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Copernicus Institute of Sustainable Development

Low-carbon electricity generation scenarios for Tanzania: implications for the country's economy and the environment

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Agenda

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Findings: Primary Energy Use and Greenhouse Gases Emissions

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Introduction and objectives

Developing countries (DCs) are considered to be the major driver for world electricity demand increase in the next decades, due to the expected growth in urban population as well as in the income per capita

Technology policies and international agreements on climate change

Objective of this study

- Novel approach to soft-link bottom-up power system optimization models with linear top-down Input-Output macroeconomic model
- Assess the economic and environmental implications due to changes in electricity production mix under different scenarios (2015- 2030) for a Developing Country (DC)
  - Primary energy use
  - Greenhouse gases emissions (GHG)

Methods and models /1

- Bottom-up power system modeling
  - The open-source OSeMOSYS energy model is applied to assess the evolution of the power sector
  - A modular linear programming optimization model, it defines the least cost technology mix required to satisfy an exogenously defined electricity demand in a given time horizon

- Top-down macro-economic modeling
  - An Input Output Analysis (IOA) is applied, relying on the open-source Full Eora 26 Multi-Regional Input Output Tables.
  - Dataset covers 187 countries (including DCs), each schematized through 26 segments of the economy, and including several environmental extensions, covering GHG emissions, air pollution, land occupation, resources extraction, and so on

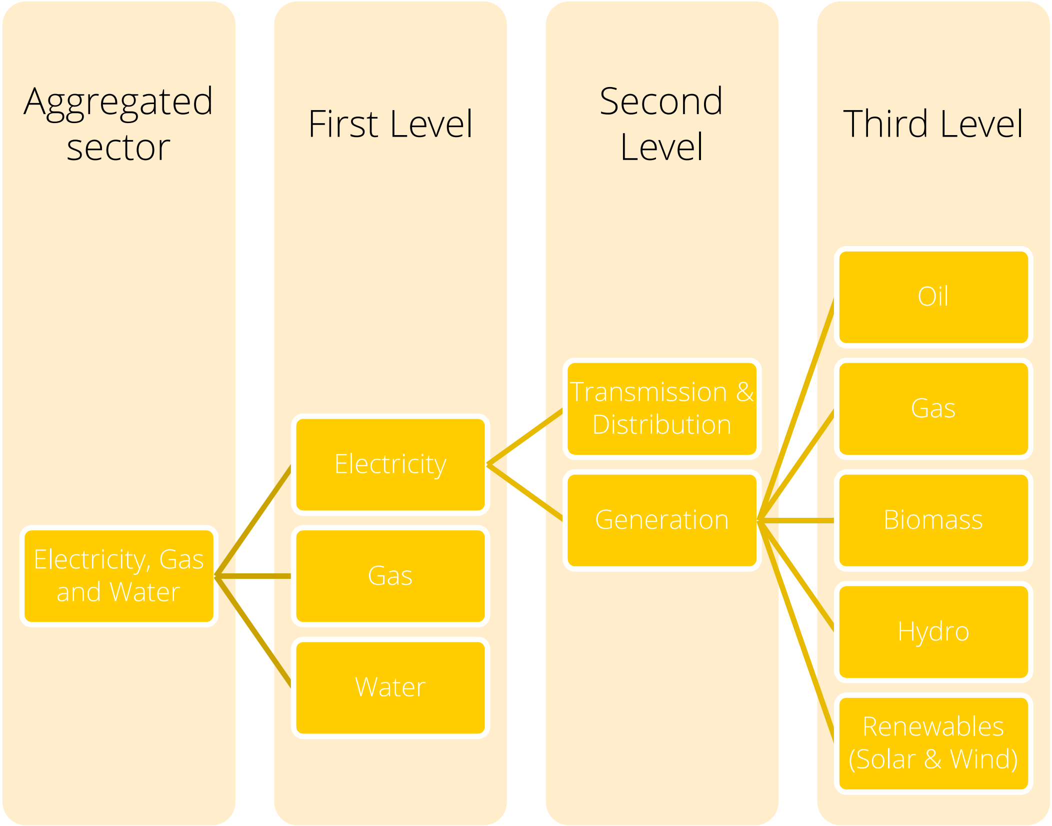
Methods and models /2

The original EORA table needs to be disaggregated

1. Disaggregation of the energy sector
2. Disaggregation of the electricity sector
3. Disaggregation of the power generation technologies

The resulting disaggregated table is converted into a hybrid units table,

A consistency test is performed to ensure the closure of the electricity generation balances



Methods and models /3

Given one economy composed by *n* sectors, each with *s* types of exogenous transactions (primary energy, GHG emissions, etc.) and considering a time frame of one year, the top-down model is represented by the operators:

$$\mathbf{A}_0 = \begin{bmatrix} \mathbf{A}_N & \mathbf{C}_U \\ \mathbf{C}_D & \mathbf{A}_E \end{bmatrix} ; \ \mathbf{f}_0 = \begin{bmatrix} \mathbf{f}_N \\ \mathbf{f}_E \end{bmatrix} ; \ \mathbf{b}_0 = \begin{bmatrix} \mathbf{b}_N & \mathbf{b}_E \end{bmatrix}$$

$$\mathbf{x}_0 = (\mathbf{I} - \mathbf{A}_0)^{-1} \cdot \mathbf{f}_0 \quad \rightarrow \quad \mathbf{R}_0 = \mathbf{b}_0 \cdot \hat{\mathbf{x}}_0$$

- A_0 (nxn) technical coefficients matrix, representing the links between all the national sectors
- f_0 (nx1) final demand vector, representing households expenditures
- b_0 (sxn) exogenous transaction coefficient matrix
- C_U (n-1×1) and C_D(1×n-1) Upstream and Downstream Cutoffs
- x_0 (nx1) total production vector
- R_0 (sxn) total exogenous transactions: consumption of resources and waste emissions directly caused by each economic sector in the baseline year

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Methods and models /4

Soft-link procedure: see figure

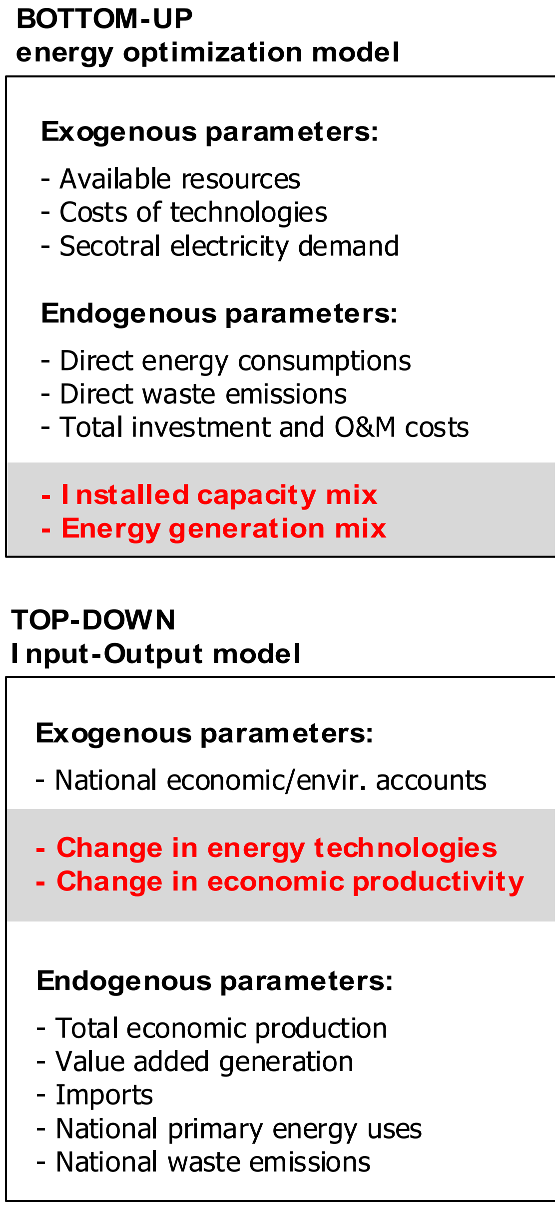
The shock is implemented in steps :

1. Change in power generation mix
2. Change in electricity households' demand
3. Change in national final demands for each sector

$$\mathbf{A}_i = \begin{bmatrix} \mathbf{A}_N & \mathbf{C}_U \\ \tilde{(} & \end{bmatrix} \; ; \; \mathbf{f}_i = \begin{bmatrix} \tilde{\cdot} \\ \tilde{\cdot} \end{bmatrix} \qquad = \begin{bmatrix} \mathbf{b}_N & \mathbf{b}_S \end{bmatrix}$$

Leontief production and impact models are applied to the shocked economy in each year (total production and exogenous transactions)

$$\mathbf{x}_i = (\mathbf{I} \,\square\, \mathbf{A}_i)^{\square 1} \cdot \mathbf{f}_i \qquad \square \qquad \mathbf{R}_i = \mathbf{b}_0 \cdot \hat{\mathbf{x}}_i$$



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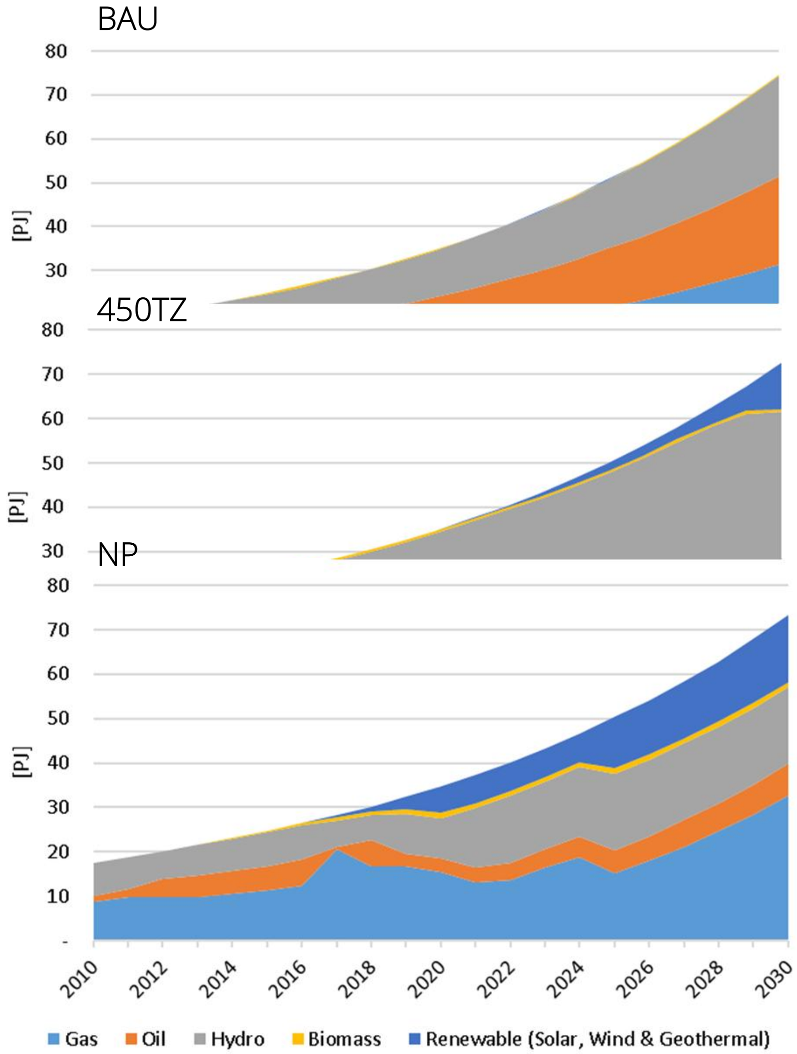
Study Case: United Republic of Tanzania

Current installed capacity in the electricity sector
1958 MW in 2015

Scenario proposition for up to 2030

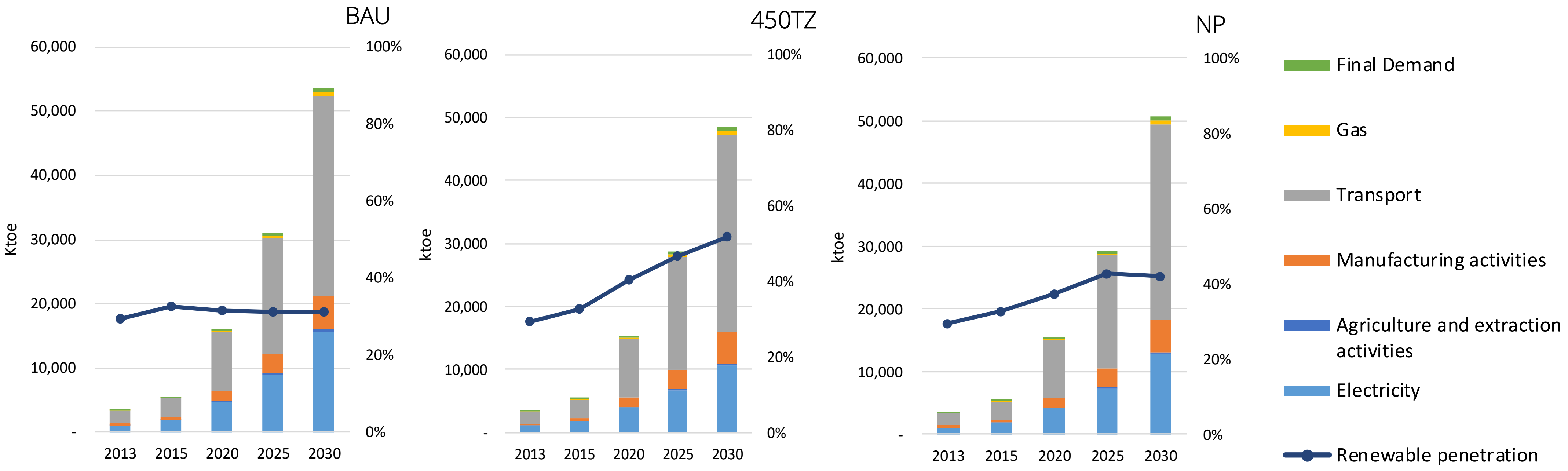
Business as Usual	450TZ	New Policies
• No new policies • 68% oil & NG • 32% hydro & other RES in 2030	• World Energy Outlook • 41% oil & NG • 58% hydro & other RES in 2030	• Government's new policies • 54% oil & NG • 45% hydro & other RES in 2030



Findings – Primary Energy Consumption

Total primary energy use (2030)
BAU: 53,701 ktoe
450TZ: 48,529 ktoe (-10%)
NP: 50,736 ktoe (-6%)

Total primary energy use electricity sector (2030)
BAU: 15,700 ktoe (29%)
450TZ: 10,635 ktoe (22%)
NP: 12,792 ktoe (25%)

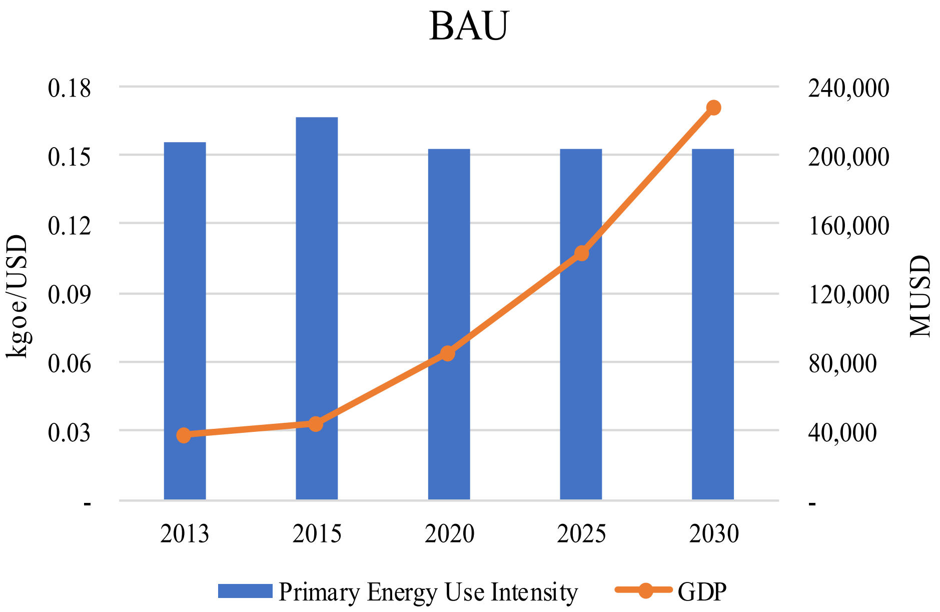


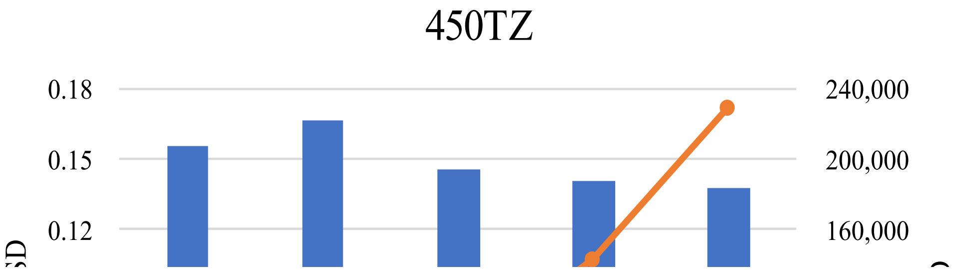
Findings – Primary Energy Consumption per unit of GDP

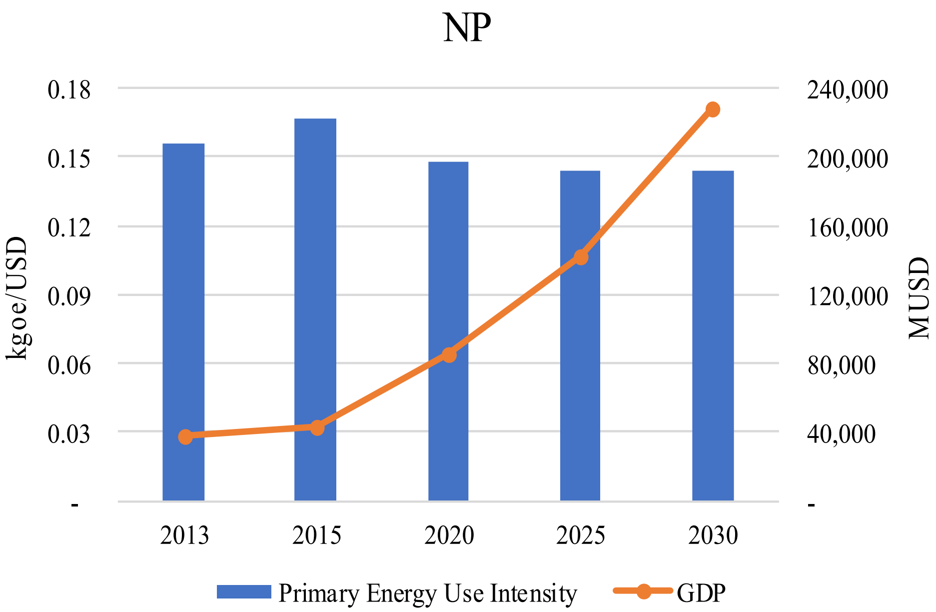
Average reduction rate of the unitary primary energy consumption (post 2015)

450TZ: 6%

NP: 4.5%

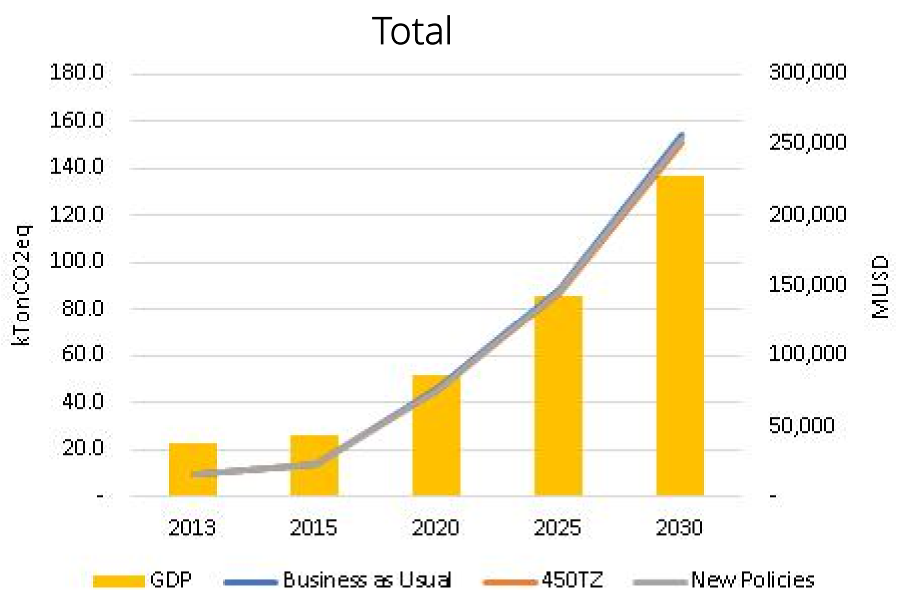




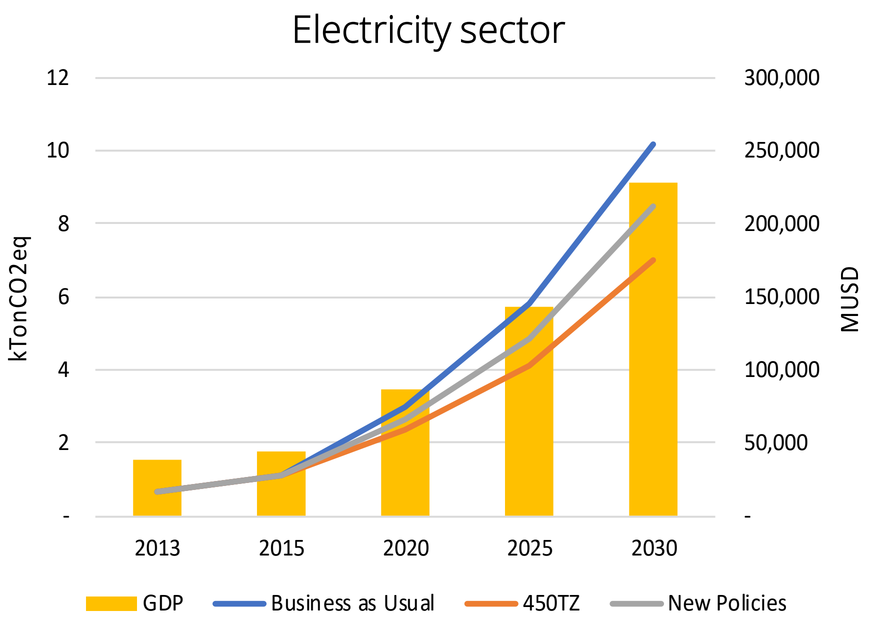


Findings – Greenhouse Gases Emissions

Total GHG emissions (2030)
BAU: 154 ktonCO_2eq
450TZ: 151 ktonCO_2eq (- 2.3%)
NP: 152 ktonCO_2eq (- 1.2%)



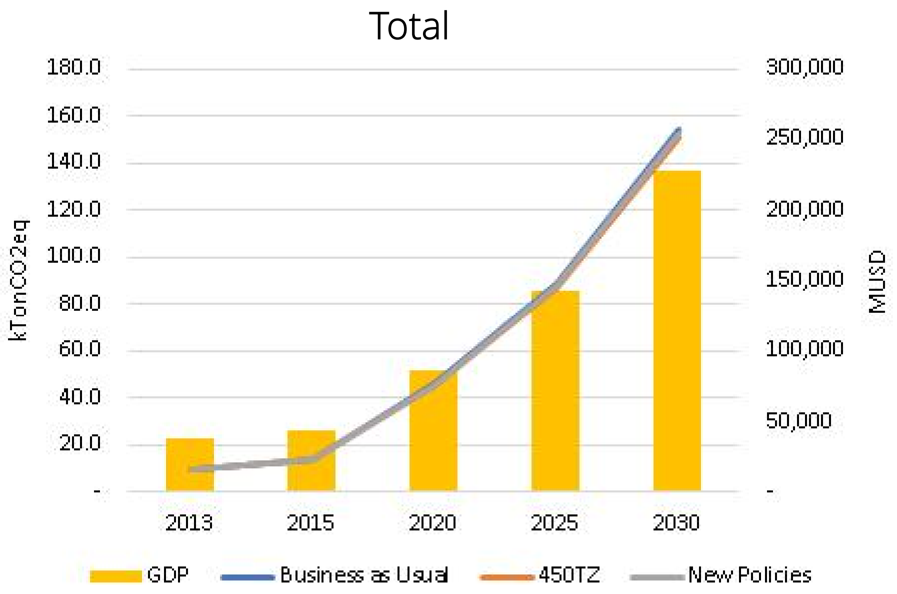
Electricity sector GHG emissions (2030)
BAU: 10 ktonCO_2eq
450TZ: 7 ktonCO_2eq (- 27%)
NP: 8 ktonCO_2eq (- 17%)

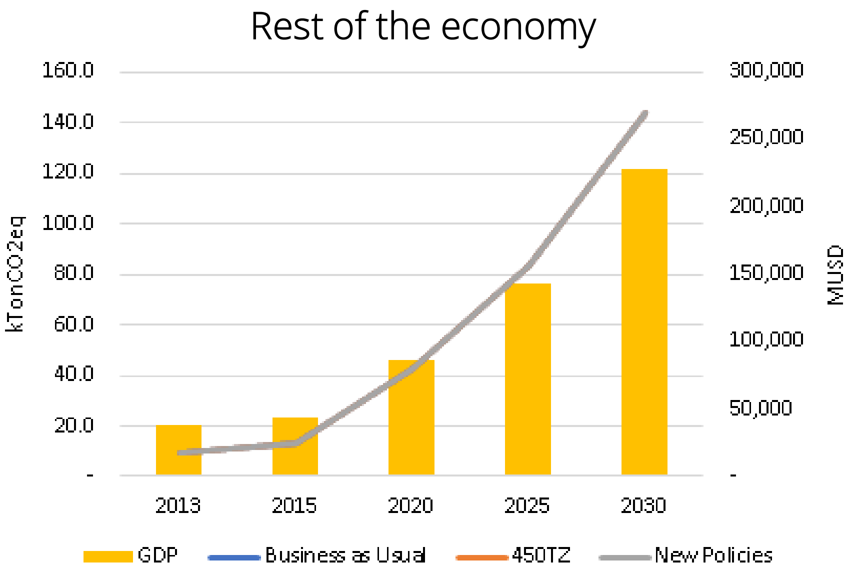


Findings – Greenhouse Gases Emissions

Total GHG emissions (2030)
BAU: 154 ktonCO2eq
450TZ: 151 ktonCO2eq (- 2.3%)
NP: 152 ktonCO2eq (- 1.2%)

Rest of the economy GHG emissions (2030)
BAU: 144.2 ktonCO2eq
450TZ: 143.8 ktonCO2eq
NP: 144 ktonCO2eq



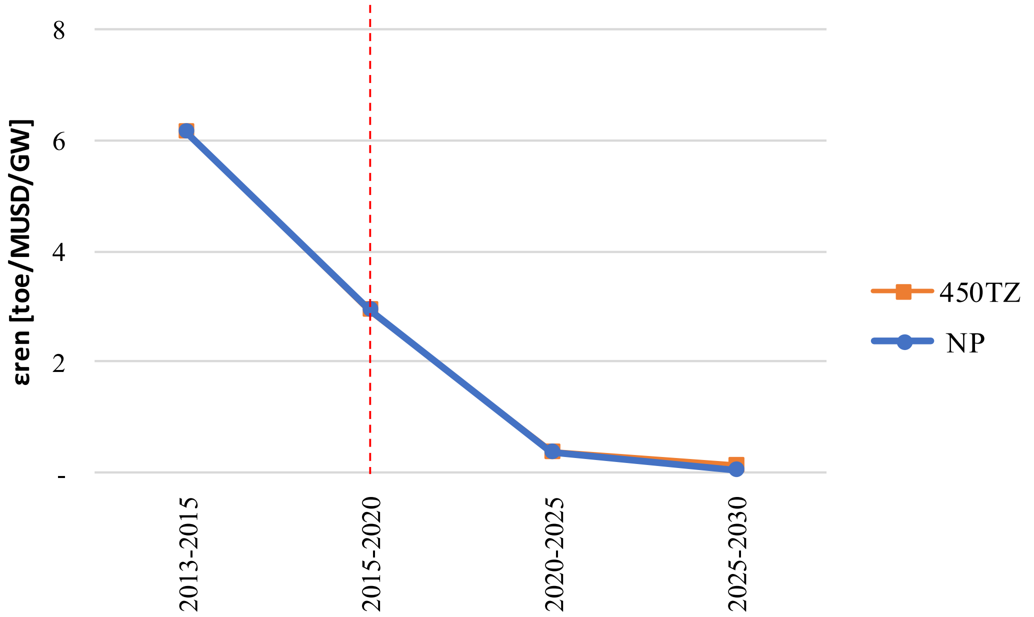


Findings – Effectiveness of RES in reducing GHG emissions

Renewable effectiveness indicator

$$\varepsilon_{ren,i\rightarrow i+1} = \left| \frac{e_{GHG,i+1} - e_{GHG,i}}{C_{ren,i+1} - C_{ren,i}} \right|$$

RES effectiveness fades out over the planning horizon, due to the persistent increases in GHG emissions by the other sectors, driven by the GDP growth



Conclusions and further work

Conclusions

- Coupling methodology between two open-source models
- Country-level economic and environmental implications resulting from the evolution of the power sector
- Study case: development of the power sector with increasing shares of renewables
    - Reduction of the primary energy uses and energy intensity
    - Reduction of GHG emissions of the power sector (Insufficient to significantly reduce prospected nationwide GHG emissions)
    - RES effectiveness fades out over time
    - Policies to increase energy efficiency and de-carbonization in other sectors as well

Further work

- Include the Energy for All scenario
- Analyse the impact of energy efficiency and/or environmental policies

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