Implications of energy sufficiency in developing countries: the case of the Bolivian power system

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Overview

According to literature, the energy sufficiency concept is typically associated with the minimum standards required to satisfy the needs of an individual and guarantee its well-being (Best et al., 2022). In this sense, energy sufficiency proposes a state in which a consumer's energy needs (at a person, community or country level), usually depicted as particular services, are met equitably (Bierwirth and Thomas, 2019). The implications from its application in developed countries has started to gain traction as a relevant development strategy to meet transition goals as it promotes the reduction of energy consumption, and therefore the mitigation of energy-related climate impacts. Additionally, sufficiency also promotes respecting planetary boundaries, fosters sovereignty and resilience, and represents a more cost-effective alternative to the current development trends (Best et al., 2022).

In this sense, studies that tackle energy transition scenarios often consider energy sufficiency cases, where alternative low-demand behaviours are expected (Tareen et al., 2024). Results typically show that sufficiency conditions enable a more equitable energy service across Europe and reduce the need for investments in capacity expansion and infrastructure development due to demand expectations reductions. However, implementing sufficiency-based measures will require significant efforts with a bottom-up perspective. Without adopting sufficiency strategies, Europe risks missing a critical opportunity for a transformative change (Wiese et al., 2024).

Nevertheless, while energy sufficiency scenarios provide exiting opportunities for the transition and downscaling of energy systems in the Global North, the concept can be expected to have different implications in developing countries. This is a result of the subjectivity of the standards considered for defining sufficiency across countries and the conditions in which these populations currently are. If "Decent Living Standards" are considered as referential values, most of the developing countries will be situated below the minimum thresholds (Millward-Hopkins et al., 2020). These discrepancies on the perception of energy sufficiency conditions can also be attributed to the inequality of international energy footprints, where higher-income countries tend to consume much more than low and middle-income countries (Oswald et al., 2020).

As a result, it can be expected that sufficiency scenarios in the global south would imply a need for increasing their current energy consumptions, instead of reducing it, in order to achieve a minimum standard that satisfies their energy needs. Within this context, this paper explores the implications of adopting an energy sufficiency scenario for the development of the power system in a low-income economy, specifically Bolivia

Methods

This study makes use of PyPSA-BO, a power system optimization model tailored from PyPSA-Earth, to characterize the country's power system and evaluate its expansion in the future under a cost-optimization approach. The model is developed following the open-source nature of its father model, facilitating access and transparency to all the modifications made and additional data used, and it can be found on its own GitHub repository[1].

To develop energy sufficiency scenarios, a demand characterization analysis is performed, where the current residential energy demands are compared to the existing energy sufficiency standards. From this analysis, the gap between these energy demand requirements is obtained and two alternative scenarios are explored: 1) a baseline consumption scenario, that assumes the historical growth trends in the power system for all sectors; 2) an energy sufficiency scenario that assumes that the residential demand growth will comply with minimum energy services standards.

1(https://github.com/CIE-UMSS/PyPSA-BO).

The resulting residential energy demands from each scenario are then treated, off-line, to proportionally modify the residential demand shares in the total electrical demands. These aggregated demands are then introduced in the PyPSA-BO model to optimize the system expansion by 2050 in each case and compare the differences between their total energy production and expansion requirements.

Results

Bolivia's case follows the general trend from developing countries regarding energy consumption and development indicators, where variables such as economic growth (Adhikari and Yanying, 2013) or development indexes (Steckel et al., 2013) are directly coupled to energy consumption. As a result, we assume that energy demand in the future will follow the expected population growth trend from the National Statistics Insitute, which projects an increment of 35% by 2050 compared to 2021. For this year, Bolivia's final energy consumption was 86 TWh, of which only 12% was linked to electricity consumption (Ministerio de Hidrocarburos y Energia, 2023).

Regarding its electric system, Bolivia's average per capita electricity consumption in 2021 was around 70 kWh/month (AETN, 2025), well below the world's average of 257 kWh/month registered in 2014, and even lower compared to the 502 kWh/month registered in the European Union for the same year (World Bank Group, 2023). However, as sufficiency standards are subjective and depend on environmental, social, and economic factors, specific sufficiency thresholds were estimated for the country using a bottom-up modeling approach based on Decent Living Standards, energy requirements to cover them, and the characterization of energy consumption based on stochastic demand curves (Sanchez-Solis et al., 2025). Results show that the average sufficiency threshold estimated for residential demands in Bolivia is 23.86 kWh/month, value which, when compared to the average energy consumption by municipality in Bolivia, allows to estimate that over 53% of the national population lives with energy demands below sufficiency thresholds with per capita consumptions of approximately 11.9 kWh/month.

With these inputs, the two alternative scenarios for 2050 are created. For the baseline scenario, the total annual electric demand is expected to be 20.26 TWh, assuming the sectorial demand shares are constant and historical growth trends are kept under Business-as-Usual conditions, similar to previous studies (Fernandez Vazquez et al., 2024). For the sufficiency scenario, total electric demand is expected to grow to 22.44 TWh, assuming that the share of residential demand below sufficiency grows until reaching the estimated standard and all other demands (including residential demands above the sufficiency threshold) are kept constant compared to the baseline. These scenarios are then run in PyPSA-BO (Fernandez et al, 2025) and a comparison of their power system's expansion is carried out. As expected, the growth of the additional demand in the residential sector (in the sufficiency scenario) implies an additional growth of the power system in the order of 10.9%. This growth in the Bolivian system implies that providing better living standards for its population represents an additional challenge, on top of the existing one that developing economies have to address in order to provide a constantly increasing energy demand for their developing economies. This in turn implies that sufficiency conditions will have an opposite effect in the Global South compared to the current concept that exists in the Global North.

Conclusions

The energy sufficiency concept holds a different significance and impact in developing economies compared to developed countries. In countries in the Global South (such as Bolivia) energy sufficiency implies an additional challenge to be considered during their planning efforts as demands can be expected to be under sufficiency thresholds. On the other hand, in the Global North (Europe), sufficiency concepts aim at descaling energy consumption and mitigation actions. This contrast in how the same concept will have different implications regarding the context where it is applied showcases the relevance of exploring the sufficiency conditions, targets, and implications in developing economies.

For the particular case of Bolivia, changes in energy demand requirements for the residential system under a sufficiency standard estimated under local conditions (around 24 kWh/month per capita) represent and increment of the consumption for the sector of 27% compared to a baseline scenario. Reaching this standard in the residential sector will imply a growth in the system's power generation capacity close to 11% compared to projections based on historical trends. However, it can be easily assumed that this growth would only increase if the sufficiency concept is also expanded to other energy services or consuming sectors.

While this study explores the energy-sufficiency concept focused on residential demands for the Bolivian case, the approach followed can be easily extrapolated to other countries or sectors of interest, as the sufficiency standards will vary depending on the local contexts and necessities. For future work the variability of sufficiency requirements from a geospatial perspective will be integrated to improve the demand characterization in the country, as energy needs will vary depending on environmental, technical and social characteristics of each region.

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