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STRATEGIC ASSESSMENT OF TECHNOLOGICAL CAPABILITIES FOR SUSTAINABLE BIOFUELS DEVELOPMENT IN NIGERIA

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ABSTRACT
The inadequate implementation of Nigeria's Biofuel Policy (2007) necessitated this strategic assessment as an input to policy reforms. The analysis entailed examining Nigeria's biofuel Research and Development (R&D) capabilities, assessing the capabilities for sustainable biofuels development, appraising the limitations to Nigeria's Biofuel Researchers' abilities, and analyzing the technological constraints to sustainable biofuels development in the country. Using questionnaire administration, data were obtained from 500 researchers in the Faculties of Agriculture, Science and Engineering/Technology, and Departments of Training & Research of 15 purposively selected National Research Institutions (ten Universities and five Research Institutes). A technology foresight and strategic-analysis methodology was used for analysis. The results showed that 54.2% of the respondents had academic/research qualifications critical to biofuel development; 28.4% had continuous research activities in the area, while only 7.4 % indicated actual research outputs in biofuel development. Capability assessment for biofuel development showed Current Performance and Future Potentials to be Low (4.57 and 3.68 respectively). The main capability in the national biofuels innovation process was determined to be Pure Research. The two major limitations to biofuel researchers' abilities were 'Lack of government funding for research' and 'Absence of Research and Development facilities (Experimental/Analytical equipment)' (both rated Very High, 9.6). The three major technological constraints to biofuel development were Limited technical entrepreneurial capabilities, Low capital and weak technical knowhow on the biofuel production process (Very High: 8.7, 8.6 and 8.6 respectively). In conclusion, the study determined technological capabilities for sustainable biofuels development in Nigeria to be weak. The study recommends developing strategies that strengthen systems for improved research, technological development, production and business development such as improved access to appropriate financial, economic and commercial mechanisms for improved R&D activities and improved professional advisory services

Key words: strategic analysis, biofuel development, Research and Development, technological capabilities, biofuel policy.

1.0 INTRODUCTION

Biofuels are a form of renewable energy made available from materials derived from biological sources. Although they may exist in the form of gas (biogas) or solid (wood), the dominant form is liquid, with the two most common types in use today being ethanol and biodiesel. There has also been increasing interests in algae-based and cellulosic-based resources. Global biofuels production is being driven by growing concerns of world energy security, the challenges of climate-change mitigation, and changes in global oil prices. The production of biofuels has implications for energy, environment, agriculture, industry, development and trade. Biofuels are argued to offer countries opportunities to reduce dependence on imported oil, curb greenhouse gas emissions, and enable employment and wealth-creating opportunities in the domestic agricultural sector.

The transport sector, consequent to its increasing use of fossil fuels and the resulting energy security, pricing and carbon emissions concerns, is the major driver of the global biofuels market. The transport sector uses biofuels in pure form or blended with petrol, diesel or aviation fuels. Apart from use in the transport sector, biofuels are also used in electricity generation, production of domestic and industrial heating, cleaning oil spills and grease, cooking, lubrication, removing paint and adhesives, and energy generation and reduction (EIA, 2020).

Many countries have enacted policies to integrate biofuels into their domestic energy mix and expanded their domestic policy initiatives beyond just liquid biofuels to include broader concepts of bioenergy and developing robust bio-economies (i.e. developing biomass products such as gaseous, liquid and solid energy products as well as adding food, feed and fibre outputs) (OECD/FAO, 2016). The global market for biofuels is growing, albeit still represents less than 1 per cent of global energy usage (OECD/FAO, 2016, OECD/FAO, 2018; Modor Intelligence, 2019). The global biofuel market, valued at USD 168 billion in 2016 is expected to reach USD 218.7 billion in 2022 and USD 230.5 billion by 2025 (OECD/FAO, 2016, OECD/FAO, 2018; Modor Intelligence, 2019; marketresearchfuture.com. 2020). Countries and regions in the forefront of biofuels production and utilization are the United States, Brazil, and the EU (OECD/FAO, 2016, OECD/FAO, 2018; Modor Intelligence, 2019). While these markets dominate the global biofuel market, trade and technology transfer have bolstered market developments in numerous developing countries in Asia such as India, China and Malaysia, and now in Africa like Mozambique and Nigeria (UNCTAD, 2014; Popoola *et. al.*, 2015; Araújo *et al.*, 2017; OECD/FAO, 2018). Nigeria has long been touted to have the potential to become the largest biofuel market in Africa ((NNPC, 2007; Ogundari *et. al.*, 2012; Ogundari, 2014; Tuggar, 2018; Verla *et al.*, 2020).

Nigeria, an oil-rich country and the world's 13th largest oil producer at slightly less than 2 million barrels per day in 2019 (EIA, 2019), quite naturally depends on oil to drive its economy and petroleum fuels to be its single largest source of commercial energy (EIA, 2020). Five sectors of the economy – household, industry, transport, agriculture, and services – are responsible for Nigeria's huge consumption of oil estimated to be 316,000 barrels per day as at 2015 (Olaopa *et al.,* 2018; IEA, 2020). Nigeria, in response to the strategic, economic and sustainability implications of national and international oil consumption, had developed policy and plans for integrating the biofuel option as suitable energy innovation in the national energy mix – specifically, the national Biofuel Development Programme (BDP) of 2005 and the Nigerian Biofuel Policy and Incentives (2007) (NNPC, 2007; Ogundari *et al.*, 2012, Ogundari, 2014; Tuggar, 2018; Verla *et al.*, 2020). The BDP and biofuel policy entailed integrating the national energy and agricultural sectors for a sustainable domestic biofuel industry targeting 10% bioethanol substitution in petrol (Premium Motor Spirit or PMS) and 20% biodiesel substitution in diesel (Automotive Gas Oil or AGO) (NNPC, 2007).

The biofuel industry was expected to take-off in 2007, promoting cleaner energy consumption, stimulating industrial activities and employment, and enabling rural economic development (Tuggar, 2018). A three-step strategy to realize this biofuels industry entailed:
Step 1 – planning the industry, with specific actions such as carrying out economic, social, environmental and regulatory analyses, elucidating the financial approach and partnership

strategies, specifying the implementation plan, and finally planning the Ethanol import program (Timeframe: 2005 – 2007);

Step 2 – building industry foundations, with activities including developing the growth model for the industry, adapting the regulatory environment, expanding infrastructural ability to supply Ethanol, and developing customer acceptance for bioethanol (Timeframe: 2007 – 2009); and

Step 3 – growing the industry and its activities involved replicating and continuously improving the growth model for the industry (Timeframe: 2009).

The Biofuel Policy and Incentives (2007) designated the biofuel industry sector as a pioneer sector, which would provide the basis for a package of tailored fiscal incentives, for example total tax, tariff and VAT exemption for 10 years. It supported the creation of a national Biofuel Energy Commission to govern the industry in relationship with established ministries and agencies and the creation of a Biofuels Research Agency to coordinate and promote the long-term development of improved varieties, techniques and processes across existing Agencies, amongst other recommendations. Fifteen years after the Biofuels Development Programme was established, however, the policy has not been successfully implemented and national bioethanol potentials have not been effectively developed.

The experience of the industrialised countries highlights that long-run national economic growth and development reflects sustained increases in national capabilities in strategic technologies and industries consequent to continuous accumulation of technological capabilities and robust strategic analyses (Aw and Batra, 1998; Wignaraja, 2001; Biggs *et al.*, 2001, Noland and Pack, 2002). For developing countries like Nigeria, Ogbimi (2007) has argued that the actualisation of science policy initiatives and the achievement of sustainable economic growth and industrialisation are dependent on national capabilities in Science, Technology, Research and Development (R&D) and Innovation.

In the industrialised countries, the demand for reliable energy supply for economic growth and development, and the realisation of the huge potentials of biofuels for energy savings as well as employment and wealth creation, has prompted their governments and corporate organisations to categorize the biofuels industry as a strategic industry and heavily invest in it. In these countries, the effective development and implementation of the policies and programmes for the exploitation of biofuels have been attributed to their robust national capabilities in the biofuel sector (OECD/FAO, 2018).

In Nigeria, national biofuel policy objectives – to establish a sustainable domestic biofuel industry and facilitate energy security, integrated rural development, employment and wealth creation, as well as national economic transformation – have not been achieved and national biofuel potentials have not been effectively developed. Limited public capabilities to institute and/or maintain the strong institutions, infrastructure, policies and plans required for sustainable biofuel development undermine these efforts (FMST, 2012; Ogundari *et al.*, 2012; Ogundari, 2014). Furthermore, the policy and planning environment surrounding national biofuels development has become more complex under new national economic and technological performance targets under the extant Economic Recovery and Growth Plan (ERGP).

The recent efforts by the Federal Government of Nigeria to revamp the national biofuel sector have met with limited success. This may be due to limited understanding of Nigeria's national capabilities' status for biofuels development (Ogundari 2014; Akarakiri 2017; Adedeji, 2019). Furthermore, public and private biofuels development projects have been initiated in several States in Nigeria based on their perceived benefits and the counsel of foreign development advisors and like the Federal Government initiatives, these efforts have had limited success (Akarakiri, 2017; Adedeji, 2019). In developing the national biofuels industry, it is imperative to investigate the strengths and weaknesses of the Nation's technological capabilities especially with respect to the critical indicators like research and industrial manpower, available resources, innovation and ideas generation, product marketing/advocacy capabilities, operations, and investment. In Nigeria today, there is a dearth of information in these areas as research work on biofuel production in Nigeria tends to focus on its scientific, technical, legal, and political or public opinion dimensions without determining the level of national capability for its sustainable development (Adedeji, 2019). To fill this gap, this study attempts a critical assessment of the national capabilities for biofuels development in Nigeria. This assessment is expected to provide strategic intelligence for the biofuel policy and planning initiatives in Nigeria.

This critical assessment would entail examining Nigeria's biofuel Research and Development (R&D) capabilities, assessing the capabilities for sustainable biofuels development, appraising the limitations to Nigeria's Biofuel Researchers' abilities, and analyzing the technological constraints to sustainable biofuels development in the country.

2.0. National Capabilities for Sustainable Biofuels Development: A Conceptual Perspective

Sustainable biofuels are a strategic technological innovation in the replacement of fossil energy with environmentally-friendly, and economically-viable energy sources. Biofuels are technologies as they are seen as the knowledge and resources needed to achieve a goal (Wright, 2008); the scientific and engineering knowledge that can be applied to the design of new products (Kevin, 2010); the knowledge embedded in products and processes, and the knowledge of creating, producing, reproducing, and using these products and processes (Mumford, 2010); and the body of knowledge and skills available to a society that is used to solve specific societal challenges – in this case the mitigation of problems associated with the use of fossil energy (Postman, 1993; Borgmann, 2006; Ogbimi, 2007; Ogundari *et al.*, 2012).

Policy makers and development specialists in a country need to understand the level of knowledge and expertise of a particular strategic technology within and outside their country, not only for national development planning, but as an integral component of national-security considerations (Guston, 2000; Borgmann, 2006). The understanding of national capabilities in strategic technologies incorporates technology capability assessment and strategic analysis techniques.

The term Technological capability (TC) has been identified to be a critical component of industrial development in a firm (or nation), and refers to those activities which enable firms (or nations) to choose and use technology, and translate them into product and process innovations, to create competitive advantage. These capabilities also enable core competencies to be developed in industry for the actualisation of strategic national development (Wignaraja, 2001; Kim and Nelson, 2000; Siyanbola, 2012; Ogundari and Ogundari, 2019). TC is also seen as the capacity to gain an overview of the technological components on the market, assess their value, select the appropriate specific technology, use it, adapt it and improve on it where necessary to create a new technology. Technological capability incorporates the additional and distinct resources needed to generate and manage technical change; including skills, knowledge, experience, institutional structures and linkages, as well as the efficient use of machinery, equipment and technologies (Lall, 1994; Bell and Pavitt, 2003). TC is the prerequisite for independent national economic and technological developments, as well as successful technology transfer (World Bank, 2001; Industrial Development Report (IDR), 2002; Ogundari and Ogundari, 2019). In fact, technological capabilities are at the centre of the new theories of economic growth which focus on technology and human capital as engines of growth (Stokey 1988; Young, 1991; Ogbimi, 2007; Siyanbola, 2012).

In a firm (or country), the strategic decision-making, and the strategic management process itself, for the successful development and deployment of technological and industrial capabilities, is based on the understanding and prediction of the internal and external environment of the technological and industrial activities, and relies heavily on the strategic analytical phase (Papula and Papulova, 2015).

3.0. Methodology

The study was carried out across the six geopolitical zones of Nigeria. The Ministries of Science and Technology, Agriculture, and National Planning as well as several Academic and Research Institutions (ARIs) across the country comprised the population for the study. Specifically, 15 national ARIs (ten Universities and five Research Institutes) were purposively selected. The five first-generation Universities were selected because of national spread, as well as depth and quality of their staff, their research and their academic programmes. The other universities were selected based on the five highest-ranked public universities other than those of the first-generation, as determined by the National Universities Commission (NUC) University ranking for 2018. These 10 Universities are the University of Ibadan, Ibadan; Ahmadu Bello University, Zaria; University of Nigeria, Nsukka; Obafemi Awolowo University, Ile Ife; University of Lagos, Lagos; University of Ilorin, Ilorin; University of Benin, Benin; University of Maiduguri, Maiduguri; Ladoke Akintola University of Technology, Ogbomosho; and Enugu State University of Technology, Enugu. The five Research Institutes were those with national recognition in energy planning and biotechnology research, namely, the National Research Institute for Chemical Technology (NARICT), Zaria; the Centre for Energy Research and Development (CERD), OAU, Ile-Ife; Energy Commission of Nigeria (ECN), Abuja; National Centre for Technology Management (NACETEM), Ile-Ife; and National Biotechnology Development Agency (NABDA), Abuja.

In each university, the Faculties of Agriculture, Science and Technology/Engineering were purposively selected. One set of questionnaire was administered to 45 randomly selected researchers across the faculties in each University, and 10 randomly selected researchers in each Research Institute sampled. The preferred rank of researchers was from Research Fellow II/Lecturer II to Research Professor/Professor in the Universities and Senior Research Officer to Director of Research in the Research Institutes. These ranks were preferred as they represent the ranks for active research in their respective institutions. A total of 500 respondents were thus administered the questionnaire in the first phase.

The second phase comprised 142 researchers who indicated continuous research activities in Bioenergy Development. This was because they were considered to be at the vantage position to give the sought-after expert opinion on the peculiarities influencing the development of the Bioenergy sector in Nigeria. Information elicited from these respondents included limitations to R&D activities, technological constraints to biofuel industry development, and so on. Other information obtained included strategic assessment indicators like the capabilities of scientific personnel, assessment of research funding, resources availability and adequacy, as well as Innovation and Ideas capabilities.

A second set of questionnaire was administered on 20 purposively selected technological capability assessment specialists from the Ministry of Science and Technology, and the National Planning Commission. Information obtained from these specialists were the variables or input factors evaluated in a strategic assessment under the PRIMO-F technique. These variables are People, Resources, Innovations/Ideas, Marketing, Operations and Finance.

For the People factor, the specific parameters examined were A – University Researchers, B – Engineers, and C – Industrial Scientists
For the Resources Availability factor, the specific parameters were D – Feedstock, E – Land, and F – Water;
For the Innovation/Ideas factor, the specific parameters were G – New Thinking, H – Process Innovation, and I – Product Innovation.
For the Marketing factor, the specific parameters were J – Domestic Marketing, and K – International Marketing.
For the Operations factor, the specific parameters were L – Feedstock Production, and M – Biofuel Processing.
For the Finance factor, the specific parameters were N – Government funding, and O – Private sector funding.

Secondary data on the PRIMO-F components were obtained from records and publications of appropriate organizations like the National Universities Commission (NUC), the Council for the Regulation of Engineering in Nigeria (COREN), the Federal Ministries of Science and Technology, Finance, Agriculture and Rural Development and Investment, Trade and Industries. The data obtained were analysed using appropriate descriptive statistics and the modified strategic analysis (PRIMO-F) technique.

3.1. The modified strategic analysis (PRIMO-F) technique

In planning, developing and implementing STI projects, it is imperative to know the capability status of an organization/institution to achieve its objectives (Armstrong and Harman, 1980; Porter, 1995; Akarakiri, 2009). In organizations/institutions, a strategic analysis technique like a Strength, Weakness, Opportunities & Threats (SWOT) analysis is used to identify priorities and areas for improvement, and determine their capability status (RapidBI, 2010; Morrison, 2013). The SWOT analysis is made up of two internal elements (Strengths – S, and Weaknesses – W) and two external elements (Opportunities – O, and Threats – T). The **PRIMO-F** model provides the structure for the analysis of the internal elements (SW) (RapidBI, 2010; Morrison, 2013), and these elements are **P**eople **(P)**, **R**esources **(R)**, **I**nnovation & **I**deas **(I)**, **M**arketing **(M)**, **O**perations **(O)** and **F**inance **(F)**.

PRIMO-F is a valuable strategic tool that allows a detailed analysis of business performance in three key areas, and the mapping out of future growth potential. The principle underlying PRIMO-F is: for a business to grow, it must be organized for effective growth. This organizational capacity is linked to two performance criteria – how a business is currently performing, and how available infrastructure equips the business for future expansion. A verdict is achieved by using the following formula:
Organisational Growth Effectiveness = Current Performance (MOF) x Future Potential (PRI)
Current performance (performance to date) is assessed by looking at the Marketing, Operations, and Finance components. The future potential looks at the People, Resources, Innovation and Ideas. Under the heading ‘People’, the model assesses the experience and capacity of staff. This includes experience managing growth and development, leadership levels, staff morale, general

experience, and level of educational qualifications. Resources include tangible items such as cash reserves and physical assets, as well as less tangible qualities like the desirability of the products and services, strategic location, business processes like IT infrastructure, planning procedures, and data control. Innovation and Ideas express the willingness to embrace new opportunities, their responsiveness to changing marketing conditions, and their ability to diversify their services over time.

PRIMO-F rates an industry for each of these factors on a Likert-like scale of 1 to 10 (with 1 as the lowest capability rate and 10 as the highest), identifying the positive and negative factors, and ranking each in terms of development priority. Average and overall capability ratings are determined by weighted average (RapidBI, 2010; Morrison, 2013). Nigeria's capability assessment for sustainable biofuels development was assessed using this modified strategic analysis (PRIMO-F) technique. This assessment rated the national internal factors (People, Resource Availability, Innovations and Ideas, Marketing, Operations and Finance) for sustainable biofuels development and showed their rankings.

Caveat:
The assessment of the current performance (to date) of Nigeria's biofuel industry cannot be readily carried out, because there is no measurable biofuel industry in the country. Consequently, variables to analyse the specific Marketing, Operations and private-sector Finance components do not exist.

This paper, in recognizing these limitations, adopted a modification of the PRIMO-F technique. This modification took into cognizance that although the identified Current Performance components were unavailable with respect to the biofuel industry, they were readily available in the national economy at large. What would most likely occur therefore would be a movement of these capabilities into the biofuel industry.

4.0. Results

This section presented the results of the analyses carried out.

4.1. Researchers with specialisations in biofuel development or fields closely related to biofuel development

Table 1 reveals the respondents (and their institutional affiliations) whose academic and research qualifications are in fields central to – or closely related to – the development of sustainable biofuels. These fields encompass Agriculture, Engineering/Technology, and the Sciences (Biological and Physical).

Table 2 provides the information that slightly more than half (54.2%) of the 500 respondents are in this category. The Table reveals a high number of the researchers have PhDs (41% of the 500 respondents). This is significant (almost 75.7% of the actual 271 respondents who indicated academic qualifications critical to biofuel development have PhDs), because it indicates that Nigeria has a huge potential to stimulate a domestic biofuel industry with her large pool of highly skilled researchers in her tertiary education system. The Table also indicates that the Universities in the country should be the drivers of Biofuel R&D for Industry as there are almost 18 times more PhDs in Biofuel Development fields in the Universities as compared to the Research Institutes. The normal takeaway from this table is that the Universities in Nigeria's tertiary educational system should be in the forefront of actualizing the National Biofuel Industry aspirations.

Table 3 however may cause any policy maker to have a re-think. The Table presents analysis of the respondents with continuous research activity in Biofuel Development, and the results are quite alarming. Only 28.4% of the 500 respondents indicated continuous research activity central to, or related to, Biofuel R&D over a 5-year period prior to the study. These research activities included feedstock analysis, growth and production; landmass characterization, adequacy and fertility analysis; food security considerations on feedstock production; industrial and environmental consequences of feedstock and biofuel production. Others are feedstock-to-biofuel conversion processes and their consequences; catalyst production; biofuel industrial process calculations; project planning of biofuel production; and waste management and public health considerations of the production of biofuels, amongst others.

Table 4 is critical to biofuel policy development. The Table presents analysis of the respondents with actual research outputs specific to Biofuel Development over the last five years.

Table 1: Fields of Academic/Research Qualifications closely related to Biofuels Development

S/N	Fields of Academic/Research Qualifications	University	RI
	Agriculture		
	Plant Science/Crop Science/Crop Protection and Production	10	2
	Agricultural Economics & Farm management	10	0
	Soil Science and Land Resources Management	10	1
	Agronomy/Agronomy and Ecological management	10	0
	Engineering/Technology		
	Agricultural/Bioresources/Environmental Engineering	12	1
	Industrial Engineering	12	1
	Mechanical Engineering	12	1
	Materials Science and Engineering	12	0
	Environmental Studies/Environmental Technology Studies	11	0
	Systems Engineering	11	0
	Transport Management Technology	11	1
	Technology Management/Project Management Technology	12	1
	Biotechnology	12	1
	Chemical Engineering	12	2
	Sciences		
	Public and Allied Health	8	0
	Chemical & Environmental Sciences	15	0
	Biological Sciences	15	0
	Biochemistry/Applied Biochemistry/Environmental Toxicology	15	1
	Chemistry (Pure/Analytical/Applied/Environmental)	16	1
	Botany/Phytochemistry	13	1
	Microbiology/Applied Microbiology/ Virology	16	2
	TOTAL	**255**	**16**

Table 2: Institutional Affiliations and Academic Qualifications of Respondents with Specialisations in or closely related to Bioenergy Development

	F	% of Total Respondents
Universities		
PhD	194	38.8
MSc	61	12.2
Total	255	51
Research Institutes		
PhD	11	2.2
MSc	5	1.0
Total	16	3.2

Table 3: Institutional Affiliations and Academic Qualifications of Respondents with Continuous Research Activity in Biofuel Development

	F	% of Total Respondents
Universities		
PhD	77	15.4
MSc	55	10.9
Total	132	26.3
Research Institutes		
PhD	6	1.3
MSc	4	0.8
Total	10	2.1

Only 7.4% of the 500 respondents indicated actual research outputs specific to Biofuel Development as determined by journal publications, conference paper presentations and patents.

This is indicative of a low pool of expertise for Biofuel research and development amongst the select leading Universities and Research Institutes in Nigeria. The quantity and quality of educated people (human capital) in a country have long been considered a critical input to sustainable economic growth and industrialisation (Ogbimi, 2007). Consequently, having a low human capital pool may be considered inimical to achieving sustainable industrialisation in any country. Based on this argument, having a low pool of researchers involved in consistent biofuel R&D may not be able to create the critical mass of manpower and expertise required to achieve maturity level in biofuel production in Nigeria. As a critical element of the National Innovation System, this limited Biofuel R&D pool could be contributory to Nigeria's inability to jump-start its Biofuel Industry aspirations over 15 years in spite of high public expectations.

Table 4: Institutional Affiliations and Academic Qualifications of Respondents with Actual Research Outputs in Biofuel Development

	F	% of Total Respondents
Universities		
PhD	23	4.6
MSc	8	1.6
Total	31	6.2
Research Institutes		
PhD	5	1.0
MSc	1	0.2
Total	6	1.2

Tables 5 and 6 respectively reveal the actual research outputs in biofuel development and the actual biofuel development research outputs by academic and research disciplines. The examination of the actual biofuel development research outputs revealed that research journal articles and conference papers together constituted 98.6% of total research outputs (44.5% for journal articles and 54.1% for conference papers), while patents constituted only 1.4%. This could infer that patent filings by University and RI researchers in the Nigerian biofuels sector is severely limited. This result is in tandem with the assertion by Ogundari (2014) that biofuel researchers in Nigeria focus more on scientific publications of their research output over the filing of patents. Furthermore. it underscores the penchant for biofuel researchers in Nigeria to focus on scientific investigations of biofuel development rather than on the development of inventions for industry. Spulber (2014) had pointed out that patents were a critical component of industrialisation and national economic growth; hence the emphasis on journal publications and conference presentations, and the limitation in patent filings by University and RI biofuel researchers may stifle the growth of the national biofuel industry.

The academic and research disciplines with the highest research outputs were Agricultural Engineering and Chemical Engineering with 13.88% of total research outputs each. Next to them were Plant Science (10.53% of total research outputs), Chemistry (10.05% of total research outputs), Microbiology (8.13%), Mechanical Engineering (7.18%), and Chemical & Environmental Science/Environmental Studies (5.26% each). These academic/research disciplines conform to Ogundari (2014) who noted that biofuel R&D in Nigeria was focused on publications in the areas of biofuel characterization and synthesis from different indigenous plants. The findings furthermore conform to (Yaoyang and Boeing, 2013) who noted that the common subject categories for biofuel R&D globally were Chemical Engineering, Agricultural Engineering, Environmental Sciences and Biosciences and applied microbiology.

Table 5: Actual Research Outputs in Biofuel Development

	F	% of Total Respondents
Universities		
Journal Articles	76	36.4
Conferences	80	38.3
Patents	3	1.4
Total	159	76.1
Research Institutes		
Journal Articles	17	8.1
Conferences	33	15.8
Patents	0	0
Total	50	23.9

Table 6: Actual Research Outputs in Biofuel Development by Specific Academic/Research Disciplines

S/N	Academic /Research Disciplines	Publications	Conferences	Patents	Total	Percentage
1	Plant Science	6	16	0	22	10.53
2	Soil Science	3	3	0	6	2.87
3	Agronomy	2	2	0	4	1.91
4	Agric Engineering	13	15	1	29	13.88
5	Industrial Engineering	2	4	0	6	2.87
6	Mech Engineering	5	8	0	15	7.18
7	Materials Engineering	4	2	0	6	2.87
8	Environmental Studies	4	7	0	11	5.26
9	Technology Mgt	6	4	0	10	4.78
10	Biotechnology	3	3	0	6	2.87
11	Chemical Engineering	15	13	1	29	13.88
12	Public/Allied Health	1	1	0	2	0.96
13	Chemical & Envr. Sc	6	5	0	11	5.26
14	Biological Sciences	3	4	0	7	3.35
15	Biochemistry	3	4	0	7	3.35
16	Chemistry	10	11	0	21	10.05
17	Botany/Phytochemistry	1	3	0	4	1.91
18	Microbiology	6	10	1	17	8.13
	Total	**93**	**113**	**3**	**209**	**100**

4.2. Capabilities assessment of the innovation process for biofuels production of biofuels in Nigeria

Table 7 provides evidence that the main capabilities in the national biofuels innovation process are in the multiple features of Pure Research (Mean rating = 8.3; Modal rating = 7), which is rated High. Capabilities in Technological Development (Mean rating = 4.6; Modal rating = 3) are rated greater than Low but less than Moderate; while a crucial part of the Innovation Process, Production

(Mean rating = 1.3; Modal rating = 1) is rated Low. Marketing capabilities (Mean rating = 1.1; Modal rating = 1) is also rated Low.

The high capabilities for Pure Research and low capabilities in the other components of the Biofuel Innovation process may indicate that higher attention is being paid to the Science of biofuel production in Universities and Research Institutes in the country and limited competences in the technical institutions like Faculties of Technologies, Universities of Technology, Polytechnics, and Colleges of Technology. This, as pointed out by Ogbimi (2007), is a clear indication of an underdeveloped, primitive or artisan economy.

Table 7: Capability Assessment of the Innovation Process for the Industrial Production of Biofuels in Nigeria

S/N	Factors	Mean Rating	Modal Rating
1	Pure Research (idea generation and scientific, technological, socio-economic research)	8.3	7
2	Technological Development (laboratory output and prototype development)	4.6	3
3	Production	1.3	1
4	Marketing	1.1	1

*(**On a Scale of 1 – 10 where 1 is lowest Rate and 10 highest Rate)**

Rate: Very Low – 1, 2; Low – 3, 4; Moderate – 5, 6 ; High – 7, 8; Very High – 9, 10

4.3. Nigeria's sustainable biofuels development capabilities

Table 8 shows the capability assessment for sustainable biofuels development in Nigeria. The table not only shows the ratings of each PRIMO-F component, but also shows the ratings of specified subsets of each component. The table shows that the Marketing component was adjudged to have the highest average rate of 9.2 out of 10, with the Resources component coming next with average rate of 6.3. The other components, in declining average rates, were People (3.4), Finance (2.7), Innovations/Ideas (2.4), and Operations (1.8). The results infer that Nigeria has very high and Moderate capabilities in the marketing and resources components respectively to develop a domestic sustainable biofuels industry, but have low capabilities in people components, and very low capabilities in the innovations and ideas, operations and finance components. The determination of current performance of the sector (the average of the sums of the ratings for the marketing, operations and finance components) reveal a rating of 4.57 which is below the benchmark for Moderate capabilities. the future potential of the sector (determined by average of the sums for the People, Resources Availability, and Innovations/Ideas components) give a score of 3.68, which falls in the Low Capabilities division. The overall national Capability rating is 4.01 which is considered to be Low.

The results from this section should be a matter of critical concern to the Nigerian Government. The results, especially the findings that the national Current Performance and Future Potential capabilities are in the Low category, infer that the government aspirations on biofuels development in Nigeria may not be achievable in the near future and that there may be a need to review the national biofuel policy direction.

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Table 7: Capability Assessment for Sustainable Biofuels Development in Nigeria

	People (5)			**Resources (2)**			**Innovation/ Ideas (3)**			**Marketing (2)**		**Operations (2)**		**Finance (2)**	
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**
Average Rate (1 is lowest and 10 is highest)	3.4	2.2	4.7	5.3	7.4	6.1	3.2	1.4	2.6	9.3	9.1	2.4	1.2	3.6	1.8
Average Rate		3.4			6.3			2.4		9.2		1.8		2.7	
Current Performance (M, O, F)					-							4.57			
Future Potential (P, R, I)					3.68							-			
Overall Capability Rating									4.01						

Legend:

People	**Resources Availability**	**Innovation/Ideas**	**Marketing**	**Operations**	**Finance**
A – University Researchers	D – Feedstock	G – New Thinking	J – Domestic Marketing	L – Feedstock Production	N – Government funding
B – Engineers	E – Land	H – Process Innovation	K – International Marketing	M – Biofuel Processing	O – Private Sector funding
C – Industrial Scientists	F – Water	I – Product Innovation			

Rate: Very Low – 1, 2   Low – 3, 4   Moderate – 5, 6   High – 7, 8   Very High – 9, 1

4.4. Limitations to Nigeria's biofuel researchers' abilities

In spite of the perceived high capabilities in Pure Research as determined in the previous section, researchers reported multiple limitations to their abilities to carry out research into Biofuel Development. Table 9 presents the mean ratings of eight identified limitations, with 'Lack of government funding for research' and 'Absence of Research and Development facilities (Experimental/Analytical equipment)' identified as the two most important limitations (Mean rating 9.6). Other key limitations were 'Obsolete facilities' with mean rating of 9.4, and 'Inadequate supply of electricity' with mean rating of 8.6. All the identified limitations are rated from Moderate to Very High with the researchers considering the lack of quality research assistants to be only a Moderate limitation (Mean Rating = 6.4).

The lack of government funding for research in biofuel development has been a major hindrance to the development of the industry (Ogundari, 2014; Adedeji, 2019). In 2017, the Nigerian government promised to set aside $50 billion to fund and stimulate investment in the production of biofuels (NIPC, 2017). This equity funding arrangement was expected to come from government parastatals, domestic and international development banks, and international development agencies (Financial Nigeria, 2017). This funding proposal is 10 years too late in the first instance, and this study found no evidence this funding has been provided for the sector. The limited public funding on biofuel R&D may be responsible for the limitations in the sector. The high ratings for pure research in biofuel development may therefore be assumed to be the concerted efforts of academic researchers in Universities and Research Institutes who may be spending their personal funds on their own research. The limited public funding may also be responsible for the non-availability or obsolesce of R&D facilities in the Universities and Research Institutes. This limited funding may also be responsible for the identified weakness Nigeria is observed to have in the shown Technological Development and Production components of the Innovation Process.

Table 9: Limitations to Nigeria's Biofuel Researchers' Abilities

S/N	Limitation	Mean Rating
1	Lack of government funding for research	9.6
2	Absence of Research and Development facilities (Experimental/Analytical equipment)	9.6
3	Obsolete facilities	9.4
4	Inadequate municipal facilities	8.6
5	Inadequate supply of electricity	8.2
6	Lack of exposure to modern laboratory skills	7.2
7	Lack of adequate incentives and remuneration	6.8
8	Lack of quality research assistants	6.4

*(**On a Scale of 1 – 10 where 1 is lowest Rate and 10 highest Rate)**

Legend:
Rate: Very Low – 1, 2; Low – 3, 4; Moderate – 5, 6; High – 7, 8; Very High – 9, 10

4.5.Technological constraints to sustainable biofuels development in Nigeria

Table 10 shows multiple technological impediments to sustainable biofuel development in Nigeria and their ratings on a Likert-type scale. These constraints have been rated to be from

Moderate to High (ratings from 6.7 to 8.7 out of a possible rating of 10). The ability to overcome these constraints, it was inferred, would provide the necessary impetus for Nigeria to develop its biofuel industry. The highest rated technological constraints were limited technical entrepreneurial capabilities (Rated 8.7 out of a possible 10), low capital (8.6), weak technical knowhow on the biofuel production process (8.6), poor infrastructure provision (8.4), limited national technical/production capability (8.4), weak institutional framework (8.1), limited business information on biofuel development (7.9) and limited biofuel refining and conversion facilities (7.6). Other technological constraints are rated Moderate – the "food vs fuel" debate (rated 6.9 out of 10) and "Indifference and low market confidence by investors" (rated 6.7 out of 10).

This was not the case in the Brazil and US biofuel industries (Light, 2010). The "food vs fuel" debate is rated "Very High" (9 out of 10 points). The argument on whether a feedstock should be used for food or fuel, or whether available landmass should be diverted away from food crops towards fuel crops has dominated biofuel policy considerations for many years. Ogundari (2014) reported that Oniemola and Sanusi (2009), Ogundari *et al* (2011) and Oshewolo (2012) had looked at these issues with respect to Nigeria and acknowledged the deep concerns on utilizing available land towards the production of fuel crops in place of food crops. Ogundari *et al* (2011) and Ogundari (2014) however argued that biofuel production in Nigeria should not have any large effect on food production as the landmass utilization was very low (in some places less than 10% of arable land available in the country). The indifference and low market confidence by investors (ranked Moderate – 6.7 out of 10 points) also reflects the status of the private sector in biofuel production. The private sector has been critical to biofuel production in the leading biofuel producers in the world, and in these countries investor confidence is high.

4.6. Strategic inferences from the results

The inability of the Nigerian State to successfully implement the national biofuel initiatives has been documented. This paper has argued that the unsuccessful policy implementation may be due to limited understanding of Nigeria's national capabilities' status for biofuels development, and examined national biofuel capabilities for strategic policy planning. The results (Tables 1 – 4) show that while 51.4% of the respondents have academic and research qualifications directly related to biofuel development, only 27.4% of the respondents had consistent research activities in biofuel R&D over the preceding 5 years, and only 7.4% of the respondents had actual research outputs (journal publications, conference presentations, and patents) in Biofuel R&D.

Table 11: Technological Constraints to Sustainable Biofuels Development in Nigeria

S/N	Technological Constraints	Rate* (Weighted Average)
1	Limited technical entrepreneurial capabilities	8.7
2	Low capital	8.6
3	Weak technical knowhow on the biofuel production process	8.6
4	Poor Infrastructure provision (electricity, water, roads, etc)	8.4
5	Limited national technical/production capability	8.4
6	Weak institutional framework	8.1
7	Limited business information on biofuel development	7.9
8	Limited Biofuel refining and conversion facilities	7.6
9	Fuel subsidy effects	7.3
10	The “food vs fuel” debate	6.9
11	Indifference and low market confidence by investors	6.7

***(On a Scale of 1 – 10 where 1 is lowest Rate and 10 highest Rate)**

Legend:
Rate: Very Low – 1, 2; Low – 3, 4; Moderate – 5, 6; High – 7, 8; Very High – 9, 10

Note: The rate for each constraint was determined by the weighted average of the respondents’ scores.

One key argument for Nigeria’s involvement in the biofuel industry was the country’s perceived strategic advantages in agriculture and agricultural technology which could be harnessed to fast-track the development of the industry (NNPC, 2007; Ogundari *et al.*, 2012; Ogundari, 2014, Akarakiri, 2017; Adedeji, 2019). The evidence from Tables 1 – 4 may require a re-assessment of this perceived strategic advantage – although it may appear that Nigeria has strategic advantages in agriculture and agricultural technology which could be harnessed to fast-track the development of the industry, the reality may be that actual research and development competences are far lower than projected.

Tables 1 – 4 may require a re-assessment of this perceived strategic advantage – although it may appear that slightly more than half (51.4%) of researchers in Nigeria’s leading tertiary institutions may have academic and research qualifications in fields related to Biofuel Development, actual research competences are far lower than presumed (only 27.4% of the respondents had consistent research activities in biofuel R&D over the preceding 5 years, and only 7.4% of the respondents had actual research outputs (journal publications, conference presentations, and patents) in Biofuel R&D. In spite of these limitations in actual consistent research activities, Table 3.8 appears to provide evidence that the main capabilities in Nigeria's national biofuels innovation process are in Pure Research, with low capabilities in Technological Development, Production and Marketing.

Leading countries/regions in the global biofuel industry include the United States, Brazil, Indonesia, China, Thailand, ASEAN and the EU (OECD/FAO, 2019). These countries/regions have demonstrated significant capabilities in biofuels research and exceptional growth in biofuel scientific knowledge, with the United States leading global biofuels research and collaborations (mainly with other productive countries – China, United Kingdom, Germany, Canada and South Korea) (Yaoyang and Boeing, 2013; IRENA, 2019). These countries also excel in the other stages of the biofuel innovation process (Technological Development, Production and Marketing) and these capabilities were critical to the development of their respective national/regional industries (Dufey, 2006; Araujo *et al.*, 2017). The innovations and technological capabilities in biofuels and bioenergy demonstrated in these countries/regions have been demonstrated in their huge domestic investments in biofuel development, their huge wealth, job creation, and economic growth opportunities, and their domination in global biofuel companies and business enterprises (Dufey, 2006; UNCTAD, 2008; Cross Border Bioenergy Working Group, 2012; Achinas *et al.*, 2019). The results from this article infer that Nigeria's low rating in national capabilities for biofuel Technological Development, Production and Marketing may be responsible for the non-implementation of the national biofuel industry. This is in contrast to evidence from the major biofuel producing countries/regions of the world.

5.0. Summary and Conclusions

This paper focused on a strategic analysis of the technological capabilities for sustainable biofuel development in Nigeria as an input to biofuel policy reforms. The strategic assessment established that although more than half the Science, Engineering and Agriculture researchers in the pre-eminent Universities and Research Institutions in Nigeria had academic and research qualifications related to biofuel development, less than a quarter of them actually engaged in consistent research activities in the subject area over a specified time frame and only 5% of them had research outputs in the field. It may be concluded that biofuel R&D capabilities in Nigeria are limited. Out of the 6 indicators for technological capabilities (People, Resources, Innovations and Ideas, Marketing, Operations and Finance) examined for sustainable biofuels development, High capabilities were reported in Marketing, Moderate capabilities were determined in Resources, while Low capabilities were indicated in People, Innovations and Ideas, Operations and Finance. The Current Performance capabilities were adjudged to be Moderate, while Future Potential capabilities were adjudged to be Low. What these results indicate is that it may be difficult to harness the required new technologies, funding and manpower to develop the sector. Out of the four components of the national biofuels innovation process (Pure Research, Technological Development, Production and Marketing), the biofuels' sector was strong in only Pure Research and weak in the other components. This may impede business development aspirations of the Biofuel Policy. The identified limitations to biofuel researchers' abilities, the identified technological constraints to sustainable biofuel development may hamper efforts to raise necessary funding, production and business development support from domestic and foreign partners that are critical to spur the biofuel sector. The overall capability rating for the sector was adjudged to be Low.

From the results, it can be concluded that technological capabilities for sustainable biofuel development in Nigeria are very weak, and the sector is severely restricted in its ability to achieve the aspirations of the National Biofuels Policy. Improving technological capabilities for the sector include developing strategies that strengthen systems for improved research,

technological development, production and business development. These strategies include improved access to appropriate financial, economic and commercial mechanisms for improved R&D activities; and improved professional advisory services for improvement in the Future Potential and Current Performance indicators.

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