

# CLIMATE CHANGE AND BIOFUELS: CURRENT STATUS AND WAY FORWARD

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## ABSTRACT

*Climate change is real and happening. Human activities such as land use and transportation are the major drivers of these climate changes. Liquid biofuels, if carefully delivered, can mitigate these changes to some extent.*

*Biofuels are considered potential renewable energy source for enhancing energy security and more importantly for reduction in GHG especially from the transport sector. Considerable attention has been given in the literature on the potential of various crops in reducing the GHG. For example, canola and soybean biodiesels have GHG savings of 58% and 50% respectively, compared to liquid fossil fuels, while corn ethanol was found to reduce emissions by only 21%. Governments across the globe have taken various mandates to incorporate biofuels into value chains for fossil fuels and, in fact, have come out with various targets for blending bioethanol and biodiesel with fossil fuels. The relevant production targets set by various Governments will require an expansion of the current areas under biofuel crops which will lead to either indirect or direct land use change (LUC). Such LUC especially with food crops such as maize, soybean will offset the advantages of Biofuels in GHG reductions.*

*The claims of GHG reductions through biofuels have been challenged mainly from a full life cycle analysis perspective. From this perspective the biofuels from some of the current crops can generate more greenhouse gas emissions than fossil fuels. The amount and nature of GHG emitted can also differ depending on the crop, where it is grown, the agronomic practices followed and its further processing. Agronomic practices and the management of crop also play an important role in determining the overall environmental impact of a bioenergy production system – the*

*so called swing potential of a crop.*

*Land-use changes such as deforestation and forest degradation accounts for approximately 12-17% of global GHG emissions. The LUC as a result of diversion of food crops for fuel purposes will also lead to 'fuel vs. food' debate.*

*To address the issue of LUC and 'fuel vs. food' debate, it is important that marginal lands that are unfit for intensive agriculture and alternate non-food or multiple use biofuel crops are considered. There is enough potential from these areas to meet the global demand. For biofuels to be considered to be sustainable in the future they should demonstrate benefits for smallholder farmers by providing locally accessible energy for their livelihood systems. Perennials incorporated in smart agroforestry systems hold the promise.*

## INTRODUCTION

Climate change will affect the human population in myriad ways some of which cannot be anticipated, especially at the local and regional level, as the models used to assess these changes are not robust enough and are still evolving. However, it is undoubtedly going to affect our lives adversely by upsetting the global food production which is a serious problem considering the future population growth.

The major causes of these climate changes are land use and transport sector which are human related or anthropogenic GHG emissions. The transport sector, especially aviation sector, will continue to rely on fossil fuels. Despite intense efforts to develop alternate renewable energy sources; it is unlikely that a true substitution is on the horizon in the conceivable future. Economic growth in countries like India and China will lead to ever increasing demand of fossil fuels. It is

expected that, in the future the demand for liquid fossil fuels will rise by 56% by year 2040 (International Energy outlook, 2013). However, the fossil fuels are the finite source and many reports suggest that the known sources of fossil fuels will run out towards the end of this century (IEA, 1999a). The prices of fossil fuels are volatile, mainly because the major producers of the crude oil are from the volatile regions of Middle East (IEA, 2008).

Biofuels can be considered an important component of transport fuel substitution mainly because of their similar inherent properties to that of fossil-based fuels. Current biofuels have emerged mainly from the oil price hike that was seen in 1970s (HLPE, 2013) and was considered to be part of country's energy mix. Many countries, such as the US and Brazil aggressively pursued modern large-scale production of biofuels in the recent past for their national energy security goals.

The drivers of emergence of biofuels include a broad range of issues from land-use to energy security, to economics and environment. If biofuels can meet these sustainability criteria, they can address both energy requirements and means to address negative impacts of climate change. Biofuels can also provide additional opportunities for income and employment generation, especially in developing countries. Because of these considerations, Governments across the globe have taken various measures to reduce the climate impact of fossil fuels by blending them with biofuels and, in fact, have come out with targets of blending ethanol and biodiesel with fossil fuels.

Several negative impacts of current biofuels have been recently identified, and efforts are underway to address these challenges. Biofuels are blamed for the food crisis in 2008 because of diversion of food crops for biofuel production. Because these biofuel crops resulted in the diversion of the food component to the biofuels, the net gain in GHG has also been questioned. Indeed, the full life cycle analysis has shown that these crops will have negative impacts on the GHG savings.

However, if managed sustainably and produced *via* non-food or multiple use feed stocks biofuels can potentially be a part of efforts to mitigate climate change risks (IEA, 2013). Trees in farm or outside forest will be the basis of future biofuels; smart agroforestry systems will be crucial to addressing the challenges faced by first generation biofuels.

This paper will describe the current climate change scenarios, its impact on food security, the causes and possible ways of mitigating these climate change risks and emergence of biofuels as a possible solution. The paper also discusses various agroforestry options including suitable crops for these areas to build a value chain and to achieve GHG reduction through Biofuels.

### **Current status of climate change**

Climate change is real and happening and is feared to affect various aspects of our lives negatively if proper measures are not taken urgently. This year in April, an atmospheric carbon dioxide concentration of 400 ppm was recorded at the Moonscape Summit of the *Mauna Loa* volcano in Hawaii. This is an unprecedented event as the value that has not reached for a few million years (Monstersky, 2013). In the history of earth, the highest atmospheric carbon dioxide concentration recorded was 300 ppm. The inflection point was recorded post 1950; a time coincides with the industrial revolution.

The observation has far reaching consequences to future climate change which is already a hot topic of scientific investigations globally. Climate change is and will continue to impact the planet's ecosystems in myriad and unpredictable ways. It has been estimated that by 2100, the global temperature will rise to 2 to 5°C relative to 1990. Increased in atmospheric GHG are the crucial components of this phenomenon (IPCC, 2007). As of now, the global temperature has increased to 0.8°C compared to pre-industrial time. In the next 20-30 years, this rise will be even more pronounced, and the global temperatures are expected to rise by 2°C. More significantly, the temperatures are expected to further rise by 4°C (with 40% surety) and even up to 5°C (10% surety)

by the year 2100 (The World Bank, 2013).

To reduce the global warming exceeding 2°C by 25% probability, the global carbon budget provided is 1000 GT till 2050 (Meinshausen *et al.*, 2009). Despite early warnings of climate change in 1960s, the human activities for economic growth continued leading to constant release of carbon dioxide to the atmosphere. An amount of 531 GT of carbon dioxide is already emitted by 2011, which is close to 53% of allocated carbon budget and the limit may be surpassed in the next 25 years (IPCC, 2007). Moreover, the world has a total of 2,800 GT worth of carbon locked up in the form of fossil fuels and reserves. Using merely 10% of these would make the allocated carbon budget to complete exhaustion (Meinshausen *et al.*, 2009).

The World Bank (2013) also suggests that the temperature will rise by 4°C by the end of this century. Unfortunately, the poorest people in the developing countries will be the most affected by this climate change and food security of these people remains a major challenge.

### **Climate change and food security**

The UN Millennium Development Goals has a specific goal (Goal 1a) on reducing the proportion of people who suffer from hunger. According to FAO (2013) around 842 million people still suffer from chronic hunger. Although this figure has fallen from 1990 figure by 132 million (FAO, 2013), the challenge is confounded by fact that almost half of the hunger is associated with small holder farmers who live in developing countries. Africa and the rest of Asia together have around 40%, hungry people. In Africa, the number of hungry grew, from 175 million to 239 million in recent times (FAO, 2012).

According to FAO (2013), steep growth in agricultural productivity is required in reducing hunger and malnutrition in countries where poor depend on agriculture for their livelihoods. Increasing the agricultural productivity in developing countries involving smallholders will be critical to reducing poverty and hunger.

As per one estimate, to feed the 9 billion people by

2050, the food production needs to increase by 70% with added burden on the land which is becoming scarce (Alexandratos and Bruinsma, 2012). Most of the future population will be prevailing in developing countries and meeting the food demand sustainably will be a big challenge. Food riots were witnessed in several parts of the world in 2008 due to the rise in food prices. Improving accessibility and availability of food for poor is important to their livelihoods. Decreased farm productivity would also make farmers less interested in agriculture.

Agricultural production, however, is extremely vulnerable to even slight disturbances to climate changes in which the crops are grown. The climate change will threaten global food production negatively and will impact livelihoods of millions of people globally - it is unlikely that the current agriculture will be able to support a population of nine billion by year 2050.

Different parts of the world will have different impacts of climate change on agriculture, depending on the current climatic and soil conditions, and the actions taken in that region on making suitable resources available to cope with climate change (Olesen *et al.*, 2006). Moreover, every crop has an optimal thermal requirement to achieve maximum yield, any rise in temperature affects the productivity negatively. Even a relatively minor increase of 1 to 2°C temperature during the growing period of a crop can significantly affect the yield of many food crops. Higher temperatures affect photosynthesis, pollination and ultimately crop yield. It is argued that the elevated carbon dioxide will add to photosynthesis and add to biomass; however, elevated temperature can offset this phenomenon. Scientists have now confirmed that a 1°C rise in temperature above the optimum temperature can affect the yields by 10% for many cereals (Peng *et al.*, 2004). According to Lobell and Asner (2003) 1-degree Celsius rise in temperature affects corn yields by 17%. Similarly, Kumar and Parikh (2005) concluded that a 2-degree rise in temperature above norms lowers the yield of wheat by 37 to 58%.

With an increase in temperature above 1.5°C, the significant yield and crop production losses will occur in regions such as Sub-Saharan Africa, South East Asia and South Asia. South Asia region will be specially burdened with these changes as it will have a challenge to feed an ever growing population of 2.2 billion by 2050 with world's largest yet poorest population. The agriculture accounts for 18% in GDP of this region and houses more than 50% of people relying on agriculture and depended on it. Around 28% of global rice cultivation takes place in this region and with increased temperature the estimated yield losses of -21% is forecasted (The World Bank, 2013). The food prices are also expected to climb by 101% for maize, 55 and 54% for rice and wheat respectively (Nelson *et al.*, 2010).

It is now certain that if drastic actions are not taken to mitigate the climate change impacts, it will not be possible to feed the world in the future. While crop diversification, breeding for heat resistant varieties and agroforestry can contribute significantly to food production. A landscape approach of integration of agriculture and livestock production system and increasing access to clean energy will play a vital role in boosting the crop productivity.

Modern agriculture requires energy inputs at almost all stages of agricultural production such as in farm machinery, irrigation, cultivation and harvesting. Even post-harvest stages such as food processing, storage and in transport to markets all require energy.

Developed countries have benefited in agricultural productivity from scientific advances and easy availability of energy. On the contrary, developing countries have lagged behind in modernizing their energy and technological inputs into agriculture. Sufficient provision of energy is therefore also vital for improving livelihood opportunities of small holder farmers who depend in one way or the other on agriculture. Generally, areas that have good quality and reliable power capitalise on this supply of energy and create new livelihood opportunities.

Access to energy has a direct relationship with

economic development in developing countries. Indeed, there is a direct relationship between the absence of adequate energy and many poverty indicators. Inadequate access to energy also leads to rapid urbanization in developing countries.

Biofuels hold out the promise of making rural areas more energy independent as well as generating new and important income sources.

### **Land use and climate change**

Two significant human activities contributing to global warming are land use changes and the emissions from the transport sector. Human development has already affected about 1/3 to 1/2 of earth land surfaces (Feddema *et al.*, 2005).

There are two types of land use change which are important to climate change: 1) direct - such as deforestation, afforestation, agriculture, and urbanization and 2) indirect changes include any changes in GHG that force changes in vegetation.

Deforestation and afforestation activities play an important role in removing or adding carbon from the earth system. Conversion to agriculture or pastureland is the primary driver of tropical deforestation. Carbon dioxide emissions from deforestation, account for approximately 35% of total global annual emissions (Turner *et al.*, 2007). According to the FAO (2005), between the periods, 1990 to 2005 approximately 13 million ha of forests were converted to agricultural land every year. Between 1858 and 1998 a total of 136 (+ 55) GT carbon has been emitted as a result of deforestation (IPCC, 2000). Deforestation by burning of the forests will also lead to release of carbon mono-oxide and methane. The emissions from agriculture and deforestation activities have occurred mainly in developing countries (Smith *et al.*, 2007 and Nabuurs *et al.*, 2007). It is not surprising that Indonesia is a top ranked carbon emitters globally attributed mainly by converting forest to agriculture especially to oil palm plantations (Harris *et al.*, 2012; Ramdani and Hino, 2013).

More than 650 million ha of forest, equivalent of 75 GT carbon emissions, are likely to be lost by 2050 (IPCC, 1995). Along with this forest and

agricultural land will also be degraded, releasing more carbon to the atmosphere. Of these emissions, at least one-third of that is from developing countries and over 60% from the lesser developing countries. In Amazon, conversion of forests to crop land resulted in drier and warmer climate of the region (Costa and Foley, 2000).

Intense agriculture also contributes to GHG emissions by releasing  $N_2O$  and methane. Both  $N_2O$  and methane contribute significantly to the anthropogenic climate change.  $N_2O$  contributes 6% while methane contributes 21% (Houghton *et al.*, 2001). Both  $N_2O$  and methane have higher potential for global warming than carbon dioxide –  $N_2O$  is 310-time more powerful and methane is 21-times more powerful than carbon dioxide (Olesen, 2006). Switching to cleaner energy and use of nitrogen fixing crops in cropping system, or nutrient use efficient crops will be needed to counter these GHG emissions.

Trees inside forests or outside the forests and in farms, and land use practices can potentially counteract the effect of greenhouse gas emissions and can help prevent negative impacts of climate change. Forests hold 20 to 50 times more carbon than if converted to other uses (Moutinho and Schwartzman, 2005).

Agroforestry practices including planting trees, preserving and managing trees outside forests, and changing cultivation practices will lead positive carbon foot print in soil. These practices could reduce net carbon emissions by 10-20 % of projected fossil fuel emissions through 2050. Indeed, the carbon sequestrations have already been increased by about 14% since 1990, largely as a result of deforestation and afforestation (Smith *et al.*, 2007).

Tree species if used as the source of biofuels will aid in further carbon sequestrations and will help mitigate the negative climate change impacts

### **Fossil fuels and climate change**

Fossil fuels are considered the most important source of carbon emissions which contribute to more than 86% of the energy used worldwide. Globally, burning fossil fuels contribute to 80%

whilst the remaining 20% of GHG emissions are attributed to land use, land use change and forestry (Casper, 2010). Globally, energy related  $CO_2$  emissions have risen to 145-fold since 1850. The emissions have increased from 200 million tons to 29 billion tons a year—and are projected to rise another 54% by 2030 (UNEP, 2013).

Transport sector is significant and fastest growing contributor to global carbon dioxide emissions and are expected to equal half of global emissions in 2050. Transport accounts for 26% of global  $CO_2$  emissions and is one of the few industrial sectors where emissions are still growing. Transportation including aviation is the principal contributors to GHG emissions. Global energy consumption is expected grow by 56% by 2040 with fossil fuels will be the dominant energy sources. Globally, use of petroleum and other liquid fuels will grow from 87 million barrels per day in 2010 to 97 million barrels per day in 2020 and to 115 million barrels per day in 2040 (International Energy Outlook, 2013).

Aviation was responsible for only 2% of global manmade  $CO_2$  emissions in 1992, but expected to increase to 3.0% by 2050 (IPCC, 1999). Emission from aviation sector is growing faster than other transport systems and has recorded significant increase of 110% especially in EU between 1990 and 2008 (European Federation for Transport and Environment AISBL, 2010).

The aviation sector will have to rely on liquid fuels for an unforeseeable future. The main reason is that the energy density of current liquid fossil fuels is the way above other sources of energy such as solar (45.8 MJ/Kg vs. 0.2-1 MJ/Kg) (Clean Energy Insight, 2009). Fuels that require larger storage are not favoured in aviation sector. Energy density and the cost are important characteristics of fuels for the aviation sector. Aviation industry globally is working on finding an alternate to current aviation fuels. Biofuels are being considered by the industry as a potential alternative.

Fossil fuels also play an important role in agriculture. In fact, modern agriculture's dependence on fossil fuels has led to serious fluctuations in food prices and social unrest as world oil prices have increased. The challenge for

poor farmers are to cushion themselves from these price fluctuations by becoming more “energy smart” – maintaining or increasing their food production without increasing dependence on costly fossil fuel inputs. Development in solar energy and wind energy can help replacing fossil fuels for electricity and to some extent surface transport. Without the increased use of renewable energy resources, it is unlikely to bring global warming under control (Casper, 2010). Sustainable biofuels hold out the promise of making rural areas more energy independent as well as generating new and important income sources.

### **Mitigation of climate change:**

The international scientific community has recommended a goal for global warming not to rise above 2°C compared to pre-industrial temperatures. Drastic decisions are required to curtail the temperature rise to below 2°C. This would mean that, atmospheric concentrations of CO<sub>2</sub> must be kept below 450 ppm in order to have a 50% chance of keeping the global mean temperature rise to below 2°C relative to pre-industrial levels or the CO<sub>2</sub> emissions from fossil sources and land use change to be restricted to below 1,440 GT CO<sub>2</sub> (Meinshausen *et al.*, 2009).

Although very little window of opportunity exists to curtail the impacts of global warming. However, if emissions are reduced substantially, it is likely that global temperatures can be held to below 2°C. Recent high emission do not necessary imply high emissions forever (van Vuuren and Riahi, 2008). Effective climate policies need to be evolved, advocated and implemented to bring emissions as per projected carbon budget to have a high probability of limiting warming to below 2°C (Rogelj *et al.*, 2013).

If intense efforts are made to stabilise the CO<sub>2</sub> levels below 400 ppm, the probability achieving this target increases to 66% to 90%. To avoid a warming in excess of 2°C, global GHG emissions should peak by 2020 at the latest and then be more than halved by 2050 relative to 1990 (EG Science, 2008).

Two actions are required to mitigate the climate change effects:

- Substituting renewable sources of energy for fossil fuels and avoiding deforestation
- Increase carbon storage through afforestation, improving soil, and crop and grazing land management

To meet the climate change risks for many developing countries, efforts in agriculture and forestry need to be intensified. Biofuels can contribute to this effort positively provided the crops are selected in such a way that it does not contribute to land use change and should have food security and livelihood components.

### **Emergence of biofuels**

Biofuels are also considered potential renewable energy sources for reduction in GHG from the transport sector. Governments across the globe have taken various measures to reduce the climate impact of fossil fuels by blending them with biofuels and, in fact, have come out with targets of blending ethanol and biodiesel with fossil fuels. The first generation biofuel crops were shown to have a GHG saving of 10-90% which triggered the rapid use of these crops for biofuels especially in USA and Europe. The main feed stocks have been corn, soybean, sugarcane, rape seed and sugar beet. The major biofuel producing areas are the USA, Europe, and Brazil. These countries together dominate the current biofuel productions and account for more than 90% of world’s bioethanol production and around 85% of biodiesel production (IEA, 2011).

In less than one decade, the world’s biofuel production has increased five times, from less than 20 billion litres/year in 2001 to over 100 billion litres/year in 2011 (HLPE, 2013). The steepest rise in biofuel production occurred in 2007/2008, which was unfortunately linked with food commodity prices (HLPE, 2011), and were also one of the precursors of food riots in many developing countries. During this time, the food prices were 2-to-2.5 times higher in 2008 compared to 2004. This is mainly because the main sources of current biofuel are edible crops,

the so called first generation biofuel crops.

The development of the biofuel sector in various countries has been influenced by national mandates and subsidies. The targets set by these Governments will require increased production of biofuels, which will necessitate expansion of these crops leading to indirect land use change or direct land use change. Currently, 2-3 % agricultural land is under biofuel crops, and it is estimated that, by 2030, the area will need to expand to 6 % to meet these targets (IEA, 2011). Land use change (LUC) especially with food crops such as corn, soybean will, however, offset the advantages of biofuels in GHG reductions. As the demand for food and feed crops will remain high to meet future population growth, it is often feared that pristine lands may be diverted to biofuel crops replacing the land meant for the food crops, and may cause a net increase in GHG emissions from indirect land use changes (ILUC).

Many studies have suggested that in fact if the forest land is cleared and used for crops like soybean, oil palm, sugar cane and wheat, the carbon payback time to get a positive GHG increases significantly and varies anywhere between 15 years to 418 years and if grass land is converted this becomes slightly positive and carbon payback time required would be 0 to 96 years. These estimates depend on the crops considered (Gallagher, 2008) and the land use changes. It is clear that except for sugarcane, other crops do not hold the promise for claiming positive carbon foot prints.

The claims of GHG reductions through biofuels have been challenged mainly from the perspective of full life cycle analysis, which does not factor LUC and ILUC. Some of the land for cultivation of biofuel crops, it is feared, will come from deforestation and forest degradation which currently account for approximately 12-17% of global GHG emissions. GHG emissions can also differ depending on the crop, location, feedstock production and fuel processing. Biofuels from first generation biofuel crops can even generate more greenhouse gas emissions than fossil fuels. A lot of attention has been given in the literature to the potential of various crops to reduce GHG

emissions. For example, Canola biodiesel and soybean biodiesel were found to reduce emissions by 58% and 50% respectively, while corn ethanol was found to reduce emissions by only 21%. However, the agronomic practices used for producing a biofuel crop also determines the overall environmental impact – so called ‘swing potential’ of a crop (Davis *et al.*, 2012). Emissions of nitrous oxide are another important factor in GHG emissions – the greenhouse gas effect of nitrogen fertilizer application is about 300-times stronger than that of carbon dioxide.

To address the issue of LUC and the ‘fuel vs. food’ debate, it is important to avoid displacing commercially attractive food crops from their most suited agro-ecologies and to use marginal land unfit for agriculture or surplus land suitable for production of second generation biofuels. It is estimated that there is enough potential from these marginal land to meet the global demand (Gallagher, 2008).

The problem with current / first generation biofuel crops is that it was meant to address only mitigation component with very little emphasis on adaptation to climate change risks. The rapid development in the expansion of these first generation food crops for biofuels were also linked with the national mandates and subsidies and were based on the assumptions of GHG savings from these crops without considering full life cycle analysis and LUC. It is now very clear that current biofuel crops (food crops) are not sustainable. Moreover, in current form and implementation, they have limitations in their ability to achieve targets for oil product substitution, climate change mitigation, and more importantly economic growth of smallholder farmers. However, if non-food or multiple use crops especially tree species are considered and smart farming systems are developed that can address food security and livelihoods of smallholder farmers and can provide local energy for agriculture production, it has the potential to address both mitigation and adaptation aspects of climate change risks.

Second generation biofuels can have positive effects on food security and can provide the new

sources of income / employment, and also provide alternative sources of energy for rural communities. Many developing countries (e.g. India) have now developed policies that specifically targets biofuels from non-food / multiple-use crops and use of marginal land. The future biofuels therefore will be based on non-food crops that would be grown in marginal land or excess land without affecting the current food production.

However, care must be taken that biofuels and the income they generate complement existing food production without exerting any pressure for land use change. Sustainable and productive feedstock and systems are needed to ensure that overall farm productivity is increased, enabling biofuels to be produced over and above the current food production system.

### **Future biofuels**

World Food Security (CFS) recently recommended a "*review of biofuels policies – where applicable and if necessary – according to balanced science-based assessments of the opportunities and challenges that they may represent for food security so that biofuels can be produced where it is socially, economically and environmentally feasible to do so*" (HLPE, 2013). To achieve this it is important that biofuels crops selected should have a negative GHG emissions considering full life cycle analysis. It is now clear that majority of crops used thus far will have very limited role in any future biofuel programmes – one exception could be sugarcane (Eisentrout, 2010). Indisputably, monoculture and high value food crops diverted to biofuels are the main culprits for the adverse publicity received by biofuels.

If the biofuels in the future have to address 2°C challenge, by 2030 the biofuels need to provide 9% of total transport fuel, up from current levels of 2.7%. Similarly, by 2050 this levels need to increase to 27% to achieve a 50% reduction in carbon dioxide (IEA, 2009). Land required to meet the growing biofuel demand vary with different assumptions and estimated be as high as 1500 Million ha (Field *et al.*, 2007). A more realistic target will be an area of 375-750 Million ha

(HLPE, 2013).

According to Alexandratos and Bruinsma (2012), 1.4 Billion ha of additional land could be brought under agriculture with some investments. However, this land is not fairly distributed across the globe and 60% of this area is shared by only 13 countries. The same authors estimate that for meeting agriculture production for 2050, 70 Million ha of additional land will be required. Therefore, it will make sense to explore the opportunity of growing alternative biofuel crops on land unsuitable or not used, thus far, for food production. Tree species can be a smart choice for future biofuels and as a mean to regenerating poor quality land through the addition of carbon to soils, resulting in carbon sequestration. India has come out of a policy in 2009 which specifically targets marginal land for biofuel production. There will be challenges, however, to utilise these marginal land due to lack of infrastructure to support crop growing.

In future, it is also important to rethink national and global biofuel strategies, especially within the context of smallholder agriculture, so as to focus on livelihood options which biofuels can provide. In this view, biofuels must have positive effects on food security, provide the new sources of income and employment, and also provide alternative sources of energy for rural communities to enable them to step forward in their quest for sustainably intensifying their agricultural practices.

Perennial species are the most suitable for biofuels as these can be integrated in agriculture using suitable agroforestry models. Agroforestry offers many advantages that make it very attractive for biofuel production: it is less demanding in terms of agricultural inputs, reduces erosion and improves soil properties, produces animal feed and/or fertilizers as co-products, provides more energy per unit of land from these crops and also brings in resilience in farming for food and nutritional security. Moreover, agroforestry can address both adaptation and mitigation components of climate change.

It has been shown that considerable GHG reductions can be achieved with perennial biofuel

crops, if forests are not replaced with these species. For example, if the forests are replaced with oil palm, a five-fold increase in GHG results whereas with best practices in areas where oil palm is not replacing forests GHG reduction of -200 g CO<sub>2</sub> eq./ MJ will result (Davis *et al.*, 2012). Similarly, growing multiple species together (LIHD Prairie system) involving perennials has been shown to have insignificant carbon debt and does not need many years for repayment compared to traditional first generation biofuel crops (with a range of between 0-to-1 year). This system apart from preserving biodiversity also generates higher energy yields, GHG reductions, less agrichemical pollution per hectare than first generation biofuel crops such as sugar cane ethanol or soybean biodiesel (Fargione *et al.*, 2008; Tilman *et al.*, 2006).

Agroforestry systems are being used by small holder farmers to produce non edible or multiple use oils from tree species and being used to generate multiple energy sources for their livelihoods. Agroforestry systems used for biofuels production have been shown to increase the productivity of food crops and also improved soil fertility (Shivakumar, 2011). While, single tree species in an agroforestry system will be useful for industrial applications, farmers can grow more than one tree species to augment his sources of income. For small holder farmers, it is also important that the non-food oil seeds are available throughout the year to meet his /her daily energy requirements. The oil bearing tree species should be selected in such a way that at least one species is in fruiting stage at any given period of time.

Many tree species are now being considered as alternate biofuel crops such as *Jatropha*, *Pongamia*, *Simarouba*, *Neem*, *Mahua*, *Macauba*, *Nipa palm* along with some annual crops such as salicornia.

- *Jatropha curcus* or *Jatropha* produces seeds containing inedible lipid oil and has been considered to produce fuel. Each seed produces 30 to 40% of its mass in oil. *Jatropha* was projected to grow well in difficult soil conditions, including arid and otherwise non-arable areas therefore
- became a choice for biofuel production. The seeds are mildly toxic to both humans and animals and are therefore not a food source. As a result, governments worldwide pushed *Jatropha*, often through large monoculture systems, as a crop for meeting their renewable fuels requirements. However, it failed to take off in many parts of the world (Ghallagher, 2008). It is now clear that *Jatropha* is not a miracle crop, and similarly to other food and/or energy crops, *Jatropha* also needs appropriate inputs and management. Additional research is still required to develop *Jatropha's* potential as a biofuel crop.
- *Pongamia pinnata*: *Pongamia* is a leguminous fast growing tree and bears fruits in around 5 years, the seeds contain up to 40% oil. It can withstand wide range of temperatures and suitable for sandy and rocky soils. The species is one of the promising tree species suitable for providing oil for biodiesel production. This tree species is found to be well spread throughout India. Considered for biodiesel in India
- *Simarouba glauca*: *Simarouba* is a native of Central America and has been introduced in India. It can grow well in tropical climate with temperature conditions between 10°C and 40°C. It can stand rainfall between 300 mm to 1000 mm, but performs better in 700 mm to 1000 mm conditions. It is resistant to storms and drought. The fruit pulp contains 11% sugar and the seed, which accounts for 40% of the fruit by weight, has 65% oil content. This species has a good potential for both biodiesel and bioethanol. This is a medium sized evergreen tree begins to bear when it is 6-8 years old (3-4 years in case of grafts) and attains stability in production after 10 years. Considered for biodiesel in India
- *Azadirachta indica*: *Neem* is a native of India and has been adapted to many tropical countries. This is a very fast

growing tree and considered to be a drought tolerant species. A single tree can produce up to 50kg seeds and seeds contain oil up to 45%. Although there are several other uses of neem oil, but can also be considered for biofuels. Considered for biodiesel in India

- *Madhuca indica / Madhuka longifolia*: *Mahua* is well adapted to semi-arid regions and grows wild in India. *Mahua* takes around 10 years long time to fruits, the flowers are rich source of sugars while kernel contains 50% oil. Very high seed yield of 20-200Kg per tree can be obtained by this tree. Considered for biodiesel in India and also has a potential for bioethanol.
- *Acrocomia aculeata*: Macauba is a spiny palm, originating in Latin America, whose varieties grow naturally from Mexico to northern Argentina. Some varieties are resistant to frost and below freezing temperatures (-5°C), with no resulting damage and as such, the palm could be planted throughout the subtropics. The yield potential is very high - on an average 70 kg fruit yields per tree can be obtained. Macauba starts fruiting in four years and considered to be drought and frost tolerant species. However, suitable for areas receiving more than 1000 mm rain falls. Being considered for biodiesel in Brazil.
- *Nypa fruticans*: *Nipa palm* the only mangrove that is also a palm tree. It is indigenous to coastlands and river mouths from the Pacific Islands to Bangladesh. Naturally, it thrives in brackish water but can also grow in freshwater, for example alongside streams. It requires tropical conditions. It can yield: 6,000 – 8,000 l/ha of bioethanol. *Nipa* starts flowering 3-4 years after germination. Being tested for biofuel production in Philippines and Malaysia.
- *Salicornia bigelovii*: *Salicornia* species are some of the most salt-tolerant terrestrial plants that grow in coastal marshes and on

seashore. *Salicornia* species are among the most promising halophyte crops for producing biofuels in saline conditions. It yields better than fresh water grown oilseed crops such as sunflower and soybean. Contains 30% oil with a potential of 1,000 – 1,200 l/ha of biodiesel.

- *Manihot esculenta*: Cassava is a year-round and multiple use crop from producing chips, pellets, flour to alcohol and starch for industry. Poor subsistence farmers are the main growers of cassava, and women are largely responsible for the work of processing it to make gari, fufu, tapioca and other products. It is considered for bioethanol production with a potential yield of 5,500 l/ha of bioethanol.

All these species are at the moment being tested at the pilot scales and it will take some time before large scale biofuels will become reality to meet national blending targets. None the less, some very exciting case studies have emerged mainly in India (Narayanaswamy *et al.*, 2009) and Mozambique (Harvard Kennedy School Magazine, 2012) for addressing the local energy requirements of smallholder farmers for livelihoods and for production of clean energy solutions to replace charcoal for cooking. Macauba is being tested in Brazil with encouraging results whereas biofuel from salicornia is being tested by the aviation industry to produce aviation biofuels.

If innovative value chains are created with these perennials, future biofuels will not only help mitigate climate change impacts, but will also provide livelihood opportunities to smallholder farmers and enhanced agriculture production.

## CONCLUSIONS

The major contributors of the current climate change are land use and transport sector. Biofuels have been considered to address the climate change as they are cleaner source of energy for transport fuel. Without considering the full life cycle analysis, the first generation biofuel crops, which are mostly the food crops, were grown on

large scale to meet national targets of various governments across the globe. It is now clear that the current biofuel crops, in the current form of use, are not environmentally friendly. Moreover, the diversion of these food crops to biofuels resulted in major food riots in 2008. This resulted in a major food vs. fuel debate. The European Parliament in September 2013 has decided to limit the use of fuels made from food crops because of fears that biofuels can push up grain prices. Global scientific communities have now suggested practicing non-food or multiple use crops which can be grown in marginal land to be used in biofuels. Perennial species and smart farming systems such as agroforestry hold the promise as a very good substitute for food crops. The tree species are probably better suited to address environmental concerns. Moreover, biofuels, if directed towards enhancing livelihoods by providing local energy will help smallholder farmers of the developing countries who are the most burdened by the climate change although have not contributed to it. Here again tree species will be helpful in providing multiple co products along with the oil for biofuels.

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