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Analysis of Future Scenarios toward a Decarbonized Society in Three African Countries

Kazumasa Nagamori[a,*], Tomoki Hirayama[b], Toshihiko Masui[c]

[a]Tokyo Institute of Technology, Japan
[b]Mizuho Research & Technologies, Ltd.
[c]National Institute for Environmental Studies, Japan
nagamori.k.aa@m.titech.ac.jp

Many countries have submitted long-term strategies to meet the emission goals stated in the Paris Agreement, but few have introduced specific measures or policies to achieve those goals and there is a need to implement specific policies to build a net-zero-emission society. This research quantitatively examines whether it is possible to achieve virtually zero emissions by 2050 in South Africa, Tunisia, and Egypt. Specifically, the study examines what measures could be taken to realize zero emissions from energy sources to implement long-term emission-reduction strategies by using decarbonization scenarios coupled with an accounting-type static simulation model. The model calculates future energy consumption and greenhouse gas (GHG) emissions for various future scenarios and analyses potential GHG emission reductions. The results show the possibility of achieving zero emissions of energy-related CO_2 in South Africa, Tunisia, and Egypt in 2050, mainly by introducing renewable energy and carbon capture and storage; they also indicate that maximising the amount of renewable energy installation is the key to achieving zero emissions in all three countries. This analysis demonstrates that this relatively simple model can contribute to quantitative considerations in emissions pathways and projections when countries develop national long-term strategies.

1. Introduction

Greenhouse gas emissions in Africa are expected to rise rapidly because of population increase and industrialisation. Many studies target Asian countries at the national and city level to calculate the future GHG emission using models such as the Asia-Pacific Integrated Model (e.g., Muhammad et al., 2019), but there few similar studies of African countries, largely because of a lack of data (Morten, 2019). It is therefore important to be able to assess the possibility of achieving zero emissions through relatively simple tools for evaluating policy and technology options as possible pathways to future decarbonization. This study aims to demonstrate a simple model's potential to contribute to the quantitative consideration of long-term national emission-reduction strategies by applying the developed model to three African countries. It focuses on energy-related CO_2, as IEA (2021) stated the importance of realizing zero energy-related emissions. Specifically, the research quantitatively examines whether net-zero emissions in the energy sector are possible by 2050 for three African countries that have submitted long-term strategies based on the Paris Agreement to the UNFCCC (South Africa and Tunisia) or published a draft of its long-term strategy (Egypt).

2. Methodology

The model developed in this study is an accounting-type static simulation model that calculates future energy consumption and GHG emissions and can be used as a tool to integrate the assumed future economic, industrial, social, and energy visions with GHG emission reduction targets as well as mitigation measures to achieve them. Considering the parameters in base year and target year, the model calculates the energy balance and CO_2 emission while ensuring consistency among sectors (Figure 1). Unlike the computable general equilibrium (CGE) and Extended SnapShot Tool (ExSS) models (Gomi et al., 2010), the model does not include industrial linkages, which makes it easier for policymakers to use when considering policy options in Africa,

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where data sources can be limited. Using this model, scenarios were developed for a decarbonized society in 2050 for the target countries. Although scenarios were developed for 2030, 2040, and 2050 for the target countries, in this paper, the focus is on the year 2050. The current industrial structure is assumed to remain the same in the future in these analyses.

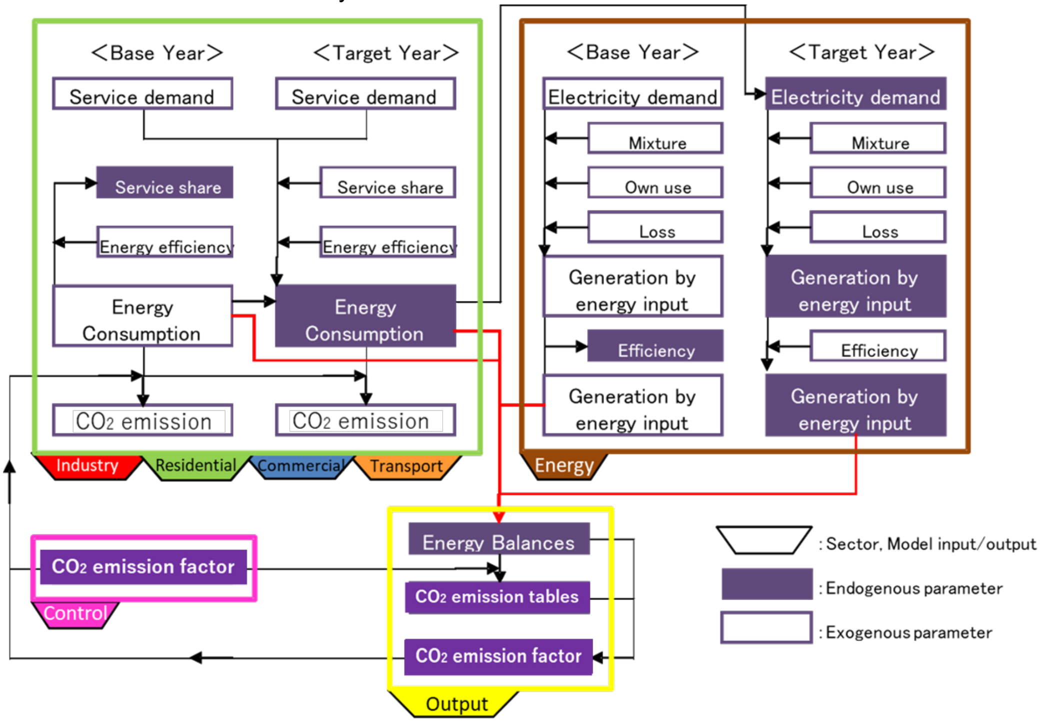

Figure 1: Structure of the model

2.1 Model Assumptions about Service Demand

For the analysis, gross domestic product (GDP) and population were used as activity indicators to quantify demand services in the industry, transportation, and residential sectors, as shown in Table 1.

Table 1: Activity indicators in 2050

Country	Activity indicator (source) (2019=100)	2019	2030	2040	2050
South Africa	GDP (PwC, 2017), with 3.7% annual growth	100	139	200	288
	Population (World Bank, 2023)	100	113	122	129
Tunisia	GDP (Republic of Tunisia, 2022), with 5% annual growth	100	171	356	454
	Population (Republic of Tunisia, 2022)	100	108	112	114
Egypt	GDP (Arab Republic of Egypt, 2016), 10–12% annual growth until 2030, GDP per capita stays steady after 2030	100	315	366	417
	Population (World Bank, 2023)	100	120	140	159

2.2 Model Assumptions about Measures

In the analysis, measures are set to realize zero emissions of energy-related CO_2 in 2050, and the difference between the countermeasure scenario and that indicated in the long-term strategy is calculated for each country. In addition, examples of the policies and measures that are needed to close that gap are examined. Tables 2, 3, and 4 describe the main measures presented in each country's long-term strategy and the measures needed for zero emissions of energy-related CO_2. Renewable energy is an important measure, and South Africa assumed a 67–81 % usage in its long-term strategy, but 90 % installation of renewable energy was assumed in its countermeasure scenario. Similarly, Tunisia assumed an 80 % contribution of renewable energy in its long-term strategy, but 90 % was assumed in its countermeasure scenario. Egypt has no quantitative targets for renewable energy in its long-term strategy, but 90 % renewable energy was assumed as the countermeasure in this analysis. Thus, the simulation assumed 90 % renewable energy and Carbon Capture and Storage (CCS) implementation for each country, which is in line with the energy structure in 2050 assumed by the IEA (2021). The target value of energy-related GHG emissions in another important factor. In South Africa, the target value was set at 168–338 Mt from its long-term strategy (South Africa's Low Emission Development Strategy; Republic of South Africa, 2020), which is 79 % of the total GHG emissions of 212–428 Mt CO_2. The target value for Tunisia was assumed to be 21 Mt CO_2 (Republic of Tunisia, 2022), and Egypt's target value in its long-term strategy (Ministry of Environment, Arab Republic of Egypt, 2016) was assumed to be 93.4 Mt CO_2 or 64.5 % of total GHG emissions of 144.83 Mt CO_2 (Ministry of Environment, Egyptian Environmental Affairs Agency, 2018).

Table 2: Long-term strategy and assumptions about measures for South Africa in 2050

Sector	Long-term strategy (CSIR, 2020; DSI, 2021)
	Model assumptions about measures in 2050
Energy	Energy mix is currently 81 % coal, expected to be 55 % by 2030 and 11 % by 2050. Wind and solar PV technologies are expected to comprise 67–81 % of the energy mix by 2050. Over 500 Kt of hydrogen generation capacity (at least 15 GW by 2040) and shift to blue and green hydrogen.
	Power supply composition: solar, 24 %; wind, 41 %; bioenergy+CCS (BECCS), 5 %; hydrogen power, 4 %; and natural gas, 10 %. Installation of CCS in natural gas-fired power plants (100 % coverage), installation of BECCS in biomass-fired power plants (100 % coverage), production of carbon-free hydrogen with electrolysis equipment (100 % coverage).
Industry	Use of hydrogen in energy-intensive industries (steel, chemicals, mining, refineries, cement).
	Improvements in the efficiency of industrial machinery (20–30 % improvement); adoption of heat pumps for boilers (50 % coverage); electrification of industrial furnaces (~20 % coverage); introduction of hydrogen burners (10 % coverage, up to 20 % in steel and cement); installation of CCS in cement and steel manufacturing (100 % coverage); extended use of biomass in paper manufacturing and installation of CCS and BECCS (100 % coverage).
Transport	Hydrogen-based fuels are expected more than 25 % of the total transport energy demand by 2050.
	progress in penetration of EVs (60 %) and fuel cell vehicle (FCV) passenger cars (40 %); progress in FCV/EV truck penetration (40 %); biodiesel in trucks (50 % mix ratio); electrification of railroads (100 % penetration); improving fuel efficiency of airplanes and ships (20 %)
Residential and Commerce	No specific description
	Electrification and improvements in the efficiency of air conditioning (100 % penetration, 20–40 % improvements); increased usage of heat pumps for water heaters (50 % coverage) and induction kitchens (30 % coverage); efficiency improvements in home appliances (50 % improvement).

Table 3: Long-term strategy and assumptions about measures for Tunisia in 2050

Sector	Long-term strategy (Republic of Tunisia, 2022)
	Model assumptions about measures in 2050
Energy	40 % of primary energy balance has shifted to renewable sources. 80 % of electricity generated is from renewables. End-use electrification accounts for 43 % of usage.
	Power supply composition: solar, 50 %; wind, 23 %; BECCS, 16 %; natural gas, 10 %. CCS installation in natural gas-fired power plants (100 %).
Industry	CCS will be employed in the cement sector by 2040, and neutralizing process emissions will start by 2050.
	Improvements in the efficiency of industrial machinery (20–30 % improvement); adoption of heat pumps for boilers (50 % coverage); electrification of industrial furnaces (20 % coverage); introduction of hydrogen burners (10 % coverage, up to 20 % in steel, cement, chemical, and mining); installation of CCS in cement and steel manufacturing (100 % coverage); extended usage of biomass in paper manufacturing and installation of CCS and BECCS (100 % coverage).
Transport	No specific description
	Progress in penetration of EVs (60 %) and FCV passenger cars (40 %); progress in FCV/EVs truck penetration (40 %); biodiesel in trucks (50 % mix ratio); electrification of railroads (100 % penetration); improvements in fuel efficiency of airplanes and ships (20 %); improvements in hydrogen-based fuels (25 % coverage); modal shift (25 % translation)
Residential and Commerce	No specific description
	Electrification and improvements in the efficiency of air conditioning (100 % penetration, 20–40 % improvements); increased usage of heat pumps for water heaters (50 % coverage) and induction kitchens (30 % coverage); efficiency improvement in home appliances (50 % improvement).

Table 4: Long-term strategy and assumptions about measures for Egypt in 2050

Sector	Long-term strategy (Ministry of Environment, Arab Republic of Egypt, 2022) / Model assumptions about measures in 2050
Energy	Energy transition to increase the share of all renewable energy sources, including green and blue hydrogen. Reduce emissions of fossil fuels. Explore the possibilities of Carbon Capture Use and Storage (CCUS) technologies.
	Power supply composition: solar: 50 %; wind, 30 %; BECCS, 8 %; other renewables, 2 %; natural gas,10 %. CCS installation in natural gas-fired power plants (100 %).
Industry	Maximize energy efficiency.
	Efficiency improvements of industrial machinery (20–30 % improvement), use of heat pumps for boilers (50 %), electrification of industrial furnaces (20 %), introduction of hydrogen burners (20 %), and CCS installation in cement manufacturing (100 %).
Transport	Convert cars from gasoline to natural gas, Maximize energy efficiency.
	Increased penetration of passenger EVs (90 %) and FCV/EV trucks (50 %, 25 %), biodiesel use in trucks (50 % mix ratio), fuel efficiency improvements of airplanes and ships (20 %).
Residential and Commerce	Maximize energy efficiency.
	Electrification and efficiency improvements of air conditioners, increased usage of heat pumps for water heating (50 %), increased usage of induction heating for cooking, efficiency improvements of other home appliances (50 % improvement)

3. Simulation results of year 2050

The difference between emissions based on the long-term strategy (LTS) and the countermeasure (2050CM) scenarios corresponds to the gap between the national target and the amount actually achievable by specific countermeasures. Under the reference scenario, GHG emissions from combustion in 2050 are 765 Mt CO_2 in South Africa, while the estimated emissions in the LTS scenario ranged from 168 to 338 Mt CO_2 (253 Mt CO_2 on average), and zero energy-related GHG emission was achieved mainly by the development of renewable energy in the CM scenario (Figure 2a, b). Tunisia's expected LTS emissions are 21 Mt CO_2, but with countermeasures, it could achieve zero energy-related CO_2 emissions (0.15 Mt CO_2, Figure 3a, b). In the CM scenario in Egypt, emissions of up to 0.27 Mt CO_2 are achieved largely by energy conservation, electrification, reductions in oil and gas consumption, and promotion of renewable energy including BECCS (Figure 4a, b).

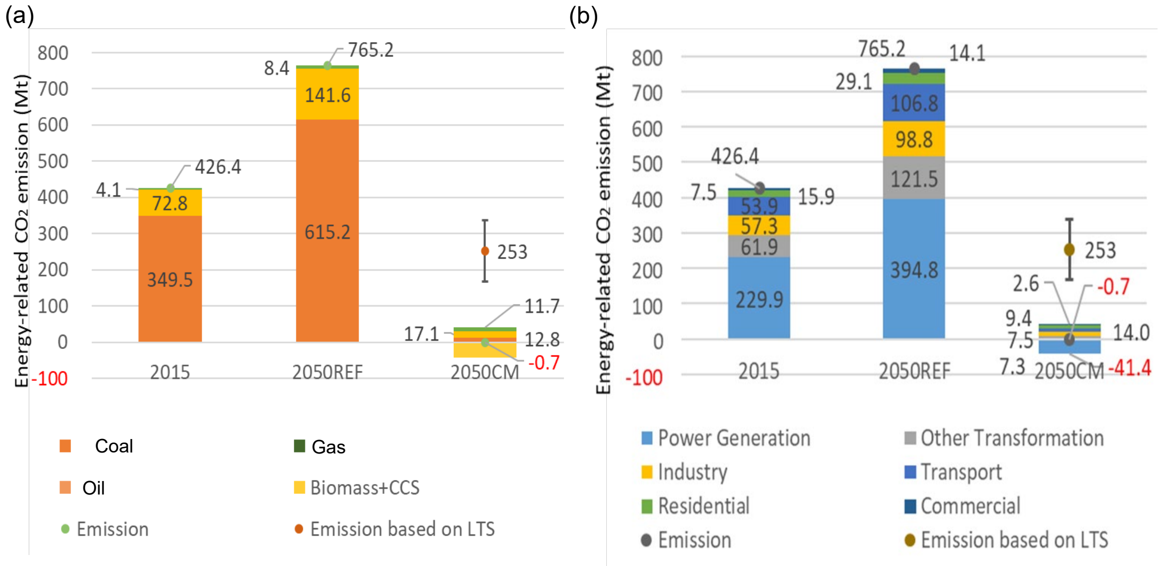

Figure 2: Energy-related CO_2 mission in South Africa by (a) energy and (b) sector

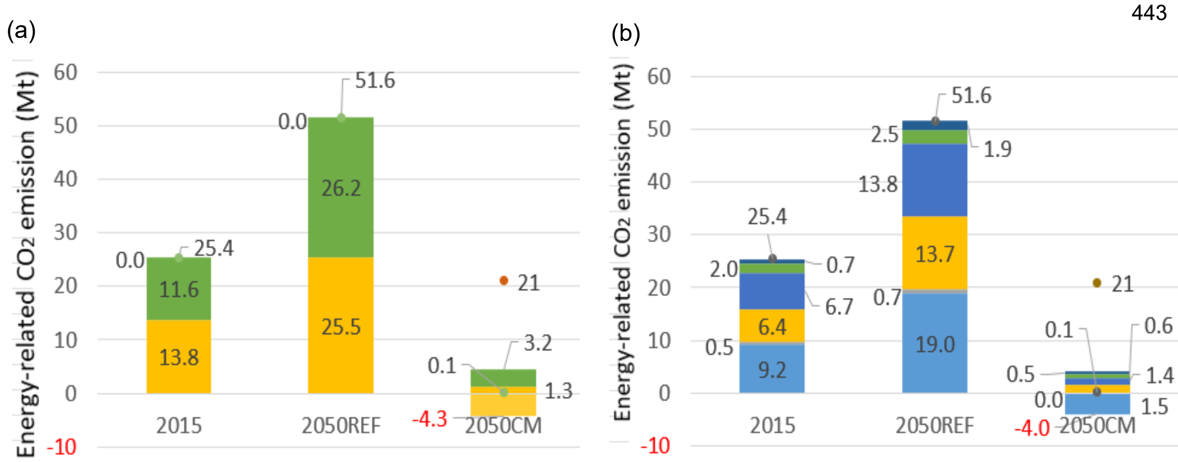

Figure 3: Energy-related CO_2 emission in Tunisia by energy(a) and sector(b)

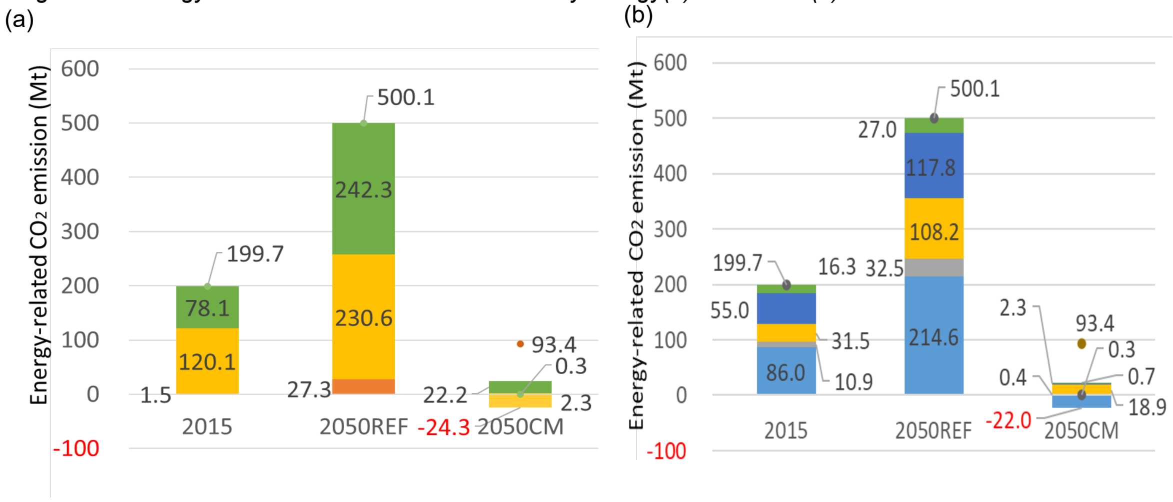

Figure 4: Energy-related CO_2 emission in Egypt by energy(a) and sector(b)

Figure 5 (a), 5(b) and Figure 7 show the contribution of different countermeasures towards realizing zero energy-related emissions in the three countries. Renewable energy makes the greatest contribution: 80 % for South Africa (Figure 5(a)), 50 % for Tunisia (Figure 5(b)), and 74 % for Egypt (Figure 6). The contribution of CCS is 8.9 %, 18.8 %, and 13.4 %, respectively.

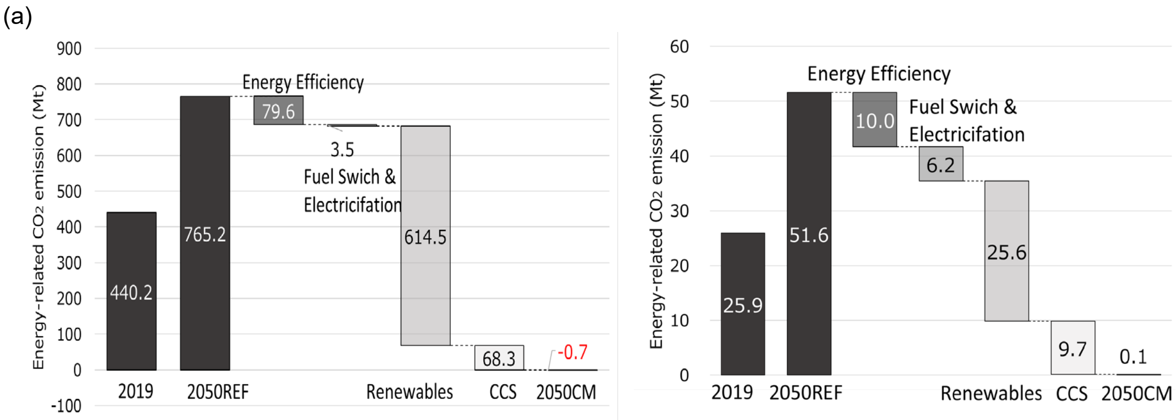

Figure 5: Reductions in emissions by implementation of countermeasures in (a) South Africa and (b)Tunisia

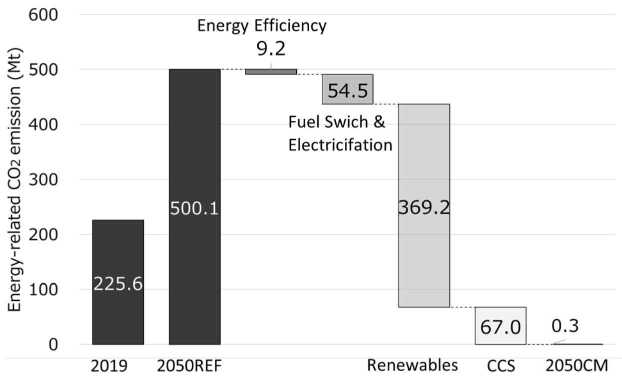

Figure 6: Reductions in emissions by implementation of countermeasures in Egypt.

4. Conclusion

By using a simplified static model, this research shows scenarios that contribute toward zero energy-related emissions in 2050 in three African countries. The results demonstrate that the model can contribute to quantitative considerations in emission pathways and projections to help policymakers to develop national long-term strategies and plans. The amount of renewable energy installed was shown to be the major contributor to achieving zero energy-related emissions, followed by energy efficiency and CCS installation. Major African countries are blessed with an abundance of renewable energy resources (IRENA, 2022). These are consistent with the IEA (2021) scenario in which approximately 90 % of electricity generation should be from renewable sources and a large amount of CO_2 should be removed via BECCS by 2050. It is necessary, however, to address technical barriers to the introduction of these technologies as well as to include cost considerations regarding the installation and use of CCS and renewable energy in future studies.

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