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Agroforestry: A Panacea to Energy Production and Food Security in Nigeria.

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Abstract

Agroforestry is an ancient practice with numerous benefits ranging from climate change to Energy supply, Shelter and structures, Plant resources, Biodiversity and improving rural livelihood. In Nigeria the adoption of the various agroforestry system varies across the different ecological zones; the practices in rainforest and derived savanna zones include homestead garden, taungya and alley farming, while scattered farm trees, shelterbelt and silvopastural are practiced in the savanna zones. Like every other developing country, Nigeria is faced with a major problem in the energy sector and it also faces a herculean task in feeding its ever-increasing population. However, these could be alleviated by annexing products and services available through Agroforestry value chain.

Nigeria is greatly endowed with abundant biomass resources which serves as raw material for the production of green energy capable of meeting her energy needs. Wood fuel consist of four main commodities namely fuelwood (firewood), charcoal, black liquor (bio oil) and wood waste in the form of sawdust. Briquette as an alternative source of energy produced from forestry and agricultural materials such as sawdust, sugarcane, wastes and some dead woods.

The multifunctional approach of Agroforestry system also increases food production by increasing resilience of crops for improved food security through the combined production of trees and agricultural crops on the same piece of land. Available data has shown that there is a considerable increase in the quality and quantity of food crops and other agricultural produce using Agroforestry techniques such as Pastoral farming in the North, Home-garden in the East and Taungya farming system in the Western part of Nigeria.

Considering the economic potential of agroforestry in food security and as renewable source of energy, various forms of agroforestry should be adopted based on its relevance to different ecological zones of Nigeria.

Keywords: *Agroforestry, Homestead, Biofuel, Briquette and Food Security*

Introduction

Agroforestry is defined as dynamic, ecologically based, natural resources management that, through integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (FAO, 2008). According to Amonum *et al* (2009) Agroforestry is widely regarded as a land use system which is capable of yielding both wood and food while at the same time conserving and rehabilitating ecosystems. Trees are deliberately integrated into farmland purposely to meet the immediate needs of the people such as food, medicines, income and ecological needs (Zommer *et al.* 2014). Agroforestry plays a vital role in increasing agricultural productivity, it has productive functions, such as the capacity of the tree component to produce fuelwood, fodder, fruit, and service functions, and most importantly soil conservation.

In developing nations such as Nigeria, Agroforestry remains an important avenue through which farmers participate in tree planting (Otegbeye and Ogigirigi 1991) basically because of the benefits attached to it. Importance of planting trees on the farm includes being a source of food such as leafy vegetables, fruits, nut, seeds, alcoholic drinks, edible fats and oils amidst other economic importance.

Agroforestry Systems in Nigeria

Agroforestry is not a new concept in the humid tropical region. Different types of traditional agroforestry systems exist, but they are not categoriresed into distinct sysytems as there was no standard classification system. Nair (1989) proposed a classification system based on structural, functional, agroecological, and socioeconomic factors. In agroforestry land use systems, three basic components are managed by people: the tree (woody perennial), the herb (agricultural crops, including pasture species), and the animal. Based on their structure and function, agroforestry systems can be classified into the following categories:

i. Agrisilviculture
ii. Silvopastoral system
iii. Agrisilvopastoral system
iv. Other systems

Benefits of Agroforestry Systems

Through the promotion of "an efficient, competitive and sustainable agricultural sector, which assures food security and increased income, agroforestry techniques offer considerable benefits for long term agricultural sustainability when land is scarce or when soil has a low fertility or is sensitive to erosion. Trees and shrubs have an important ecological and economic role in farming systems, hence Agroforestry is important in the following purposes:

(i) Soil Protection. This is by increasing nutrients in poor soils; and improving the structure of soil so that it holds more water).

(ii) Energy supply by Providing cheaper and more accessible woodfuels; Woodfuels include fuelwood, charcoal, sawdust and its products (e.g. Pellets). Producing better quality woodfuels depending on the species planted).

(iii) Shelter and structures (Providing cheaper building materials; Protecting animals, crops and humans from wind and sun; Providing fencing to protect crops from livestock and wild animals).

(iv) Plant resources/biodiversity (Improving local environmental conditions for naturally occurring plants to grow; Maintaining and increasing the number of species of plants).

(v) Cash income (Providing additional or off-season employment; Enabling the sale of tree products; Providing investments such as orchards, tree products, agri-business and long-term supplies of materials for the production of crafts.

Agroforestry and Energy Production

Agroforestry residue as potential for electricity generation in Nigeria towards 2040

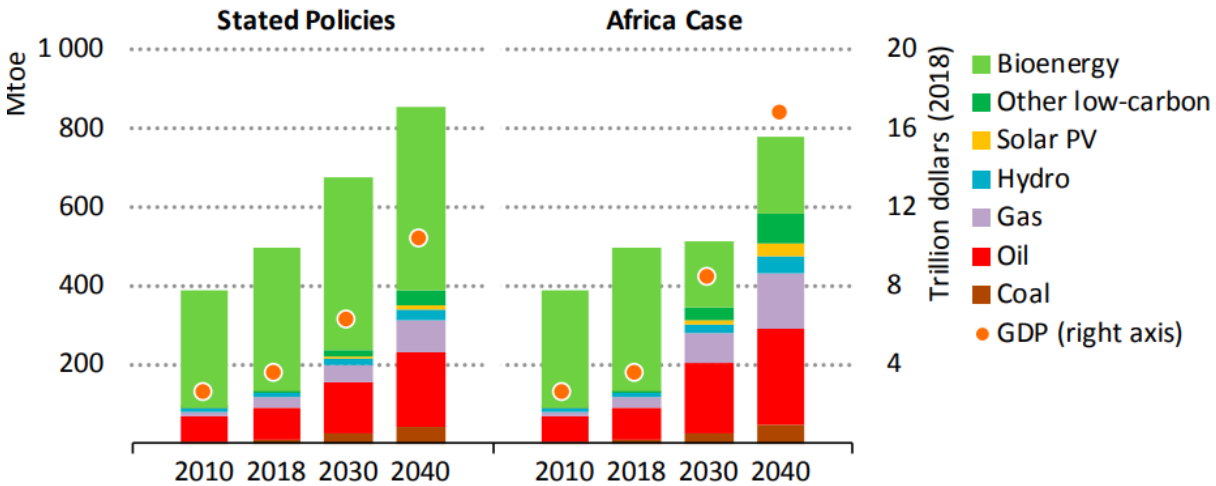
There is no doubt that the advancement of world economy has raised energy interest (Irfan *et al.,* 2019), because of the energy area's inborn bond to environmental changes and a dangerous atmospheric deviation, the replacement of fossil energy for alternative energy sources with low fossil fuel byproducts could be a feasible answer to manage developing energy interest and accomplish energy security (Chapman *et al.,* 2018). Renewables like breeze and sun based, because of high force quality and low capital expense, assume a fundamental part in miniature lattices (Wang *et al.*, 2020). These resources' helpful activity and ideal management experience the ill effects of nature (Aghajani

and Ghadimi, 2018). Not at all like sunlight based and wind assets, as biomass portrayal given so many advantages, handling irregularity as a promising and dependable choice of energy (Irfan *et al.,* 2019).

Biomass can be saved and used to produce power or changed into transportation powers and synthetic forerunners (Ferrario *et al*., 2018; Shahraki Shahdabadi *et al.,* 2020). Consequently, utilizing biomass into items and energy arose bio-economy idea as a progress from a fossil-based to a bio-based society and transformed biomass into a thrilling contribution to monetary movement (Vainio *et al*., 2019). Bio-economy follows reasonable development focuses by associating different areas some of which includes; forestry, agriculture, food, energy, waste management and chemical industries for reusing, recuperation and circularity (European Commission, 2018). The deployment of renewable technologies and improved energy conversion efficiency can substantiate these goals (Neofytou *et al*., 2020).

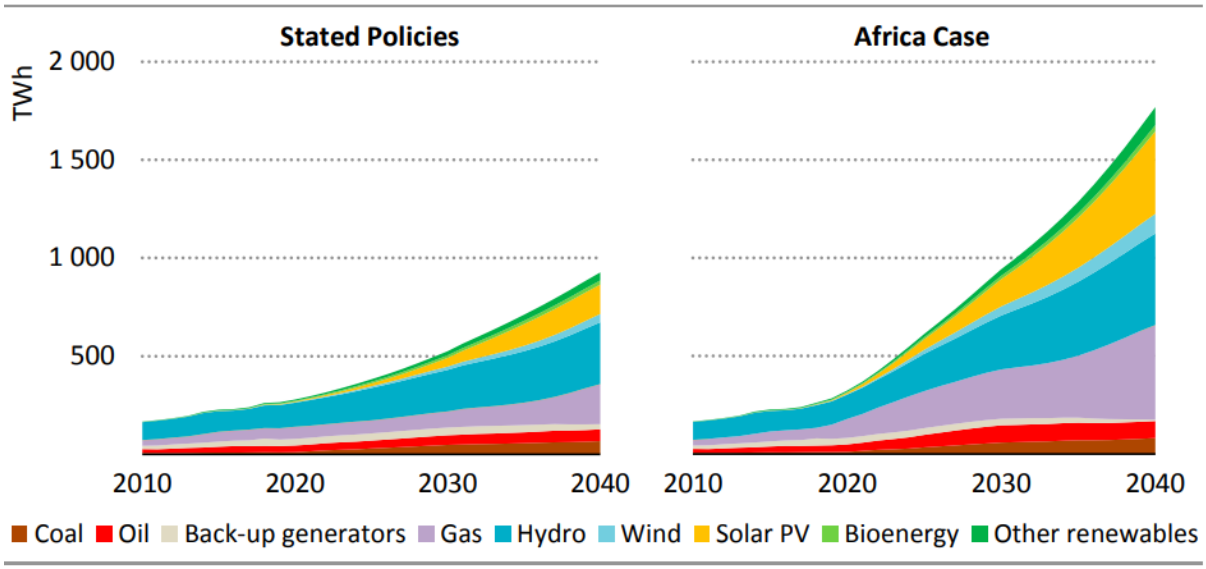
Nigeria like other countries of the world, has a huge potential to create bioenergy because of huge regional extension, the availability of plants and oilseeds, animals and metropolitan waste, close by long haul insight in using biomass deposits to deliver ethanol, power and warm in cogeneration units (Adegoke and Fuwape, 2008). According to the report of Africa Energy Outlook (2019), Natural gas remains the main source of power in the Africa continent, although there is a shift towards solar power as countries starts to exploit their large solar potential. Nigeria remains Africa's largest economy with over 80% of her power generation coming from gas and crude oil. Nigeria is the largest user of oil-fired back-up generators on the continent, Nigeria will however require less energy demand if the energy mix were to be diversified.

Although, a number of policies has been stated to promote energy generation by 2040 that will drastically improve energy efficiency which can be projected to accelerated move away from solid biomass to supply from natural gas and renewable sources which could be expand in both scenarios to meet rising demand for energy and electricity access and clean cooking facilities for all (Fig 1)



Source: Africa Energy Outlook 2019

Fig 1: Nigeria primary energy demand and GDP



Source: Africa Energy Outlook 2019
Fig 2: Nigeria electricity generation by technology

Today's power mix, dominated by hydro, gradually diversifies as solar power and natural gas increasingly make inroads into the power system. The combined share of solar and natural gas has been projected to reaches the level of hydro by 2040. Today, natural gas (27%) passes hydropower (26%) as the largest source of power supply by 2040 while the share of solar power rises to 24%. The main grid connects around 70% of the 230 million people gaining electricity access by 2030, alongside decentralised options for the remainder in more remote areas. In 2030, 530 million people remain without access. Decentralised solutions are the least-cost option for more than two-thirds of the 530 million additional people connected by 2030 to reach full access

Agroforestry residue and sustainable Energy source

Agroforestry residues include a wide range of materials during the cultivation and harvesting activities, such as straw, leaves, stumps, branches and treetops. Besides, by-products from agroindustry, sugarcane bagasse, rice husk, and residues from wood industry are secondary agroforestry waste (Egbewole, 2018). From an economic perspective, the use of agroforestry residues has a set of significant advantages since they constitute an alternative to the use of other biomass types (Rajabi Hamedani *et al*., 2019). Biomass use for electricity generation has been increasing in Nigeria, mainly through cogeneration systems supplying steam and electricity to sugar and alcohol mills.

Theoretical biomass energy potential calculation

Theoretical biomass energy potential identifies the overall annual biomass energy production from agricultural and forestry residues. This potential is a function of annual crop and forest productivity, residue to product ratio and available residue. In line with preserving organic carbon and nutrients in the soil, the availability factor represents the permissible fraction of collecting residues (Egbewole 2020).

Theoretical biomass potential is calculated as;

$$\sum_{1}^{N} P * AF * LHV * RPR \ldots\ldots\ldots (1)$$

Where:

P is the amount of forestry products and crops produced per year in tons;

AF is the availability factor indicating the fraction of residue available to be collected for energy use in percentage terms

LHV is the lower heating value of biomass residue in MJ/kg,

RPR is a residue-to-product ratio.

Technical potential of Agroforestry products

Biomass conversion technologies for electricity production vary based on technical features such as capacity ranges, types of primary conversion reactors and related efficiency, types of pre-treatments required for each technology, levelized electricity cost, and technology maturity level (Lora et al., 2019).

Organic Rankine Cycle (ORC) technology offers a solution of lower capital, operation and maintenance cost requirement than gasification. Nonetheless, the notably higher power-to-heat ratio of the gasification technology boosts electricity generation revenue and offsets technology related cost (Rentizelas *et al*., 2009).

In a study conducted by Lidiane *et al*., 2021 on the theoretical and technical assessment of agroforestry residue potential for electricity generation in Brazil, Conventional Rankine Cycle (CRC), Organic Rankine Cycle (ORC) and gasifiers coupled with internal combustion engines were selected to estimate biomass technical potential. It was reported that the viability of technology installation depends on the power plant capacity and the available biomass quantity. Therefore, the appropriate geographical distribution of technologies in the assessment of biomass technical potential is of great importance (Table 1).

Table 1: Technical assessment of agroforestry residue potential for electricity generation

Primary conversion technology	Prime mover	Characteristic	Power range
CRC	Steam turbine	Basic CRC schemes are relatively inefficient and can provide efficiencies in the range of 7 to 15% for typical pressures of 20 bar, depending on the equipment's efficiency that makes up the cycle and the type of turbine used. Higher efficiencies require steam parameters to increase and implement schematic improvements, such as steam reheating and regenerative heating; these measures require a detailed cost/benefit analysis (Franco and Russo, 2002)	>5000 kWe
ORC	Steam turbine	ORC is an efficient technological alternative for converting low and medium temperatures fluids into electricity on small and micro scales (Quoilin et al., 2013). The working fluids in an ORC cycle have a low boiling point and latent	160–1000 kWe

		heat of vaporization lower than water, allowing evaporation from lower temperatures. Smaller enthalpy drop of organic fluids while expanding allows an efficient turbine design (Bao and Zhao, 2013).	
Gasification	Internal combustion engine	Biomass conversion is carried out through partial oxidation of the biomass at high temperature, usually between 500–1100 ◦C. The oxidizing agent used can be air, pure oxygen, steam and its mixtures (Decker et al., 2012). Gasification seeks to convert the maximum amount of biomass into a mixture of fuel gases used as fuel in an internal combustion engine (Demirbaş, 2001). However, there is a need to incorporate a gas cleaning system to reduce contaminants in the gas to engine manufacturers' levels (Prabhansu Karmakar et al., 2015).	1000–5000 kWe

Food security

Food is a basic necessity of life which is essential for good health and optimum growth; it must however be of good quality and consumed in the right quantity. According to the United Nations' Committee on World Food Security, Food security implies that all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life (FAO 2008). A family is food secure when its members do not live in hunger or fear of hunger.

A major challenge to global food security is the need to approximately double food production over the next few decades, especially due to the rapidly growing demand from the developing world (Godfray *et al*., 2010). In Africa one in five people are hungry, making Africa the region with the highest prevalence of hunger in the world (FAO *et al.,* 2020). As reported by Omodero & Adeyemo (2020), the rate of Food insecurity in Nigeria is increasing and this poses a serious challenge to her citizens. Nigeria has been unable to meet the domestic food requirements of its ever increasing populace though agriculture (FMARD 2016), climate change and insecurity in some parts of the country is also partly responsible for the low agricultural productivity.

Combating Food security and Various Agroforestry

Agriculture contributed significantly to the tune of 50% of Nigeria's GDP up to the time of independence in 1960 and it also accounted for more than 75% of export earnings. However, with the discovery of crude oil and its rapid expansion in the late 1960s and early 1970s, the agricultural sector was neglected and the agricultural sector progress has been slower than expected inspite of the launching of various agricultural improvement programmes under different governments.

The rise of the oil industry has led to a decline in agricultural productivity, primarily affecting such formerly important export crops as cocoa, groundnuts, and cotton, but also hurting output of such basic foods as yams, millet, rice, beans, and cassava. Nigeria imported 40 percent of its food in 1980, at an estimated cost of $2billion (Igbokwe 1983).

Nigeria is one of the ten countries that accounted for 60% of the world population and has a population of 140 million (Sutton, 1996). Mounting population pressure resulted in ever-smaller farm size and the need to sacrifice 'unproductive' trees in favour of planting food crops. Moreover, the inability to raise yield levels forced the growing population to bring more land, often marginal land, under cultivation at the expense of the natural vegetation (Ed Verheij, 2007). Baumer (1990) reported that before long these trends led to alarming reports about deteriorating land use systems: expanding 'dust bowls' and deserts (because of wind erosion), degraded land following loss of topsoil and silting up of irrigation systems (all because of water erosion), declining soil fertility and yield levels (because of inadequate inputs such as manure and fertilizer and the opening up of marginal lands), etc. However, such negative experiences during the period led some farmers to experiment with agroforestry practices combining a diversity of livestock, annual crops with cultivated trees and use wild forest products such as cocoa. Previous researchers (Akinnifesi *et al.*2008; Adegbehin and Igboanugo, 1990) suggests that Agroforestry science and its application in development by small holders throughout the tropics plays an important role in achieving greater food security. Akinnifesi *et al.*(2008) reported that decade long trial in Malawi in which maize was intercropped with Nitrogen fixing tree *Gliricida sepium*, produced yields that averaged 3.7 tonnes a hectare, compared to 1.1 tonnes on plots without *Gliricida*. Small additions of mineral fertilizer push the yields above 5 tonnes. Similar results were observed in Zambia, Kenya, Tanzania and other countries of Southern and Eastern Africa.

Conclusion

In Nigeria as well as other part of the world several attempts have been made to adopt Agroforestry practices particularly in the area of agrisilvicultural types, in the tropics (Adegbehin and Igboanugo, 1990). However, the system has not been fully accepted due to the slow and/ or long term returns from the trees. A farmer would rather engage in cultivating annual crops that would bring in cash to cater for his necessary and immediate needs. Besides, perennial plants like trees, shrubs have the potential to provide large quantities of bio fuel feed stock. Given a relatively fixed land base, any Agroforestry practice can be designed to produce a harvestable product and at the same time provide a conservation service which helps to bridge the competition between agriculture and forestry land uses for energy crop production.

High and increasing population densities in large areas of many African countries have generated a negative impact on agricultural production and environmental integrity. Evidence has revealed that owing to increasing human and livestock population pressure on arable land and forest resources large areas in Sub-Sahara Africa have been exposed to serious loss of soil fertility, degradation and

ecological imbalance. One significant result is the declining agricultural productivity which is why poverty in the continent is so heavily concentrated among the rural populace.

In the past 15years, the interest in the adoption of agroforestry practices has increased dramatically. The primary reasons for this expanded interest have been for economic diversification and conservation benefits. Trees introduce both vertical and horizontal structural variation in agricultural landscapes. Agroforestry adds plant and animal biodiversity to the landscape that might otherwise contain only monocultures of agricultural crops. Agroforestry can serve to connect forest fragments and other critical habitats in the landscape.

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References

Adegoke, I. A., & Fuwape, J. A. 2008. *Combustion properties of briquettes as affected by production process in products and natural resources management.* Paper presented at the Proceedings of the First National Conference of the Forest and Forest Products Society Federal University of Technology, Akure, Nigeria.

Africa Energy Outlook 2019. International energy agency and World Energy Outlook Special Report ;an Overview of Nigeria. www.iea.org/reports/africa-energy-outlook-2019 (English version)

Aghajani, G., Ghadimi, N., 2018. Multi-objective energy management in a micro-grid. Energy Rep. 4, 218–225. http://dx.doi.org/10.1016/j.egyr.2017.10.002.

Akinnifesi, F.K; Chirwa, P; Ajayi, O.C; Gudeta, S; Matakala, P; Kwesiga, F.R; Harawa, H and Makumba, W. 2008. Contribution of Agroforestry research and development to livelihoods of smallholder farmers in Southern Africa. *Agricultural Journal Vol.3: 58-75*

Adegbehin, J.O and Igboanugo, A.B.I 1990. Agroforestry practices in Nigeria. *Agroforestry Systems* 10: 1-22

Amonum J.I., Babalola F.D. and Agera S.I.N., 2009. AGROFORESTRY SYSTEMS IN NIGERIA: REVIEW OF CONCEPTS AND PRACTICES. JOURNAL OF RESEARCH IN FORESTRY, WILDLIFE AND ENVIRONMENT. 1. 18-30.

Baumer, M., 1990. Agroforestry and Desertification. The potential role of agroforestry on combating desertificaton and environmental degradation with special reference to Africa. CTA, Wageningen, The Netherlands, 250 p. ISBN 92-081-039-4

Chapman, A.J., Mclellan, B.C., Tezuka, T., 2018. Prioritizing mitigation efforts considering co-benefits, equity and energy justice: Fossil fuel to renewable energy transition pathways. Appl. Energy 219, 187–198. http://dx.doi.org/10.1016/j.apenergy.2018.03.054.

Ed Verheij, 2007. Agroforestry. Agrodok 16. Agromisa, Wageningen, The Netherlands. *85 Pages*, *Published 2007* I*SBN-13: 978-90-8573-072-9, ISBN: 90-8573-072-4*

Egbewole Z.T. 2020. Correlate of lumber recovery from high forest tree species in Nigeria. Lambert academic publisher Germany. ISBN 9783659548512. p. 120.

Egbewole, Z. T., Falade, L. O., Rotowa, O. J., Kuje, E. D. and Mairafi, H. H 2018. Evaluation of the Effect of Agricultural Crop on the Growth Performance of *Gmelina arborea* under Agroforestry System. Proceedings of the 36th Annual Conference of Horticultural Society of Nigeria (Hortson). *ISSN 978-978-54729-6-7.*

European Commission, 2018. A sustainable bioeconomy for europe: strengthening the connection between economy, society and the environment. http://dx.doi.org/10.2777/478385

FAO, 2008. The future of global land use and World Agroforestry Congress, in Nairobi, Kenya 24 28th August, 2009. In Dennis Garrity Agroforestry Symposium United Nations 16/12/2009.

FAO, ECA and AUC. 2020. Africa Regional Overview of Food Security and Nutrition 2019. Accra. https://doi.org/10.4060/CA7343EN

Ferrario, M., Rajabi Hamedani, S., Del Zotto, L., Simone, S., Bocci, E., 2018. Techno-economic analysis of in-situ production by electrolysis, biomass gasification and delivery systems for hydrogen refueling stations: Rome case study. Energy Procedia 148, 82–89. http://dx.doi.org/10.1016/j.egypro.2018.08.033

FMARD. 2016. The agriculture promotion policy (2016 – 2020): Building on the successes of the ATA, closing key gaps. Retrieved from https://fscluster.org/sites/default/files/documents/2016-nigeria-agric-sectorpolicy-roadmap_june-15-2016_final1.pdf

Godfray C., Beddington J., Crute I., Haddad L., Lawrence D., Muir J., Pretty J., Robinson S., Thomas S. and Toulmin C. 2010. Food Security: The Challenge of Feeding 9 Billion People. Science (New York, N.Y.). 327. 812-8. 10.1126/science.1185383.

Igbokwe, Echeazu Jude, 1983. "The effect of oil production on the agricultural economy of Nigeria, 1970-1980" (1983). Retrospective Theses and Dissertations. 16518. https://lib.dr.iastate.edu/rtd/16518

Irfan M, Zhao Z-Y, Ahmad M, Mukeshimana M.C. 2019. Solar Energy Development in Pakistan: Barriers and Policy Recommendations. *Sustainability*. 2019; 11(4):1206. https://doi.org/10.3390/su11041206

Lidiane La Picirelli de Souza, Sara Rajabi Hamedani, Electo Eduardo Silva Lora, Josè Carlos Escobar Palacio, Gabriele Comodi, Mauro Villarini, Andrea Colantoni, 2021. Theoretical and technical

assessment of agroforestry residue potential for electricity generation in Brazil towards 2050, Energy Reports, Volume 7, 2021, Pages 2574-2587, ISSN 2352-4847, https://doi.org/10.1016/j.egyr.2021.04.026.

Lora, E.S., Santiago, Y.C., Román, Q., Bertel, Q., Venturini, O.J., 2019. Metodología para la selección de tecnologías de generación de electricidad basadas en la conversión termoquímica de biomasa en pequeña, mediana y escala industrial Methodology for the selection of technologies for electricity generationbased on biomass. In: 25th Int. Congr. Mech. Eng. pp. 1–10.

Nair P. K. R. (ed.). 1989. Agroforestry systems in the tropics. Kluwer Academic Publishers, in cooperation with ICRAF. 664 pages. ISBN 90-247-3709-7

Neofytou, H., Nikas, A., Doukas, H., 2020. Sustainable energy transition readiness: A multicriteria assessment index. Renew. Sustain. Energy Rev. 131, 109988. http://dx.doi.org/10.1016/j.rser.2020.109988.

Omodero, C.O., & Adeyemo, K.A. (2020). Food Insecurity and Covid-19 Pandemic: the Inevitability of Improving Agriculture Emphasized. *Academy of Entrepreneurship Journal, 26*.

Otegbeye, G.O and Ogigirigi, M.A. 1991. Towards amelioration of the ecology of the semi-arid areas Nigeria through afforestation: Problems and prospects, paper presented at the international workshop on ecology and society in the history of the African Sahel and Savannah 22nd -28th September, 1991, Maiduguri, Nigeria.

Rajabi Hamedani, S., Colantoni, A., Gallucci, F., Salerno, M., Silvestri, C., Villarini, M., 2019. Comparative energy and environmental analysis of agro-pellet production from orchard woody biomass. Biomass Bioenergy 129, 105334. http://dx.doi.org/10.1016/j.biombioe.2019.105334.

Rentizelas A., Tatsiopoulos I.P. and Tolis A. 2009. 'An Optimization Model for Multi-biomass Tri generation Energy Supply', Biomass and Bioenergy, Vol. 33 (2), pp. 223-233.

Shahraki Shahdabadi, R., Maleki, A., Haghighat, S., Ghalandari, M., 2020. Using multi-criteria decision-making methods to select the best location for the construction of a biomass power plant in Iran. J. Therm. Anal. Calorim. http://dx.doi.org/10.1007/s10973-020-10281-1.

Sutton, W.R.J. 1996. Long Term Future of Wood. Paper presented at the Commonwealth Forestry Association Heathrow conference on "privatization of public forests" 2nd June, 1996. Kew Gardens. London.

Vainio, A., Ovaska, U., Varho, V., 2019. Not so sustainable? Images of bioeconomy by future environmental professionals and citizens. J. Clean. Prod. 210, 1396–1405. http://dx.doi.org/10.1016/j.jclepro.2018.10.290.

Wang, P., Wang, D., Zhu, C., Yang, Y., Abdullah, H.M., Mohamed, M.A., 2020. Stochastic management of hybrid AC/DC microgrids considering electric vehicles charging demands. Energy Rep. 6, 1338–1352. http://dx.doi.org/10.1016/j.egyr.2020.05.019.

Zomer R.J., Trabucco A., Coe R., Place F., van Noordwijk M., Xu J.C. 2014. Trees on farms: an update and reanalysis of agroforestry's global extent and socio-ecological characteristics. Working Paper 179. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. DOI: 10.5716/ WP14064.PDF