The bigger picture of Biofuels

J. Gane (Julius Gane)
Energy Research Institute,
Faculty of Engineering, University of Leeds
Leeds, UK
Contact email: pmjga@leeds.ac.uk or mawusegane@yahoo.com

***Abstract*— This paper makes some significant observations regarding what is currently counted as sustainable biofuel development; relating them towards research and regulatory improvement. It acknowledges the role of dynamism in biofuel innovation and sustainability, examining some existing policies - road transport fuel obligation (RTFO) in context with biofuels production, application and air pollution gas emission. Present literature (on biofuels and sustainability) has extensively manifest biofuels and transportation in context with net energy relations (NER) - mainly global warming potential (GWP) and abiotic depleting potential (ADP) issues – but other ways these can be driven more in-depth along with environmental health has been the focus of this paper. The ultimate objective is maximization of *sustainability significance* (described in the text as minimal effects on society, economy and environmental quality) of biofuels as alternative sustainable transport energy resources. Certain limits of engine and vehicle based technology (i.e. cost implications) have created a critical role for biofuels in sustainable transportation. How the production and application of these alternative sustainable transport mechanism can be well managed is the focus of this article. Improvement on existing impact assessment scopes and method can produce higher environmental quality outcomes from biofuel innovation, development and use. A framework for this purpose is proposed; offering a more significant insight about how various biofuels can optimize sustainability.**

***Keywords*—Biofuels, Alternative fuels, Biofuels and sustainability, Biofuels and impact assessment**

I. Introduction

Motor vehicles act as the engine of world development (6), but this significance is escorted by pollutant emissions; air pollution gases that can cause harm to human health and the environment. Historically, varied efforts have been channeled towards regulating air pollution from road transport in particular; but these have mostly been slow to adopt. Attempts to reduce number of vehicles on roads (i.e. car demand management strategies) is one; aside others such as: promotion of park and ride, bicycle lanes or even public transport. The main challenge, as has been shown so far has been attributed to the notion that socially, many people have adapted their lives to independence and freedom of movement (7).

To maintain a quest for world development, or even the independent value needs of transport, two main policy efforts have been on the lead for decades now. Vehicle or engine technologies, that for example help to improve thermal efficiency and thereby managing obnoxious gases has for some time now been at the forefront of air pollution control from mobile sources. There can be various techniques involved with this technology (e.g. common rail systems, turbochargers, exhaust gas recirculation and exhaust gas after treatment devices) but for all the primary objective has been towards combustion optimization or controlling air pollution at the tail-pipe or vent (7, 33). Aside the cost implications of these vehicular or engine-based techniques, fuel consumption implications also compound the challenges faced in adapting and relying on these technologies for pollution control from road transport sources. Alternative fuels have therefore now emerged as promising complement options even as emission regulation is becoming more stringent (33); but these are mostly promoted for carbon reduction rather than other possible air pollution gases.

In this article, biofuels are examined as emerging, mandatory and alternative transport fuels; but there is a greater emphasis on possible negative impacts on tank to wheel (TTW) effects. Presently, various regulatory provisions are available within the context of the European Union (EU) – e.g. Renewable Energy Directive (RED) and also the Fuel Quality Directive (FQD) - but the present paper critically examined the reference of biofuels and sustainability. It is recognized that the TTW carbon footprint of biofuels already form part of the global carbon cycle (25), but do we have other exhaust emissions of environmental health significance to be concerned about? Compared to petroleum diesel, reduced emission levels can be expected when biofuels or blends (with petroleum based diesel) are used (33). But some of these emissions can be trans-boundary and persistent in nature - i.e. nitrous oxide, sulphur dioxide, volatile organic compounds (VOCs) etc. (9) – aside the fact that biofuels from different origins and feedstock types (25) can have varied chemical composition; thereby capable of producing variable TTW emission effects. In other words, although reduced pollutant emissions are predicted for renewable alternative fuels (33), diversified feedstock provision can affect a broad generalization of TTW air pollution gas effects from these sources.

Whether obtained from the United Kingdom (UK) or outside, the Department for Transport (DfT) has shown that utilized or used cooking oil (UCO) constitutes the highest feedstock supply for biofuel production for the UK - i.e. 35% feedstock supply from outside and 43% derived from the UK (12). Consequently environmental quality impact issues regarding these type of biofuels cannot be overemphasized. Globally various air quality directives mandate a requisite monitoring or emission test campaigns in order to address risk of adverse environmental health effects that can arise through air pollution from mobile sources. The present paper identifies that biofuels are produced from diverse feedstock, and can be associated with varied conversion or processing methods to produce the biofuels. On this account air pollution and environmental quality regulation must be concerned about sustainability from these other angles too; mainly concerned about impacts due to different feedstock supply and production, as well as conversion methods; but also cognizant of TTW effects.

Biofuels are produced for use in combustible engines, therefore it will be needful to draw attention towards impacts produced during the process, especially now we seem to have a mounting efforts channeled in managing those impacts emerging from feedstock supply and conversion. The bioconversion of food waste to produce biofuels (23), deemed to have addressed debated issues and discourses about food prices, starvation, land-use competition and other related socio-economic challenges (1, 25) is one of them. While technological improvement to convert feedstock to more optimum and sustainable biofuels is also shown by Li *et al.* (2014). In terms of biofuel combustion and obnoxious pollution gases not very much discourse or regulatory concerns has been raised in the literature. The assumption here is that if biofuels were produced from different feedstock, and varied in chemical composition terms then different TTW exhaust emissions can be anticipated for the varied types of biofuels. Environmental quality effects of air pollution gases are not only localized issues; some air gases can cause transboundary air pollution; described as transportation of an air pollutant in the atmosphere either from country to country or region to region, with tendencies of chemical transformation (9) over any 'transboundary journey.' Ignoring air pollution from different biofuel use or the TTW exhaust emission can therefore not only present localized exposure risks, but undesirable detrimental consequences that can affect an entire population locally, nationally or even regionally.

The past decades and years have seen biofuel development mostly associated with reduction of greenhouse gas (GHG) emissions, as well as contribution to energy security (25, 29). The UK's RTFO policy for instance identifies managing carbon intensity and sustainability which is based on carbon reduction as primary objectives (12). Transportation fuel use and pollution span beyond GHG emissions (33, 17), as such, any other trade-off effects, outside the predominant context of carbon footprint must also constitute research and regulatory concern.

Predominantly, those impacts due to feedstock supply (i.e. food security, rebound effects due to land conversion etc.), or even when these (feedstock) are converted or processed as biofuels are altogether receiving adequate attention; but the overall environmental quality significance of different feedstock and biofuels will not be realized properly when assessments and controls are limited only to these. Attributable TTW air pollution effects (i.e. GHGs and other air pollution gases) from biofuels must well be investigated for biofuels of different origin, kinds and processing protocols and methods. Straight utilized cooking oil (SUCO) biofuel for example can produce a negligible TTW carbon footprint, on account that carbon emissions are part of the global carbon cycle (25), but as shown by Rakopolous *et al.* (2006) and Gaffney *et al.* (2009), emission of other air pollution gases are also possible.

The paper examines some relevant literature on biofuels and sustainability; to determine improved ways to maintain the sustainability significance of biofuel development and application. From a critical assessment viewpoint (i.e. holding a value of air pollution and environmental quality), the present paper presents an assumption that biofuels are produced from varied feedstock, which will probably have varied chemical composition too. Therefore impact assessment must be explored beyond feedstock production and supply, or even the processing stages that produce the biofuels. The paper reflects in-depth on sustainability in context with transport biofuels; adopting a new concept, sustainability balance transfer (SBT), to explore other possible impacts of sustainability along the production and use of diverse biofuels. In other words, biofuels can be renewable in context of carbon reduction, but from different feedstock source and type, the risk of other air pollution gas effects cannot be predetermined.

II. Methodology

We have quite a significant number of published literature broadly on biofuels. The present paper is more concerned about how published literature addresses impacts of biofuel innovation, development and application. The focus as this paper shows is contemporary published literature, specifically 2014, with the assumption that emerging literature is often constituted on the previous. The primary objective is to examine NER factor issues and trade-off effect discourses in context of biofuel production and sustainability. Approaching the present paper from an environmental point of view (which represents the academic background of the primary author), the authors focussed more on pollution and health issues as discussed in existing literature. A preliminary review of literature (involving mainly a title review of published literature on the subject at web of knowledge) indicated we have an enormous published literature on the subject broadly in relation to sustainability; nonetheless, impacts relating in specific terms to air pollution outside carbon emission is not common. Building on preliminary observations, the present paper sets out to examine air quality issues that may be relevant for biofuel development and sustainability. The primary objective is to examine ways to better optimise sustainability significance of biofuel development and use in road transportation. Moreover, the subject is perceived as politically inclined, therefore reference was also made to some published literature from UK-based government institutions (i.e. Department for Transport, Department of Health, etc.). The overall aim is to explore adequate ways in maximizing the application of low carbon transport energy in context with embedded sustainability issues; but with greater focus on air pollution gas emission and environmental quality.

III. OBSERVATIONS & DISCUSSIONS

Biofuels and trade-off issues

Removing trees (deforestation) to cultivate feedstock for biofuels (16) or purposefully growing up algal population for the same purpose 4; 30) can altogether produce some negative impacts on environmental quality. Whether as a rebound or a NER effect as has been described by Rocha *et al*. (2014), all these possible impacts are receiving a wide range of research and regulatory attention. The RTFO is one the regulatory packages under the EU/UK environmental quality and sustainability scheme. These initiatives have triggered varied forms of innovations and technologies such as the bioconversion of waste to energy (WtE) (23), beneficial in addressing some of the impacts of rebound effect and NER or even socio-economic related consequences such as food insecurity issues. As demonstrated by Li *et al.* (2014) there seems to be promising avenues towards optimum and sustainable conversion of biofuel feedstock from waste resources (i.e. UCO).

Assessing the significance of biofuels only based on energy security and carbon reduction is considered in this paper as inadequate, if existing thoughts, actions and aspirations; either in research or regulation fail to take stock of various trade-off consequences from feedstock production through to its conversion to biofuels and the use of the biofuels. In theoretical terms regulatory instruments have no room for unsustainable biofuels (11), and very best evidence and practicable opportunities are sought in biofuel policy and regulation (11). This requires in-depth reflection beyond the beneficial outcomes of biofuels through to the negative outcomes also. Though not fully embraced globally (14), considering that certain pollution gases produced from biofuel combustion in transportation are persistent and trans-boundary (9) like polycyclic aromatic hydrocarbons (PAHs) this paper perceives in-depth research as well as requisite regulation towards a better understanding and management of biofuel and sustainability issues. Exposure to PAHs for example can pose various physiological and toxicological health risks (22, 32), possibly mutagenic (24, 32) and/or carcinogenic (3). Unless sustainability trade-off issues are thoroughly observed, processed and managed properly beyond feedstock and processing stages of biofuel development, it is anticipated that certain risk issues will remain latent to damage environmental health security in an era of quest for energy security through biofuels.

Biofuels and environmental quality issues are dealt with differently (by scope and methods) in the literature. The NER concept is one of those, but relates broadly to the impact (in energy loss or benefit terms) caused as a result of biofuel development. It mainly describes losses that take place (or will take place) in bid to produce an alternative fuel, in this instance representing biological or renewable energy resources (i.e. biofuels). For example, the equivalent energy output in carbon emission terms for SUCO and its counterpart biodiesel, UCO as well as petroleum diesel is shown as 1.76 gCO_2e/MJ, 3.80 gCO_2e/MJ and 87 gCO_2e/MJ respectively (25). This means that a lower energy (in terms of carbon footprint) is anticipated to produce UCO compared to petroleum diesel; even as a higher is predicted for UCO compared with SUCO. In other words, compared with the other two sources of transport energy (i.e. petroleum diesel and UCO) SUCO is expected to come out as a more promising; having a better prospect of environmental quality in GHG emission terms. GHG emission saving is just one aspect in biofuel sustainability impact assessment.

NER, one of the impact assessment tools or methods typically emphasize impacts caused by the origin, type or supply of feedstock for biofuels. The past decade has seen a significant expansion of biofuel development due to unsustainable reliance on fossil fuel energy resources (34, 2, 25, 31, and 39). According to the Department of Energy and Climate Change (DECC) the transport sector, between the years of 2000-2012 for example had witnessed the least decrease in energy consumption compared to other energy demand sectors (8). In an increased economic and population expansion situation a greater uptake can even be anticipated (34, 29) considering that transportation is the engine of world development (6), and also benefits of freedom of movement or personal independence (7). With these attributes or value issues demand for transport energy is envisaged to grow more steadily in the years, decades or even centuries ahead. The International Energy Agency (IEA) has predicted a modest rise in biofuel production globally (21). If that happens, then impact or challenge issues cannot be ignored concerning biofuel production and utilization. Demands or competition also from other sectors (i.e.

housing, transport, industry etc.) will also impact overall on energy demand issues globally; inclusively creating a useful avenue for biofuels for example in road transport. Without the alternatives (to fossil fuel energy resource) depletion and higher risks of climate change are anticipated (34, 2, 31, and 39). Largely, the quest for alternative energy resources will be more beneficial under rational and efficient end-use technologies (33). The earlier we emphasize in-depth assessment of impacts along production-conversion and utilization chains of varied biofuels, the better for management of sustainability or environmental quality and health.

Net Energy Relations

From the above examples, comparing petroleum diesel, UCO and SUCO in terms of well-to-tank (WTT) carbon footprint as shown by Li *et al*., (2014) SUCO is considered the most desirable transport fuel. But Rocha *et al* (2014) have explored the impacts of WTT biofuel production beyond the global warming or GHG emission effects. Overall, these have been categorized into five (5) potential impact groups, and include; Abiotic Depletion Potential (ADP), Global Warming Potential (GWP), Human Toxicity Potential (HTP), Acidification Potential (ACP) and Eutrophication Potential (ETP). Abiotic factors represent non-living (i.e. habitat and climate) but supportive systems of life (i.e. biotic factors); needful in keeping ecosystems. In other words ADP effects represent habitat loss consequences which in effect can impact on species number or extinction issues, or even leading to loss of recreational values to certain ecosystems. In broad terms, land conversion for some types of feedstock – i.e. Jatropha (5) – affects habitat and environmental quality as consequences of carbon debt (i.e. GWP) or even ecological damage (19, 20, 25, and 27).

Again, biofuel feedstock from other sources such as algae (especially when produced on a large scale) can also contribute to eutrophication effects (9, 4). ETP effects can affect water oxygen levels, sometimes leading to water toxicity especially when certain types of algae species are purposefully grown, impacting on species number, diversity, and even damaging the recreational values of affected water bodies (36). Though this can be salvaged through improved decisions and technology, the cost implications are seen as a major barrier (4, 26).

Aside the illustrated impacts relating to ADP, GWP, ETP, HTP and ACP; others in terms of impacts on the society and the economy are also reported. For example biofuel feedstock produced from rapeseed palm, sunflower, soybean, which are all edible food products are criticized as risk factor issues to food security, high commodity prices, land use change and competition (25, 28). It is apparent from the above discourses that impacts of biofuel production are well focused on supply and production of feedstock. But sustainability negative effects can be explored and kept in focus beyond the existing dimensions. Improving feedstock conversion or processing can also yield beneficial outcomes for sustainability. For example Li *et al.* (2014) have shown that eliminating the trans-esterification process in UCO production reduces further the WTT carbon footprints in production of its counterpart biofuel, SUCO. This shows that further to sustainability concerns at biofuel feedstock supply and production, there are still other aspects in biofuel production, processing and utilization stage that should require sustainability attention.

Biofuels are produced for transportation, therefore possible impacts for example from road transport use of these must also receive adequate attention and improvement technologies the same as the feedstock supply and conversion are. Combustion processes impact on the atmospheric system through the release of varied obnoxious air pollutants (17). GHG from road transport is quite significant, estimated as 90% of total emissions from the transport industry (38, 25). But in terms of the TTW CO2 emissions from biofuels (e.g. SUCO) negligible carbon footprint has been predicted on the basis that this already forms part of the global carbon cycle (25). But as shown by Rakopolous *et al*. (2006), carbon emissions are not the only air pollution gases produced in fuel combustion. We also have other obnoxious air pollution gases to be concerned about (33, 17). PAH for example can be transboundary and also persist in the environment (39, 9) posing various environmental health risks (e.g. cancer).

It is evident that biofuel innovation, development and use has played a significant role in climate change mitigation or even world development security according to Britto *et al.* (2014). However, we must thoroughly be concerned about trade-off effects that can possibly arise in the production and use. In other words, sustainable production and use of biofuels in an era of biofuel need must constitute the basis of alternative fuel policy decisions and planning.

Biofuels and EU Sustainability requirement

It is possible to define the term sustainability in different ways; by scope, purpose or probably value factor relations. For example an economist may look at sustainability within the domains of cost savings, while environmentalists also from the viewpoint of environmental quality and health. Sustainability is more concerned about the steady-state economy (10) or securing a better future for generations to come, in socio-economic and environmental terms (15). But according to the World Commission on Environment and Development (WCED) the term sustainability describes “meeting the needs of the present without compromising the ability of future generations to meet their own need” (37: 39). This shows that the agenda for carbon reduction and also road transport fuel security must be targeted with minimal challenge for future generations. Sustainability agenda, as shown in a recent paper (18) can be attained at different magnitudes, with the best circumspect steps attaining the optimum attainable magnitude. In other words, if seen as an achievable goal, then sustainability achievements can assume varied magnitudes or scales of that goal; if the optimum attainable status ever existed.

The EU policy on biofuels has two key agenda; reduction of carbon intensity and sustainability of biofuels – which is also concerned about GHG savings of the biofuel produced or more closely related to ADP and GWP. For instance the RED and FQD have three essential requirements of biofuel sustainability. Firstly, to achieve 35% GHG savings from biofuel, and also that biofuel feedstock is not obtained from land with high biodiversity value, or last but not the least feedstock for biofuels are not obtained from land with high carbon stock such as forests (11). If sustainability issues affects the society (37, 15, 10), then other aspects of impacts aside these GWP and ADP related concerns and assessment must also be observed especially under the RTFO.

Sustainability Balance Transfer (SBT)

Looking from a financial point of view, more specifically in banking (cash) transactions, a bank customer can engage in a balance transfer transaction in order to relief oneself for example from a higher interest rate. For whatsoever reasons, bank balance transfers will often take place for some value reasons. But when these occur, a transferred amount still makes the customer a debtor. Relating this illustration with alternative fuel innovation, intended to manage climate change, or for energy security; creating other environmental damage impacts as a result of biofuel development will still make environmental health policy indebted to certain issues of sustainability (or environmental quality). Addressing one environmental quality issue to create another will probably defeat the sustainability significance of biofuels. Climate change is a global and slow or gradual event, but emission of obnoxious or air pollution gases (e.g. PAH) beyond certain threshold levels can produce immediate or even delayed effects, adversely affecting the status quo of environmental quality and health. The prospects of biofuels in climate change reduction must not be promoted and achieved to create other repercussions that may affect sustainability either in the short or long-term. Improving negative impacts due to different biofuel feedstock is well advanced; as we now have WtE methodologies; same as improvement of processing methods of feedstock to produce biofuels. Relevant emission test campaigns will create a better understanding about the exhaust emission risk factors associated with this biofuel innovation. The key assumption under the SBT concept is that, emergence of other environmental quality risk issues will discount the sustainability significance of alternative low carbon fuels or biofuels. Regulation relies on environmental sustainability security of biofuels UK (10), therefore relevant emission test campaign will appropriately inform policy regarding air pollution gas emission risks from low carbon biofuels such as SUCO.

How impacts must be approached in biofuel production

Assessment of the sustainability significance of biofuels (i.e. maximizing the environmental quality and socio-economic benefits and not losses) will require a thorough reflection over the embedded possible negative consequences, beyond feedstock production and conversion improvement. Biofuels support a diversified supply of energy for transport and climate change reduction but impacts due to its production and use must also receive adequate research and regulatory attention in order not to tarnish the original intended purpose (of environmental quality and health). Different biofuels are produced from varied feedstock; the possibility therefore that impacts will vary especially in relation to environmental quality due to those different sources and types of feedstock, and also the processing and utilization of the varied biofuels must be critically examined at occupational and population health levels.

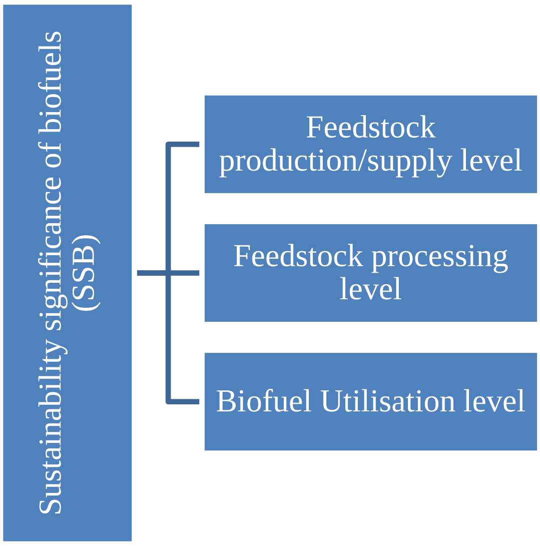

Figure 1: A module to account for sustainability significance of different biofuels

Present literature emphasizes environmental quality significance of biofuels at the utilization stage (in motor vehicles) mostly based on mitigation of GHG emissions. Considering however its main use in engine combustion or road transportation, emission of other air pollutants, outside the scope of GHG must also receive necessary attention due to the risk effects. Rakopolous *et al.* (2006) and Gaffney *et al.* (2009) have shown the need for emphasis on this next level of impact assessment (i.e. utilization level, see fig. 1) for each biofuel. The framework shown in fig 1 above will produce a better overview regarding the sustainability significance of different biofuels.

IV. CONCLUSION

This paper anticipates an inexhaustible sustainability inventory management in biofuel innovation, technology and development; especially when feedstock for its production continually remain varied. In other words, the use of a wide-ranging types and origins of biofuel feedstock can present a varied challenges of sustainability significance. Existing discourses along NER, leading to certain national, regional or international directives (i.e. RED, FQD and RTFO, etc.) can be improved in making the role of biofuels in an era transport dependency worthwhile. Biofuel utilization involves engine combustion, a process which can produce pollution gas effects; and can when biofuels from different origins have, different chemical composition and processing protocols. Despite the immense recognition towards different impact issues in biofuel production, impacts outside carbon saving has not received as high recognition. As perceived by the present paper, environmental context of sustainability must span beyond mitigating GHG emissions and climate change; to investigate various air pollution gas emissions from different kinds of biofuels. In context of the bigger picture of environmental quality; recognizing, assessing and managing well emissions from biofuel from diverse origins and kinds, or even the varied processing as well as the engine combustion conditions in motor vehicles will not only save public health. Proper inventory regimes (either at feedstock supply, processing and user levels), will not only account for the risk, but will also create an avenue for improvement. Biofuel innovation for air emission regulation and energy security or for whatsoever other value or relevant reason can be characterized by embedded environmental quality as well as socio-economic issues; each of which must be well attended to by reviews, research and regulation at the relevant levels of feedstock supply, processing and utilization (fig 1 above). It is suggested that trade-off effect issues, especially at the utility level of any biofuels development chain must gain grounds in public/environmental health regulation in order to enhance a better understanding of biofuel sustainability (environmental quality) significance. Attributable air quality risk due to varied sources and processed methods of bio-converted materials for transport fuel will need thorough examination to unlock any concerns with regard to regulated and non-regulated exhaust emissions. Research and policy have to start thinking more creatively about biofuel technology while recognizing that air pollution and health risk issues must catch up with a changing trend of biofuel innovation and utility. The paper examines another way to thoroughly reflect on the overall possible impacts due to biofuel technology, along the production-utilization chain, beyond existing remedial measures (i.e. waste-to-energy to address food insecurity issues, or eliminating trans-esterification stage in processing biodiesel to further reduce carbon impacts).

REFERENCES

[1]E. Acheampong, and B. B. Campion, "The Effects of Biofuel Feedstock Production on Farmers' Livelihoods in Ghana: The Case of Jatropha curcas", *Sustainability*, Vol 6, Is. 7, 2014, pp 4587- 4607

[2] M. H. M. Ashnani, A. Johari, H. Hashim and E. Hasani "A source of renewable energy in Malaysia, why biodiesel?" *Renewable & Sustainable Energy Reviews,* Vol. 35, 2014, pp. 244-257.

[3] A. Bhargava, R. N. Kharma, S. K. Bhargava and S. Kumar, "Exposure risk to carcinogenic PAHs in indoor-air during biomass combustion whilst cooking in rural India". *Atmospheric Environment,* Vol. 38, n. 28, 2004, pp. 4761-4767

[4] H. Blaas and C. Kroeze, "Possible future effects of large-scale algae cultivation for biofuels on coastal eutrophication in Europe", *Science and the total environment,* Vol. 496, 2014, p. 45-53

[5] F. Boamah, "How and why chiefs formalise land use in recent times: the politics of land dispossession through biofuels investments in Ghana", *Review of African political economy*, Vol. 41, Is. 141, 2014, pp 406-423

[6] R. F. Britto and C. A. Martins, "Experimental analysis of a diesel engine operating in Diesel-Ethanol Dual-Fuel mode". *Fuel,* Vol. 134, 2014, pp. 140-150.

[7] J. Colls, *Air Pollution*, 2nd Ed. Taylor and Francis: London, 2002

[8] The Department of Energy and Climate Change (DECC), "Energy consumption in the UK". Available at <https://www.gov.uk/government/statistics/energy-consumption-in-the-uk>, *2014,* Accessed on 05/11/2014

[9] Department of Environment, Food and Rural Affairs (Defra), "National Atmospheric Emissions Inventory: overview of air pollutants". Available at < <http://naei.defra.gov.uk/overview/ap-overview>, 2013, Accessed on 02/12/2014

[10] R. Dietz and D. O'neil, *Enough is Enough: Building a sustainable economy in a world of finite resources*. Routledge: London, 2013

[11] Department for Transport (DfT), "Low carbon Transport: a greener future", Available at <http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/sustainable/carbonreduction/low-carbon.pdf>, 2009, Accessed on 07/11/2014

[12] Department for Transport (DfT), "Developing evidence based low carbon transport policy". Available at <https://www.gov.uk/government/policies/reducing-greenhouse-gases-and-other-emissions-from-transport/supporting-pages/developing-an-evidence-based-low-carbon-transport-policy>, 2012, Accessed on 21/10/2014

[13] Department for Transport (DfT), "Biofuel Statistics: Year 6 (2013-2014), report 5". Available at <https://www.gov.uk/government/statistics/biofuel-statistics-year-6-2013-to-2014-report-5>, 2014, Accessed on 12/12/2014

[14] W. Du and D. H. Liu, "Biodiesel from Conventional feedstock. *Biotechnology in China" Iii: Biofuels and Bioenergy,* Vol. 128, 2012, pp. 53-68.

[15] European Communities (EC), "A sustainable future in our hands: guide to the EU's sustainable Development Strategy". *European Communities*: Luxembourg, 2008

[16] Y. Gao, M. Skutsch, R. Drigo, P. Pacheco and O. Masera, "Assessing deforestation from biofuels: Methodological challenges", *Applied Geography*, Vol. 31, Is. 2, 2011, pp. 508- 518

[17] J. S. Gaffney and N. A. Marley, "The impacts of combustion emissions on air quality and climate - From coal to biofuels and beyond". *Atmospheric Environment*, Vol. 43, n. 1, 2009, pp. 23-36.

[18] J. Gane, "Ghana's oil and gas in the philosophical arena" In: *Conference Proceedings for the emerging Oil and Gas Industry in Ghana: Social Dimensions* held at the International Centre for Innovative Learning, KNUST on August 28-31, 2013, 2013, pp. 66-74, ISSN 2343-6875

[19] A. Gohin, "Assessing the Land Use Changes and Greenhouse Gas Emissions of Biofuels: Elucidating the Crop Yield Effects", *Land Economics*, Vol 90, Is 4, 2014, pp 575- 586

[20] S. B. Hansen, S. I. Olsen and Z Ujang, "Carbon balance impacts of land use changes related to the life cycle of Malaysian palm oil-derived biodiesel. *International Journal of Life Cycle Assessment, Vol.* 19, n. 3, 2014, pp. 558-566.

[21]. International Energy Agency (IEA), "IEA forecasts a modest rise in global biofuel production to 2020", *International Sugar Journal*, Vol. 116, Is. 1390, 2014, pp. 725-725

[22] P.I. Jalava, P. Aakko-Saksa, T. Murtonen, M.S. Happo, A. Markkanen, P. Yli-Pirila, P. Hakulinen, R. Hillamo, J. Maki-Paakkanen, R. O. Salonen, J. Jokiniemi and M. K. Hirvonen, "Toxicological properties of emission particles from heavy duty engines powered by conventional and bio-based diesel fuels and compressed natural gas". *Particle and Fibre Toxicology,* Vol. 9, 2012

[23] E. U. Kiran, A. P. Trzcinski, W. J. Ng and Y. Liu, "Bioconversion of food waste to energy: A review". *Fuel,* Vol. 134, 2014, pp. 389-399.

[24] J. Krahl, G. Knothe, A. Munack, Y. Ruschel, O Schroder, E. Hallier, G. Westphal and J. Buenger, "Comparison of exhaust emissions and their mutagenicity from the combustion of biodiesel, vegetable oil, gas-to-liquid and petrodiesel fuels". *Fuel,* Vol. 88, n. 6, 2009, pp. 1064-1069.

[25] H. Li, J. Ebner, P. Ren, L. Campbell, et al., "Determination of carbon footprint using LCA method for Straight Used Cooking Oil as a fuel in HGVs", SAE Int. J. Fuel Lubr. Vol. 7, Is. 2, 2014

[26] D. Mu, M. Min, B. Krohn, K. A. Mullins, R. Ruan and J. Hill, "Life Cycle Environmental Impacts of Wastewater-Based Algal Biofuels", *Environmental Science & Technology*, Vol. 48, Is 19, 2014, pp. 11696-11704

[27] I. Mukherjee and B. K. Sovacool, "Palm oil-based biofuels and sustainability in Southeast Asia: A review of Indonesia, Malaysia, and Thailand". *Renewable & Sustainable Energy Reviews*, Vol. 37, 2014, pp. 1-12.

[28] A. Pradhan and C. Mbohwa, "Development of biofuels in South Africa: Challenges and opportunities". *Renewable & Sustainable Energy Reviews*, Vol. 39, 2014, pp. 1089-1100.

[29] A. Quek and R. Balasubramanian, "Life Cycle Assessment of Energy and Energy Carriers from Waste Matter - A Review". *Journal of Cleaner Production*, Vol. 79, 2014, pp. 18-31.

[30] J. C. Quinn, A. Hanif, S. Sharvelle and T. H. Bradley, "Microalgae to biofuels: Life cycle impacts of methane production of anaerobically digested lipid extracted algae", *Bio-resource Technology*, Vol. 171, 2014, pp. 37-43

[31] S. M. A. Rahman, H. H. Masjuki, M. A. Kalam, A. Sanjid and M. J. Abedin, "Assessment of emission and performance of compression ignition engine with varying injection timing". *Renewable & Sustainable Energy Reviews,* Vol. 35, 2014, pp. 221-230.

[32] N. Rajput and A. Lakhani, "Measurements of polycyclic aromatic hydrocarbons in *urban atmosphere of Agra, India"* Available at < *www.ejournal.unam.mx/atm/Vol23-2/ATM002300204.pdf*>, 2010, Accessed on 09/11/2014

[33] C. D. Rakopoulos, K. A. Antonopoulos, D. C. H. Rakopoulos, D. T. Hountalas and E. G. Giakoumis, "Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or biodiesels of various origins", *Energy conversion and management*, Vol. 47, 2006, pp.3272-3287

[34] A. Ribeiro, J. Carvalho, J. Castro, J. Araujo, C. Vilarinho and F. Castro, "Alternative Feedstocks for Biodiesel Production". In: A. M. P. Pinto and A. S. Pouzada, (Ed.). *Advanced Materials Forum Vi, Pts 1 and 2*, Vol. 730-732, 2013, pp 623-629.

[35] M. H. Rocha, R. S. Capaz, L. E. E. Silva, N. L. A. Horta, L. M. M. Vicente, R. M. L. Grillo and O. O. Almazan del, "Life cycle assessment (LCA) for biofuels in Brazilian conditions: A meta-analysis", *Renewable & Sustainable Energy reviews*, Vol. 37, 2014, pp 435- 459

[36] United Nations Environment Programme (UNEP), "Water Quality: the impact of Eutrophication", *Lake and Reserviors*, Vol. 3 Available at < http://www.unep.or.jp/ietc/publications/short_series/lakereservoirs-3/1.asp>, 2014, Accessed on 24/11/2014.

[37] The United Nation World Commission on Environment and Development (UN-WCED), “Report on the World Commission on Environment and Development: Our Common Future”, Available at <http://un-documents.net/our-common-future.pdf>, 1987, Last Access 27/06/2013]

[38] Vehicle Certification Agency (VCA), “Cars and carbon dioxide”. Available at < http://www.dft.gov.uk/vca/fcb/cars-and-carbon-dioxide.asp>, 2014, Accessed on 12/10/2014

[39] X. Zhang, H. Chen, W. Chen, Y. Qiao, C. He and Q. Wang, “Evaluation of an Oil-Producing Green Alga Chlorella sp C2 for Biological DeNO(x) of Industrial Flue Gases”. *Environmental Science & Technology***,** Vol. 48, n. 17, 2014, pp. 10497-10504.