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Global electricity infrastructures

Historic developments, associated material stocks, and their relevance for societal wellbeing

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Electricity infrastructures are key for the provision of fundamental energy services and economic prosperity. Profound knowledge on past development and current stocks of electricity infrastructures is of crucial importance, e.g. for assessing the challenges of decarbonizing the power sector or providing universal access to electricity. By combining data from various sources and through modelling of transmission and distribution infrastructures, we present a global inventory of electricity infrastructures and corresponding material stocks. Greenhouse gas emissions associated with stock-building materials are minor in relation to combustion emissions from conventional power plants. Still, increased awareness of these aspects is warranted due to the high material intensities of some renewable energy technologies and the considerable grid expansion needed to accommodate large shares of intermittent energy sources and ensuring reliable electricity supply for a rising world population.

A consistent infrastructure inventory for 1980 to 2017

Publicly available databases on global power plant capacities vary in detail and timeframe. We combined time series provided by the International Renewable Energy Agency, the U.S. Energy Information Administration and the United Nations Statistics Division to obtain a consistent country-level database for the timeframe 1980 to 2017, differentiating between 14 technologies/fuel types (Fig. 1). An overview of regional differences in installed capacities and technology choices is provided by georeferenced data shown in Figure 2.

Data on the lengths of transmission and distribution grids as well as transformer capacities are less readily available. We used statistical data for individual countries and extracted grid lengths from GIS data (Open Street Map) to derive regression models and estimated the global grid lengths and transformer capacities. We found that transmission grids in 2017 accounted for 4.7 million circuit km and distribution grids for about 100 million circuit km. Transformer capacities in 2017 were estimated at 40.6 ± 4.5 Teravolt-Ampere. Together with the above-mentioned data on power plants, these results, broken down by further categories (voltage levels, transformer types), were used to estimate the global material stocks embodied in electricity infrastructures.

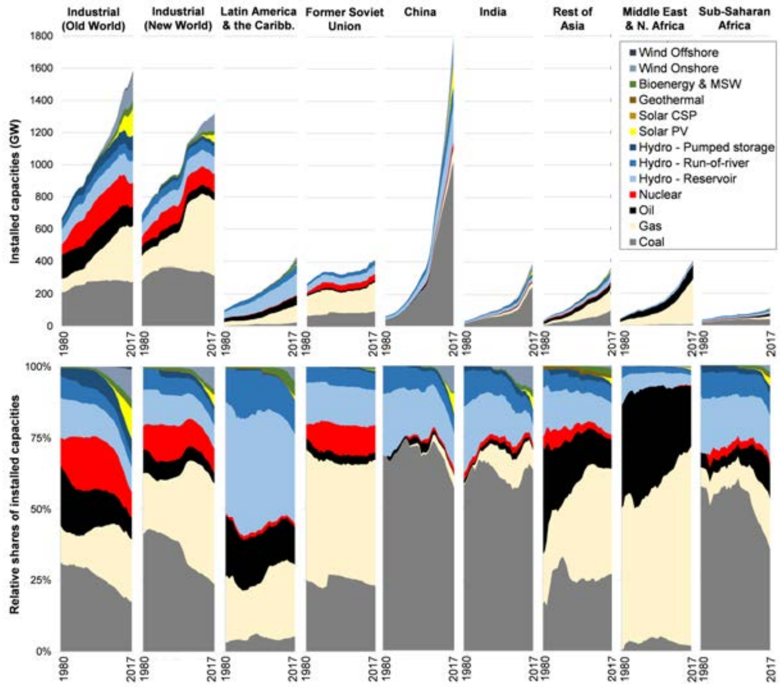

Fig. 1. Development of installed capacities in nine world regions from 1980 to 2017 (Kalt et al., 2021a, based on data obtained from EIA, 2020; IRENA, 2020; UNSD, 2020). Wave/tidal plants are disregarded due to negligible capacities.

Material stocks in electricity infrastructures

During 1980 to 2017, the stocks of the main bulk materials in electricity infrastructures, iron and steel, concrete, copper and aluminium, have risen by factors between 2.5 and 3.5 (Fig. 3). The contributions of the various infrastructures are highly diverse among the considered materials: Iron and steel stocks are composed of about 50 % power plants, 44 % grids (primarily transmission) and 6 % transformers. Concrete stocks are dominated by hydropower plants. Conversely, aluminium stocks are mainly composed of conductors in grids. The expansion of solar power has become a quite relevant driver for aluminium stock accumu-

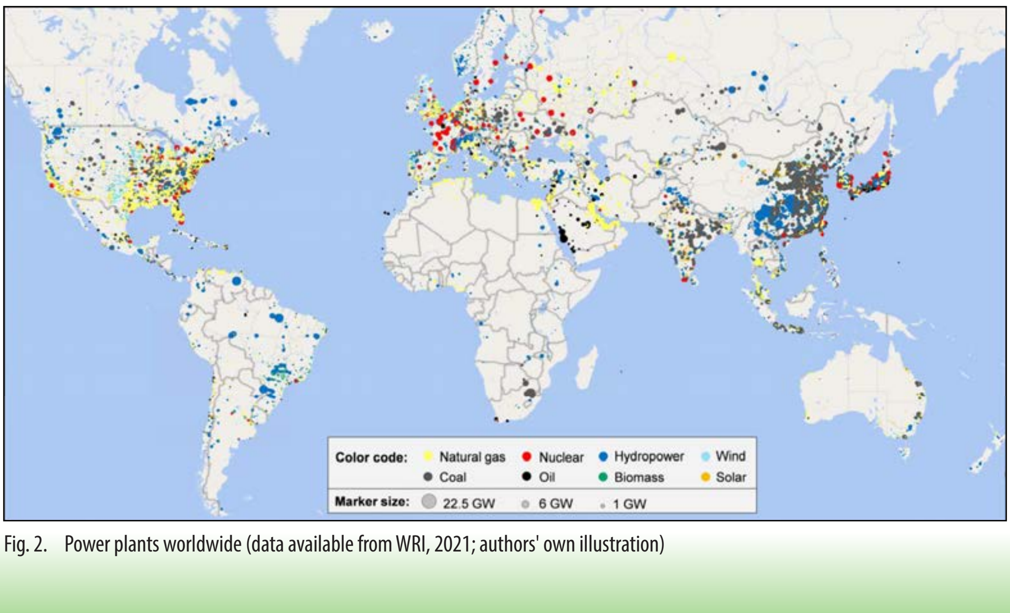

Fig. 2. Power plants worldwide (data available from WRI, 2021; authors' own illustration)

lation, and wind power, contributing about 4.5 % to global electricity supply, already accounts for close to 10 % of iron/steel stocks in electricity infrastructures. Copper stock developments are similar in quantity to those of aluminium but not significantly affected by the uptake of solar and wind power in recent years.

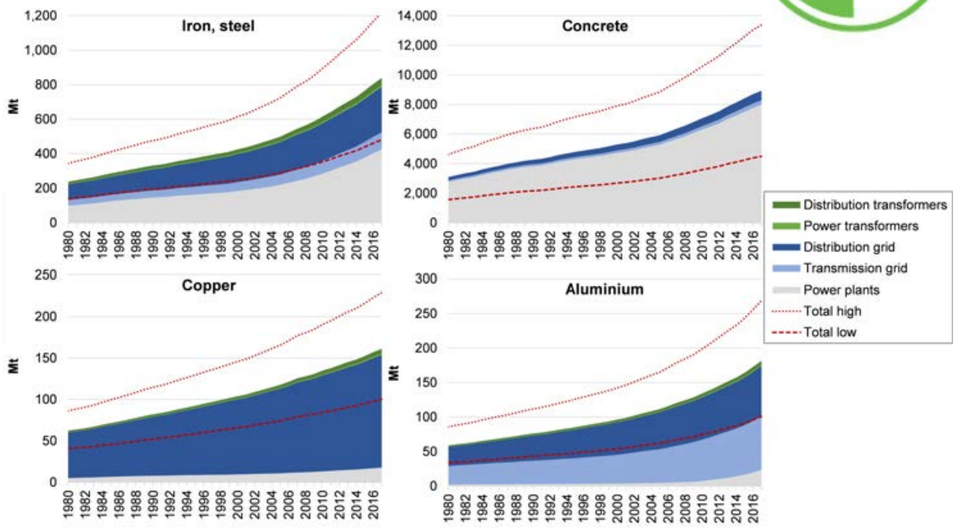

Fig. 3. Power plants worldwide (data available from WRI, 2021; authors' own illustration)

Electricity infrastructures facilitate fundamental energy services and are essential for economic prosperity

The high relevance of electricity for modern societies is undisputed. Empirical studies on this topic usually consider per capita electricity consumption as quantitative indicator, disregarding the fact that differences in final conversion efficiencies and fuel mixes are often considerable and may lead to grave distortions when country comparisons only focus on per capita electricity consumption. Shifting the focus towards infrastructures, we explored per-capita metal stocks in electricity infrastructures as an alternative indicator and investigated the correlation with indicators for the quality of electricity supply (WEF, 2018) and social well-being indicators ("basic human needs" and "foundations of wellbeing"; SPI, 2020). The results suggest that, despite the high diversity of electricity generation mixes across countries, a certain level of per capita metal stocks is indispensable for achieving high scores in these indicators (Fig. 4).

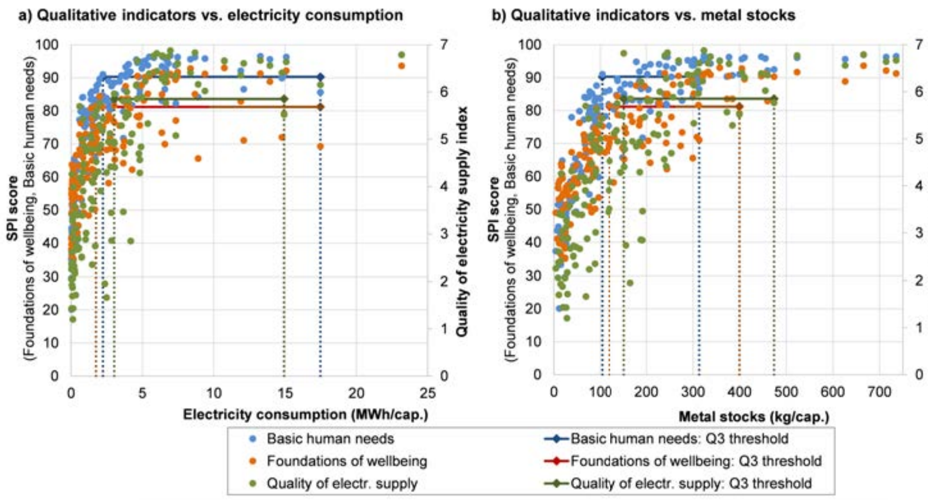

Fig. 4. Per-capita electricity consumption (a) and metal stocks (b) plotted against Social Progress Index indicators (SPI, 2020) and the WEF (2018) indicator for quality of electricity supply (Kalt et al., 2021b). Third quartile values of the qualitative indicators ("Q3 thresholds") are here considered as benchmarks.

These results are of course contingent on current technologies, and a clear-cut quantification of minimum metal requirements for achieving high levels of supply quality and service provisioning remains elusive. Nevertheless, they demonstrate the fundamental importance of material stocks for societal well-being and indicate that vast material stock expansion will be necessary for providing universal access to electricity to a world population projected to reach 8.5 billion by 2030, as proclaimed in the United Nations' Sustainable Development Goal No.7.

Publications:

Kalt, G., Thunshirn, P., Haberl, H., 2021a. A global inventory of electricity infrastructures from 1980 to 2017: Country-level data on power plants, grids and transformers. Data in Brief (submitted).

Kalt, G., Thunshirn, P., Wiedenhofer, D., Krausmann, F., Haas, W., Haberl, H., 2021b. Material stocks in global electricity infrastructures – An empirical analysis of the power sector's stock-flow-service nexus. Resources, Conservation and Recycling 173 (2021): 105723. https://doi.org/10.1016/j.resconrec.2021.105723.

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