturbations, such as falling trees, tempests, gales etc. Concerning the third indicator, literature says that some priority areas such as hospitals are more protected against energy outages. As a result, the more hospitals around the less vulnerable is the area. Finally, the indicator related to the green cover considers that only trees that are potentially threatening to the electrical grid. For that reason, the more trees per hectare the more vulnerable is the area.

By crossing these four indicators we found four classes of energy vulnerability in São Paulo, focusing only residential areas in this phase of the research, as following:

VERY HIGH – Resulting from 90-100% electricity contribution (up to 10% of gas contribution); overhead grid; more than 1 km from a hospital; more than 12 trees /hectare.

HIGH – 90-100% of electricity (up to 10% of gas contribution); overhead grid; 501 to 1000m from hospitals; 7-11 trees/hectare.

MEDIUM – Less than 90% of electricity contribution (more than 10% of gas contribution); overhead grid; 101-500m from hospitals; 3-6 trees/hectare.
LOW – Less than 90% of electricity contribution (more than 10% of gas contribution); undergrounded grid; up to 100m from hospitals; 0-2 trees/hectare.

It is interesting to observe that different social classes are not an efficient indicator to energy vulnerability, in opposition to what we could imagine. It is due to the fact that in richer areas we find much more trees per hectare than in poorer areas. Moreover, in richer areas the demand for energy is much higher, pressing constantly the grid that may collapse. For those reasons, we expect to find higher vulnerability in richer areas.

One pending decision is about the different weight of each indicator. Certainly, overhead grid combined with a higher density of trees count more decisively to a higher vulnerability result. Therefore, higher weight should be attributed to theses indicators. We will base the weight attribution on some recognized methodologies, such as the Analytic Hierarchy Process (AHP), proposed by Thomas L. Saaty in which He compares the relative weight between elements of a certain analytical universe using a scale of numerical combination (SAATY, 2008). Through this methodology, we expect to attribute adequate weights to our four indicators, which will probably change the final design of the areas representing different vulnerability classes. In addition, we have to consider that, while the first and second indicators do not vary much, the second and third will vary significantly, which may influence the weight attribution.

Likewise, as another pending task, the four classes must be validated by the information of frequency and duration of energy outages in all areas. We expect to find more and longer outages in areas we classified as very high, and less and shorter outages in areas we classified as low.

Mapping partial results

By applying the vulnerability concept and the classes derived from it, we could draft a first map of vulnerability to the city of São Paulo, as follows.

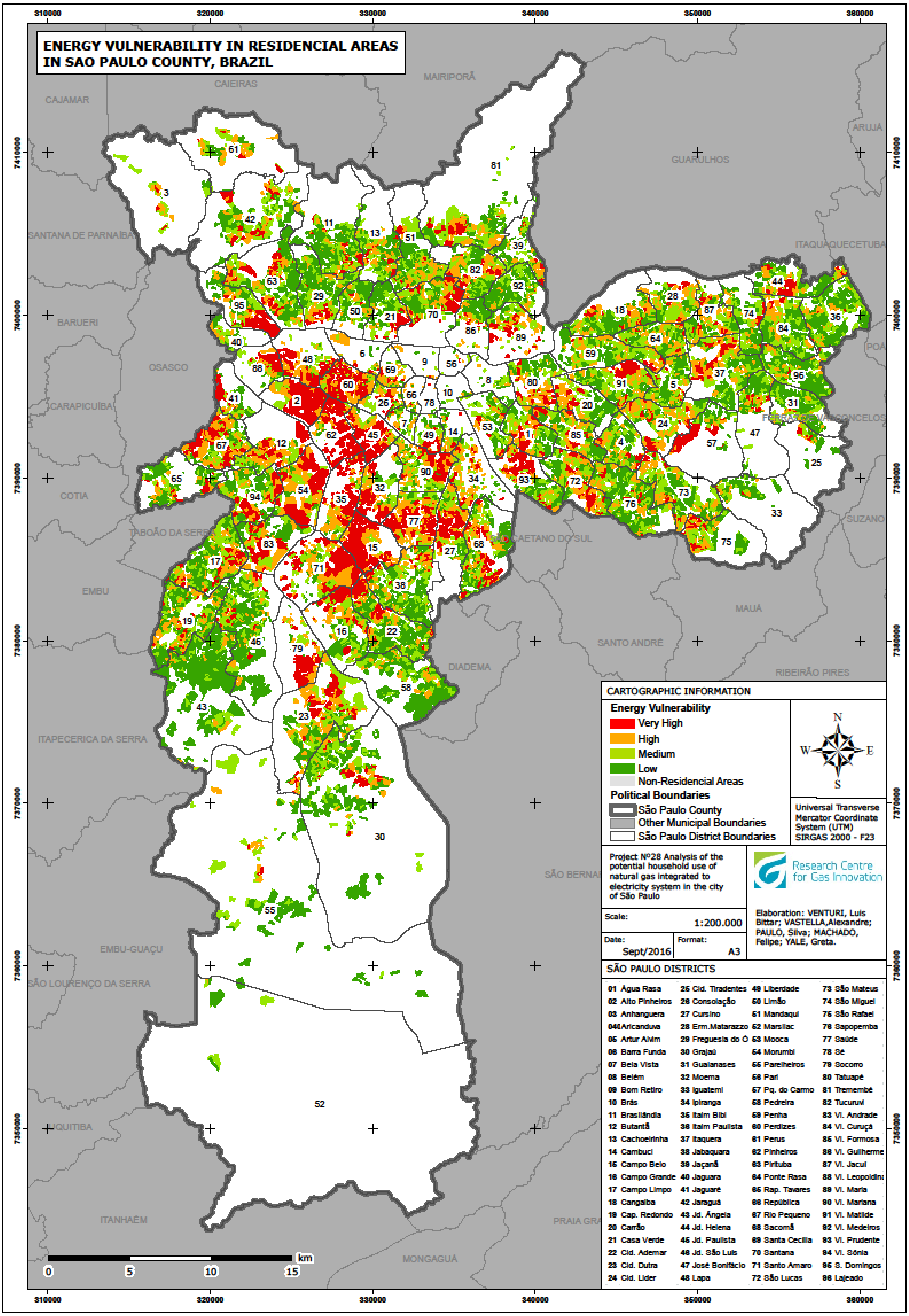

Figure 1 – Map of energy vulnerability of São Paulo. First approach.

As we have used only information about the third and fourth indicators (proximity of hospitals and number of trees, respectively), this map is a first approach, which means it will change as we insert data about the first and second indicator.

Partial conclusions

Several others indicators could be included to frame vulnerability classes. Overhead grid, for instance, has different techniques of electricity distribution, being some safer than others. An area may be less vulnerable just by receiving electricity from several small power stations, or being served by a high-tension grid and so on. All those technical variations will not be considerate in this first approach, though. Moreover, efficiency of maintenance services concerning trees trimming or electrical grid maintenance itself could change significantly vulnerability classes. Also, climate features should be considered in some contexts affected by hurricanes, typhoons and earthquakes, for instance. In São Paulo, on one hand, electricity is highly predominant and almost all grid are overheaded. Because of that we had no much choice and these indicators had to be chosen and they did not change much among the classes. On the other hand, we did not choose natural hazards, once the city is seldom affected by extremes of climate and never by seismic events.

In conclusion, indicators are not fixed and may vary according to different contexts resulting in different vulnerability classes.

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