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Electrification pathways for Tanzania: Implications for the economy and the environment

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ABSTRACT

The role of electricity availability in promoting the economic growth of low-income countries is a highly debated issue. Taking the Tanzanian government's view that a lack of infrastructure for power generation, together with a low electrification rate, are a limitation to growth, this paper studies the implications on the country's sustainable development of expanding the electricity sector. The analysis is based on the joint use of the OSeMOSYS open-source power system optimization model and the Leontief Input-Output model (based on the Tanzanian Social Accounting Matrix). Four scenarios are considered, representative of alternative technological and environmental policies, characterized by different timing to achieve full electrification. Results indicate that while an expansion of the electricity sector can contribute significantly to economic growth, the associated direct and indirect growth in carbon emissions is equally remarkable. Relying on the country's renewable generation potential would be important but might not be sufficient to lower the economy-wide carbon intensity, particularly under the assumption of reaching full access already in 2030. Targeting energy efficiency and/or decarbonization efforts in the industrial sectors as well as in the provisions of services would also be necessary. The latter is particularly relevant as, per effect of an average income increase, household consumption habits contributes to drive the economy away from its traditional, agricultural base.

1. Introduction

The question of whether energy availability, and electricity in particular, has a role in promoting a country's economic development is not only extremely relevant in practice, but also highly debated in the literature (Burke et al., 2018; Lechthaler, 2017; Lee et al., 2017). While scholars seem to agree, at least, on the fact that electricity is an important, direct factor of production for several industrial sectors of the economy, and the enabler of indirect effects on economic growth, particularly in low-income countries (Bos et al., 2018; Salmon and Tanguy, 2016), recent efforts to expand the electricity sector and ensure universal access have been quite remarkable (Karplus and Von Hirschhausen, 2019). Still, a number of countries, in particular, in the region of Sub-Saharan Africa, continues to present low electrification rates and limited infrastructures, in the face of increasing demand projections and commitments to achieve a sustainable economic growth (Peng and Poudineh, 2017).

The United Republic of Tanzania is representative of this latter region of the world in numerous ways. A significant annual growth in Gross Domestic Product (in the order of 6%) was registered over the past decade (World Bank, 2016). Yet, the electrification rate in 2016 was only 33%, the weighted average of 65% in urban areas and 17% in rural regions (Choumert-Nkolo et al., 2019). As it can be expected, government plans and expectations to convert Tanzania to a middle-income country by 2025 are accompanied by projections of increased electricity consumption, as well as strategies to expand the electricity generation sector and the network infrastructure quite significantly (Philip Isdor Mpango, 2016; VV AA, 2016a,b). At the same time, the country has pledged to embark on a climate resilient development pathway (VV AA, 2015) and, in this regard it is important to recall that while Tanzania is responsible for small fraction of global CO_2 emissions (0.59% in 2014), carbon intensity in 2014 was almost eleven times the world average, indicating significant potential for improvement (USAID, 2018).

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Within this context, the present work provides an approach to modelling alternative electrification scenarios for Tanzania, and to estimate their potential impact on the country's economy and environment. The main goal is to gain a better understanding of how policy decisions concerning the power sector can contribute to achieve national sustainable development goals in a representative country in Sub-Saharan Africa.

Only a couple of scholarly articles have looked at alternative scenarios for the development of the electricity sector in Tanzania. One encompasses the entire Sub-Saharan Africa (Bazilian et al., 2012), making for a low-level of country-specific details, while the other, focusing specifically on Tanzania, dates to a few years back and includes only centralized, grid-connected power production (Kichonge et al., 2015). Other, recent studies of the Tanzanian electricity sector have, instead, addressed investment-related issues (Gregory and Sovacool, 2019; Peng and Poudineh, 2017; Sergi et al., 2018), conducted an environmental assessment via a life cycle approach (Felix and Gheewala, 2012), or have focused on a specific technology, looking at the potential for micro-hydro (Adebayo et al., 2013) and solar PV (Aly et al., 2019; Amars et al., 2017). In short, there are no up-to-date, country-specific studies that look at the development of the Tanzanian electricity sector under alternative sets of assumptions regarding technological, economical, and policy aspects, while including the role of both on- and off-grid technological solutions.

The first part of this study contributes to filling this gap. Four alternative *electricity scenarios* are considered, each of them a plausible representation of how the Tanzanian electricity sector might evolve over time, from 2015 to 2030. These sets of assumptions are translated into input data for the open-source OSeMOSYS model, which is employed to compute the least-cost, technically feasible technology mix, that meets the electricity demand projections in each year of the observation period (Howells et al., 2011). Notably, the model includes a novel approach to allow for both on-grid and off-grid technological solutions in case of new accesses. The model's output comprises four alternative *electrification pathways* for Tanzania, which are contrasted in terms of annual electricity production and carbon emissions.

The second part of this work moves a step further from the existing literature and consists in assessing the country-wide impact of these four electrification pathways. Previous studies addressing the potential effects on the country's economy and carbon emissions of a growth in the electricity sector are not available. The contribution by Arndt et al. (2012), explores the potential implications on economic growth of different biofuels production options and the study by Sjølie (2012) looks at the effect on greenhouse gas emissions of substituting more carbon-intensive fuels with charcoal products.

As for this second part of the study, a linear meso-economic optimization model is employed, based on the Leontief's Input-Output framework (Miller and Blair, 2009), and effectively tailored to the scope of this work. The rationale of the modelling effort is to quantify the economic development that could be potentially achieved by fixing the electricity production yield as a constraint. This is consistent with the position of the Tanzanian government (VV.AA., 2016b, 2016a), as well as with a "growth hypothesis", i.e. the existence for Tanzania, of a unidirectional causal relationship between energy (electricity) availability and economic growth (Odhiambo, 2009).

A first set of novel results obtained with this original model consists in the sectoral value added generation and fuel combustion-related CO_2 emissions resulting from a greater electricity availability. A second set derives from the analysis of the year by year evolution of households' consumption patterns and its effect on the country's carbon emissions. This additional conceptual and modelling effort is motivated by the desire to examine more closely the potential trade-off between economic growth and environmental sustainability generated by alternative policy interventions in the power sector.

The rest of this paper is organized as follows. Section 2 outlines alternative options for the development of the Tanzanian electricity sector. Section 3 describes the modelling approach used to study the impact of these electrification pathways on the country economy and the environment. Section 4 presents and discusses the results. Conclusions and further research opportunities are presented in Section 5.

2. Electrification pathways for Tanzania

This section introduces the future scenarios of the Tanzanian power system adopted for this study (Section 2.1), presents the electrification pathways obtained under each set of assumptions, and contrasts the technology mix and carbon emission of the power sector under the same alternatives (Section 2.2).

2.1. Designing electricity scenarios

This work considers four scenarios for the development of the electricity generation sector in Tanzania over the period 2015–2030. The selection of the modelling horizon is consistent with the nature of the adopted modelling approach. As more extensively explained in Section 3, the Input-Output model relies on economic empirical data that provides a description of the Tanzanian economy structure in 2015. Except for the electricity supply sector, the economic structure of all the other industries must be assumed as constant and not perturbated by changes in future households' demand pathways. Since this assumption becomes weaker when the modelling horizon gets longer, the time horizon was limited to 15 years.

The scenarios are designed to contrast alternative policy interventions for the power sector. Nevertheless, they share the same initial conditions in terms of installed generation capacity (less than 2000 MW in 2015) and retirement schedule, technology options for future developments (including both on-grid and off-grid solutions), as well as relevant parameters that characterize each technology from a technical, economic and environmental perspective (e.g., rainfall patterns, carbon emissions per fuel type, evolution of fuel costs, etc.). The scenarios also share the same system constraints, such as an overall cap on the intermittent renewable production and a minimum reserve margin.

The four scenarios differ for a few key assumptions. As illustrated in Table 1, the *Business As Usual* (BAU) scenario assumes no specific policy is adopted for the electricity sector, no changes in the electricity generation mix, as well as no changes in the grid rate (ratio of consumers connected to the transmission network over all consumers with a connection to electricity). The electrification rate (the percentage of population with access to electricity) is expected to reach 100% in 2050, as indicated in the Tanzanian government plans (Philip Isdor Mpango, 2016; VV.AA., 2016a). The *New Policy* (NP) scenario includes, instead, the existing technology policies proposed by the Tanzanian government and, therefore, a generation mix which develops over time according to the latest Power System Master Plan (VV AA, 2016b). The *Energy For All* (E4A) scenario assumes the same technology policies as in the NP scenario, but it is driven by the goal of reaching universal electricity access by 2030 (two decades earlier than in the NP). Finally, the so-called 450TZ scenario, inspired by global efforts to keep temperature increases well below 2 °C, simulates the expansion of the power generation sector under an environmental policy (a carbon tax starting at 10 $/ton of CO_2 and increasing up to 75 $/ton in 2030) – a

Table 1
Electricity development scenarios.

Scenario	Generation mix	Electrification rate	Policy	Solar PV and wind overnight investment cost decrease
BAU	Constant at 2015 and fixed grid rate	100% in 2050	No policy	40% and 10%
NP	Meet national targets at 2025 [PSMP, 2016]	100% in 2050	Technology policy	40% and 10%
E4A	Meet national targets at 2025 [PSMP, 2016]	100% in 2030	Technology policy	40% and 10%
450TZ	No restrictions	100% in 2050	Environmental policy	70% and 25%

policy not yet proposed by the Tanzania government. With respect to the other scenarios, more optimistic assumptions are also made regarding the decrease of the overnight investment costs of renewables, such as wind and solar PV IEA, 2016; IRENA, 2014) and no technology policies are imposed on the development of the generation sector.

These four sets of assumptions are simulated using the OSeMOSYS open-source modelling framework, which calculates the least-cost, technically feasible technology mix that meets electricity demands projections, while respecting a number of exogenous constraints (Howells et al., 2011). In essence, the exogenous OSeMOSYS model parameters are related to:

(a) the types and techno-economic specifications of available resources (e.g., availability and cost of natural gas, availability and intensity of solar radiation) and the available energy conversion technologies (e.g., costs and performances of coal power plants);
(b) features of the transmission and distribution infrastructures;
(c) definition and features of the energy demand, assumed as perfectly rigid with respect to the energy price changes;
(d) other policy or technical constraints that may be required to define the scenarios (e.g. political decision to ban a technology after a defined year).

Notably, this modelling framework enables the user to increase the space resolution of the analysed region by defining multiple sub-regions, and it accounts for the variability of available resources and demand yields over time by defining them according to time-slices: the time and space scopes and detail level of the modelled energy system depend on the available data and on the research question to be addressed.

Once the demand of electricity and the energy supply resources and technologies have been characterized for the desired scenarios, the model returns several endogenous parameters, the most relevant of which are: electricity production and installed capacity, resources consumption, investment and operative costs, emissions, all defined by year and by technology.

In this paper, the original structure of OSeMOSYS was improved by means of a geo-spatial definition of the electricity demand, clustering and distinguishing among several types of end users (urban and rural), and by considering different distances from the Tanzanian national grid. In other words, differently from standard applications of the OSeMOSYS model, this study's is based on a geospatial characterization of the Tanzanian territory, so that different geographical areas in terms of population density and distance from the grid are identified. This information is then used to set a priority rule for the adoption of on-grid vs. off-grid solution for new connections.

Among the results obtained from the simulation of the alternative scenarios, Section 2.2 will focus only on two indicators: annual electricity production by technology, and annual carbon emission from the power sector. As for the latter, carbon emissions are the sum, for all type of fossil fuels, of the product of the annual amount of fuel employed in the electricity sector times a fuel-specific emission factor. All the details on the modelling effort conducted with OSeMOSYS are collected in a separate paper (Rocco et al., 2020).

2.2. Estimated electrification pathways

Fig. 1 illustrates the annual electricity production, in PJ, by technology type under the assumptions made for the four scenarios. Installed generation capacity in 2015 in Tanzania is 1857 MW. Should BAU conditions prevail, this capacity is simulated to increase up to 9840 MW in 2030, in order to meet the projected demand increase estimated by the Tanzanian government (VV AA, 2016b). The share of electricity production by technology remains the same as in 2015, equal to 45% natural gas, 22% oil and diesel, 31% hydro, 1% biomass (with an increase in diesel off-grid up to 5% in 2030). Overall, the annual production grows by almost five times, from 25 PJ to 123 PJ in 2030 (from 7 TWh to 34 TWh).

Under the conditions specified for the 450TZ scenario, the installed capacity reaches instead 14498 MW in 2030 (because of the lower capacity factors of renewables), the generation mix includes greater shares of hydro (38% in 2030), geothermal (4% in 2030), wind (7% in 2030) and solar PV for off-grid applications (22% in 2030) while oil is phased out and the share of natural gas decreases over time (21% in 2030). Annual production in 2030 amounts to 116 PJ (32 TWh). This is lower than in the BAU due to a larger use of off-grid solution (hence, lower transmission and distribution losses).

The electrification pathway which derives from the NP assumptions is intermediate between the previous two. Installed capacity in 2030 is simulated to grow up to 11931 MW and the share of generation by technology in 2030 is dominated by natural gas (54% in 2030), includes coal (4% in 2030), and relies less on hydro (15% in 2030). Overall the generation mix is more diversified, with contributions from geothermal and wind (both at 4% in 2030), solar PV on-grid (1% in 2030), and solar PV off grid (11% in 2030). Annual production in 2030 reaches 118 PJ (33 TWh).

Finally, the E4A pathway presents, by design, the same generation mix observed in the NP. It requires, however, greater installed capacity (15821 MW) in 2030, in order to provide access to the entire population by the same year. Of course, also the production is higher, reaching 150 PJ (42 TWh) in 2030.

These results are only partially comparable with those derived by Kichonge et al. (2015), who consider exclusively on-grid technologies and three scenarios (Business As Usual, Low Consumption and High Consumption). Their estimated installed capacity in 2030 (between 5.0 and 6.0 MW, depending on the scenario) is significantly lower than the one found in the present study. Naturally, also the production in 2030 (between 28.4 and 35.1 TWh) is comparably smaller. The initial share of electricity generation by technology is similar to the one assumed in the present study and mainly derives from hydro (between 42.2% and 44.7% depending on the scenario) and natural gas (between 53.8% and 56.5%), with small contributions from biomass (around 1%) and oil (0.2%). In 2030 the contribution of hydro is greater than in 2015 (between 56.5% and 69.8%), while the role of natural gas decreases (between 11.8% and 14.5%), similarly to what occurs in this paper's 450TZ scenario (although with different rates of change). The share of coal raises significantly

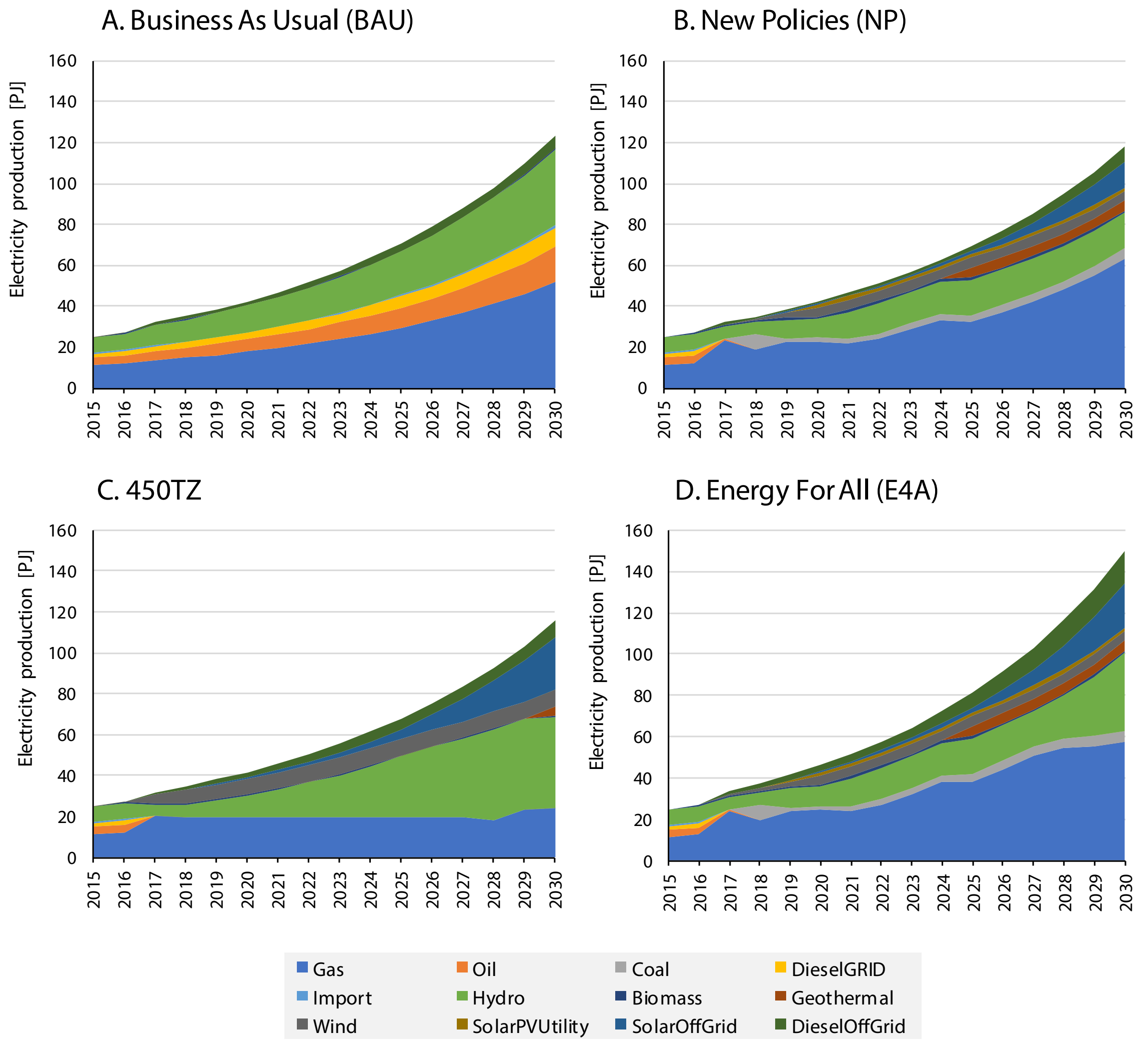

Fig. 1. Electricity production per technology (in PJ) between 2015 and 2030 for all the analysed scenarios: A-Business As Usual (BAU), B-New Policies (NP), C-450TZ, D-Energy For All (E4A).

(between 6.6% and 15.0%), assuming a higher role than estimated in this paper's NP scenario. Finally, as in the present study, Kichonge et al. (2015) attribute a decreasing role to biomass and oil. Nevertheless, the main discrepancy with the present work derives from the absence of solar, wind and geothermal energy in the production mix. This result is driven both by higher cost assumptions for the same technologies, as well as by the lack of a solar off-grid option.

Carbon emission from the power sector are consistent with the contribution to electricity production described above. As illustrated in Fig. 2, CO_2 emissions increase by five times, from 3.0 Mton per year in 2015 to 15.2 Mton per year in 2030, in the BAU scenario. Such results are in line with those of Kichonge et al. (2015), who estimate an annual growth in carbon emission between 9.5% and 11.7%.

Only the environmental policy assumed under the 450TZ scenario is successful in decreasing CO_2 emissions below 2.0 Mton per year since 2017 and in keeping the contribution of the power sector below 2.1 Mton until 2030. The technology policy proposed by the Tanzanian government (NP scenario) contains the emission initially, but electricity production by gas and coal conduces the yearly contribution of the power sector to 8.9 Mton in 2030 (more than four times as much as in the 450TZ). Sharing the same

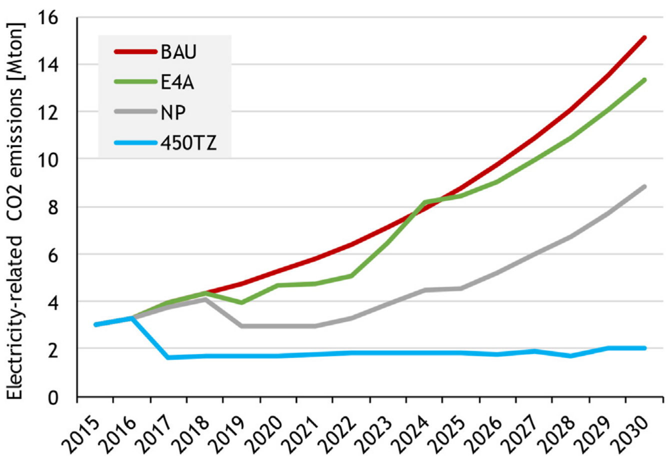

Fig. 2. CO_2 emissions per year from the electricity sector (in Mton) between 2015 and 2030, for all the analysed scenarios (corresponding to different colours, listed in the legend). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article).

assumption in terms of technology policy, but assuming full electrification by 2030, the E4A pathway presents CO_2 emissions rather similar to those observed for the BAU pathway, reaching 13.3 Mton in 2030.

3. Modelling impacts on the economy and the environment

The economy-wide impacts resulting from these electrification pathways are assessed by means of an original, linear optimization model based on the Leontief's Input-Output framework (Miller and Blair, 2009). While this is illustrated in the following Section 3.1 (general framework) and Section 3.2 (tailored model), it is worth mentioning here that the analytical expressions of the equations provided in this chapter are authors' own elaborations, and that newly developed scripts (in Python) and all the input data used throughout the study (and briefly described in Section 3.3) are shared as open-source material in the electronic supplementary material section.

3.1. The Leontief-Kantorovich model

Leontief's Monetary Input-Output Tables (MIOTs) provide a comprehensive overview of a national economy (or a network of national economies) in one defined time frame (usually one year). MIOTs are grounded on empirical data, expressing the value of goods and services consumed and exchanged among industries, provided as sectoral investments, and invoked by households for final consumption. Linear and non-linear planning optimization models based on MIOTs are widely adopted for a variety of economic and environmental assessments (Mahajan et al., 2018; Pauliuk et al., 2015a). In macroeconomic modelling, Social Accounting Matrices (SAMs) are usually preferred with respect to MIOTs, because they can provide a more detailed characterization of the roles of labour, households, and the social institutions of the economy, including such factors as income from employment and its disposition, labour costs, and the demographics of the work force that comprise the market for supply and demand of labour. SAMs are then particularly useful as ground data for Computable General Equilibrium models (CGE) (Burfisher, 2011). An extensive and comprehensive references to empirical datasets for macroeconomic models are provided by the literature (Miller and Blair, 2009; United Nations, 2010).

As for the present work, a *multi-sectoral optimal resource allocation model* is adopted: this model, also known as *linear programming model* or *planning model*, is extensively descripted in the literature (Economics and Ecology, 2009; Eurostat, 2008; Miller and Blair, 2009), and its underlying assumptions can be deeply customized based on the available data and the complexity of the market mechanisms to be modelled. Specifically, the selected linear optimization model, is based on a constant input-output technology structure (usually referred to as the *Leontief* technology assumption) and on a fixed final demand structure (sometimes called *Kantorovich* assumption), thus implying no technological change, no substitutability between inputs and a perfect elasticity of the demand with respect to price changes (Révész and Zalai, 2007). Consistently, it will be referred to as the *Leontief-Kantorovich* model (Révész and Zalai, 2007). It is important to note that although the impact of future policies is often studied with CGE models, also in the case of low income countries (Babatunde et al., 2017), the strong hypotheses and the large amount of data required by the same models fully justify the use of simpler and less data-intensive planning optimization models (Duchin et al., 2016; Pauliuk et al., 2015b).

Let us consider one generic national economy for which the national economic and environmental accounts are assumed to be available. The economy is composed by n industries classified according to a standard protocol, like the ISIC one (United Nations, 2008), l final demand categories (households' and govern expenditures, investments and exports), k factors use categories (labour, capital, rents and royalties, taxes), and j environmental transactions (for example: primary energy use, CO_2 emissions, water use, etc.).

The Input-Output database is constituted by the intermediate transactions matrix $\mathbf{Z}(n \times n)$, expressing the supply and consumption of goods and services among industries, the final demand matrix $\mathbf{Y}(n \times l)$, the factor use matrix $\mathbf{V}(k \times n)$, and the environmental transactions matrix $\mathbf{R}(j \times n)$. The fundamental national production balance states that total economic production by sector $\mathbf{x}(n \times 1)$ equals the sum of intermediate and final consumptions, and it is expressed by equation (1) (where $\mathbf{i}$ vectors are known as summation vectors of appropriate sizes). Finally, the assumption of constant technology structure also implies a fixed share of imported products by each sector, identified by the imports matrix $\mathbf{M}(n \times n)$.

$$\mathbf{Z} \cdot \mathbf{i}_{n\times1} + \mathbf{Y} \cdot \mathbf{i}_{l\times1} = \mathbf{x} \tag{1}$$

Considering the analysed national economy in a generic time frame (say $t = 0$), the primal optimization problem (2) consists in finding an optimal allocation of factors (namely labour and capital) able to maximize the global final demand yield (y, scalar objective function) with a given level of available primary resources (constraint b), and by satisfying the given structure of final demand for each country (constraint a).

In problem (2), the technical coefficients matrix is defined as $\mathbf{A} = \mathbf{Z} \cdot \hat{\mathbf{x}}^{-1}$, factors use coefficients are derived as $\mathbf{v} = \mathbf{V} \cdot \hat{\mathbf{x}}^{-1}$, and total factors use is the column sum of the factor use matrix $V = \mathbf{i}_{1\times k} \cdot \mathbf{V}$. The structure of final demand $\mathbf{s} = \mathbf{Y} \cdot y^{-1}$ represents the share of final demand covered by each industry in each country with respect to the overall final demand, and it is here referred to as the *consumption basket* of final demand. Environmental transactions coefficients $\mathbf{B} = \mathbf{R} \cdot \hat{\mathbf{x}}^{-1}$ may be needed in case the problem has to be constrained with respect to pollutants/GHG emissions caps or in case of limited natural resources availability (constraint c). Finally, constraint d avoids negative non-sensical results.

$$\begin{array}{l} max y = \mathbf{i} \cdot \mathbf{Y} \\ s.t. a : (\mathbf{I} - \mathbf{A}) \cdot \mathbf{x} \geq y \cdot \mathbf{s} \\ b : \mathbf{v} \cdot \mathbf{x} \leq V \\ c : \mathbf{B} \cdot \mathbf{x} \leq \mathbf{R} \cdot \mathbf{i} \\ d : \mathbf{x} \geq 0 \;\; ; \;\; \mathbf{Y} \geq 0 \end{array} \tag{2}$$

While only the essential constraints are included in problem (2), many others can be added to provide a better description of the real structural features of the country. This can be achieved, for instance, by including trade barriers or demand/imports elasticities, by putting limits in overspecialization of industries, etc. Moreover, the *reversible* nature of the available factors needs to be specified: for instance, labour may or may not be allowed to be transferred across sectors, countries and/or skill levels. Finally, the proposed model can be employed to contrast different system configurations by estimating different optimal states (on the contrary, the model cannot be used to describe the dynamic transition to a different optimum).

Consistently, the assessment of the impact of policy shocks can be performed by comparing the results of problem (2) before and after the introduction of changes in industries' efficiencies and environmental performances, or in the structure of the final demand (say from $t = 0$ to 1), leading to changes in the overall sectoral production $\mathbf{x}$, and therefore to changes in the related sectoral economic and environmental impacts, as expressed by relation (3)

$$\varDelta(\mathbf{A},\mathbf{v},\mathbf{B},\mathbf{s})_{0\rightarrow 1}\rightarrow\begin{cases}\varDelta\mathbf{V}=\varDelta(\mathbf{v}\cdot\widehat{\mathbf{x}})_{0\rightarrow 1}\\ \varDelta\mathbf{R}=\varDelta(\mathbf{B}\cdot\widehat{\mathbf{x}})_{0\rightarrow 1}\end{cases} \tag{3}$$

3.2. A tailored version of the Leontief-Kantorovich model

To address the specific objective of this study, a number of modifications are proposed for the LK-IO problem (2), leading to the modified problem (4).

$$\begin{aligned}&max y=\mathbf{i}\cdot\mathbf{Y}\\&s.t.a:(\mathbf{I}-\mathbf{A})\cdot\mathbf{x}\geq y\cdot\mathbf{s}\\&b:x_{el}\leq\tilde{x}_{el}\\&c:\mathbf{x}\geq 0\ ;\ \mathbf{Y}\geq 0\end{aligned} \tag{4}$$

The LK-IO problem (4) consists in finding an optimal allocation of economic factors able to maximize the global final demand yield while satisfying a given structure of final demand (constraint *a*), with a given level of available electricity supply (constraint *b*) and avoiding negative results (constraint *c*). The main idea of the proposed approach is to investigate the economy-wide impacts of several prospected electricity scenarios assuming that the economic growth is constrained by the exogenously imposed electricity supply.

The specific features of the problem can be described as follow:

- **Constrained total electricity supply.** With respect to problem (2), sectoral factor use $\mathbf{V}=\mathbf{v}\cdot\widehat{\mathbf{x}}$ becomes an endogenous result, while values of electricity supply $\tilde{x}_{el}$, derived from the OSeMOSYS electricity scenarios (see Section 2.2) are exogenously defined as a new constraint (*b*). This implies unlimited investment capacity, which is required to enable the yearly increase in electricity production levels.
- **Unconstrained environmental transactions.** Unlimited resources availability and unconstrained pollutants/GHGs emissions are assumed. This assumption is consistent with the scope of the study, which focuses on the potential economic growth enabled by the availability of electricity and the amount of resources and pollutants/GHG emissions that are respectively consumed and produced to satisfy a given demand of industrial products (including electricity).
- **Variable environmental transactions coefficients**. MIOTs and SAMs databases are almost always provided with high sectoral aggregation. Except for few rare exceptions (like the *Exiobase* database (Merciai and Schmidt, 2018)), electricity generation technologies are lumped all together into one unique aggregated industry (i.e. *Electricity, Gas and Water Supply*), and the related technical and environmental transactions coefficients are then an average description of the sectoral habits. The basic LK-IO model is then unable to reproduce the (environmental) impact related to changes in the electricity production mix. To overcome this issue, the average Environmental transactions coefficients of the power sector $\overline{\mathbf{B}}_{\mathbf{el}}(j\times 1)$ are here expressed as function of the electricity production technology mix according to equation (5): E_i represents the electricity produced by the *i-th* technology over the whole year, $\mathbf{B}_{el,i}$ the environmental transactions of the *i-th* technology, and the subscript *tech* refers to the number available operative power technologies.

$$\overline{\mathbf{B}}_{el}=\frac{\sum_{tech}(E_i\cdot\mathbf{B}_{el,i})}{\sum_{tech}E_i} \tag{5}$$

While environmental transactions coefficients of the power sector can be derived relatively easily according to equation (5), the same cannot be said for technical coefficients, that have been assumed constant throughout the years and independent by the changes in power sector technology mix. The latter assumption is strong, but very often accepted in performing an analysis of the energy sector based on Input-Output models, due to the high uncertainty and unavailability of raw technology-specific empirical data (Kamidelivand et al., 2018).

- **Variable final demand structure.** The LK-IO model (4) can be used by considering a fixed structure of final demand $\mathbf{s}(n\times l)$. However, households with different income levels may be characterized by different consumption habits, each one with different economic and environmental impacts.

With reference to the Tanzanian case, Fig. 3 (left side) presents the structure of households' final demand by income quintiles. Clearly, the average consumption basket significantly differs across households with different income levels. Between 70% and 80% of goods consumed by households in the lower quintiles are products of the agricultural and fishing sectors (primary activities), while services (including education, health, communication and leisure), transportation, and energy amount on average to around 10%–15% of the consumption basket. By contrast, the same goods and services makes for almost 50% of the consumption basket of households in the higher income quintiles.

The related economic and environmental impacts, illustrated on the right side of Fig. 3 and respectively expressed in terms of Value Added and CO_2 emissions embedded in the unit of final demand expenditure, are based on the Tanzanian SAM of 2015 (IFPRI, 2015). As expected, households' quintiles with different consumption habits exhibit sensible differences in CO_2 emissions, reaching almost 60% between the first and the fifth quintiles, while a less relevant difference is visible in terms of value added embedded (10%).

Consistently, the structure of the final demand for the *i-th* year is formulated as a function of the change in workers' income of the previous year based on the following assumptions:

- The number of workers in the country n_W is assumed to be constant throughout the analysed time frame. Workers are assumed to be fully employed and distinguished into different income categories, assumed as known for the baseline year 0 only. In this application, only Low-income and High-income workers are distinguished, so that $n_W=n^i_{W,LI}+n^i_{W,HI}$ (superscripts refer to the *i-th* year).
- The yearly average final demand expenditures per capita for each income category $\overline{y}_{pc,LI}$ and $\overline{y}_{pc,HI}$ are assumed to be known and constant throughout the analysed time frame, and equal to the baseline year 0.
- The structures of final demand of each income category $\mathbf{s}_{LI}$ and $\mathbf{s}_{HI}$ are assumed to be constant throughout the analysed time frame, and equal to the baseline year 0.

With these assumptions, it is possible to evaluate the new overall structure of final demand in the next year $\mathbf{s}^{i+1}$ as the average of the final demand structures of the different income categories weighted on the overall number of workers for each category. First, the change in overall labour compensation of Low-income workers in the *i-th* year caused by the policy shock is calculated based on the application of the LK-IO model (4), according to equation (6). Notice that among the *k* factor use categories in matrix $\mathbf{V}(k\times n)$, only labour compensation needs to be considered here.

$$\varDelta V^i_{LI}=\left(\mathbf{v}\cdot\varDelta\mathbf{x}^i\right)\cdot\frac{n^i_{W,LI}\cdot\overline{y}_{pc,LI}}{V^i} \tag{6}$$

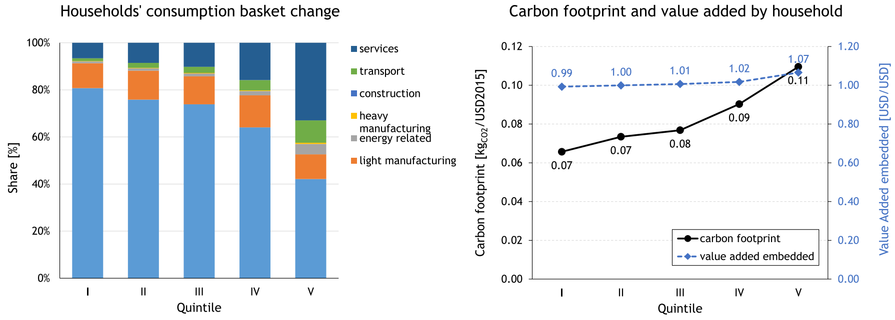

Fig. 3. Composition of final demand baskets for the Tanzanian households' quintiles (left side). Economic and environmental impacts of households' quintiles per USD2015 of final demand (right side).

Secondly, the number of workers that shift from low to high income category in the next year $\Delta n_{W,LI\rightarrow HI}^{i+1}$ thanks to the change in earnings of the previous year is evaluated based on equation (7).

$$\Delta n_{W,LI\rightarrow HI}^{i+1} = \frac{\Delta V_{LI}^{i}}{\overline{y}_{pc,HI} - \overline{y}_{pc,LI}} \tag{7}$$

Subsequently, the number of workers in low- and high-income categories resulting from the shift in next year is assessed based on equation (8) (notice that the overall number of workers remains constant).

$$\left.\begin{aligned} n_{W,HI}^{i+1} &= n_{W,HI}^{i} + \Delta n_{W,LI\rightarrow HI}^{i+1} \\ n_{W,LI}^{i+1} &= n_{W,LI}^{i} - \Delta n_{W,LI\rightarrow HI}^{i+1} \end{aligned}\right\} n_{W,HI}^{i+1} + n_{W,LI}^{i+1} = n_W \tag{8}$$

The new overall structure of final demand in the next year $\mathbf{s}^{i+1}$ is finally evaluated based on equation (9).

$$\mathbf{s}^{i+1} = \frac{\mathbf{s}_{HI} \cdot n_{W,HI}^{i+1} + \mathbf{s}_{LI} \cdot n_{W,LI}^{i+1}}{n_W} \tag{9}$$

3.3. *Reference datasets and model setup*

This research is grounded on empirical meso-economic data retrieved from the Tanzanian Social Accounting Matrix (Randriamamonjy and Thurlow, 2017), developed by the *International Food Policy Research Institute* (IFPRI, www.ifpri.org) for the reference year 2015: being this SAM the most recent empirical meso-economic database of the Tanzanian economy, year 2015 is selected as the beginning year of the analysed scenarios time frame.

Other fundamental economic and social indicators are found in the *World Bank Open Data* repositories (www.data.worldbank.org) on energy data, retrieved from the *International Energy Agency* database (www.iea.org), and on sectoral CO_2 emissions, retrieved from the *PRIMAPHIST dataset* (Gütschow et al., 2016).

The Tanzanian SAM is shaped as a *Supply and Use table*, expressed in 2015 LCU (Shillings). Its core features are the following:

- The economy is disaggregated into 68 industries and 70 products, classified according to the *ISIC rev.4 standard* (United Nations and Department of Economic and Social Affairs, 2008). The SAM has been produced for agricultural policy analysis, so its disaggregation level is very thin especially for agricultural products and industries, while other sectors are much more aggregated.
- Factor use is disaggregated into 3 categories: *Labour*, *Capital* and *Land* (all expressed in monetary units). Labour is distinguished among *rural* and *urban*, both classified with four educational levels.
- Households' final demand is classified as *rural farm*, *rural non-farm* and *urban.* All these categories are subdivided in quintiles.
- Other accounts are related to *govern expenditures*, *taxes* (classified by type), *change in stocks* and *imports/exports.*

The SAM was properly manipulated to fit the LK-IO model descripted in Section 3.2. In particular, it was transformed to a *Symmetric Industry-by-Industry Input-Output table* by considering an *industry-based technology* assumption, according to the procedure illustrated in detail in (Miller and Blair, 2009). Finally, the 68 industries in the resulting MIOT were aggregated into 20 industries, and the CO_2 emissions by sector defined (see the electronic supplementary material for further details).

4. Results and discussion

Results are presented and discussed in terms of economic growth and its implications on economy-wide carbon emissions. Section 4.1 focuses on the first set of simulations, conducted under the assumption that households' consumption baskets remain unchanged. Section 4.2 considers, instead, the results obtained when changes in households' consumption baskets are simulated.

4.1. *Economic growth and environmental impact — no changes in consumption*

A first outcome of the LK-IO model (4) is illustrated in Fig. 4 (left side), where annual Value Added generation is reported for all four electrification pathways, over the period 2015–2030 (in 2015 U.S. dollars). The estimated economic growth enabled by a development of the electricity sector is quite remarkable, going from 54.9 billion $/year in 2015 to 155.3 billion $/year in 2030 under the BAU scenario — and, respectively, 149.5 and 147.1 billion $/year under the NP and 450TZ scenarios. Differences across the three cases are small, as the annual electricity availability is similar (see Fig. 1). As expected, a significantly greater economic growth is observed when considering the electrification pathway computed under the E4A scenario (up to 182.4 billion $/year in 2030). This occurs because the electricity availability constraint is less binding, over the entire observation period.

As reported in Fig. 4 (right side), economic growth is noticeably accompanied by a similar increase in carbon emissions — from 15.1 Mton of CO_2 in 2015 to 45.7 Mton in 2030, for the electrification pathway obtained under the BAU scenario. Contrasting cases with

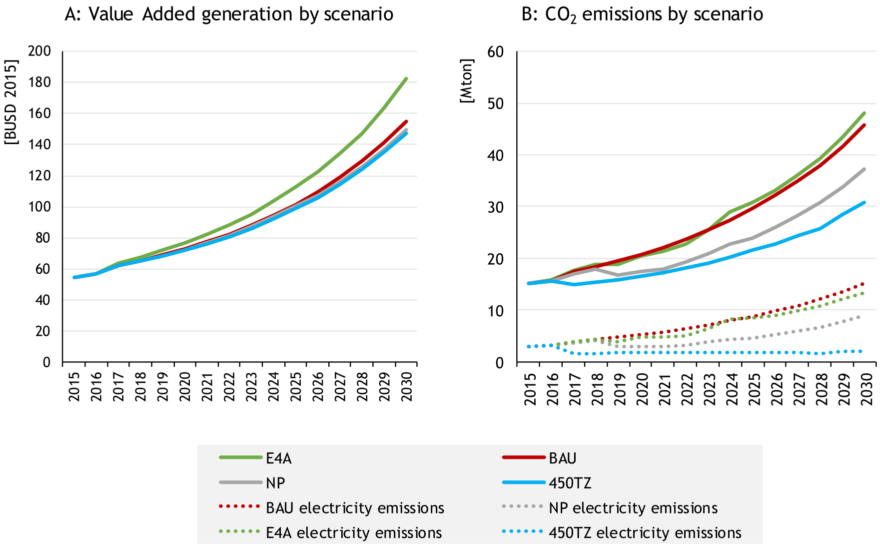

Fig. 4. Value Added generation (left side), carbon emissions (right side) between 2015 and 2030, for all the electrification pathways, without considering changes in consumption baskets. Carbon emissions are distinguished in economy-wide emissions (solid lines) and electricity-related emissions (dotted line).

comparable economic growth (BAU, NP, and 450TZ), it is clear that the introduction of technology policies in the power sector could lower economy-wide emissions significantly (37.3 Mton of CO_2 in 2030 for the electrification pathway derived under the NP scenario), and that an environmental policy would be even more effective in this regard (considering the electrification pathway derived under the 450TZ scenario, emissions reach 30.8 Mton in 2030). Nevertheless, the higher economic growth implied by the electrification pathway obtained under the E4A scenario, together with the use of off-grid diesel for rural electrification, leads to higher carbon emissions than under the NP scenario, despite similar assumptions regarding technology policies (48.0 Mton of CO_2 in 2030). Remarkably, even if the emissions from the electricity sector alone are lower (or equal) in the electrification pathway derived for the E4A scenario than in the one derived under BAU assumptions (despite electricity production being greater — see Fig. 1), after 2023 economy-wide carbon emissions for the electrification pathway obtained under E4A assumptions become higher than in the pathway obtained under BAU.

To put these results in context in the absence of similar scholarly work, an option is to look at the recent International Energy Agency (IEA) country profile for Tanzania (IEA, 2019). In particular, IEA considers a Stated Policies (SP) scenario, based on current and announced policies, which can be compared to this paper's NP scenario. According to IEA (2019), electricity production in 2030 is, similarly, just above 30 TWh, GDP in 2030 is almost twice in 2030 compared to 2018, making the NP scenario estimated in the present work relatively more optimistic (GDP in 2030 is 2.2 times as large in 2030 with respect to 2018 in the NP scenario), and coherently estimates a doubling of carbon emissions the over the same time period, as in the present study.

The country's carbon intensity captures, within a single indicator, the environmental implications of a higher level of electricity availability when this is reflected in the production of all sectors of the economy. As illustrated in Fig. 5**,** under BAU assumptions carbon intensity increases from 0.27 kg of CO_2 per $ of Value Added in 2015 to 0.29 kg in 2030. Decarbonization efforts directed at the power sector can significantly contribute to decrease the same indicator due to the relatively high CO_2 intensity of the energy sector (see below). The largest reduction is achieved under the 450TZ scenario when the country's carbon intensity decreases to a value of 0.21 kg of CO_2/$ in 2030. The implementation of a technology policy (NP scenario) similarly leads to a value of 0.25 kg of CO_2/$ in 2030. However, the positive effect of reducing the emission of the power sector is weakened as the economy experiences a more significant growth. Differently, in the E4A scenario, a decrease in the first part of the simulation period is followed by a peak in 2024 (0.28 kg of CO_2/$), followed by another reduction in carbon intensity down to 0.26 kg of CO_2/$ in 2030).

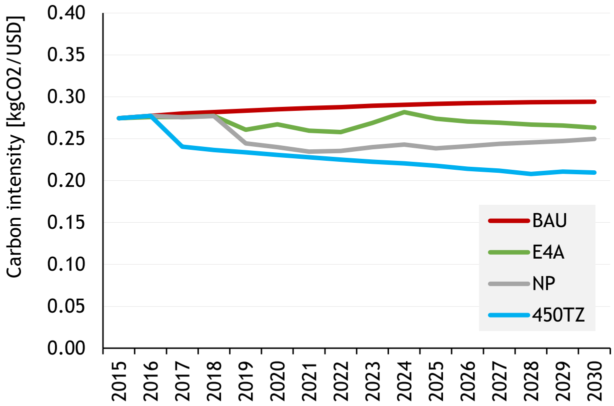

Fig. 5. Economy-wide carbon emissions intensity between 2015 and 2030, for all the electrification pathways (different colours, listed in the legend), without considering changes in consumption baskets. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Overall these results suggest that acting on the decarbonization of the power sector is certainly a step forward in terms of sustainable growth. Nevertheless, to further reduce the country's carbon intensity, efforts should be directed to other carbon intensive sectors of economy — the industrial sector among others. To support this claim, Fig. 6 reports the sectorial contribution to Value Added generation (left side) and carbon emissions (right side) for a representative scenario. Under BAU assumptions, agriculture & fishing grow from 27.9 billion $/year in 2015 to 78.8 billion $/year in

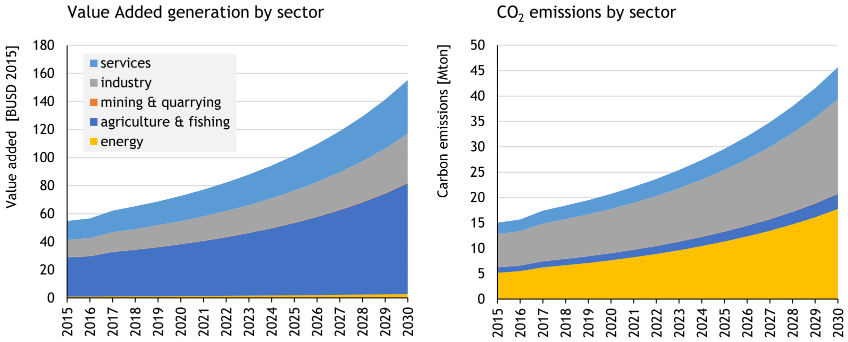

Fig. 6. Sectorial value added generation (left side) and carbon emissions (right side) between 2015 and 2030 – BAU assumptions – without considering changes in consumption baskets.

2030, the industrial sector increases from 12.3 billion $/year in 2015 to 34.9 billion $/year in 2030, and services from 13.5 billion $/year in 2015 to 38.3 billion $/year in the same 15-year period. In this first round of simulations, the relative contribution to the country economy of these three main sectors remains constant over time (51% agriculture & fishing, 22% industry, 25% services). Notably, the development of the electricity sectors provides a very small direct contribution to the creation of Value Added. Electricity is part of the energy sector, which itself constitutes 2% of the economy. This grows from 1.0 billion $/year in 2015 to 2.9 billion $/year in 2030 in the BAU scenario. By contrast, the right side of Fig. 6 illustrates that the share of energy-related CO_2 emissions is quite significant (34.5% of total emission in 2015, increasing to 39% in 2030). Hence, the relatively large CO_2 intensity of the energy sector. Only industry-related emissions are larger (43.4% in 2015 and 40.5% in 2030), while contributions from services are around 14%. As industry and services contribute in similar way to the country's GDP, the former presents a larger CO_2 intensity than the latter. Much smaller contributions to the country's emissions derive from the agricultural & fishing sector (7.0% in 2015 and 6.5% in 2030).

4.2. *Economic growth and environmental impact – changes in consumption*

The trade-off between economic growth and environmental performance suggested by the first set of simulations is further analysed here in light of potential changes in households' consumption baskets.

Fig. 7 (left side) compares value added generation between 2015 and 2030, with and without changes in consumption for a representative scenario. Under E4A assumptions, differences between the two sets of simulations are hardly noticeable (Value Added in 2030 is, respectively, 182.4 and 186.1 billion $/year in the first and in the second set). When considering the economy-wide CO_2 emissions over the period 2015 and 2030, under the same E4A assumptions, more remarkable differences emerge (Fig. 7, right side). For instance, the simulated change in household consumption increases emissions in 2030 from 48.0 to 57.2. Similar results hold for all electrification pathways. In other words, changes in consumption deriving from economic growth via an increase in the compensation of the employees, have a significant impact on the country's carbon emission levels.

Consistently, the evolution of the country's carbon intensity between 2015 and 2030 also appears quite different when changes in household consumption baskets are simulated. As illustrated in Fig. 8, carbon intensity increases significantly from 0.27 kg of CO_2 per $ of Value Added in 2015 to 0.34 kg in 2030, under BAU assumptions. The most successful policy in reversing this trend remains the environmental one: under 450TZ assumptions, carbon intensity decreases to a value of 0.23 kg of CO_2/$ in 2030. The implementation of a technology policy (NP scenario) leads, instead, to a lower decrease of same indicator. The positive effect of this less aggressive decarbonization of the energy sector also means that carbon intensity begins to rise again after 2022, returning to 0.28 kg of CO_2/$ in 2030. The limited efficacy of decarbonization policies as the economy grows is also evident when considering the E4A scenario. Carbon intensity under the E4A assumptions begins to diverge from the one observed in the NP scenario as early as in 2019, starts to increase significantly after 2022 and reaches a value of 0.31 kg of CO_2/$ in 2030.

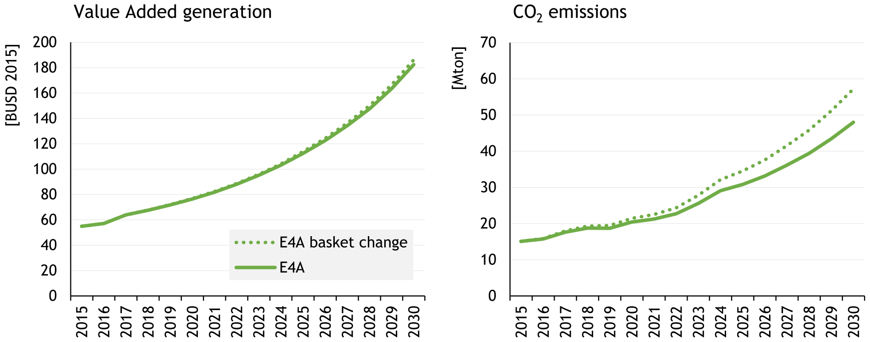

Fig. 7. Impact of changes in households' consumption baskets on Value Added generation (left side) and economy-wide CO_2 emissions (right side) between 2015 and 2030 – E4A assumptions.

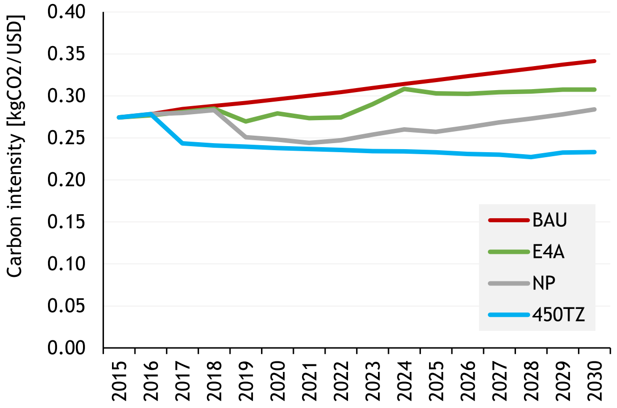

Fig. 8. Carbon intensity between 2015 and 2030 – all electrification pathways – changes in households consumption baskets.

In this regard, it should be noted that, as expected for this second round of simulations, the relative contribution of the different sectors to the country economy does not remain constant over time. As illustrated in Fig. 9 (left side), 51% agriculture&fishing, 22% industry, 25% services become 42%, 25% and 31% in 2030, when E4A assumptions are considered. Accordingly (Fig. 9 right side), the sectorial contributions to the country's carbon emissions in the same representative scenario (E4A) shows that agriculture (initially at 7%) decreases to 5.1% in 2030, industry remains almost constant (from 43.4% in 2015 to 42.7% in 2030), while services register an increase from 14.9% in 2015 to 16.5% in 2030 (also energy increases from 34.5% in 2015 to 35.5% in 2030).

In sum, the results of this second set of simulations indicate that the sustainability of the economic growth of the country can be significantly affected by changes in household consumption habits. As households acquire relatively less goods from primary activities and relatively more products from the tertiary sector, transportation and energy, the country's carbon intensity is bound to increase. At the same time, this apparent trade-off between economic growth and environmental concerns is also driven by the indicator chosen to measure the former. Of course, as more households benefits from essential services, such as education and health, and gain access to modern energy the well-being of the population increases in manners which cannot be captured by Value Added generation alone.

5. Conclusions

Considerable debate exists concerning the role of electricity availability in the economic growth, particularly of low-income countries. Starting from the observation that the Government of Tanzania considers the lack of infrastructure for power generation and the current low access-rate among the obstacles to growth (URT, 2016), this paper proposes a modelling approach which enables a better understanding of the economy-wide implications of expanding the electricity sector.

The electrification pathways considered in this study are four and differ in terms of share of renewables in electricity production, as well as in the timing to achieve full electrification. They are estimated via an adapted OSeMOSYS model and designed to simulate existing and potential technological and environmental policies for the power sector. On the basis of these results, a tailored macroeconomic Input-Output model is then employed to analyse their impact on the country's economic growth and carbon emissions.

The model results indicate that while all electrification pathways lead to a remarkable economic growth over the observed period, the direct and indirect effects on the environment of expanding the electricity sector are similarly conspicuous. Policies aimed at decarbonizing the electricity generation sector appear effective in reducing the country's carbon intensity (emissions relative to Gross Domestic Product, GDP). Nevertheless, to limit the increase in emissions as the economy growth, particularly under the assumption of reaching full access already in 2030 in line with the UN Sustainable Development Goals (General Assembly, 2015), it would be important to introduce energy efficiency and/or decarbonization policies in other sectors of the economy as well – in particular, in the industrial sector, currently the largest contributor to carbon emissions.

Further insights derive from enabling the macroeconomic model to capture the effect of economic growth on the compensation of the employees and, ultimately, on the average income of households. By focusing on the consumption side of the economy, the model results indicate that changes in household consumption habits might contribute significantly to the country's carbon emissions – as the average income increases households consume more of carbon intensive goods and services. This suggests that, when designing policies and interventions directed at reaching sustainable development goals, the Government of Tanzania should also pay particular attention to potential reductions in the carbon intensity of the service sector.

In sum, while relying on the country's renewable generation

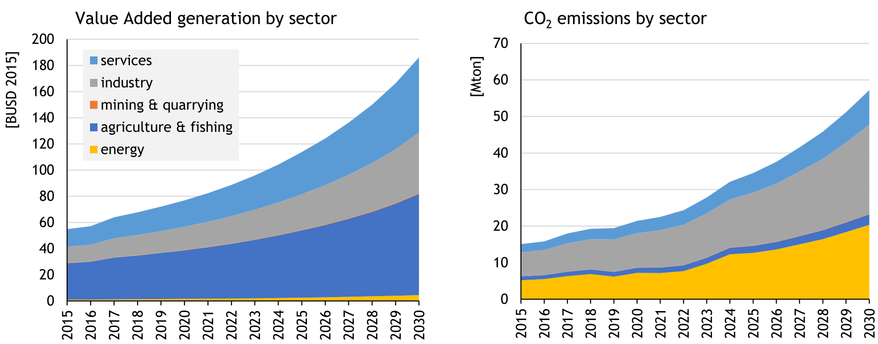

Fig. 9. Sectorial value added generation (left side) and carbon emissions (right side) between 2015 and 2030 – E4A assumptions – changes in households consumption baskets.

potential in the power sector is, indeed, an effective policy instrument to meet national sustainability goals, additional policy interventions are also necessary to address the sustainability concerns associated with the expansion of the industrial sector, as well as the increasing demand for (essential) services.

The analysis conducted in this paper has several limitations, some of which can be addressed in further work. Specifically, to fully explore the potential benefits and economy-wide impact of full electrification, it would be important to improve the characterization of household consumption in the macroeconomic model, distinguishing, for example, between urban and rural consumers, as well as new accesses and capacity or reliability increases. Moreover, by improving the segment of the model capturing the effect on household consumption habits and income growth, issues related to poverty and income inequality might also be addressed. Finally, it would be interesting to consider the effect of alternative policies across other sectors of the economy, such as measures directed at energy efficiency or instruments designed to curb carbon emissions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Matteo V. Rocco: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Francesco Tonini:** Formal analysis, Investigation, Data curation. **Elena M. Fumagalli:** Resources, Validation, Investigation, Writing - original draft, Writing - review & editing. **Emanuela Colombo:** Conceptualization, Validation, Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.121278.

Acronyms

CGE	Computable General Equilibrium
HI	High income
LI	Low income
MIOT	Monetary Input-Output Table
OSeMOSYS	Open Source energy Modelling SYStem
pc	per capita
SAM	Social Accounting Matrix

Symbols

$\mathbf{A}$	technical coefficients matrix
$\mathbf{B}$	environmental transactions coefficients matrix
$\mathbf{I}$	identity matrix
$\mathbf{M}$	imports matrix
$\mathbf{R}$	environmental transactions matrix
$\mathbf{V}$	factor use matrix
$\mathbf{Y}$	final demand matrix
$\mathbf{Z}$	intermediate transactions matrix
$\mathbf{i}$	summation vector
$\mathbf{s}$	structure of final demand
$\mathbf{v}$	factor use coefficients matrix
$\mathbf{x}$	total production matrix
E	electrical energy
V	sum factor uses
W	subscript for workers
el	subscript identifying the power sector
j	number of environmental transactions
k	number of factors of production
l	number of final demand categories
n	number of sectors in a country
y	sum of final uses

References

Adebayo, E., Sovacool, B.K., Imperiale, S., 2013. It's about dam time: improving microhydro electrification in Tanzania. Energy Sustain. Dev. https://doi.org/10.1016/j.esd.2013.03.003.

Aly, A., Moner-Girona, M., Szabó, S., Pedersen, A.B., Jensen, S.S., 2019. Barriers to large-scale solar power in Tanzania. Energy Sustain. Dev. https://doi.org/10.1016/j.esd.2018.10.009.

Amars, L., Fridahl, M., Hagemann, M., Röser, F., Linnér, B.O., 2017. The transformational potential of Nationally Appropriate Mitigation Actions in Tanzania: assessing the concept's cultural legitimacy among stakeholders in the solar energy sector. Local Environ. https://doi.org/10.1080/13549839.2016.1161607.

Arndt, C., Pauw, K., Thurlow, J., 2012. Biofuels and economic development: a computable general equilibrium analysis for Tanzania. Energy Econ. https://doi.org/10.1016/j.eneco.2012.07.020.

Babatunde, K.A., Begum, R.A., Said, F.F., 2017. Application of computable general equilibrium (CGE) to climate change mitigation policy: a systematic review. Renew. Sustain. Energy Rev. 78, 61–71. https://doi.org/10.1016/j.rser.2017.04.064.

Bazilian, M., Nussbaumer, P., Rogner, H.H., Brew-Hammond, A., Foster, V., Pachauri, S., Williams, E., Howells, M., Niyongabo, P., Musaba, L., Gallachóir, B. ó, Radka, M., Kammen, D.M., 2012. Energy access scenarios to 2030 for the power sector in sub-Saharan Africa. Util. Pol. https://doi.org/10.1016/j.jup.2011.11.002.

Bos, K., Chaplin, D., Mamun, A., 2018. Benefits and challenges of expanding grid electricity in Africa: a review of rigorous evidence on household impacts in developing countries. Energy Sustain. Dev. https://doi.org/10.1016/j.esd.2018.02.007.

Burfisher, M.E., 2011. Introduction to Computable General Equilibrium Models, Introduction to Computable General Equilibrium Models. https://doi.org/10.1017/CBO9780511975004.

Burke, P.J., Stern, D.I., Bruns, S.B., 2018. The impact of electricity on economic development: a macroeconomic perspective. Int. Rev. Environ. Resour. Econ. https://doi.org/10.1561/101.00000101.

Choumert-Nkolo, J., Combes Motel, P., Le Roux, L., 2019. Stacking up the ladder: a panel data analysis of Tanzanian household energy choices. World Dev. https://doi.org/10.1016/j.worlddev.2018.11.016.

Duchin, F., Levine, S.H., Strømman, A.H., 2016. Combining multiregional input-output analysis with a world trade model for evaluating scenarios for sustainable use of global resources, Part I: conceptual framework. J. Ind. Ecol. 20, 775–782.

Economics, I., Ecology, I., 2009. Handbook of input-output economics in industrial Ecology edited by sangwon suh. J. Ind. Ecol. 13, 830–832. https://doi.org/10.1111/j.1530-9290.2009.00173.x.

Eurostat, 2008. Eurostat Manual of Supply, Use and Input-Output Tables. Publications Office of the European Union, Luxembourg.

Felix, M., Gheewala, S.H., 2012. Environmental assessment of electricity production in Tanzania. Energy Sustain. Dev. https://doi.org/10.1016/j.esd.2012.07.006.

General Assembly, U.N., 2015. Transforming Our World: the 2030 Agenda for Sustainable Development. https://doi.org/10.1007/s13398-014-0173-7.2. https://sustainabledevelopment.un.org/content/documents/7891Transforming%20Our%20World.pdf, 1-5.

Gregory, J., Sovacool, B.K., 2019. The financial risks and barriers to electricity infrastructure in Kenya, Tanzania, and Mozambique: a critical and systematic review of the academic literature. Energy Pol. https://doi.org/10.1016/j.enpol.2018.10.026.

Gütschow, J., Jeffery, M.L., Gieseke, R., Gebel, R., Stevens, D., Krapp, M., Rocha, M., 2016. The PRIMAP-hist national historical emissions time series. Earth Syst. Sci. Data 8, 571–603. https://doi.org/10.5194/essd-8-571-2016.

Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., Hughes, A., Silveira, S., DeCarolis, J., Bazillian, M., Roehrl, A., 2011. OSeMOSYS: the open source energy modeling system: an introduction to its ethos, structure and development. Energy Pol. 39, 5850–5870. https://doi.org/10.1016/J.ENPOL.2011.06.033.

IEA, 2019. Africa Energy Outlook 2019.

IFPRI, 2015. Tanzania, Social Accounting Matrix for Year 2015 [WWW Document]. URL. www.ifpri.org.

International Energy Agency (IEA), 2016. World Energy Outlook 2016. IEA,Paris 684. https://doi.org/10.1787/weo-2016-en.

International Renewable Energy Agency (IRENA), 2014. Renewable Power Generation Costs in 2012: an Overview. IRENA. https://doi.org/10.1007/SpringerReference_7300.

Kamidelivand, M., Cahill, C., Llop, M., Rogan, F., O'Gallachoir, B., 2018. A comparative analysis of substituting imported gas and coal for electricity with renewables – an input-output simulation. Sustain. Energy Technol. Assessments. https://doi.org/10.1016/j.seta.2018.08.003.

Karplus, V.J., Von Hirschhausen, C., 2019. Electricity access: an introduction. Econ. Energy Environ. Policy. https://doi.org/10.5547/2160-5890.8.1.vkar.

Kichonge, B., John, G.R., Mkilaha, I.S.N., 2015. Modelling energy supply options for electricity generations in Tanzania. J. Energy South Afr. https://doi.org/10.17159/2413-3051/2015/v26i3a2128.

Lechthaler, F., 2017. Economic growth and energy use during different stages of development: an empirical analysis. Environ. Dev. Econ. https://doi.org/10.1017/S1355770X16000243.

Lee, K., Miguel, E., Wolfram, C.D., 2017. Electrification and Economic Development: A Microeconomic Perspective. EEG State-of-Knowledge Pap. Ser.

Mahajan, S., Beutel, J., Guerrero, S., Inomata, S., Larsen, S., Moyer, B., Remond-Tiedrez, I., Rueda-Cantuche, J.M., Simpson, L.H., Thage, B., 2018. Handbook on Supply, Use and Input-Output Tables with Extensions and Applications.

Merciai, S., Schmidt, J., 2018. Methodology for the construction of global multi-regional hybrid supply and use tables for the EXIOBASE v3 database. J. Ind. Ecol. https://doi.org/10.1111/jiec.12713.

Miller, Ronald E., Blair, P.D., 2009. Input-output Analysis: Foundations and Extensions. Cambridge University Press.

Odhiambo, N.M., 2009. Energy consumption and economic growth nexus in Tanzania: an ARDL bounds testing approach. Energy Pol. https://doi.org/10.1016/j.enpol.2008.09.077.

Pauliuk, S., Majeau-Bettez, G., Müller, D.B., 2015. A general system structure and accounting framework for socioeconomic metabolism. J. Ind. Ecol. 19, 728–741. https://doi.org/10.1111/jiec.12306.

Pauliuk, S., Majeau-Bettez, G., Müller, D.B., 2015. A general system structure and accounting framework for socioeconomic metabolism. J. Ind. Ecol. 19, 728–741. https://doi.org/10.1111/jiec.12306.

Peng, D., Poudineh, R., 2017. An appraisal of investment vehicles in the Tanzania's electricity sector. Util. Pol. https://doi.org/10.1016/j.jup.2017.09.002.

Philip Isdor Mpango, 2016. National Five Year Development Plan 2016/17 - 2020/21. Minist. Financ. Plan.

Randriamamonjy, J., Thurlow, J., 2017. 2015 Social Accounting Matrix for Tanzania: A Nexus Project SAM. Intl Food Policy Res Inst.

Révész, T., Zalai, E., 2007. CGE Modelling : A Training Material - Modelling of Energy Technologies Prospective in a General and Partial Equilibrium Framework.

Rocco, M.V., Fumagalli, E., Vigone, C., Miserocchi, A., Colombo, E., 2020. Improved Modelling and Critical Analysis of Future Electrification Pathways: the Case of Tanzania (Under Rev).

Salmon, C., Tanguy, J., 2016. Rural electrification and household labor supply: evidence from Nigeria. World Dev. https://doi.org/10.1016/j.worlddev.2016.01.016.

Sergi, B., Babcock, M., Williams, N.J., Thornburg, J., Loew, A., Ciez, R.E., 2018. Institutional influence on power sector investments: a case study of on- and off-grid energy in Kenya and Tanzania. Energy Res. Soc. Sci. https://doi.org/10.1016/j.erss.2018.04.011.

Sjølie, H.K., 2012. Reducing greenhouse gas emissions from households and industry by the use of charcoal from sawmill residues in Tanzania. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2012.01.008.

United Nations, 2010. System of National Accounts 2008, System of National Accounts. https://doi.org/10.18356/4fa11624-en, 2008.

United Nations, 2008. International Standard Industrial Classification of All Economic Activities, Revision 4, Statistical Papers. Series M. https://doi.org/10.1017/CBO9781107415324.004.

United Nations, Department of Economic and Social Affairs, 2008. ISIC (international standard industrial classification of all economic activities). Rev. 4.

URT, 2016. National Five Year Development Plan 2016/17 - 2020/21. Minist. Financ. Plan.

USAID, 2018. Greenhouse Gas Emissions Factsheet: Tanzania [WWW Document]. URL. https://www.climatelinks.org/resources/tanzania-ghg-emissions-factsheet, 9.20.08.

VV AA, 2016. National Electrification Program Prospectus. United Republic Of Tanzania.

VV AA, 2016. Power System Master Plan 2016 Update. Ministry Of Energy And Minerals.

VV AA, 2015. INTENDED NATIONALLY DETERMINED CONTRIBUTIONS (INDCs), Republic of Tanzania 2015.

World Bank, 2016. The World Bank DataBank. Data Bank [WWW Document].