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Review

Situating coupled circular economy and energy transition in an emerging economy

Chukwuebuka Okafor[1,*], Christian Madu[1,2], Charles Ajaero[1], Juliet Ibekwe[1] and Festus Otunomo[3]

[1] SHELL Center for Environmental Management and Control, University of Nigeria, Enugu Campus, Enugu, 410001, Nigeria
[2] Department of Management and Management Science, Lubin School of Business, Pace University, New York, NY 10038, USA
[3] Nuclear Science and Technology, Department of Engineering, North-West University, Potchefstroom Campus, 11 Hoffman Street, Potchefstroom, South Africa

* **Correspondence:** Email: ebukao263@gmail.com; Tel: +2347069713586.

Abstract: Fossilized energy system and linear economy model are associated with many of the environmental challenges facing the globe today. The current take-make-dispose model of production causes resource depletion and waste generation; while the highly fossilized energy system is associated with greenhouse gases emissions and climate change. Hence, the current study examined the challenges and opportunities of implementing coupled circular economy and energy transition model in Nigeria. Review and synthesis of literature was adopted for the study. Transitions to the two models are highly situated in socio-technical context. The barriers and potentials connected with both and their coupled transitions is dependent on the country's development stage (economic and infrastructure development), institutions, technological capacity and political will (evident in effective and enforceable legislations). Industrial symbiosis and waste-to-energy path are some of the operational approaches that couples CE and ET. Both also allows for resource efficiency and sustainability—environmental, social and economic. Effective policy actions and sustainable financing are critical enablers for developed CE and ET.

Keywords: circular economy; energy transition; sustainability; socio-technical system; waste management; renewable and low-carbon energy; biomass; economic development

Abbreviation: CE: Circular economy; ET: energy transition; RE: renewable energy; EPR: extended producer responsibility; IS: industrial symbiosis; BE: bioeconomy; EOL: end-of-life

1. Introduction

The present global economy runs largely on fossil fuel, which is highly associated with greenhouse gases emissions, global warming and climate change. Similarly, global economy operates on linear model take-make-dispose. The two issues (fossil fuel and linear economy) are responsible for many of the present global environmental challenges [1]. Accordingly, the growing interest on circular economy (CE) and energy transition (ET). The two models are vested in resource efficiency and decoupling GDP growth from environmental degradation. Though the two overlapping frameworks are different in definitions, aims, principles and application approaches, they have common characteristics—environmental and economic concern (sustainability) [2].

In the extraction of resources, energy is required. Similarly, transformation of raw materials into finished goods/services and their distribution requires energy. Disposal of the end-of-life products signifies the discarding of embodied energy and the material, and therefore is highly unsustainable. For example, in [3], it is estimated that in the next forty years, global use of materials such as biomass, fossil fuels, and minerals will increase by 100%. The finite nature of resources suggests that its unsustainable extraction and use is not to the advantage of the earth and humans. Similarly, the increasing global warming and climate change, as a result of anthropogenic activities is altering biogeochemical nature of the ecosystem. Some studies show the pathway to a renewable/low-carbon energy system is CE and the criticality of low-carbon ET to CE. For example, the nexus between the two systems with emphasis on non-energy use of hydrocarbons (NEU) [2]; circular pathways to a low-carbon future, such as Urban Eco-cluster, etc [4]; bioenergy-bioeconomy nexus [5]; recycling of EOL PV system (a critical instrument of low-carbon and renewable ET) [6].

Though the concepts of CE and low-carbon ET have grown in recent times, modest discussion has been created between the two. This is seriously lacking in developing countries such as Nigeria [7–12]. There are many neglected advantages which will result from integration of the two models. CE in the energy system involve designs, processes and frameworks which optimizes resourceful use of natural resources for energy production, end-use of energy, surplus energy and others [4]. Therefore, CE ensures reduction in energy consumption and its ecological footprint; while ET assures efficient use of renewable or low-carbon energy in production in order to reduce ecological footprint. CE and ET models are basically established on the two pillars of resource and energy efficiency and low-carbon/RE. Practical coupling of the two models will foster efficiency, energy and material conservation, climate resilient economic system and sustainable development. This is important as energy demand is increasing in Nigeria.

Considering the impact of linear economy model which has generated huge waste, Nigeria poor waste management system, growing GHG emissions due to increasing fossil fuel consumption. The aim of the paper is to review and proffer the way forward towards coupled sustainable energy and production system. The paper has the following objectives: to examine CE and ET, the relationship between the two; the role of socio-technical system in sustainability transition, pathways towards coupling the two models and importance of financing to sustainability transitions. In the first section of the paper, brief introduction was presented. In the second section, the concepts of CE and ET were discussed, their differences and interconnection synthesized. Also, systems approach (socio-technical) which is critical to deployment of technological innovation in society and its relation to current sustainable transitions were examined. In the third section, future directions in Nigeria was discussed.

The paper, a review, is a qualitative study and adopted literature review. The keywords for literature search and review were circular economy and energy transition. The concept 'circular economy' and 'energy transitions' were summarized and synthesized from reviewed literature. From literature synthesis, the paper highlighted the similarity and differences between CE and ET. The similarities (overlap) shows that coupling of CE and ET include among others: circularity of renewable and low-carbon energy technologies, bioeconomy and industrial symbiosis (IS). Accordingly, the three were discussed. Reviewed literature shows policy actions, legislative framework and 'green' finance are critical enablers for sustainability transitions. Hence, the importance of the three to coupling of CE and ET were discussed. They are premised on socio-technical transition system (STS). Synthesis from literature were then discussed with reference to Nigeria, in order to situate sustainable transitions in the country.

2. Conceptual framework

2.1. Circular economy

CE developed in response to linear economy (LE). In LE, GDP growth is equivalent to more waste production. Thus, the importance of decoupling [7,8]. 'Decoupling' is decrement in amount of resources utilized to produce economic growth [5]. Estimate shows that CE will reduce global energy production by about 12.7%, and help to achieve Paris climate Agreement [2]. CE is defined as *"industrial system that is restorative or regenerative by intention and design. It replaces the "end-of-life" concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models"* [13]. Supported by transition to RE sources, the CE model produces economic, natural and social capital through three principles; designing out waste and pollution, keeping products and materials in use, and regenerating natural systems [14]. There are two different cycles in CE model: technical and biological cycles. In biological cycle, there is only consumption. For example, food and bio-based materials such as cotton or wood, which are produced to be returned back into the system through processes like composting and anaerobic digestion. Technical cycles recover and refurbish products, parts, and materials through actions such as reuse, repair, remanufacture or as last resort, recycling [14].

Innovative design (eco-design) is critical to CE, and traverse product development and manufacturing processes, institutions and systems to reuse, recycle and reprocess EOL products. Eco-design aims to elongate lifecycle, simplify disassembly for refurbishment and replacement, and introduce innovative revenue systems [4]. Figure 1 shows CE model (Ellen MacArthur Foundation).

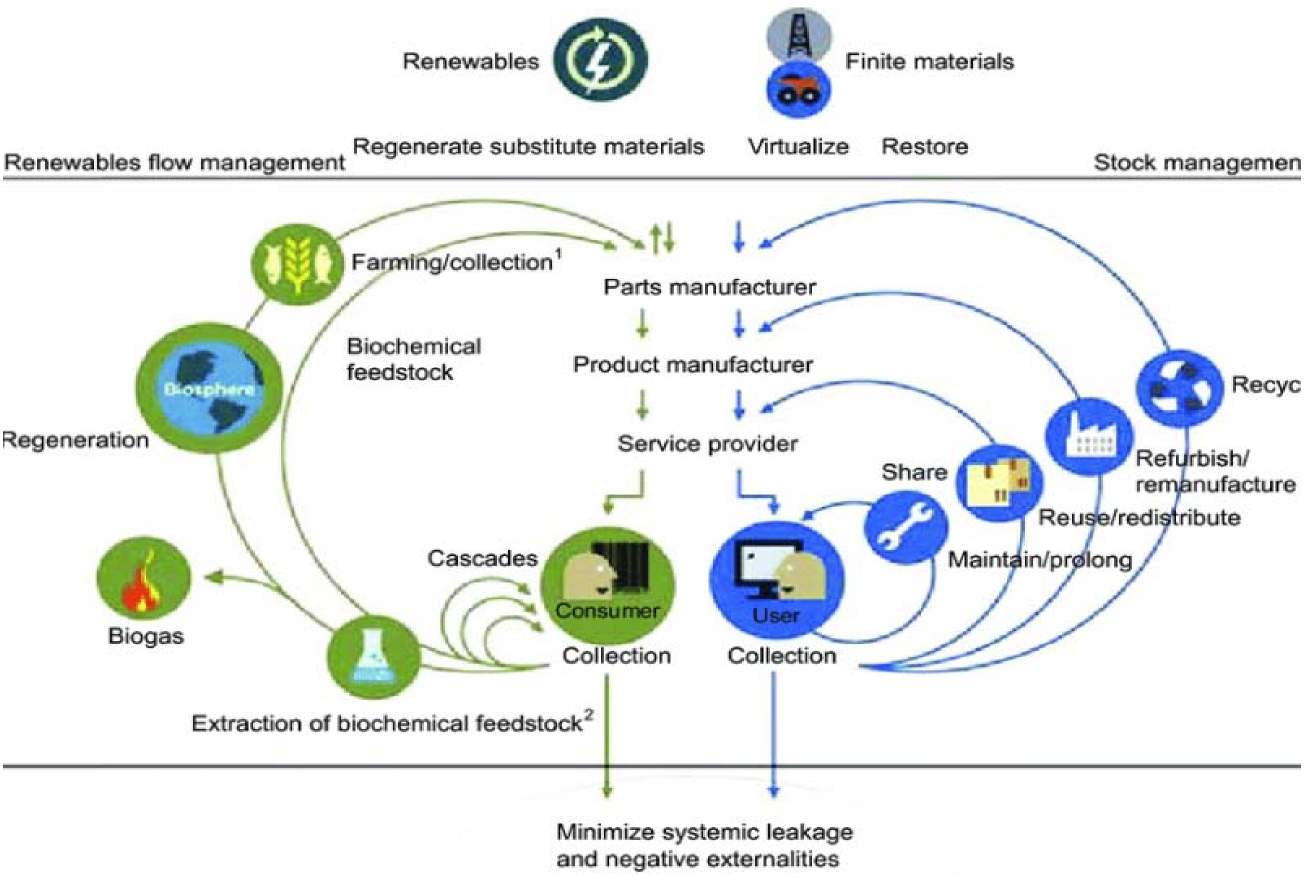

Figure 1. Circular economy model [13].

Central to CE is the 3R—reduce, reuse, recycling—and lifecycle assessment approaches [2]. This is achieved by: decreasing amount of materials input for provision of a service; energy-efficiency in production and consumption processes; substituting materials that are harmful or complex to recycle in products and production processes; building a market for secondary raw materials or 'end-of-life' (or recyclates); waste reduction and separation and cluster activities (industrial symbiosis) [15]. In an emerging economy such as Nigeria, the major drivers for CE are profitability/benefit, reduction in cost and business principle; while the critical barriers in its implementation are unawareness, cost and financial limitation and technical incapability. The importance of environmental awareness in business and economy-wide culture supported by stakeholder pressure and legislative framework/regulations in driving CE in is shown by [16]. Digitization and technologies such as blockchain to CE has been researched by [17,18]. They reduce carbon footprint and material use in transaction and communication process along value chain. This is especially critical for developing countries where supply chains are growing because of increase in consumer demand produced by population and economic growth [19].

Management approaches of CE include: extended producer responsibility (EPR), free market system and tax system. EPR shifts the financial burden of managing 'wastes' from municipalities and governments to producers. EPR takes many forms such as take-back requirements, advance disposal fees (ADF) and mostly, a cooperative EPR system managed by a PRO (Producer Responsibility Organization). Single producers have also created their own management scheme [8].

2.2. Energy transition

ET is a structural change in the energy system: extraction, conversion, transport, consumption and management of energy resources. Present ET emphasizes low-carbon and/or renewable energy. U.S. EPA defined renewable energy to "include resources that rely on fuel sources that restore themselves over short periods of time and do not diminish". RE include solar, wind, hydropower, biomass and biofuels. Most renewable energy sources are carbon-free, whereas biomass and biofuels are considered "carbon-neutral" [20].

Broadly, three energy transitions have occurred in primary energy mix—transitions from (i) wood (biomass) to coal (fossil fuel), (ii) coal to hydrocarbons—oil and gas—and, (iii) traditional fossil fuel to non-fossil fuel (renewables) [9,21]. Energy transitions generally have moved from higher carbon content fuel to lower ones. For example, calorific value of coal is 26.3 tons per Terajoule (t/TJ), crude oil (20.1 t/TJ) and natural gas (15.3 t/TJ) [21]. Though, the carbon contents may have been reducing through the past transitions, intensified industrialization and population growth has enlarged energy use and emissions [9]. Cost of RE is steadily decreasingly, and has become comparatively cost-competitive to fossil fuels. In the US, the price of wind and solar power in 2013 was $11c and $17c per kilowatt hour (kW/h), respectively. In 2020, they were estimated at $5c/kWh and $6c/kWh, respectively [22].

Although solar and wind power, in the foreseeable future, it may not provide total decarbonzation of complex sectors such as maritime transport and chemical industry. Substitution of fossil fuel with biofuel such as ethanol (low-carbon) is one of the sources. For example, in [10], using ethanol in vehicles decreased carbon monoxide emissions from 50 g/km to 5.8 g/km between 1980 to 1985. Therefore, increasing ethanol fuel use will highly mitigate CO_2 emission.

The potential futures of the energy system will depend on two factors: basic organization of the social and scale of the energy system. The social includes: ownership, access, decision-making and governance, within the political scope of society [20]. Figure 2 shows the future energy systems.

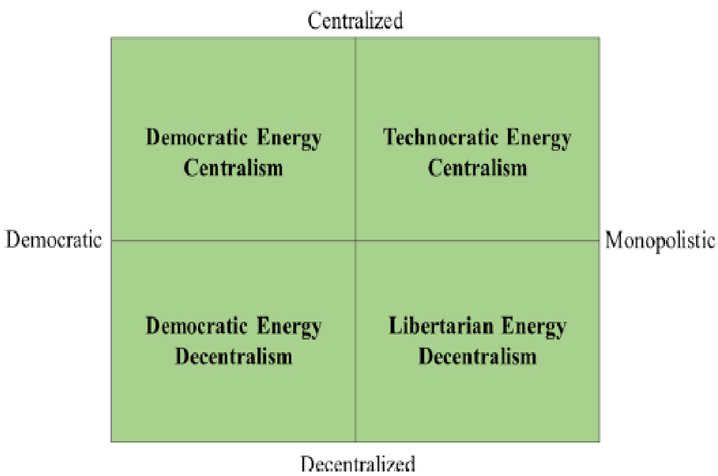

Figure 2. Future energy system pathways [23].

For democratic energy centralism, the energy systems and technologies are centralized (grid), with a bureaucratic governance system. The energy system may include wide scale renewable energy cooperatives where consumers over a wide locality democratically control the energy systems—production, transmission and distribution. For technocratic centralized energy system, it includes solar farms, wind farms or hydro, which is based on centralized infrastructure network (grid). Technocratic (monopolistic) energy centralism is similar to present energy system of many localities where decision making and control are vested in institutions (private or public), utilities and government regulatory agencies. They are generally monopolistic. Democratic energy decentralism is comparable to democratic energy centralism, but the energy system is decentralized. Libertarian (monopolistic) energy decentralism is controlled by few wealthy who manage the economic, political and civil dimensions of the energy system and society. It encompasses distributed energy technologies mainly held and run by private making companies, with minimum government regulations [23].

2.3. Interconnection between CE and ET

2.3.1. Comparison

ET and CE framework differs in background: discipline, definition, aims, basic principles and operational applications, but their goals are similar [2]. Both models are geared towards sustainable production and consumption of products and energy. Both are concerned with environment, economic growth and sustainable development. There are two dimensions to achieving the goals of both—producing differently and consuming differently. For ET, it is transforming production systems by changing from carbon-based energy (hydrocarbons) to renewable energy. It is also very important to take actions on demand-side-consumers (organizations and households). Demand-side actions are summed in energy efficiency. CE principle which aims at efficient resource utilization is therefore a critical enabler for increasing inventive energy transition solutions. Beyond transformation in the way material and energy are produced, both CE and ET also requires extensive society behavioural transformation. Policy and legislative framework are critical enabler to both in setting targets. Legislative framework also provides instruments or systems to achieve the desired aims. For example, for CE, it includes market mechanisms such as EPR, free market system and tax system. For ET, it includes incentives and tax rebates for investments in low-carbon and RE sources, energy-efficiency principles such as energy-saving appliances and technologies, etc. Both require full participation of both businesses and consumers. Businesses which are essential actors—upstream and downstream—in both transitions should be suitably coupled with good incentives connecting producers, investors, distributors, consumers, and for CE (recyclers).

2.3.2. Differences

CE evolved from industrial ecology, while current ET is from energy, environment and climate studies. ET centers principally on energy, while CE encompasses materials and energy. Operational approach of CE focuses mostly at production (design, reverse logistics) and product lifecycles, for example, closed-loop supply chains. Resource management system of CE includes the 3Rs—*reduce, reuse* and *recycle,* and applies throughout the product lifecycle [2]. For ET, operational approaches centers on energy systems, such as development of RE, energy-efficiency (both supply and demand side) and behavioural transformation in the society or publics enclosed in the energy system [9].

Table 1. Differences and similarity between ET and CE.

	Criteria	Energy transition	Circular economy
Differences	Supporting background	Supported mostly by climate change mitigation policies and actions	Supported mostly by policies mitigating natural resources depletion/regenerative economy.
	Aim/Objectives	Sustainable energy system.	Sustainable product lifecycle (and energy)—extraction, production and consumption.
	Operational/functional strategies	Operational approaches include renewable and low-carbon energy, energy-efficiency, consumer behavioural change.	Functional strategy includes eco-design, the 3Rs, close-loop production, energy and material recovery, consumer behavioural change.
	Barriers and challenges	Militating factor includes current socio-technical systems, fixed interests such as coal and hydrocarbon industry, weak geopolitical mechanisms like carbon pricing.	Socio-technical barriers are mostly non-acuity on the part of consumers, company culture and innovative adaptation.
	Governance	Supports energy access/democratization, and energy equity.	Management systems include EPR, free market system (take-back, advanced deposit fee, trade-ins).
	Disciplines	Vested in energy, environment and climate studies.	Vested in industrial ecology.
Similarities	Model	Low carbon and renewables and energy efficiency.	Regenerative production and consumption supported by eco-design.
	Goals and objectives	Avoids GHGs emissions and pursues environmental equilibrium.	Designs out waste (material and energy) and regenerate natural systems.
	Efficiency	Low-carbon and renewables which abates emission and energy intensity.	Reduced material and energy requirement and emissions across product value-chain.
	Targets	Biologic cycle such as biomass, etc, are crucial mix in the transition.	Energy recovery, among others are targets of the CE.
	Targets	Technical cycles (e.g., EOL RE technologies) are to be recycled.	Geared towards recycling of EOL RE technologies for sustainability.
	System	Socio-ecological system.	Socio-ecological and socio-technical system.
	Aims	Environmental sustainability (climate regime) and socioeconomic growth	Ecological sustainability (natural resource conservation) and socioeconomic growth

CE is a product of numerous sustainability forms—sustainable use of resources, supported by low-carbon and RE sources [24]. Therefore, CE saves energy (and emission abatement) and prevents overuse of natural resources without surpassing earth's regenerative capacity as regards climate regime, biodiversity and environmental quality [5]. Table 1 shows differences and similarities between ET and CE.

Below, the paper discusses some paths that offers coupled CE-ET model.

2.4. Circularity of renewable and low-carbon energy technologies

Acceleration of low-carbon and RE installations implies increase in components that will reach their end-of-life or 'disposed' because of defects. Global installed PV capacity is projected to exceed 4500 GW by 2050. With a lifespan of 25 years, global solar PV waste is estimated to be about 78 million tonnes by 2050 [6,25]. In 2016, PV wastes were about 43,500–250,000 metric tons, representing 0.1%–0.6% of collective mass of all mounted panels (4 million metric tonnes). Basic estimate show that by 2030, raw materials approximately recoverable from PV panels may produce a value of about $450 million (of 2016 level). This is comparable to the sum of raw materials presently required to produce about 60 million new panels or 18 GW electricity generation capacities. By 2050, the total recoverable value will surpass $15 billion, which equals 2 billion panels or 630 GW [25]. Over 80% of a usual PV panel's weight is glass and aluminum materials, both of which are recyclable [26].

Recognizing the complexity of EOL renewable energy installations, the EU waste electrical and electronic equipment (WEEE) directive required all 'producers' furnishing PV panels to EU market to fund the costs of recovery and recycling of EOL PV panels [25]. PV modules may be reused or restored to offer secondary applications such as generating electricity. Most refurbished modules are usually deployed to off-grid or non-grid related uses, as long as they meet relevant building codes and standards [26]. Collaboration throughout the value chain is required to scale CE principles in low-carbon and RE development. It includes R&D organizations, repair/reuse service industry and recycling treatment industry [26].

The critical challenge antithetic to environmental sustainability (which is the purpose of the current energy transition) is the issue of wastes, when the batteries reach their end-of-life. By 2035, worldwide energy storage market is estimated to grow 10 times, to $546 billion. There could be as much as 11 million tons of lithium-ion battery waste from electric vehicles, by 2030. Current design of lithium-ion batteries makes it very complex to repair, remanufacture and recycle. Failure of a battery component means disposal of the whole battery unit. Usually, more than 80% of the potential lives of the disposed or failed battery are unused. By 2025, there may be deficient supply of lithium. The development may be a most important obstacle to scaling-up RE. Consequently, two very critical resource-efficiency and environmental issues emerges with the current state of battery storage: (i) the disposal of these batteries, with large amount of them still having their charging capacity unused; and (ii) the valuable resources (materials, energy and other production inputs) utilized in the production of these batteries lost from the economy [27]. Specifically, the solution entails CE. There are complex technical and economic issues associated with recycling lithium-ion batteries. On the other hand, the incentive to recover from the batteries cobalt and other materials is huge.

2.5. Bioeconomy

One of the concepts which synergizes CE and ET is bioeconomy. Bio-based economy (BBE) and bioeconomy (BE) are at times alternatively used. However, BBE is concerned with the production of non-food goods, while BE encompasses both BBE and the production and utilization of food and feed [28]. By situating biological cycle in their CE conception, BE is a critical component of the CE [13,27]. OECD defined bioeconomy as *"the type of economy that uses natural renewable biological resources, from both land and ocean, to obtain food, materials, and energy in a sustainable way without compromising their availability for future generations"*. Agriculture produce, fisheries, forestry, pulp and paper, microbes, algae and animals in addition to their produced wastes or residues are part of the "renewable biological resources" group, whereas waste and residues turns into feedstock for the production of food, feed, industrial bioproducts, and energy [5]. Thus, sustainable BE should be a critical component of renewable energy transition. This is supported by the First Global Bioeconomy Summit in 2015 which categorized three fundamentals of bioeconomy as (i) renewable biomass, (ii) supporting and converging technologies, and (iii) integration across applications: primary production (entire biotic natural resources), and industry (chemicals, plastics, enzymes, pulp and paper, bioenergy). Bioenergy (renewable energy) therefore is one of the goals of BE, as it is geared towards decreasing reliance on non-renewable capital, for example, fossil fuels and fossilized natural resources [28]. Thus reducing greenhouse gas emissions, and its effects. Adequate infrastructure is required to support the transition [30].

With expected enlarged demands on water bodies and natural system, land-use alteration and intensified agriculture, the sustainability of BE is questioned. The concerns have caused European Commission to integrate *sustainability* and *circularity* as the core of BE, resulting to the term 'circular bioeconomy' (CBE). CBE is an intersection of CE and BE. Though definition of the term CBE is scanty, its approach is geared towards better resource-efficient economy, for example, integrated biorefineries, and cascading utilization of biomass (low-carbon and renewables) [29].

Globally, new business model in biomass value-chain represents about 295 billion USD in 2020, which is three-fold the value in 2010. The new biomass value chains include agricultural feedstock, biomass production and trade, bio-refining input, such as pre-treatment methods of biomass. It is estimated that by 2030, BE will contribute about 2.7% to OECD GDP, under "business-as-usual" scenario. This is even more significant for developing countries (such as Nigeria), where primary production (agriculture) contributes significantly to the GDP. However, it involves considerable input as regards knowledge, policies and institutions [28]. Biomass is predicted to play a critical part in achieving Paris Agreement climate objectives, which is the goal of present ET. It is among the small number of alternatives to substitute fossil inputs with renewable capital in chemical, heavy duty transport and aviation. As noted in the study of bioeconomy clusters by [29], all the countries (Northwest Europe) with functioning BE have established and functional CE policies and waste management system.

FAO show that globally, about 30% of food produced for human consumption is wasted. For EU, this represents about 123 kg/person/year [31]. For sustainable bioenergy to play a critical part in expected energy systems, it is crucial to create maximum utilization of biomass resources with lesser ecological implications (that decreases GHG emissions), while promoting improved socioeconomic effects [5].

2.6. Industrial symbiosis (IS)

Although much emphasis of IS in literature is on materials, it is also applicable to energy. By extensively adopting circular approach, IS enables industries and organizations to function similar to natural ecosystem where there is no waste generation. Material-based IS enables using, recovering and redirecting of material 'wastes' (resources), thereby ensuring that materials remain in productive use in the economy for a longer period. IS represents the association of CE and "sustainable energy" or circular energy transition [32]. Three major benefits of IS are (i) by-product reuse, which is the exchange of company-specific materials or energy sources among two or more companies for use as substitutes for raw materials or energy; (ii) services/infrastructure commonality such as energy, water, etc; and (iii) combined delivery of services, which meets common needs such as fire protection, transportation and food provision [33]. Two major conventional models of IS are (i) intended eco-industrial park and (ii) self-organized symbiotic model. Other models include: "the Build and Recruit model", where public or private developers build an industrial park and find well-suited renters; Retrofit industrial park and Circular economy eco-industrial park [34].

IS is concerned with the (re)use of waste materials and energy created by a production process as a substitute for conventional production inputs or other usually disconnected processes, belonging to the same or dissimilar companies. A waste, for example, a company's production process is used for energy production by another production process of same or different company. There are three basic forms of symbiotic energies. They are: energy cascade, fuel substitution, and biofuel production [32].

Energy cascade connecting two processes take place when waste energy (for example, waste heat or steam) produced by a process is used by another. The decrease in energy requirement amount to avoided CO_2 emission. For examples, energy cascading accounts for about 12.6 and 45.5 kiloton per year CO_2 emission abatement in Liuzhou (China) and Ulsan (South Korea), respectively. It reduces considerably emissions and energy costs [32]. The process requires more than simply fostering a linkage between two or more companies. Actually, several IS relationship or dealings are complex than mere exchange of resources. 'Used' resources may need some type of processing to make it suitable for a new purpose. It may require extraction process, grinding or other treatment. IS creates business opportunities, decreases stresses on earth's resources, and offers platform to build a circular economy [32,34] and also increasing use of renewables and energy-efficiency.

2.7. Socio-technical system (STS)

Sustainability is built on system thinking which emphasize co-development of social and technical systems (STS) that explains how systems are displaced and substituted by new prevailing practices [1,35–37]. Production and energy system are nested in society and controlled by wider values in particular culture. STS therefore follows when an established system is altered and produces a new mode of functioning economic activity. In addition, system innovation includes technological changes that facilitates 'clean production' (for example, low-carbon energy and resource efficiency), co-evolution of new relationships (cultural, social and political establishments) which direct or restrain transitions to sustainability [38]. Socio-technical system establishes the settings under which innovation assists in transformation of energy systems [35,37] and economic system (production/consumption), and as well why they are not succeeding [9,21].

There are multi-level approaches in STS. They are:

i. **large scale transformation**—it indicates the wider external environment—political, social, cultural norms and institution—that influences the development of the socio-technical system and adjusts gradually [36,40]. Extensive modification critical for sustainability involve substantial societal displacement and consequences that are expected to follow such modifications [1,35,37].

ii. **socio-technical regime**—it indicates existing set of laws, policies and regulations that orders and organizes the course of social group actions and stabilizes socio-technical system. Established regimes produces gradual increase in innovation, whereas far-reaching innovations are produced by niches [35,39]; and

iii. **niches (knowledge systems)**—is described as a locus or "incubation rooms" of fundamental innovation changes. It is a learning process and ecosystem which forms social set-up that supports innovations. It can be a small market niche or local community niche, which is supported by specific condition from the existing system or technological niche structure. It requires huge resources and funding (all things being equal) to produce broad social, economic and technological changes [35,37,39].

Figure 3 shows integrated CE-ET in STS framework.

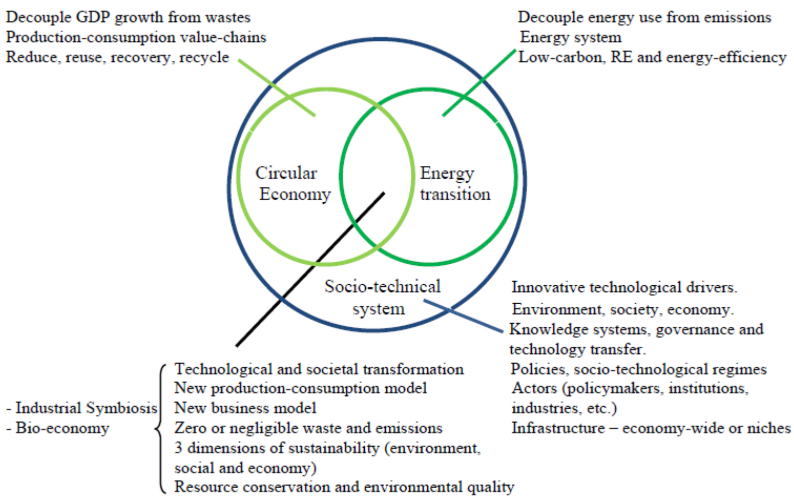

Figure 3. Coupled CE-ET in a Socio-technical system.

Communities (niches) are meeting point for STS research since they are spaces where government support ecological mitigation policies and actions resulting in developments compliant with or directing country, regional or international standards and regulation. Extensive adoption needs the right settings, changes, transitions and differences between the niche and other levels [38]. Stakeholders involvements in policies promote public participation in community sustainable programs or plans [2]. The change involves transformation in the social and technical assets, that can be appreciated as interrelated systems of actors (such as producer or customers, businesses, and other groups), institutions. Within the larger society, sustainability will involve new infrastructure, businesses and methods for recovery, treatment and reprocessing of "wastes." Similarly, the deployment of innovative sustainable products could lead to changes in consumers' behaviour and attitude [40].

Sustainable transitions are complex course and may involve substantial timeframe as is characteristic of socio-technical transitions [40]. It is very difficult for technical models to factor in all societal dynamics (behaviours, feedbacks, etc). System models may underrate the indirectness, eventualities and deviations of system change, and provide a very wide scale of innovation characteristics. Though relationship exists between local, regional, national and global systems in energy and production systems, they are different in economic, bio-physical, physical infrastructure, community, and governance (public institutions, laws, rules, norms) systems [35,41]. Socio-technical systems must be situated in the society which it is intended for. The relationships within a system are usually non-linear. Hence, the importance of actors (public and private actors), technology advancement and R&D, to innovative transitions is critical. They help to fill important gaps between policy objective and tangible outcomes. It merges a focus on the technical possibility of transitions with the political viability of policy transformation. This will encourage community and policymakers support of important policy change. Modification in institutional and governance framework is required to support the transformation [35]. New system connotes destruction of the old, thus, 'different policy culture'. STS involves challenging influential fixed interest [37]. In a market which is highly unchanged, major actors of technological substitution are situated mostly in industry and politics [35].

3. The study area

Nigeria is located in the tropical region of Sub-Sahara Africa. The population of Nigeria is given as 140,431,790 by National Population Commission census of 2006. Growing at an annual rate of 2.7%, the present population (2020) is estimated at 206 million. With high population growth and annual urbanization rate of 3.5%, great expanse of forest resources is cleared to provide housing and other infrastructure for the populace. About 51.6% of Nigerian population currently lives in urban areas [42]. These have significant implications for energy and production system, as demand has increased substantially. Large wastes are generated annually in Nigeria. Assuming per capita waste generation of 0.43 kg/capita/day [43], 206 million Nigerians produces about 32.3 billion kg of wastes per annum.

Higher composition of wastes are organics [43]. Assuming national average of 0.43 kg/capita/day waste generation [43], this suggests that Nigeria generates about 88.5 million kg of wastes per day. Furthermore, assuming 70% composition of the wastes are organic, Nigeria produced about 62 million kg/day of organic wastes in 2020. Accordingly, disposal to dumpsites is highly correlated with methane. EPA estimate that landfills is the third leading source of anthropogenic emissions, representing about 13–30% of global methane emissions or 223 million metric tons of carbon equivalents (MMTCE) [44]. Major ways to achieve this include waste-to-energy and resource pathways. The growing transition to low-carbon and renewable energy across the globe will disrupt Nigerian economy, especially if the country fails to diversify its economy. The impact can be categorized into three (i) economic collapse, (substantial contraction in revenue) because of abandonment of fossil fuel; (ii) secondary economic losses because treasury might not be capable to finance the public sector from diminished oil revenues; and (iii) loss of geopolitical position in region and global politics, as fossil fuel is substituted with regional or global access to variable renewable energy sources [9,45]. Substantial long term decline in government revenue will increase unemployment and escalate furthermore the population of the poor, result to governments' inability to finance basic services and amenities and disappearance of very poor available social nets [9].

GHGs emission estimate show that per capita emission of Nigeria is about half the world average, similar to that of other sub-Sahara Africa countries and lesser than middle-income countries such as South Africa, Brazil and Mexico. Conversely, relative to emissions per unit GDP, Nigeria produces above 100% of the global average, which is higher than comparative countries. If the carbon intensity of Nigeria economy continues as it was in 2005, emissions will be about five to six times by 2030 [46]. Transition to renewable energy sources (which are under-utilized) offers substantial opportunity to reduce emissions in Nigeria. Table 2 shows Nigeria's renewable energy potential.

Table 2. Renewables potential and their current utilization in Nigeria.

Resources	Amount	Current Use
Large hydropower	11,250 MW	1930 MW (17.1%) used
Small hydropower	3,500 MW	64.2 MW (1.83%) used
Solar	4.0–6.5 kWh/m^2/day	27% Capacity Factor (Negligible)
Wind:	2–4 m/s @ 10 m hub height	
-Onshore wind	1,600 MW	Negligible use
-Offshore wind	800 MW	Negligible use
Geothermal	500 MW	Negligible use
Biomass (Non-fossil fuel):		
Municipal waste	30 million tonnes/year	0.5 kg/capita/day
Fuel wood	11 million hectares of forest	43.4 million/tonnes/yr consumed
Animal waste	1.05 tonnes/day	Negligible use
Agricultural residues	91.4 million tonnes/yr produced	Negligible use
Energy crops	28.2 million hectares of arable land	8.5% cultivated

Source: [49]

Transition to CE and renewables and low-carbon energy sources does not only ensure sustainability, but also will help decouple Nigerian economy from oil.

4. Future directives

In pursuit of the paper objectives, which is to examine CE and ET framework, and their relationship (coupling) and importance of socio-technical system (and 'green' financing), the paper discusses the future directions for Nigeria. The future directives were deduced from reviewed literature.

4.1. Policies development and legislative framework

Though there is a national policy on RE in Nigeria [9–11,46] there is no defined CE policy [8,12]. Still, implementation of the RE policy is very poor [11]. Hence, policy action is required to address the challenges of implementing coupled CE-ET [2,4,10,28,32,33]. It should be supported by frameworks which are unique to the needs and situations of each region or country [25]. The economic and energy system is an element of the wider society structure. Countries which have scaled renewable/low-carbon energy and CE have advanced objectives and targets established in legislative framework [2,4,8,14,24]. Currently, there is no clear CE objectives in Nigeria. Rather, what is obtainable is a piecemeal method, for example metal and plastic recycling which is highly premised on scavenging from dumpsites and disposal sites [8]. Though roadmaps and elements of RE—energy efficiency—have been drafted in Nigeria energy system for example, Nigeria Renewable Energy and Energy Efficiency Policy (NREEEP), there has not been a meaningful achievement in the area. Poor political will, societal inertia, technological incapacity and heavy reliance on fossil fuel economy may be some of the reasons for the traction. Sustainability action plan is premised on investment in R&D, policy exchange and stakeholder commitment; and improved markets cooperation [47]. These three factors are very critical to integrating both CE and ET. Figure 4 shows coupled CE and renewable and low-carbon energy.

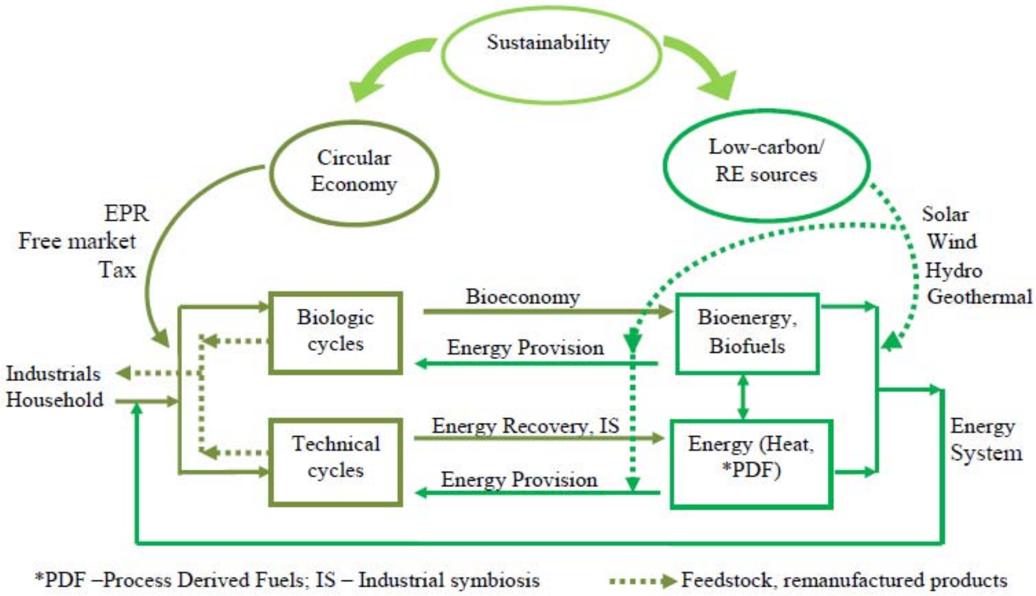

Figure 4. Coupled CE-Low-carbon and RE sources.

From Figure 4, advancing the mutual benefits resulting from coupled CE-ET cannot be a reality without first developing the frameworks of both. Both systems (CE and ET) should first be clearly specified and delineated in legislation, since they are premised on two inter-related but different systems—energy and production. Granted, energy is critical to production system, but CE does not only entail energy recovery, it also includes remanufacturing of materials which should be underpinned by renewables and low-carbon energy sources. Therefore, even in CE model, RE and low-carbon should be integral. Developing the two system differently first, especially for a developing country like Nigeria, will help to strongly identify nexus, and will also remove technical and economic difficulties. Coupling the two models involves an innovative understanding of their overlap.

4.1.1. Implementation of a 'defined' circular economy

CE as the emerging production-consumption model of the future is not restricted to developed industrialized countries. Though CE model offers substantial benefits, it requires suitable articulation for its implementation, starting with legislative and policy framework support. But there is no singular integrated legislation specifically directed at functional CE in Nigeria. The concept (such as recycling) may exist as a very weak subset in some environmental legislations [8]. Though NESREA adopted a guideline for EPR system for waste electrical and electronics products in 2013. But enforcement of the guideline and evaluation of its success has been largely unnoticed. There is no clarity in the functions and duties of stakeholders—importers, collectors and recyclers, municipalities, consumers and the PRO. The situation is made more difficult considering that most (93%) of the importers of electrical and electronic equipment is not registered [12]. Same applies to tyres [8]. Therefore, to support CE model which can take the form of EPR, tax or free market system for recovery of EOL, it is important to (i) determine or quantify product or waste characterization (registry/record); (ii) effectively regulate the informal sector; (iii) implement non-fiscal motivations that will support consumers returning 'waste' products or goods for reprocessing or finance for the removal of their waste; (iv) establish a monetary structure to finance proper ecological recycling; and (v) efficient data/information maintenance that is simple to access to assist cogent investment decisions [8,12]. The importance of niche—incubation and learning process (socio-technical system) in accelerating innovation can be deduced from Dalian city in China, a pilot study for CE during 2006–2010. The implementation focused on small-scale facilities. Its successes provided fitting examples for other Chinese regions with comparable characteristics [55]. Major challenges and difficulties that may put off or delay implementation of CE in Nigeria include deficiency in dependable data/information and advanced technologies, non-existent CE legislative and institutional framework, poor or non-existing economic incentives, weak enforcement of legislations, poor management of the development plan, non-existence of public understanding about the need and benefits of CE, and lack of standard method for evaluating CE's performance [8,12,48]. Therefore, Nigeria should as a matter of urgency develop its national data/statistics capability, develop a CE package driven by policy and legislative support and create a suitable infrastructure crucial for the model to thrive in the country. The package should include EPR, tax system and others.

Though CE is beyond management of waste disposal, proper waste management system is critical to achieving CE principles which make disposal to landfill last option [13–15,48,49]. Majority of Nigerians do not have access to proper waste collection and disposal amenities. Instead, wastes are carelessly disposed of in the environment, or at best, semi-formal dumpsites [8]. Thus, Nigeria (state and local governments) should adequate pursue and develop proper waste management system.Proper waste management involves the 3Rs (reduce, reuse, recycle) which basically implies redefinition of wastes as a valuable resource [8]. The components of the strategic actions should include: (i) devising ways to collapse administrative difficulties to decision-making bodies, and (ii) promoting adoption of financing to maintain investments in technologies and processes [49].

For ‘waste products’ (biologic cycle) such as organics and biomass, which are mainly produced by households, and which is strongly important to bioproducts and biofuels, it can be argued that instruments such as EPR, may not work. Accordingly, the importance of effective and resourceful waste management institution in synergy with bioenergy production enterprises is very proper. The system commenced from consumers appropriately segregating their wastes. Financial support through various mechanisms (tax waiver, grants) should be instituted to support the ventures. [1,10,42].

4.1.2. Strong development of renewables and low-carbon energy sources

Nigeria’s Nationally Determined Contribution (NDC) pledged to reduce GHG emissions from 20 to 45% relative to a business-as-usual scenario by 2030. Measures to achieve that include enlarged utilization of renewables, energy efficiency, decreased flaring of gas. Accordingly, the National Renewable Energy Action Plan of 2016 aims that 16% of electricity production comes from renewables by 2030 [9,46]. Nigeria, a tropical country has great potential for renewable and low-carbon energy development. However, high subsidization of oil products is a critical barrier to exploitation of these resources [9]. There is very poor roadmap on market outlook as regards financial support mechanism for private ventures interested in their development. Therefore, financing is a very major limitation, since low-carbon and RE technologies requires substantial initial costs relative to carbon-intensive technologies they are meant to replace [1,11,46]. Hence, the importance of analytical evaluation of cost of capital, project risk and profits, so as to provide useful tools for policymakers to create adequate inducement that will draw sufficient investments [1]. This considers the undeveloped RE market in the country, which cannot support long-term funding thereby making RE development difficult compared to hydrocarbon investments. Realistically, factors unique to Nigeria suggests that at least in the intermediate period, low-carbon fuel (biomass, natural gas) will substantially feature in energy mix, together with renewables such as solar, wind and geothermal in energy transition in Nigeria. For example, estimate shows natural gas will reach its peak around 2060, while for oil, it is 2040 [21].

To strengthen the use of renewables and low-carbon energy in Nigeria energy mix, policy actions and implementation strategy should address the following:

i. Oil subsidies should be decreased or totally remove and the revenue channeled towards low-carbon and RE sources development; and implementation of a carbon tax;
ii. Strong implementation of regulatory frameworks to market decarbonized fuels (such as solar, wind, biofuels, etc) as components for promoting energy transition. It should also provide for interconnection of different sectors, for example, resource development, waste management and energy industry;
iii. National, regional or local targets should be established and sustainable activity blueprints devise and implemented to achieve it. Though plans have been made to increase renewables by 16% by 2030, political will, institutional and innovative (business) capacity and society cooperation is crucial. Finance is pertinent to any growth.
iv. Point (ii) and (iii) above should be accelerated by encouraging and supporting with economic incentives various low-carbon and RE sources such as reuse of waste energy sources (waste heat and gases), biomass, etc. This strongly supports development of policy actions such as VRE, industrial symbiosis-eco-industrial park (which should be granted generous tax waivers), and proper waste management system.

4.2. *Integrated CE and ET pathways for Nigeria*

Implementation of coupled CE and low-carbon/RE solutions involves policy changes to eliminate difficulties. Currently, policies for circular economy is lacking in Nigeria. While there is a policy for RE (Nigerian Renewable Energy and Efficiency Policy-NREEP), the pursuit has been very poor. The process call for making project financing obtainable to facilitate changes that would not normally be convenient. For example, transforming the value of 'wastes' (e.g., biomass) into important resources which can be used for agriculture purpose (composting) or energy recovery (biofuels) requires societal shift in values, financing, technologies and institutions [3,5,10,28,37,40]. Situating socio-technical transition framework in Nigeria, which is important to scaling up new and innovative technological process, policy actions should incorporate the three forms—macro landscape, socio-technical regime and niches. The transition can progress through (i) waste-to-material [5,7,8,12,30,47] and energy recovery [1,4,10,32,37,46] systematically using CE instrument such as EPR, tax and free market system; and (ii) renewable energy sustained electrification (distributed energy generation) to support production system. In accordance with socio-technical system multi-level approach [35,38,39], they can be developed either in niches or wider society (macro-landscape). However, the following should be addressed: Nigeria poor state of technological development; heavy dependency on oil economy (socio-economics); poorly defined and functional waste management policies and systems; and inadequate and poor data/information management.

Accordingly, development of low-carbon and RE from circular model perspectives in Nigeria, has to integrate various instruments such as industrial symbiosis and energy recovery from technical and biologic cycles. Non-recognition of waste as a potential resources and poorly disaggregated information on waste management is a fundamental limitation to creating financial ability and sustenance of reuse, recovery and reprocessing of wastes in Nigeria [7,8]. Additionally, there is a supply and demand gap (because of non-existent association) between waste generators (households and industries) and possible users (recyclers, etc). Thus, the importance of effective policy and information management to address value-chain—recovery, management and recycling in Nigeria. Clearly defined directive is critical to CE-ET. For example, the EU Waste Framework Directive (Directive 2008/98/EC) defined the key features connected with waste management. It includes the definition of waste, and five-stage waste management hierarchy—prevention, reuse, recycling, recovery and disposal. It also called for targets to reduce amount of waste disposal to landfills [49].

Conversely, in Nigeria, wastes are ubiquitous in the environment constituting pollution and impacting public health. Therefore, first step towards implementing CE in the country is to redefine and re-imagine waste and waste management. There is an association between targets to increase waste (EOL) recycling and reduction of waste landfilling. This is dependent on availability of proper data management, fitting infrastructure and technological capacity. As regards data management, there is need for Nigeria to (i) characterize waste generation into useful quantity which will support development plan of businesses, and (ii) systematize capable supply chains that functions at maximum height of ecological and social efficiency. Waste characterization is important to determining material and energetic recovery. For energy transition, it is important to develop and support our variable renewable energy (VRE) and low-carbon energy sources.

Four important factors that drives transformation to sustainable and innovative transitions are: political principles and state orientation, publics, institutional and policy transformation, and transition dynamics [50]. There is a relationship between the factors, especially between institution and policy transformation and transition dynamics. The economic dimension addresses the fiscal cost of transitioning to dependable, decarbonized and resource efficient system. The costs include infrastructure development, negative economic value of "stranded assets" and potential economic gains. The transitions therefore require Nigeria societal transformation (social factor) in pattern, technologies and behaviours towards resources use (supply and demand side).

Two major paths in sustainable transitions are distinct in theory and policy literature [24]—(i) economy-wide application, and (ii) application with attention on a collection of sectors, products, materials and substances. At the local and provincial levels, the most widespread example of systemic economy-wide implementation is the industrial parks, or 'eco-industrial parks' [32,34]. It is premised on industrial symbiosis—sharing of resources and recycling of waste (material or energy) across industries. Niche form is both applicable in the two models. Thus, Nigeria need to develop symbiosis between industrial processes to foster environmental and economic objectives. This requires incentives, subsidies and other fiscal inducements.

Restructuring Nigerian economic and energy system to provide circular and low-carbon/RE-fueled system requires a major transformation in infrastructure, industrial processes and legislative framework. It should include adequate waste management system, industrial ecology programs (such as eco-industrial park), enabling environment for scaled reverse logistics, RE and suitable bioenergy production technologies and methods; and remanufacturing technologies [8,9,37,43]. Initial investment costs for CE and energy transition technologies and solutions may be very high for many businesses and enterprises in Nigeria, especially for technology-demanding solutions. But long-term benefits will compensate for the initial investments. Accordingly, situating sustainable transitions in Nigeria, the following factors should be addressed—policy development and legislative framework, which should include (a) renewable energy and low-carbon electrification [1,35,50]; (b) proper waste management system and its functionality to support sustainable energy sector [4,5,8]; and (c) industrial symbiosis which support both energy system and circular resource utilization [32–34].

4.2.1. Development of industrial symbiotic model

Bringing eco-industrial park development to Nigeria, various industrial layouts exists across different locations in Nigeria, established by various state governments, for example Emene industrial layout (Enugu State), and about 14 industrial estates in Lagos. In Lagos state, there are more than 7000 functional industries and less than 10% have treatment facilities for waste and effluents treatment before release to the environment. For example, Lagos lagoon has become so polluted with wastewaters from water used for various industrial purposes—breweries, textiles, pharmaceuticals, etc. [33,34] posits that geography may not pose limitation to IS if properly harnessed and designed. Hence, fostering IS—eco-industrial parks will promote quality environment, resource reutilization, energy conservation and new business model with job creation. But it requires strong policy directive and technological advancement. Legislative framework is central to development of IS. For example, Greece recent National Strategic Reference Framework (ESPA) 2014–2020 addresses innovation and enterprises of products and services for environmental improvement. [34]. The law required that Industrial and Business parks may be built either by private or public organizations. Thus, in pursuit of sustainability, it is important that Nigeria through environmental and industrial policy integrates the concept of "symbiosis" in production system. Building of industrial park is a step in the right direction. However, tax breaks, grants and credits towards ventures that integrates product or energy wastes in their processes is required. Therefore, fiscal incentives are very crucial to foster accelerated IS. Producers should be motivated to reuse ‘wastes’ from other company or even from their own activities. Other issues beyond ‘waste’ and energy, should be addressed such as water, logistics, capability and know-how.

Generally, the eco-industrial parks should include the following—(i) exchange of by-products or wastes through linkages of businesses which implements such exchanges; (ii) assembly/collection of recycling ventures; (iii) collection of businesses using eco-friendly technology; (iv) collection of businesses producing eco-friendly goods and services; (v) designed on a particular environmental issue (e.g., industrial park functioning on solar energy); (vi) common infrastructure or network; and (vii) mixed use development [34].

4.2.2. Waste-to-energy production

Wastes are increasingly being adopted as an energy resource [4,8,10,20,30,32,43], and this offers a huge potential for Nigeria. With an average waste generation of 0.43kg/capita/day, Nigeria generates about 88.5 million kg each day. 70% are organic, suggesting that the country produces about 62 million kg/day of organic wastes. If properly developed, it offers valuable resources for energy production. Electrification and sustainable bioenergy is a major way to decarbonize energy and economic system [9,10,37,46]. A growing system critical to deployment of renewable and low-carbon sources is distributed-generation network, which is highly opposite of the present grid system existing in Nigeria. A key enabler of integrated low-carbon energy and circular economy transitions is distributed renewable energy (DRE) generation [51]. DRE is generally close to the users which most times are the producers and can be households, local businesses, etc. RE is greatly dependent on geography. Cost-effectiveness of emissions reduction and decarbonization measures depend on a country’s geography-related factors. They are local climate, carbon dioxide storage prospects, local agriculture methods and the land obtainable for—carbon sink (reforestation), renewable energy (wind farms and solar plants) [52].

Nigeria is the ninth leading methane emitter, with our dumpsites producing about 1% of global landfills methane emissions. Proper situation of CE principles in waste management framework will go a long way to solve poverty issue, providing bioproducts, bioenergy, etc, for sustainable development. Therefore, a national strategy should be strongly pursued to convert wastes to resources. The current informal (scavenging) method should be fully incorporated into the strategy, without regulation and deployment of proper technologies. Development of waste-to-energy requires adequate infrastructure [30] including proper waste management system, transportation, conversion plants, etc. Finance is critical to support the transition in Nigeria. State and local governments in cooperation with private ventures should build and operate local waste-to-energy plants. Similarly, large production companies can integrate the model into their energy supply system. Connection of the small-scale waste-to-energy generating plant output can produce a Renewable Local Energy Network, in [51]. It can further supply national (centralized) or decentralized wide-scale areas [23] in Nigeria. ‘Green’ financial mechanism should be devised to support the system adoption [8,37,53].

4.3. Sustainability ("green") financing

Sustainable transitions (ST) entails destruction of existing dominant system and replacement with new models [37]. Replacement can either proceed with adaptation (modification) of existing infrastructure to suit new sustainable model, or building new infrastructure [1,37]. Sustainable transitions (green projects) have high technology risk profile and are capital intensive. Hence, the sole or joint support of private and public sector financing instrument is critical. It goes beyond the mind-set of shorter-term profits [53]. It should include PPP framework that enables reverse logistics and reuse of 'wastes' for material and energy recovery, etc. The complexity and uncertainty of sustainable transition poses challenges to securing financing [54], especially in undeveloped markets like Nigeria. 'Green' finance therefore plays a crucial role in the transitioning, as it produces a level playing field between the established and green economy [54]. This suggests implementation of a "tailored" policies so as to unlock the great potentials of green finance [55]. Fiscal instruments across developed and industrialized countries which is speeding up green investments is carbon tax and pricing (emission trading). However, Nigeria is yet to design or implement one [56]. Emission trading is not feasible in current Nigeria, because of inadequate technology, undeveloped market, poor monitoring and lack of industries emission baseline and transparency [57]. A practical scenario where emission trading should be vigorously implemented in Nigeria is in oil and gas sector (gas glaring). Practical and possible fiscal instrument for the economy-wide application in Nigeria is carbon tax. For instance, carbon tax should be set on fossil fuel consumed or imported to the country. This way, it will cover both stationary and mobile, industrial and non-industrial processes, and be all encompassing—transportation, electricity generation, etc. The broad application of the carbon tax will produce three important transformations: behaviour changes, energy-efficiency (processes, consumption, etc) and increasing use of renewables [9,58].

Accordingly, there is need for adoption and implementation of carbon tax across broader Nigerian economy. Since Nigerian primary energy consumption is fossil fuel, addition of carbon tax will raise substantial revenue. The revenue should support low-carbon and renewable energy, and efficient waste management system which is crucial for circularity. The universal imposition of the tax in the upstream sector will make its administration simple considering poor data and monitoring mechanism of the country. The tax should be differentiated based on the carbon content of the fossil fuels (gasoline, diesel, petrol, DPK, etc). Three critical factors which policy actions must surmount to achieve the systems in Nigeria are: perceived regressive effect of climate policy and public interest and support [56].

Cooperation between informal and institutional actors across all levels must be achieved, and redirecting of national institutional actors towards a more active role to support finance for green investment [55]. For carbon tax to be very effective, the tax must be very high. At a low level, the tax could only sluggishly induce substitution processes [59]. Further higher prices of fossil fuel will impact the poor more. This poses a socio-political challenge for Nigerians, as most Nigerians rely on fossil fuels for transportation, self-generation, etc. Hence, the carbon tax should be moderate while other fiscal instruments should be integrated. Assessing a moderate carbon tax on 57.2 million liters/day of petrol (PMS) [60] which Nigeria consumes will produce a substantial fund to support green investments, while also improving behavior changes and energy efficiency. For carbon taxation, Nigerian fiscal regulators in collaboration with financial institutions and other agencies should set criteria for investments, funding access for ventures and enterprises to deepen climate change-mitigating business, inverse logistics and proper waste management ventures. Therefore, for decarbonization and green investments; policy should support mix instruments to scale green financing. Other fiscal instruments should include green bonds issued by public agencies for investment in green transition, direct subsidies for innovative SMEs that introduces clean energy and energy-efficiency [59], as directed in Nigeria's NREEEP.

5. Conclusions

Many ecological problems (wastes, resource depletion and climate change) are associated with exploitation, extraction, production and use of material and energy sources. Thus, the growing transition to circular economy (CE) and low-carbon and renewable/low-carbon energy sources. CE and ET 'decouples' economic growth and energy system from waste generation and emissions, respectively. Transitions to the two models are highly situated in socio-technical context, which assumes multi-level approach: (i) large scale transformation, (ii) socio-technical regime, and (iii) niches, which is "incubation rooms" —knowledge system—that drives innovation. Scaled coupling of CE and ET may occur in two fundamental ways: accelerated low-carbon and RE supply across production and consumption value chain; and transformation of 'waste' from production-consumption functions to supply raw material and energy services. It can be economy-wide application (local, regional, countrywide and global), or concentration on a collection of sectors, products, materials and substances. Nigeria should adequately improve its waste management system so as to foster recovery of 'wastes' as a valuable resource for further remanufacturing and energy recovery. The importance of eco-industrial park (industrial symbiosis) which integrates both CE and ET basic principles is crucial to environmental and economic development of the country. The above are premised on effective legislative, institutional framework and sustainable financing instruments. Accordingly, there is need for Nigeria to reimagine and rethink waste management and energy system in its socio-technological structure.

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Conflict of interest

The authors declare no conflicts of interest in this paper.

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