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Prospects for the Transitioning of Industries towards Deep Decarbonization: Implications for Nigeria's Industrial Sector

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Abstract
A global effort in climate action is towards strategies for decarbonizing the energy-intensive industries for a low-carbon industrial sector. The present work sets to answer the question by conducting a systematic literature review (SLR) of the Nigerian industrial sector intertwined with some countries having similar economic conditions and industrial structures. The SLR identified cement, iron and steel, and chemicals (CIandSCM) as the major emissions culprits in the industry, with an estimated 55.69 % of total emissions in the industry. Additionally, emissions drivers were observed to stem from the direct energy consumption concerning electricity generation from fossil fuels, and processes involving CIandSCM. However, the SLR submits that limited work has been devoted to decarbonization strategies of the industrial sector in Africa. Central to this, studies on long-term scenario modelling, which gives quantitative insight into low carbon development pathways in the Nigerian industrial space are absent. The review identified low carbon technologies with respect to direct energy use (green power generation), novel industrial processes involving CIandSCM, and a scenario modelling framework that will support robust long-term modelling efforts to provide high fidelity quantitative data to equip policymakers to provide long term energy plan for Nigeria's industrial sector. It is hoped that the findings will facilitate the building and integration of the identified emissions drivers and mitigation technologies in a long-term modelling platform. It is expected that the modelling platform would drive economic growth while achieving the net-zero pledge of the Federal Government of Nigeria.

Keywords: *Industrial, Emissions, Pathways, Decarbonization*

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1. Introduction

Energy remains one of the crucial indicators for economic growth and is linked to numerous industrial applications which require a vast amount of energy in the form of electricity, industrial processes, and heat with resultant emissions (Salman et al., 2019; Ahmad and Zhao, 2018). Several forms of pollution, including greenhouse gases (GHG), come from the industrial sector. Nevertheless, the industrial sector remains one active domain for both developed and developing nations due to its huge positive economic benefits while contributing to large GHG emissions. Among the three largest economies of the world between 2015 and 2019, the industrial sector accounts for about 23 and 19.1 % of emissions and gross domestic product (GDP) in the US (USEPA, 2019; TWFB, 2022), 84 and 40.5 % in China (NBSC, 2016; TWFB, 2022), 36 and 30.1 % in Japan (Kiko network, 2008; TWFB, 2022) in that order. In Nigeria, the statistics show that the country's share of industrial emissions was 16 % in 2018 (DCC, 2021), while the GDP ranged from 14.16 and 33.34 % between 1988 and 2018 (NBS, 2018) (Fig. 1).

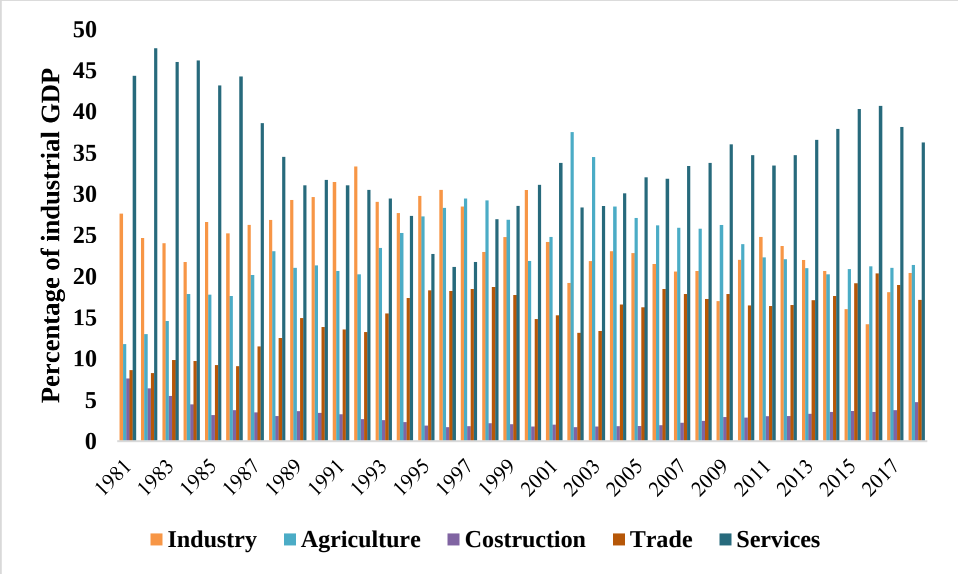

Fig. 1: Nigeria's GDP sectorial contributions from 1981 to 2018 (Source: Nigeria Bureau of Statistics, 2018)

These large emissions from the sector (6230 million tons of CO_{2eq} from direct energy use and 3156 million tons of CO_{2eq} from industrial processes) are directly related to energy requirements linked to the fuel types mostly fossil-based (IPCC, 1995) and numerous industrial processes that continue to pollute the environment. Coal, natural gas, diesel and liquefied petroleum gas (LPG) are some of the main fuels used in the world's energy-intensive industries (IPCC, 1995). Realistically, efforts towards curbing emissions and reducing global rising temperatures are being structured through decarbonization action plans in many countries (Tovilla and Buira, 2017; Shukla et al., 2015; Altieri et al., 2015). To avoid major negative ecosystem alteration, world governments, through the Paris Agreement (PA), have agreed to limit global temperature rise (UNFCCC, 2015). Besides, all scenarios from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), both 2 °C and 1.5 °C targets will require reaching net zero emissions of CO_2-eq by around 2050, with projection of risk in the near-term (2021–2040), the mid (2041–2060) and long term (2081–2100), at different global warming levels and for pathways that overshoot 1.5°C global warming level for multiple decades(IPCC, 2018; IPCC, 2022). Another effort is the Conference of the Parties (COP) which reviews and monitors the implementation of the United Nations Framework Convention on Climate Change (UNFCCC) within its 197 member nations (UNFCCC, 2020).

Similar efforts are being proposed in the interim for emissions reduction in the industrial (Liu et al., 2021; Huang and Wu, 2021), transport (Tovilla and Buira, 2017; Karkatsoulis et al., 2017; Balcombe et al., 2019), oil and gas (Charabi et al., 2018; Shojaeddini et al., 2019), agriculture, forestry and land use (AFOLU) (Hamilton and Kelly, 2017; Hewson et al, 2019), power (de Lira Quaresma et al., 2018; Sanni, 2018; Breyer et al., 2021), and residential (Xing et al., 2021; Dioha, 2018; Shi et al., 2016; Zhang et al., 2020) sectors using various scenario approaches, pathways and technologies with the aid of state-of-the-art algorithms. Although there exist technologies and policy solutions for low carbon national transition and rapid climate action that is affordable by many developed nations (IPCC, 2018). However, effective measures for policy implementation are still lacking (IPCC, 2018; Fazey et al., 2018). The dominant approaches have not generated action near the rate, scale or depth needed to avoid potentially catastrophic futures, despite many years of climate negotiations under the UNFCCC, and wide-ranging actions at national and sub-national levels (UNFCCC, 2020). These approaches have, so far, focused on the external world of wider socio-economic structures, governance dynamics, economic incentives, and technology (Mundaca et al., 2019).

Given Nigeria's obligation to the UNFCCC to align with recent global efforts to reduce emissions, both in the short and long term, to achieve sustainable economic growth, it is required to systematically scale up the creation of scenarios for the design and implementation of pathways for a net zero economy. Achieving a net zero economy would entail the deep decarbonization of critical sectors like the industrial sector. One strong incentive to deep decarbonize Nigeria would be the consideration of the efforts to decarbonize the industrial sector. Therefore, this paper aims to highlight current literature efforts in curbing emissions and the implications for Nigeria's industrial sector with respect to the modelling and development of scenarios to decarbonize its industry. The objectives are to determine (1) what long-term strategies the industrial sector will take to ensure deep decarbonization while achieving sustainable development; (2) what energy transition technologies are locally and economically feasible in the Nigerian industrial space for ambitious deep decarbonization without interference with economic growth; and (3) what economic investments are required in decarbonizing the Nigerian industrial sector.

2. Materials and methods

2.1 The PRISMA framework and literature resource

The literature survey was done in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The PRISMA methodology provides syntheses of the state of knowledge in a field, from which future research priorities can be identified. It can address questions that individual studies could not answer; and identify problems in primary research that should be rectified in future studies (Page *et al.,* 2020). The methodology adopted includes the formulation of research questions to guide the review. This was then subjected to a research string that captured the research questions keywords. The Web of Science and Scopus were then used as the literature resource for selecting suitable research journals within the identification, screening, and eligibility categorization. Thereafter, the literature was identified, screened, and selected based on the selection criteria in section 2.1.1.

2.1.1 Literature eligibility and inclusion criteria

Web of Science and Scopus were used for the selection of the materials. The research string and detailed selection criterion are shown in Tables 1 and 2, respectively. A total of 7231 journals were obtained from the Web of Science. Similarly, 4000 journals were obtained from Scopus, while 4 were from the public repository. The journals were screened based on duplicates, territory, title and abstract to obtain 426. Thereafter, with respect to scenario-based modelling, decarbonization and emissions decoupling and decomposition, the literature review was narrowed to 30 journals.

2.2 Literature summary

Within the domain of the industrial sector, the literature covered other industrial subsectors. These include cement, iron and steel, petroleum and coal exploitation, chemicals, fabrication and mechanical devices manufacture and tourism. Six (6) studies were based in Nigeria, covering households, industry, transport, commercial, service and agriculture all lumped together (Dioha et al., 2019; Emodi et al., 2017; Nobert, 2018; Onyije et al. 2018; Akpan, 2015; Elum and Mjimba 2016), while twelve (12) studies were based in China (Guo et al., 2021; Sun et al., 2021; Wei and Dajian, 2012; Yu et al., 2015; Liu et al., 2021; Wang and Chen, 2019; Wang et al., 2020; Tang et al., 2020; Lin and Long, 2016; Xie et al., 2016; Hu and Zhang, 2015; Xu et al., 2016). Three (3) studies were based in Sweden (Obrist et al., 2021; Ahman et al., 2017; Toktarova et al., 2020), one in Ukraine (Shatokha, 2016).), and one (1) each in Qatar (Kazi et al., 2021), Malaysia (Shaharudin and Fernando, 2015), United States (Hasanbeigi et al., 2019), Taiwan (Huang and Wu, 2021) and Indonesia (Dewi et al., 2019), with emphasis on iron and steel and cement industries. Others are one each in Mexico (Birlain et al., 2018), Morocco (Choukri et al., 2017), and Lithuania (Gaigalis and Skema, 2015). The methodologies employed were bottom-up modelling using LEAP (Liu et al., 2021; Emodi et al., 2017; Birlain et al., 2018), TIMES (Obrist, et al., 2021; Wang and Chen, 2019), the logarithmic mean divisia index (LMDI) (Sun et al., 2021; Wei and Dajian, 2012; Lin and Long, 2016; Xie et al., 2016), and other methods (Guo et al., 2021; Yu, B., Li, X., Yu et al. 2015; Huang and Wu, 2021; Hasanbeigi et al., 2019; Dewi et al., 2019; Kazi et al.,2021; Michel et al., 2021; Dioha et al., 2019; Wang et al., 2020; Tang et al., 2020; Hu and Zhang, 2015). The literature summary is shown in Fig. 2, while the percentage distribution of the literature based on methodologies adopted is shown in Fig. 3.

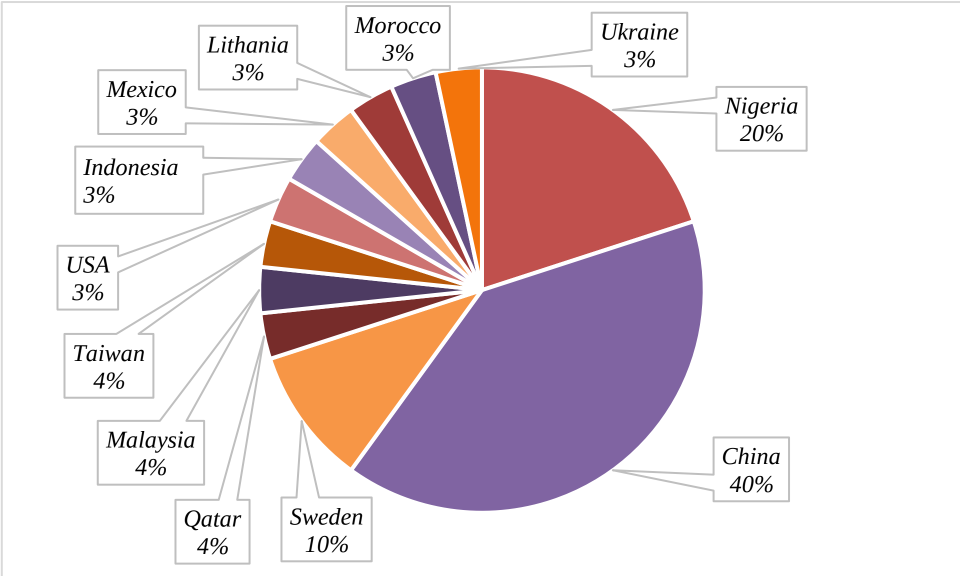

Fig. 2: Summary of surveyed literature by country

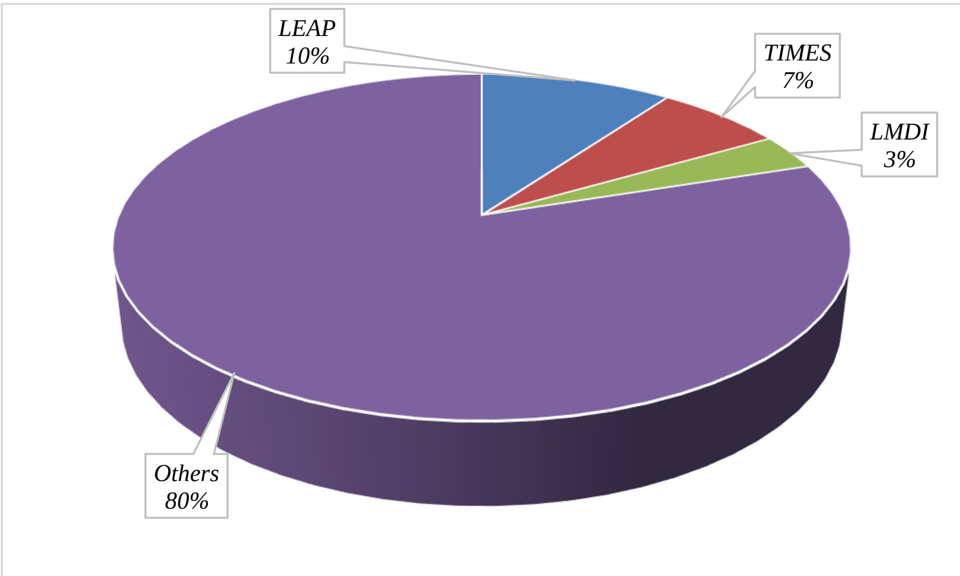

Fig. 3: Summary of literature based on the adopted methodology

Table 1: Summary of literature for the review

Study	Modelling approach				Software				SCN	Industrial Subsector							
	SM	DCM	DCP	OTH	LEAP	TIMES	LT/TM	OTHS		CM	IandS	PCFM	MAN	CHM	TOU	PREF	OTHS
Guo et al., (2012)				x				X									x
Sun et al., (2012)		x						X			x						
Wei and Dajian, (2012)		x						X									x
Akpan, (2015)				x				X									x
Yu et al., (2015)				x				X			x						x
Ahman et al., (2017)				x				X									x
Huang and Wu (2021)	X							X	x	x							
Liu et al, (2021)	X				x				x						x		
Obrist et al. (2021)	X					x	X		x	x							
Hasanbeigi et al. (2019)				x				X		x							
Dewi et al, (2019)				x				X			x						
Wang and Chen, (2019)	X					x											x
Nobert, (2018)				x				X					x				
Onyije et al., 2018				x				X								x	
Kazi et al., (2021)				x				X									x
Dioha et al., (2019)				x				X									x
Emodi et al., (2017)	X				x				x								x
Birlain et al., 2018	X				x				x					x			
Choukri et al., (2017)				x				X									x
Toktarova et al, (2020)	X							X	x		x						
Wang et al, (2020)		x						X			x						
Gaigalis and Skema, (2015)				x				X									x
Tang et al, (2020)		x						X									x
Xu et al, (2016)	X							X	x	x							
Elum and Mjimba, (2016)				x				X									x
Shatokha, (2016)				x				X	x		x						
Lin and Long, (2016)		x						X						x			
Xie et al., (2016)		x						X	x			x				x	
Shaharudin and Fernando, (2015)				x				X					x				
Hu and Zhang, (2015)				x				X									x

SM: Scenario modelling; DCM: Decomposition; DCP: Decoupling; OTH: Others; LT/TM: LEAP/TIMES; CM: Cement; IandS: Iron and Steel; PCFM: Petrol, chemical, fabrication and manufacturing; MAN: Manufacturing; CHM: Chemical; TOU: Tourism; PREF: Petroleum refining; SCN: Scenarios.

3. Results and discussion

3.1 Industrial emissions contribution

The industrial sector is strongly linked with emissions from energy use by burning fossil fuels and several industrial processes. In Nigeria, for example, the industrial sector contributed up to 16 % of GHG emissions in 2018 out of the 336 million tons of CO_{2eq} (DCC, 2021). However, due to low economic development, Nigeria's greenhouse (GHG) emissions remain relatively low in major sectors such as agriculture, electricity, forestry, industry, oil and gas, transport, and waste (NDC 2021). With this emission level, Nigeria compares well with South Africa in terms of emitting less than 1 % of global emissions. Nevertheless, its economy is expected to grow rapidly by at least 7% per annum, particularly in the post COVID-19 period, to meet the demands of its large population that is projected to increase to about 402 million by 2050.

Globally, the industrial sector contributes about 19 % of emissions, with 6230 million tons of CO_{2eq} from direct energy use and 3156 million tons of CO_{2eq} from industrial processes. It is the second highest sector in emissions after the power sector, which has up to 31 % of global emissions (WRI, 2017; IEA, 2018). In 2014, global industrial emissions were 9,386 million tons of CO_{2eq}, with 63.38 % of these from energy-related consumption while 33.62 % were from industrial processes (see Fig. 4). Furthermore, within the subsectors of the industry, iron and steel, chemical and plastics, and cement production accounted for 55.69 % of the emissions (Fig. 5). Accordingly, 48.4 % of the literature on industrial decarbonization was on these subsectors. Generally, emissions from the iron and steel industry account for 5 % of the global emissions, whereas they are responsible for more than 11% in China (Xu 2009). Of these, 95% of China's iron and steel industry emissions is caused by fossil fuel combustion (Zhang et al., 2010). In Taiwan, the industrial sector accounted for 34% of the total energy consumption and produced 49 % of the total emissions (Huang and Wu, 2021). In Sweden, Obrist et al. (2021) reported that cement production accounts for 36 % (2.5 Mt) of the CO_2 emissions in the Swiss industrial sector in 2015. Other industrial emissions contributions were reported as 8.2 $MtCO_2$ in 2017 in the US for cement production (Hasanbeigi et al., 2021), 11.25 million tons of CO_{2eq} or 9.17% of the total industrial emissions in iron and steel for Indonesia (Dewi et al., 2019). In Nigeria, industrial emissions are up to 16 % of total emissions and are projected to reach 29 % in 2040 without deploying technologies and policies for deep decarbonization (Emodi et al., 2017).

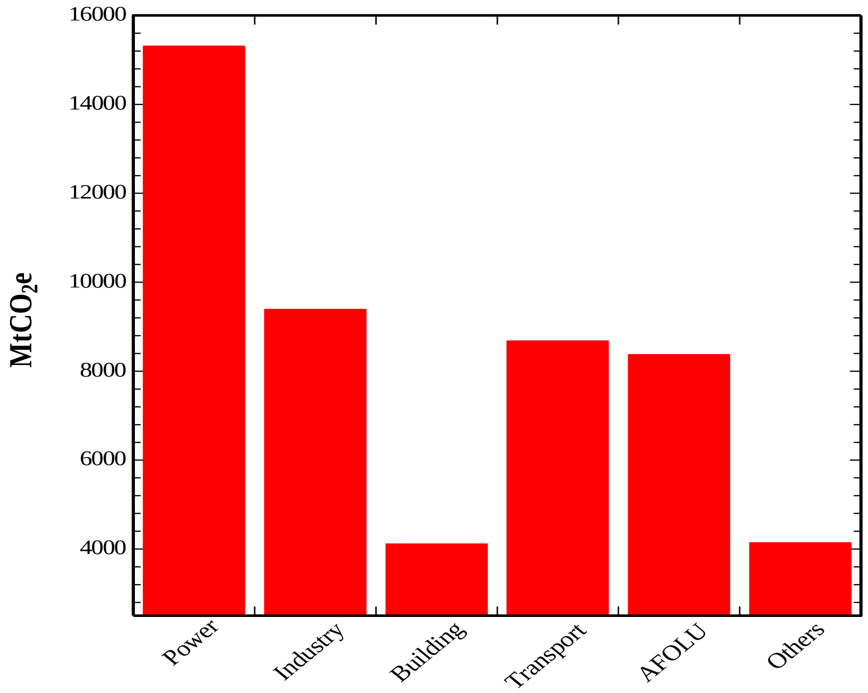

Fig. 4: Global GHG emissions by sectors in 2014 (Source: WRI, 2017; IEA, 2018)

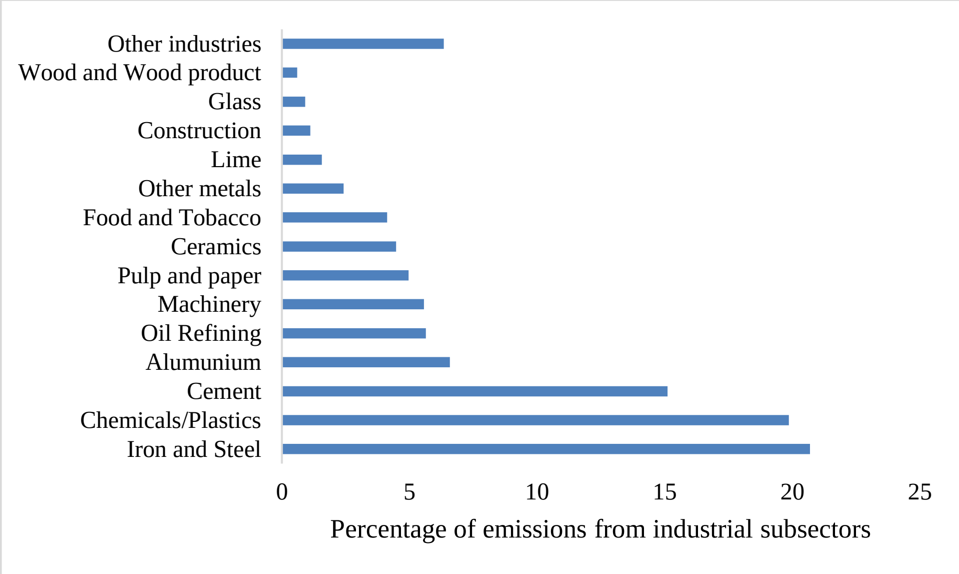

Fig. 5: Share of global GHG emissions within industrial subsectors in 2014 (Source: WRI, 2017; IEA, 2018)

3.2 Drivers of emissions

Emission drivers in the industrial sector are direct energy use and industrial processes. Quantification of emissions industrial drivers is done using the IPCC method (IPCC, 1995), where 17 types of fuels, including raw coal, washed clean coal, coke, coke oven gas, other gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, LPG, natural gas, other petroleum products, other coking products, electricity and heat were identified as basic industrial fuels. These are then aggregated using the emission factors of the listed fuels when they are directly quantifiable. However, this method only relates the emissions with fuel types used without reference to other indicators like the output in the form of GDP, energy intensity, and industrial structure, amongst others. Accordingly, drivers of emissions in the industry, in addition to fuel type identification, are also related to numerous factors, including emission factor, energy mix, energy intensity, industry structure, economic output factor, and several other factors where index decomposition analysis (Ang and Zhang, 2000) is used to track the relative contributions on emissions from these factors (Sun et al. 2012; Wei and Dajian, 2012; Wang et al. 2020; Lin and Long, 2016). In the iron and steel industrial subsectors, emission factors of the different energy sources, energy structure, and energy consumption per unit of steel production were identified as the main factors influencing the energy-related carbon dioxide emissions and are linked to various fuels including coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas, and electricity (Sun et al. 2012). Labour force, labour mobility, gross labour productivity, energy intensity, fuel mix, and emission coefficients are also identified as industrial emission drivers (Wei and Dajian, 2012), where the relative contribution of these factors can be decomposed using the logarithmic mean divisia index (LMDI), factor decomposition and Kaya's identity (Ang et al., 1998; Sun, 2003). Industrial processes in cement making, iron and steel, and chemical manufacturing are some of the other industrial emission drivers (Rissman, 2018; WSA, 2019) that are not directly measurable but can be estimated with the magnitude of emissions reduction over time. For Nigeria, scenario modelling involving storylines for industrial deep decarbonization can be modelled as a function of these emissions drivers using real data from Nigerian industries. Hence, the findings can be useful to the deep decarbonization pathways project or other decarbonization efforts in Nigeria.

3.4 Emission reduction options

a. Technology

The survey indicates that industrial emissions reduction comprises technologies related to green electricity generation and low emission-based industrial processes across all the industry subsectors. Due to the energy intensity and associated emissions from iron and steel, cement, chemicals and oil refining, 48.4 % of the surveyed literature on industrial decarbonization was focused on these subsectors, while the remaining were on other industrial subsectors. Emission reduction technologies for industrial processes are reported specifically for iron and steel, cement, chemicals and oil refining (Sun et al. 2012; Yu et al. 2015; Huang and Wu, 2021; Obrist et al., 2021; Hasanbeigi, et al. 2019; Dewi et al., 2019; Wang and Chen, 2019; Michel et al. 2021; Toktarova 2020; Xu et al. 2016; Lin et al., 2016). Whereas, massive electrification using low emitting fuel sources and technologies was identified as decarbonization options for direct energy-related processes for these top three subsectors and others. In the cement industry, Huang et al. (2021) proposed replacing older rotary kilns with new technologies (e.g. fluidized-bed advanced cement kiln systems) to obtain energy savings, thereby reducing emissions. Alternative fuels and clinker substitution (i.e. replacing clinker with SCMs in cement or in concrete), carbon capture utilization and storage are also tipped to make the largest contribution to CO_2 emissions reduction in the cement industry in the long term, and fuel switching. Energy efficiency technologies for power production is also required to provide additional emissions abatement (Obrist et al., 2021; Hasanbeigi, et al., 2019). In addition to carbon capture and clinker substitution, efficient kilns and precalciners, low-pressure drop cyclones, replacement of ball mills with vertical roller mills and the deployment of high-efficiency classifiers for finishing grinding are also proposed for emission reduction in cement making (Michel et al., 2021). In the iron and steel subsector, Sun et al. (2012) proposed energy conservation technologies in the form of coke dry quenching (CDQ), top-pressure recovery turbine (TRT), high temperature air combustion (HTAC), and the establishment of an energy management center (EMC) as alternatives for emissions reduction. Increased use of scrap, the penetration of low-carbon technologies (not indicated explicitly), and substitution of fossil fuels to low emission fuels are also needed for reduced emissions in the iron and steel industrial subsector (Dewi et al., 2019).

Furthermore, top gas recycling blast furnace (TGRBF), carbon capture and storage, substitution of pulverized coal injection (PCI) with biomass, steel-making process with hydrogen direct reduction of iron ore (H-DR) and an electric arc furnace (EAF); as well as a secondary steel production route with EAF, where fossil fuels are replaced with biomass, are other emissions reducing technologies proposed for the iron and steel industrial subsector (Toktarova et al., 2020).

Energy related technologies for power generation are also needed to reduce industrial emissions up to 63.38 % deduced from historical energy related industrial emissions (WRI, 2017; IEA, 2018). When applied, these technologies will also have a huge impact on decarbonization by nearly 90 % in other sectors (like building and power) that are directly dependent on electricity. This is because burning fossil fuel in thermal power plants contribute 69.34 % of global electricity generation (Dev and Attri, 2015). Therefore, preliminary but potent measures for emissions reduction in the industry and related sectors will require developing and deploying net zero emission technologies for power generation. Within the industrial sector, technologies for emissions reduction proposed in electricity generation include application of alternative waste-derived fuel sources and the installation of carbon capture and utilization systems (Huang et al., 2021; Hasanbeigi, et al., 2019). Also proposed is the implementation of regional cogeneration projects, which would substitute the cogeneration unit for small heating boilers (Lin and Long, 2016). Others are the massive use of solar and wind plants for electricity generation and bio-energy with ethanol alcohol, gasoline, hydrogen and dimethyl ether as realistic representatives (Guo et al. 2012). While hydrogen is a good energy carrier for net-zero electricity generation, it is challenging and expensive to store (Davis et al., 2018). Additionally, the production of hydrogen results in massive GHG emissions with high-cost implications. For instance, hydrogen production from fossil fuels globally amounts to 830 Mt of CO_2 equivalent annually (International Energy Agency, 2019), which is equivalent to 2.47 times Nigeria's total emissions in 2018 (LTV, 2050).

b. Policy and economics of reduction options

Appropriate, realistic and implementable policies within socio-economic structures and governance dynamics are needed for the implementation of the technologies needed for deep industrial decarbonization. However, most of the policies for industrial decarbonization are tilted towards direct energy generation technologies with few on industrial processes. For instance, a survey on the most important policies that should be implemented for effective industrial decarbonization favours carbon pricing, energy efficiency standards per unit product, government procurement of low-carbon materials and products, and financial incentives for the use or production of low-carbon materials. Others are a subsidy for the use of alternative fuels and renewable energy; CCS mandates or/and incentives (Riss et al., 2020).

Other alternative policies include using bio-energy for power generation, with the leading representatives of ethanol alcohol, gasoline and dimethyl ether, increasing investment in wind power projects and solar energy and wind (Guo et al. 2012). In China, ethanol alcohol gasoline is projected to provide 6 million jobs and 6 billion US dollars in income in the industrial sector, with 10 % reduction in oil imports (Guo et al. 2012). In the iron and steel industrial subsector, promoting metallurgical energy supply toward low-carbon energy sources such as renewable energy and decreasing the share of coal and coke used to decrease the carbon emissions from iron and steel manufacturing have been suggested as implementable policies for consideration (Sun et al. 2012).

Further policy measures include the highlighting of technological expenditure and upgrading, especially with respect to technologies having key impacts on carbon emission reduction, making it a major driver for obtaining emissions targets in the industrial sector (Yu et al., 2015). These policies are proposed within the surveyed materials, and some may not be realistic options in other lands. However, the proposed technologies can facilitate the formulation of local policies within the Nigerian context that can integrate industrial emissions reduction technologies, strategies and pathways.

4. Summary of findings on industrial decarbonization strategies

4.1 Technology

Net zero industrial decarbonization in the long term has the potential to cut global emissions by 18.8 % (percentage of current industrial emissions share) with the deployment of technologies and industrial processes, especially for the cement, iron and steel, chemicals and oil refining industrial subsectors. The surveyed literature shows that industrial emissions are from industrial processes (mostly in cement production, iron and steel, and oil refining), and energy-related consumption in the form of electricity obtained from fossil fuel burning. Additionally, the sector contributes about 19 % of emissions, with 6230MtCO_{2eq} from direct energy use and 3156MtCO_{2eq} from industrial processes. In cement making, fluidized-bed and advanced cement kiln systems are proposed technology options in place of rotary kilns to obtain energy savings, thereby reducing emissions. Alternative fuels and clinker substitution, carbon capture utilization and storage are also tipped to make the largest contribution to CO_2 emissions reduction in the cement industry and fuel switching.

In iron and steel, carbon capture and storage, the substitution of pulverized coal injection with biomass, steelmaking process with hydrogen, direct reduction of iron ore and a secondary steel production route are the potential technology pathways to decarbonize the steelmaking process. Other alternative policies include using bio-energy for power generation, with the leading representatives of hydrogen, ethanol and dimethyl ether. Increasing investment in wind power projects and solar energy as well as utilization of geothermal sources for power generation are also suggested.

4.2 Policy

Several policy measures for curbing transportation emissions are country specific due to its level of technology and infrastructure. Among the many proposed policies for industrial decarbonization include the establishment of energy efficiency standards per unit product, procurement of low-carbon materials and products, carbon capture mandates, and carbon capture incentives. Nigeria may not be able to adopt all measures in the interim. The use of alternative fuels like biodiesel will bring more hardship on Nigerian industries due to perceived scarcity. However, the use and adoption of low sulphur fuel is practical in the country with its current level of industrial infrastructure. The fossil fuel products used in Nigeria contain nearly 100 times the sulphur level permissible in Europe. The government can adopt a fuel emission policy to limit fuel-sulphur-content to 50 ppm for both diesel and petrol.

4.3 Modelling pathways

The studies on industrial decarbonization modelling are centred on energy intensity reduction as a function of production paths and fuel consumption. This method involves the bottom-up aggregation of industrial indicators using flexible modelling tools. In the review, LEAP and TIMES were mostly used for industrial bottom-up modelling as they allow flexibility in constructing energy flows in line with available data that best represent emissions trends.

However, these modelling approach offered in LEAP and TIMES do not offer some provision in aggregating several other emission indicators not directly related to energy intensity in the industry. Additionally, decomposition modelling techniques including LMDI, factor decomposition, and the general index decomposition analysis method are also used to formulate the relationship between emissions and several other driving variables. The decomposition methods can establish several other energy intensities with respect to GDP and labour force, structure of energy consumption, economic structure, amongst others and then disaggregate the relative effect of these drivers on emissions. However, unlike bottom-up modelling platforms, it is not efficient in projecting future energy demand and related emissions, and it is not flexible in accommodating several emissions reduction scenarios.

5. Conclusion

Decarbonizing the industrial sector is inevitably central to achieving climate balance in line with both short- and long-term targets of keeping global temperature rise below 2 ºC. Globally, efforts are made in terms of climate action towards strategies for decarbonising energy-intensive industries. With Nigeria's commitment to decarbonize its economy, and with no existing systematic study for this need, it is pertinent to gain insight into the emission drivers and decarbonization pathways for the Nigerian industrial sector. The present work performed a systematic literature review of the Nigerian industrial sector intertwined with some countries having similar economic conditions and industrial structures. A review of the drivers of industrial emissions, available low emissions technologies for different industrial processes at subsectoral level, and realistic and achievable policies with economic implications for industrial decarbonization pathways formulation were identified. The industrial sector is strongly linked with emissions from energy use by burning fossil fuel and several industrial processes. Within the subsectors in the industry, iron and steel, chemical and plastics, as well as cement production accounted for 55.69 % of the emissions. Thus, a robust industrial decarbonization approach will involve these three subsectors. Furthermore, emissions drivers were observed to stem from direct energy consumption with regard to electricity generation from fossil fuel, and processes involving CI and SCM. Low carbon technologies with respect to direct energy use (i.e. green power generation), and novel industrial processes involving CI and SCM are identified as effective means to decarbonize the industry. It is hoped that the findings will facilitate the building and integration of identified industrial emissions drivers and technologies in the construction of models and scenarios of how Nigeria can realize long-term economic growth while achieving ambitious greenhouse gas emission reduction in the industrial sector.

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