European Journal of Sustainable Development Research
2020, 4(4), em0129
e-ISSN: 2542-4742
https://www.ejosdr.com/
Research Article
MODESTUM
OPEN ACCESS

Advanced Biofuels: Review of Effects on Environment and Socioeconomic Development

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Citation: Usmani, R. A. (2020). Advanced Biofuels: Review of Effects on Environment and Socioeconomic Development. *European Journal of Sustainable Development Research, 4*(4), em0129. https://doi.org/10.29333/ejosdr/8245

ARTICLE INFO

Received: 17 Dec. 2019

Accepted: 27 Apr. 2020

ABSTRACT

In the current scenario when depleting crude oil sources pose a challenge against energy security the advanced biofuels seems as suitable alternate for transport sector. Because of lignocellulosic biomass based production advanced biofuels are considered as environment friendly and they have positive income and employment impacts on the socioeconomic conditions. The study has objectives to test the aforementioned claims on the basis of a review of available literature. It is found that the GHG emission from conventional biofuels is not as much lower as claimed. But the advanced biofuels found to be more environment friendly than their counterparts. The data on socioeconomic impacts of advanced biofuel is scarce and only available for the USA which is reported in this study. It is found that the agriculture sector is significantly benefited sector by the industrial scale production of the advanced biofuels. For the assessment of large scale impacts it is assumed that the dynamics of spreading of socioeconomic impacts of advanced biofuels industry is same as the conventional biofuel industry. On the basis of aforementioned observations, this study also supports the notion of positive environmental and socioeconomic impacts of the advanced biofuels but on the conditions of sustainable and decarbonized supply chain.

Keywords: advanced biofuels, environment, greenhouse gas, socioeconomic impacts, farmer's income, rural development

INTRODUCTION

Biomass is the primary renewable energy source and ~40% of the global population rely on the biomass for their energy needs (Sakthivadivel and Iniyan, 2018). The group of liquid and gaseous fuels produced by biomass is known as biofuels, and biofuels explicitly produced from the lignocellulosic biomass is known as advanced biofuels (Hamelinck and Faaij, 2006; Tanaka, 2010). Liquid and gaseous biofuels have application for the transport sector. The growth of transport sector led to the over-exploitation of crude oil sources and put the supply security at risk. Further, the greenhouse gas (GHG) emission from transport sector is responsible for the 23% of the world's energy-related emissions (Ribeiro *et al.*, 2007). Biofuels are considered as renewable and sustainable transport fuels because they have properties like lesser emissions of greenhouse gasses and particulate matter (Demirbas, 2008). The reason for lesser GHG emissions is the presence of significant oxygen content (10% - 45%) in biofuels, while fossil fuels do not have oxygen in their molecular structure. Due to higher oxygen content, biofuels have better antiknock value and combust efficiently with reduced GHG emissions (A Demirbas, 2009).

Presently, food based biofuels or conventional biofuels have dominating share in market. The credit goes to their relatively simple and mature production technology and well-developed supply chain. The feedstock for these biofuels includes starch and sugar containing crops for ethanol production and oilseeds for biodiesel production (Ayhan Demirbas, 2009). The continuous use of food biomass for biofuel production instigates the food versus fuel debate. Additionally, conventional biofuels are also not cost-competitive with the existing petroleum based fuels without subsidies except Brazilian ethanol from sugarcane (Larson and Larson, 2008). Further, their environmental sustainability is in question after considering the emission from the entire supply chain (Araújo et al., 2017).

Because of production from novel technologies and lignocellulosic biomass, advanced biofuels are considered as more suitable than the conventional biofuels. Biomass from agricultural and woody residues are widely used as feedstock for energy production (Sakthivadivel et al., 2019). Lignocellulosic biomass is not used as food and are available in large quantity. It is estimated that the worldwide quantity of biomass by terrestrial plants is around 170-200 × 109 Gt (Giga tonne) (Pauly and Keegstra, 2008).

The objective of this study is to evaluate the environmental sustainability and socioeconomic impacts of advanced biofuels via a review of existing literature. It is well known that in today's world the success of any industry is evaluated in terms of its

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positive impacts on the environment and society which is as equally important as the economic and monetary gains. For the evaluation of environmental impacts of advanced biofuels, data on GHGs emission by the combustion of advanced biofuels for releasing of one mega joule (MJ) of energy is collected and evaluated from the available literature. The data available on advanced biofuel's socioeconomic impacts is limited. Therefore, for the evaluation of their economic and social benefits, it was assumed that the dynamics of spreading of these effects over society are the same as of conventional biofuels. Due to this, mostly the data and examples are taken from the conventional biofuel industry. The study is structured as follows; *section two* highlights the environmental impacts of the advanced biofuels and; *section three* deals with the socioeconomic impacts.

ENVIRONMENTAL IMPACTS

GHG Emissions and Transport Sector

GHGs include Carbon dioxide (CO_2), Carbon monoxide (CO), Methane (CH_4), Nitrous Oxide (N_2O), Ozone (O_3) and Chlorofluorocarbons (CFCs). Carbon dioxide is the most abundant GHG and represents 76% of the total GHGs (combined emission from transport, agriculture and industry). GHGs traps solar heat and help in maintaining the life-sustaining atmospheric temperature (Change, 2015). Due to the heat-trapping property, the excess of these gases causes additional rise in temperature than is required in the ecosystem. This unnecessary warming of atmosphere is termed as the 'global warming'.

After the industrial revolution, the atmospheric concentration of carbon dioxide escalated by 36%. The use of fossil fuels in transport and industrial sector is the major cause of rising atmospheric concentration of CO_2 (Change, 2015). The massive consumption of fossil fuels was responsible for 6.3 Giga tonne (Gt) of carbon dioxide emission in 2004 (Ilyama, Kariuki, Kristjanson, Kaitibie, and Maitima, 2008). The transport sector is the end user of liquid petroleum fuels and consumes ~95% of the supply. Since 1990, the emission from road transport had been increased by 68% and is responsible for 75% of the transport sector emissions in 2013 (IEA, 2015). Globally, transport fuel consumption is growing at the rate of 2% per year and this rate of growth is expected to maintain in the coming years (Eisentraut, Brown, and Fulton, 2011)**.**

Advanced Biofuels for Transport Sector

Advanced biofuels are produced from the lignocellulosic biomass which is non-edible and available in huge quantity. Approximately, 70% of the total terrestrial biomass is considered as lignocellulose (Pauly and Keegstra, 2008). Also, purposively cultivated energy crops which include Miscanthus, Switchgrass, perennial grasses, etc. could be an additional source of the lignocellulosic biomass. These energy crops can grow on marginal land without much requirements of input and care. Thus, in their complete life cycle, they could prove to be a better option for GHG mitigation (Larson and Larson, 2008; Petroleum, 2013).

The blending of transport fuels with biofuels has significant positive impact on GHG emissions. For instance, the mixing of ethanol in gasoline resulted in more efficient combustion of gasoline with a lesser emission of particulate matter and GHGs (Greene *et al.*, 2004). The blending of ethanol also replaced the tetraethyl led which is an anti-knocking agent and a pollutant. Blending results in the replacement of petroleum fuels in the same proportion. For example, the 10% blend of ethanol reduces 10% use of gasoline, which resulted in 10% lesser carbon emitted in the atmosphere (Kheshgi, Prince, and Marland, 2000) (Ladanai and Vinterbäck, 2010).

GHG Emissions and Advanced Biofuels

The lower GHGs emissions is a key facet of environmental sustainability of the advanced biofuels. There is a growing recognition that advanced biofuel technologies are more carbon neutral and promising for GHG mitigation (Eisentraut, Brown, and Fulton, 2011). Evidence of the GHG emission from the Life Cycle Analysis (LCA) of cellulosic ethanol is presented here (**Table 1**). It is the most studied advanced biofuel and there is a huge optimism regarding their GHG reduction abilities. The optimism is based upon the fact that cellulosic ethanol requires a lesser quantity of fossil fuel inputs in their production as compared to other conventional biofuels (Eisentraut, 2010b; Farrell, 2006; Lynd, 1996).

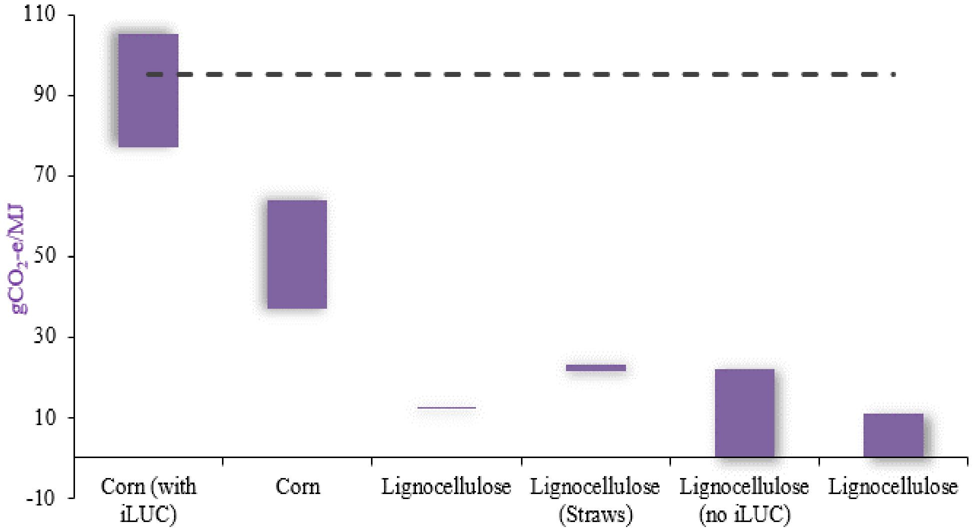
Table 1. GHG emissions from ethanol produced by different type of feedstock

Study	GHGs (gCO2 e/MJ)	Feedstock	Source
Hamelinck	37 - 64	Corn	(Hamelinck, De Loveinfosse, and Koper, 2012)
Eisentraut	77 - 105	Corn of which 30 g CO2-eq/MJ is from iLUC	(Eisentraut, 2010a)
Eisentraut	95	Gasoline	(Eisentraut, 2010a)
Hamelinck	11	Lignocellulose	(Hamelinck, De Loveinfosse, and Koper, 2012)
Purohit	21.6 - 23.1	Lignocellulose (straws)	(Purohit and Fischer, 2014)
Eisentraut	22	Lignocellulose (wood and forestry residues)	(Eisentraut, 2010a)

Table 1 shows the GHG emissions for obtaining a one MJ of energy by the combustion of ethanol produced from different sources of lignocellulosic biomass and ethanol produced from corn grains. The emission from gasoline has used as a benchmark for identification of the real GHG savings which is 95 gCO_2-e (gram carbon dioxide equivalent per mega joule) for obtaining one MJ of energy. Corn ethanol emits in between 37 - 105 gCO_2-e/MJ, when emission from the indirect land use change (iLUC) is added in the LCA. Without addition of iLUC in LCA, the total emission from corn ethanol is in between 37 - 64 gCO_2-e/MJ.

The GHG emission from cellulosic ethanol is in between the range of 11 - 23 gCO_2-e/MJ. A study reported 12.3 - 12.4 gCO_2-e/MJ emission for ethanol obtained from lignocellulosic biomass (Khan and Usmani, 2016). The conversion of straws into ethanol emission emits 21.6 - 23.1 gCO2-e/MJ (**Table 1**). The range of GHG emission by ethanol from different lignocellulosic biomass is significantly lower than ethanol produced from corn and the gasoline.

Figure 1 represents the range of CO_2 emission by biofuels produced from different types of biomass and gasoline. It is clear from **Figure 1** that the CO_2 emission from corn ethanol is approximately equal to that from gasoline if the emission from land use change has been taken into consideration. It means, the indirect clearing of carbon-intensive areas for production of corn crop have negative effects on GHG emission savings achieved by corn ethanol.



Source: Based on Eisentraut (2010a), Hamelinck, De Loveinfosse, and Koper (2012), and Purohit and Fischer (2014)

Figure 1. Range of GHG emission from different sources

The GHG saving by advanced biofuels depends on the production pathway through which the biofuel is produced (Zah, 2007). **Table 2** shows the mitigation of GHG emission by the cellulosic ethanol reported by different studies. Studies reported the diverse range of GHG savings. The range of GHGs savings is in between 10% - 102%. In most of the cases, GHGs savings is more than 50% and usually around 80% (**Table 2**).

Table 2. GHG emission savings from the advanced biofuels

Study	GHGs savings	Source
Farrell	88%	(Farrell, 2006)
Edwards	76-88%	(Ackom, Emmanuel; Mabee, Warren, and Saddler, 2010)
Grood	93-98%	(Groode and Heywood, 2007)
Unnash	10-102%	(Unnasch and Pont, 2007)
Wang	86%	(Wang, Wu, and Huo, 2007)
Zah	80%	(Zah, 2007)
Pallav	80%	(Purohit and Fischer, 2014)
Wang	85%	(Wang, 2005)

Carbon Sequestration by the Cultivation of Lignocellulosic Feedstock

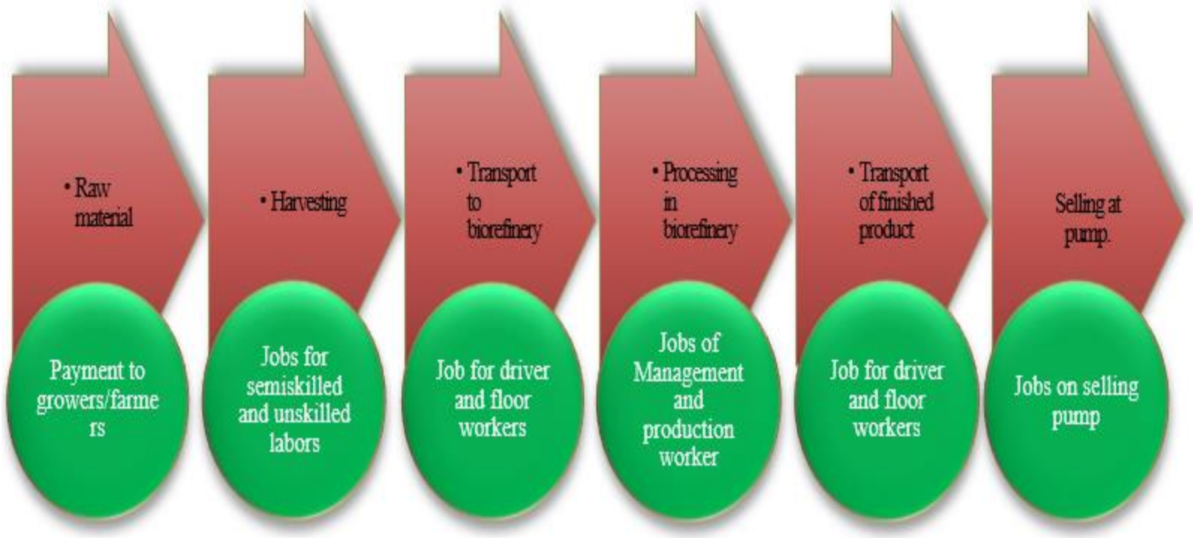
Energy crops, if cultivated on marginal lands and through afforestation of the deforested areas with fast growing tree species we could create a carbon sink. As the plantation grows, it captures atmospheric carbon and converts it into biomass. For instance, a study reported the carbon sequestration from cultivation of Miscanthus as ~1 tone from one hectare in one year (1 tC/ha/yr) (Anderson-Teixeira *et al.*, 2009). Another study reported that the carbon sequestration from Miscanthus on grassland is around 0.4-0.5 tC/ha/yr and 0.55-0.65 tC/ha/yr on the pasture land (Dunn *et al.*, 2013). Repeated plantation of successional herbaceous plants on marginal land shows a considerable positive impact on GHG savings. For instance, a study reported 800 - 900 gCO_2-e mitigation capacity from the production of successional herbaceous plants (Gelfand *et al.*, 2013). In comparison with that, corn vegetation has only 370 - 430 gCO_2-e mitigation capacity (Gelfand *et al.*, 2013).

SOCIOECONOMIC IMPACTS

The socioeconomic impacts of biofuel industry could be measured by its positive impact on income and employment. Biofuel industry is making some measurable contributions to the individual income and employment and as well as global economy.

Most of the third world countries have a sizeable amount of agroforestry residue and marginal land. Till now, agroforestry residue is considered negligible in terms of economic value but if used for production of biofuels, their demand will increase either for domestic biofuel production or for export as a feedstock (International Energy Agency, 2012). The diversion of agroforestry residue will generate substantial economic value for agroforestry residues by balancing the forces of demand and supply (Eisentraut, 2010a). The prices paid as a payment of agroforestry residues will help in raising farmer's income and will have a positive impact on economic growth, poverty alleviation and food security (FAO, 2008).

Purposely cultivated feedstock i.e. energy crops have significant positive impact on the income of farming communities. Potential for job creation along the supply chain of advanced biofuel is significant (**Figure 2**). The jobs are created by cultivation of feedstock and will absorb low skilled poor workers of rural areas (Langevin, 2005). The quality of jobs is better for them because of the lower element of seasonality with possibility of increasing wages over time (Macedo, 1995). Moreover, because of cultivation on marginal land the energy crops do not compete with resources used for food production. Indeed, they may contribute to improving the food security which will help in avoiding the pressure on low-income consumers, particularly in developing countries (FAO, 2018).



Source: Author

Figure 2. Possibilities of job creation in the supply chain of advanced biofuels

Income and Employment Impacts of Advanced Biofuels

The production of advanced biofuels has a positive impact on the generation of income and employment. Currently, the advanced biofuels industry is in a developmental stage but the encouraging future impacts cannot be overseen. The market for advanced biofuels is expected to grow at the CAGR (compound annual growth rate) of 41.8% and projected to reach up approximately $100 billion in 2023 from $8.64 billion in 2016 (Stratistics, 2017).

Table 3 shows the income and employment impacts of advanced biofuels by a single plant constructed and operated in North Dakota. For the plant capacity of 50-million-gallon ethanol per year, around $36 million will be needed to invest in the feedstock, which is 68% of the total expenditure. The payment for feedstock represents income to farmers (**Table 3**). The rest of the sectors of the economy also get benefited but the income impacts for farmers are more pronounced. Also, a total of 2,477 jobs were generated throughout the supply chain from the mentioned plant capacity. The plant employed 77 workers directly on a payroll of $2.7 million. Also, about 2400 jobs are spread throughout the supply chain (**Table 3**) (Hodur and Leistritz, 2009).

Table 3. Direct economic impacts of cellulose based ethanol ($ million)

Sector	Million USD	% share
Income distribution		
Feedstock purchase	36	68%
Feedstock transportation	8.82	17%
Retail trade	1.84	3%
Finance Insurance and real state	2.16	4%
Households	18.45	35%
Other	2.56	5%
Total	53.01	100%
No. of jobs		
Direct employment	77	
Indirect employment	2400	

Source: (Hodur, Leistritz, and Hertsgaard, 2006)

Impacts of Biofuel Industry on Income and Employment on Global Scale

The information available about the income and employment effects by large scale production of advanced biofuels is limited because the industry is in development stage. Therefore, for evaluation of the income and employment effects of the advanced biofuels as an industry, it is assumed that the dynamics of spreading of these effects are the same as the conventional biofuel industry.

The production of ethanol has considerable positive impacts on global income and employment. For instance, the global production of ethanol in 2010 was around 93 Gl. This amount of production needs the investment of $87.3 billion in feedstocks and other inputs. The return on this investment has a gross value of around $301.5 billion along with a value added output of $125.2 billion. Moreover, it supports 1.1 million jobs (**Table 4**).

Table 4. Global impacts on income and employment by biofuels (2010)

Biofuels	Quantity of biofuels giga litres (Gl)	Investment on feedstock (billion USD)	Gross Output in 2010 (Million $)	Value added output	No. of jobs
Ethanol	93	87.3	301,480	125.2	1,088,229
Biodiesel	17.6	21.6	72,952	30.3	291,129
Total	100.16	108.9	374,432	155.5	1,379,358

Source: (Urbanchuk, 2012)

The global biodiesel production was 17.6 Gl in 2010. This amount of production needed the investment of about $21.6 billion on feedstocks and other inputs. The production of biodiesel generates $73 billion of gross output, $30.3 billion of values-added output and 3 million jobs (**Table 4**).

The total amount of biofuels is around 100 Gl and demands the total investment of about $109 billion. The return on this investment is $375 billion in gross value and $155 billion in terms of value added output (**Table 4**). The total number of jobs created by conventional biofuel industry is around 1.4 million, spread throughout all sectors of the economy on the global scale.

Income and Employment Impacts in Major Biofuel Producing Countries

Table 5 shows the income and employment impacts by production of biofuels in top producing countries. USA and Brazil are two biggest producers of fuel ethanol. The quantity of ethanol is around 50 Gl in the USA and 26 Gl in Brazil, which constitutes 54% and 28% share of the global ethanol production (**Table 5**). The income and employment generated by ethanol production is significant and generates gross revenue of $129 billion in the USA and $111 billion in Brazil (**Table 5**). Around 0.4 million jobs in USA and 0.44 million jobs in Brazil are created by production of ethanol. USA and Brazil jointly represents 37% and 41% of the global employment generated by the ethanol industry (**Table 5**). Ethanol production in India also have measurable income and employment effects. In 2010, around 2 Gl of ethanol was produced in India which represents 2% of the global ethanol output, 3% of the gross value output and 3% of the global employment creation (**Table 5**).

Table 5. Income and employment impacts of biofuels

Country	Biofuel output (Mil litres)		Gross output (Mil $)		No. of Jobs	
	Ethanol	Biodiesel	Ethanol	Biodiesel	Ethanol	Biodiesel
U.S.	50.3 (54)	1.19 (7)	12.92 (43)	4.9 (7)	400677 (37)	19713 (7)
Brazil	26.2 (28)	1.55 (9)	111.35 (37)	6.4 (9)	444378 (41)	25633 (9)
EU-27	4.46 (5)	9.18 (52)	17.4 (6)	38 (52)	69343 (6)	151840 (52)
India	1.89 (2)	1.79 (1)	8.1 (3)	0.74 (1)	32088 (3)	2967 (1)
Other	1.04 (11)	5.5 (31)	35.5 (12)	22.8 (31)	141743 (13)	90976 (31)
Total	**93**	**17.6**	**301**	**73**	**1088229**	**291129**

Source: (Urbanchuk, 2012),

* the value in parenthesis () shows percentage contribution in total. Value in ($2010)

European Union is the number one producer of biodiesel. In 2010, around 9 Gl of biodiesel was produced in the EU, which represents 52% of the global biodiesel production. The income and employment impacts of biodiesel production are significant in the EU. In 2010, $38 billion gross value worth of biodiesel was produced in the EU and 0.15 million jobs were created which represents 52% of the global job creation by biodiesel production (**Table 5**). Biodiesel production in India has measurable income and employment effects. In 2010, around 2 Gl of biodiesel was produced in India. It represents the 1% of the global biodiesel output, 1% of the gross value output and 1% of the global employment generation (**Table 5**).

Industrial Breakdown of Income and Employment Impacts of Biofuel Production

It is pertinent to identify most important and benefited sectors of the economy and the sectoral distribution of income and employment in order to understand the impact of biofuel production on economy. **Table 6** indicates that, the income and employment impacts of ethanol production is distributed in approximately all sectors of the economy. From ethanol production in USA, income of around $23 billion and 0.35 million jobs are generated (**Table 6**).

In terms of income, agriculture sector is the most benefited sector of the economy. It generates income of about $9 billion which represents 39% of the total income generated in the USA via ethanol production. The number of jobs created in agriculture sector via ethanol production is around 81734, which represents 23% of the total jobs (**Table 6**). In terms of job generation, the service sector dominates over other economic sectors and generates 146218 jobs which represents 41% of the total jobs in the ethanol industry. In terms of income, service sectors generate $7.2 billion which represents 31% of the total income from the ethanol production in USA (**Table 6**).

Table 6. Breakdown of income and employment impacts (USA)

Economic Sectors	No. of jobs	Income billion USD	% Share of jobs	% Share of income
Agriculture	81734	9.2	23%	39%
Mining	5247	0.36	1%	2%
Construction	18514	0.71	5%	3%
Manufacturing	27569	2.75	8%	12%
Transportation/Public Utilities	22570	1.16	6%	5%
Wholesale/Retail Trade	52145	1.92	15%	8%
Services	146218	7.28	41%	31%
Government	3410	0.22	1%	1%
Total	357407	23.5	100%	100%

Source: (Urbanchuk, 2014) values in ($2015)

CONCLUSION

This study has reinforced the notion of positive impacts of advanced biofuels on the environment and socioeconomic conditions. Larger greenhouse gas benefits from advanced biofuels are observed in this study. Because of the inclusion of literature concerned with the elaborated analysis of life cycle emissions of advanced biofuels in addition to the carbon sequestration potential by the cultivation of energy crops. Due to larger GHG savings, the climatic benefits of advanced biofuels will be more pronounced and have potential to mitigate climate change if used on a large scale for a long time. But sustainability considerations regarding land use change and decarbonisation of the supply chain are the preconditions to achieve aforementioned GHG benefits. The potential for generation of income and employment by production of advanced biofuels is observed throughout the whole supply chain. The potentials for income and employment benefits from advanced biofuels production are found to be significantly beneficial for the farmers. The feedstock trade places considerable positive effects on the employment and income of farmers. Other sectors of the economy involved in supply chain of advanced biofuels also get benefited. This study strengthens position of advanced biofuels as a strong alternate of petroleum based transport fuels with the aforementioned benefits. What left is the large scale uptake of production and application of advanced biofuels to reap aforementioned benefits, which are not achievable without a proper policy and monetary support from the public sector.

ACKNOWLEDGEMENTS

The author is thankful to Aligarh Muslim University, Aligarh, UP, India for providing basic support during the research work.

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