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Interactions between proposed energy-mix scenarios and non-energy Sustainable Development Goals (SDGs): a Sub-Sahara African perspective

Ruseh Elohor Oghenekaro[1] and **Shashi Kant**[2,*]

[1] Institute for Management & Innovation, University of Toronto Mississauga, University of Toronto, 3359 Mississauga Rd, Mississauga, ON L5L 1C6, Canada

[2] Institute for Management & Innovation, University of Toronto Mississauga, University of Toronto, 3359 Mississauga Rd, Mississauga, ON L5L 1C6, Canada

[*] Author to whom any correspondence should be addressed.

E-mail: ruseh.oghenekaro@mail.utoronto.ca and Shashi.kant@utoronto.ca

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Abstract

Sub- Sahara Africa (SSA) has the lowest access to energy globally which is partly responsible for its dismal socio-economic indices. The continent, however, has the unique opportunity to fuel its sustainable development using clean and sustainable energy. Given the continent's aspirations, as well as its position and peculiarities within the context of the Sustainable Development Goals (SDGs) such as its hosting up to 90% of the world's poorest countries, and generally lagging behind in development as most countries in Africa are not on track to meet the SDGs with the exception of the SDG on climate action, an assessment of the interactions and implications between the goal to provide access to clean, reliable, affordable, sustainable, and modern energy (SDG 7) and the other non-energy related SDGs is important for coherent cross-sectoral sustainable development planning and decision-making. This paper analyzes the interactions between SDG 7 and selected non-energy SDGs for three energy-mix scenarios—the current (2018), 2040 energy mix scenario proposed by International Energy Agency (IEA), and 2065 energy mix scenario proposed by Joint Research Centre (JRC) of the European Commission. The analyses are done for two countries - Nigeria and Ethiopia—that capture the wide variation in economic growth and energy sources across SSA. The analyses were carried out by adapting a seven-point scoring typology proposed by Nilsson *et al* (2016). The results indicate that in the case of Nigeria, the interactions between SDG 7 and many non-energy SDGs, such as SDGs 2, 6, and 13, become negative for the IEA 2040 scenario while they were positive for 2018 scenario. For the same two scenarios (IEA 2040 and the current), for Ethiopia, there are some negative influences on selected non-energy SDGs, but the direction of overall interactions does not change from positive to negative. In the case of JRC 2065 scenario, there are marginal negative influences on some non-energy SDGs, but neither in Nigeria nor in Ethiopia, there is no complete reverse change from positive to negative for any non-energy SDGs. Hence, JRC 2065 scenario is preferred. The study concludes with recommendations for policy interventions that would prevent the change of the interactions that move from positive in the 2018 scenario towards negative in the 2065 scenario (such as those that protect the rights of local communities to natural resources), as well as policies that may reduce the influence of negative interactions seen in both scenarios (such as reduction of air pollution).

Introduction

The call for the decarbonization of global energy systems that will transition the system from the use of fossil fuels to zero or low carbon energy sources and technologies has become quite urgent as the energy sector is the largest contributor to the climate crisis. According to the IPCC (2018), if we are to limit the increase in average global temperatures to 1.5 °C above pre-industrial levels, global anthropogenic CO2 emissions would need to hit net-zero around 2050 (2045–2055 interquartile range). The energy transformation to achieve this rapid and far-reaching aspiration has been described as needing to be radical (Jewell, Cherp and Riahi 2014). With the expected large-scale shift towards renewable energy as one of the major panaceas to transform our global energy architectures (IRENA 2017, Gielen *et al* 2019), energy systems are set to be disrupted, with albeit unintended social, environmental, economic, and geopolitical implications. As systems do not operate in isolation, a very good understanding of collisions or interactions between projected energy scenarios and other non-energy related UN's Sustainable Development Goals (SDGs) is essential for sustainable development planning. These interactions are expected to be context-specific, varying between the developed, developing, and least developed regions and nations of the world (Nilsson 2017).

Given Africa's position and peculiarities within the context of achieving the UN's SDGs, access to energy is a key driver for the attainment of the continent's Pan-African vision that supports its socio-economic transformation as enshrined in the 2063 Africa Agenda. With targets to achieve a 50% increase in electricity generation and distribution, and a 70% increase in electricity access by 2023, the decisions made by the continent's governments on the pathways of universal energy access will have critical implications for Agenda 2063 as well as the sustainability of the global energy system. The judicious development of a unique mix of energy resources by respective African governments that would not jeopardize the continent's ambitions would be required. It would therefore be important to assess the interactions and implications between the goal to provide access to energy and the other non-energy related SDGs. The study of interactions will also help in striking a balance between pushing the requisite energy lever and actualizing the aspirations in a manner that ensures inclusive growth and prosperity for all its citizens. Without a contextual approach, Africa may grapple with finding a just and integrative pathway to its sustainable future.

This paper explores such an approach and analyzes the interactions from an integrated perspective by assessing the potential impacts that the energy scenarios projected for Africa could have on the other non-energy SDGs. Based on the review of scientific and grey literature, the interactions between the increased energy access from specific energy sources and selected non-energy SDGs are scored within each scenario, and policy recommendations are proposed based on score outcomes. This approach builds on studies by McCollum *et al* (2018) and Fuso-Nerini *et al* 2018 in which SDG interactions were evaluated from an energy vantage point (SDG 7). While these studies aimed at highlighting how energy policies may impact other SDG objectives as well as provide researchers with the current 'lay of the land' as pertains to SDG interaction studies relevant for energy in general, this study goes a step further to enhance the methodology by evaluating the interactions not just from the broad SDG 7 perspective, but from within the context of specific energy sources, such as fossil fuels, hydropower, and other renewables, that have been projected for African countries. A comparative assessment of the differences in the interactions between the energy sources as projected in the Africa Case 2040 scenario by the International Energy Agency (IEA) 2019 Africa Outlook report, and that of the 2 °C decarbonization 2065 scenario by the European Commission's Joint Research Center (JRC) 2019 technical report for Africa, with respect to the current 2018 scenario was conducted.

These two reports from globally reputed agencies were selected for the study as they provide high quality and in-depth discussions on national, regional and continental level energy profiles and projections, and also make reference to Africa Agenda 2063 as contexts for projecting energy demand in the Continent. The IEA has had a keen eye on Africa's energy sector for decades and its Africa Energy Outlook 2019 report claims to be significantly unrivaled in its breadth and depth of the subject matter with a granular focus on Sub-Saharan African countries. The European Commission's JRC report is also in-depth and individually models the energy supply systems of forty-seven African countries for the period 2015–2065.

The IEA's Africa Case 2040 scenario examines how to provide universal access to clean, reliable, affordable, sustainable, and modern energy, and how the energy sector can foster economic growth, in line with the Agenda 2063 adopted by the African Union in 2015 (IEA) 2019. The IEA uses the World Energy Model (WEM) as its principal tool to generate detailed sectoral and regional projections for its World Energy Outlook scenarios. The WEM is a large-scale simulation model which provides medium to long-term projections and is designed to replicate how energy markets function and covers energy demand, energy transformation, and energy supply. The technical report by the Joint Research Centre (JRC) which is the European Commission's science and knowledge service, has projected the energy mix for African countries up to 2065, under different scenarios (Pappis *et al* 2019). The JRC uses the Electricity Model Base for Africa (TEMBA) for its projections and was extended to include a simple representation of the full energy system, as well as updated to include new data. Simulations were run using the medium to long-term Open Source Energy Modelling System tool (OSeMOYS). TEMBA consists of final energy demand with a least-cost optimization objective of current and future investment and operation of the energy systems. The outputs of the WEM and TEMBA, therefore, differ in their fundamental structures with the former being a simulation model and the latter, an optimization model. The difference between the projections from both institutions is the higher renewable energy-intensive scenario of the latter as compared with the former which allows for a comparative analysis to highlight the impact of different energy mix scenarios. Comparing the interactions and interlinkages and how they impact the achievement of other environmental, social and economic goals in these scenarios with that of the interactions from the current energy scenario (2018) provides some nuance as to the direction that energy planners and policymakers should focus on for a prosperous Africa.

The goal of this study is to spur conversations in African developmental sector that would fill the gaps on the linkages and interactions between the SDGs, in this case, between the energy-related and non-energy-related SDGs, and inform effective decision making for designing holistic and integrated regional and local policies for sustainable development of Sub-Saharan Africa (SSA). Being at the receiving end of developmental recommendations from the Western world and the global community, it is imperative that recommendations are analyzed and fine-tuned to suit specific African regional and sub-regional contexts before they are adopted and implemented. In this regard, the policy implications from the research findings could aid actions and decisions which ensure that achieving access to reliable, affordable, sustainable, and modern energy in SSA is consistent with achieving the other sustainability goals at the very least.

We conduct our analyses for Nigeria and Ethiopia that cover variation in geographical location, economic growth, natural energy sources, and climate across SSA. These two countries are the most populous in SSA and Africa. Nigeria is located on the West Coast of Africa with a tropical climate while Ethiopia is located in the north-eastern part of the continent with a temperate climate in the plateau and hot in the lowlands. While both countries are rich in renewable energy sources, Nigeria has the largest oil and gas reserves in SSA, and Ethiopia has the second largest hydropower potential with also significant wind, solar, and geothermal potential. Nigeria is a lower middle-income country while Ethiopia is low-income country, and more than 90% of countries in SSA fall in these two income categories.

The 10 non-energy SDGs were chosen based on literature that showed explicit or implicit interconnections between energy sources and these SDGs. Due to general data paucity, the literature used in the analysis included country-specific literature and, other relevant literature from jurisdictions with similar contexts. The assessment was unidirectional which means that only the interactions of the energy sources on the other SDGs were analyzed and not vice versa. These interactions, which are based on the state of current national contexts, circumstances, economic policies, and governance structures were used to make policy recommendations for sustainable development of both countries and SSA. The analysis, being based on the existing current evidence of interactions in country-specific literature, does not account for future reforms/developments in policies, economic systems, governance, and technologies. Similarly, the existing evidence is more about the direction of interactions (positive, negative, or neutral) between SDGs and not quantitative outcomes of interactions. Our analysis is also focused on the net impact on interactions due to different percentages of energy sources in different energy scenarios. In the next section, we present our methodology which is followed by results and discussion sections.

Methodology

The conceptual framework presented by Nilsson *et al* (2016) and used by McCollum *et al* (2018), with some modifications, was used in this study. The framework is a significant starting point for building an evidence base to portray the SDG interactions in specific local, national, or regional contexts (Nilsson, Griggs and Visbeck 2016) and it consists of a seven-point typology that scores the respective SDG interactions positively (indivisible, reinforcing, or enabling), negatively (constraining, counteracting, or canceling) or as consistent with each other.

The data of the Total Primary Energy Supply (TPES) for Nigeria and Ethiopia were obtained from the IEA report (Africa case) and JRC's Temba model (2 °C scenario) for the years 2040 and 2065, respectively. The most current 2018 energy mix scenarios were obtained from the IEA database for both countries. The TPES of both countries were categorized into Fossil fuels (oil, gas, coal), Renewable energy (hydropower), and Renewable energy (others) which include solar PV, wind, bioenergy[3], and geothermal (Ethiopia only). In order to maintain the comparability of different scenarios, nuclear energy, included only in Nigeria's energy mix (about 5%) by the JRC report, was not factored into the scoring model. These three energy sources—Fossil Fuels, Renewable Energy, and Renewable Energy (others) were then assigned weights based on their contribution to the energy mix in the three scenarios as shown in table 1.

In the case of Nigeria, the TPES does not change significantly in the IEA scenarios going from 2018 to 2040, though the contribution from oil and gas fossil fuels increases significantly as gas is expected to contribute more to supply, while renewables principally from bioenergy source (biomass burning) decreases accordingly. The JRC scenario (2065) show absolute increments in renewables contributing about thrice the amount of energy

[3] Bioenergy refers to both solid biomass (with Carbon Capture and Sequestration (CCS) for JRC 2065) and liquid biofuels.

Table 1. Sources for the Total Primary Energy Supply for Nigeria and Ethiopia for 2018, 2040 and 2065.

Ethiopia			Nigeria		
Source	Mtoe Mtoe	Percent	Source	Mtoe	Percent
JRC (2065)[a]					
Fossil Fuel (Oil, Gas, Coal)	5.9	10%	Fossil Fuel (Oil, Gas, Coal)	108.2	42%
Renewable (Hydro)	4.5	7%	Renewables (Hydro)	5.4	2%
Renewables (others)	50.1	83%	Renewables (others)	146	56%
Total	**60.5**	**100%**	**Total**	**259.6**	**100%**
IEA (2040)[b]					
Fossil Fuels (Oil, Gas, Coal)	20	29%	Fossil Fuels (Oil, Gas, Coal)	99	66%
Renewables (Hydro)	6	9%	Renewables (Hydro)	2	1%
Renewa bles (others)	42	62%	Renewables (others)	49	33%
Total	**68**	**100%**	**Total**	**150**	**100%**
IEA (2018) Source					
Fossil Fuel (Oil, Gas, Coal)	4	9.50%	Fossil Fuels (Oil, Gas, Coal)	39	24.7%
Renewables (Hydro)	1	2.60%	Renewables (Hydro)	1	0.3%
Renewable (others)	38	88%	Renewable (others)	120	75%
Total	**43**	**100%**	**Total**	**160**	**100%**

[a] As a 2 degrees constrained model, new power plant options for power generation to include CCS and different cooling types were added for biomass, coal and natural gas (CCS) and Bio Energy Carbon capture and Sequestration (BECCS) in the JRC 2065 model.

[b] The IEA 2040 model does not make mention of CCS as an input to the energy projections.

than in the IEA 2040 scenario, while fossil fuels marginally increased. For Ethiopia, the TPES increases from 2018 to 2040 in the IEA scenarios with fossil fuels supply largely responsible for the increase. The TPES in 2065 is lower than the 2040 scenario, with fossil fuels contributing even less.

Next, critical non-energy related SDGs representing social, environmental, and economic indices were identified and selected for evaluation based on the availability of relevant SDG and SDG related data specifically in the context of SSA as relates to energy sources in literature[4]. Databases used in the search primarily include important publication repositories like Scopus, Science Direct, and IEEE Xplore Digital Library. Google scholar, other academic research databases, as well as Grey literature sources, were also used. The context-specific (SSA) analysis being the focus of this work, the non-context-specific sources of data were not included in the analysis. The details of the selected 10 non-energy SDGs and their targets are given in table 2.

For the future scenarios, we do not have the data about the composition of all the different energy-mixes, such as the composition of renewable energy sources—traditional biomass, solid biomass for electricity production, and biofuels, and evidence from the contextual literature about future technologies, policies, and economic reforms and their impacts on the interactions between SDG 7 and non-energy SDGs in the two countries. We, therefore, conducted our analysis like a thought experiment[5] in which we took the projected TPES of the future, 2040 and 2065, for Nigeria and Ethiopia, and dropped it on the current technological, policy, and economic system of Nigeria and Ethiopia, and examined what the interactions will be. The thought experiment resulted in an implicit assumption that the traditional biomass will continue to play the same role in future as of the present due to the lack of data on the composition of future renewal energy sources. The objective of our analysis is not to forecast or predict energy composition in future, but to analyze the interactions between SDG 7 and non-energy SDGs. Hence, the implicit assumption results in the outcomes of interactions that are subject to the continuation of the same role, as of the present, of the traditional biomass. We use these outcomes of our analysis to suggest policy, economic, and technological interventions to reduce the role of traditional biomass and negative outcomes of interactions with non-energy SDGs in future.

The recent two (2020 and 2021) Sustainable Development Goals Reports of United Nations have reported that population growth outstripped growth in access for clean energy and 85% population continues to rely on fuelwood and charcoal in SSA[6]. In the light of these recent trends of the consumption of the traditional biomass in SSA, our analysis resulting from the implicit assumption provides very useful context-specific findings and recommendations to intervene in the energy and other related sectors.

In the first step of scoring, interaction of each energy source with the selected targets of 10 non-energy SDGs were scored using 7 points scale of Nilsson's framework. The current national contexts and circumstances, geography, technology, and level of governance, were used to determine the principal unidirectional interactions between the specific energy source and the underlying targets of 10 non-energy SDGs. These interactions were summarized and scored as either positive, negative, or consistent with each other as well as having no interactions at all. For interactions having both positive and negative interactions, scores were assigned as either negative or positive where there was significantly more evidence to support either interaction. Where an almost equal number of positive and negative interactions for a target was found, a net score was obtained.

In the second step of scoring, the interaction scores obtained for each energy source in the previous step were then aggregated by using a weighted average based on the proportion of the energy source's contribution to the energy mix. The scores were rounded off to single decimal places where applicable and were interpreted based on the adapted 13 points typology scale which is given in figure 1. This adaptation involved the addition of sub-points to allow for results that did not sum up to whole numbers due to the weighted averaging of energy sources.

In addition to scores of interactions, we also calculated the strength of literary evidence, which was classified, similar to McCollum *et al* (2018), as low, medium, and strong for 0–3, 4–7, and $\geqslant$8 literary sources, respectively.

All the coding and scoring of interactions, to avoid the inter-coder variability, were done by the first author of this paper. However, it is important to note that the results obtained are not necessarily applicable for any

[4] Studies such as McCollum, *et al* (2018), Fuso-Nerini *et al* (2018) have discussed interactions of SDG 7 with other SDGs but provide general rather than place-specific analysis. Our paper is focused on SDG 7 interactions with other SDGs in the context of the SSA, and therefore we selected only 10 other SDGs for which we could find evidence of interactions in the context of the SSA.

[5] We are grateful to a reviewer to draw our attention towards our analysis being a thought experiment.

[6] Two observations from the United Nations Reports are cited below.'In sub-Saharan Africa, population increases outstripped growth in access, leaving about 85 per cent of the population reliant on inefficient and dangerous cooking systems. The majority of the poor rely on harmful and polluting fuels such as wood and charcoal to cook, making them especially vulnerable to COVID-19.' United Nations, 2021,p. 40'However, in sub-Saharan Africa, population growth between 2014 and 2018 outstripped growth in access by an average of 18 million people each year. Slow progress towards clean cooking solutions is of grave global concern, affecting both human health and the environment. Under current and planned policies, 2.3 billion people would still be deprived of access to clean cooking fuels and technologies by 2030. This means that nearly one third of the world's population, mostly women and children, will continue to be exposed to harmful household air pollution.' United Nations, 2020, p. 38.

Table 2. Details of the Selected Non-energy SDGs and Targets.

SDG	TARGETS
1: No Poverty	1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day
	1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions
	1.3 Implement nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable
	1.4 By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance
	1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters
2: Zero Hunger	2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round
	2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons
	2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment
3: Good Health And Well Being	3.1 By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births
	3.2 By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births
	3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases
	3.4 By 2030, reduce by one-third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being
	3.7 By 2030, ensure universal access to sexual and reproductive health-care services, including for family planning, information and education, and the integration of reproductive health into national strategies and programmes
	3.8 Achieve universal health coverage, including financial risk protection, access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all
	3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination
4: Quality Education	4.1 By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes
	4.2 By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education
	4.3 By 2030, ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university
	4.4 By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship
	4.5 By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations
	4.6 By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy
	4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development
6: Clean Water And Sanitation	6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all
	6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

Table 2. (Continued.)

SDG	TARGETS
	6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
	6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
	6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
	6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
8: Decent Work And Economic Growth	8.1 Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries
	8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors
	8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services
	8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead
	8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value
	8.6 By 2020, substantially reduce the proportion of youth not in employment, education or training
	8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products
10: Reduced Inequalities	10.1 By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average
	10.2 By 2030, empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status
	10.3 Ensure equal opportunity and reduce inequalities of outcome, including by eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action in this regard
	10.4 Adopt policies, especially fiscal, wage and social protection policies, and progressively achieve greater equality
13: Climate Action	13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
	13.2 Integrate climate change measures into national policies, strategies and planning
	13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
14: Life Below Water	14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution
	14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans
	14.5 By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information
15: Life On Land	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements
	15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally
	15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development
	15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species
	15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species

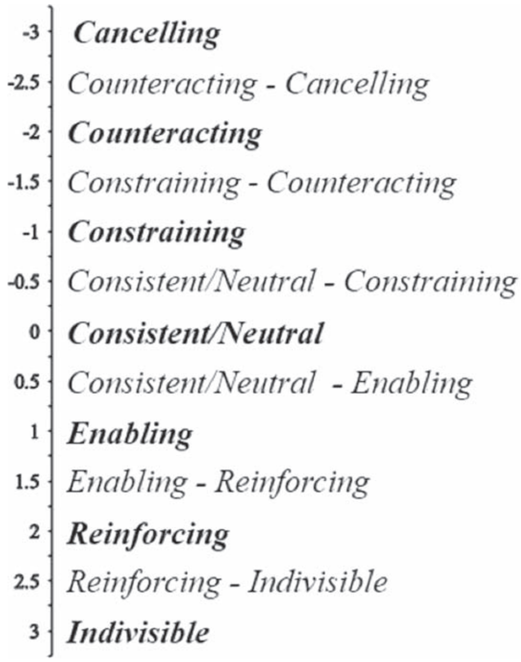

Figure 1. 13 *Points Scoring Scale.*

generic country with the same mix of energy sources but are rather country specific for Nigeria and Ethiopia while not factoring in future governance, policies, etc.

Results

The comparative assessment of two countries is presented in figure 2. The key insights revealed from this comparative assessment of two countries show that Ethiopia with a higher renewable energy mix in all the scenarios, has more positive interactions with the non-energy SDG target categories and net positive interactions on the non-energy SDGs as a whole, than Nigeria with a predominantly fossil fuel mix in all the scenarios. The disparity in the interaction results between Nigeria and Ethiopia is quite significant as regards the number of positive and negative interactions that the different energy scenarios have on the non-energy SDG targets and target categories. Looking at the net impacts of the SDG interactions as depicted in figure 2, Nigeria has more negatives (constraining and counteracting) than Ethiopia. An example of a net positive interaction for Ethiopia is SDG 13 *Combatting climate change* where in the IEA 2040 scenario, interactions with fossil fuels scored −2 (counteracting), renewables (hydro) scored −1 (constraining) and renewables (others) scored (+2), resulting in a slightly net positive score of +0.6 (consistent/neutral—enabling) based on the weighted average contribution of each of the energy sources in this scenario.

There are a few SDG interactions that are indeterminate given the presence of varied interactions with the target categories within the SDG. For example, the net interaction on SDG 3 for both Nigeria and Ethiopia cannot be classified as positive, negative or neutral because, in all the three scenarios for both countries, there are varied impacts on each of the target categories for SDG 3. Specifically, for Nigeria in the IEA 2040 scenario, interactions on the target category *Disease and mortality* by fossil fuels, renewables (hydro) and renewables (others) scored −2 (counteracting), −1 (constraining) and +2 (reinforcing), respectively. The aggregate score based on the weighted average of each of the sources gave a score of −0.7 (consistent/neutral - constraining). For *Healthcare Provision*, the scores were +1 (enabling) for all the energy sources, with the same aggregate score of +1, while the scores were −2 (counteracting) for both fossil fuels and renewables (others) and +2 (reinforcing) for renewables (hydro) giving an aggregate score of −2 (counteracting) for *Air Pollution.* In all, this resulted in an indeterminate effect on SDG 3 as a whole.

The summaries of the SDGs interactions, scores, and the strength of evidence for Nigeria and Ethiopia are given in appendix A and B, respectively.

Figure 2. Identified target interactions in Nigeria and Ethiopia in the three scenarios.

Comparative analysis of IEA 2018, IEA 2040 and JRC 2065 scenarios

In these three scenarios, the key distinguishing feature is the proportion of fossil fuels which is quite different for Nigeria and Ethiopia. Hence, the comparative results of interactions of SDG7 with other SDGs are also quite different for the two countries.

For example, in both countries, SDGs 14—*Marine protection*, SDG 15—*Healthy Terrestrial Ecosystems* and SDG 3 target category *Air pollution*, have negative interactions regardless of the energy mix scenario. This appears to be counterintuitive as there should ordinarily be a difference in the interactions between the high fossil fuel and high renewable energy scenarios, however, we see this outcome because while a high fossil fuel energy mix results in land and marine pollution from oil and gas exploration, production, transportation and utilization activities, a high renewable energy mix with bioenergy accounting for the bulk also results in air pollution from biomass burning and land degradation related to deforestation and intensive cultivation of energy crops, with the attendant effect on marine resources. It is important to note that the traditional use of biomass contribution to bioenergy may reduce in the future to allow for more advanced technology use that may have better outcomes with respect to impacts on these SDGs. However, as stated earlier, due to nonavailability of data regarding the composition of bioenergy sources in 2040 and 2065 in the IEA and JRC reports, respectively, we conducted our analysis using the current bioenergy composition scenario as seen in the literature focused on the SSA and these two countries. Looking at interactions with *Air Pollution* for Ethiopia in the JRC 2065 scenario, interactions with fossil fuels and renewables (others) scored -2 (counteracting) while renewables (hydro) scored $+2$ (reinforcing), resulting in an aggregate interaction score of -1.7 (constraining-counteracting) when factoring in the weighted average proportion of each energy source in the mix for that scenario.

The differences in the dominant energy sources in each of the scenarios show changes in the nature of the interactions in each of the years. In Nigeria for example, SDG 1 changes from being positive in IEA 2018 to indeterminate in IEA 2040 and JRC 2065 scenarios as the proportion of fossil fuels in the mix increases. The increase in fossil fuels contribution from 24.7% in 2018 to 66% in 2040 results in a significant increase in negative interactions. The SDG 1 target categories *Rights to natural resources* and *Vulnerability to climate related shocks* become negative with only *Poverty and development* staying positive. However, the net interactions of these target categories result in overall indeterminate interactions with SDG 1. This is the case because fossil fuel production and utilization activities have led to the loss of arable farmlands and pollution of water bodies in the Niger-Delta region, resulting in declined agricultural productivity and death of fish and other water proteins, denying the host communities their rights to use their natural resources to sustain their livelihoods, even though the presence of energy generally improves poverty and development indices as shown. In addition, SDG 2- *Food security and Agricultural productivity*, SDG 6—*Water Availability and Water Quality,* SDG 10—*Empowerment and Inclusion* and SDG 13- *Combatting climate change* all change from being positive in 2018 to negative in 2040. The *SDG* 3 target category- *Disease and Mortality*, also becomes negative in 2040. These results show the impact that high fossil fuel proportion in the energy mix can have on achieving other SDGs. This is especially true for Nigeria which is a large producer and consumer of oil and gas with evidence of such impacts (Pitkin 2013, Numbere 2018) which could magnify as fossil fuel contribution to the energy mix increases. As expected, some of the interactions are less negative, albeit not positive in 2065 with a reduced fossil fuel contribution of 46% as compared to 66% in the 2040 scenario.

For Ethiopia, the fossil fuels' proportion changes from 9.5% in 2018 to 29% in 2040, and therefore its impacts are not as drastic as Nigeria. SDGs 2- *Food security and Agricultural productivity* and SDG 10- *Empowerment and Inclusion* change from positive to neutral. Target categories in SDG 1 - *Rights to natural resources* and SDG 3- *Disease and Mortality* also become less positive in the 2040 scenario. There are however no changes in the interactions between the 2018 and the 2065 scenarios as expected, as the difference in the fossil fuel contributions in both scenarios is quite marginal at 0.5%. Ethiopia does not have a current or projected fossil fuel scenario as high as Nigeria, and though these impacts may manifest as fossil fuels contribution to the mix increases from 9.5% in the current scenario up to 29% in the IEA 2040 scenario, the aggregated effects from other cleaner dominant sources such as solar, hydro, and geothermal, are more positive, making the interactions mostly overall positive with the exceptions of the aforementioned SDGs which have negative interactions in all the three scenarios.

Comparative analysis of energy sources

In general, all energy sources i.e., oil and gas, hydro and other renewables have net positive interactions on SDG 4 and SDG 8 for both countries with enabling-reinforcing effects on all the target categories i.e. *Equal access to education* and *Human capital*, and *Employment opportunities* and *Economic growth.* This aligns with the general expectation that access to energy for the underserved communities enable the siting of schools within these communities. The availability of energy is also needed for commercial and industrial enterprises, thereby leading to job creation and economic prosperity. All the energy sources have positive interactions on SDG 3 target category *Healthcare provision* for both countries as access to any source of energy leads to the provision of better healthcare facilities. There's also a positive interaction on SDG 1's target category *Poverty and Development* for both Nigeria and Ethiopia, though higher in magnitude for the latter. This underscores the important role that energy plays in poverty eradication and the economic growth of any nation. These interactions are quite reasonable as there is a general corollary between energy poverty and economic poverty, as energy has strong interlinkages with poverty reduction through income generation, healthcare, access to education, economic growth, etc., (Saghir 2005, Sovacool and Drupady 2016). It is asserted that climate change mitigation and poverty eradication are the twin challenges faced by human-kind and the former should not trap developing countries in a state of poverty (Steckel, Brecha *et al* 2013), We find that energy, regardless of the source, therefore, seems key for both Nigeria and Ethiopia to reduce poverty levels and grow their economies. It is important to note that energy provision on its own is not a guarantee for poverty eradication but needs to be combined alongside other enabling factors (Karezeki *et al* 2012).

Hydropower was found to have neutral impacts *on Equal access to education* and *Human capital* as well as *Water availability* and *Water quality* in Ethiopia as the country's hydropower developments have not necessarily improved the achievement of these SDG targets. The exploitation and development of oil and gas resources, and development of large hydropower projects are shown to infringe upon the locals' rights to natural resources and affect food security and agricultural productivity. Oil and gas development was found to have negative to neutral interactions on *Water quality* and *Availability*, *Disease and mortality* as well as *Empowerment and inclusion* target categories, depending on the degree of contribution.

The interactions on SDG 14 target category *Marine protection* and SDG 15 target category *Healthy Terrestrial Ecosystems* are all negative (constraining-counteracting) regardless of the energy sources for both countries. There are also negative interactions of different magnitudes for SDG 3 target category *Air pollution* for all the energy sources for both countries. While the combustion of oil and gas contributes to air pollution, the status quo use of bioenergy in both countries are also significant sources of air pollution. These interactions are quite important to note as it shows that both fossil fuel and cleaner energy sources have impacts on the environment. Adverse impacts on the natural environment have attendant social and economic multiplier effects on humans who are inextricably linked with nature, as environmental problems are social problems (Bell *et al* 2021). It is, therefore, necessary to tread cautiously in the enactment and enforcement of related policies.

Conclusions, policy implications and recommendations

There is a significant shift in policy as well as academic discussions towards SDGs during the last 5 years. However, the same shift has not occurred in development planning processes, and planning processes have been dominated by sector and target-specific planning. Such processes totally ignore the interactions between different SDGs which result in inefficiencies and ineffectiveness of these processes. In this paper, we analyzed the interactions between SDG 7 and 10 non-energy SDGs for three energy scenarios of the SSA, one present and two future (2040 and 2065) scenarios.

As stated in our Methods section, due to non-availability of the data about the composition of different energy-mixes, such as the composition of renewable energy sources, for future scenarios, our analysis is based on a thought experiment. The experiment resulted in an implicit assumption that the traditional biomass will continue to be a major portion of the renewable energy in future. Given the dismal performance of the SSA on all five performance indicators of SDG 7 - electricity access, use of dangerous and inefficient cooking systems, the share of renewal energy, energy efficiency, and international financing—during the last five years (United Nations 2020, 2021), there is an urgent need of policy, economic, and technological interventions to improve the performance of the SSA on SDG 7 and other non-energy SDGs. Hence, the implicit assumption of the continuation of the traditional biomass is more of a blessing than a curse for our analysis which is aimed on understanding the interactions between SDG 7 and non-energy SDGs and making policy and other recommendation so that negative interactions can be reduced and positive interactions can be enhanced. Hence, our recommendation will help national governments to design their future interventions in the areas of new technologies, policies, and economic reforms related to SDG 7 as well as 10 non-energy SDGs.

The results confirm high-level interactions between SDG 7 and non-energy SDGs, existence of both positive and negative interactions, and the variation in the direction of interactions being dependent on energy sources. The identified interactions for Nigeria and Ethiopia are based on the available resources each country can harness to meet its energy needs. It is however important to understand how meeting these energy needs may impact meeting the other crucial developmental needs as reflected in these interactions. This study has shown that even the application of cleaner energy resources may constrain or counteract the pursuit of other developmental goals, and to checkmate this, holistic, coherent, and effective cross-sectoral sustainable development planning and decision-making processes are essential.

The varying interactions in both countries are an indication of some of the impacts that the deployment of large-scale renewable energy may have under current practices or policy scenarios. While each of the energy sources has its specific interactions with each of the SDGs and their target categories, the aggregate effects are what this study highlights. From the SSA perspective, interactions seen in Nigeria show how a high fossil fuel energy mix may impact on achieving the selected SDGs while interactions seen in Ethiopia show what the impacts could be in a high renewable energy mix given current practice and technology levels. The achievement of most of the selected SDGs may be best served from an energy mix higher in renewable energy sources while ensuring that the negative impacts within these energy mixes are mitigated by better policies as discussed next.

Our key findings are that the IEA 2040 scenario with the highest fossil fuel mix has the most negative impacts on the other non-energy SDGs while the JRC 2065 scenario has much less negative interactions compared to the IEA 2040 scenario. Hence, energy planning and development for the future should focus more on increasing renewable energy into the energy mix for both countries, especially in Nigeria which has large oil and gas reserves. This stands to prevent achieving energy goals while not simultaneously impeding or worsening the state of the other non-energy SDGs as seen in the 2040 scenario.

In the case of the preferred 2065 scenario, polices that prevent the negative movement of many target categories from the 2018 scenario to the 2065 scenario need to be strengthened and enforced or developed where absent. For instance, the goals to ensure the rights to natural resources, food security and agricultural productivity can be achieved through the enactment of people-oriented policies that do not hinder rights to natural resources in communities affected by oil and gas development as well as large hydropower schemes and irrigated agricultural schemes. Ensuring food security and agricultural productivity is another area that is applicable given the contribution of bioenergy to the energy mix. Policies that are geared towards the avoidance of competition for land and water between energy and food sources should be formulated. This would also mitigate effects on agricultural prices and thus on food security. Bioenergy production on degraded land should be emphasized and energy production from non-bioenergy agricultural and municipal waste should be maximized as these are potentially viable fuel sources. Legislation that protects indigenous agricultural lands should also be enacted in view of both local and global demand for biofuels.

In addition, for Nigeria, policies that ensure the energy system is gradually decarbonized through increased diffusion of renewable energy technologies are crucial in limiting the extent of global climate change, and therefore the exposure of the poor to climate-related extreme events. The negative interaction seen in disease and mortality is linked to high fossil fuel use which creates significant short-term health risks (e.g., from the use of kerosene for cooking and lighting, gasoline, and diesel generators for electricity, etc.) and medium to long term health risks (e.g., from direct and indirect impacts from climate change resulting from greenhouse gas emissions). Although there is evidence in general literature of direct correlations between air pollution from use of biomass in high renewable energy scenario and disease and mortality rates, this study did not find sufficient direct contextual evidence, in the literature focused on the SSA and these two countries, linking biomass burning to disease and mortality rates to present negative net scores and interactions for disease and mortality in all the three scenarios. We did not use generic evidence for this interaction in particular, because that would require the same treatment for all the other SDGs alike. This would have defeated the main purpose - being context-specific - of this study. There are also communicable and non-communicable diseases linked with hydro dams and relevant health and environmental policies that tackle diseases at source need to be developed or strengthened. Transitory legislation promoting renewables use across multiple sectors is encouraged to reduce the negative impacts on the health of both rural and urban populations. The negative impact on water availability and quality is a pointer for water management strategies and policies that integrate energy and water management markets, and systems development planning would be beneficial. The use of hydropower and bioenergy sources also have impacts on water systems if not managed properly, and so energy and water policies that mitigate the adverse side-effects of these renewable energy options would also be beneficial. The alignment of energy and water management policies to minimize negative impacts on aquatic ecosystems from thermal and chemical pollution is also recommended.

In addition, given the preferred interactions in high renewable energy scenarios, Nigeria which has large oil and gas reserves, and are expected to be a major part of its energy mix in the coming decades, should proactively begin to foster and incentivize the uptake of renewables, bearing in mind the global transition to decarbonized economies. Tried and tested market-based and policy-based measures in other jurisdictions can be adapted to the Nigerian context to leapfrog fossil fuel consumption in many rural areas. Also, the potential for carbon capture and storage technologies in fossil fuel plants should be explored to inform future policy decision-making. According to Steckel *et al* (2013), leapfrogging fossil fuels would remain an unrealized aspiration if capital accumulation remains a pertinent driver of economic growth in the future as developing countries may repeat historical patterns of energy use by their developed counterparts. This may be counteracted by massive improvements in energy intensity through radical improvements in energy efficiency and simultaneously providing the latest technologies to developing countries. However, the energy transition is considered complex with important implications on the structure of economies and development prospects in the future. For instance, the Africa Energy Outlook 2014 report shows between 2010 and 2014, 30 percent of the global oil and gas discoveries were made in SSA. This is an indication that developing nations like Nigeria may continue to seek the most attractive energy resource options that are able to drive both internal and external revenue generation to aid its economic development despite cheaper and cleaner renewable alternatives. This approach is nonetheless shortsighted given the globally changing energy landscape.

For Ethiopia, there is no difference in the interactions between the current 2018 scenario and the preferred 2065 scenario. The negative interactions seen for Air pollution, Marine protection and Health terrestrial systems occur in both scenarios. Given this potential for constraining or counteracting interactions on reducing air pollution and ensuring marine protection and healthy terrestrial ecosystems, regardless of energy mix scenarios in both countries, energy policies that take a holistic view in mitigating the impact of achieving these SDG targets are needed. For instance, biomass burning for cooking and heating is a major source of deforestation and air pollution. To curb this, energy policies that support clean cooking-stove purchases to reduce traditional biomass consumption, promote the use of Liquified Petroleum Gas (LPG) for cleaner cooking, as well as increase electrification to reduce the use of kerosene lamps for lighting (and cooking) should be strengthened and enforced. The up-front costs for these alternatives are usually prohibitive and requires supportive regulatory mechanisms to either support uptake or drive down costs for consumers. There is also need for the promotion of integrated planning and multi-stakeholder participation in large infrastructure energy projects that may impact marine and terrestrial ecosystems and the livelihood of local communities. Policy mechanisms to manage the energy, land, fertilizer, and water inputs for agriculture would mitigate negative interactions in the aquatic and terrestrial environments.

Energy, regardless of the source, also plays an enabling role in promoting economic growth, productive employment, and spurring innovation, as seen from the interactions in Ethiopia and Nigeria. To keep these interactions positive in 2065, policies that remove the obstacles to educational attainment, employment acquisition, and economic growth that are caused by a lack of energy access should be designed. This is prevalent in rural and peri-urban areas which form a large part of the vast population in both countries. In addition, policies that leverage the local development and deployment of renewable energy and energy-efficient technologies could drive innovation and economic diversification. Importation of these technologies would not benefit the populace as much as if there is in-country capacity for local design and manufacture. In this regard, policy-driven support and incentives for small and medium-scale enterprises and start-up ventures would go a long way in the attainment of this goal.

Developmental plans to hasten micro-economic and human capital development of host communities should be implemented. While one cannot quite compensate people for infringing on their traditional social and economic lifestyles, adequate dialogue and compensation should be integrated into governance frameworks where these will be affected by energy projects.

Importantly, sound financial policies that can support the implementation of all the recommended policy actions are quite critical. Ethiopia and Nigeria are both developing nations and while prudent management of revenue is advised, policies that foster a more self-sustaining investment climate through the strengthening of institutional capacities, increased transparency, and accountability, as well as the development of sustainable and innovative business models, is important for achieving any of the SDGs.

These observations and recommendations may also be useful to other countries of the SSA which have similar income, energy sources, climate, and culture. However, the key dimensions that have shaped the interactions are contextual given current country scenarios and the current state of knowledge and the literary evidence, and as such policy implications identified are dependent on the current state of governance, geography, technology, and time-frame scenarios. Hence, the specific quantitative values of interactions presented in this paper should be used as a basis for dialogue between science and policy communities for more informed sustainable development planning and decision-making. The future studies should be enriched by incorporating lifecycle impacts of renewable energy technologies which may reflect other impacts of using renewable energy resources from resource extraction to end-of-life.

Finally, as we stated earlier, our SDG interactions analysis is based on the strength of the current literary evidence as specifically relates to Sub-Sahara Africa. There may be interactions at present that are not captured by current context-specific literature, such as the relationship between Air pollution due to burning of the traditional biomass and Disease and Mortality rate, and some new interactions may also arise in the future due to the introduction of new technologies or the first use of old technologies in the SSA. Similarly, there will be reforms and changes in policies, economic systems, governance, and technologies that will influence the interactions between SDG 7 and other SDGs. The energy forecasting agencies, such as the IEA and the JRC, may also include more detailed data about the composition of energy sources including renewable energy sources in their future modeling. Hence, to have an updated understanding of these interactions, similar studies need to be conducted regularly. We hope that this paper will open a new area of research focused on SSA.

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Data availability statement

No new data were created or analysed in this study.

Appendix A. Summary of Identified Interactions and Scores for all three energy-mix scenarios – Nigeria

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
1: No Poverty	Poverty and Development (1.1/1.2/1.3)	Fossil Fuels: Oil & Gas has both positive and negative effects on poverty and development. While oil and gas revenues, as well as thermal electricity generation, have contributed to poverty alleviation and national development, exploration (spills and gas flaring) has impacted negatively on the host communities, increasing the poverty rates. This interaction got a score of +1 after netting off positive and negative interactions.	Effiong and Etowa 2012, Pitkin 2013, Siddig *et al* 2015, Numbere 2018, Osuagwu and Olaifa 2018, Mensah *et al* 2019, Owolabu *et al* 2019, Adewuyi *et al* 2020	Strong	IEA (2018)	[+1.8]	Reinforcing
		Hydro: Nigeria has both large hydropower and small hydropower potential which can benefit the country nationally and locally through decentralized systems. Small hydropower projects have the ability to significantly reduce poverty and enhance the quality of life in the communities they serve. A 2018 study of the three major hydropower stations in Nigeria shows increased human activities downstream of the dams with mainly farming and grazing thereby helping the local people. This interaction scored +2.	Igweonu and Joshua 2012, Kela *et al* 2012, Olukanni and Salami 2012, Osokoya *et al* 2013, Ijeoma and Briggs 2018, Imo *et al* 2020	Medium	IEA (2040)	[+1.3]	Enabling
		Other Renewables: The promotion of renewables could cause price shocks and would add to the challenges of improving the standard of living for the world's poorest. However, some of the poorest parts of the world have some of the highest RE (e.g., biomass and solar power in Nigeria), and making use of this potential help to reduce poverty; Access to modern energy forms (electricity, clean cook-stoves, high-quality lighting) is fundamental to human development as the energy services made possible help alleviate chronic and persistent poverty. This interaction scored +2	Nnaji *et al* 2010, Griggs *et al* 2017, Mainali *et al* 2018, McCollum *et al* 2018, Bisaga *et al* 2020, Dal Maso *et al* 2020, Wassie and Adaramola 2021, Mshelia 2012, Fuso Nerini *et al* 2018	Strong	JRC (2065)	[+1.6]	Reinforcing
	Rights to Natural Resources (1.4)	Oil and gas extraction in Nigeria has typically caused land-use changes, degraded land and water in the Niger Delta denying the local indigenes the right to use their natural resources to sustain their livelihoods. This interaction scored -2	United Nations Environment Programme 2011, Pitkin 2013, Ugwukah and Ohaja 2016, Numbere 2018	Medium	IEA (2018)	[+0.3]	Consistent / Neutral
		Hydro: A 2018 study of the three major hydropower stations in Nigeria shows increased human activities downstream of the dams evidencing no denial of rights to natural resources. However, people are usually displaced from their lands and homes for the establishment of large hydropower dams, denying them access to their ancestral lands and resources though they eventually resettle in other lands. This interaction scored -1.	Olukanni and Salami 2012, Aboi *et al* 2019	Low	IEA (2040)	[-1]	Constraining
		Other Renewables: The production of biofuel crops appears to have a greater negative impact on local communities' land rights, access to natural resources, and means of livelihood than the fossil fuels they are supposed to	Friends of the Earth International 2010, Emenyonu *et al* 2017, Nilsson 2017, Okoro *et al* 2018, Adenle 2020, Ashukem 2020, Bisaga *et al* 2020, Masron and Subramaniam 2021	Strong	JRC (2065)	[-0.3]	Consistent / Neutral

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
		replace. However, in general, poverty analysis indicates that biofuel investment is largely pro-poor (Rural households are more beneficiaries from this investment in all scenarios poverty head count, gap, and severity at national, rural, and urban level decline). This interaction scored a net +1 from negative and positive interactions. Oil and gas extraction in Nigeria has typically caused land-use changes, degraded land and water in the Niger Delta denying the local indigenes the right to use their natural resources to sustain their livelihoods. This interaction scored -2.					
	Vulnerability to Climate Related Shocks (1.5)	Fossil Fuels: The continuous combustion of fossil fuels is a precursor for climate change and the related climate-related extreme weather events, though not the only factor. While many people are vulnerable to environmental degradation, climate change-induced droughts and/or floods have been forcing individuals, families, and communities into destitution. Climate change will hasten the demise of poor and vulnerable communities in Nigeria. This interaction scored -2.	Adejuwon 2006, AFDB; ADB; DFID; OECD; UNDP; UNEP; The World Bank 2009 , Amusa *et al* 2019, Intergovernmental Panel on Climate Change 2007, Lekwot *et al* 2012, Ozor and Umehai 2009, Urama *et al* 2017	Medium	IEA (2018)	[+0.3]	Consistent / Neutral
		Hydro and other Renewables: Though not evident on a local scale in the short-medium term, Renewables and energy efficiency are a necessary pre-condition for limiting global climate change as deployment will aid climate change mitigation efforts, and this, in turn, can help to reduce the exposure of the world's poor to climate-related extreme events, negative health impacts, and other environmental shocks. This interaction scored +2.	Griggs *et al* 2017, Nilsson 2017, Ashukem 2020, Bisaga *et al* 2020	Medium	IEA (2040)	[-1]	Constraining
					JRC (2065)	[-0.3]	Consistent / Neutral
2: Zero Hunger	Food Security and Agricultural Productivity (2.1/ 2.2/2.3)	Fossil Fuels: Energy price (oil price) has a significant impact on food prices as agricultural food prices respond positively to any shock from oil prices. There is a linkage between energy and food security through price volatility; In the Niger Delta, environmental degradation has led to a substantial decline in local food production. This has contributed to scarcity and an astronomical increase in the price of food, placing it beyond the reach of a vast majority of the local people. This interaction scored -2.	Inoni *et al* 2006, Ojimba 2012, Ajugwo 2013, Ubani and Onyejekwe 2013, Otunkor and Ohwovorione 2015, Akubugwo *et al* 2016, Babatunde 2017, Numbere 2018, Osuagwu and Olaifa 2018, Amusa *et al* 2019, Taghizadeh-Hesary *et al* 2019	Strong	IEA (2018)	[+0.3]	Consistent / Neutral
		Hydro: A recent study on the impact of the three major hydropower plants in Nigeria showed an increase in land area and farming and grazing activities downstream. The floodplain around Kainji and Jebba reservoirs has good fertility and is extensively farmed, with soils being regularly replenished by flood waters; Nigeria has good small hydropower potential which can be harnessed to boost agricultural productivity in the local farming and fishing	Okpanefe and Owolabi 2002, Onyema 2010, Kela *et al* 2012, Olukanni and Salami 2012, Chiromo *et al* 2016, Diji 2019, Imo *et al* 2020	Medium	IEA (2040)	[-1]	Constraining

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
		communities. However, there are negative impacts on farmlands when water regulation is needed and dam reservoirs are opened causing flooding which destroys farmlands. This interaction scored +2 as there were more positive than negative interactions identified.					
		Other Renewables: If not restricted to degraded lands, large-scale global production of purpose-grown energy crops could drive up food prices and so constrain the achievement of ending hunger for the poor; The use of biomass as a renewable energy source could lead to the competition of land and water resources needed to achieve food security. Solar PV also takes up large spaces and could compete with land use for agriculture. However, affordable energy for agriculture through off-grid and decentralized systems may facilitate increases in food production, farmer revenues, and indirectly food and nutrition security. In Nigeria, losses easily exceed one-third for many crops, because of lack of energy, since practically our thermal and hydropower stations cannot provide steady and reliable electricity to the agricultural sector. This interaction scored +1 after netting negative and positive interactions.	Onyema 2010, Zhu and Cheung 2012, Ali *et al* 2016, Giwa *et al* 2017, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Mainali *et al* 2018, McCollum *et al* 2018, Adewuyi *et al* 2020, Bisaga *et al* 2020, Dal Maso *et al* 2020, Jimenez-Aceituno *et al* 2020, Sarkodie and Owusu 2020	Strong	JRC (2065)	[-0.2]	Consistent / Neutral
3: Good Health And Well Being	Disease and Mortality (3.1/3.2/3.3/3.4)	Fossil Fuels: Energy development involving non-clean energy sources creates substantial short-term health issues (e.g., from direct exposure to short-lived climate pollutants from combustion) and very large threats in the medium- to long-term (e.g., direct and indirect impacts from climate change caused by greenhouse gas emissions) Also life expectancy rates of the people of the Niger Delta were found to be lower than the country's average. This interaction was scored -2.	United Nations Environment Programme 2011, Effiong and Etowa 2012, Pitkin 2013, Adesanmi *et al* 2016, Ali *et al* 2016, Griggs *et al* 2017, Ite 2018, Adenle 2020, Dal Maso *et al* 2020, Tiba and Belaid 2020, Onabote *et al* 2021	Strong	IEA (2018)	[+1]	Enabling
		Hydro: The presence of hydro dams has been linked to increased cases of diseases (communicable and non-communicable) such as Malaria, Dysentery, Cholera, Schistosomiasis, etc. in a study of the 3 large hydro projects in Nigeria. This interaction was scored -1.	Burrows 2016, Ijeoma and Briggs 2018, Mainali *et al* 2018	Low	IEA (2040)	[-0.7]	Constraining
		Other Renewables: Access to modern energy services, including but not limited to distributed renewables, can contribute to fewer injuries and diseases related to traditional solid fuel collection and burning and the utilization of kerosene lanterns. This interaction was scored +2	Newsom 2012, Griggs *et al* 2017, Holmaa *et al* 2018, Maji *et al* 2019, Ajator *et al* 2020	Medium	JRC (2065)	[+0.3]	Consistent / Neutral
	Health Care Provision (3.7/3.8)	Fossil Fuels: The use of fossil fuels to generate electricity either centrally through the grid or decentralized systems creates the enabling environment for effective health care services. This interaction scored +1.	Griggs *et al* 2017, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Brecha 2019, Bisaga *et al* 2020	Medium	IEA (2018)	[+1]	Enabling
		Hydro: Electricity generation from hydro increases the provision and access to health services. Hydropower can provide both central and decentralized	Okpanefe and Owolabi 2002, Griggs *et al* 2017, Ijeoma and Briggs 2018, Brecha 2019	Low	IEA (2040)	[+1]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
		power for local communities depending on proximity and ease of grid extension as well as cost-effectiveness; especially as Nigeria has SHP potential that can help many rural communities gain access to electricity for health services to thrive. This interaction was scored +1.					
		Other Renewables: Access to electricity through off-grid and decentralized energy systems as provisioned by renewable energy sources facilitates better health care provision in rural communities. Preserving vaccines is reported as one of the biggest impacts brought about by access to electricity, especially considering the better reliability of mini-grids compared to the national grid. Refrigeration enables rural populations to store the medicines and vaccines necessary for ensuring community health, facilitating improved health care provision, medicine and vaccine storage, utilization of powered medical equipment, and dissemination of health-related information and education. This interaction was scored +1.	Nnaji *et al* 2010, Newsom 2012, Griggs *et al* 2017, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Ouedraogo and Schimanski 2018, Brecha 2019, Adenle 2020, Bertheau 2020, Bisaga *et al* 2020, Dal Maso *et al* 2020, Wassie and Adaramola 2021	Strong	JRC (2065)	[+1]	Enabling
	Air Pollution (3.9)	Fossil Fuels: Use contributes to pollutant emissions such as NOx, PM 2.5, PAHs and SOx, VOCs, which are air pollutants with adverse health impacts. Indoor and outdoor air pollution is strongly correlated to the SDG 3, Good health and well-being. For instance, the use of more of the derivative products of fossil fuels such as kerosene for lighting causes indoor air pollution which has been reported to kill more people than AIDS and Malaria combined (WHO, 2018). This interaction was scored -2.	Sonibare *et al* 2007, Adesanmi *et al* 2016, Ali *et al* 2016, Griggs *et al* 2017, Adenle 2020, Ajator *et al* 2020, Bertheau 2020, Dal Maso *et al* 2020	Strong	IEA (2018)	[-2]	Counteracting
		Hydro: For an analyzed hydro project, Air quality was the only improved dimension. The improved quality of air was due to the hydro-electric plant, which replaces diesel thus avoiding pollutants emissions such as NOx, SOx, etc. This interaction was scored +2	International Energy Agency 2016, Fuso Nerini *et al* 2018	Low	IEA (2040)	[-2]	Counteracting
		Other Renewables: Renewable energy sources are linked to achieving major reductions in air pollution. This target is reinforced by modern energy access and to renewable sources of energy via a reduction in indoor and outdoor air pollution. This interaction is strongest outdoors in urban areas and indoors in rural areas of rapidly developing economies like Nigeria. However, the current utilization of bioenergy via biomass burning increases gaseous air toxins just like fossil fuel combustion. Pollutants associated with combustion of biomass are NOx, CO, Volatile organic compounds (VOC), particulate matter, SO2 will increase with bioenergy contributing the largest to primary energy supply. This interaction scored -2.	Newsom 2012, Oyedepo 2012, Zhu and Cheung 2012, Akubugwo *et al* 2016, International Energy Agency 2016, Griggs *et al* 2017, Nilsson 2017, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Maji *et al* 2019, Adenle 2020, Bertheau 2020, Bisaga *et al* 2020, Dal Maso *et al* 2020, Hoeltl *et al* 2020, Tiba and Belaid 2020, Wassie and Adaramola 2021	Strong	JRC (2065)	[-1.9]	Counteracting
			Fuso Nerini *et al* 2018	Low		[+1]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
4: Quality Education	Equal Access to Educational Institutions (4.1/4.2/4.3/4.5)	Fossil Fuels: Fossil fuels contribute to more than 80% of Nigeria's electricity generation but with the insufficient and unreliable power supply, a large proportion of the rural and poor populations have no access to educational institutions which have to rely on captive generation for supply. The rural and poor cannot afford most of these institutions. With increased generation from fossil fuels, electricity access will increase with more people gaining access to educational institutions. This interaction scored +1.			IEA (2018)		
		Hydro: Small hydropower has the potential to provide decentralized energy for rural communities and the provision of electricity in these communities will support other socio-economic development such as schools, enabling retention of teachers and the ability of students to study for longer hours. This interaction scored +1.	Okpanefe and Owolabi 2002, Olukanni and Salami 2012	Low	IEA (2040)	[+1]	Enabling
		Other Renewables: Improving electricity access through off-grid or decentralized energy grids like solar technologies enables students to spend more time studying. Rural electrification is a key lever to retaining teachers in rural areas thereby enhancing the quality of rural electrification; Access to modern energy is necessary for schools to have quality lighting and thermal comfort, as well as modern information and communication technologies. This interaction scored +1.	Vladimirova and Le Blanc 2015, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Adenle 2020, Adewuyi *et al* 2020, Dal Maso *et al* 2020, Jimenez-Aceituno *et al* 2020, Tiba and Belaid 2020	Medium	JRC (2065)	[+1]	Enabling
	Human Capital (4.4/4.6/4.7)	Fossil Fuels: The Oil & Gas sector has allowed the establishment of oil and gas training institutes in Nigeria such as the petroleum training institute, institute of drilling and petroleum engineering, institute for petroleum studies with at least 16 universities offering petroleum engineering or related courses. This interaction scored +1.	*	Low	IEA (2018)	[+1]	Enabling
		Hydro: Small hydropower projects provide technical training and energy efficiency responsiveness to ensure the technology is maintained locally and sustainably. The National Agency for Science and Engineering Infrastructure, NASENI is developing capacity in the manufacture of SHP Equipment. This interaction was scored +1.	Sambo 2008, Kela *et al* 2012	Low	IEA (2040)	[+1]	Enabling
		Other Renewables: Renewable energy training institutes especially for solar energy are springing up all over Nigeria, empowering an army of young people with solar technology skills in a country where unemployment is a huge challenge. This interaction scored +1.	Zubrinich 2020	Low	JRC (2065)	[+1]	Enabling
6: Clean Water And Sanitation	Water Availability (6.1/6.2/6.4/6.5/6.6)	Fossil Fuels: Thermal cooling and resource extraction require vast amounts of water; More water is required for plants with recirculating cooling systems like Oil, coal, natural gas, and nuclear power. Globally, 15% of freshwater	Griggs *et al* 2017, Ite 2018, Mainali *et al* 2018, Mathesta *et al* 2019, Dal Maso *et al* 2020, Sarkodie and Owusu 2020	Medium	IEA (2018)	[+1]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
		withdrawal is related to energy production which is around 580 billion cubic meters/year (bcm/year). Out of this water withdrawal, 66 bcm/year is consummative and not returning to the source. This interaction was scored -2.					
		Hydropower: Expanding hydropower use could increase pressure on water resources; hydropower technologies could, if not managed properly, have counteracting effects that compound existing water-related problems in a given locale; In addition to land loss, hydro-development also had detrimental effects on drinking water supply. There was a neutral impact of the perceived problem of drinking water quality and water availability, worsened underground water quality after specific hydro project. However, Nigeria has good water resources and the impact of hydropower should be mild. This interaction scored -1.	Zhu and Cheung 2012, Vladimirova and Le Blanc 2015, Ali *et al* 2016, Griggs *et al* 2017, Olatunji 2017, Fuso Nerini *et al* 2018, Aboi *et al* 2019, Mathesta *et al* 2019	Strong	IEA (2040)	[-0.7]	Constraining
		Other Renewables: The total water withdrawal for the footprint of renewable energy sources such as solar PV and wind is significantly lower than in conventional energy production from fossil-based fuels. However, expanding biofuels use could increase pressure on water resources. In most cases, increasing the share of renewables in the energy mix would support the water targets. For example, concentrated solar power tends to be installed in locations with ample sunshine, and these areas are often the same ones under water stress. Today's water pumping, conveyance, and treatment systems require a considerable amount of energy for operation. This interaction scored +2.	Nnaji *et al* 2010, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Mainali *et al* 2018, McCollum *et al* 2018, Adenle 2020, Bertheau 2020, Jimenez-Aceituno *et al* 2020	Strong	JRC (2065)	[+0.3]	Consistent/ Neutral
	Water Quality (6.2/6.3/6.6)	Fossil Fuels: Wastewater from the energy sector releases large quantities of thermal and chemical pollution into aquatic ecosystems; Groundwater and surface water were found to be polluted in Ogoniland in Niger Delta (UNEP Env Assessment. Samples collected from wells showed hydrocarbon contamination values exceeding the Nigerian standard for drinking water of 3ug/l. This interaction was scored -2.	United Nations Environment Programme 2011, Pitkin 2013, Griggs *et al* 2017, Seiyaboh and Izah 2017, Ite 2018, Mainali *et al* 2018, Mathesta *et al* 2019, Dal Maso *et al* 2020, Sarkodie and Owusu 2020	Strong	IEA (2018)	[+1]	Enabling
		Hydro: Water quality was affected by a study carried out on hydropower in Nigeria (degradation of water quality). This interaction was scored -1.	Olatunji 2017, Aboi *et al* 2019	Low	IEA (2040)	[-0.7]	Constraining
		Other Renewables: Cleaner and affordable energy can enhance access to clean water, and sanitation. An up-scaling of renewables and energy efficiency should lead to lower levels of water pollution (chemical and thermal) than a fossil-dominant energy system. (e.g., solar pumps, sterilizers, etc.). An up-scaling of renewables and energy efficiency should lead to lower levels of water pollution (chemical and thermal) than a fossil-dominant energy	Nnaji *et al* 2010, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Ite 2018, Mainali *et al* 2018, McCollum *et al* 2018, Adenle 2020, Bertheau 2020, Jimenez-Aceituno *et al* 2020	Strong	JRC (2065)	[+0.3]	Consistent/ Neutral

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
		system. The impacts of bioenergy deployment will need to be evaluated on a case-by-case basis. This interaction was scored +2.					
8: Decent Work And Economic Growth	Employment Opportunities (8.2/8.3/ 8.5/8.6)	Fossil Fuels: The sector is providing job opportunities for many Nigerians. Employment rules in Nigeria's 2010 Oil and Gas Industry Content Development Act and related regulations are favorable for supporting employment (all junior and intermediate posts must be held by Nigerians; and, any post held by a non-Nigerian can only be held for four years maximum, after which it must be filled by a Nigerian. This interaction scored +1.	Ugwukah and Ohaja 2016, Fuso Nerini *et al* 2018, Cooper 2019, Mensah *et al* 2019, Varrella 2020	Medium	IEA (2018)	[+1]	Enabling
		Hydro: Hydropower has the potential to create jobs, improve livelihoods and open up the market in rural areas. This trend will continue to drive both small and large hydropower plants. Provision of energy access can play a critical enabling role for new productive activities and employment. This interaction scored +1.	Aliyu and Eleagba 1990, Fasipe *et al* 2017, Ebhota and Tabakov 2018, Fuso Nerini *et al* 2018, Imo *et al* 2020	Medium	IEA (2040)	[+1]	Enabling
		Other Renewables: Deploying renewables when combined with targeted monetary and fiscal policies can encourage innovation and reinforce local, regional and national industrial and employment objectives. A 2018 ILO study found that for African countries additional electricity generation from renewable sources were related to higher job creation than additional generation from fossil-fuel-based technologies (Design, manufacture, and installation of renewables and energy-efficient technologies can create conditions for new and higher-paying jobs. Solar PV has been reported to be the tech with the highest number of jobs per average MW produced considering construction, installation, manufacturing, operations, and maintenance. This interaction scored +1.	Fuso Nerini *et al* 2018, McCollum *et al* 2018, Cooper 2019, Adenle 2020, Dal Maso *et al* 2020, Jimenez-Aceituno *et al* 2020, Tiba and Belaid 2020	Medium	JRC (2065)	[+1]	Enabling
	Economic Growth (8.1/8.2/8.4)	Fossil Fuels: There's a positive relationship between fossil fuel prices and economic growth for oil-exporting countries like Nigeria. the petroleum industry accounts for about nine percent of Nigeria's GDP and over 90 percent of all export value. This interaction scored +2.	Pitkin 2013, Ugwukah and Ohaja 2016, Mensah *et al* 2019	Low	IEA (2018)	[+1.2]	Enabling
		Hydro: Hydropower has the potential to create jobs, improve livelihoods and open up the market in rural areas. Hydropower will provide electricity for industry and commerce for economic growth. This interaction was scored +1.	Aliyu and Eleagba 1990, Fasipe *et al* 2017, Ebhota and Tabakov 2018, Imo *et al* 2020	Medium	IEA (2040)	[+1.7]	Reinforcing
		Other Renewables: The main finding of the study is that renewable energy consumption has a significant positive impact on inclusive growth in Africa, particularly in African countries experiencing low levels of economic inclusive growth. This interaction scored +1.	Fuso Nerini *et al* 2018, McCollum *et al* 2018, Maji *et al* 2019, Dal Maso *et al* 2020, Jimenez-Aceituno *et al* 2020, Sarkodie and Owusu 2020, Vural 2020	Medium	JRC (2065)	[+1.4]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
10: Reduced Inequalities	Empowerment and Inclusion (10.1/ 10.2/10.3/10.4)	Fossil Fuels: Local production of fossil fuels should increase economic growth and reduce inequalities, however, Nigeria's strides in economic growth and reducing inequality are uneven across socio-economic, rural/urban, educational, and ethnic lines. This interaction scored -1.	United Nations Environment Programme 2011, Pitkin 2013, Seiyaboh and Izah 2017, Ebhota and Tabakov 2018, Aboi *et al* 2019	Medium	IEA (2018)	[+0.5]	Enabling
		Hydro: From the studies in Nigeria, there have been positive and negative impacts of large hydropower infrastructure on local host communities. Hydropower dams and irrigation schemes tend to enhance social differences and may therefore lead to social transformation and disintegration. This interaction scored 0, netting negative and positive impacts.	Adewuyi *et al* 2020, Bertheau 2020, Bisaga *et al* 2020, Dal Maso *et al* 2020, Adeyemi-Kayode *et al* 2021	Medium	IEA (2040)	[-0.3]	Consistent/ Neutral—Constraining
		Other Renewables: Provision of energy access can free up resources (e.g., financial, time savings) that can then be put towards other productive uses (e.g., educational and employment opportunities), especially for women and children in poor, rural areas. However, if costs fall disproportionately on the poor, then this could work against the promotion of social, economic, and political equality for all. It is expected that with the increase in energy generation via the inclusion of renewable energy generation, income distribution would be widespread. Decentralized renewable energy systems (e.g., home- or village-scale solar power) can enable a more participatory, democratic process for managing energy-related decisions within communities. This interaction was scored +1.	Fuso Nerini *et al* 2018, McCollum *et al* 2018, Kouton 2020, Tiba and Belaid 2020, Masron and Subramaniam 2021	Medium	JRC (2065)	[+0.1]	Consistent/ Neutral
13: Climate Action	Combatting Climate Change (All targets)	Fossil Fuels: Continuous combustion of fossil fuels is a precursor to increased global warming and inconsistent with the Paris agreement goals; Conversely, the global overreliance of energy production on the fossil fuel combustion process results in the emission of greenhouse gases, which accelerates climate change. This interaction scored -2.	Zhu and Cheung 2012, Ali *et al* 2016, Griggs *et al* 2017, Ite 2018, Mainali *et al* 2018, Mathesta *et al* 2019, Mensah *et al* 2019, Dal Maso *et al* 2020, Tiba and Belaid 2020	Strong	IEA (2018)	[+1]	Enabling
		Hydro: The reservoir created by dams become a significant source of greenhouse gas emissions, especially carbon dioxide and methane due to the microbial decomposition of the submerged forest; Reservoirs may have net positive greenhouse emissions if large areas of vegetation and trees are submerged, and studies have found that impounded water can contribute to methane emissions. This interaction scored -1.	Tremblay *et al* 2003, Ali *et al* 2016, Imo *et al* 2020	Low	IEA (2040)	[-0.7]	Constraining
		Other Renewables: The universal energy access target is fully consistent to combat climate change, as it is likely to have only a minor effect on global carbon emissions; Decarbonizing energy systems through an up-scaling of renewables and energy efficiency is a necessary but not sufficient condition	Ali *et al* 2016, Griggs *et al* 2017, Adenle 2020, Modibbo *et al* 2020	Medium	JRC (2065)	[+0.3]	Consistent/ Neutral-Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
		for combatting climate change. However, less fossil energy means lower GHG emissions. This interaction scored +2					
14: Life Below Water	Marine Protection (14.1/14.2/14.4/14.5)	Fossil Fuels: Visible hydrocarbon pollution is seen on surface waters from the proliferation of artisanal refining which is itself an outcome of complex social, economic, and security situations. Oil production in Nigeria has impacted aquatic life. Dead or dying mangroves coated with oil no longer provide a healthy habitat for fish or other aquatic life causing a catastrophic collapse of aquatic food chains and marine biodiversity. As fishing is a major livelihood activity in Ogoniland and ND in general, the destruction of mangroves will lead to a collapse of fisheries. This interaction scored -2.	United Nations Environment Programme 2011, Pitkin 2013, Ali *et al* 2016, Griggs *et al* 2017, Olatunji 2017, Seiyaboh and Izah 2017, Fuso Nerini *et al* 2018, Ite 2018	Strong	IEA (2018)	[-1.2]	Constraining
		Hydro: The impoundment of the reservoirs in large hydropower projects has led to the loss of aquatic biodiversity, wildlife habitat, and species diversity. Dam impoundments have also impacted the movement of some species leading to changes in upstream and downstream species composition of Jebba and Kainji. Dams can cause radical changes in river ecosystems both downstream and upstream. This interaction scored -1.	Zhu and Cheung 2012, Ali *et al* 2016, Chiromo *et al* 2016, Fuso Nerini *et al* 2018, Zhang *et al* 2018, Aboi *et al* 2019	Medium	IEA (2040)	[-1.7]	Counteracting
		Other Renewables: More energy infrastructure in coastal and marine areas may have negative impacts; for example, by increasing spatial competition with other uses (coastal and marine protected areas, fisheries, aquaculture, tourism especially in Nigeria). The intensive harvesting of biomass will increase soil erosion, water degradation, and the removal of nutrients. In addition, the use of pesticides and fertilizer could pollute water resources. This interaction scored -1.	Zhu and Cheung 2012, Ali *et al* 2016, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Holmaa *et al* 2018, McCollum *et al* 2018	Medium	JRC (2065)	-1.4]	Constraining
15: Life On Land	Healthy Terrestrial Ecosystems (15.1/15.2/15.4/15.5/15.8)	Fossil Fuels: Oil spillage and gas flaring have caused severe environmental damages, loss of plants, animals, and human lives, and loss of revenue to both the oil-producing companies and the government. Petroleum exploration, exploitation, production, storage, distribution, and transportation activities affect the environment in a conspicuously negative manner. Vegetations are removed to make way for seismic lines, sites for rigs are leveled, roads are built and drilling mud and oil sometimes find their way to the streams, surface waters, and land thus accidental impacts from energy production and transport activities on aquatic habitats, and marine thermal pollution from cooling at coastal power plants. This interaction scored -2.	United Nations Environment Programme 2011, Effiong and Etowa 2012, Zhu and Cheung 2012, Pitkin 2013, Ali *et al* 2016, Seiyaboh and Izah 2017, Fuso Nerini *et al* 2018, Ite 2018, Numbere 2018	Strong	IEA (2018)	[-1.2]	Constraining
		Hydro: Hydropower plants often cause irreparable damage to the surrounding environment and local communities; Land-use changes involved in extensive renewable energy production such as hydroelectric dams may conflict	Zhu and Cheung 2012, Ali *et al* 2016, Olatunji 2017, Aboi *et al* 2019, Diji 2019	Medium	IEA (2040)	[-1.7]	Counteracting

(Continued.)

SDG	Target Category	Interactions Identified for Nigeria	Supporting Literature	Evidence	Scenario	Score	Interaction
		with SDG 15. Large hydropower project requires the displacement of people residing within the flooding area. A recent study on the impact of the three major hydropower plants in Nigeria showed an increase in land area but a decrease in forestation. This interaction was scored -1.					
		Other Renewables: Biomass is the least land-efficient RE source (higher land-use footprint) and makes up the bulk of TPES in Nigeria. Solar PV also has a high land footprint, The construction of solar farms on a large-scale needs land clearing, which adversely affects the natural vegetation, wildlife, and their habitats. Wind energy also has biodiversity impacts on birds and bats species. However, ensuring access to modern energy services would reinforce the objective of halting deforestation, since firewood taken from forests is a commonly used energy resource among the poor. this interaction was scored -1.	Zhu and Cheung 2012, Ali *et al* 2016, Fuso Nerini *et al* 2018, Holmaa *et al* 2018, McCollum *et al* 2018, Ouedraogo and Schimanski 2018, Ashukem 2020, Hoeltl *et al* 2020, Sarkodie and Owusu 2020, Adeyemi-Kayode *et al* 2021, Masron and Subramaniam 2021	Strong	JRC (2065)	[-1.4]	Constraining

Appendix B. Summary of Interactions and Scores for all three energy-mix scenarios -Ethiopia

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
1: No Poverty	Poverty and Development (1.1/1.2/1.3/1.4)	Fossil Fuels: Oil is the second-largest primary energy supply in Ethiopia and contributes to fueling economic prosperity via the increase in manufacturing and industrial capacities which helps reduce poverty by uplifting the living standards of the population. Though currently imported, Ethiopia has begun the development of its oil and gas reserves. The country expects that development of its fossil fuel reserves would further spur human development. This interaction scored +2.	The World Bank 2016, Mensah *et al* 2019, Taka *et al* 2020	Low	IEA (2018)	[+1.9]	Reinforcing
		Hydro: Gilgel Gibe III hydro-project was shown to have positive impacts on the local community, including infrastructure for sustainable livelihood which contributes to poverty reduction. However, there was more evidence of negative impacts on the indigenous communities who were displaced by the existing hydro projects in the country e.g., violent resettlements of indigenous peoples living along the Omo River were carried out by the police and the military. Indigenous communities are neither informed nor consulted regarding the dam project counteracting their ability to alleviate poverty. This interaction scored -2.	Ethiopian Electric Power Corporation EEPCO 2009, Hailemariam 2011, Mishra and Kahssay 2015, Carr 2017, Schapper *et al* 2020	Medium	IEA (2040)	[+1.6]	Reinforcing
		Other Renewables: The promotion of renewables could cause price shocks and would add to the challenges of improving the standard of living for the world's poorest. However, some of the poorest parts of the world have some of the highest RE (e.g., biomass and solar power in Ethiopia), and making use of this potential help to reduce poverty; Access to modern energy forms (electricity, clean cook-stoves, high-quality lighting) is fundamental to human development as the energy services made possible help alleviate chronic and persistent poverty. This interaction scored +2	Abadi *et al* 2017, Berhanu *et al* 2017, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Mainali *et al* 2018, McCollum *et al* 2018, Bisaga *et al* 2020, Dal Maso *et al* 2020, Wassie and Adaramola 2021	Strong	JRC (2065)	[+1.7]	Reinforcing
	Rights to Natural Resources (1.4)	Fossil Fuels: By 2040, Ethiopia is expected to be self-reliant on oil and gas production and consumption. If current policy scenarios are anything to go by, there may be direct interactions between fossil fuels and access to indigenous resources. F instance, the Chinese state-owned developer is said to display a total disregard for the lives and livelihoods of communities who reside around oil extraction sites, while their poor living standards have been exacerbated by a brutal disruption in their particular way of life as nomadic communities who depend wholly on their livestock for survival. Oil exploration activities have essentially shrunk the lands that nomads rely on for grazing	Farah 2019	Low	IEA (2018)	[+0.7]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		while imposing new restrictions around the movement of animals. This interaction scored -2.					
		Hydro: Large hydro projects in Ethiopia have typically displaced indigenous landowners and communities from their resources and means of livelihoods imposing a constrain on their ability to fight poverty. This interaction scored -1.	Ethiopian Electric Power Corporation EEPCO 2009, Hailemariam 2011, Mishra and Kahssay 2015, Carr 2017, Schapper *et al* 2020	Medium	IEA (2040)	[0]	Consistent/ Neutral
		Other Renewables: The production of biofuel crops appears to have a greater negative impact on local communities' land rights, access to natural resources, and means of livelihood than the fossil fuels they are supposed to replace. However, in general, poverty analysis indicates that biofuel investment is largely pro-poor (Rural households are more beneficiaries from this investment in all scenarios poverty headcount, gap, and severity at national, rural and urban level decline). This interaction scored a net +1 from negative and positive interactions.	Friends of the Earth International 2010, Nilsson 2017, Adenle 2020, Ashukem 2020, Bisaga *et al* 2020, Masron and Subramaniam 2021	Medium	JRC (2065)	[+0.6]	Enabling
	Vulnerability to Climate-related shocks (1.5)	Fossil Fuels: The continuous combustion of fossil fuels is a precursor for climate change and the related climate-related extreme weather events, though not the only factor. Rain-fed agriculture is the mainstay of Ethiopia and the impacts of climate change on water resources have a direct impact on the vulnerable poor. This interaction scored -3 as the country is heavily dependent on agriculture.	Adejuwon 2006; AFDB; ADB; DFID; OECD; UNDP; UNEP; The World Bank 2009; Amusa *et al* 2019; Intergovernmental Panel on Climate Change 2007; Zerga and Gebeyehu 2018	Medium	IEA (2018)	[+1.5]	Enabling - Reinforcing
		Hydro and other Renewables: Though not evident on a local scale in the short-medium term, Renewables and energy efficiency are a necessary precondition for limiting global climate change as deployment will aid climate change mitigation efforts, and this, in turn, can help to reduce the exposure of the world's poor to climate-related extreme events, negative health impacts, and other environmental shocks. This interaction scored +2.	Griggs *et al* 2017, Nilsson 2017, Ashukem 2020, Bisaga *et al* 2020	Medium	IEA (2040)	[+0.6]	Enabling
					JRC (2065)	[+1.5]	Enabling - Reinforcing
2: Zero Hunger	Food Security and Agricultural Productivity (2.1/ 2.2/2.3)	Fossil Fuels: Oil exploration activities in Ethiopia have essentially shrunk the lands that nomads rely on for grazing while imposing new restrictions around the movement of animals. These s restricted areas are made up of confiscated lands that have led to a systematic pattern of forced displacements and the loss of farming and grazing land. This interaction scored -1.	Ali 2018, Farah 2019	Low	IEA (2018)	[+0.8]	Enabling
		Hydro: From Ethiopian case studies, there's a sharp increase in malnutrition throughout the region where the hydropower power projects are located, with conditions of starvation taking hold in both riverine and regional	Olana 2006, Ethiopian Electric Power Corporation EEPCO 2009, Hailemariam 2011, Olukanni and Salami 2012, Carr 2017, Schapper *et al* 2020	Medium	IEA (2040)	[+0.2]	Consistent / Neutral

(Continued.)

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		dryland plains areas; Water shortage for people and livestock, as well as famine, have become recent phenomena in this watershed. Hydro projects may therefore worsen the famine conditions. This interaction scored -1.					
		Other Renewables: If not restricted to degraded lands, large-scale global production of purpose-grown energy crops could drive up food prices and so constrain the achievement of ending hunger for the poor. The use of biomass as a renewable energy source could lead to the competition of land and water resources needed to achieve food security Solar PV also takes up large spaces and could compete with land use for agriculture, However, in general, poverty analysis indicates that biofuel investment is largely pro-poor (Rural households are more beneficiaries from this investment in all scenarios poverty headcount, gap and severity at national, rural and urban level decline). Affordable energy and improving energy efficiency for agriculture may facilitate increases in food production, farmer revenues, and indirectly food and nutrition security. A recent study that looks into the amount of land that is required to produce biodiesel for local consumption in Ethiopia also concludes that biofuel production does not constrain the supply of agricultural land. This interaction scored a net +1 from negative and positive interactions.	Lashitew 2011, Zhu and Cheung 2012, Andualem and Gessesse 2014, Ali *et al* 2016, Debela and Tamiru 2016, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Mainali *et al* 2018, McCollum *et al* 2018, Adewuyi *et al* 2020, Bisaga *et al* 2020, Dal Maso *et al* 2020, Jimenez-Aceituno *et al* 2020, Sarkodie and Owusu 2020	Strong	JRC (2065)	[+0.7]	Enabling
3: Good Health and Well Being	Disease and Mortality (3.1/3.2/3.3/3.4)	Fossil Fuels: Energy development involving non-clean energy sources creates substantial short-term health issues (e.g., from direct exposure to short-lived climate air pollutants from combustion) and very large threats in the medium- to long-term (e.g., direct and indirect impacts from climate change caused by greenhouse gas emissions). Ethiopia is currently developing its oil and gas resources and could become more exposed to these health hazards which will increase as consumption of fossil fuels increases. This interaction was scored -2.	Andualem and Gessesse 2014, Ali *et al* 2016, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Ite 2018, Adenle 2020, Dal Maso *et al* 2020, Tiba and Belaid 2020, Onabote *et al* 2021	Strong	IEA (2018)	[+1.5]	Enabling - Reinforcing
		Hydro: Electricity from hydropower had the advantage to be useable for both cooking and heating, discouraging the use of traditional solid fuels. However, from studies of hydropower projects in Ethiopia, the health status dimension was worsened. During the construction phase, there were 36 work-related deaths, while there was an increase in pandemic cases (such as HIV positivity) due to the heavy influx of people into the project areas. A major spike in disease incidence and conditions promoting widespread increases in malaria, dysentery, and other diseases, facilitated by large areas of stagnant water along the river, in canals and backup channels or pools, with a severe threat of cholera and other diseases. This interaction was scored -1.	Olana 2006, Ethiopian Electric Power Corporation EEPCO 2009, Hailemariam 2011, Carr 2017, Colombo *et al* 2018	Medium	IEA (2040)	[+0.6]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		Other Renewables: Other Renewables: Access to modern energy services, including but not limited to distributed renewables, can contribute to fewer injuries and diseases related to traditional solid fuel collection and burning and the utilization of kerosene lanterns. This interaction was scored +2	Griggs *et al* 2017, Fuso Nerini *et al* 2018, Holmaa *et al* 2018	Low	JRC (2065)	[+0.4]	Consistent/ Neutral
	Health Care Provision (3.7/3.8)	Fossil Fuels: Fossil fuel currently contributes only about 2% to the electricity mix in Ethiopia and increasing this will increase the available electricity to support health facilities generally. this may be good for Ethiopia's rural population only if the electricity grid is extended to their communities or if diesel or gasoline generators to power the health services are provided to rural communities (this is however counterproductive). The govt of Ethiopia has an integrated grid and off-grid expansion plan where rural communities too far from the grid can be electrified through decentralized diesel or hydropower systems. This interaction scored +1.	Griggs *et al* 2017, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Brecha 2019, Bisaga *et al* 2020	Medium	IEA (2018)	[+1]	Enabling
		Hydro: Electricity generation from hydro increases the provision and access to health services. Hydropower can provide both central and decentralized power for local communities depending on proximity and ease of grid extension as well as cost-effectiveness. This interaction scored +1.	Griggs *et al* 2017, Brecha 2019	Low	IEA (2040)	[+1]	Enabling
		Other Renewables: Access to electricity through off-grid and decentralized energy systems as provisioned by renewable energy sources facilitates better health care provision in rural communities. Preserving vaccines is reported as one of the biggest impacts brought about by access to electricity, especially considering the better reliability of mini-grids compared to the national grid. Refrigeration enables rural populations to store the medicines and vaccines necessary for ensuring community health, facilitating improved health care provision, medicine and vaccine storage, utilization of powered medical equipment, and dissemination of health-related information and education. This interaction was scored +1.	Griggs *et al* 2017, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Ouedraogo and Schimanski 2018, Brecha 2019, Adenle 2020, Bertheau 2020, Bisaga *et al* 2020, Dal Maso *et al* 2020, Wassie and Adaramola 2021	Strong	JRC (2065)	[+1]	Enabling
	Air Pollution (3.9)	Fossil Fuels: Use contributes to pollutant emissions such as NOx, PM 2.5, PAHs and SOx, VOCs, are air pollutants which have adverse health impacts. Indoor and outdoor air pollution is strongly correlated to the SDG 3, Good health and well-being. For instance, the use of more of the derivative products of fossil fuels such as kerosene for lighting causes indoor air pollution which has been reported to kill more people than AIDS and Malaria combined (WHO, 2018). This interaction was scored -2.	Andualem and Gessesse 2014, Ali *et al* 2016, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Adenle 2020, Bertheau 2020, Dal Maso *et al* 2020	Medium	IEA (2018)	[-1.9]	Counteracting
		Hydro: For an analyzed hydro project in Ethiopia, Air quality was the only improved dimension. The improved quality of air was due to the hydro-	Olana 2006, Ethiopian Electric Power Corporation EEPCO 2009, Hailemariam 2011, Carr 2017, Colombo *et al* 2018	Medium	IEA (2040)	[-1.6]	Counteracting

(Continued.)

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		electric plant, which replaced the diesel power plant, thus avoiding pollutants emissions such as NOx and SOx, etc. This interaction scored +2.					
		Other Renewables: Renewable energy sources are linked to achieving major reductions in air pollution. This target is reinforced by modern energy access and to renewable sources of energy via a reduction in indoor and outdoor air pollution. However, the current utilization of bioenergy via biomass burning increases gaseous air toxins just like fossil fuel combustion. Pollutants associated with combustion of biomass are NOx, CO, Volatile organic compounds (VOC), particulate matter, SO2 will increase with bioenergy contributing the largest to primary energy supply. This interaction scored -2.	Zhu and Cheung 2012, Andualem and Gessesse 2014, Abadi *et al* 2017, Griggs *et al* 2017, Nilsson 2017, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Adenle 2020, Bertheau 2020, Bisaga *et al* 2020, Dal Maso *et al* 2020, Hoeltl *et al* 2020, Tiba and Belaid 2020, Wassie and Adaramola 2021,	Strong	JRC (2065)	(-1.7)	Counteracting
4: Quality Education	Equal Access to Educational Institutions (4.1/4.2/4.3/4.5)	Fossil Fuels fossil fuel contributes only 2% to Ethiopia's electricity mix and is not likely to be a valuable, cost-effective contribution to off-grid rural electrification that could aid better educational outcomes. Most non-educated Ethiopians live in rural areas. The govt of Ethiopia has an integrated grid and off-grid expansion plan where rural communities too far from the grid can be electrified through decentralized diesel or hydropower systems. With improved access to electricity that thermal plants can provide, we can infer this may gradually enable more equitable educational access to the rural poor. This interaction scored +1.	Fuso Nerini *et al* 2018	Low	IEA (2018)	[+1]	Enabling
		Hydro: For a hydro project in Ethiopia, there was worsened performance in school enrolment in the community as youngsters dropped out of school to work during the construction of the plant. However, the electricity that hydropower enables higher school enrolments and retention of teachers in rural communities. This interaction scored 0 by netting the negative and positive interaction to give a neutral effect.	Chen 2016, Colombo *et al* 2018	Low	IEA (2040)	[+0.9]	Enabling
		Other Renewables: Improving electricity access through off-grid or decentralized energy grids like solar technologies enables students to spend more time studying. Rural electrification is a key lever to retaining teachers in rural areas thereby enhancing the quality of rural electrification; Access to modern energy is necessary for schools to have quality lighting and thermal comfort, as well as modern information and communication technologies. Access to modern lighting and energy allows for studying after sundown and frees constraints on time management that allow for higher school enrollment rates and better literacy outcomes. This interaction scored +1.	Nnaji *et al* 2010, Vladimirova and Le Blanc 2015, McCollum *et al* 2018, Adenle 2020, Adewuyi *et al* 2020, Dal Maso *et al* 2020, Tiba and Belaid 2020	Medium	JRC (2065)	+0.9]	Enabling
	Human Capital (4.4/4.6/4.7)		*	Low	IEA (2018)	[+1]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		The planned development of Fossil fuel reserves in Ethiopia could open up petroleum training institutes, etc. which would build human capital in that sector and the country generally. This interaction scored +1.					
		Hydro: For a hydro project in Ethiopia, there was a neutral effect on the project on training courses offered and worsened performance in school enrolment in the community as youngsters dropped out of school to work during the construction of the plant. it did however improve plant O&M transferred capabilities. This interaction scored 0 for a neutral effect.	Chen 2016, Colombo *et al* 2018	Low	IEA (2040)	[+0.9]	Enabling
		Other Renewables: Collaboration with the Ashegoda Wind Farm has enabled Mekelle University to add an Energy-Technology concentration to its Master's program. As of early 2016, there were thirty Ethiopian engineers and seven foreigners operating the Ashegoda Wind Farm; The off-grid solar sector offers and creates demand for vocational training and technical capacity building. This interaction scored +1.	Bertheau 2020, Bisaga *et al* 2020, Adeyemi-Kayode *et al* 2021	Low	JRC (2065)	[+0.9]	Enabling
6: Clean Water And Sanitation	Water Availability (6.1/6.2/6.4/ 6.5/6.6)	Fossil Fuels: Thermal cooling and resource extraction require vast amounts of water; More water is required for plants with recirculating cooling systems like Oil, coal, natural gas, and nuclear power. Ethiopia will need more water for its thermal plants as it develops its oil and gas reserves. This interaction scored -2.	Griggs *et al* 2017, Ite 2018, Mainali *et al* 2018, Mathesta *et al* 2019, Dal Maso *et al* 2020, Sarkodie and Owusu 2020	Medium	IEA (2018)	[+1.6]	Reinforcing
		Hydro: Expanding hydropower use could increase pressure on water resources; hydropower technologies could, if not managed properly, have counteracting effects that compound existing water-related problems in a given locale; In addition to land loss, hydro-development also had detrimental effects on drinking water supply. There was however a neutral impact on the perceived problem of drinking water quality and water availability, which worsened underground water quality after a specific hydro project. However, Ethiopia has abundant water reserves and is said to have the greatest water reserves in Africa. This interaction scored 0.	Olukanni and Salami 2012, Zhu and Cheung 2012, Vladimirova and Le Blanc 2015, Ali *et al* 2016, Griggs *et al* 2017, Colombo *et al* 2018, Fuso Nerini *et al* 2018, Mathesta *et al* 2019, Muller-Mahn and Gebreyes 2019	Strong	IEA (2040)	[+0.7]	Enabling
		Other Renewables: Other Renewables: The total water withdrawal for footprint of renewable energy sources such as solar PV and wind is significantly lower than in conventional energy production from fossil-based fuels. However, expanding biofuels use could increase pressure on water resources. In most cases, increasing the share of renewables in the energy mix would support the water targets. For example, concentrated solar power tends to be installed in locations with ample sunshine, and these areas are often the same ones under water stress. Today's water pumping, conveyance, and treatment	Griggs *et al* 2017, Fuso Nerini *et al* 2018, Mainali *et al* 2018, McCollum *et al* 2018, Alrefai and Pourmovahed 2019, Adenle 2020, Bertheau 2020, Jimenez-Aceituno *et al* 2020	Medium	JRC (2065)	[+1.5]	Enabling - Reinforcing

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SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		systems require a considerable amount of energy for operation. This interaction scored +2.					
	Water Quality (6.2/6.3/6.6)	Fossil Fuels: Wastewater from the energy sector releases large quantities of thermal and chemical pollution into aquatic ecosystems. From other oil-producing African nations, there's the potential for groundwater and surface water pollution. This interaction was scored -2.	Griggs *et al* 2017, Ite 2018, Mainali *et al* 2018, Mathesta *et al* 2019, Dal Maso *et al* 2020, Sarkodie and Owusu 2020	Medium	IEA (2018)	[+1.5]	Enabling - Reinforcing
		Hydro: Underground water quality was found to be affected by a hydro project in Ethiopia. This interaction scored -1.	Olukanni and Salami 2012)	Low	IEA (2040)	[-0.6]	Constraining
		Other renewables: Other Renewables: Cleaner and affordable energy can enhance access to clean water, and sanitation. An up-scaling of renewables and energy efficiency should lead to lower levels of water pollution (chemical and thermal) than a fossil-dominant energy system. (e.g., solar pumps, sterilizers, etc.). An up-scaling of renewables and energy efficiency should lead to lower levels of water pollution (chemical and thermal) than a fossil-dominant energy system. The impacts of bioenergy deployment will need to be evaluated on a case-by-case basis. This interaction was scored +2.	Griggs *et al* 2017, Fuso Nerini *et al* 2018, Ite 2018, Mainali *et al* 2018, McCollum *et al* 2018, Adenle 2020, Bertheau 2020, Jimenez-Aceituno *et al* 2020	Medium	JRC (2065)	[+1.4]	Enabling
8: Decent Work And Economic Growth	Employment Opportunities (8.2/8.3/8.5/8.6)	Fossil Fuels: Development of the oil and gas sector in Ethiopia will open up job opportunities for the requisite skills needed to operate the sector along the value chain from extraction, production, refining, etc. This interaction scored +2.	Andualem and Gessesse 2014, Debela and Tamiru 2016, The World Bank 2016, Fuso Nerini *et al* 2018, Mensah *et al* 2019, Taka *et al* 2020	Medium	IEA (2018)	[+1.1]	Enabling
		Hydro: From local examples in Ethiopia, the diverse processes of hydro-development have affected local communities and their livelihoods in multiple ways, most notably by changing access to land, and to a lesser degree also to water. The Fincha-Amerti-Neshe scheme forced many people to abandon their land, leave their homes, and look for other sources of income. It led to a more or less involuntary transformation of farming practices and left people with a feeling of insecurity and powerlessness. Major 'outmigration' by tens of thousands of households in response to their livelihoods collapsing in the Omo riverine and northern lake region. A hydro project had a positive impact on local direct employment and local indirect and lasting employment but a neutral impact on local non-money-based commercial activities. This interaction had a net score of +1 by netting off positive and negative interactions identified.	Degefu *et al* 2015, Colombo *et al* 2018, Fuso Nerini *et al* 2018, International Hydropower Association 2018, Muller-Mahn and Gebreyes 2019	Medium	IEA (2040)	[+1.3]	Enabling
		Other Renewables: Ethiopia has strict labor laws as companies are only allowed to bring in expatriate experts only if their expertise, knowledge, and skills are not available in the country. Solar PV, Geothermal, Wind, etc. would	McCornick *et al* 2008, Andualem and Gessesse 2014, Debela and Tamiru 2016, Berhanu *et al* 2017, McCollum *et al* 2018, Adenle 2020, Dal	Strong	JRC (2065)	[+1.1]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		therefore be good avenues for local job creation. Provision of energy access can play a critical enabling role for new productive activities, livelihoods, and employment. Reliable access to modern energy services can have an important influence on productivity and earnings; the Design, manufacture, and installation of renewables and energy-efficient technologies can create conditions for new and higher-paying jobs. Solar PV has been reported to be the tech with the highest number of jobs per average MW produced considering construction, installation, manufacturing, operations, and maintenance. This interaction scored +1	Maso *et al* 2020, Jimenez-Aceituno *et al* 2020, Tiba and Belaid 2020, Wassie and Adaramola 2021				
	Economic Growth (8.1/8.2/8.4)	Fossil Fuels: There's a negative relationship between fossil fuel prices and economic growth for oil-importing countries like Ethiopia, but the country plans to be self-reliant on oil and gas by developing the proven reserves. The oil and gas sector in Ethiopia, currently at a very early stage of development, shows good potential for development in the long-run and will contribute to the much-needed economic growth through domestic use and export revenue. This interaction scored +2.	Andualem and Gessesse 2014, Guta and Börner 2015, Debela and Tamiru 2016, The World Bank 2016, Berhanu *et al* 2017, Mensah *et al* 2019, Taka *et al* 2020	Medium	IEA (2018)	[+1.1]	Enabling
		Hydro: Hydropower-based development in Ethiopia provides a gateway to economic transformation through industrialization, urbanization, and through the provision of access to modern energy to rural areas. It is the highest contributor to the energy mix in Ethiopia. It may however have a negative local impact on host communities which are usually displaced for these projects. This interaction was scored +1.	Degefu *et al* 2015, Colombo *et al* 2018, International Hydropower Association 2018, Muller-Mahn and Gebreyes 2019	Medium	IEA (2040)	[+1.3]	Enabling
		Other Renewables: The main finding of the study is that renewable energy consumption has a significant positive impact on inclusive growth in Africa, particularly in African countries experiencing low levels of economic inclusive growth. For instance, Biofuel investment raises national GDP and factor returns which in turn increases both rural and urban households. income. This interaction scored +1.	Andualem and Gessesse 2014, Debela and Tamiru 2016, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Dal Maso *et al* 2020, Jimenez-Aceituno *et al* 2020, Sarkodie and Owusu 2020, Vural 2020	Medium	JRC (2065)	[+1.1]	Enabling
10: Reduced Inequalities	Empowerment and Inclusion (10.1/10.2/10.3/10.4)	Fossil Fuels: Local production of fossil fuels should increase economic growth and reduce inequalities, however, Ethiopia's strides in economic growth and reducing inequality are uneven across socio-economic, rural/urban, educational, and ethnic lines. Economic growth has been differentially enjoyed by well-educated, urban elites from minority ethnic groups such as the Tigray. This inequality may arise with the development of the oil and gas sector as well. This interaction scored -1.	Kuznar 2019, Kouton 2020	Low	IEA (2018)	[+0.8]	Enabling
				Medium		[+0.2]	

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SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		Hydro: Hydropower dams and irrigation schemes tend to enhance social differences and may therefore lead to social transformation and disintegration. This becomes critical when it leads to higher vulnerability of some groups as seen in Ethiopia. However, it was found that equity & inclusiveness of target area communities increased since the local electricity use broadened much more than expected. This interaction scored -1.	Carr 2017, Colombo *et al* 2018, Kuznar 2019, Gebreyes *et al* 2020, Kouton 2020, Schapper *et al* 2020		IEA (2040)		Consistent/ Neutral - Constraining
		Other Renewables: Provision of energy access can free up resources (e.g., financial, time savings) that can then be put towards other productive uses (e.g., educational and employment opportunities), especially for women and children in poor, rural areas. However, if costs fall disproportionately on the poor, then this could work against the promotion of social, economic, and political equality for all. It is expected that with the increase in energy generation via the inclusion of renewable energy generation, income distribution would be widespread. Decentralized renewable energy systems (e.g., home- or village-scale solar power) can enable a more participatory, democratic process for managing energy-related decisions within communities. This interaction was scored +1.	McCollum *et al* 2018, Kuznar 2019, Adewuyi *et al* 2020, Bertheau 2020, Dal Maso *et al* 2020, Kouton 2020, Tiba and Belaid 2020, Adeyemi-Kayode *et al* 2021, Masron and Subramaniam 2021	Strong	JRC (2065)	[+0.7]	Enabling
13: Climate Action	Combatting Climate Change (All targets)	Fossil Fuels: Continuous combustion of fossil fuels is a precursor to increased global warming and inconsistent with the Paris agreement goals; In Ethiopia, considering the technological advancement and foreign direct investments in the industrial, agricultural, and service sectors, a rising fuel mix share of 49.4% was observed (0.045 in 1990 to 0.89 in 2017). This indicated a high rate of consumption of fossil fuels in the country. The rising intensity of fuel mix was observed accompanied by rising economic growth and industrialization, indicating rapid carbonization of the local economy. This scenario is bound to increase when Ethiopia develops its oil and gas sector and increases the share in its energy mix. This interaction scored -2.	Zhu and Cheung 2012, Andualem and Gessesse 2014, Ali *et al* 2016, Chiromo *et al* 2016, Griggs *et al* 2017, Ite 2018, Mainali *et al* 2018, Mathesta *et al* 2019, Mensah *et al* 2019, Dal Maso *et al* 2020, Taka *et al* 2020, Tiba and Belaid 2020, Onabote *et al* 2021	Strong	IEA (2018)	[+1.5]	Reinforcing
		Hydro: The reservoir created by dams becomes a significant source of greenhouse gas emissions, especially carbon dioxide and methane due to the microbial decomposition of the submerged forest. However, reservoirs may have net positive greenhouse emissions if large areas of vegetation and trees are submerged, and studies have found that impounded water can contribute to methane emissions. There were improved CO2 emissions avoided seen from a hydro project in Ethiopia; Hydroelectric dams can produce significant amounts of carbon dioxide and methane, although figures vary from dam to dam. Many regions including Eastern and Southern Africa are at risk of	Tremblay *et al* 2003, McCornick *et al* 2008, Effiong and Etowa 2012, Mishra and Kahssay 2015, Ali *et al* 2016, Colombo *et al* 2018	Medium	IEA (2040)	[+0.6]	Enabling

(Continued.)

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		climate impacts on par with fossil fuels in the near-term following the development of new hydro facilities therefore caution should be used for developing hydropower in several parts of Africa if reducing climate impacts is of concern. This interaction scored -1.					
		Other Renewables: The universal energy access target is fully consistent to combat climate change, as it is likely to have only a minor effect on global carbon emissions; Decarbonizing energy systems through an up-scaling of renewables and energy efficiency is a necessary but not sufficient condition for combatting climate change. However, less fossil energy means lower GHG emissions, for instance, in a project in Ethiopia, the biogas digesters employed (4500) reduces about 1984 tonnes CO2eq of GHG emissions per year This interaction scored +2.	Andualem and Gessesse 2014, Ali *et al* 2016, Griggs *et al* 2017, Adenle 2020	Medium	JRC (2065)	[+1.4]	Enabling
14: Life Below Water	Marine Protection (14.1/14.2/ 14.4/14.5)	Fossil Fuels: When Ethiopia begins oil production, there is a tendency for an impact on aquatic ecosystems from extraction, transportation, and consumption i.e., e.g., in the Nile basin). accidental impacts from energy production and transport activities on aquatic habitats, and marine thermal pollution from cooling at coastal power plants; the availability of more fossil fuel for consumption in the country on the long term would increase the impacts. This interaction was scored -1.	Ali *et al* 2016, Griggs *et al* 2017, Fuso Nerini *et al* 2018, Ite 2018	Low	IEA (2018)	[-1]	Constraining
		Hydro: The impoundment of the reservoirs in large hydropower projects has led to the loss of aquatic biodiversity, wildlife habitat, and species diversity. Dam impoundments have also impacted the movement of some species leading to changes in upstream and downstream species composition. Dams can cause radical changes in river ecosystems both downstream and upstream. This interaction scored -1.	Olukanni and Salami 2012, Zhu and Cheung 2012, Ali *et al* 2016, Carr 2017, Fuso Nerini *et al* 2018, Zhang *et al* 2018, Schapper *et al* 2020	Medium	IEA (2040)	[-1]	Constraining
		Other Renewables: More energy infrastructure in coastal and marine areas may have negative impacts; for example, by increasing spatial competition with other uses (coastal and marine protected areas, fisheries, aquaculture, tourism especially in Nigeria). The intensive harvesting of biomass will increase soil erosion, water degradation, and the removal of nutrients. In addition, the use of pesticides and fertilizer could pollute water resources. This interaction scored -1.	Zhu and Cheung 2012, Ali *et al* 2016, Griggs *et al* 2017, Fuso Nerini *et al* 2018, McCollum *et al* 2018	Strong	JRC (2065)	[-1.1]	Constraining
15: Life On Land	Healthy Terrestrial Ecosystems (15.1/ 15.2/15.4/ 15.5/15.8)	Fossil fuels: When Ethiopia begins oil production, there is a tendency for an impact on terrestrial ecosystems from extraction, transportation, and consumption i.e., e.g., in the Nile basin). accidental impacts from energy	Zhu and Cheung 2012, Ali *et al* 2016, Fuso Nerini *et al* 2018, Ite 2018, Numbere 2018	Medium	IEA (2018)	[-1]	Constraining

(Continued.)

SDG	Target Category	Interactions Identified for Ethiopia	Supporting Literature	Evidence	Scenario	Score	Interpretation
		production and transport activities on aquatic habitats and marine thermal pollution from cooling at coastal power plants. This interaction scored -1					
		Hydro: Hydropower plants often cause irreparable damage to the surrounding environment and local communities; Land-use changes involved in extensive renewable energy production such as hydroelectric dams may conflict with SDG 15. Large hydropower project requires the displacement of people residing within the flooding area, as well as the change of natural habitats for animals and vegetation. The submerged area containing houses, heritage landmarks, burial grounds, crops, and ancestral land are destroyed causing socioeconomic hardship leading to the loss of ancestral lands and forests where they have been living independently and on which they have been relying for their agriculture, hunting, and gathering of forest products. This interaction was scored -2 for Ethiopia with potential for large and medium hydropower potential versus smaller hydropower with less environmental impacts.	Zhu and Cheung 2012, Ali *et al* 2016, Chen 2016, Carr 2017, Colombo *et al* 2018, Schapper *et al* 2020, Zwaan *et al* 2018, 70,72	Strong	IEA (2040)	[-1.1]	Constraining
		Other Renewables: Biomass is the least land-efficient RE source (higher land-use footprint), and makes up the bulk of TPES in Ethiopia. Solar PV also has a high land footprint; The construction of solar farms on a large-scale needs land clearing, which adversely affects the natural vegetation, wildlife, and their habitats. Wind energy also has biodiversity impacts on birds and bats species. However, ensuring access to modern energy services would reinforce the objective of halting deforestation, since firewood taken from forests is a commonly used energy resource among the poor. this interaction was scored -1.	Zhu and Cheung 2012, Ali *et al* 2016, Chen 2016, Fuso Nerini *et al* 2018, McCollum *et al* 2018, Ouedraogo and Schimanski 2018, Ashukem 2020, Hoeltl *et al* 2020, Sarkodie and Owusu 2020, Tesfahunegny *et al* 2020, Adeyemi-Kayode *et al* 2021, Masron and Subramaniam 2021	Strong	JRC (2065)	[-1.1]	Constraining

ORCID iDs

Ruseh Elohor Oghenekaro https://orcid.org/0000-0001-9628-4607
Shashi Kant https://orcid.org/0000-0001-7012-4306

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