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IMPACTS OF LOCAL CONDITIONS ON SUSTAINABILITY OF LIQUID BIOFUELS PRODUCTION

Master´s thesis

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No fine work can be done without concentration and self-sacrifice and toil and doubt.

(Max Beerbohm)

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ABBREVIATIONS AND SYMBOLS

GHG – green house gas

WTW – well to wheel

SCE – solar energy conversion

LCA – life cycle assessment

Pt – eco indicator point

mPt – mili eco indicator point

FU – functional unit (L 100 km^{-1})

CYP – climate yield prediction model

EU – European Union

CO_2 – carbon dioxide

HC – hydro carbons

VOC_s – volatile organic compounds

NO_x – nitrogen oxides

PM – particulate matter

SCE – solar energy conversion efficiency

MJ – mega joule

°C – degree Celsius

mm – millimetre

LCA – life cycle assessment

USA – United States of America

UK – United Kingdom

IPCC – Intergovernmental Panel on Climate Change

ARSO – Environmental Agency of the Republic of Slovenia

ABSTRACT

Throughout human history, energy sources have been changing due to intense exploration, technological progress and expanded development. Although the invention of the combustion engine was started with the use of biofuel, consumption of the latter died out due to cheaper oil. However, the facts of decreasing reserves of fossil fuels and emerging global climate change have brought about a revival of liquid biofuels.

The aim of this thesis is to analyse the impacts of local conditions on liquid biofuel sustainability. In first part, climate yield prediction models were calculated with the Wolfram Mathematica 7.0 software. Models are based on the correlation between yields of feedstock for biofuel production and weather variables. Data about the yield for selected feedstock were obtained from the Faostat database, while data on temperatures and precipitation were gained from Climate Research Unit.

In the second part, an environmental impact assessment of liquid biofuels production was conducted. Data on energy and inventories flow for biofuel production were obtained from various scientific papers. For environmental impact assessment, Sima Pro 7.1 software and the Eco indicator 99 method were used.

In the third part, the results of environmental impacts were compared according to the rates of subsidies for biofuels that are given in each country. The results show that the yield of feedstock for biofuel production is strongly influenced by temperature ($p<0.05$) and less by precipitation; therefore, increasing temperatures will decrease the yield of feedstock. The results of the climate yield prediction models also show that biofuel production under expected climate changes will decrease by up to 40% by the end of 2100. The results of the environmental impact assessment show much larger environmental impacts for analysed biofuels in comparison to fossil diesel or petrol. The reason is that the production of first-generation liquid biofuels still consumes large amounts of fertilizers and non-renewable sources of energy in pre-harvest and post-harvest operations. A comparison of environmental impacts and subsidies shows that countries are not promoting biofuel production from feedstock that affect the environment less. From that, it follows that environmental impacts are not criteria for subsidy rates. Therefore, it can be concluded that the first-generation liquid biofuels cannot represent a long-term solution, neither by ensuring sufficient quantities at projected global changes, nor from the environmental or economical perspectives.

Key words: sustainability, liquid biofuels, environmental impacts, climate change, subsidies rates.

1 INTRODUCTION

Energy sources in history of mankind have been changing due to intense exploration, technology and development. Some evidences exists that mankind learned to control fire more than 500.000 years ago. In early 1600`s people in Europe discovered how useful coal for heating is and after 1850, when steam engine was discovered, the coal consumption increased exponentially. In the 1900`s so called age of the combustion engine that is based on petrol extensive consumption began (Rajagopal and Zilberman, 2007; Demirbas et al., 2009).

The current energetic paradigm of our society that is based on the massive use of fossil fuels needs to be changed rapidly. The need upon quick changes has crucial importance for direct problems: increase of oil prices, limited of reserves (Derimbas, 2008) and political instability in the main oil producers' countries and also indirect problems that are shown as impact on the climate and environment. These impacts to the environment are consequence of releasing large amount of emissions of greenhouse gases (GHG) into the atmosphere (Stern, 2007; Baruch, 2008; Pin–Koh and Ghazoul, 2008).

The mobility has crucial importance in our modern industrialized society (Lomborg, 2001). Apart from a few exceptions, the transport of people and goods is sustained by liquid fuels. Despite the known fact, of limited petroleum resources, the consumption is still growing. Therefore a number of various studies put the date of the global peak in oil production between 1996 and 2035 (Demirbas, 2008; Pimetel et al., 2007).
The transport sector accounts for more than 30% of final energy consumption in the European Union (EU) and is expanding, along with carbon dioxide (CO_2) emissions. By 2010 the transport related CO_2 emissions are estimated to reach 1.11 billion tonnes. The main culprit is road transport, which accounts for 84 % of those CO_2 emissions. Additionally, the transport sector depends to 98 % on fossil oil (Directive 2003/30). On the other hand, the world population keeps growing (UN, 2004) and improving the standard of living, are the facts that lead to a significant increase of energy consumption (IEA, 2008a).

Renewable energy sources, unlike fossil fuels, can be used without ever being used up. By that it is important to point out that the renewable energy sources release the equal amount of CO_2 when being burned as it is used in process of photosynthesis (Rutz and Janssen, 2007; Chauhan et al., 2009; Stephard, 2003; Clair et al., 2008).

Promoting the use of biofuels together with sustainable agriculture and forestry practices laid down in the rules governing the common agricultural policy could create new opportunities for sustainable rural development in a more market orientated common agriculture policy and to respect for flourishing country life and multifunctional agriculture, and could open a new market for innovative agricultural products with regard to present and future (Directive 2003/30).

There are two global bio renewable liquid transportation fuels that might replace gasoline and diesel fuel. Those are ethanol and biodiesel. Ethanol is produced from sugar or starch crops, while biodiesel is produced from vegetable oils or animal fats (Rutz and Janssen, 2007; Hamelinck et al., 2004; Worldwatch institute, 2006).

Nevertheless, renewable energy sources represent only 13.6% of the global energy production. By that biomass, feedstock for liquid biofuels presents only 0.4% (Lomborg, 2001). Today`s question is no longer whether the renewable biofuels will play a significant role in providing energy for transportation, but rather what are the implications of their use and how it is going to reflect in economy, environment, global security and in the health of whole mankind (Worldwatch institute, 2006).

REVIEW OF LITERATURE

1.1 HISTORY OVERVIEW OF LIQUID BIOFUELS

Most of the transport in now days relies on liquid fossil fuels despite that the invention of internal combustion engines was done with biofuels (Antoni, 2007). Already, early in the nineteenth century, alcohols were repeatedly reported as biofuels (Kovarik, 1998). Nikolaus August Otto developed his prototype of a spark ignition engine in the 1860s using ethanol and was sponsored by the sugar factory of Eugen Langen who was interested in the mass production of ethanol (Antoni, 2007).

Early in the mid 1800s, transesterification was used as a strategy for the soap making. Early feed stocks were corn oil, peanut oil, hemp oil, and tallow. The alkyl esters resulting from the process were originally considered just as by products. The story about diesel engine began in 1893, when Rudolph Diesel published a paper entitled “The theory and construction of a rational heat engine”. The paper described a revolutionary engine run on vegetable oil (Demirbas, 2008). Deutz Gas Engine Works designed one third of their heavy locomotives to run on pure ethanol in 1902 since safety and cleanness were advantageous factors (Pahl and Heinberg, 2007).

Prior to the American Civil War, an ethyl alcohol mixed with turpentine, known as camphene was widely used as lamp oil. The tax on alcohol during the Civil War dramatically reduced the use of industrial alcohol until 1906, when the tax becomes repealed. So the ethanol comeback as a fuel used especially for internal combustion engines (Pahl and McKibben, 2008).

Ethanol was soon recognised as an anti knocking additive for internal combustion engines and was added to gasoline between 1925 and 1945. The presence of ethanol in the fuel allows higher piston compression and by that increased the engine efficiency. Henry Ford was active in the chemurgical movement whose purpose was to bring farm products into field of production of energy supplies, especially during the time of “great depression” (Finlay, 2004). These activities resulted, among others, as development of the car running on 100% bioethanol known as” Model T”. Despite the development of the car that has almost total reliance on diesel, the idea of using vegetable oil as an alternative source of diesel fuel was not completely forgotten (Mousdale, 2008; Hulse, 2007).

There were a number of experiments on the use of vegetable oils in the beginning of 1920 continuing to the early 1940s. Most of the experiments were going among European nations within colonies, especially in Africa. In 1937 a Belgian patent was granted to G. Chavanne of the University of Brussels for the use of ethyl esters of palm oil. The following year, a commercial passenger buses operated between Brussels and Louvain that were run on palm oil ethyl ester.

Shortly before World War II, there were some experiments carried out in South Africa. In the experiment where included large farms were was used fuels derived from sunflower seed oil. Unfortunately these promising experiments were abandoned due to South Africa’s abundant coal reserves from which the synthetic liquid was obtained.

During World War II, vegetable oils were used as emergency fuels by various nations when normal supplies of petroleum based fuels were disrupted (Pousa et al., 2007).

Brazil utilized cottonseed oil in place of important diesel fuel. Argentina, China, India and Japan all used some form of vegetable oil during the war years. The Japanese battleship Yamato is reported to have used refined, food grade soybean oil as bunker fuel. But after the war, with return of steady supplies of cheap petroleum oil, virtually all research on vegetable oil fuels was abandon (Pahl and McKibben, 2008; Goettemoeller, 2007).

Nevertheless in 1979 in response to the ongoing international oil crisis, ethanol gasoline blends were recognised that gasoline additives, such as tetra ethyl lead, required for high compressions in ethanol free engines, were environmental and health hazards. Despite these apparent risks, the petro derived gasoline finally came to dominate the transport market after World War II (World Watch Institute, 2006; van der Laak et al., 2007). Ethanol as a fuel was revived in the 1970s in Brazil where one of the largest bioethanol industries is still located today. First, Brazil developed a ‘‘Pro alcohol’’ program in 1975 based on sugarcane in response to the 1973 OPEC Arab oil embargo. Over half of the cars in Brazil ran on 95 % anhydrous ethanol (E95) in the late 1980s, though a late 1980s sugar shortage and price have reduced that figure to where it is today, at 20 percent of cars (Solomon et al., 2007). Since the late 1990s interest has picked up again largely for environmental and social reasons helped by changes in the international energy market (Pandey and Padwar, 2006).

The forces pushing the renewable transport fuels vary from country to country. The production of biofuels has increased greatly during the last five years (Figure1). Moreover, production is expected to increase since many of the world largest economies have plans to expand their output (Wiggins, 2008). And therefore there are some new challenges that the biofuels industry must confront with.

On one hand there are ethical discussions like: “Is it ethically to use foodstuffs for fuel since billions of people are starving?” (Rajagopal et al., 2007; Srinivsan, 2009; Stein, 2007; Pimentel et al., 2009) and on the other hand there are environmental issues like: “How extensive are environmental impacts of liquid biofuels, especially in relation to projected global changes?”

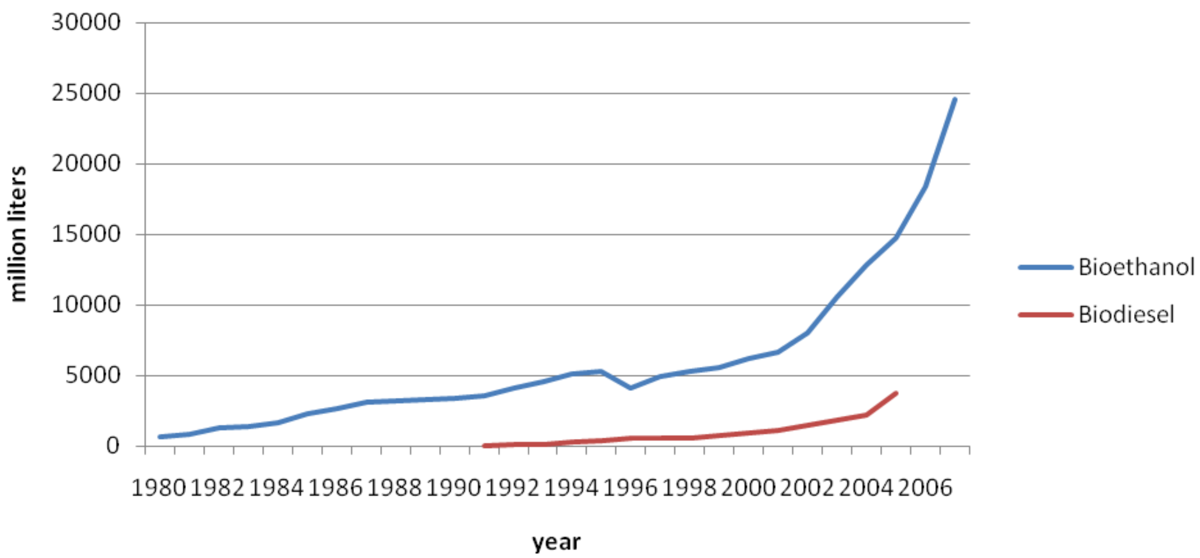


Figure 1: World production of bioethanol (1980-2006) and biodiesel (1991-2005) in million litres (Brown, 2008).

World leading countries in bioetanol production are USA followed by Brazil and China. Together they are presenting more than 90% of total world produced bioetanol. The higher the production is the more intense is the green colour on Figure 2.

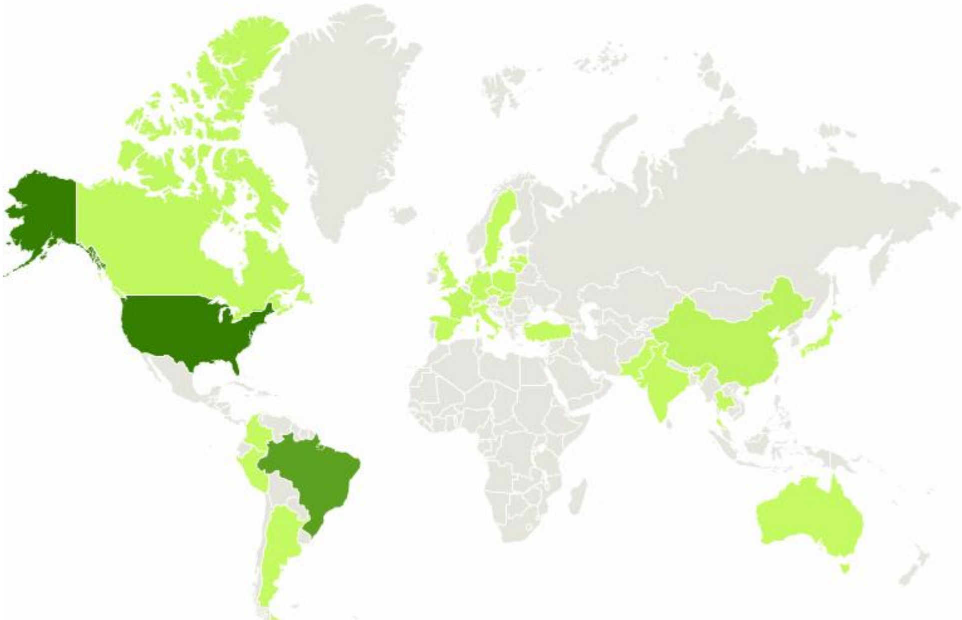


Figure 2: World leading countries in bioethanol production in 2008 (Biofuels Platform, 2009).

Figure 3 shows countries with the highest production of biodiesel in year 2008. World leading country is Germany that produces 20% of total world biodiesel, followed by USA (16%) and France (13%).

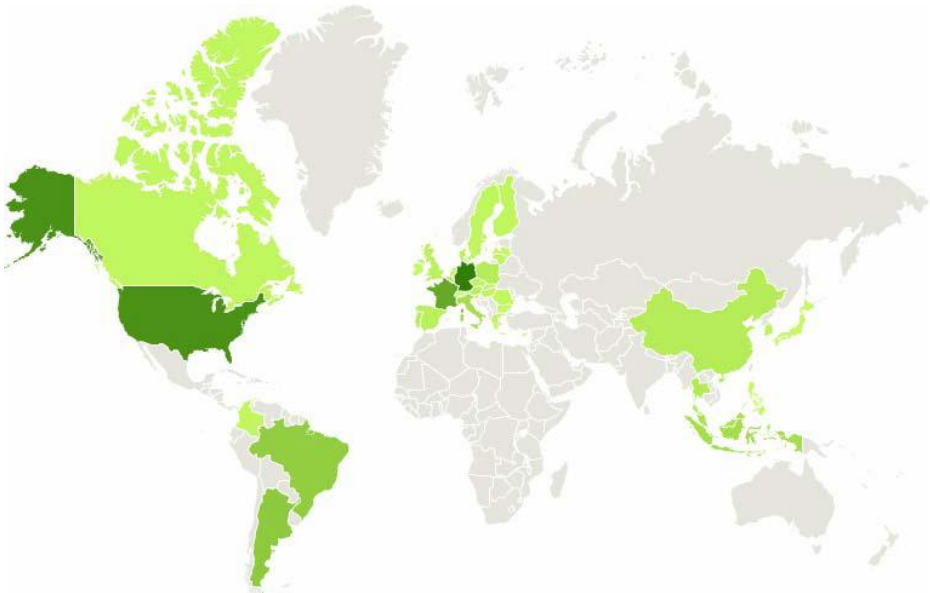


Figure 3: World leading countries in biodiesel production in 2008 (Biofuels Platform, 2009).

1.2 FEEDSTOCK FOR LIQUID BIOFUELS PRODUCTION

Ethanol can be produced by fermenting sugars or starch. Sometimes lingo cellulosic biomass, containing celluloses, lignin and hemicelluloses, is also used for producing ethanol. They are called second generation feedstock: examples are wood waste, straw and plant waste. Sugary plants can be mashed directly and fermented to ethanol by alcohol fermentation. Starchy plants such as corn must first go through enzymatic saccharification, before alcohol fermentation can be carried out (James, 2005). The most common feedstock for ethanol production are sugar beet *(Beta vulgaris)*, sugar cane *(Saccharum)*, corn *(Zea mays)*, wheat *(Triticum* spp*.)* and barley *(Hordeum vulgare)* (Rutz and Janssen, 2007). Meanwhile the biodiesel is the most common made of fats like sunflower (*Helianthus annuus*), soybean (*Glycine max*), sorghum grain *(Sorghum bicolour)*, rapeseed (*Brassica napus, B. nigra, Sinapis alba, Camelia sativa*) and waste oils (Rutz and Janssen, 2007).

1.2.1 Bioethanol

A variety of common sugar crops can be used as the feedstock for producing ethanol fuel, including sugar cane stalks, sugar beet tubers and sweet sorghum stalks, all of which contain a large portion of simple sugars. Once these sugars have been extracted they can be fermented easily into ethanol. Starch crops such as corn, wheat and cassava can also be hydrolysed into sugar, which can then be fermented into ethanol (IEA, 2004).

Bioethanol production processes from sugar or starch crops are the most traditional and developed pathways. Fermentation is performed by microorganisms in the absence of oxygen according to the following main reaction:

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2 \tag{1}$$

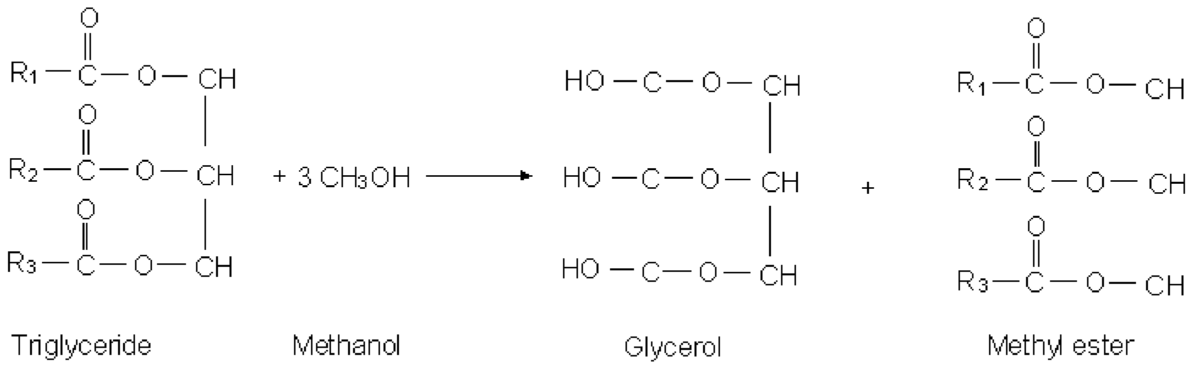
(Chiaramonti, 2007).

The theoretical maximum of ethanol yield is 0.51 kg of bioethanol and 0.48 kg of CO_2 per kg of sugar (Chiaramonti, 2007). Although several microbial hosts have been investigated for ethanol production, *S. cerevisiae*, *E. coli* and *Z. mobilis* remain the most mature platforms.

With multiple steps distillation the necessary fortification of the ethanol to a purity level of 96% can be achieved. The remaining wash consists of water and organic materials (James, 2005; Chang, 2007). A fuel ethanol market has been developed in Brazil based on sugarcane while the U.S. has been relied on cornstarch for commercial production of fuel ethanol (Brown, 2007).

1.2.2 Biodiesel

Biodiesel is composed of monoalkyl esters (2), a long chain of fatty acids usually agricultural residue such as soybeans or animal fats (Rutz and Janssen, 2007). In a vehicle, it can be used neat or blended with petroleum diesel using 20% biodiesel and 80% petroleum diesel, which helps to alleviate the fact that it freezes at a higher temperature than conventional diesel (Kreith and Goswami, 2007; Van Gerpen and Pruszko, 2004). Vegetable oil, once it has been through the esterification process, is called biodiesel. In this process the fat molecules are separated into three individual fatty acid ester chains according to following reaction:



(Demirbas, 2009).

(2)

The physical properties of the vegetable oils are changed in such a way that they correspond to those of conventional diesel fuel. After esterification the molecules have a viscosity that is similar to that fossil diesel fuel (Mousdale, 2008). Biodiesel can also be produced from used cooking fats and oils as well as from natural vegetable oils. The esterification process requires alcohols, in most cases methanol. Glycerine emerges as a by product from esterification and, after purification, can be used in the chemical industry as a base material (James, 2005).

1.3 FIRST GENERATION BIOFUELS

First generation biofuels like bioethanol, the current protential candidate as a petroleum replacement for internal combustion engines, is a fuel generally derived from food crops such as sugarcane, sugar beet, maize, sorghum and wheat, although other forms of biomass can also be used, and may even be preferable (Maxwell, 2009). The vast majority of first generation biofuel feedstocks, especially in the case of bioethanol, constitute comestible materials, which has led to concerns about biomass previously destined for human consumption being diverted to fuel production. The most significant concern, however, relates to the inefficiency of first generation biofuels (Reijnders and Huijbregts, 2009). Large amount of energy is expended on cultivating, harvesting and processing the biomass, even though only a relatively small proportion is used to derive energy (Charles et al., 2007; BioFuel, 2007). Some authors pointed out that usage of first generation biofuels has impact on food prices worldwide (Alexander and Hurt, 2007; Kessler, 2008; Rajagopal et al., 2007; Srinivsan, 2009; Stein, 2007; Pimentel et al., 2009).

1.4 SECOND GENERATION BIOFUELS

Second generation or lingo cellulosic biofuels are derived from feed stocks not traditionally used for human consumption. As a result, there is much less concern about the use of these fuels leading to famine in developing countries, or adversely affecting consumer prices in developed nations (Maxwell, 2009; Demirbas et al., 2009). The benefits of using these second generation biofuels are manifold. Aside from reducing the threat of food supplies being diverted to fuel production, second generation biofuels are argued to be more environmentally appropriate and produce less GHGs than first generation biofuels. (Charles et al., 2007). Ligno cellulosic biomass, such as trees and grasses can be grown on poorer quality land than crops, thus avoiding competition for agricultural land. Research and development efforts on second generation biofuels feedstock are promising, but they are not yet commercially available on large scale since their conversion technologies are still in the development stage (OECD, 2008; Rutz and Jansen, 2007).

Whereas ethanol production in the 1980s concentrated on using starchy and sugary plants, research and development practices today focus on lingo cellulosic biomass. This is often more cost effective, because lingo cellulosic waste is available on the market and is not used in the foodstuffs sector. Therefore production from non sugar and non starch plants could mean a breakthrough for the production of ethanol from biomass (Brown, 2007).

1.5 THIRD GENERATION BIOFUELS

Algae fuel, also called oil algae or third generation biofuel, are biofuels made of algae. Algae have low input and high yield feedstock to produce biofuels using more advanced technology (Demirbas, 2008).These technologies are in the early stages of development but offer intriguing prospects for the future (Newton, 2008).

1.6 ENVIRONMENTAL ASPECTS OF BIOFUELS

One of the major arguments behind support for biofuel developments worldwide is the concern about global climate change which is primarily caused by burning fossil fuels and potential of biofuels to reduce it (Are Biofuels Sustainable, 2008; Soetaert and Vandamme, 2009).

Some biofuels can lead to substantial GHGs emission reductions when compared to fossil fuels (Zah et al., 2007; WorldWatch Institute, 2007), particularly with the development of advanced technologies that rely on agricultural wastes and dedicated cellulosic crops such as switch grass (Smeets et al., 2009). But there are also other environmental considerations like acidification, eutrophication, photo smog, health hazards, ozone depletion, loss of biodiversity and impact on ground water (Rutz and Janssen, 2006; Rajagopal and Zilberman, 2007). These environmental impacts are mainly associated with agriculture and the production process of feedstock. But also impacts of biomass transport, biofuel production, distribution, and consumption have to be considered (Rutz and Janssen, 2006; Lal, 2004). Finally biofuels also consume a significant amount of energy that is derived from fossil fuels. Inputs to production include tillage, fertilizers, pesticides, irrigation, operation of machinery for transport, steam and electricity for processing (Pimetel and Paztek, 2005; Farrell, 2006). Therefore some concerns appeared that expansion of biofuels market will increase pressure to intensify agriculture and also to expand agriculture into natural habitats (Are Biofuels Sustainable, 2007).

1.6.1 Environmental impacts related to production of biofuels

Expanding the cultivation of biofuel crops has the potential to contribute to soil depletion and erosion, habitat loss, and reduced biodiversity (Kaltner et al., 2005; Clay, 2004). On the other hand, cellulosic biofuels could be produced from perennial grasses and trees that protect lands vulnerable to erosion and restore lands degraded by overuse (Worlwatch institute, 2006). Therefore the size of negative impacts predominantly depends on different parameters, and especially on the practices of feedstock producers. But if feedstock production is done in a sustainable manner, environmental impacts can also be positive (Rutz and Janssen, 2007).

Impacts on water

Water consumption for the production and processing of bioethanol is not negligible. The amount of water used for agriculture depends on the aridity of the cultivated region and on the water demand of the feedstock type. But also for the conversion process much water is needed (Rutz and Janssen, 2007).

Bio energy crops optimized for rapid growth generally consume more water than natural flora or many food crops. Some biomass crops like sugarcane compete directly with food crops for irrigation water. Others have been observed to lower the water table, reduce stream yields, and make wells less reliable; this is one reason local agricultural communities have often opposed the introduction of tree plantations.

Certain practices, like harvesting residues, cultivating tree crops without undergrowth, and planting species that do not generate adequate amounts or types of litter, can reduce the ability of rainfall to infiltrate the soil and replenish groundwater supplies, exacerbating problems of water overconsumption (Hazell and Pachauri, 2006).

Agricultural water use is a serious concern, especially in southern parts of Europe, where water is scarce and highly variable from year to year and where agricultural use of total water consumption exceeds 50 %. The irrigable area in EU increased from 12.3 million ha to 13.8 million ha between 1990 and 2000. In the Mediterranean countries like France, Greece and Spain, the irrigable area increased by 29 % during the same period. Irrigation is also important for arable production in the south eastern EU (EEA, 2007).

The impacts of increased water abstraction and irrigation include loss of wetlands and the disappearance of habitats due to the creation of dams and reservoirs, soil salinization and contamination, salt water intrusion in coastal aquifers, and the destruction of extensive, biodiversity rich land use systems, such as arable pseudo steppes (EEA, 2007).

Yang et al (2009) pointed out that in China meeting the biofuels targets for 2020 will be difficult since extremely small per capita arable land in China; it is very difficult to spare this amount of land from currently cultivated land for feedstock. The associated water requirement further lowers the possibility because much of the northern land already endures serious water shortage. Meanwhile Renouf et al (2008) find out that sugar beet show great advantages according to low eutrophication potential due to other crops like sugarcane or corn.

Kim and Dale (2005) found that some cropping systems offered environmental benefits in terms of non renewable energy consumption and global warming impacts, but planning cover crops was necessary to prevent acidification and eutrophication.

Diffuse losses from agriculture continue to be an important source of nitrate and phosphate pollution in European waters. Nitrate concentrations in waters in most central and southern EU regions are still high and are ranging between 20 to 40 mg/l NO_3 and cause large problems with eutrophication and the recreational use of lakes and estuaries. European Fertiliser Manufacturers Association shows that nutrient inputs are highest on wheat, maize, potatoes and rapeseed rape, but also that these vary strongly between countries (EFMA, 2006).

In EU there is a recent trend towards reducing pesticide residue in water. Nevertheless, the occurrence of pesticides in water bodies above regulated standards remains a problem. The main negative effects of pesticide pollution are on aquatic, terrestrial flora and fauna (EEA, 2007; FAO, 2006). Therefore carful crop selection can affect both water use and quality by reducing the need to irrigate, and lowering if not elimination the need for chemical fertilizers and pesticides, meaning that the water draining from their soils will have lower concentrations of chemicals (Powlson et al., 2005).

Furthermore, some crops can filter the nutrients that leach off adjacent farmland, ensuring that they do not reach nearby water bodies (GTZ, 2005).

In case of spilling and leakage ethanol is biodegraded, since is naturally occurring substance produced during the fermentation of organic matter (Granda et al., 2007). Biodiesel is much less harmful to water and soil then conventional one. This is due to fast biodegradability. Additionally biodiesel is far more water soluble that fossil diesel, enabling marine animals to survive in far higher concentrations if fuel spills occur. This is not only important to maritime shipping, but also to groundwater and biodiversity, agriculture and drinking water issues (Heinloth, 2006). Since pure plant oil contains no trace of methanol, it is even less harmful than biodiesel. Pure plant oil is risk free. Besides the direct influence of biodiesel and pure plant oil themselves on water and soil, also feedstock production and fuel processing influences water issues (Rutz and Janssen, 2007).

Impacts on soil

The quality of land use practices strongly influences habitat and biodiversity aspects, as well as soil, water and air quality (Clay, 2004). Ethanol yields per hectare are generally far greater than for biodiesel. Expansion of monocultures could irreversibly destroy the unique and complex ecosystems (Rutz and Janssen, 2007).

Biomass feedstock such as corn, soybeans, and mixed species grassland biomass differ in current or proposed application rates of fertilizers and of pesticides. Phosphorus application rates are lower for soybeans than for corn. Nitrogen application rates are much lower for soybeans than for corn because soybeans, which are legumes, fix their own nitrogen from the atmosphere. Pesticide application rates for soybean are about half those for corn (Schnoor and others, 2008).

Soil erosion risks are particularly high in the Mediterranean region, which is characterised by long dry periods followed by heavy bursts of rainfall falling on steep slopes with unstable soils. As a result of dry summers in these areas, soil cover is also limited in summer which increases the risk of erosion in autumn when rainfall starts. In northern parts of Europe erosion by water is not such a problem as rainfall is spread out more evenly over the year and there are fewer regions with steep slopes and shallow soils. Severe erosion incidents were observed in Northeast Germany, with soil losses of more than 40 t/ha/yr (EEA, 2007).

The risk of soil compaction depends on the use of heavy machinery, soil texture, soil particle size and characteristics of plant rooting. Compaction can reduce water infiltration capacity and increase erosion risk by accelerating run off. In addition, it has adverse effects on the soil biodiversity and soil structure and may lead to problems such disturbed root growth (EEA, 2007).

In Brazil, two major environmental problems encountered in the past were the improper disposal of untreated vinasse and field burning prior to the harvesting of sugarcane. One litter of ethanol produces approximately 10 to 15 litters of vinasse, a hot corrosive pollutant with a very low pH and an extremely high mineral content. Before cane is cut, the fields are set on fire to eliminate the voluminous amount of biomass. When this is done; huge clouds of black smoke blankets the areas. Both the state of São Paulo and the federal government have passed legislation setting a time table for gradually phasing out the burning of sugarcane fields. At present only São Paulo is enforcing the time table. Twenty percent of sugarcane fields no longer burn the cane trash before harvesting (Kojima and Johnson, 2005).

Different crops have different GHG emissions of carbon sequestration characteristics, depending upon factors as fertilizer requirements and root systems. Associated emissions also vary depending upon where the feedstock is grown because climate, solar resources and soil productivity all affect crop yields and fertilizer application rates (Worldwatch Institute, 2007).

Biomass feedstocks are generally transported from fields to bio refineries by truck, travelling a few dozen to a few hundred kilometres (Aden et al., 2002). Transport by train or pipeline, where feasible, could significantly reduce associated emissions, but today the fuels requirements and associated emissions are minimal for distribution of biofuels to the refuelling station (Arnold et al., 2005).

Hamelinck et al (2005) concluded that shipping of refined solid biomass and biofuels is possible at relatively low costs and modest energy losses. Most important will be minimizing the transport of wet untreated biomass (Hamelinck et al., 2005).

1.6.2 Environmental impacts related to use of biofuels

Impacts on air pollution

Well to wheel (WTW) CO_2 emissions of sugar crane ethanol are estimated to be, on average 0.20 kg per litter of fuel used, versus 2.82 kg for gasoline. In contrast, ethanol from corn shows very small GHG reductions within all potential feedstock options. Using commercial processes, the use of ethanol derived from grains, brings a 20% to 40% reduction in WTW CO_2 equivalent GHG emissions, compared to gasoline. For Europe, ethanol production from sugar beets is important, due to its high dominance in several European countries. The use of E10 achieves a 25% or greater reduction in carbon monoxide (CO) than petrol fuel. Meanwhile ethanol blended petrol emits higher evaporative hydrocarbons (HC) and others volatile organic compounds (VOCs) than petrol. This is primary due to increase of higher vapour pressure of ethanol mixture. Nevertheless, raising the ethanol concentrations further does not lead to significant further increases. Impacts of ethanol on nitrogen oxides (NO_x) are generally minor, and can either be increased or decreased, depending on conditions (Chauhan et al., 2009). Adding cetane enhancers like di-tert-butyl peroxide at 1% or 2-ethyl hexyl nitrate at 0.5% can reduce NO_x emissions from biodiesel. NO_x emissions from biodiesel blends could possibly be reduced by blending with kerosene or Fischer– Tropch diesel (Chauhan, et al., 2009).

Composition of gasoline and ethanol increase emission of most toxic air pollutants like benzene, 1,3-butadiene, toluene and xylene. This is consequence of dilution effect of ethanol which substitutes some part of gasoline, which emits toxic air pollutants (Rutz and Janssen, 2007).

Up to 78% reduction of CO_2 is estimated by using soybeans. Also the estimates for GHG emission reductions from rapeseed derived biodiesel range about 40 – 70% when compared with conventional diesel fuel. Meanwhile Halleux (2008) pointed out that exhaust emissions for some biofuels can be even higher than in case of fossil fuels.

Since for pure plant oil transesterification step is not applied, some GHG can be saved. If the feedstock of biodiesel or pure plant oil is waste cooking oil, the GHG balance for these fuels is even greater than for all other lipid biofuels. This is due to the fact, that no emission from ecologically relevant compounds during fertilizer manufacture, cultivation, harvesting and oil recovery are considered for waste oils. Also other negative effect like eutrophication, acidification and stratospheric ozone depletion, that are associated with dedicated grown energy crops, may be migrated or even reversed by using waste vegetable oil as feedstock source. Biodiesel reduced CO_2 emissions by 78%, PM by 32%, CO by 35% and SO_x by 8% (Rajagopal and Zilberman, 2007; Gaffney and Marley, 2009; Dorado et al., 2003).

Nevertheless it must be considered that the wider environmental impacts of biofuels are as variable as the potential GHG savings and depend very much on location and production method. A case by case assessment might therefore be required (Zah et al., 2007). With the exception of a few studies that report associated increase in GHG emissions, most studies find a significant reduction in both global warming emissions from both ethanol and biodiesel relative to conventional transport fuels (Fulton, 2004; Quirin et al., 2004; Farel et al., 2006).

The range of estimates for GHG emissions reductions from biodiesel is also large (from -92 to +107). Many studies (Armstrong et al., 2002; Demirbas, 2009; Krahl et al., 2007; Hill et al., 2006; Pimetel, 2003) show a reduction in emissions, with waste cooking oil providing the greatest savings (Beer et al., 2001). The exception in Delucchi (2003), who estimates that biodiesel from soybeans, will lead to significant emissions increases (Delucchi, 2003).

Through a meta analysis of several studies, Farell et al. (2006) conclude that although current corn ethanol technologies will result in reduction in crude oil use, the GHG are, however, only marginally lower than for gasoline.

1.7 ENERGY EFFICIENCY

There are several equations to establish the overall conversion efficiency of technologies for the conversion of solar energy, there should be a correction for the cumulative energy demand associated with the biofuel life cycle and the life cycle of physical conversion technologies (Reijnders and Huijbregts, 2007). For instance, if the lower heating value of fossil fuel inputs amounts to 20% of the lower heating value of a biofuel, the solar energy conversion efficiency will be corrected by this percentage. The result thereof is the overall energy efficiency of biofuel. This is summarized in the following equation (3):

$$SCE_x = \frac{Y_x \cdot E_x \cdot FE_x}{E_{solar}} \cdot 100$$

(Reijnders and Huijbregts, 2007).

(3)

Where SCE_x is the solar energy conversion efficiency of biomass or biofuel type x (%), Y_x is the yield of biomasss type x (kg ha^{-1} year^{-1}), E_x the energy content of biomass or biofuel type x (MJ kg^{-1}), FE_x the correction factor for fossil fuel input in the life cycle of biomass or biofuel type x (MJ MJ^{-1}), and E_{solar} is the yearly solar irradiation (MJ ha^{-1} year^{-1}) (Demirbas, 2009).

Nguyen et al (2007; 2008) in a net energy analysis of ethanol from cassava in Thailand find a net energy value of 9.15 MJ L^{-1}, which is almost twice that of ethanol. Notably, their calculations do not include any co products and yet find higher net energy value than corn ethanol in the United States. Sheehan et al (2000) find that substituting B100 for petroleum diesel in buses was found to reduce the life cycle consumption of petroleum by 95%.
The von Blottnitze and Curran in their review of assessments concluded that it takes less energy to make and distribute ethanol that can be delivered by the fuel. The results of the studies that evaluated other environmental impact categories beyond energy and greenhouse gases were mixed, but most of them occurred during the harvesting and processing of the biomass (von Blottnitz and Curran, 2007). Similar results reported Hill et al (2006) that corn grain ethanol and soybean biodiesel production result in positive net energy balance. Meanwhile Pimentel et al (2008) pointed out that more fossil energy is still required to produce a litre of ethanol than the energy output is released.
Assessments of the environmental impact of biofuels often significantly differ in methodological choices and consequently in their results (Gnansounou et al, 2009).

1.8 BIOFUELS POLICY

The increase use of renewable sources constitutes an important part of package of measures needed to reduce GHGs emissions and comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (Figure 4). In particular, increased use of biofuels for transport is one of the most effective tools by which the Community can reduce its dependence on imported oil (Directive, 2003/30).

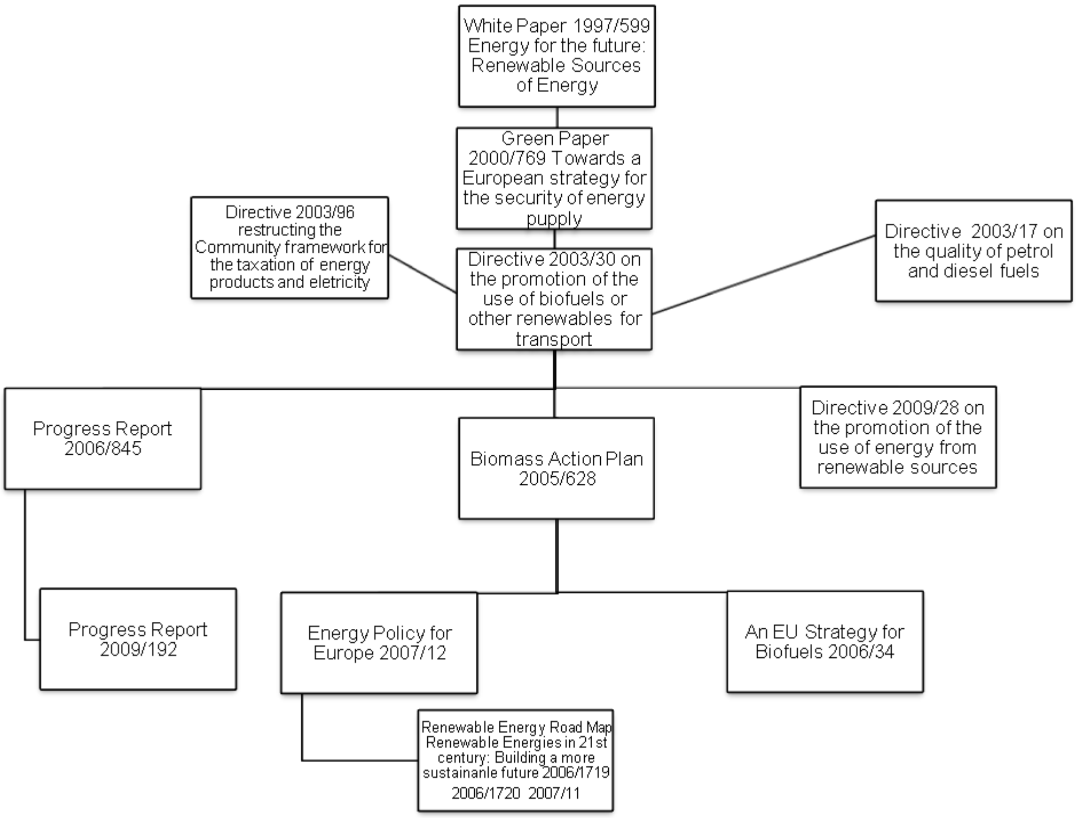


Figure 4: Flowchart of liquid biofuels legislation

Bio energy has the potential to mitigate climate change. In the EU, increased bio energy use is promoted through targets and measures favouring bio energy over fossil fuel based energy (Hansson and Berndes, 2009).

The EU biofuels market is mainly determined by the EU policy and legislation on biofuels. The release of the European Biofuels Directive in 2003 has created a legislative framework in the Member States and set off a rapid increase in biofuels production and use. States transpose EU policies into their own legislations, thus the EU has to develop policies that address all the issues of its 27 Member States (Bolter et al., 2007; Bringezu et al., 2009).

The first relevant EU document published in 1997 with regard to biofuels was the European Commission´s White Paper for a Community Strategy “Energy for the future: Renewable Sources of Energy”. This document sets out a strategy how the share of renewable energies in gross domestic energy consumption can be doubled by 2010 to 12%. It also includes an Action Plan with a timetable how this objective can be achieved (White paper, 1997; van Thuijl and Deurwaarder, 2006).

In 2000 the European Commission came forward with the Green Paper talking about long term strategy for energy. EU rebalance, changing consumer's behaviours and priority to fight against global warming (Green paper, 2000).

The EU "Biofuels Directive 2003/30/EC" was published in 2003. It sets reference values for the market share of biofuels, 2% by the end of 2005 and 5.75% by the end of 2010 (Hodson, 2004). The EU Member States are obliged to set national indicative targets, taking into account these reference values (Directive 2003/30 EC). Recent assessments have concluded that the 2010 targets are unlikely to be achieved, and further efforts are needed (Biofuels in the EU, 2006).

The EU Biofuels Directive has lead to the creation of favourable legislative frameworks in most Member States and has therefore triggered rapid market implementation of biofuels. By now all of the Member States have set national targets, most of them aim for the proposed 5.75% market share by 2010 or earlier. Each EU Member State has to send annual reports to the EC, stating the implemented measures, the annual biofuel production and the market share achieved (Bolter et al., 2007).

Necessary related documents are the "Energy Taxation Directive" and the work on the standardisation of transport fuels and biofuels for transport. The Energy Taxation Directive was adopted in October 2003. It encourages Member States to grant tax reductions and tax exemptions in favour of biofuels. These tax concessions may not be implemented without prior authorisation by the Commission (Directive 2003/96/EC; Schnepf, 2006).

With the "Fuel Quality Directive 2003/17/EC" in 2003 the environmental specifications for market fuels were amended to establish specifications for petrol and diesel. The CEN (European Committee for Standardization) has set limits on biodiesel blending to no more than 5% share by volume for technical reasons. The biodiesel itself needs to comply with standard EN 14214. With a maximum blend of 5% biodiesel the target of 5.75% biofuels by 2010 cannot be met by blending alone (Directive 2003/17/EC)

The production of energy crops in the EU is encouraged by the Common Agricultural Policy (CAP) with direct aids or incentives. Since 1992 these aids have been gradually decoupled from production. The CAP reform in 2003 was the latest reform in this regard. The "Single Payment Scheme" helps to facilitate the supply of energy crops. Together with this the set aside obligation has been integrated which allows the cultivation of non food crops and energy crops on set aside areas (Bolter et al., 2007).

In December 2005, the Commission published the "Biomass Action Plan" describing how the use of energy derived from forestry, agriculture and waste materials can be increased. This plan also includes measures to improve the supply of and demand for biomass and to overcome technical barriers (Biomass action plan, 2005).

The Commission´s Communication "An EU Strategy for Biofuels" was published in February 2006. In this EU Strategy a range of market based, legislative and research measures are presented to boost the production of biofuels. It complements the Biomass Action Plan of December 2005 (Bolter et al., 2007).

In 2006 the EC opened a public consultation on the Biofuels Directive that found wide interest in the fast growing biofuels community and triggered 144 responses. These responses were summarized by

the Energy Research Centre of the Netherlands in a report called “Review of EU Biofuels Directive – Public consultation exercise – Summary of the responses” in October 2006. The main outcome was that the Biofuels Directive should be further pursued, and a lot of suggestions were made on possible modifications (Londo et al., 2006).
Basing on the responses gathered through the public consultation in 2006, the Commission reviewed the Biofuels Directive and thereupon published the “Biofuels Progress Report” in January 2007. According to this report the Commission estimates that the incorporation rate of biofuels in the EU will be at about 4.2% in 2010. This setback towards the Directive objective of 5.75% indicates that the European biofuel production needs further support (Biofuels progress report, 2007).

The development of a powerful EU biofuels strategy is still ongoing: In March 2006 the European Commission set out its vision for a “Strategic EU Energy Review”. In the beginning of 2007 the so called “Renewable Energy Roadmap” and the “Energy Policy for Europe” were published, aspiring to a 20% share of renewable in the EU´s energy mix and a minimum target of 10% for biofuels in transport by 2020. Member States are required to establish National Action Plans that outline their specific objectives and sectoral targets for each of the renewable energy sectors; electricity, biofuels and heating and cooling (Bolter et al., 2007).

1.8.1 Sustainability of biofuels

The most common definition of sustainability was given by the World Commission on Environment and Development in 1987. It means to satisfy our present needs without compromising the future generations’ ability to meet their own needs. The definition implies the balance of three components, stated in the Declaration of Rio on Environment and Development in 1992; environmental protection, economic growth and social development (Mawhinney, 2002).

Consequently, the sustainable production of bio energy is defined as the production of biomass based fuels for transportation, heat and electricity generation that allows an economic growth preserving the natural environmental and promoting a well balanced social development.

Due to the exponential growth in biofuels production, significant concerns have been raised about the sustainability of the production strategy. Certain risks to the economic growth, the preservation of natural environment and the social development have been identified. The economic performance of the biofuel production strategy depends on oil prices. Due to the instability and fluctuation of the oil markets, the sustainable economic growth of the biofuel production system is not always guaranteed. Moreover, the scale economy plays an important role in achieving the economic viability. The life cycle emission, deforestation for feedstock production, the degradation of soils, and consumption of water and loss of biodiversity may impact more or less severely the natural environment. Finally, the food availability, the working conditions, and the distribution of benefits introduce risks of imbalances in the social development. Hence, a consistent framework and robust methodology are needed to verify that biofuels are produced in a sustainable way (Gnansounou et al., 2007).

1.8.2 Subsidies

In recent years, governments of numerous countries have promoted industrial scale production and use of liquid biofuels and backed that commitment with financial support. In year 2006 total support of biofuels associated with polices of the EU and Member States were around 3.7 billion EUR. This is probably a gross underestimate of the total amount of support provided, as many subsidies are underreported (Kutas et al., 2007).

Biofuels have attracted particularly high levels of assistance in some countries given their promise of benefits in several areas, including agricultural production, GHG emissions, urban air quality, energy security, rural development and economic opportunities for developing countries. Such alleged benefits have enabled those promoting biofuels to assemble unusually broadly based support for fiscal and regulatory relief (Quirke et al., 2008).

Major financial incentives for production of biofuels are decided and implemented by individual Member Stats, the most common type of support being the part of total exemption of biofuels from excise tax. Several countries have also implemented biofuels obligations, where suppliers of transport fuels are obliged to incorporate a fix percentage of biofuels in total sales (Kutas et al., 2007).

Exemption from fuel excise taxes is one of the main financial incentives used to support the production and consumption of biofuels in the EU. The possibility for Member States to exempt biofuels from these taxes, partially or totally, is embodied in the Directive EC 2003/96, commonly known as the energy taxation directive. Since tax concessions are considered as state aids, they must be notified to and authorized by the Commission. The majority of Member States have notified tax exemption schemes and as of July 2007 the Commission had approved all the requests it had received so far. Exemptions are usually granted for a fixed period of six years, and can be renewed (Kutas et al., 2007). EU Member States have chosen different options regarding the taxation of biofuels. Some of them provide full or partial tax exemptions to all types of biofuels, while others limit this benefit to specific types of biofuels such as pure biodiesel (B100) or E85. While some countries have opted for a production quota system, where tax relief is only granted to the agreed amount of production from approved operators, other countries provide tax relief for an unlimited quantity of biofuels. Finally, some Member States have imposed mandatory supply objectives for biofuels and grant partial, full or simply no tax exemptions to all or some types of biofuels. The variety of schemes applied increases the complexity of analyzing the EU policy of support granted through tax relief. This difficulty is compounded by the frequent changes in Member States policies and policy settings (Kutas et al., 2007).

At the start of supply chain are subsidies for goods and services that are consumed in the production process (Figure 5). The largest of these are subsidies to producers of feedstock crops used to make biofuels. However, the production of the feedstock crops creates a demand for subsidies; the

proportional share of the total subsidies to those crops used in the production of biofuels can be considered one element of the gross costs to government of promoting biofuels (Steenblik, 2007).
Second are subsidies to intermediate inputs are often complemented by subsidies to value adding factors like capital goods; labour employed directly in the production process; and land (Steenblik, 2007).
Further down the chain are subsides directly linked to output; this includes import tariffs on ethanol and biodiesel; exemptions from fuel excise taxes; and grants or tax credits related to the volume produced, sold or blended (Steenblik, 2007).

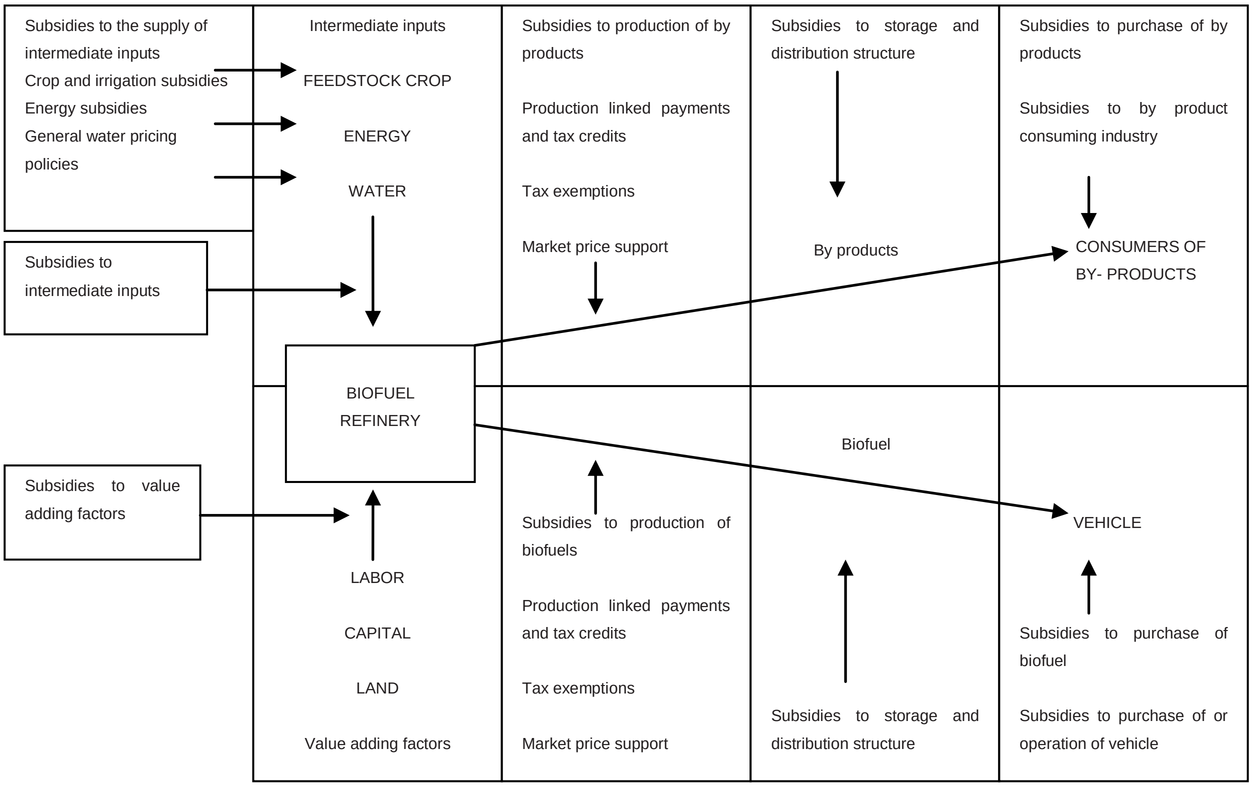


Figure 5: Subsidies provided at different points in the biofuel supply chain (Koplow, 2006).

Many of the existing subsidies scale linearly with production capacity levels, and the resulting rate of growth in the subsidy payments can be quite large. In addition, subsidies do not decline as the price of the gasoline rises, as is the case for some subsidies benefiting petroleum and natural gas (Koplow, 2006).
In some countries, multiple polices covering the range of options have been enacted to support biofuel development and the presence of multiple polices within these jurisdiction means that determining the effectiveness of individual polices is difficult (Mabee, 2007).

1.9 METEOROLOGICAL FACTORS

The growth of agricultural crops is influenced by multitude factors such as climate, soil texture, nutrient availability and the occurrence of pests and diseases, and their interactions (Kenter et al., 2006). Data about the effect of weather conditions on plant growth can be induced in yield prediction mode, which have recently gained in importance for examining the impact of future climate change on crop production (Jones et al., 2003).

1.9.1 Solar irradiation

Biofuels are ultimately based on the ability of photosynthetic organisms to use solar irradiation for the conversion of CO_2 into glucose and subsequently into biomass. In practice only part of incident solar radiation is captured by plants. And of the solar irradiation captured by plants approximately 43 – 45% of radiation in the visible part is photo synthetically active (Vasudevan and Briggs, 2008).

The average daily solar irradiation varies; depend on latitude, climate and season. When on the equator, maximum solar irradiation is on a horizontal plane, but away from the equator, for the maximum intercept of solar radiation by a fixed plane, the plane should have angle corresponding latitude (Çelik, 2006). Average daily solar irradiation that may support feedstock for biofuel production varies roughly between 7 and 25 MJ m^{-2}. The daily worldwide average irradiation is about 15.5 MJ m^{-2}, or 180 Wm^{-2}. Differences between days can be large (Akkerman et al., 2002). The greatest annual input of solar radiation tends to occur in subtropical regions at latitudes between 20° and 30° and little could cover. Humid tropical regions have somewhat lower irradiation. When going pole-ward from latitude of about 30°, solar irradiation tends to decrease. As for major areas for current biofuels production, in Brazil, where sugar cane ethanol is produced daily solar irradiation is on average about 220 Wm^{-2} (Demirbas, 2009).

The relative importance of individual weather variables depends on the development stage of the plant and is also site specific. The early growth of sugar beet in Central Europe was found to be strongly influenced by temperature (Durr and Boiffin, 1995) and in England the crop growth rate was proportional to absorbed solar radiation (Scott and Jaggard, 1993).

1.9.2 Temperature

Temperature is an important climatic factor which can have profound effects on the yield of crops. Changes in seasonal temperature affect the grain yield, mainly though phonological development processes. Winter crops are especially vulnerable to high temperature during reproductive stages and differential response to temperature change to various crops has been noticed under different production environments (Karla et al., 2002).

Peng et al (2004) reported that rice yields decline with higher night temperatures. Lobel and Asner (2003) showed that corn and soybean yields in the US could drop by as much as 17% for each degree increase in the growing season.

You et al (2009) find that temperature as well as precipitation in wheat growing seasons has a significantly negative impact on wheat yield in China, but the magnitude of impact is less than those reported by previous studies in other regions.

Sustained temperature increases over the season will change the growing period of crop, whereas short episodes of high temperature during the critical flowering period of a crop can impact yield independently of any substantial changes in mean temperature. Temperature is also a key determinant of evaporative and transpirative demand.

1.9.3 Water

Unlike temperature and radiation, the water supply to plants is not affected by weather conditions alone, but is a function of rainfall and temperature together with evaporative demand and the water holding capacity of the soil (Freckleton et al., 1999). Of the four soil physical factors that affect plant growth e.g. mechanical impedance, water, aeration, temperature, water is the most significant. Soil moisture plays an important role in plant productivity by controlling transpiration between soil, plant and atmosphere. Several studies in various geographical regions (Ridolfi et al., 2000; Srinivasan et al., 2000; Porporato et al., 2003) have demonstrated that soil moisture is often one of the main stress factors for vegetation and crop yield.

In most parts of the world, crop production depends on rainfall. However, not all rainfall is effectively used in crop growth, as some is lost by runoff, infiltration and evaporation. Heavy and high intensity rainfalls are lost most from soils because of losses from surface run off or to groundwater. Among other factors, the effectiveness of rainfall is strongly influenced by topography, which determines the redistribution of summer precipitation as runoff (Saue and Kadaja, 2009).

Combination of various meteorological factors is well described by Penman-Monteith equation (4) to compute the evaporation from an open water surface from standard climatologically records of sunshine, temperature, humidity and wind speed.

$$\lambda ET = \frac{\Delta (R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)}$$

(Allen et al., 1998).

(4)

Where R_n is the net radiation, G is the soil heat flux, (e_s – e_a) represent the vapour pressure deficit of the air, ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air, Δ represent the slope of the saturation vapour pressure temperature relationship, γ is the psychometric constant, and r_s and r_a are the bulk surface and aerodynamic resistance (Allen et al., 1998).

2 AIM AND HYPOTHESES

Aim of master thesis is to analyse impacts of local conditions on sustainability of liquid biofuels production.

In this work existing integral indicators for environment assessment are corrected with factors, which take into account local conditions as well as expected climate changes in the future. Since the comprehensive sustainability assessment includes also economical value of reduced emissions, this thesis also contains assessment of environmental suitability of financial supports that are set by countries that are producing liquid biofuels.

Followed hypotheses were formatted:

1.) Environmental impacts like climate change, ecotoxicity, eutrophication/acidification are distinguished due to type of liquid biofuels, technology, feedstock and local conditions of production.

2.) Corrections of integral indicators accounting local meteorological conditions and expected climate changes allows sustainability assessment also on limited geographical areas.

3.) Countries that are producing liquid biofuels are not using environmental impacts as criteria for rates of subsidies.

3 METHODS

3.1 WEATHER VARIABLES AFFECTING THE FEEDSTOCK PRODUCTION FOR BIOFUELS

Seasonal temperature and precipitation are important climatic factors which can have profound effects on the yield of crops. Changes in seasonal temperature affect the grain yield, mainly through phenological development processes (Kalra et al., 2008). Since climate and agriculture are inextricably correlated weather variations needs to be studied in detail so that it can subsequently be used for evaluating the impact of climate-change on crop production (Salinger 2005).

For purpose of thesis average yields (t ha^{-1}) in period 1980 – 2000 were obtained from data base Faostat-Food and Agriculture Organization of United Nations. Meanwhile average annual temperature (°C) and precipitation (mm) were gained from the Climate Research Unit, United Kingdom. Solar irradiation data were not included; since there is statistical significant correlation between air temperature and solar irradiation (Annex 5). And Richardson et al. (2002) also modelled prediction of solar irradiation from air temperature and found strong correlation.
Five the most common feed stocks like sugar beet, sugarcane, corn, rapeseed and soybean were selected for biofuels production impact assessment (Rutz and Jansen, 2007). For soybean 25 locations were selected, for maize 38, for sugar beet 23, sugarcane 22 and for rapeseed 22. All locations with missing data were excluded. Egypt was also excluded, since great yield results to irrigation from river Nile and not from precipitation. Data with standard deviation can be seen in Annex 1.
Data were plotted in three dimensional figures in Wolfram Mathematica 7.0 and polynomial function was calculated using function FindFit. Since yield is function of temperature and precipitation calculated models were named Climate Yield Prediction (CYP) models. Also linear regression was calculated to access statistical correlation between yield and meteorological parameters.

Verification of CYP models was done by comparing results of models to yields gained from research articles: Dagˇdelen et al., 2005; Malvar et al., 2007; Ines and Hansen, 2006; Singh et al., 2008; Al-Jaloud et al., 1996; Daroub et al., 2003; Dogan et al., 2007; Singh et al., 2003; Bhatia et al., 2008; Kenter et al., 2006; Tzilivakis et al., 2005; Inman-Bamber et al., 2002; Halleux et al., 2008; Malça and Freire, 2006; Macedo et al, 2008; Chiung-Lung and Yuh-Ming, 2009; Kaltschmitt et al., 1997; Hovelius and Hansson, 1999; Stephenson et al., 2008. For the selected location yield was calculated by CYP models and for the same location reference yield was assessed from available literature. Correlation was evaluated using R^2. For all numerical models (5-9) at least 3 reference values of yield were obtained and compared.

An overview of past climate trends over the last millennium is provided as a context to view current climate variability and future trends for providing increasing preparedness of agriculture and forestry to future variability and change (Salinger, 2005). One of the simplest ways to evaluate how climate change and variability affect crop yield is through historical records, and this approach has been utilized for several decades (Almaraz et al., 2008).

3.2 ENVIRONMENTAL ASSESSMENT OF LIQUID BIOFUELS PRODUCTION

Adverse environmental consequences of fossil fuels and concerns about petroleum supplies have spurred the search for renewable transportation biofuels. To be a viable alternative, a biofuel should provide a net energy gain, have environmental benefits, be economically competitive, and be producible in large quantities without reducing food supplies (Hill, et al., 2006).

The first stage of this work was data gathering on bioethanol and biodiesel energy and inventories flow, based on international conditions (Renouf et al., 2008; Barthiaume et al, 2001; Yang et al., 2009; Halleux et al., 2008; Langeveld et al, 2008; Malça and Freire, 2006; Macedo et al, 2008; Chiung-Lung and Yuh-Ming, 2009; Kaltschmitt et al., 1997; Hovelius and Hansson, 1999; Stephenson et al., 2008; Pimetel and Patzek, 2008; Panichelli et al., 2009).

For impacts assessment of liquid biofuels production on different aspects of environment, software Sima Pro 7.1 and method Eco indicator 99 was used. The software has been chosen because it is a widely used Life Cycle Assessment (LCA) tool, both by professionals and researchers. Its main advantages are the several available databases and the ability to produce and evaluate results, which can be translated into a number of impact categories, such as acidification, climate change etc., and demonstrate the environmental impacts.

According to ISO 14040 and 1042 LCA is essentially meant to improve the understanding of the results of the inventory phase. In order to determinate the interaction between a product and the environment it is necessary to understand the environmental aspects of products. Therefore in the method Eco indicator 99 environment is definite as set o biological, physical and chemical parameters influenced by man, that are conditions to the functioning of man and nature. These conditions include human health, ecosystems quality and sufficient supply and resources.
From this definition it follows that there are basically three damage categories; human health, ecosystem quality and resources (Goedkoop and Spriensma, 2001).

Human health

Human health can be damaged either by reducing its duration of life by premature death or by causing a temporary or permanent reduction of body functions. According to current knowledge, the environmental sources for such damages are mainly following; infections disease, cardiovascular and respiratory disease, as well as forced displacement due to the climate change, cancer as result of ionising radiation, cancer and eye damages due to ozone layer depletion, respiratory disease and cancer due to toxic chemicals in air, drinking water and food. These damages represent the most important damages to human health caused by emissions from product systems (Goedkoop and Spriensma, 2001).

Ecosystem quality

Ecosystems are very complex, and it is very difficult to determine all damages inflicted upon them. The species diversity is used as an indicator for ecosystem quality. Therefore damage is expressed as a percentage of species that are threatened or that disappear from a given area during a certain time (Goedkoop and Spriensma, 2001).

Ecotoxicity

This method determines the potentially affected fraction (PAF) of species in relation to the concentration of toxic substances. PAFs are determined on the basis of toxicity data for terrestrial and aquatic organisms like microorganisms, plants, worms, algae, amphibians, molluscs, crustaceans and fish. The PAF expresses the percentage of species that is exposed to concentrations above no observed effect concentration. The higher the concentration is the larger is the number of species that are affected. The PAF damage function has a typical S-curve (Goedkoop and Spriensma, 2001).

Acidification and eutrophication

This method is based on observed affects from acidification and eutrophication on plants. From these observations the probability that a plant species still occurs in an area can be determined. This is called probability of occurrence, which is translated to potentially disappeared fraction. Since acidification and eutrophication do not necessary reduce number of species, target species were used. Those are the species that should occur on a specific type of ecosystem if there would have been no anthropogenic changes in the nutrient level or acidity. The damage model calculates to what extend the numbers of target species increase or decreases if an additional deposition is added to the background. It is not possible to determine whether damage is caused by changes in the nutrient level or the acidity. For this reason the impact categories have been combined (Goedkoop and Spriensma, 2001).

Land use

For land use potentially disappeared fraction was used. The damage model is rather complex as four different models; local affect on land occupation, conversion, regional effect on land occupation and conversion. The local affect refers to changes in species numbers occurring on the occupied or converted land itself, while the regional effect refers to changes on the natural areas outside the occupied or converted area (Goedkoop and Spriensma, 2001).

Resources

In the Eco indicator 99 methodology only models of mineral and fossil fuels are available. The use of agricultural biotic resources and the mining of resources such as sand or gravel are considered to be adequately converted by the effects on land use.
In the case of non-renewable resources, it is obvious that there is a limit on the human use of these resources, but it is rather arbitrary to give figures in the total quantity per resources existing in the accessible part of the earth crust. Because of this problem, the Eco indicator 99 methodology does not consider the quantity of resources as such, but rather the qualitative structure of resources (Goedkoop and Spriensma, 2001).

Normalisation

The three damage categorise all have different units. In order to use a set of dimensionless weighing factors from the panel we must make these damage categories dimensionless. Standard Eco indicators are numbers that express the total environmental load of a product or process.

The standard Eco indicator values can be regarded as dimensionless figures. As name we use Eco indicator point (Pt). The absolute value of the points is not very relevant as the main purpose is to compare relative differences between products or components. The scale is chose in such way that the value of 1 Pt is representative for one thousandth of the yearly environmental load of one average European inhabitant (Goedkoop and Spriensma, 2001).

3.3 CORRELATION BETWEEN ENVIRONMENTAL IMPACTS AND YIELD OF FEEDSTOCK

Results of impact assessment of liquid biofuels production on environment (Chapter 5.2) were compared to yield (Chapter 5.1) of feedstock for biofuels production. Statistical method Annova was used to calculate linear regression; factor of correlation, p-value and coefficient of determination were calculated.

3.4 GLOBAL BIOFUELS PRODUCTION BY END OF 2100 WHILE MEETING THE EXPECTED CLIMATE CHANGES

According to the IPCC average global air surface temperature is projected to increase for 1.1 to 6.4 °C relatively to baseline average in period 1980-1999 and precipitation will increase for 20% in some area, but will decrease for 20% in others. Therefore confidence for temperature is much higher that for precipitation. From this point of view all four combination scenarios were taken into account for estimating influences of climate change on global yield for selected feedstock.

scenario 1: precipitation increase for 20%; temperature increase for 1.1ºC.
scenario 2: precipitation increase for 20%; temperature increase for 6.4ºC.
scenario 3: precipitation decrease for 20%; temperature increase for 1.1ºC.
scenario 4: precipitation decrease for 20%; temperature increase for 6.4ºC.

3.5 POTENTIAL BIOFUELS PRODUCTION IN CASE OF SLOVENIA AND EXPECTED CLIMATE CHANGES

In Slovenia, corn, sugar beet and rapeseed are feedstock with the highest production share among feedstock selected in this thesis and therefore also highest potential for first generation liquid biofuels production.
Data about expected climate changes for Slovenia were accessed at Environmental Agency of the Republic of Slovenia (ARSO). It is expected that air temperature in Slovenia will increase for 1°C to 4 °C to the 2060 regard to average in period 1961 to 1990. Since projections about change in precipitation are not so precise it is predicted that precipitation will increase for 20% or decrease for 20% (ARSO, 2003). Therefore all four combination scenarios were taken into account when estimating influences of climate change on yield.

scenario 1: precipitation increase for 20%; temperature increase for 1ºC.
scenario 2: precipitation increase for 20%; temperature increase for 4ºC.
scenario 3: precipitation decrease for 20%; temperature increase for 1ºC.
scenario 4: precipitation decrease for 20%; temperature increase for 4ºC.

At first step average yield for period 1961 – 1990 was calculated regard to CYP models (Chapter 5.1). In second step expected changes in temperature and precipitation were inputted in model for each feedstock to calculate the yield. Area harvested for each feedstock was accessed in Faostat database and was provided that area is not changing. In further step conversion factors were used (Appendix 2) to calculate bioethanol or biodiesel production.

3.6 CORRELATION BETWEEN ENVIRONMENTAL IMPACTS AND SUBSIDIES

In recent years, governments of numerous countries have promoted industrial scale production and use of liquid biofuels and backed that commitment with financial support (Kutas et al., 2007).

Nevertheless some interrogation appeared if a country that produces liquid biofuels takes into consideration also environmental criteria when rate the subsidies.

Therefore results of liquid biofuels production impacts on environment (Pt) were compared to amount of subsidies for biofuels production that each country is given for. Since rates and forms of support vary from country to country total subsidies were taken into account.

For statistical analysis annova linear regression was used, comparing if countries are promoting biofuels from feedstock with least impact on environment. Data about subsidies rates were access from report Biofuels – At What Cost. Governmental support for ethanol and biodiesel in selected OECD countries (Steenblik, 2007).

4 RESULTS

4.1 WEATHER VARIABLES AFFECTING THE FEEDSTOCK PRODUCTION FOR BIOFUELS

Air temperature and precipitation are one of the most influential weather factors that are affecting the growth of plants. Therefore correlation between yield, temperature and precipitation were calculated creating CYP models. Calculated numerical models are presented as equations (5-8). Results show that increasing the temperature and precipitation will affect the corn yield by decreasing it (Figure 6). Correlation between temperature and yield is statistically significant (Table 1); meanwhile in case of precipitation correlation is not significant.

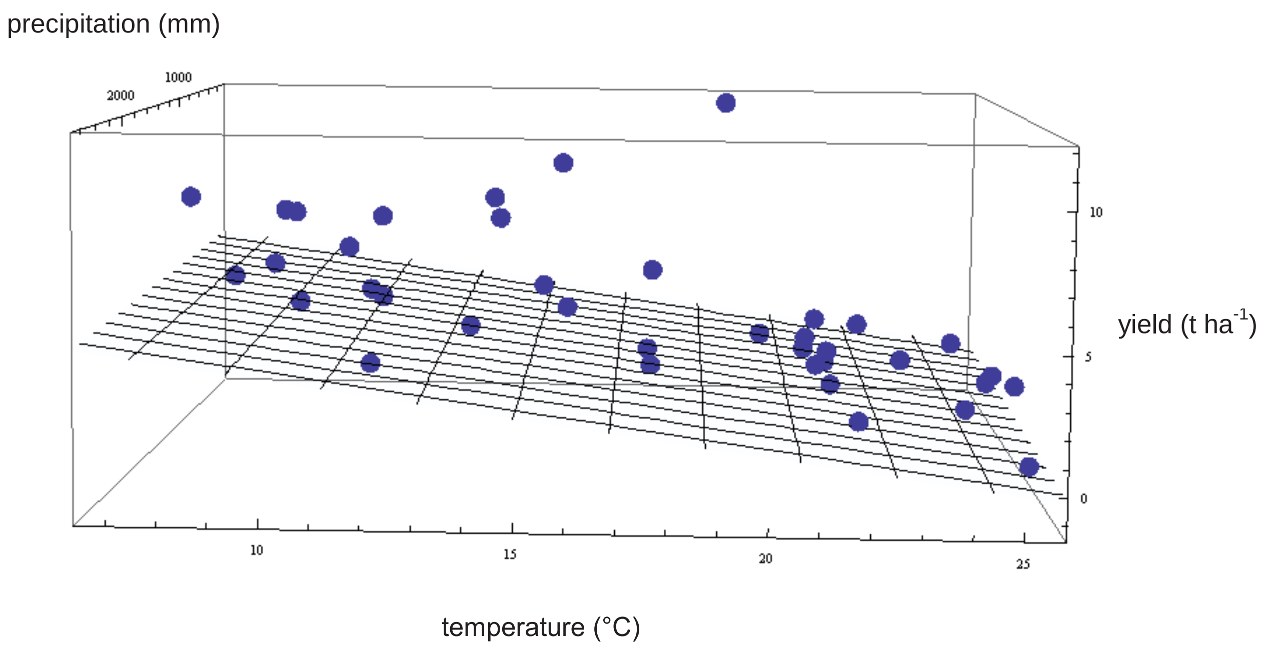


Figure 6: Corn`s yield regarding to temperature and precipitation.

$$yield_{(corn)} = c_1 * p + c_2 * t + 7 \tag{5}$$

yield [t ha^{-1}]

c_1 = -0.000283 [t ha^{-1} mm^{-1}]

c_2 = -0.248571 [t ha^{-1} °C^{-1}]

p = precipitation [mm]

t = temperature [°C]

Table 1: Results of nonlinear regression for maize yield

	range of model	correlation matrix		p-value	95% conf. region
precipitation	87-2690 (mm)	1	-0.856	0.694	0.5
temperature	7-25 (°C)	-0.856	1	5.490^10^{-7} *	

Legend: *statistical significant ($p<0.05$)

Figure 7 shows reduction of sugar beet`s yield by increasing the temperature and precipitation. Correlation between yield and precipitation is statistically significant (Table 2), meanwhile in case of temperature is not statistically significant (p value is >0.05).

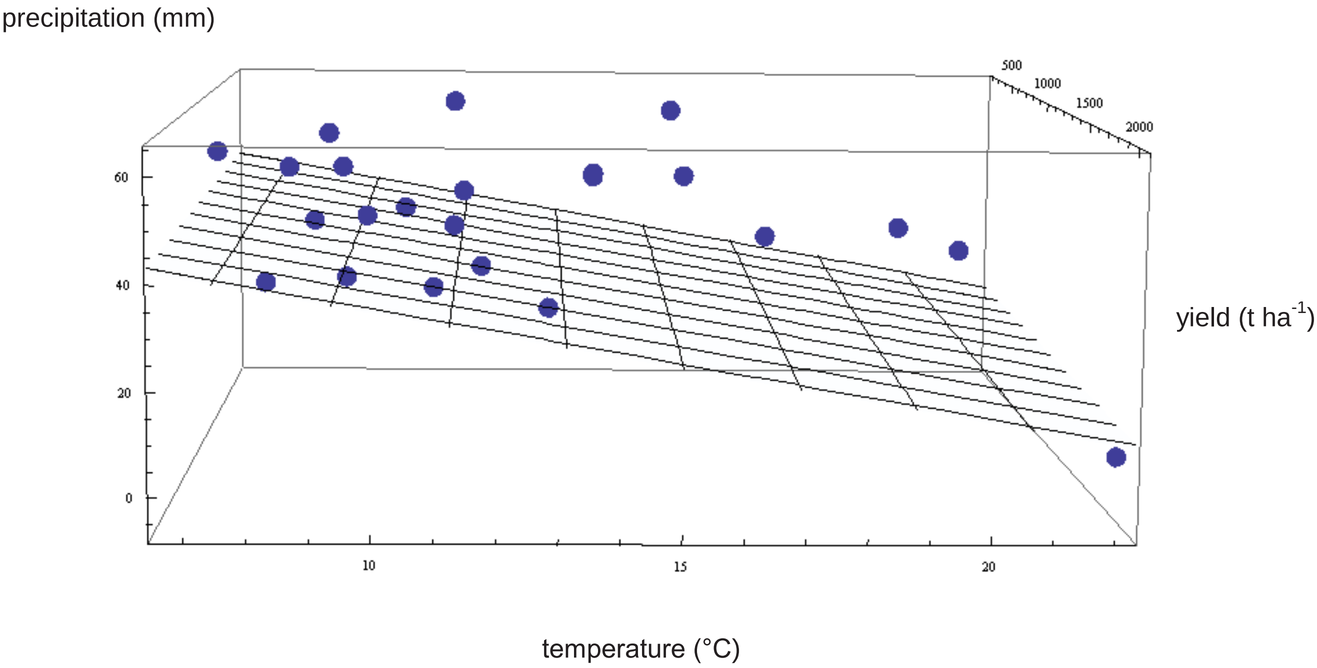


Figure 7: Sugar beet`s yield regarding to the temperature and precipitation.

$$yield_{\ (sugar\ beet)} = c_1 * p + c_2 * t + 59 \tag{6}$$

yield [t ha^{-1}]

c_1 = - 0.015893 [t ha^{-1} mm^{-1}]

c_2 = -2.0476300 [t ha^{-1} °C^{-1}]

p = precipitation [mm]

t = temperature [°C]

Table 2: Results of nonlinear regression for sugar beet yield

	rage of model	**correlation matrix**		**p-value**	**95% conf. region**
precipitation	208-2066 (mm)	1	-0.823	0.817	0.5
temperature	7-22 (°C)	-0.823	1	1.8193^10^{-4} *	

Legend: *statistical significant (p<0.05)

Results of nonlinear regression show decrease of sugarcane yield (Figure 8) due to increase of the temperature and precipitation. But also minor increase in interval 10 to 13 °C can be seen. Correlation between temperature and yield is statistically significant; meanwhile precipitation is not (Table 3).

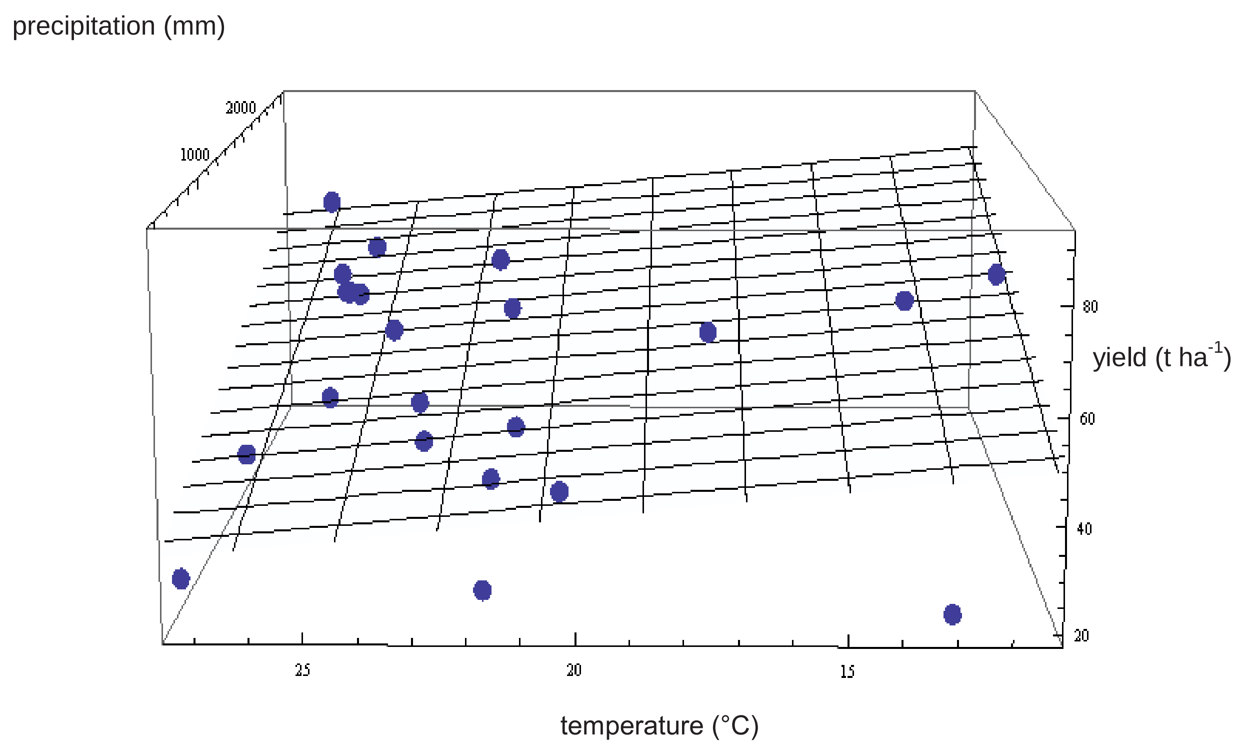


Figure 8: Sugarcane`s yield regarding to the temperature and precipitation.

$$yield_{\ (sugarcane)} = c_1 * p + c_2 * t + 60 \tag{7}$$

yield [t ha^{-1}]

c_1 = 0.0107005 [t ha^{-1} mm^{-1}]

c_2 = -0.970942 [t ha^{-1} °C^{-1}]

p = precipitation [mm]

t = temperature [°C]

Table 3: Results of nonlinear regression for sugarcane yield

	rage of model	**correlation matrix**		**p-value**	**95% conf. region**
precipitation	143-3056 (mm)	1	-0.867	0.104	0.5
temperature	11-27 (°C)	-0.867	1	$3.598\text{^}10^{-4}$ *	

Legend: *statistical significant (p<0.05)

Figure 9 show reduction of rapeseed`s yield by increasing the temperature and precipitation. Correlation between yield and precipitation is not statistically significant (p=0.895); although p value in case of temperature is lower than 0.001(Table 4).

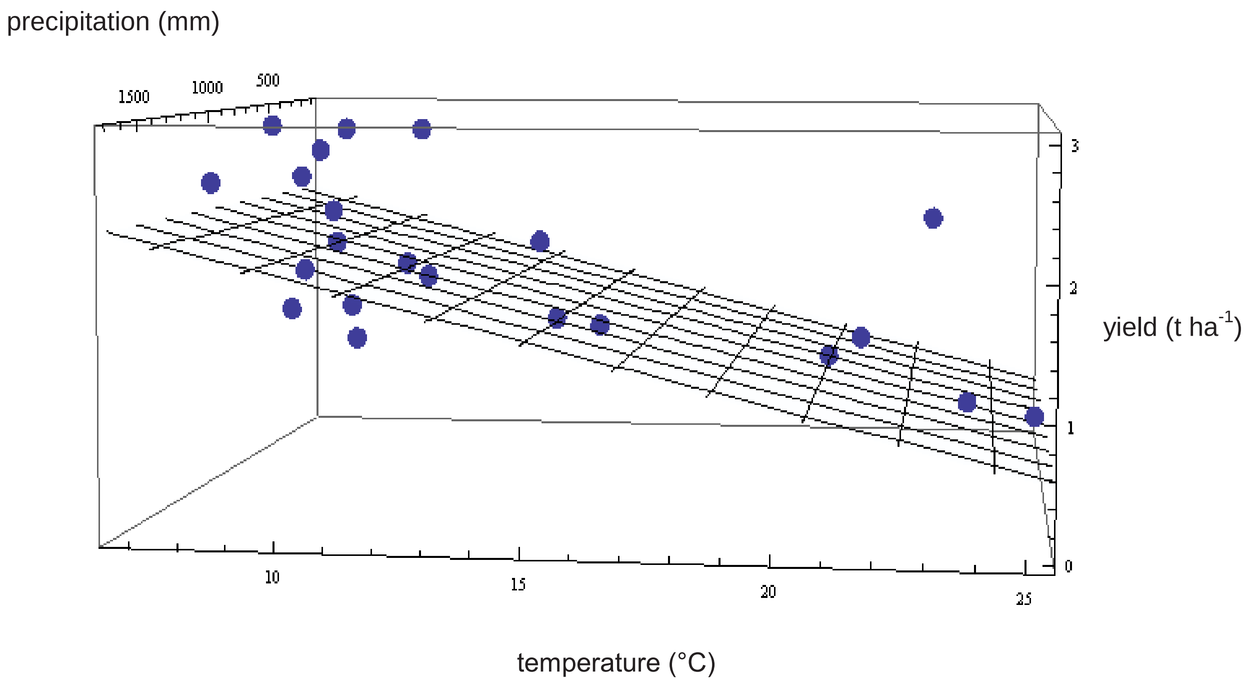


Figure 9: Rapeseed`s yield regarding to the temperature and precipitation

$$\textit{yield}_{\ (rapeseed)} = c_1{*}p + c_2{*}t + 2.8 \qquad (8)$$

yield [t ha^{-1}]

c_1 = -0.0000312 [t ha^{-1} mm^{-1}]

c_2 = -0.0899614 [t ha^{-1} $°C^{-1}$]

p = precipitation [mm]

t = temperature [°C]

Table 4: Results of nonlinear regression for rapeseed yield

	rage of model	**correlation matrix**		**p-value**	**95% conf. region**
precipitation	87-1722 (mm)	1	-0.814	0.895	0.5
temperature	7-25 (°C)	-0.814	1	$1.595 \text{^} 10^{-5}$ *	

Legend: *statistical significant (p<0.05)

Figure 10 show increase of soybean`s yield by increasing the temperature and precipitation at the same time. Table 5 show results of nonlinear regression, where correlation between temperature and yield is statistically significant, but is not in case of precipitation ($p>0.05$).

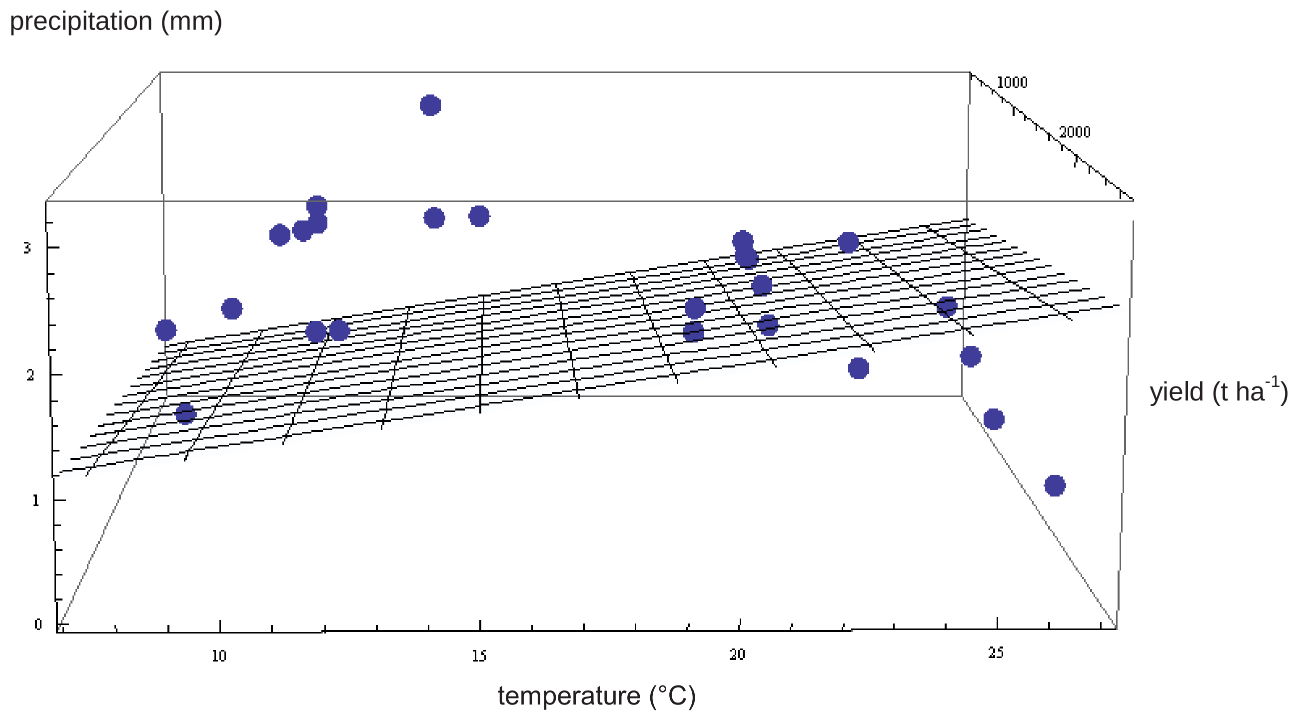


Figure 10: Soybean`s yield regarding to the temperature and precipitation.

$$yield_{(soybean)} = c_1 * p + c_2 * t \tag{9}$$

yield [t ha^{-1}]

c_1 = 0.0002577 [t ha^{-1} mm^{-1}]

c_2 = 0.0653770 [t ha^{-1} °C^{-1}]

p = precipitation [mm]

t = temperature [°C]

Table 5: Results of nonlinear regression for soybean yield

	range of model	**correlation matrix**		**p-value**	**95% conf. region**
precipitation	208-2704 (mm)	1	-0.883	0.444	0.5
temperature	7-27 (°C)	-0.883	1	0.005*	

Legend: *statistical significant ($p<0.05$)

Verification of climate yield prediction models

Verification of created CYP was performed by comparison of yields calculated by CYP model and yield assessed from publications published in research articles. For all numerical models (5-9) at least 3 reference values of yield were obtained and compared.

On Figure 11 linear correlation (R^2= 0.9) between CYP model for corn and reference yield can be seen. Results show that both CYP model and reference yield are similar. Comparison included five data of yields, obtained from scientific articles.

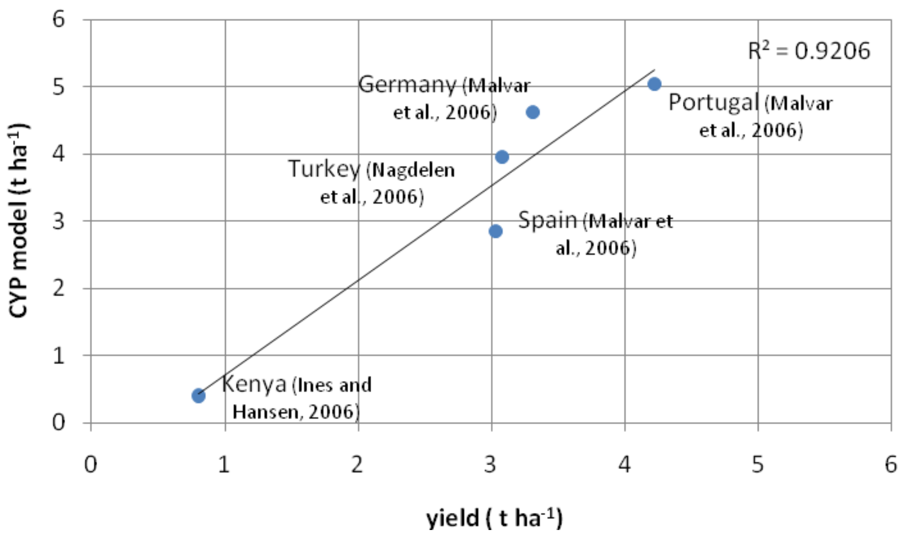


Figure 11: Correlation between CYP model for corn and yield.

Results of CYP model and reference yield comparison (Figure 12) show correlation that can be addressed as linear (R^2= 0.76). Authors like Halleux, 2008; Kenter et al., 2006 and others find similar yields for selected feed stocks.

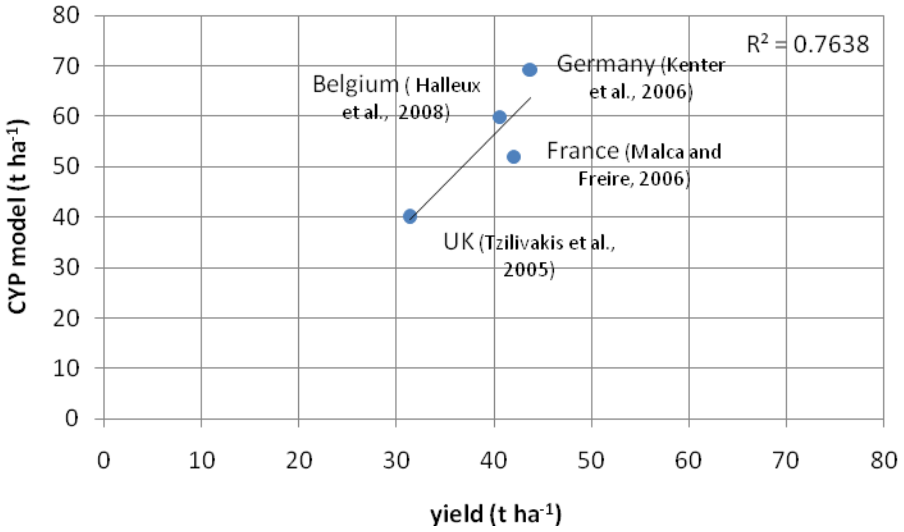


Figure 12: Correlation between CYP model for sugar beet and yield.

Figure 13 shows correlation between numerical model for sugarcane yield production and reference yield value. Results show that both CYP model and reference yield are similar.

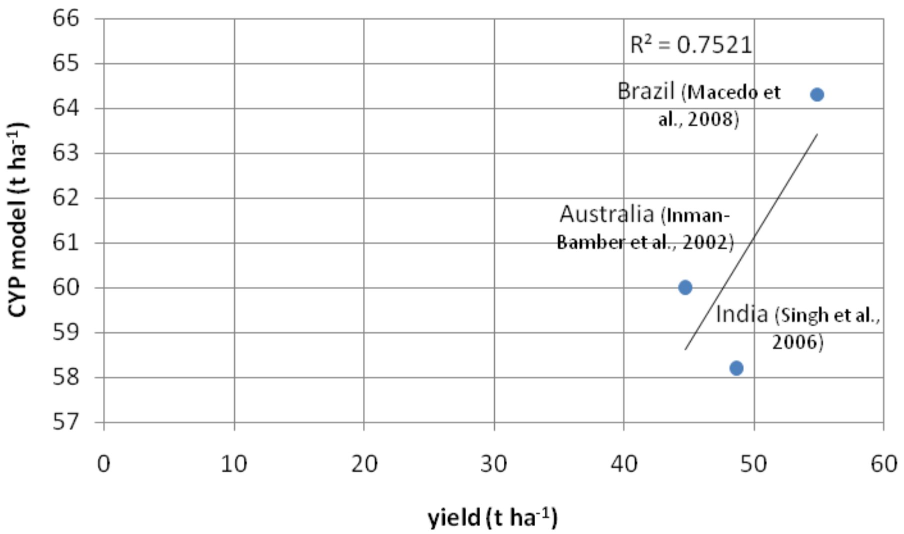


Figure 13: Correlation between CYP model for sugarcane and yield.

Correlation between CYP model for rapeseed and reference yield can be addressed as linear (R^2=0.85). Results of model are similar those published in scientific literature (Figure 14).

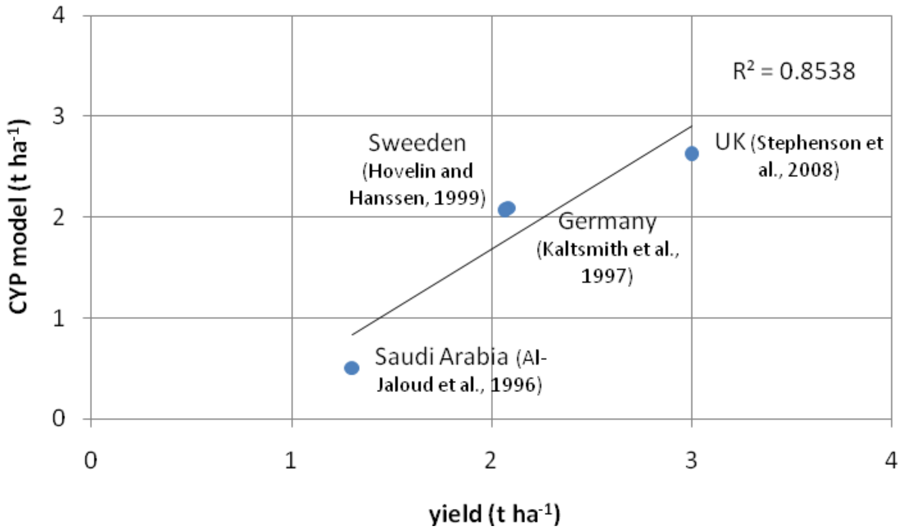


Figure 14: Correlation between CYP model for rapeseed and yield.

Results of CYP model and reference comparison show linear correlation (R^2=0.86) can be seen on Figure 15. Yields calculated by models are similar as reference values.

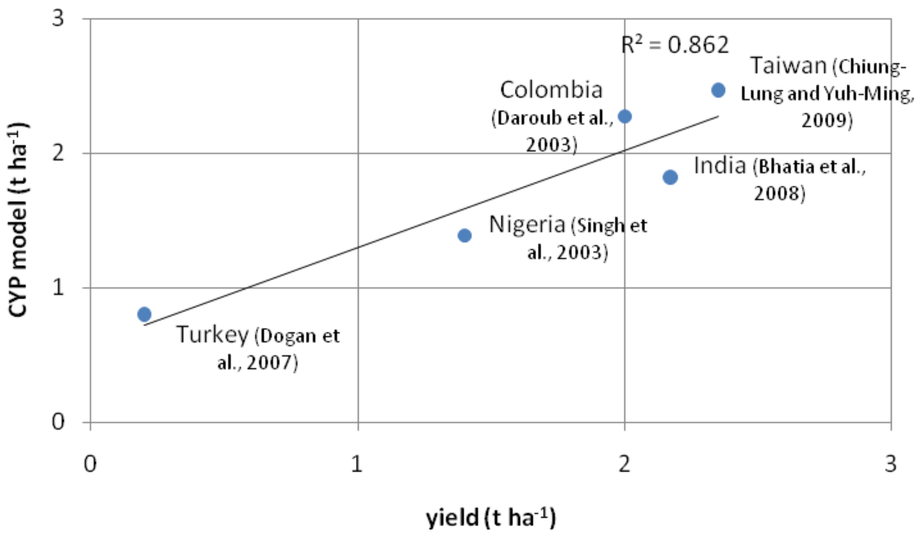


Figure 15: Correlation between CYP model for soybean and yield.

Results of verification shows correlation between yield calculated by CYP models and yield gained from research articles since for the same location CYP models and literature shows resembling yield. Correlation was in all five cases addressed as linear due relative high value of R^2. Howsoever any types of numerical model have some level of uncertainly. And since plants are dynamic systems depended of far more complex variables that temperature and precipitation are; result should be used cautiously.

4.2 RESULTS OF ENVIRONMENTAL ASSESSMENT OF LIQUID BIOFUELS PRODUCTION

4.2.1 Bioethanol

Corn

The diagram shows contribution of single inventory to whole process of corn`s ethanol producing (Figure 16). The greatest impacts have fossil fuels like diesel, gas and oil, which are used in agricultural operations.

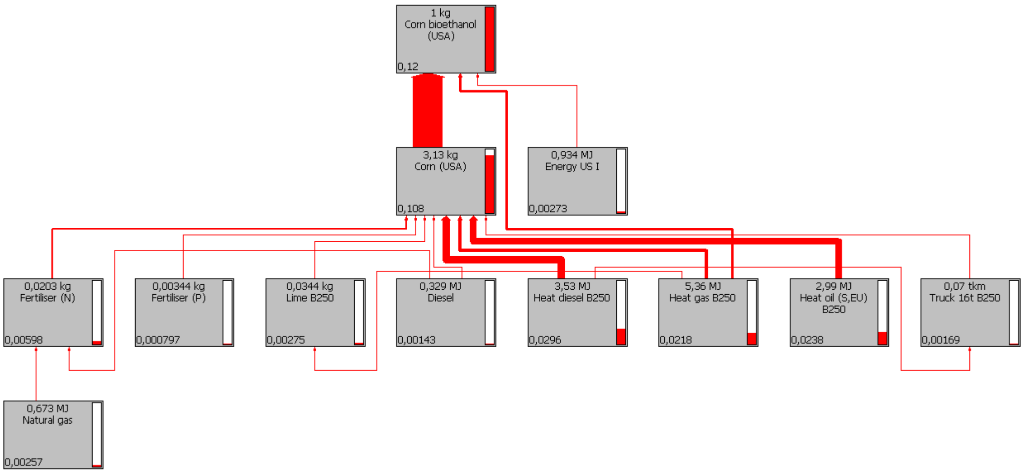


Figure 16: Flowchart of corn`s bioethanol USA.

Figure 17 show corn`s ethanol producing affects on different categories in milli eco points (mPt). Large impact can be seen on use of fossil fuels and respiratory inorganic compounds, mainly due to cultivation of corn.

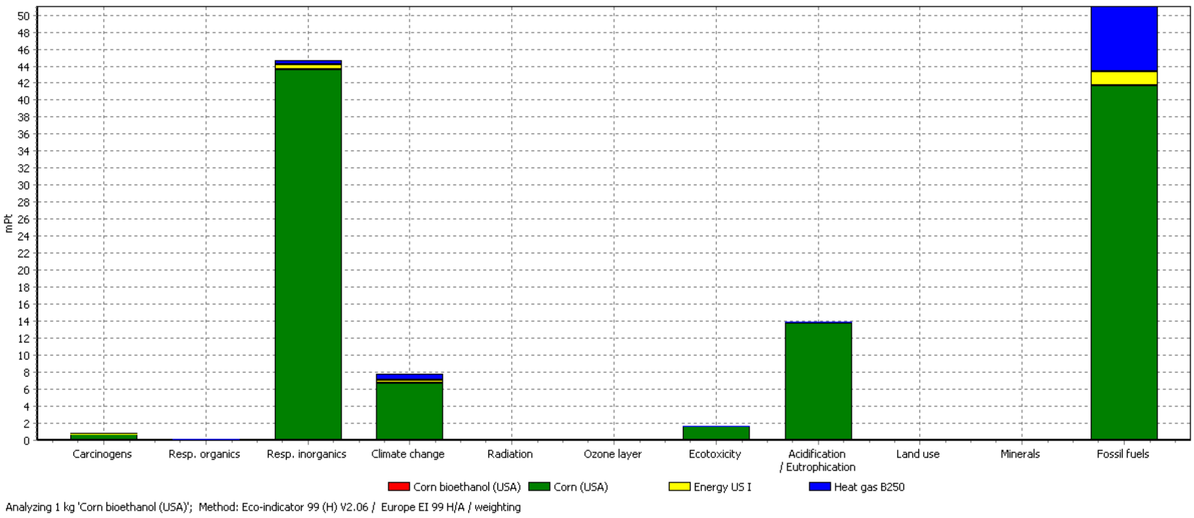


Figure 17: Damage assessment of corn`s bioethanol in USA.

Flowchart of corn`s bioethanol production shows that the most abundant process of bioethanol production is cultivation of the corn. This fact is due to the use of potassium fertilizer and fossil diesel in agricultural operations (Figure 18).

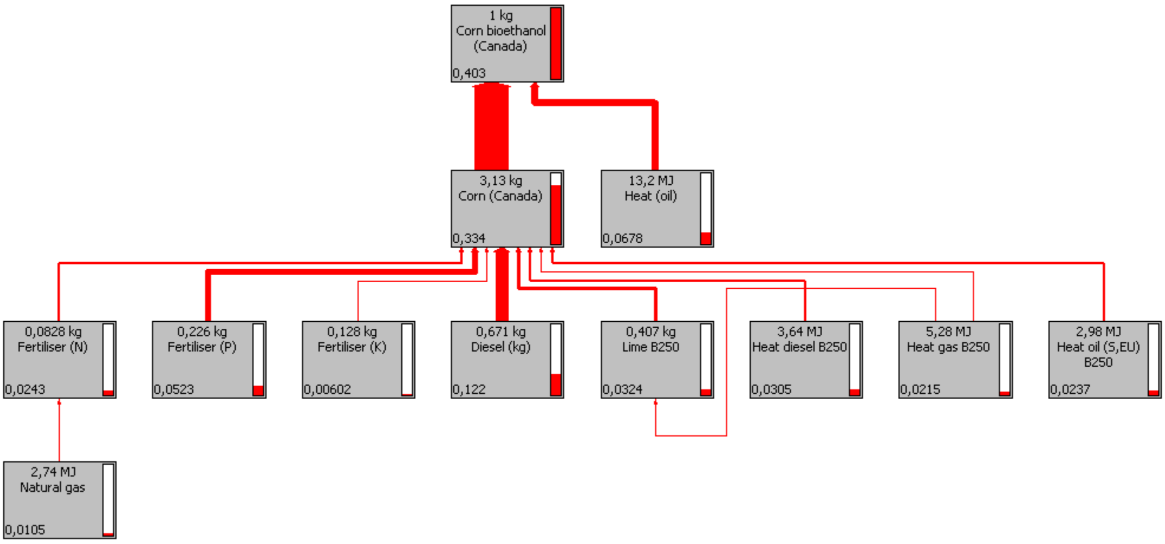


Figure 18: Flowchart of the corn`s bioethanol production in Canada.

Figure 19 show impacts of Canadian's corn`s bioethanol production on 11 categories. The major impacts are being seen on fossil fuels consumption, respiratory inorganic compounds and climate changes. Among all inventories feedstock is evidently abundant, followed by fossil oil.

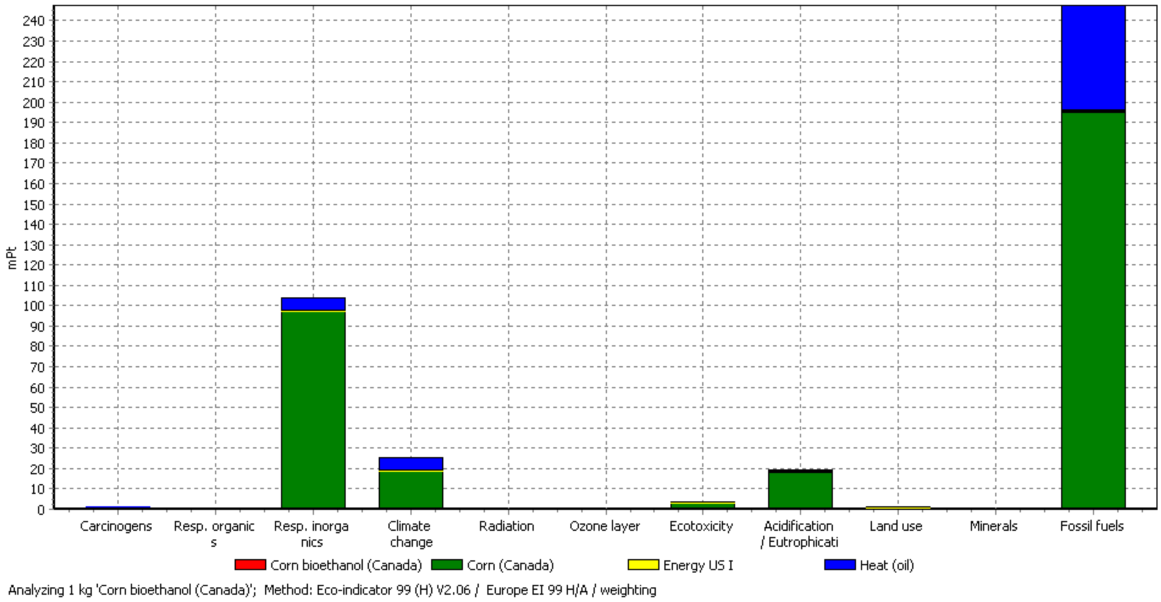


Figure 19: Damage assessment of corn`s bioethanol production in Canada.

Diagram is showing that nitrogen fertilizer play's important role in material and energy flow in case of corn bioethanol production in China (Figure 20). By that, also used fertilizer`s impact is not negligible.

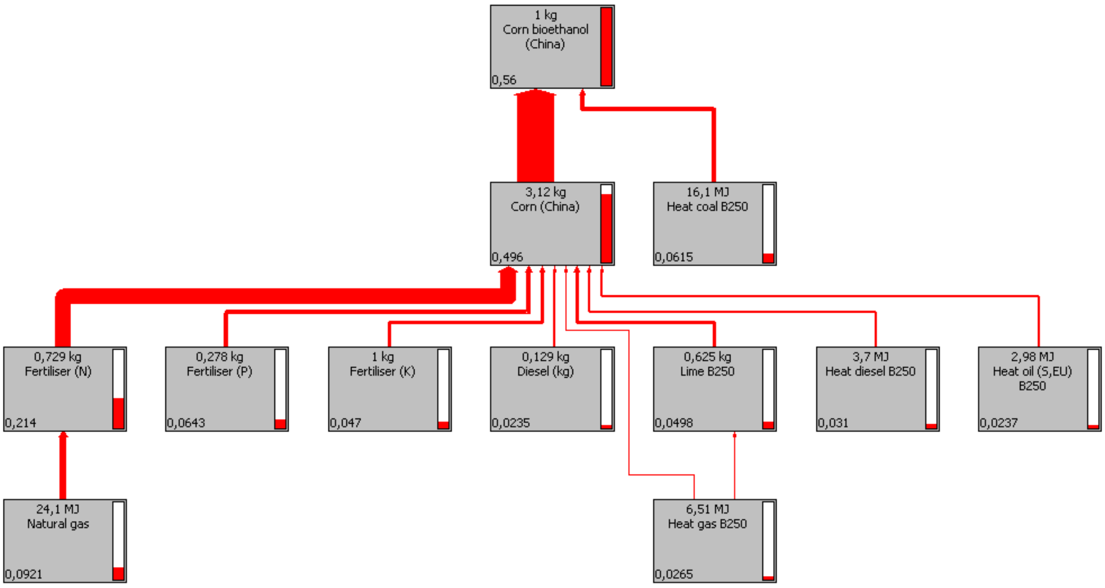


Figure 20: Flowchart of corn`s bioethanol production in China.

Figure 21 is showing contribution of several inventories to different aspects of environment in relative scale (mPt). The most important for ethanol production is feedstock. Mainly due to this is fertilizers use. Follows heat coal for ethanol distillation whit its carcinogenic emissions.

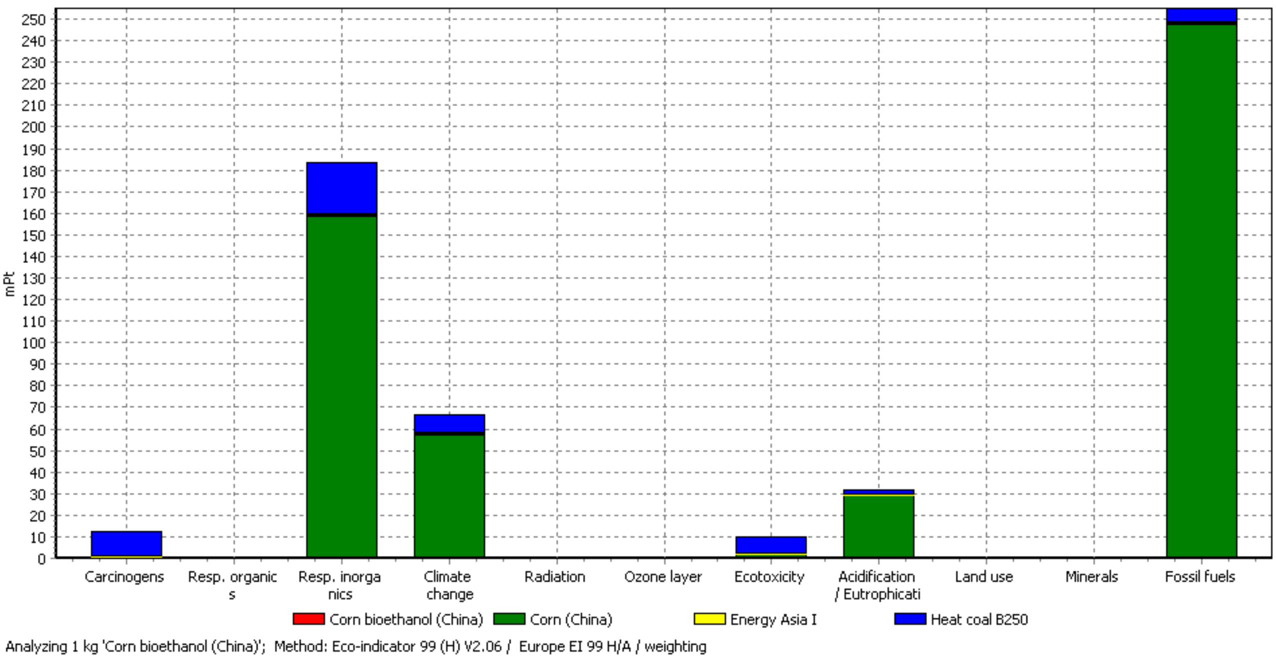


Figure 21: Damage assessment of corn`s bioethanol in China.

Fossil fuel consumption, respiratory inorganic compounds and climate change are the most affected categories per functional unit (FU) (L 100 km^{-1}); according to the compared damage assessment data (Figure 22). In all categories corn bioethanol is showing larger environmental load then fossil fuels or/and electricity except in case of corn bioethanol produced in USA. In this case the impact on resources is similar those in category of petrol and/or diesel.

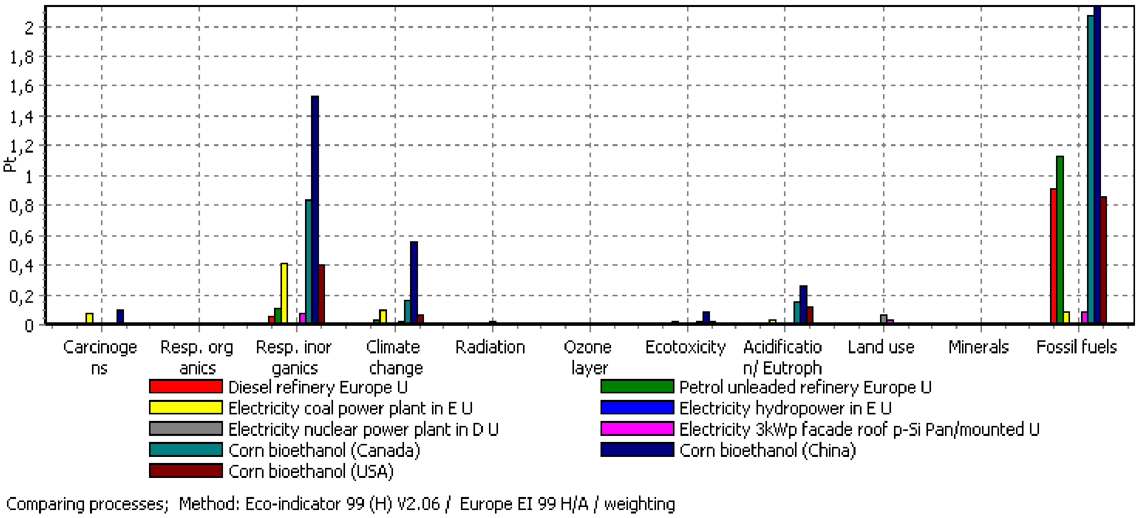


Figure 22: Comparison of damage assessment for corn`s ethanol (from USA, Canada China) and diesel, petrol and electricity (from various sources) per impact category per impact category and per FU.

Comparison of corn bioethanol production with other sources of energy per functional unit show larger impacts for biofuels. Only corn bioethanol from USA is showing similar total load like petrol (Figure 23).

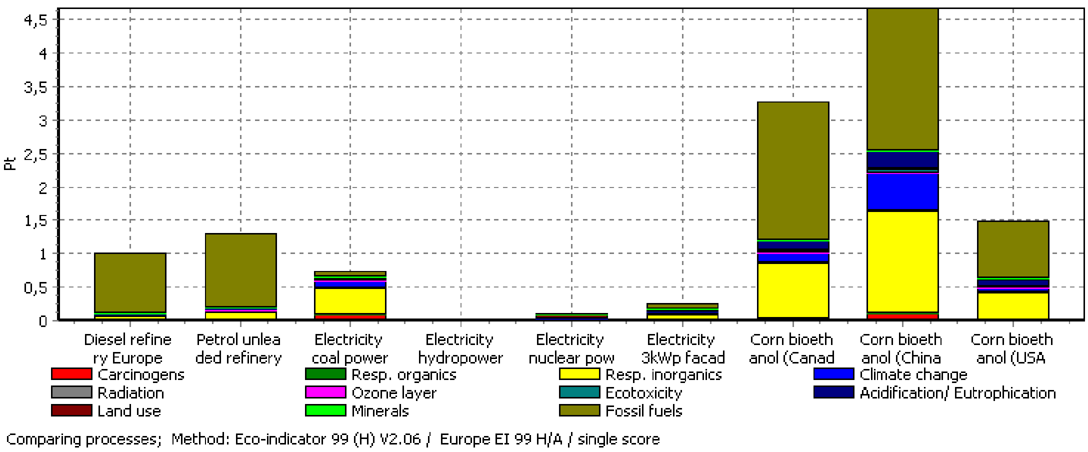


Figure 23: Comparison of damage assessment for corn`s ethanol from USA, Canada, China and diesel, petrol and electricity from various sources per FU and total impacts.

Sugar beet

Flowchart (Figure 24) shows that production of ethanol from sugar beet in Belgium is the most affected by production of feedstock, especially nitrogen fertilizer and fossil diesel are playing important role.

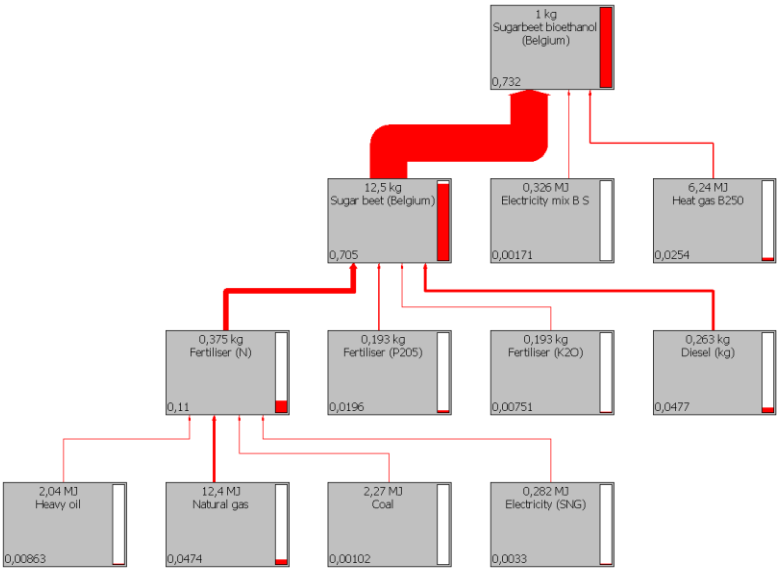


Figure 24: Flowchart of sugar beet`s bioethanol production in Belgium.

Figure 25 show that production of ethanol from sugar beet is affecting health and acidification /eutrophication. The most contributed inventories are feedstock cultivation and natural gas.

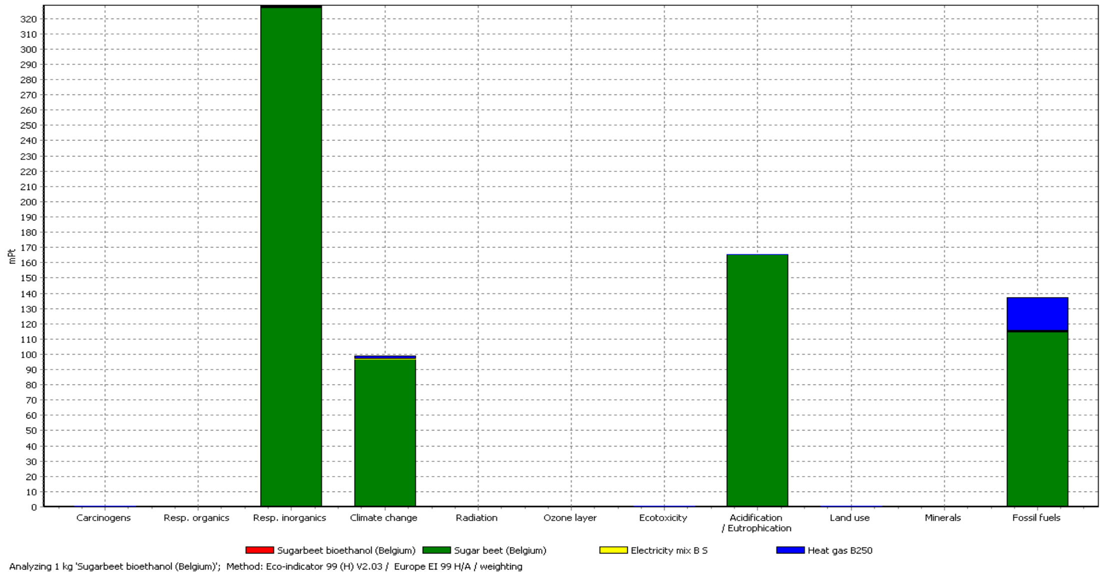


Figure 25: Damage assessment of sugar beet`s bioethanol in Belgium.

In France as well as in most selected countries production of feedstock is a major contributor to whole process of ethanol production. Other inventories are negligible can be seen on Figure 26.

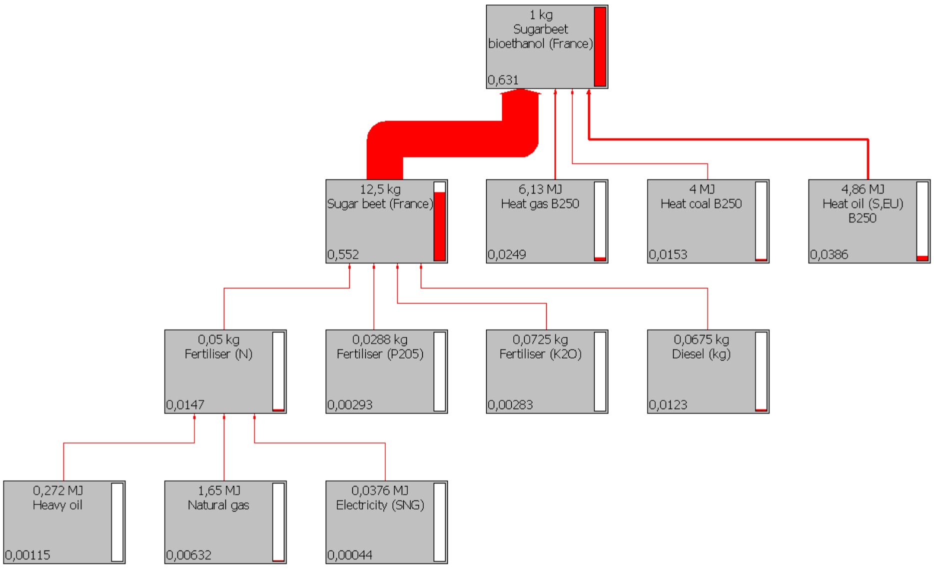


Figure 26: Flowchart of sugar beet`s bioethanol production in France.

Ethanol production from sugar beet is affecting health and acidification/eutrophication, mostly due to feedstock production and fossil fuels use (Figure 27).

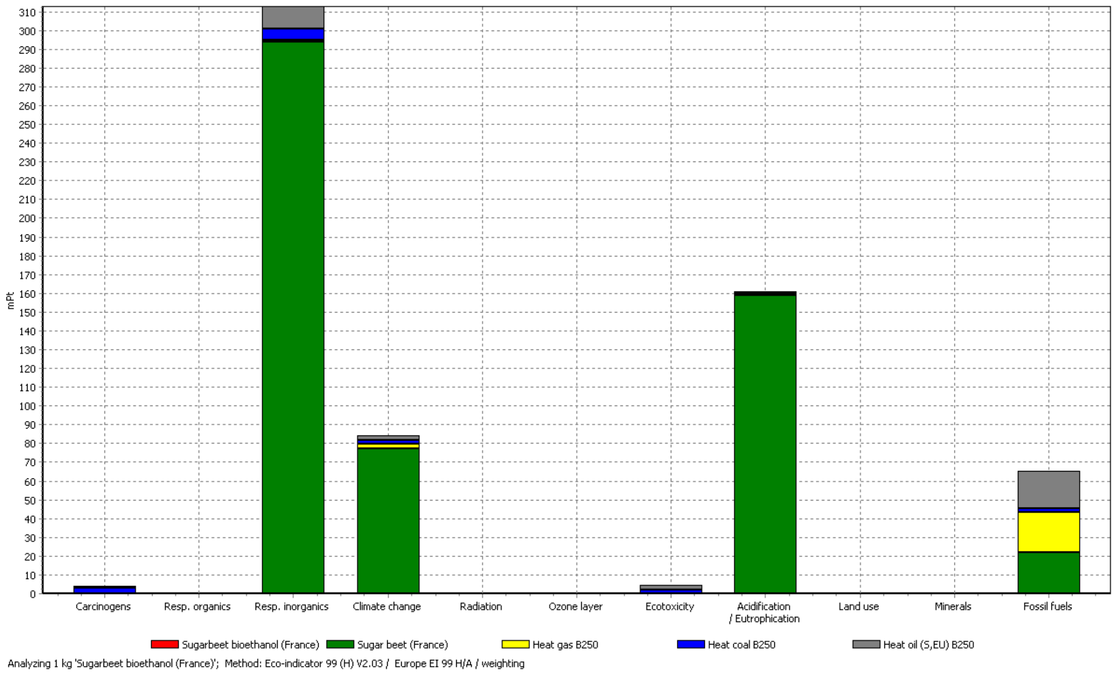


Figure 27: Damage assessment of sugar beet`s bioethanol production in France.

In UK, the process of ethanol production from sugar beet is the most abundant by sugar beet production, especially due to nitrogen fertilizer. Figure 28 is showing that large amount of fossil fuels are used for fertilizers production.

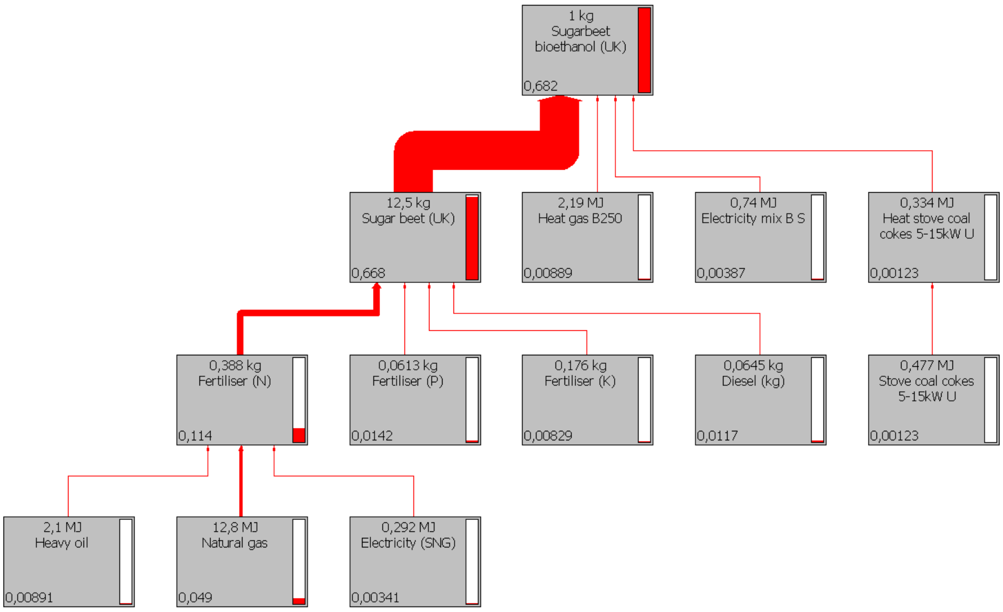


Figure 28: Flowchart of sugar beet`s bioethanol production in UK.

Figure 29 shows that in UK bioethanol production from sugar beet is affecting health, mostly by respiratory inorganic compounds. Follows acidification/eutrofication and climate changes.

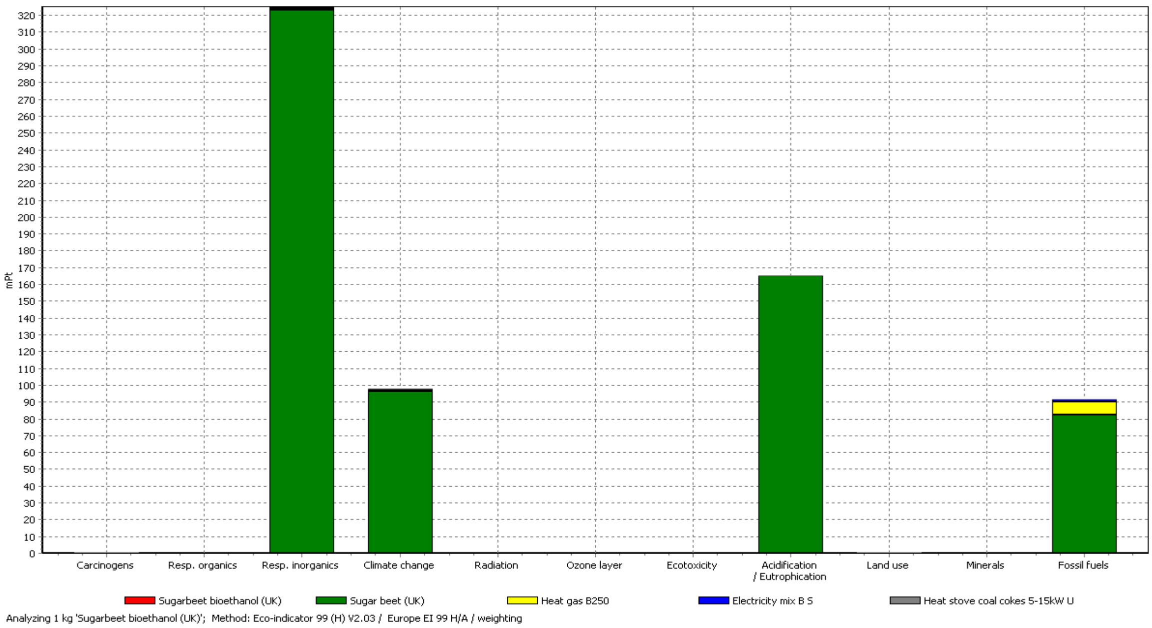


Figure 29: Damage assessment of sugar beet`s bioethanol in UK.

Figure 30 show that ethanol obtained from sugar beet in Belgium and UK has similar impact on selected categories. Comparing results of fossil diesel and petrol to various sources of electricity for cars per FU show significant differences.

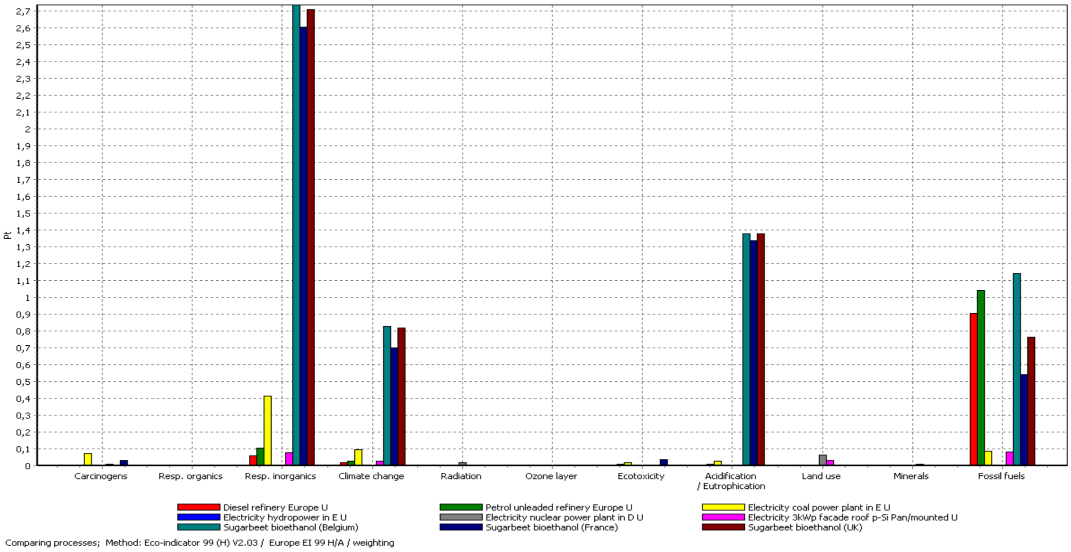


Figure 30: Comparison of damage assessment for sugar beet`s ethanol from Belgium, France, UK and diesel, petrol and electricity from various sources per impact category and per FU.

Figure 31 show huge total environmental load for sugar beet`s bioethanol in comparison with other sources of energy per FU.

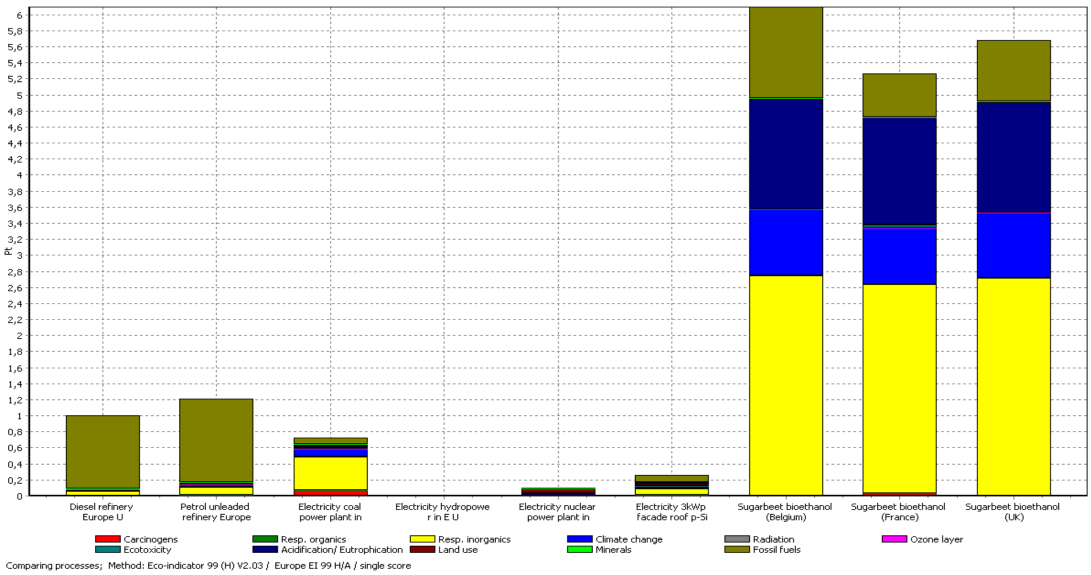


Figure 31: Comparison of damage assessment for sugar beet`s ethanol from Belgium, France, UK and diesel, petrol and electricity from various sources per FU and total impacts.

Sugarcane

Flowchart (Figure 32) shows that the feedstock process for ethanol extraction is representing minor contributes regarding to the feedstock production. This figure is also showing important contribution of fossil fuels in agricultural operations.

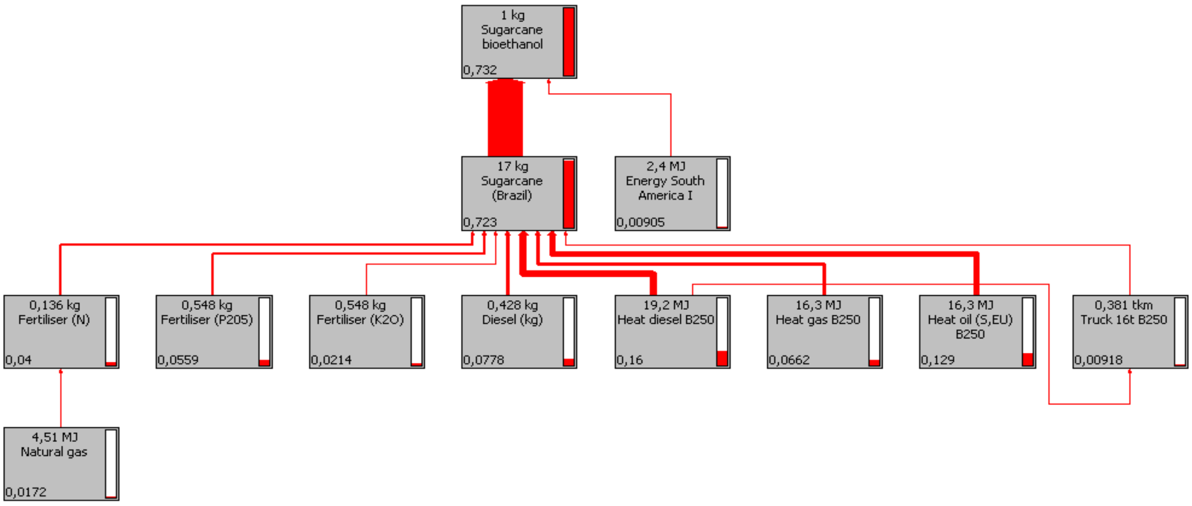


Figure 32: Flowchart of sugarcane`s bioethanol production in Brazil.

Use or fossil fuels, respiratory inorganic compounds and acidification/eutrophication are the most affected categories in sugarcane production in Brazil (Figure 33).

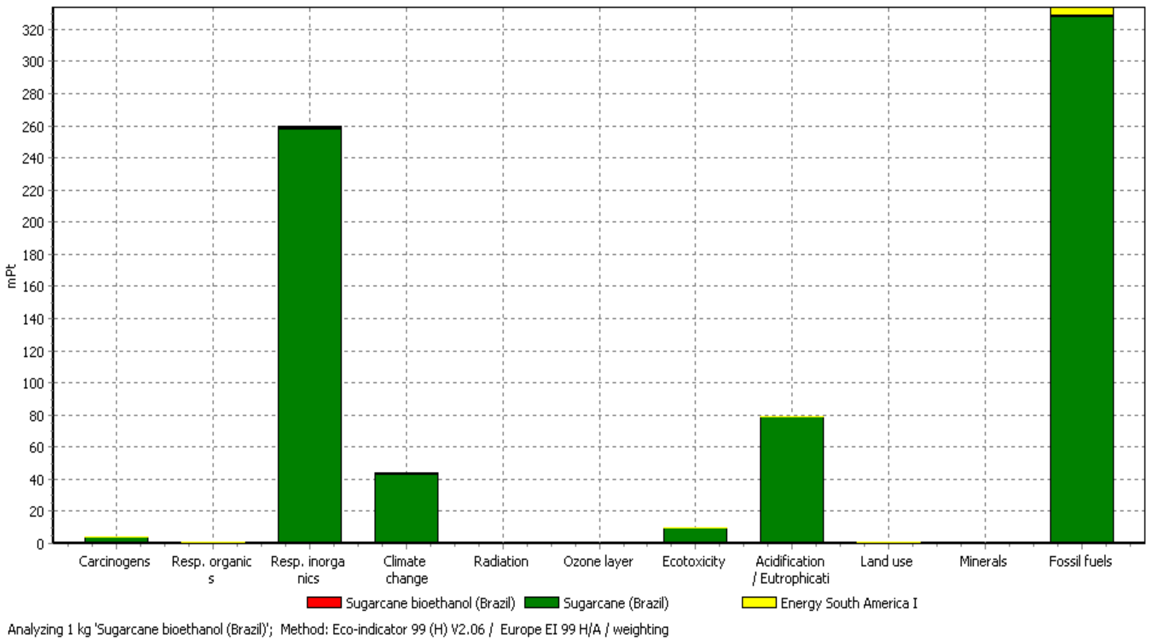


Figure 33: Damage assessment of sugarcane`s bioethanol in Brazil.

The most important inventory, from aspect of material and energy, with 0.291 Pt is nitrogen fertilizer. Follows fossil diesel with 0.16 Pt can be seen on Figure 34.

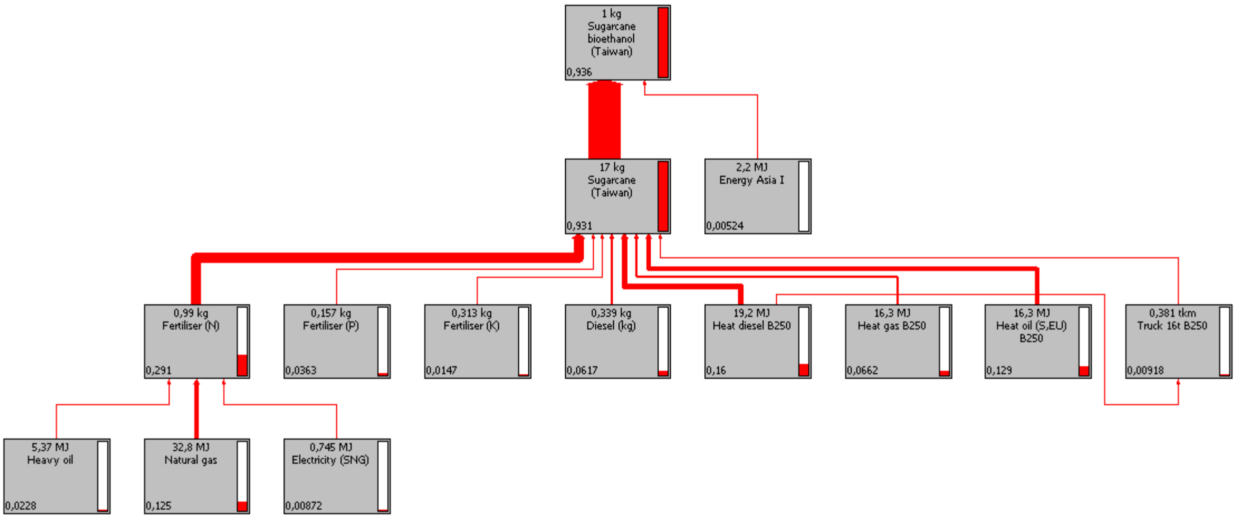


Figure 34: Flowchart of sugarcane`s bioethanol production in Taiwan.

Non renewable energy, effects on human health and acidification/eutrophication are the most expressed effects of bioethanol production in Taiwan (Figure 35). Production of feedstock is major culprit, compared to other inventories.

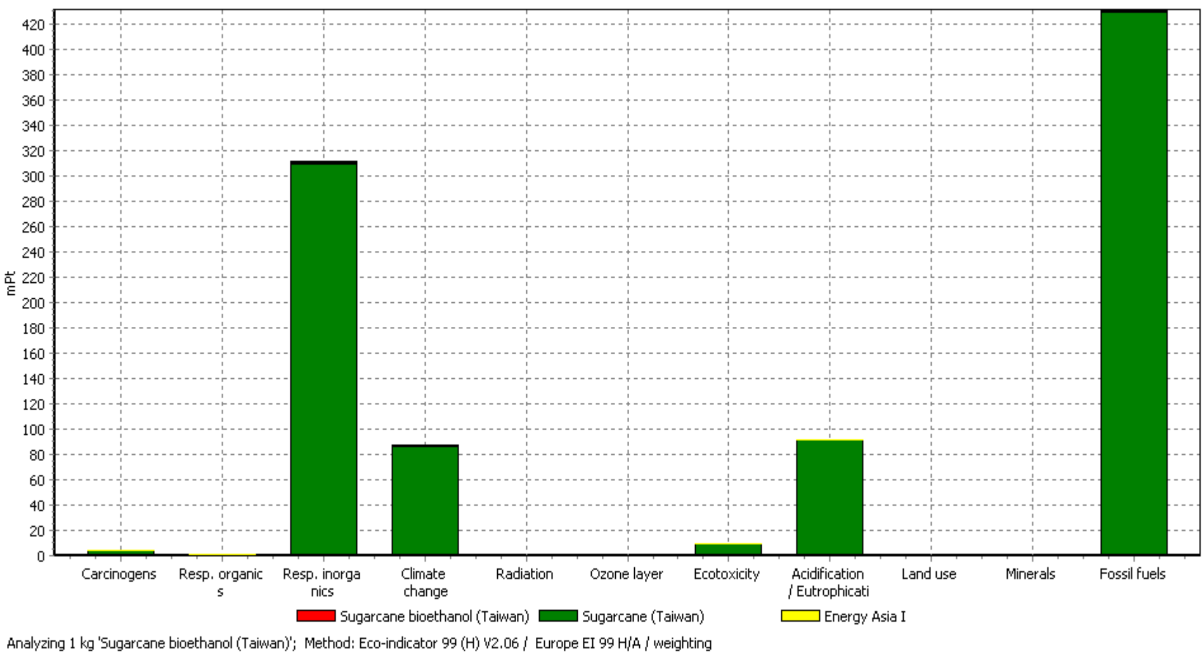


Figure 35: Damage assessment of sugarcane`s bioethanol in Taiwan.

The sugarcane feedstock cultivation in Australia is much more contributed process then the processing of ethanol can be seen on Figure 36.

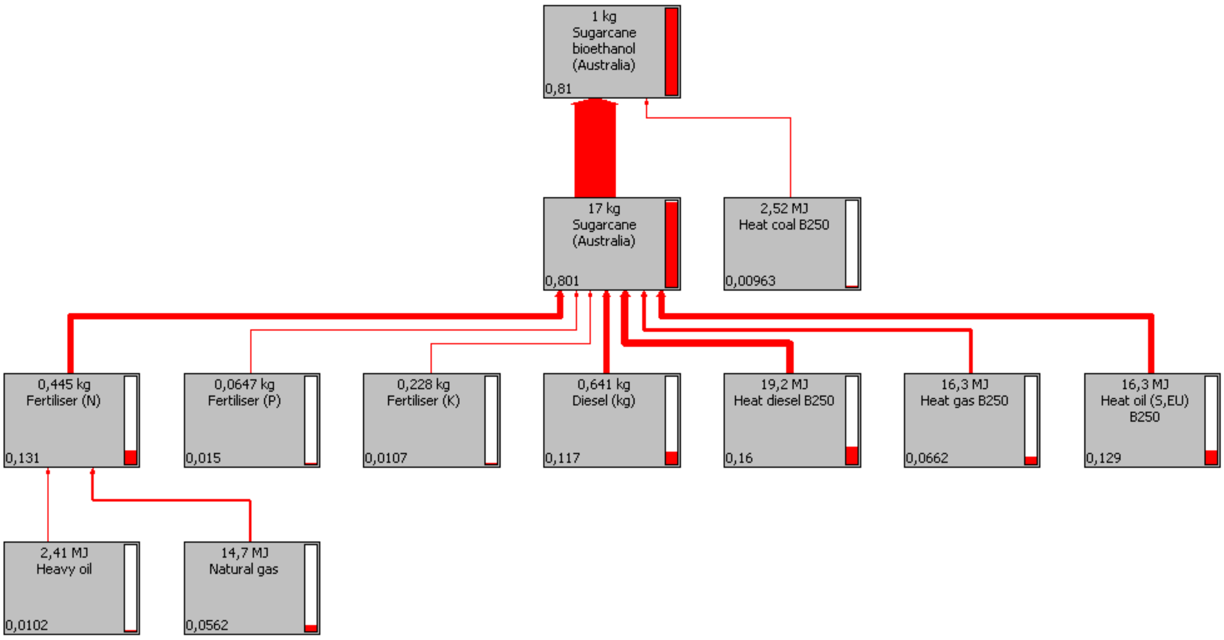


Figure 36: Flowchart of sugarcane`s bioethanol production in Australia.

Figure 37 show that process of ethanol is affecting especially fossil fuels consumption, respiratory inorganic compounds and acidification/eutrofication.

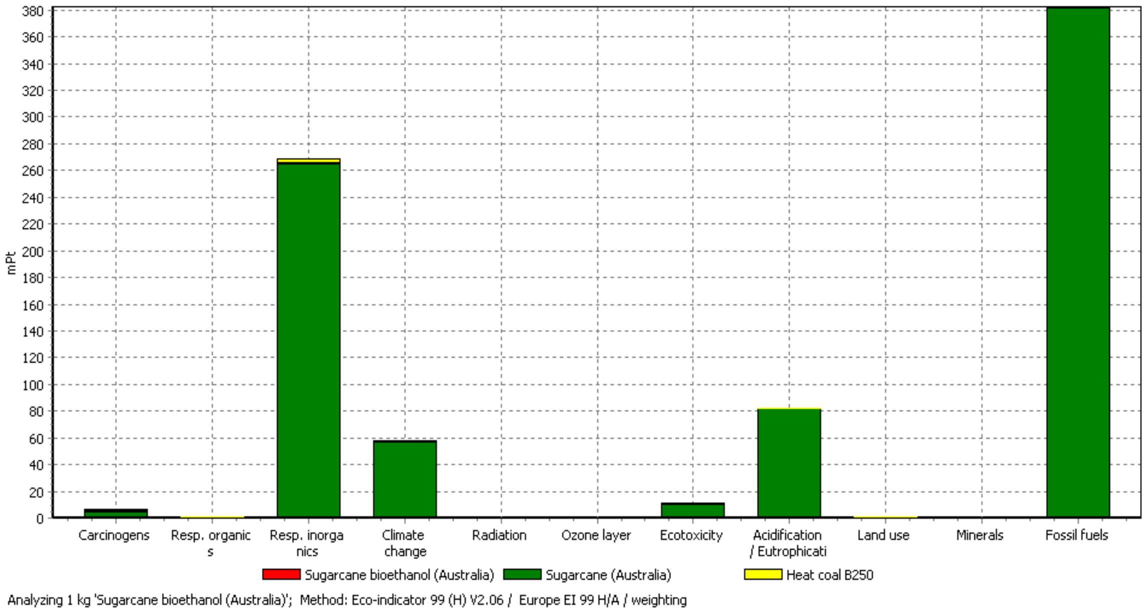


Figure 37: Damage assessment of sugarcane`s bioethanol in Australia.

In all three locations sugarcane ethanol production affects the non renewable sources of energy, human health (respiratory inorganic compounds) and acidification/eutrofication per FU. With the comparison of these results to results of production affects of diesel, petrol, electricity (gained from coal, nuclear, hydro power plant and also photovoltaic) bioethanol obtained from sugarcane it is shown larger environmental damage (Figure 38).

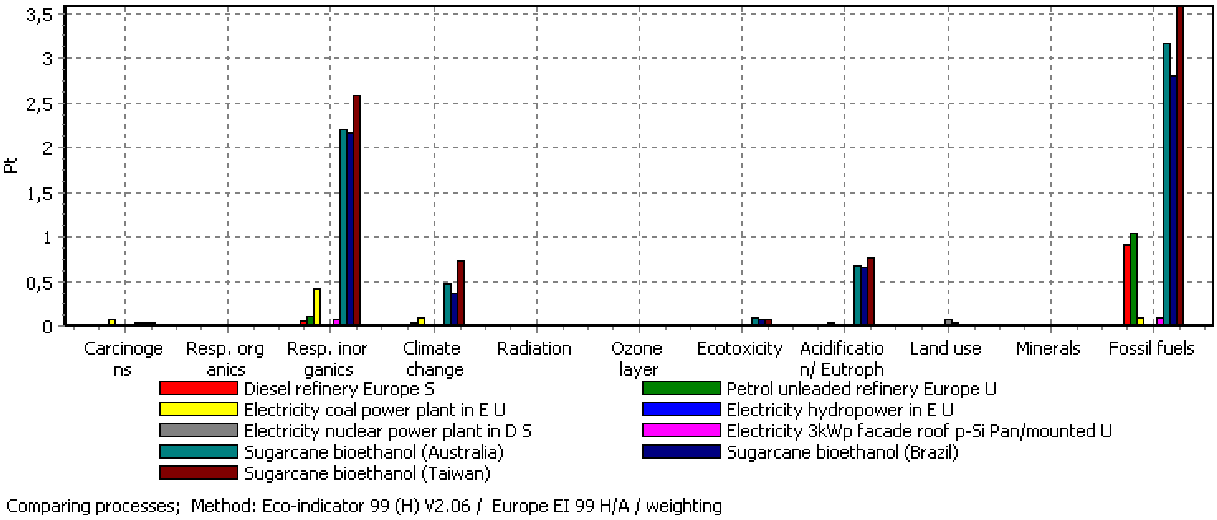


Figure 38: Comparison of damage assessment for sugarcane`s bioethanol (from Brazil, Taiwan, Australia) and diesel, petrol and electricity (from various sources) per impact category and per FU.

Environmental impacts are larger for sugarcane`s bioethanol than for other sources of energy per FU can be seen on Figure 39.

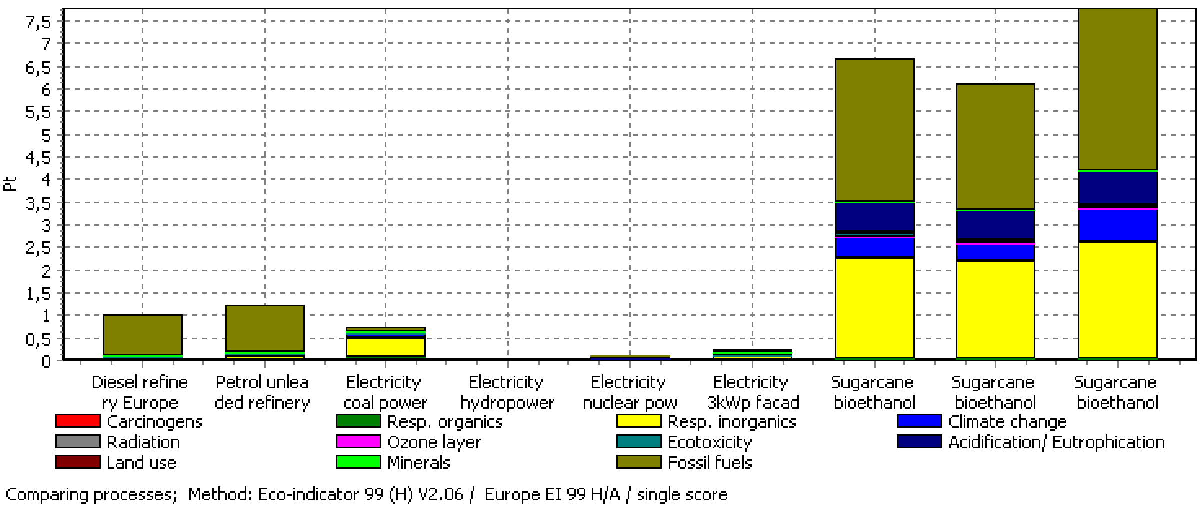


Figure 39: Comparison of damage assessment for sugarcane bioethanol (from Brazil, Taiwan, Australia) and diesel, petrol and electricity (from various sources) per FU and total impacts.

4.2.2 Biodiesel

Rapeseed

The major contributors to process of rapeseed biodiesel production are: diesel fuel used for farm agriculture operation and nitrogen fertilizer. Others inventories show a minor importance (Figure 40).

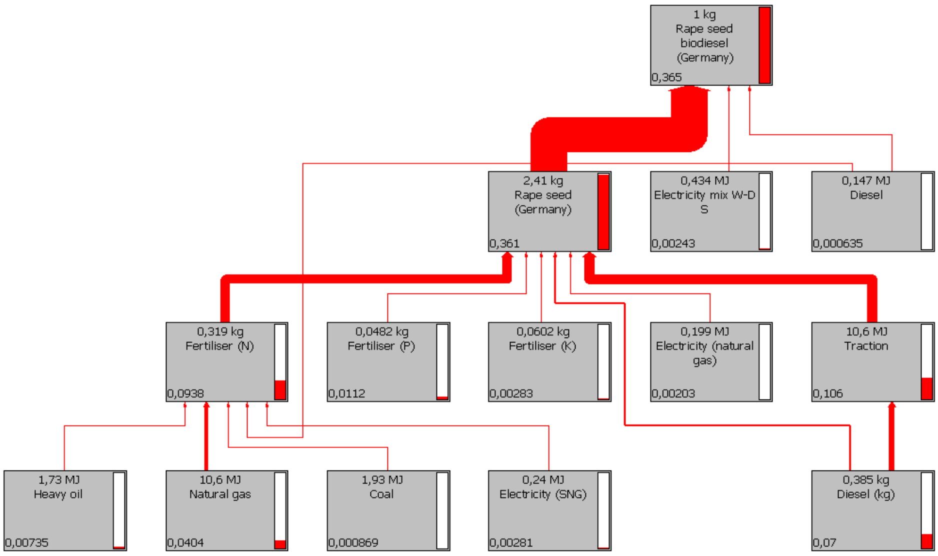


Figure 40: Flowchart of rapeseed biodiesel`s production in Germany.

The rapeseed biodiesel production in Germany affects human health, fossil fuels consumption, climate change, acidification/eutrofication. The major contributor is rapeseed production can be seen on Figure 41.

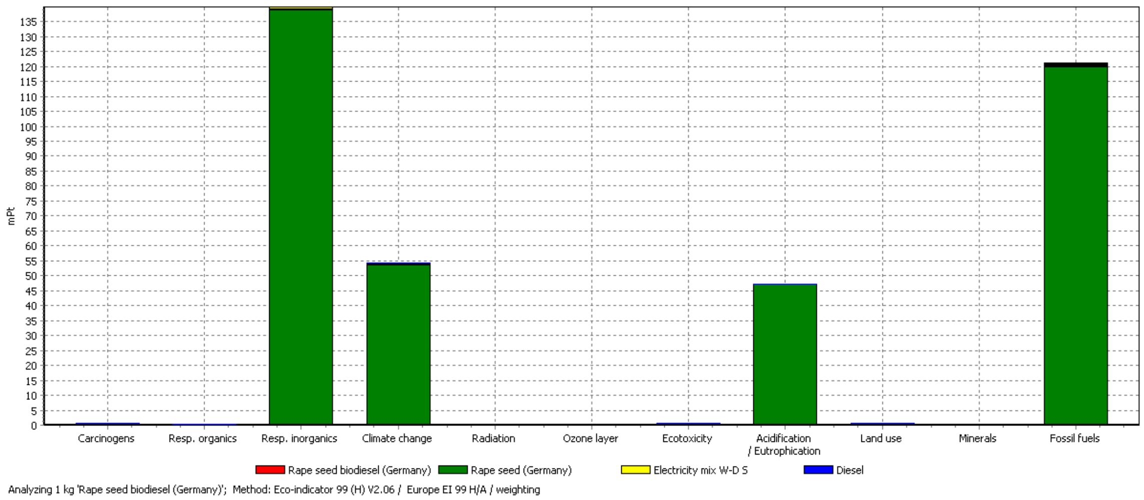


Figure 41: Damage assessment of rapeseed`s biodiesel in Germany

As in case of Germany (Figure 40) are in the case of Sweden (Figure 42) the most abundant inventories nitrogen fertilizer and diesel fuel used for agricultural operations.

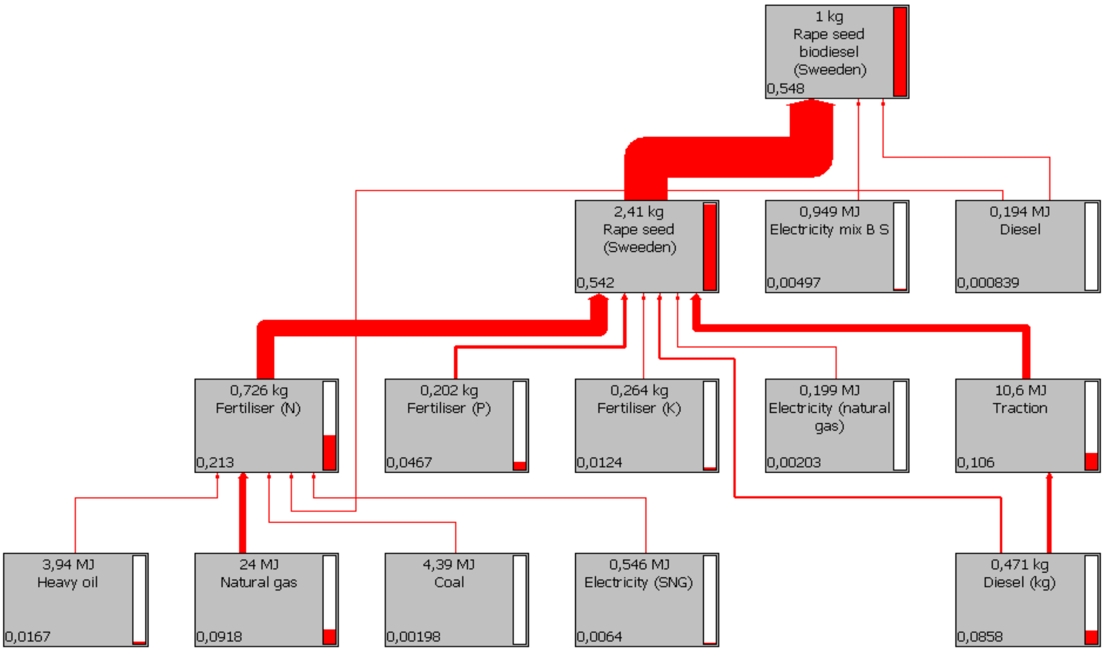


Figure 42: Flowchart of rapeseed`s biodiesel production in Sweden.

In Figure 43 are presented the most affected categories Due to this is cultivation of rapeseed. Consumption of electricity for rapeseed conversion to rapeseed oil shows minor contributor.

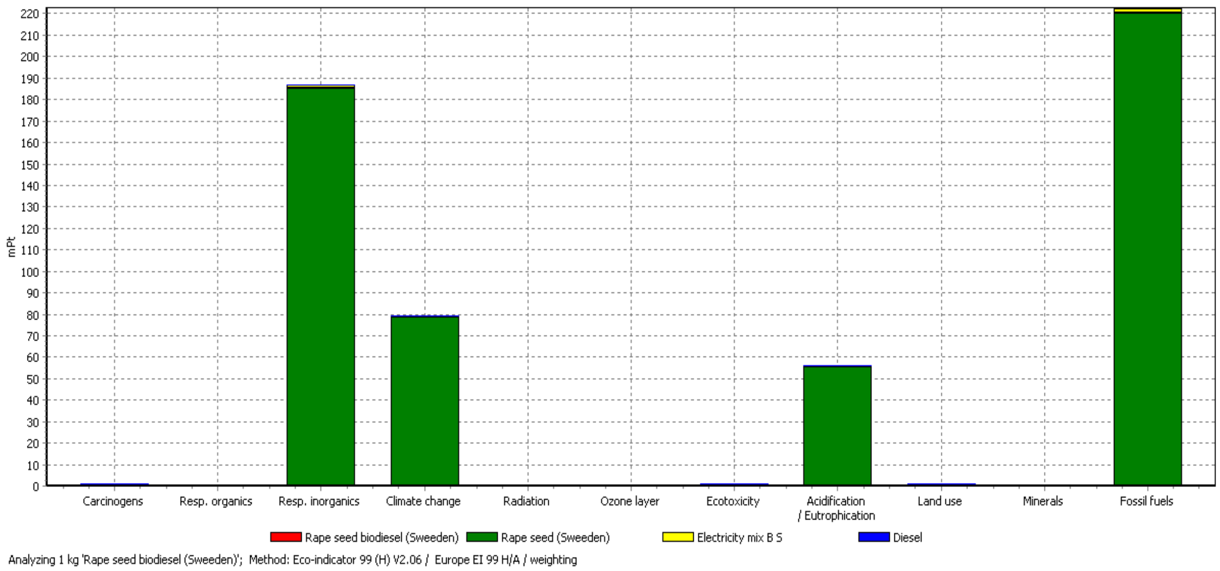


Figure 43: Damage assessment of rapeseed biodiesel in Sweden.

As in previous cases nitrogen fertilizer and agricultural operation play a crucial role in rapeseed biodiesel production in UK (Figure 44).

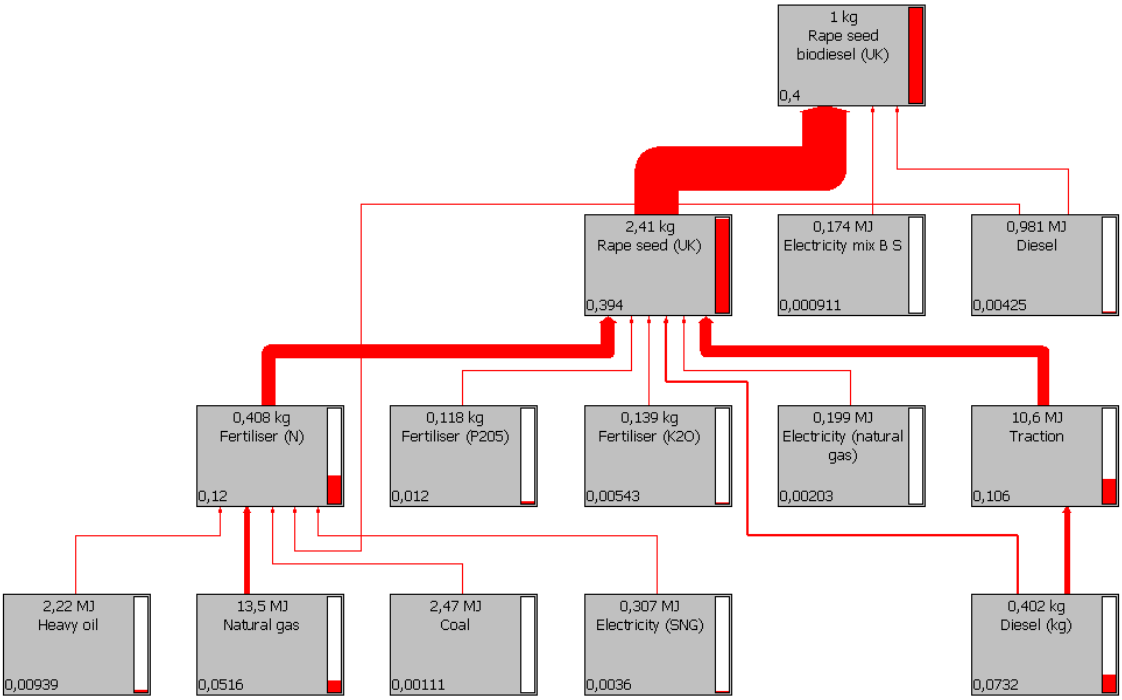


Figure 44: Flowchart of rapeseed`s biodiesel production in UK.

Figure 45 show that respiratory inorganic compounds and fossil fuels are the most represented categories, mainly due to rapeseed production.

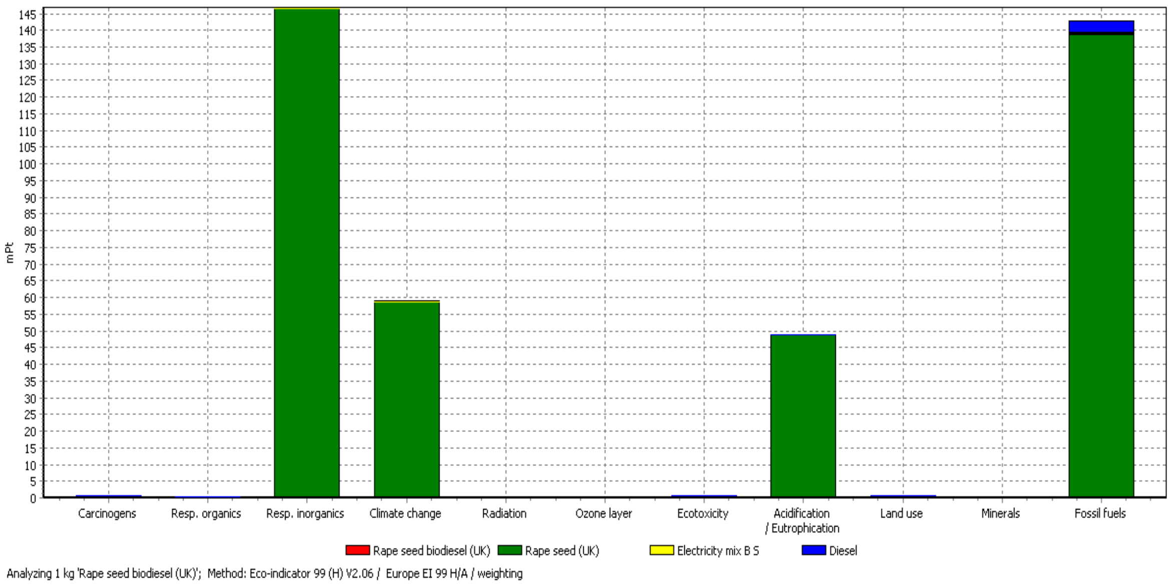


Figure 45: Damage assessment of rapeseed`s biodiesel in UK.

Figure 46 show that biodiesel obtained from rapeseed in Sweden is affecting all the categories. The values are shown per function unit (L100 km^{-1}). Only German biodiesel obtained from rapeseed show potential in case of resources use. Other selected technologies show least environmental impact per FU in production process.

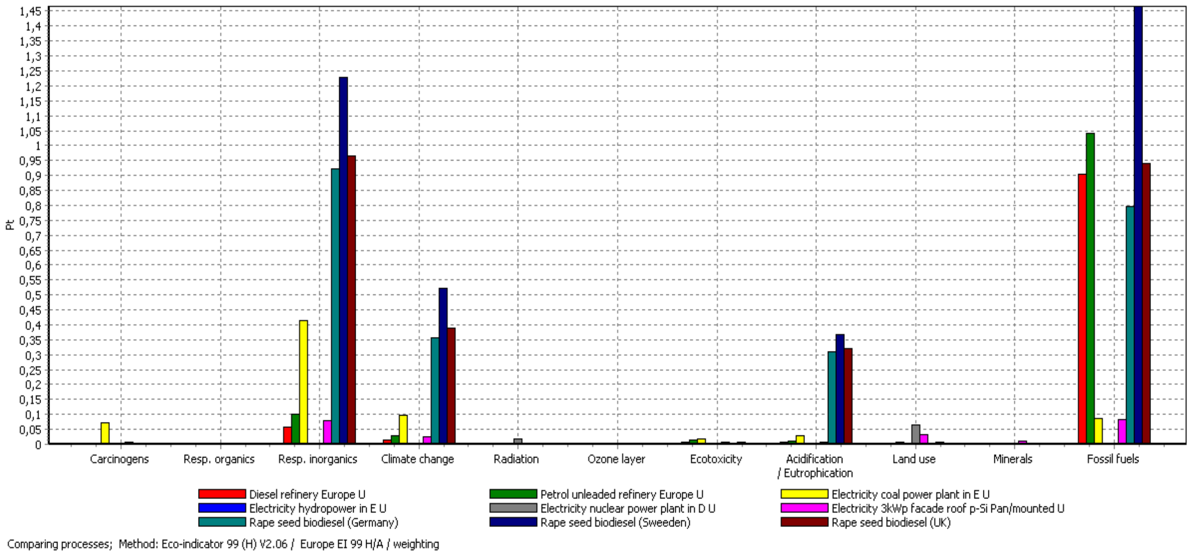


Figure 46: Comparison of damage assessment for biodiesel obtained from rapeseed (from Germany, Sweden, UK) and fossil diesel, petrol and electricity (from various sources) per impact category and per FU.

Figure 47 show that biodiesel obtained from rapeseed cause larger environmental impacts than fossil fuels or electricity from various sources.

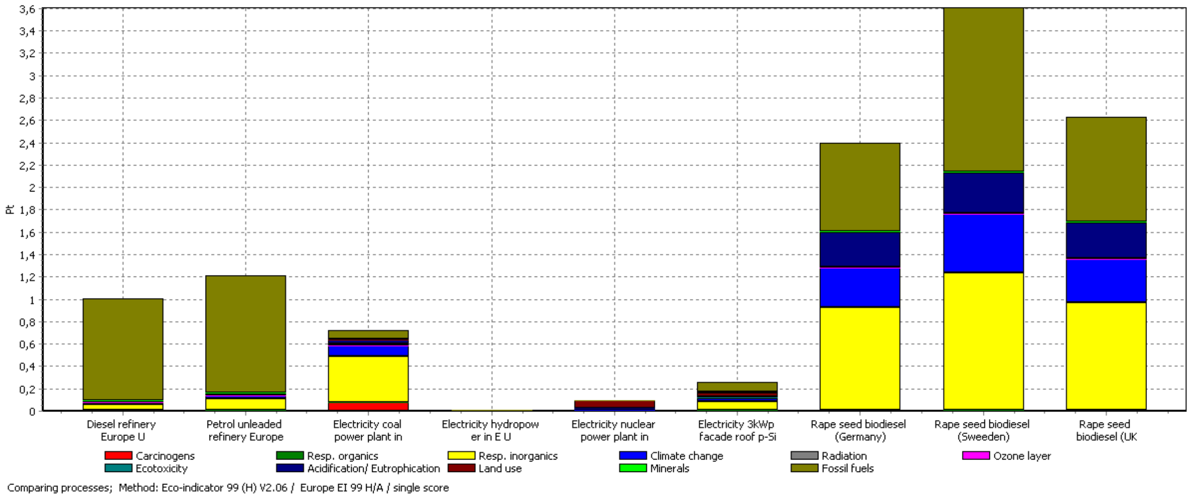


Figure 47: Comparison of damage assessment for biodiesel obtained from rapeseed (from Germany, Sweden, UK) and fossil diesel, petrol and electricity (from various sources) per FU and total impacts.

Soy bean

Diagram shows that phosphorous fertilizer and fossil diesel fuel for agricultural operations are the most abundant contributor in case of soybean`s biodiesel production in USA (Figure 48).

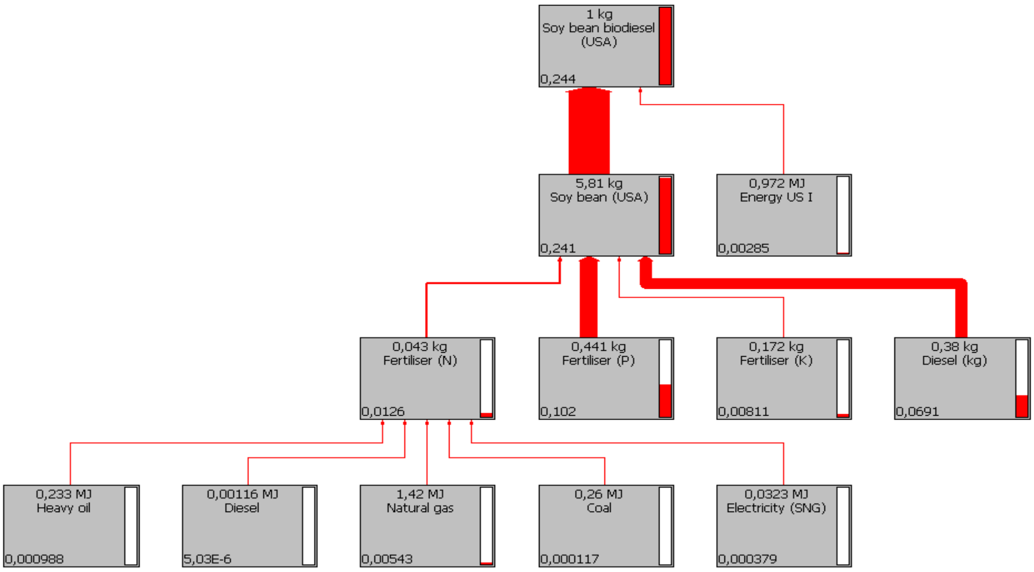


Figure 48: Flowchart of soybean`s biodiesel production in USA.

Fossil fuels, many used in process of soybean cultivation are the most affected category (Figure 49), followed by climate change and respiratory inorganic compounds.

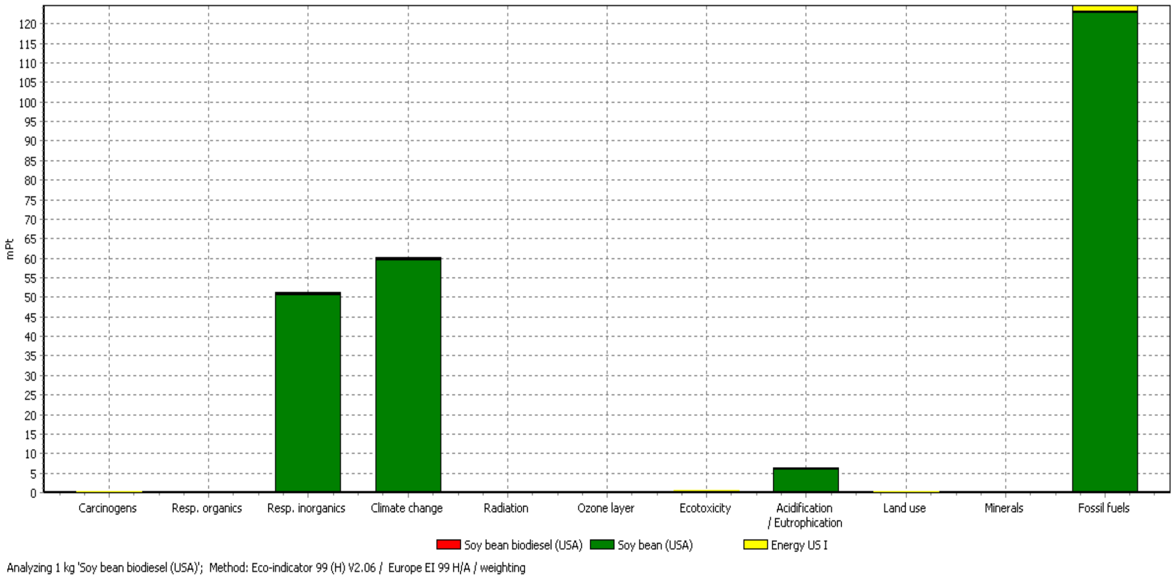


Figure 49: Damage assessment of soy bean`s biodiesel in USA.

The most important inventories for biodiesel production in Taiwan are diesel and nitrogen fertilizer (Figure 50).

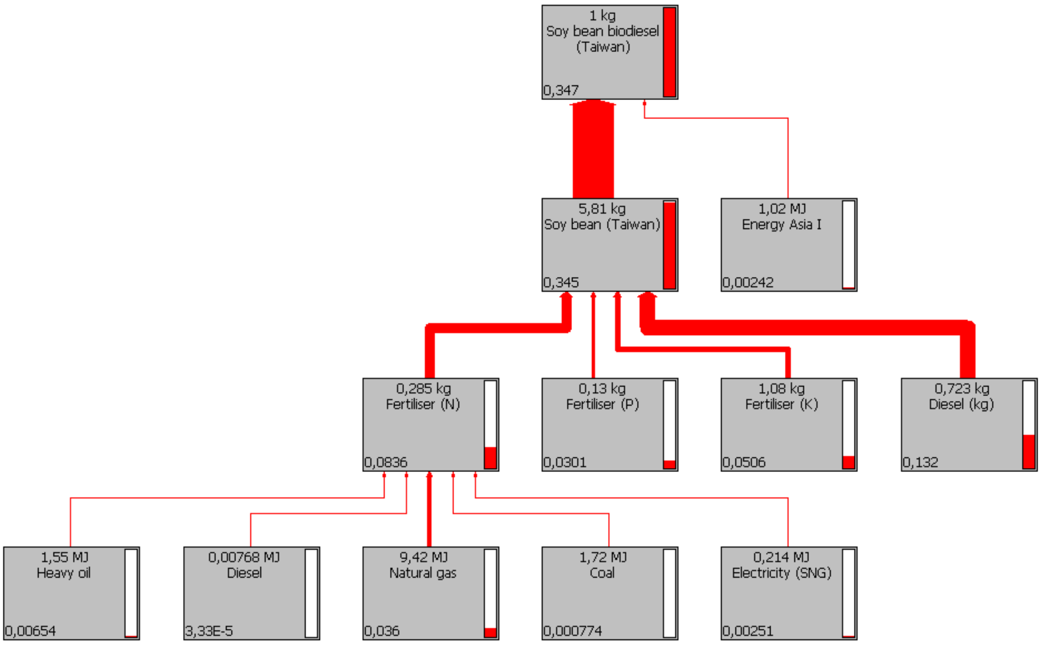


Figure 50: Flowchart of production soybean`s biodiesel in Taiwan.

The most affected category, in case of soybean biodiesel in Taiwan, are non renewable energy sources, followed by climate change and respiratory inorganic compounds (Figure 51).

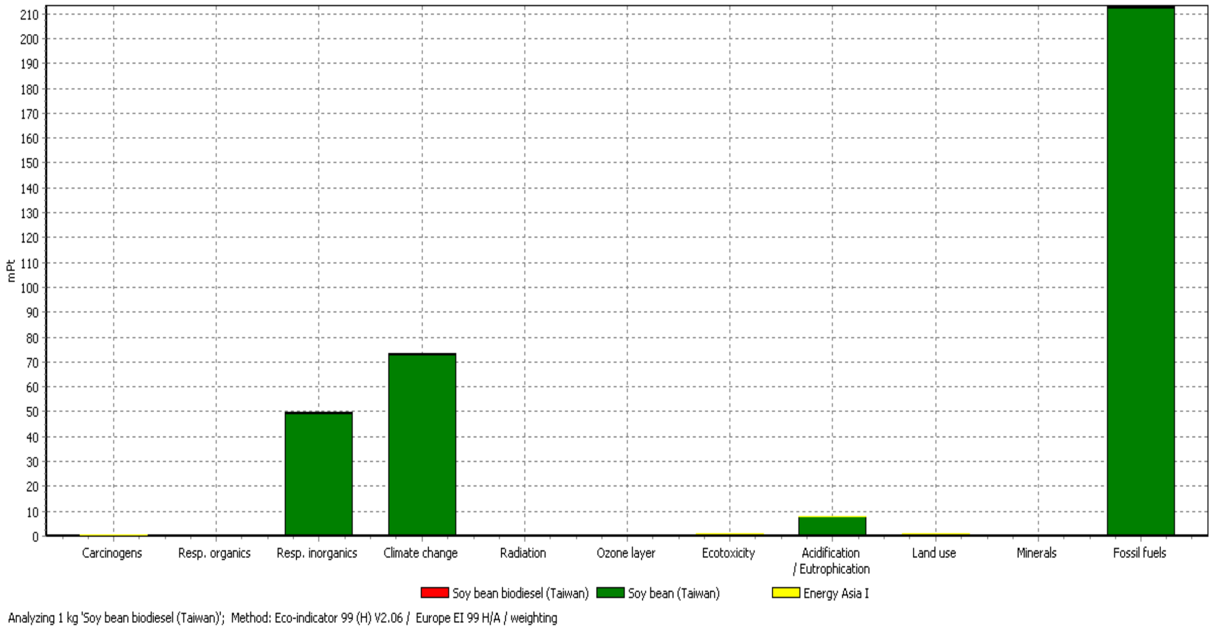


Figure 51: Damage assessment of soybean`s biodiesel in Taiwan.

Fossil fuels use and fertilizer phosphorous are the most abundant resources used for soybean`s biodiesel production in Argentina (Figure 52).

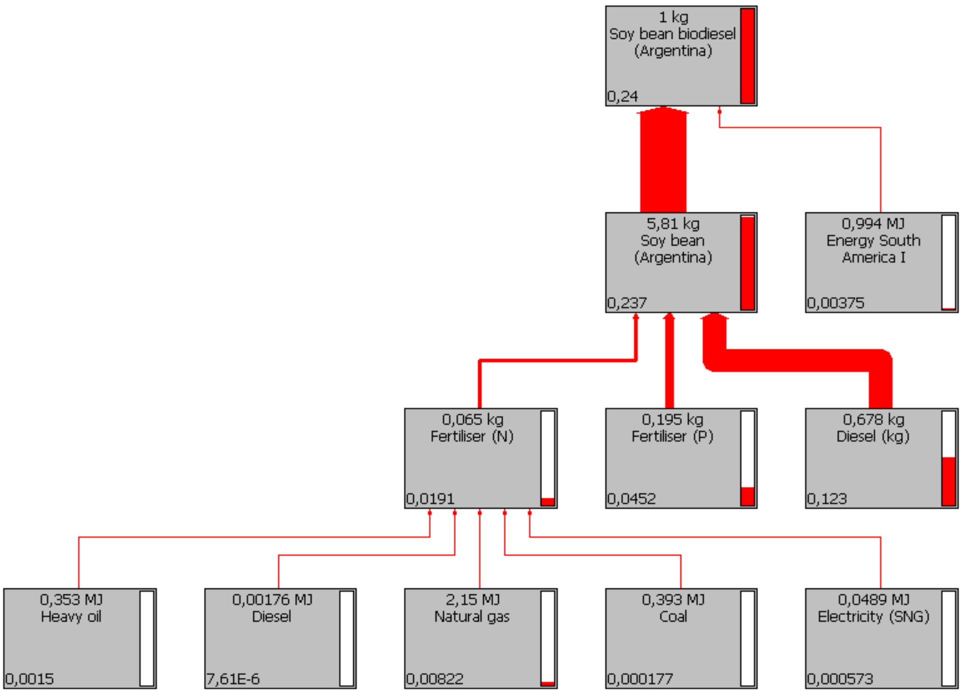


Figure 52: Flowchart of production soybean`s biodiesel in Argentina

Like in other cases fossil fuels consumption followed by climate change are the most affected categories in Argentina can be seen on Figure 53.

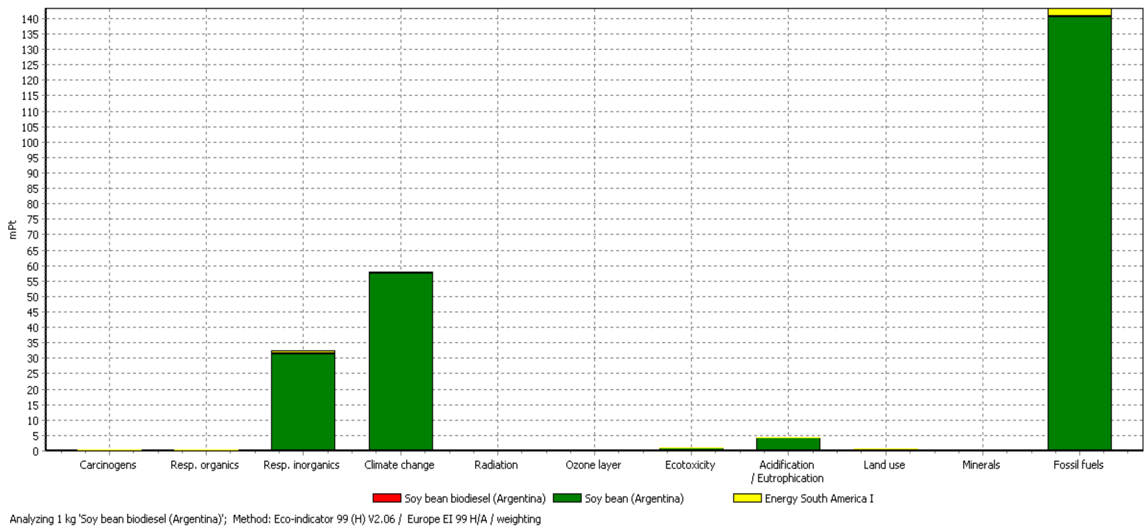


Figure 53: Damage assessment of soybean`s biodiesel in Argentina.

Figure 54 is showing that biodiesel obtained from soybean in Taiwan has larger influence on selected categories. This is especially shown when these data are compared to diesel, petrol and electricity (from various sources) as potential energy sources for cars.

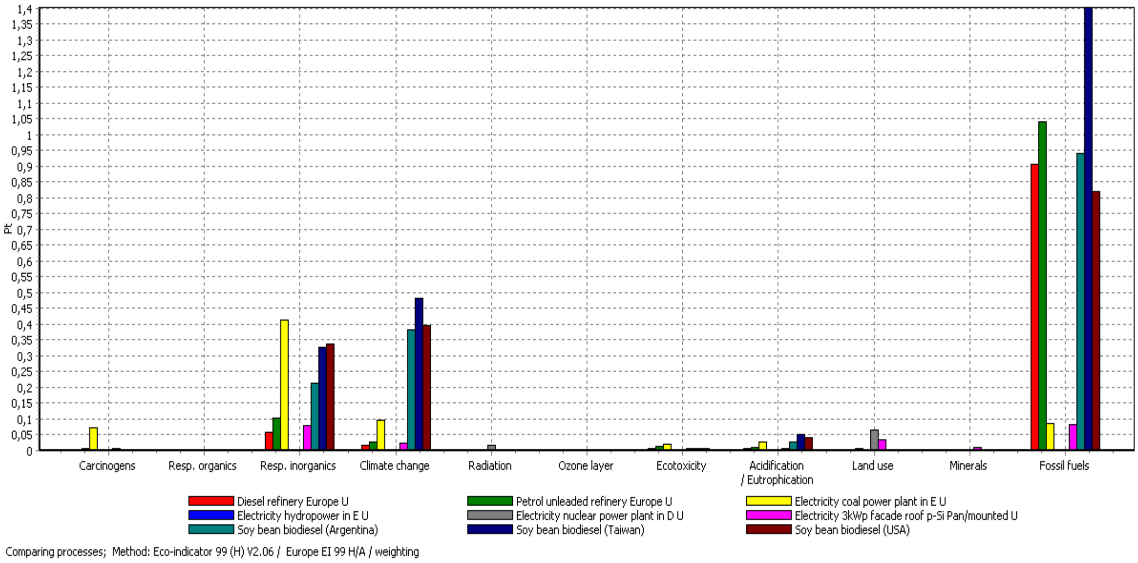


Figure 54: Comparison of damage assessment for soybean`s biodiesel (from USA, Taiwan, Argentina) and fossil diesel, petrol and electricity (from various sources) per impact category and per function unit.

Figure 55 show that soybean biodiesel affects the environment more extensively than other sources of energy.

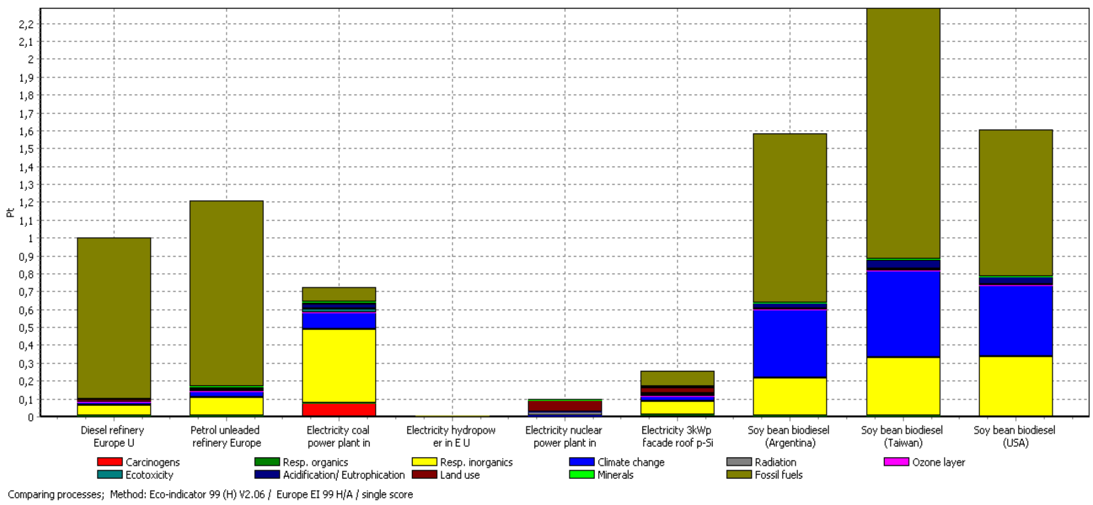


Figure 55: Comparison of damage assessment for soybean`s biodiesel (from USA, Taiwan, Argentina) and fossil diesel, petrol and electricity (from various sources) per FU and total impacts.

Comparison of all selected locations for production of bioethanol and biodiesel is shown in Figure 56. The lowest impact can be seen for case of bioethanol obtained from corn in USA and the highest for Taiwan ethanol obtained from sugarcane.

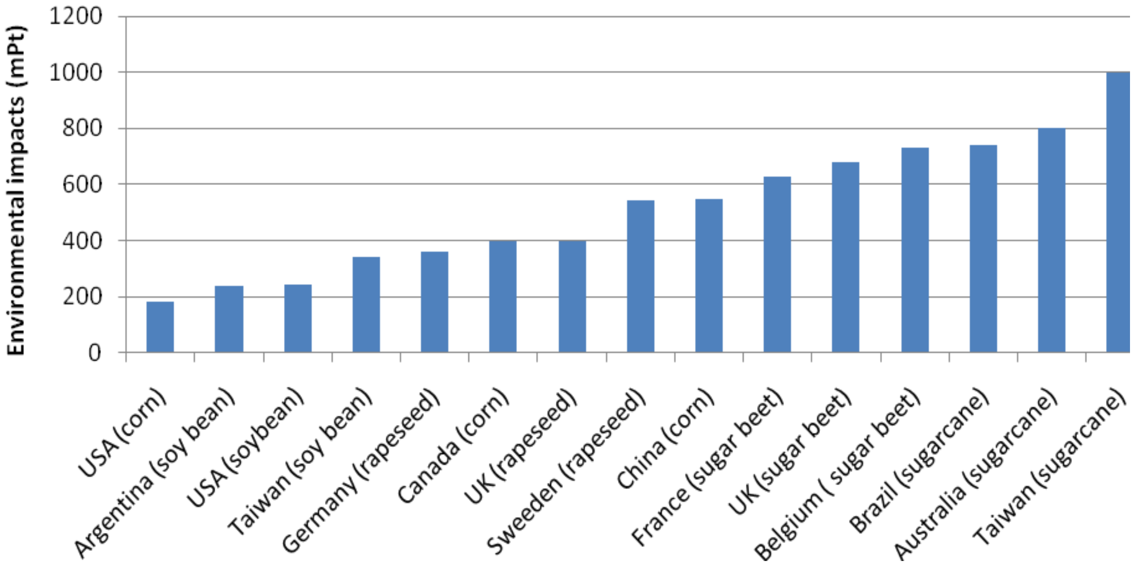


Figure 56: Comparison of all selected locations for production of biodiesel and bioethanol.

4.3 RESULTS OF CORRELATION BETWEEN ENVIRONMENTAL IMPACTS AND YIELD OF FEEDSTOCK

Correlation between environmental impacts (mPt) and yield for each feedstock is shown in Figure 57. As it is shown in the figure, there are two groups of feedstock. First is represented by sugarcane and sugar beet, where correlation is weak. Second group is represented by corn, rapeseed and soybean; where correlation can be addressed as linear. Table 6 points out that the correlation between yields of selected feedstock and environmental impacts are not statistically significant ($p>0.05$). Detailed analysis show that in first group differences among energy and material inventories are small and therefore, it is predicted that the changes and environmental impacts are result of meteorological conditions. In second group there are significant differences in inventories inside the same group. The cause of these differences are agro-technical procedures.

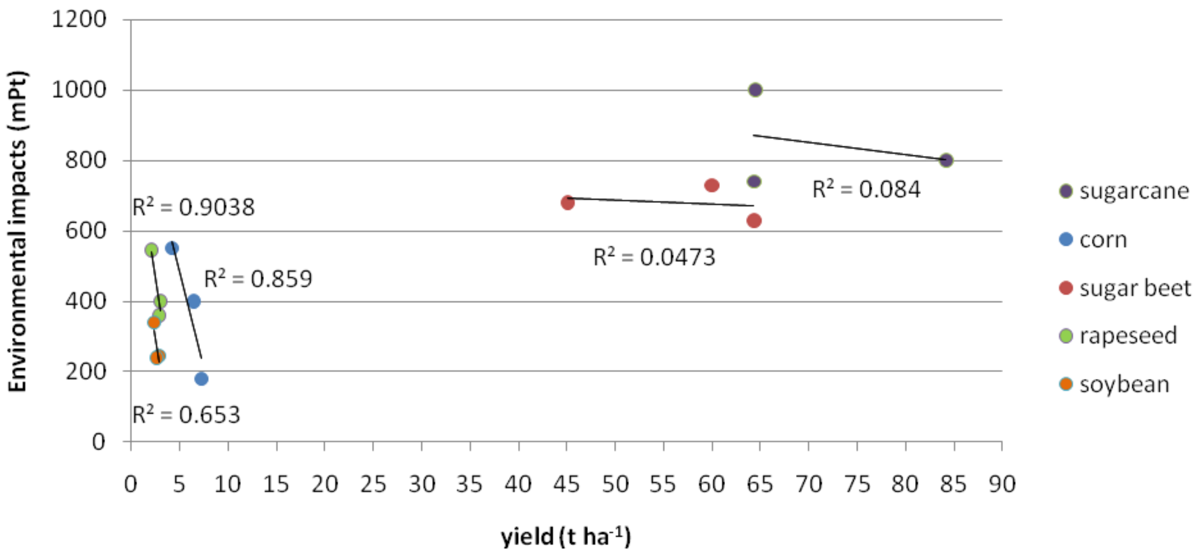


Figure 57: Correlation between environmental impacts (mPt) and yield (t ha^{-1}).

Table 6: Results of statistical analysis of correlation between yield of selected feedstock and their environmental impacts.

feedstock	**corn**	**sugar beet**	**sugarcane**	**rapeseed**	**soy bean**
p-value	0.25	0.86	0.81	0.20	0.40

Legend: *statistical significant ($p<0.05$)

4.4 GLOBAL BIOFUELS PRODUCTION BY END OF 2100 WHILE MEETING THE EXPECTED CLIMATE CHANGES

Decrease in corn`s yield for different scenarios is shown in Figure 58. The most devastating will be combination of temperature increase for 6.4 °C and precipitation for 20%. Such scenario would result in more than 50% decrease of yield.

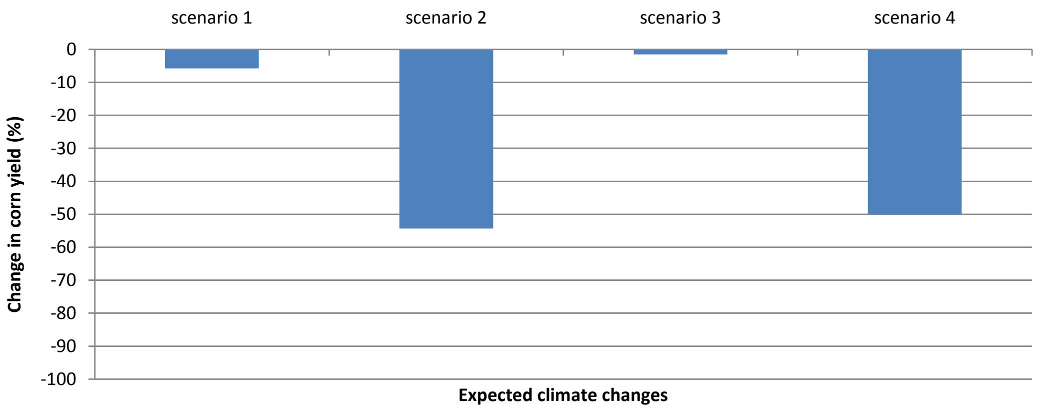


Figure 58: Change in yield (%) for corn regarding to global climate changes.

Increase of air temperature regarding to average baseline (1980-1999) will cause large yield decrease for sugar beet (Figure 59). Increase in temperature shows important impact; meanwhile projections about precipitation are not so significant.

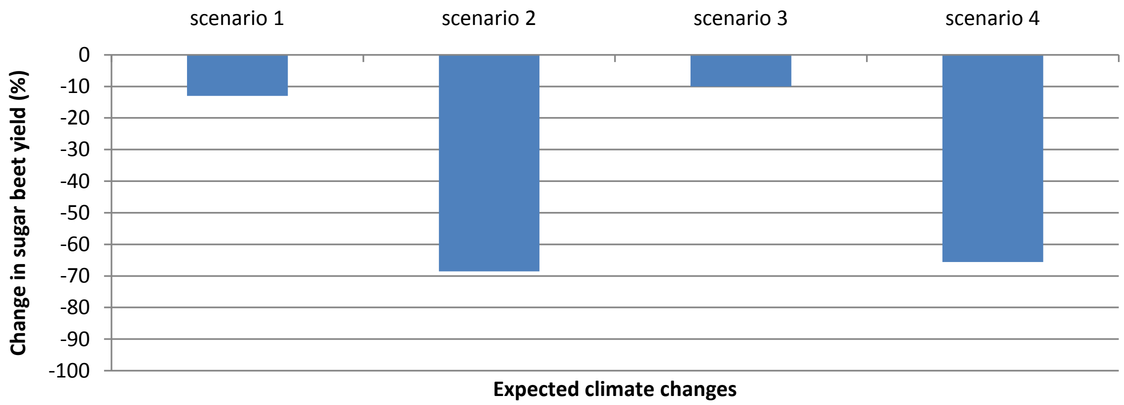


Figure 59: Change in yield (%) for sugar beet regarding to global climate changes.

Figure 60 points out that small increase in temperature (1°C) and precipitation for 20% can have some positive effects on yield for sugarcane. By that it is very important to note that any further increases will reduce the yield. In case of worst case scenario, sugarcane yield will decrease for less that 20%.

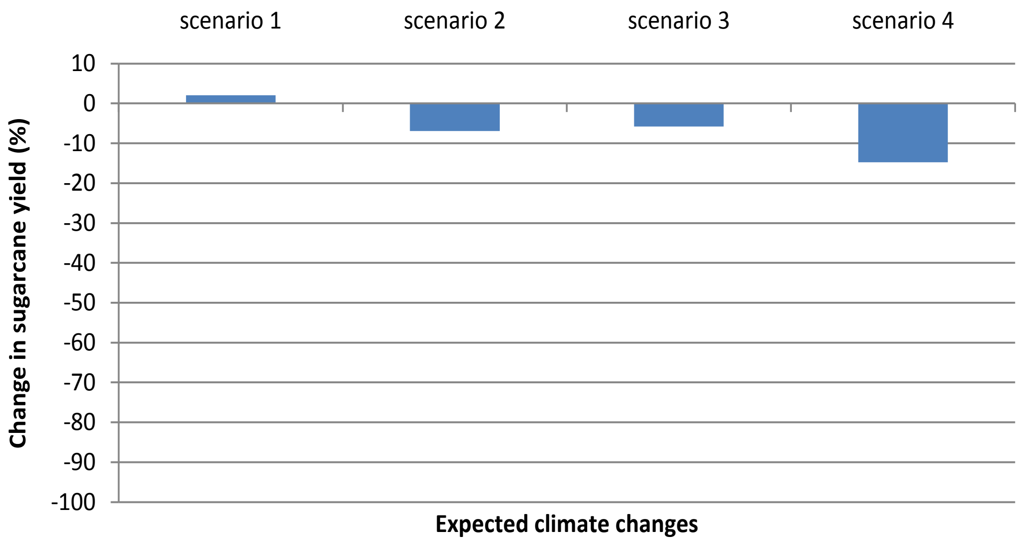


Figure 60: Change in yield (%) for sugarcane regarding to global climate changes.

If the temperature increases for 6.4 the rapeseed yield will decrease for almost 40%. Precipitation increase or decrease will cause minor changes on yield can be seen in Figure 61.

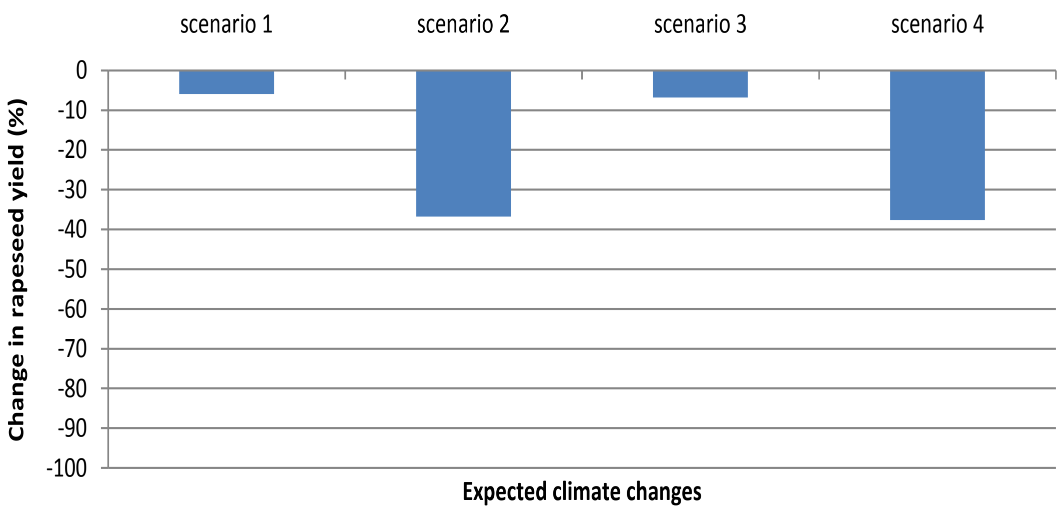


Figure 61: Change in yield (%) for rapeseed regarding to global climate changes.

Among all selected feedstock for production of liquid biofuels, only soybean will be affected positively by climate change (Figure 62). The larger increase in yield can be seen under scenario 2 (temperature increase for 6.4 °C and precipitation for 20%). Meanwhile, in case of drought the yield would be for 10% smaller.

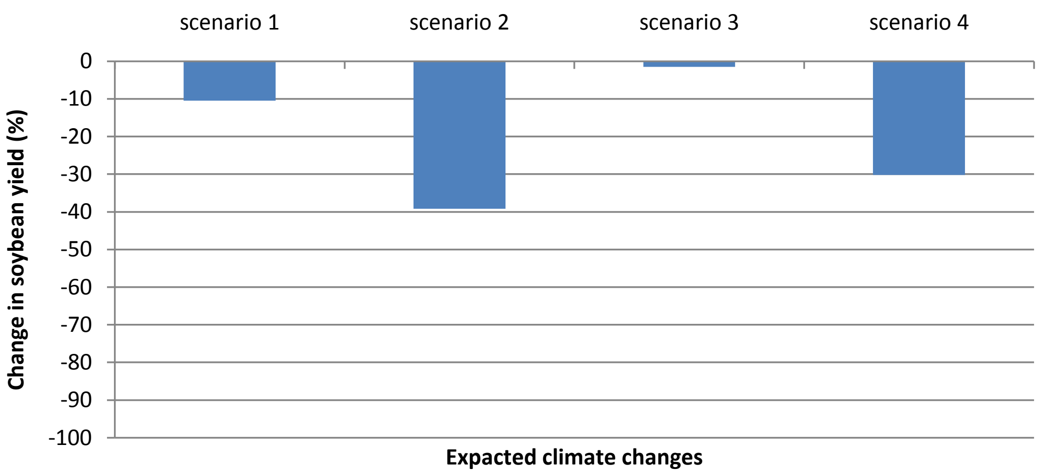


Figure 62: Change in yield (%) for soybean regarding to global climate changes.

Projected global changes show that temperature will increase in average for 1.1 to 6.4 and that precipitation will increase or decrease for 20% relatively to baseline 1980-1999 (Figure 63). Such scenarios will decrease production of biodiesel and bioethanol almost up to 40%, according to average production in baseline period.

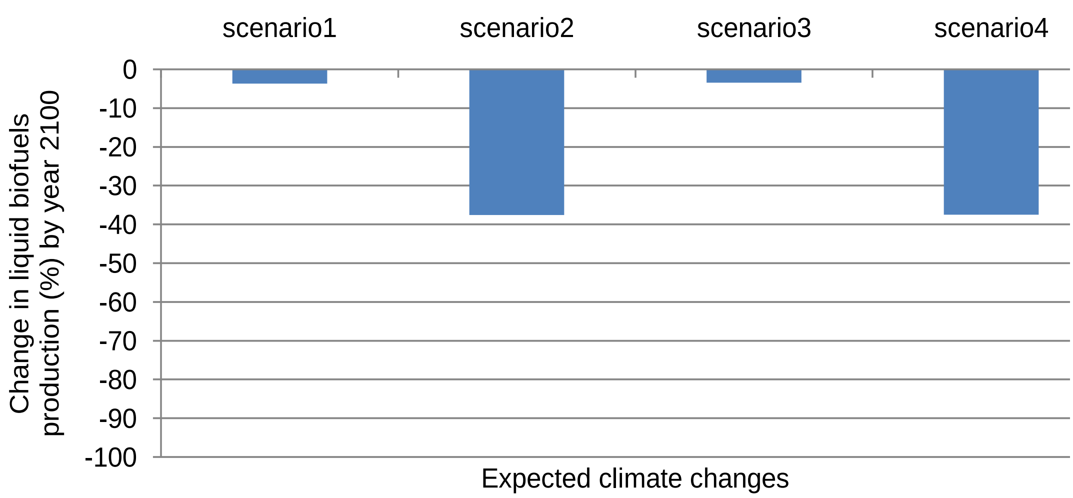


Figure 63: Change in biodiesel and bioethanol production by year 2100.

4.5 POTENTIAL BIOFUELS PRODUCTION IN CASE OF SLOVENIA

For Slovenia expected changes in air temperature and precipitation are predicted for 2060 regard to average in period from 1961-1990. Therefore also changes in yield are presented relatively to the baseline scenario. Results of projected yield regard to the expected climate changes show that scenario 4 where decrease in precipitation for 20% and increase of temperature for 4°C would reduce yield for most of cases (Tables 8,9,10). Potentially if all feedstock in Slovenia would be converted in liquid biofuels, policy plans in context of quantities for 2010 could be achievable (Table 7); by end of 2010 Slovenia should assure 70,000 tonnes of liquid biofuels to meet 5.75 % share.

Table 7: Predicted feedstock yield and biofuel production in baseline scenario (1961-1990)

	Predicted feedstock yield (t ha^{-1})	Predicted biofuels production (t)
Corn	4.369	56,913
Sugar beet	35.750	20,020
Rapeseed	2.035	4,561
Total		81,494

Table 8: Expected yield of corn and bioethanol production in Slovenia, regard to predicted climate changes

	Predicted feedstock yield (t ha-1)	Predicted biofuels production (t)
Scenario 1	4.045	52,688
Scenario 2	3.269	42,586
Scenario 3	4.177	54,402
Scenario 4	3.401	44,299

Table 9: Expected yield of sugar beet and bioethanol production in Slovenia, regard to predicted climate changes

	Predicted feedstock yield (t ha-1)	Predicted biofuels production (t)
Scenario 1	32.976	18,466
Scenario 2	25.762	14,426
Scenario 3	33.715	18,880
Scenario 4	26.501	14,840

Table 10: Expected yield of rapeseed and biodiesel production in Slovenia, regard to projected climate changes

	Predicted feedstock yield (t ha-1)	Predicted biofuels production (t)
Scenario 1	32.976	18,466
Scenario 2	25.762	14,426
Scenario 3	33.715	18,880
Scenario 4	26.501	14,840

Figure 64 shows that the major impact on corn's yield is expected due to temperature increase; meanwhile change in precipitation at same temperature show negligible effects.

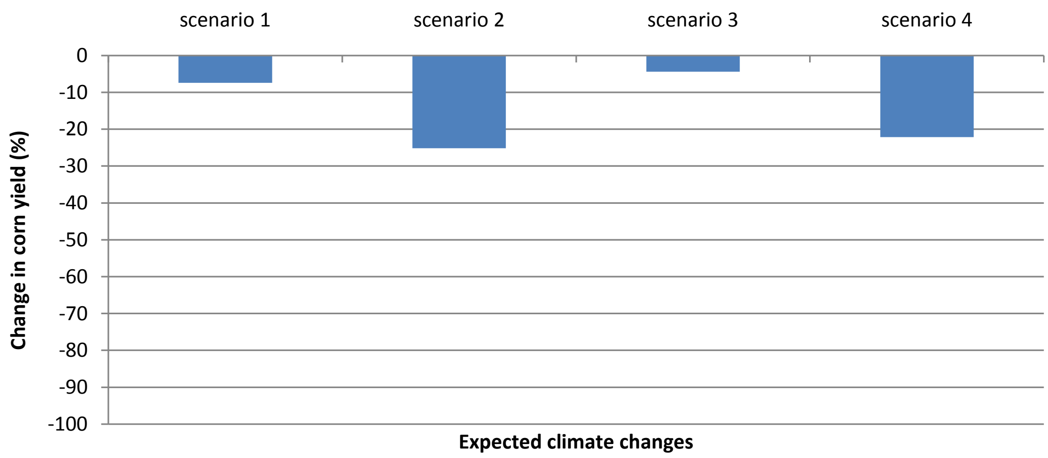


Figure 64: Change in yield (%) for corn regarding to expected climate changes in Slovenia

For sugar beet production increase of temperature would result as more than 20% of yield decrease (Figure 65). Among analysed crops, sugar beet would be the most affected.

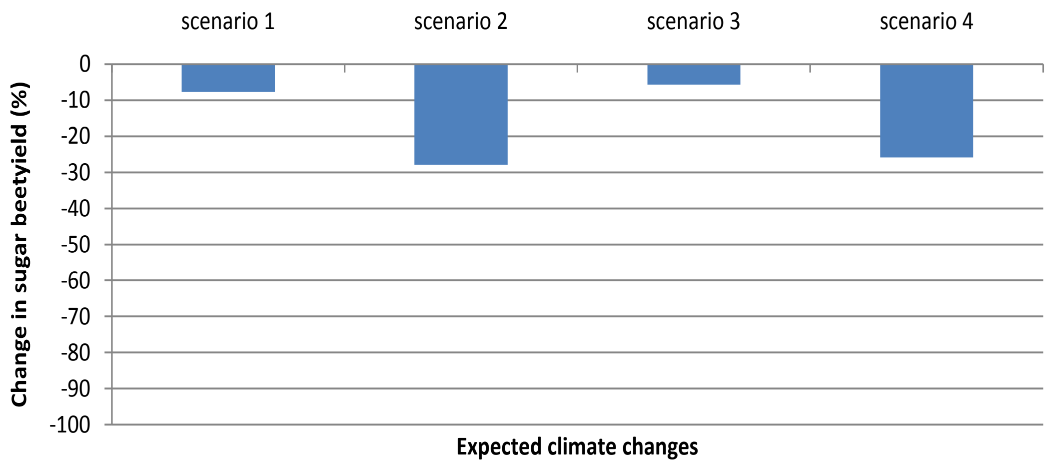


Figure 65: Change in yield (%) for sugar beet regarding to expected climate changes in Slovenia.

Figure 66 shows decrease in yield for rapeseed. The production may become reduced in case of combination of drought and high temperature. The worst case scenario will reduce yield up to 18%.

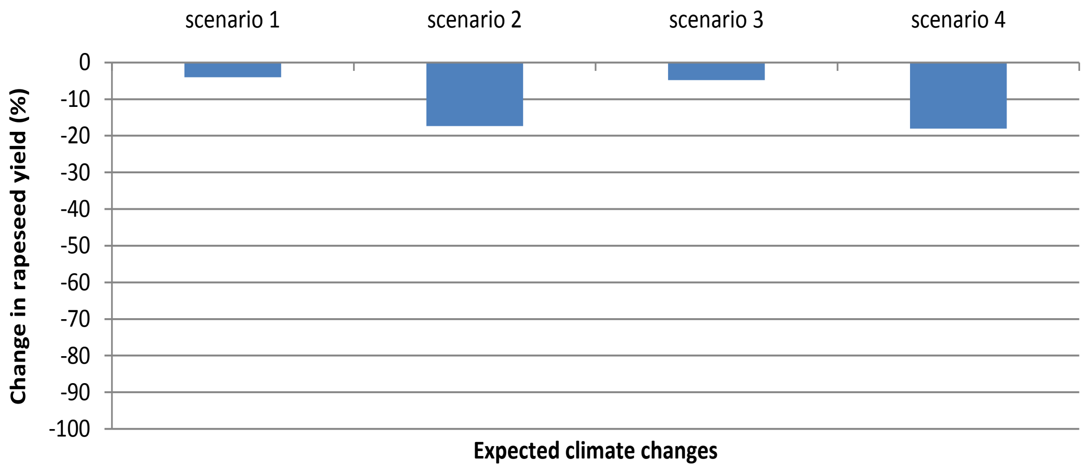


Figure 66: Change in yield (%) for rapeseed regarding to expected climate changes in Slovenia

Data are showing that second scenario will affects production of liquid biofuels, the most. Especially increase in precipitation will decrease the yield (Figure 67).

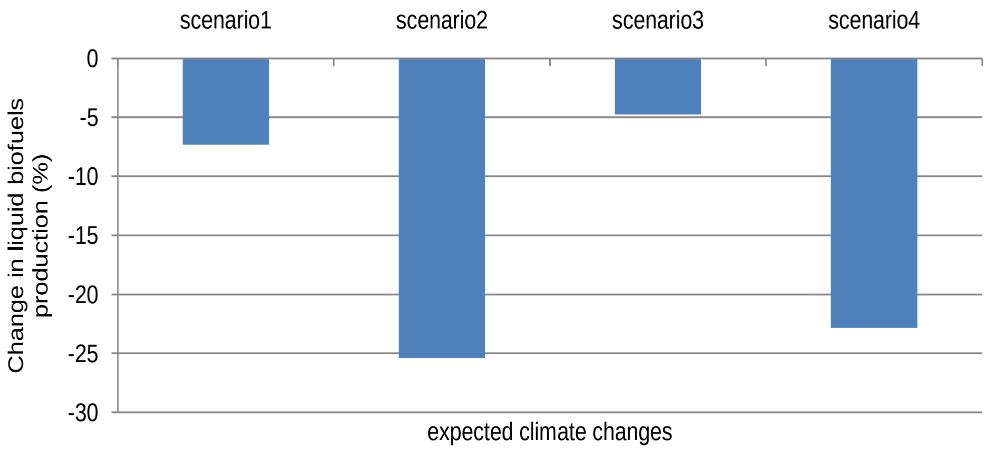


Figure 67: Change in liquid biofuels production regarding to expected climate changes for Slovenia.

4.6 RESULTS OF CORRELATION BETWEEN ENVIRONMENTAL IMPACTS AND SUBSIDIES

Results show that the support rates vary among selected countries (Table 11, 12) also differences between minimum and maximum rates are relatively large. Correlation between environmental impacts and amount of rate is not statistically significant ($p>0.05$).

Table 11: Comparison of subsidies for bioethanol per tonne of CO_2 equivalent avoided to environmental impacts

Country	Support per tonne of CO_2 equivalent avoided (€/t)			Eco points (mPt)
	min	max	average	
USA	0	450	160	180
EU	700	5500	2231	680 [a]
Canada	250	1700	767	400
Australia	250	1900	696	800

[a] average for sugar beet Belgium (730 mPt), France (630 mPt), UK (680 mPt)

Table 12: Comparison of subsidies for biodiesel per tonne of CO_2 equivalent avoided to environmental impacts

Country	Support per tonne of CO_2 equivalent avoided (€/t)			Eco points (mPt)
	min	max	average	
USA	250	600	303	245
EU	260	1000	450	435 [b]
Canada	160	600	250	no data
Australia	250	450	271	no data

[b] average for rapeseed Germany (360 mPt), Sweden (545 mPt), UK (400 mPt)

Figure 68 show that in USA subsidies rate are higher for biodiesel than for bioethanol, meanwhile in case of EU is reverse. Nevertheless both countries are setting higher rates for biofuels with larger environmental impacts. Therefore we can assume that environmental impacts are not criteria for subsidies rates. Figure show average support in EUR per avoided tonne of CO_2 equivalent, but in brackets above columns rage of subsidies is presented.

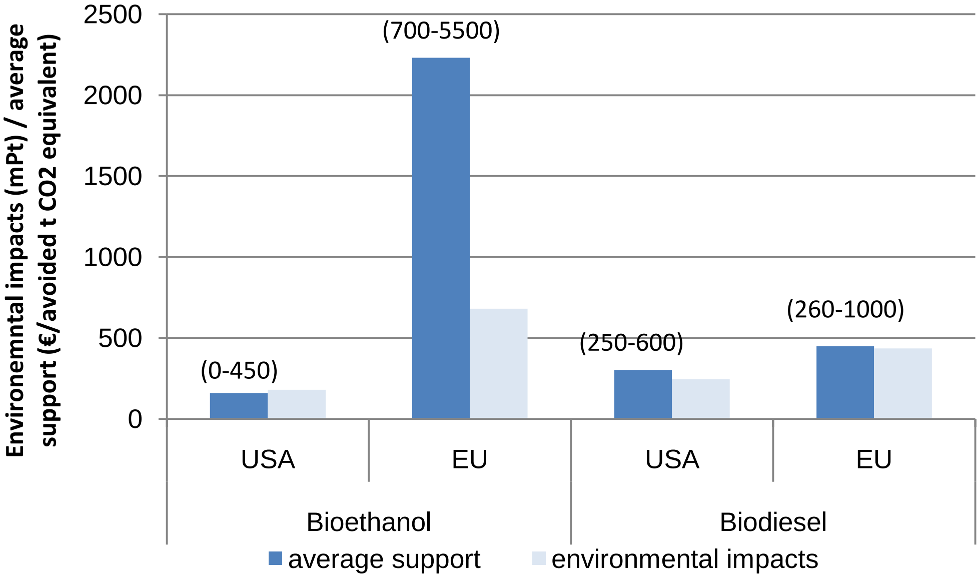


Figure 68: Comparison of USA and EU average support and environmental impacts for bioethanol and biodiesel

5 DISCUSSION

Literal meaning of biomass from which biofuel is obtained is “mass made of life” (gr. *bios*- life; *maza*-mass) and although “life” of combustion engine started by liquid biofuels, their consumption decrease due to the chipper oil. But in recent years consumption of biofuels grows exponentially (Figure 1). This biofuels consumption increase can be assigned on one hand to the concerns about climate changes and on second hand to limited resources of petrol. Therefore liquid biofuels are revived as potential substitution for fossil fuel. Although liquid biofuels are made of renewable energy sources, it is not necessary that do not represent damage to environment.

At the same time two main concerns appeared. One is dealing with ethical issues e.g. combusting the food for power the vehicles, while billions are starving, and the second, which this thesis is based on are consideration on sustainable production; for example environmental impacts of liquid biofuels production and economical value of avoided tonne of CO_2 equivalent. And above all will we be capable to produce enough quantities of biofuels to achieve goals that were set by policy while meeting the projected climate changes.

Weather variables affecting the feedstock production

Since 1906, global air temperature has increased in average for 0.74ºC ± 0.2. For the next two decades it is expected that the air temperature will arise for about 0.2 ºC per decade. According to the recent observed trends (IPCC, 2007) it is expected that the highest temperature arise will occur over the land. The peak of the air temperature arise will occur in the area of northern latitudes. The minor air temperature arise is expected to be in the area of Southern Ocean and northern North Atlantic.

There have been numerous studies caries out to find out the possible impacts of air temperature increase or decrease (Almaraz et al, 2008; De Jong et al, 2001; Jones, 2003; Kenter et al, 1997; Lobel et al, 2007; Save and Kadja, 2009; You et al, 2009). These results pointed out that the most affected sector by climate change and variability will be agriculture. This fact is due to the crop’s production dependence on climate (Salinger, 2005; Motha and Baier, 2005). It is expected that the length of growing season for crops in agriculture will extend (Bootsma et al., 2004). According to the expected changes it is predicted that yields of soybean, winter wheat and potato will increase in a warmer climate with higher humidity, meanwhile corn yield will decrease (Almaraz et al, 2008). Similar results to these showed also our research. All selected feedstock for production of liquid biofuels will decrease if the temperature and precipitation keeps rising, only in case of soybean results are pointed out that global changes will affect yield in a positive way (Figure 10). At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (IPCC, 2007). To achieve the goal to increase the share of biofuels according to action plan and to establish food production system that will assure enough food for all opens some consideration about mitigation plan for global changes.

One of the simplest ways to evaluate how climate change and variability can affect yield is though retrospective analysis of historical records (Almaraz et al., 2008). This research uses a three dimensional figures where the function is calculated as combination of temperature and precipitation not separately for each meteorological factor like most of studies does (Almaraz et al., 2008; Kalra et al., 2008; Lobell and Field, 2008; Lobell at al., 2007; You et al., 2009; Kenter et al., 2006).

Environmental impact assessment of liquid biofuels production

Many countries are struggling to reduce GHGs emissions, using different approaches. EU has created favourable framework on promotion of biofuels. Directive 2003/30 EC sets up promising goal to increase portion of biofuels by end of 2010 to 5.57%. Recent assessments have concluded that the 2010 targets are unlikely to be achieved, and because of that some further efforts are needed (Biofuels in the EU, 2006).

Nevertheless some extensive studies should be done on environmental impact of new fuels that may replace the fossil ones. Therefore before new pollution sources are established, it is important to assess their potential effects on environment. Although most of liquid biofuels studies shows lower emissions in internal combustion engines regarding to fossil diesel or petrol, in assessment of most studies the production process of these fuels are not included.

In recent years so call “from cradle to grave” or LCA assessment was developed, where not only consumption, but also production is included. Several different methods for estimating environmental impacts are available. Method “Eco indicator 99” is one of the objective ones. In this method social values like, damage to historical heritage and such kind values are not included since they are hard to estimate.

Several authors are showing results of one or two biofuels obtained from different feedstock (Halleux et al., 2008; Hill et al., 2006; Pimentel and Patzek, 2005). When compared to others with different method, results are incomparable.

Among other, one of aims of this study was to make extensive research on bioethanol and biodiesel impacts on different parts of environment; comparing its impacts inside the same feedstock group and comparing feedstock between each group. In comparison as reference value fossil diesel and petrol were used, since biofuels should replace them and also electricity from coal, nuclear, hydro power station and photovoltaic as electricity is another source of energy for transportation in future. All fuels were compared per function unit (L per 100 km) since efficiency of internal combustion engine and electric motors are different.

When compared corn bioethanol production, at different location, major influence is being noted on fossil fuels resources, impacts on human health. These differences are mainly due to respiratory inorganic compounds and affect on acidification or eutrophication. In all the cases the most abundant process is cultivation of corn, especially in China (315 kg ha^{-1}), where large amount of fertilizers are being used. Beside corn cultivation, fossil fuels consumption should not be negligible. Fossil fuels are placed on second place, counting 11% of total material and energy needs for China an up to 30% for Canada. In case of China (Figure 20) an important contribution of coal that is used in production phase of ethanol, can be seen. Impact are beside health effects and climate change also ecotoxicity and carcinogens, categories, that are not often represented in other cases. If we closely look all three locations that were included in this study results for China show the largest influence for all categories, followed by Canada and USA (Figure 19).

When comparing total load, on all categories, China is leading (550 mPt), on second place is Canada (400 Pt) and with lowest damage impact is corn ethanol made in USA.

Assessment of sugar beet that is used as feedstock for ethanol production shows important contribution to entire process of bioethanol processing. As figure 24 shows other inventories, like electricity or heat, in processing are negligible. In case of UK and Belgium nitrogen fertilizers also plays an important role and fossil fuels rising from its production. Producing bioethanol made of sugar beet in all three location causes important effects on human health by respiratory inorganic compounds (>300 mPt). Although there are no differences between observed impacts on human life and ecosystem quality among selected location, mayor deviation can be observed in case of resources use. The most influential is production of bioethanol in Belgium (0.15 Pt), followed by UK (0.10 Pt) and least France (0.06 Pt). When all three locations are compared to production of fossil diesel (Figure 31) per FU all locations are leading in most categories, except in case of resources use, when fossil diesel is causing 1 Pt and Belgium 1.15 Pt. France and UK are far below these numbers.

Brazil is second major producers of bioethanol and first from sugarcane, counting more than 35% of world production (24,500 million litters). Impact on different spheres of environment are present, but the larger load can be seen in use of fossil fuels (Figure 33), flowed by health effects and acidification/eutrofication. Meanwhile in Taiwan nitrogen fertilizer seems to be the most influential inventory in whole process. In case of Taiwan the major impact can be seen on human health (400 mPt), resources (450 mPt) and minor on environment (100 Pt). In Australia, like in Taiwan fertilizers and fossil fuels are the most influential in whole process of ethanol producing, (Figure 33) causing high load on fossil fuel category (380 mPt), respiratory inorganic compounds (270 mPt) and acidification/eutrophication (80 mPt). Comparing all three locations, Brazil show the lowest impact (740 mPt), followed by Australia (800 mPt) and Taiwan with the largest impacts (1 Pt). If the production of bioethanol made of sugarcane is compared to environmental impacts of fossil diesel, petrol or electricity, impact on selected categories of the later one show minor impacts (Figure 39).

Biodiesel of first generation is manly made of rapeseed and soybean. These two feed stocks are also abundant in Europe. For rapeseed production in Germany the most significant input materials are nitrogen fertilizer and fossil fuel for agricultural operations (Figure 41). The most affected among selected categories are respiratory inorganic compounds (140 mPt), followed by fossil fuel use (120 mPt) and climate change (55 mPt). Similar consequences on environment can be seen in case of UK, meanwhile in Sweden larger load is expected on resources (220 mPt) use than on health (185 mPt). This is due to fact that Sweden use per kilogram of biodiesel about 0.07 kg fossil diesel, UK 0.04 kg and Germany 0.03 kg. When compared to non renewable resources and electricity smaller per FU impacts of biodiesel can only be seen in case of Germany and UK in category of fossil fuel use (Figure 47). Since soy is leguminosae and is therefore capable to fix nitrogen directly from air, smaller contribution to whole process of biodiesel making is present (Figure 48, 52). Also hierarchy of environmental impacts is changed. In most of previous cases affects on human health because respiratory inorganic compounds are presented. In case of soybean biodiesel from all three locations large impact on climate change can be seen (60 mPt). In USA fertilizer phosphorus is representing major process contributor (50%), meanwhile in Argentina no potassium is used in agricultural process for soy cultivating (Panichelli et al., 2009). But in all selected locations for soybean biodiesel production large amount diesel is consumed. If soybean biodiesel is produced in Taiwan large (220 mPt) impacts are expected on fossil fuel use, climate change and respiratory inorganic compounds. Also when compared to fossil fuels and electricity per FU, much higher load is present in all categories (Figure 55).

Figure 56 show that among all analysed feedstock and locations, USA corn ethanol is the most sustainable (180 mPt) and Taiwan sugarcane ethanol the last (1 Pt). It is interesting, that on second, third and fourth place are all soybean diesel and on last three all sugarcane locations. When compared to fossil diesel, petrol or electricity the implementation of liquid biofuels is questionable. Although ecosystem quality is among all three supra categories the least affected, but human health as second the most threatened should not be overlooked. The most affected category is resource, especially use of fossil fuels. But beside environmental concerns, decreasing oil availability is also one reason implementing biofuels. According to the results of this study long term substituting fossil diesel and petrol with liquid biofuels is not a solution.

Liquid biofuels on itself should not be declared as "environmental sustainable", since the impact on environment is changing due to location of feedstock cultivation. Therefore beside the type of biofuel also the feedstock and location of production should be addressed.

The EU Member States have implemented Directive 2009/28 on the promotion of the use of energy from renewable sources. This directive lays down set of the environmental sustainability criteria for biofuels and other bioliquids. First criteria are that the biofuels only with GHG savings at least 35% regard to fossil fuels can be treated as sustainable. GHG have direct impact on global warming, but our research show that the most abundant impacts resulting from biofuels production are fossil fuel use and impacts on human health. As described in Chapter 1.8.1 sustainable biofuels can be address only if the satisfying environmental, economic and social criteria. Not only that directive is not defining only environmental guidelines, nor is accounting all environmental impacts. Since GHG should not be the only criteria for biofuels sustainability, directive should be revised. Results of biofuels climate change impacts show much larger impacts than fossil fuels, therefore selected liquid biofuels cannot meet criteria set in the directive.

Correlation between environmental impacts and yield of feedstock

Aim of this part of research was to link together yield for selected locations and its environmental impacts; whether the higher production also mean higher environmental load. Figure 57 show correlation between environmental impacts (mPt) and yield for each feedstock. As figure shows there are two groups of feedstock. First group presents sugarcane and sugar beet, where correlation is weak. Second group is presented by corn, rapeseed and soybean, where correlation can be address as linear. Correlation between yields of selected feedstock and environmental impacts are not statistical significant. Detailed analysis show that in first group differences upon energy and material inventories are minor. Therefore it can be predicted that changes in environmental impacts in the first group are result of meteorological conditions, meanwhile in the second group where large differences are being shown in fertilizer and fossil fuel consumption can reasons for changes attributed to the agro-technical procedures. Therefore environmental impacts in biofuels production and yield of feedstock cannot be correlated.

Global biofuels production by end of 2100 while meeting expected climate changes

Results of this part of research show that weather variables, especially temperature have important impact on yield and therefore also indirect impacts on first generation liquid biofuels production. According to results the most affected will be sugar beet, follows corn and rapeseed. The least threatened will be sugarcane and the positively affected will be soybean yield. Especially if climate scenario 2 and 4 would come through there would be devastating impact on selected feedstock (Figures 59-61). Therefore, it can be assumed that for the same shares that yield will be reduced harvest areas will have to be increased to sustain the same quantity of biofuels. Expected climate changes will have, according to models in this research, large impact on biofuels production. In the worst case scenario, production can be reduced up to 40% (Figure 63). According to these results a question in itself appears: Will the global production meet the biofuels consumption needs? Even in amounts projected in recent political documents.

Potential biofuels production in case of Slovenia

According to the Directive 2003/30 every Member States should ensure a minimum proportion of biofuels and other renewable fuels on their markets and, to that effect, shall set national indicative targets. A reference value for these targets shall be 2 %, calculated on the basis of energy content, of all petrol and diesel for transport purposes placed on their markets by end of 2005 and 5.75% by end of 2010.

National rule on biofuels content in fuels for motor vehicles Gazette No. 108/2005 and 103/2007 set down a plan for reaching the directive’s goals. According to the policy, Slovenia shall assure up to year 2011 about 70,000 tonnes of liquid biofuels for transport sector (Petrol, 2003).

In Slovenia corn, sugar beet and rapeseed are the most often cultivated crops among selected in this research. Others crops, like soybean and sugarcane, are negligible or even are not being cultivated yet. Nevertheless, if all produced feedstock of selected crops would be used for biofuels production, these would make more than 81,000 tonnes. These quantities would assure expected goals of biofuels. But, crop production that would be used as feedstock for biofuel production cannot be produced in these amounts in Slovenia, because of lack of farmland. In Slovenia is only 8% of its total land meant for agriculture; meanwhile in EU is 26%. Just to grow enough crops for food production, in

Slovenia, we would need to increase farmland from 880 m^2 per capita to 2,000 m^2 (Fink and Jevšnik, 2009). By that there were not taken into account projections for biofuels consumption.
At this point of view some ethical concerns appear when trying to realize next phrase: "filling the tank without emptying the stomach". The question of concern is: "How to achieve goals of biofuels implementation that production and use of biofuels could contribute to a reduction in energy import dependency. Young et al (2009) made similar conclusion for China.
In 2003, ARSO carried out a study about global changes and its impacts on agriculture. In the report are presented expected changes of air temperature and precipitation due to the baseline time period from 1961 until 1990. According to this paper the air temperature may increase between 1 and 4°C, meanwhile the average precipitation may increase or decrees for 20% (ARSO, 2003).

Results show that corn would be affected by yield decrease if the temperature will increase for 1 or 4 ºC. Especially devastating will be the combination of temperature and precipitation decrease (Figure 64). Although temperature change for sugar beet also means decrease in yield, it seems that at the same temperature, increase of precipitation, will decrease yield. Among all analysed potential crops for liquid biofuels, sugar beet yield would be the most affected in combination of temperature increase for 4 ºC and precipitation for 20%. In case of rapeseed similar effects of climate change on yield can be projected; in worst case scenario (Figure 66) yield would decrease for more than 15%. If all potential crops would be converted to biofuels production due to climate changes will be decreased for 22,338 t (scenario 4), followed by 20,576 t (scenario 2), 6,027 (scenario 3) and 4,218 (scenario 1). But the major problem of Slovenia lies in farmland for biofuels production according to fact that there is lack of harvesting area for food production. Regard to all these results, Slovenia's only option is to import enough quantities of biofuels to meet policy goals.

Correlation between environmental impacts and subsidies

Biofuels benefit from a broad range of public support measures as well as in the EU as in Member States. Excise tax exemptions account for the largest share of support and amounted to almost 3 billion EUR in 2006. Because this type of subsidy is directly linked to production or consumption, the cost of this measure is expected to rise significantly in the coming years as biofuels production is boosted to reach the Commission's targets (Kutas et al., 2007).
If we have a quick look at the table 11 and 12 reveals it can be seen that the countries are promoting biofuels from obtained from feedstock that has larger impact on environment, but correlation is not statistically significant ($p > 0.05$). Findings become more obvious when comparing environmental damage and amount of support in the same country (Figure 68). EU is giving in average 2231 EURs per tonne of avoided CO_2 equivalent from bioethanol and 450 EURs per tonne of avoided CO_2 equivalent from biodiesel, although bioethanol is affecting environment in average by 680 mPt (Table 11) and biodiesel in average 435 (Table 12). Similar results can be seen in USA, where every tone of avoided CO_2 equivalent from bioethanol is promoted by 160 EURs and causing 180 mPt, meanwhile

biodiesel affecting the environment by 245 mPt and promoted in average by 303 EUR per tonne of avoided CO_2 equivalent.

Directive 2009/28 on the promotion of the use of energy from renewable sources set environmental sustainability mention above. The same directive in its annex 7 also list bioethanol and biodiesel from various feed stocks that are meeting the criteria. Typical GHGs savings are in average for bioethanol 57.6 ±11.5% (from 48% to 74%; N=6) and for biodiesel 57.1 ±13.1% (from 38% to 83%; N=9). Since there is no difference is it unknown according to what mechanism EU is setting the amount of support.

And despite all, price for offset 1 tonne of CO_2 equivalent are ranging on Carbon Exchange Market from 3.5 to 18 EUR (Eco business link, 2009). There are several carbon offsetting services profit and non profit selling the coupons for emitting the CO_2. One of the most known are Chicago Climate Exchange and Europe Climate Exchange.

Therefore country is paying more for subsidizing the biofuels that would pay for emitting the CO_2 from transport sector into the environment. Since purpose of supports is promoting better choice, this aim did not meet the goal from environmental point of view, but also fail from economical issue. And these results also put some questions of efficiency of Carbon trading scheme that should reduce carbon burden by trading CO_2 coupons and since paying for polluting is cheaper that supporting the sustainable development some doubts appeared.

This study combined on one hand environmental impacts of liquid biofuels production, and on other economical impacts, in general issue that do not fit together. And show that collaboration between environmental and economy sector should go more hand by hand to the common goals.

Results of this thesis show that each country shall make own individual decision plan (Figure 69) if potential biofuel is sustainable or not since environmental impacts vary from country to country. Flowchart shows process of decision making for sustainability assessment for liquid biofuels. First potential feedstock has to be selected, followed by environmental assessment impacts. If biofuels are acceptable from environmental point of view, comparison of environmental impacts to other sources of energy has to be made. Comparison can be made to existed fuels like diesel or petrol is or can be done to other potential sources like electricity. In next step projection has to be done how vulnerable is feedstock for biofuels production at projected climate changes. Since from different feedstock different amount of biofuels can be produced, and some plants consist more sugar of fats than other, some have very small yield, some large. Therefore agricultural and processing steps should be taken in to the account. Since amount of saved GHG emission is important indicator of sustainability also value of saved tonne of CO_2 equivalent should take in to account. New technology also means new jobs therefore have to assess how many new jobs are created. If during the assessment single answer is negative; assessment should start with new potential feedstock. Such flowcharts can serve for policy makers as base for decision making whether biofuel is sustainable or not.

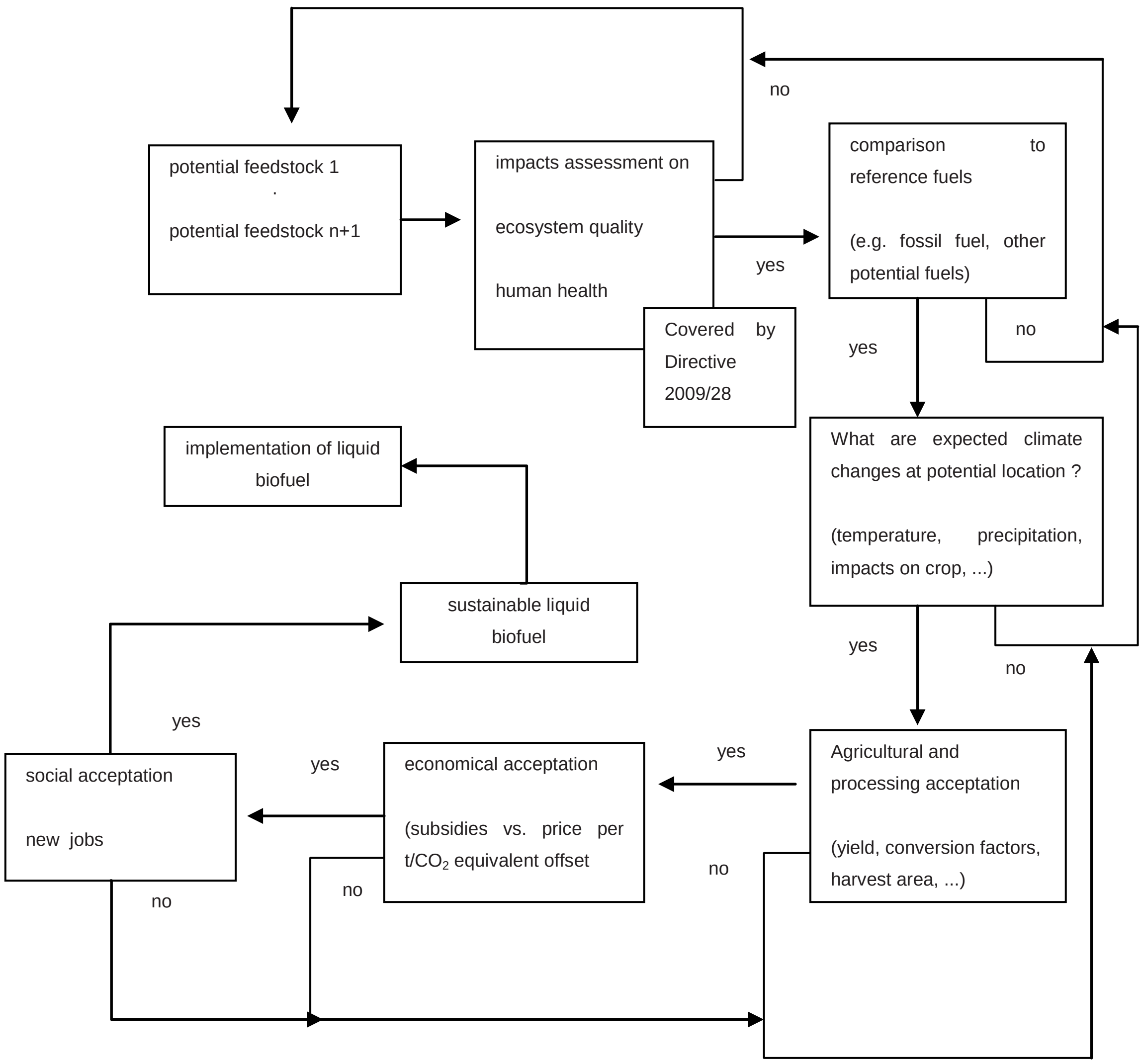


Figure 69: Flowchart of decision acceptance of biofuel sustainability

Limitation of research

Weather variables affecting the feedstock production for biofuels

Climate change is a concern today, and science is engaged in understanding its impact on growth and yield of crops, and also identifying suitable management options to sustain the crops' productivity under the climate change scenarios (Kalra et al., 2008). Therefore predictions of yields for future climate scenarios always have some degree of uncertainty since study is based on average meteorological data. Data on yield for specific feedstock were gained form Faostat database that provides data at national level, considering both irrigated and rain feed crops. Moreover precipitation (mm) can vary from countries' one area to another and have major impacts on crop yield. Consequently results have to interpret with some level of uncertainties.

Although Lobell and Field (2007) used firstly average yield, temperature and rainfall and secondly maximum and minimum temperature. Howsoever authors report minor differences in models. Also You et al. (2009) used similar method. Factors like extreme weather events e.g. drought, floods and hails also decrease yield production of feedstock and should be taken into the account.

Since plants are complex systems it is challenge is to separate the climate change effect from the non-climate effect on crop yields like impacts of irrigation, fertilizers, pesticides, agricultural practices ects.

While these numerical models do not attempt to capture details of plant physiology or crop management, vapour pressure deficit, combined effects of temperature and elevated CO_2 concentration on photosynthesis, transpiration and water use efficiency they do capture the net effect of the entire range of processes by which climate affects yields, including the effects of poorly modelled processes are present.

But on other hand projected climate change scenarios by IPCC and ARSO are expressed in change of average temperature and average precipitation due to baseline scenario. IPCC estimates that average global temperature by 2100 will change 1.1-6.4 relatively to baseline average in period 1980-1999. Therefore use of different weather variables as scenarios are based on will only increase uncertainty of biofuels feedstock prediction.

Several simplifying assumptions were made with respect to parameters used in the analysis, which may also contribute to uncertainty in the results of this study. However, it is quite possible that the uncertainties in the assumptions made relative to the parameters are less than the uncertainties associated with the future climate predictions.

Environmental assessment of liquid biofuels production

In analyse of environmental impacts of liquid biofuels production 5 most common feed stocks on three different locations were included. There is a possibility that environmental impacts can be different in other locations and with other feedstock.

The LCA approach is an effective method to select the environmentally optimum. There is a large variety of available relevant software tools beside Sima Pro (EMIS, GaBi, Regis, Umberto, etc), that not only focus on the assessment of the product production process, but also on its waste management.

Damage category for human health is not completed. For instance, damage from emissions of cadmium, lead, endocrine disrupters, etc. cannot be modelled. Furthermore health damages from allergic reactions, nose and odour cannot yet be modelled.

Eco indicator 99 allow to assess the contribution of a product LCA to the greenhouse effect, acidification and other environmental problems, while the total environmental impact remains unknown. The reason is lack of mutual weighting of the environmental effects (Goedkoop and Spriensma, 2001).

6 CONCLUSION

Alarming global climate changes and limited reserves of fossil fuels expanded the market with biofuels. Despite the rapid marked expand there are still some questions to be answered before fully substituting the fossil fuels with liquid biofuels. One of these questions is environmental sustainability of biofuels.

- the results of this research show that feedstock yield for biofuels production are strongly influenced by local meteorological conditions like temperature and precipitation;
- environmental impacts are distinguished, due to type of liquid biofuel and technology, but not by local meteorological conditions. Therefore this hypothesis can be partly confirmed;
- since the environmental impacts are related to yield of feed stocks, it is questionable whether the countries would assure enough quantities of biofuels to meet the policy goals. Small countries like Slovenia with few farmlands will have to rely on import. The challenge is being addressed also to reach increasing demand to biofuels and at the same time decrease environmental impacts;
- comparing production of selected liquid biofuels to production of fossil diesel, petrol and electricity from various sources show significant larger impacts of biofuels to environment per functional unit;
- results of this research show that expected climate changes will decrease yield and therefore also biofuels production;
- corrections of integral indicators taking into account local meteorological conditions allow sustainability assessment also on limited geographical areas. Therefore this hypothesis can be confirmed;
- nevertheless, current tax policy and carbon trading scheme promoting emission more than its reduction, since tone of offset CO_2 equivalent is much cheaper than avoided by biofuels production. Although correlation between subsidies and environmental impacts is not statistically significant data are pointing that environmental load is a not criterion for rates of financial support. And therefore third hypothesis can be partly confirmed;
- to sum up the results, it can be concluded that the first generation of liquid biofules should not become a long term solution for energetic crises that the mankind is being faceted with.

7 SUMMARY

Modern society is confronted with the consequences of an energy paradigm that both causes problems of limited oil reserves and global climate change due to the intense use of fossil fuels. Liquid biofuels as renewable energy sources are expected to replace fossil fuels in the future. However, there are some doubts regarding the suitability of liquid biofuel production. One concern is their sustainable production, particularly under emerging global climate change. Since 1906, the average global air temperature has increased by 0.74ºC and it is expected that will increase in future. Air temperature increase is expected to be greatest over land and at most high northern latitudes, and least over the Atlantic. One of the sectors more affected by climate change and its variability will be agriculture, since crop production depends directly on climate. Therefore, the aim of thesis is to analyse the impact of local conditions on the sustainable production of liquid biofuels.

The study focused on the five most common feed stocks (sugar beet, sugar cane, corn, soybeans and rapeseed) for the production of first-generation liquid biofuels. Data about average feedstock yields for biofuels production were obtained from the Faostat database (Food and Agriculture Organization of United Nations); average annual air temperature (°C) and precipitation (mm) were obtained from the Climate Research Unit, United Kingdom. The Wolfram Mathematica 7.0 software was used to assess the correlation between yield and meteorological parameters such as precipitation and temperature. The level of statistical significance was defined as $p<0.05$.

Based on the correlation, climate yield prediction models were created and verified. Expected global climate changes were defined as four scenarios according to the projections of the Intergovernmental Panel on Climate Change and the Environmental Agency of the Republic of Slovenia. For the impact assessment of liquid biofuel production on the environment, Sima Pro 7.1 software and the Eco indicator 99 method was used. Impacts on environment are defined as eco-indicator points. The value of one eco-indicator point is representative for one thousandth of the yearly environmental load of one average European inhabitant. The results of the environmental impacts of biofuels were analyzed according to location and feedstock, and compared with fossil fuel impacts on the environment. Following that, the research results of environmental impacts were compared to the amount of subsidies for biofuel production given in each country. The aim of this comparison was to analyse whether countries are promoting biofuels production made of feedstock with smallest environmental load.

The results of the thesis shows that weather variables, especially temperature ($p<0.05$), have significant impact on yield and therefore direct impact on first-generation liquid biofuel production. More specifically, the expected climate changes will, according to models in this research, have a major impact on biofuel production. The worst-case scenario (an increase temperature by 6°C) could reduce the production of biofuel feedstock by up to 40%.

One of the aims of this study is to extensively research biofuel impacts on the environment, i.e., to compare impacts with regard to feedstock type and production location. In the comparison of environmental impacts fossil diesel and petrol were also included, since biofuels should replace them. Electricity from various sources, including coal, nuclear, hydro power and photovoltaics were also

included in assessment as a potential source of energy for cars in future. All fuels were compared per functional unit, which means consumption of fuel per one hundred kilometres, since the efficiency of internal combustion engine and electric motors are different. The results show that biofuel production has a much larger environmental impact than fossil fuels or electricity energy derived from various sources. For first-generation liquid biofuel production, large amounts of fertilizers, pesticides and non-renewable sources of energy are consumed. Bioethanol obtained from corn in the United States of America shows the greatest potential, while sugarcane bioethanol made in Taiwan has the largest impacts according to this research. This is because Taiwan uses larger quantities of non-renewable energy sources than United States of America in process of bioethanol production.

At present, the greatest challenge is to increase the production of biofuels while simultaneously reducing environmental impact. The result of subsidies and environmental impact comparison indicates that those countries are not promoting biofuels from feedstock with the smallest impacts on environment. The European Union is giving an average of 2,231 euros per tonne of avoided carbon dioxide equivalent that is saved from bioethanol production and 450 euros per tonne of avoided carbon dioxide equivalent from biodiesel, although bioethanol is affecting the environment on average by 680 milli-eco-indicator points and biodiesel on by average 435 milli-eco-indicator points. From that, it follows that environmental impacts were not the main criteria for the subsidies' rates. Despite all of the afore-mentioned, the prices for offsetting 1 tonne of carbon dioxide equivalent range from 3.50 to 18.00 euros on Carbon Exchange Market. That means that countries are paying more for subsidizing the biofuels than they pay for emitting the carbon dioxide into the environment. The purpose of financial support is promoting better choices; this aim did not meet the goal from the environmental point of view, but also failed from the economical point of view. Therefore, it can be concluded that first-generation liquid biofuels cannot represent a long-term solution, neither by ensuring enough quantities at projected global changes, or from an environmental point of view.

8 POVZETEK

Sodobna družba se vse pogosteje sooča s posledicami energetske paradigme, ki na eni strani prinaša probleme omejenih zalog fosilnih goriv, po drugi strani pa globalne spremembe, ki so posledica njihove intenzivne uporabe. Tekoča biogoriva, kot obnovljivi viri energije naj bi v bližnji prihodnosti nadomestila fosilna goriva. Vendar pa se pojavlja kaj nekaj dvomov v primernost uporabe tekočih biogoriv. Ena od skrbi je njihova sonaravna proizvodnja, še posebej ob pričakovanih globalnih spremembah. Saj se je od leta 1906 povprečna temperatura zraka na svetu povečala za 0,74 °C in se bo v prihodnosti še povečevala. Pričakovati je, da bo globalno segrevanje najbolj izrazito nad kopnim in nad severnimi geografskimi širinami, manj pa nad Atlantskim oceanom. To pomeni, da bo kmetijstvo eden od sektorjev, ki ga bodo globalne spremembe še posebej prizadele, saj je produkcija rastlin neposredno povezana s podnebnimi pogoji. Zato je namen magistrske naloge raziskati vpliv lokalih pogojev na sonaravno proizvodnjo tekočih biogoriv.

Raziskava je osredotočena na pet najpogostejših surovin (sladkorna pesa, sladkorni trs, koruza, soja in oljna repica) za proizvodnjo tekočih biogoriv prve generacije. To so biogoriva, ki so proizvedena iz sladkorja, oziroma škroba kmetijskih rastlin. V raziskavi so bili podatki o povprečni produkciji izbranih rastlin za proizvodnjo biogoriv pridobljeni v bazi podatkov Faostat Organizacije Združenih Narodov za Prehrano in Kmetijstvo, medtem ko so podatki o povprečni temperaturi zraka (°C) in povprečnih padavinah (mm) bili pridobljeni v bazi podatkov Climate Research Unit. Podatki so bili vneseni v matematično orodje Wolfram Mathematica 7.0, kjer je bila uporabljena funkcija FindFit za ugotavljanje povezave med produkcijo, temperaturo in padavinami. Meja statistične značilnosti je bila določena kot $p<0,05$. Tako so bili izdelani in verificirani modeli za oceno vplivov klimatskih pogojev na produkcijo surovin za biogoriva. Pričakovane globalne spremembe so bile definirane kot štirje scenariji, ki jih na globalni ravni opredeljuje Intergovernmental Panel on Climate Change in na območju Slovenije Agencija Republike Slovenije za okolje. Scenariji so bili vneseni v omenjene modele in izračunan je bil delež spremembe produkcije surovin za proizvodnjo biogoriv. Za oceno vplivov proizvodnje biogoriv na okolje je bilo uporabljeno programsko orodje Sima Pro 7.1 in metoda Eco indicator 99. Vplivi na okolje so definirani kot ekološke točke, kar pomeni, da ena točka predstavlja tisočletni vpliv povprečnega evropskega prebivalca na okolje.

Rezultati vplivov biogoriv na okolje so bili analizirani glede na lokacijo in surovino, ter primerjani z vplivi fosilnih goriv na okolje. V nadaljevanju raziskave so bili rezultati vplivov na okolje primerjani z obsegom subvencij, ki jih države proizvajalke namenjajo za proizvodnjo tekočih biogoriv, z namenom ugotoviti ali države spodbujajo proizvodnjo biogoriv iz tistih surovin, ki povzročajo najmanjše vplive na okolje. Rezultati raziskave kažejo, da imajo klimatski pogoji kot so temperatura in padavine močan vpliv na proizvodnjo surovin za tekoča biogoriva. Predvsem temperatura je tista, ki ima značilen vpliv ($p<0,05$), saj bi se proizvodnja biogoriv do leta 2100 lahko zmanjšala tudi za 40%, če bi se globalna temperatura v najslabšem scenariju povišala za pričakovanih 6 °C. Eden od namenov magistrskega dela je poglobljena analiza vplivov tekočih biogoriv na okolje in primerjava vplivov na okolje med različnimi surovinami in lokacijami proizvodnje. V primerjavo so bili vključeni tudi vplivi na okolje pri proizvodnji fosilnega dizla, bencina in elektrike iz različnih virov energije, saj se električna vozila

pojavljajo kot alternativa motorjem z notranjim izgorevanjem. Goriva so bila med seboj primerjana na funkcionalno enoto, kar pomeni porabo goriva na 100 km, ker so izkoristki motorja z notranjim izgorevanjem drugačni kot elektro motorja. Rezultati kažejo, da imata biodiesel in bioetanol iz različnih surovin veliko večje vplive na okolje kot fosilna goriva. Vzrok je v dejstvu, da gojenje surovin za biogoriva zahteva velike količine gnojil in fosilnih goriv tako v kmetijskih opravilih kakor tudi v procesih predelave. Bioetanol iz koruze narejen v Združenih državah Amerike kaže največji potencial, saj so vplivi na okolje med izbranimi biogorivi najmanjši, medtem ko bioetanol narejen iz sladkornega trsa povzroča največje vplive na okolje. Največji izziv na področju prve generacije tekočih biogoriv je, zagotoviti zadostne količine biogoriv ob pričakovanih globalnih spremembah in hkrati zmanjšati vplive na okolje. Rezultati primerjave med vplivi na okolje in višino subvencij kažejo, da države proizvajalke ne spodbujajo proizvodnje tekočih biogoriv iz surovin, ki imajo najmanjše vplive na okolje. Evropska unija v povprečju prispeva s subvencijami 2.231 evrov na tono ekvivalenta zmanjšanih emisij ogljikovega dioksida na račun proizvodnje bioetanola, medtem ko za biodiesel le 450 evrov, čeprav bioethanol obremenjuje okolje s 680 mili eko točkami, biodiesel pa s 435 mili eko točkami.
Zato lahko zaključimo, da okoljski kazalniki niso kriteriji za odmerjanje subvencij pri proizvodnji tekočih biogoriv. Cena za emitiranje 1 tone ekvivalenta ogljikovega dioksida se giblje na trgu med 3,5 do 18 evri, kar pomeni, da države plačujejo več za subvencioniranje proizvodnje biogoriv, kot pa bi plačevale za onesnaževanje. Ker je namen subvencioniranja spodbujati naprednejše in boljše tehnologije, namen ni bi dosežen tako iz ekološkega, kot tudi ekonomskega vidika. Zaključimo lahko, da prva generacija tekočih biogoriv ne more prestavljati dolgoročne rešiteve zagotavljanja zadostnih količin biogoriv zaradi pričakovanih sprememb, kakor tudi ne iz ekološkega in ekonomskega vidika.

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ANNEXES

Annex 1: Data on temperature, precipitation and yield with standard deviation for corn, rapeseed, soybean, sugar beet and sugarcane

Corn

Yield (t/ha)	Standard deviation	Temperature (ºC)	Standard deviation	Precipitation (mm)	Standard deviation
1.63	± 0.12	12.97	± 0.42	325.98	± 63.00
1.55	± 0.75	22.88	± 0.38	87.44	± 13.73
0.44	± 0.15	21.87	± 0.24	977.39	± 101.07
3.97	± 0.91	14.92	± 0.30	611.90	± 61.52
8.23	± 0.97	6.76	± 0.73	1107.15	± 85.30
0.97	± 0.28	25.09	± 0.35	2690.66	± 288.67
1.64	± 0.20	21.43	± 0.31	1176.67	± 127.29
0.31	± 0.20	21.95	± 0.40	369.98	± 91.08
2.16	± 0.41	25.16	± 0.25	1640.70	± 499.37
3.65	± 1.14	10.63	± 0.57	582.54	± 89.82
7.25	± 1.99	8.60	± 0.21	693.22	± 72.31
4.22	± 0.68	7.29	± 0.41	628.61	± 27.65
0.77	± 0.10	24.60	± 0.19	1628.16	± 115.10
1.20	± 0.34	25.30	± 0.32	1291.10	± 299.65
1.15	± 0.18	22.05	± 0.41	2066.82	± 485.29
7.26	± 1.15	11.11	± 0.61	876.33	± 88.35
7.18	± 1.03	8.88	± 0.84	707.01	± 77.13
9.39	± 0.70	15.36	± 0.49	610.92	± 94.14
5.50	± 1.07	10.07	± 0.71	578.15	± 74.85
4.16	± 1.74	17.57	± 0.64	226.71	± 35.57
1.97	± 0.39	21.74	± 0.62	208.06	± 42.03
11.99	± 4.12	19.35	± 0.53	422.25	± 111.55
8.04	± 1.05	13.78	± 0.45	811.46	± 78.27
2.33	± 0.29	11.41	± 0.59	1661.70	± 194.84
1.69	± 0.23	24.93	± 0.24	642.30	± 105.55
2.05	± 0.29	21.32	± 0.31	745.57	± 61.45
0.67	± 0.28	17.47	± 0.40	307.95	± 79.27
1.43	± 0.17	20.32	± 0.42	306.06	± 52.86
1.91	± 0.36	23.39	± 0.40	1189.59	± 147.20
4.73	± 0.73	8.25	± 0.90	592.94	± 60.78
3.34	± 1.47	15.55	± 0.40	816.10	± 137.33
3.09	± 0.66	8.90	± 0.70	618.83	± 100.38
6.91	± 1.44	13.83	± 0.46	595.42	± 71.46
3.64	± 0.77	11.08	± 0.58	794.90	± 967.58
1.76	± 0.81	17.60	± 0.31	1294.39	± 176.03
2.28	± 0.60	25.43	± 0.27	1914.29	± 154.96
1.73	± 0.42	21.79	± 0.37	901.30	± 205.83
1.38	± 0.49	21.32	± 0.47	643.29	± 148.01

Rapeseed

Yield (t/ha)	Standard deviation	Temperature (ºC)	Standard deviation	Precipitation (mm)	Standard deviation
1.99	±0.08	22.88	±0.38	87.44	±13.73
1.15	±0.26	14.92	±0.30	611.90	±61.52
2.51	±0.30	6.76	±0.73	1107.15	±85.30
1.00	±0.27	25.16	±0.25	1640.70	±499.37
1.89	±0.51	8.60	±0.21	693.22	±72.31
1.26	±0.16	7.29	±0.41	628.61	±27.65
2.48	±0.34	7.83	±0.90	727.44	±83.11
2.93	±0.40	11.11	±0.61	876.33	±88.35
2.90	±0.36	8.88	±0.84	707.01	±77.13
1.67	±0.29	10.07	±0.71	578.15	±74.85
0.77	±0.16	23.81	±0.23	1059.54	±87.56
2.81	±0.69	9.57	±0.45	1210.24	±72.68
1.96	±0.55	13.78	±0.45	811.46	±78.27
1.75	±0.18	11.41	±0.59	1661.70	±194.84
1.14	±0.46	21.32	±0.31	745.57	±61.45
2.03	±0.25	10.60	±0.41	1722.16	±78.48
0.76	±0.12	20.32	±0.42	306.06	±52.86
2.14	±0.33	8.25	±0.90	592.94	±60.78
1.00	±0.25	8.90	±0.70	618.83	±100.38
1.20	±0.40	13.83	±0.46	595.42	±71.46
1.64	±0.63	11.08	±0.58	794.90	±967.58
3.02	±0.30	8.72	±0.49	1294.42	±99.99

Soybean

Yield (t/ha)	Standard deviation	Temperature (ºC)	Standard deviation	Precipitation (mm)	Standard deviation
1.16	±0.36	11.63	±0.53	944.13	±135.87
2.10	±0.26	14.92	±0.30	611.90	±61.52
1.74	±0.26	21.43	±0.31	1176.67	±127.29
1.83	±0.28	25.16	±0.25	1640.70	±519.75
1.94	±0.30	10.63	±0.57	582.54	±89.82
0.96	±0.34	7.29	±0.41	628.61	±27.65
2.01	±0.09	24.57	±0.28	2563.42	±259.78
2.34	±0.28	11.11	±0.61	876.33	±88.35
1.89	±0.32	10.07	±0.71	578.15	±74.85
0.86	±0.17	23.81	±0.23	1059.54	±87.56
1.06	±0.13	26.10	±0.18	2704.57	±235.50
1.43	±0.26	21.74	±0.62	208.06	±42.03
3.29	±0.35	13.78	±0.45	811.46	±78.27
1.62	±0.20	11.41	±0.59	1661.70	±194.84
1.77	±0.25	21.32	±0.31	745.57	±61.45
0.60	±0.10	8.26	±0.47	1296.75	±180.98
0.41	±0.20	26.93	±0.27	1130.43	±106.13
0.72	±0.37	20.32	±0.42	306.06	±52.86
2.16	±0.57	23.39	±0.40	1189.59	±147.20
1.71	±0.44	19.74	±0.41	1469.90	±193.79
1.17	±0.39	8.90	±0.70	618.83	±100.38
2.07	±0.31	13.83	±0.46	595.42	±71.46
2.13	±0.53	11.08	±0.58	794.90	±967.58
1.18	±0.45	21.79	±0.37	901.30	±205.83
1.86	±0.32	21.32	±0.47	643.29	±148.01

Sugar beet

Yield (t/ha)	Standard deviation	Temperature (ºC)	Standard deviation	Precipitation (mm)	Standard deviation
9.37	±6.15	12.97	±0.42	325.98	±63.00
28.09	±8.25	11.63	±0.53	944.13	±135.87
55.01	±5.65	6.76	±0.73	1107.15	±85.30
18.01	±5.05	10.63	±0.57	582.54	±89.82
55.30	±9.37	8.60	±0.21	693.22	±72.31
19.66	±4.45	7.29	±0.41	628.61	±27.65
47.75	±5.64	7.83	±0.90	727.44	±83.11
7.63	±1.95	22.05	±0.41	2066.82	±485.29
64.33	±7.06	11.11	±0.61	876.33	±88.35
47.71	±6.03	8.88	±0.84	707.01	±77.13
60.38	±3.99	15.36	±0.49	610.92	±94.14
36.88	±5.17	10.07	±0.71	578.15	±74.85
26.03	±2.70	17.57	±0.64	226.71	±35.57
22.46	±5.35	21.74	±0.62	208.06	±42.03
42.48	±5.14	9.57	±0.45	1210.24	±72.68
46.91	±4.08	13.78	±0.45	811.46	±78.27
53.04	±3.74	11.41	±0.59	1661.70	±194.84
29.29	±5.05	20.32	±0.42	306.06	±52.86
33.95	±4.11	8.25	±0.90	592.94	±60.78
47.22	±8.04	15.55	±0.40	816.10	±137.33
20.92	±3.04	8.90	±0.70	618.83	±100.38
45.35	±8.51	13.83	±0.46	595.42	±71.46
35.41	±4.76	11.08	±0.58	580.62	±63.37

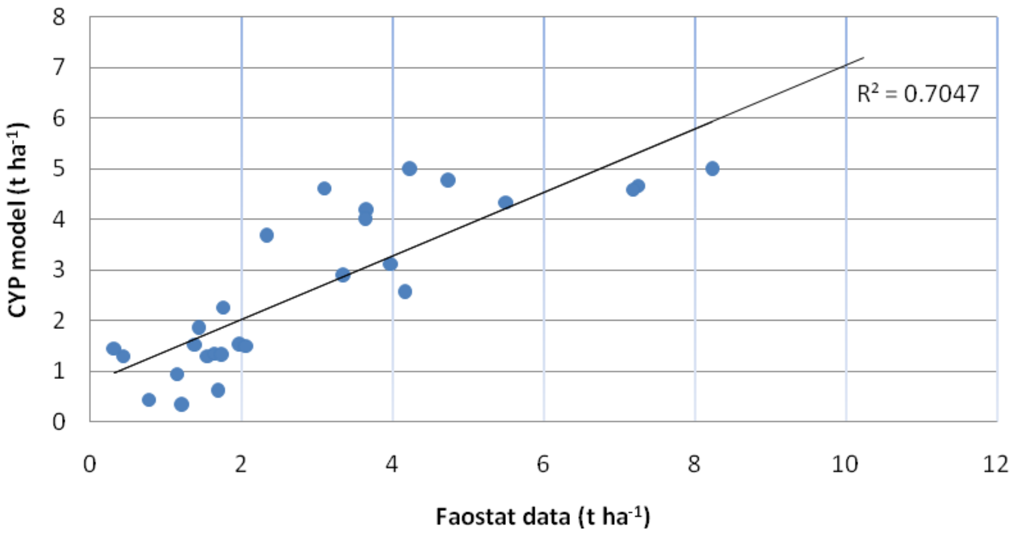
Sugarcane

Yield (t/ha)	Standard deviation	Temperature (ºC)	Standard deviation	Precipitation (mm)	Standard deviation
19.27	0.00	12.97	±0.42	325.98	±63.00
34.17	0.00	21.87	±0.24	977.39	±101.07
41.64	0.00	21.43	±0.31	1176.67	±127.29
63.44	0.01	25.16	±0.25	1640.70	±499.37
45.92	0.00	25.30	±0.32	1291.10	±299.65
65.38	0.01	22.05	±0.41	2066.82	±485.29
62.91	0.01	23.81	±0.23	1059.54	±87.56
73.46	0.01	17.57	±0.64	226.71	±35.57
25.72	0.00	21.74	±0.62	208.06	±42.03
60.07	0.01	25.27	±0.31	1909.22	±369.96
67.04	0.01	11.41	±0.59	1661.70	±194.84
71.30	0.01	21.32	±0.31	745.57	±61.45
28.86	0.00	27.28	±0.37	143.42	±37.16
36.70	0.00	26.91	±0.28	1124.44	±100.20
42.67	0.00	20.32	±0.42	306.06	±52.86
50.59	0.01	25.54	±0.31	2650.68	±283.16
56.95	0.01	25.40	±0.16	3056.06	±365.42
46.50	0.00	23.39	±0.40	1189.59	±147.20
74.78	0.01	25.98	±0.24	2379.36	±281.31
74.64	0.01	13.83	±0.46	595.42	±71.46
39.97	0.00	23.27	±0.28	1092.70	±155.89
64.06	0.01	25.43	±0.27	1906.15	±158.70

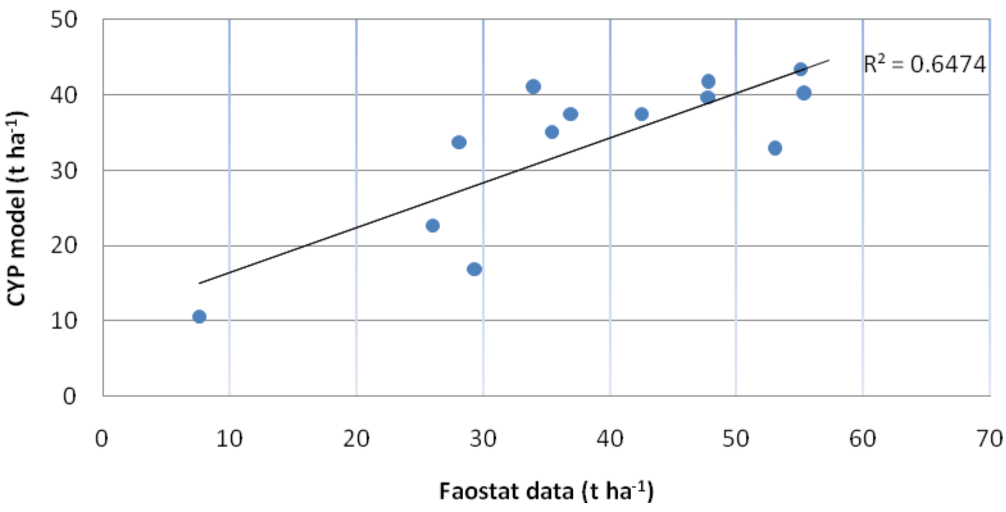
Annex 2: Comparison of climate yield prediction models to Faostat data

Comparison of models was done by correlation data from Faostat database and numerical models. Aim of this comparison was to evaluate how CYP models vary due to originate data from Faostat.Figures below show correlation between data and model for each feedstock.

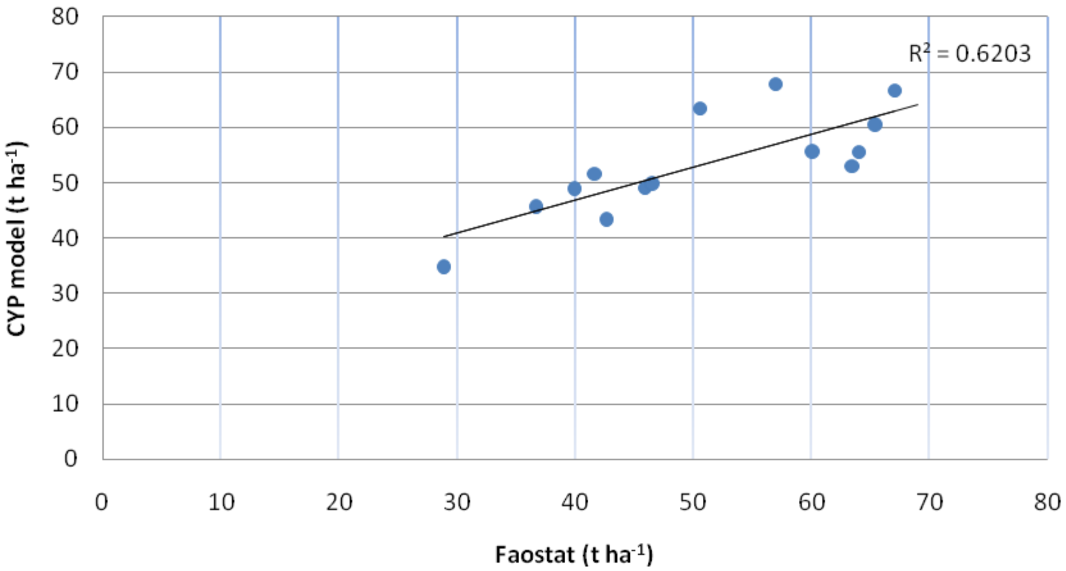
Correlation between data from Faostat database and model can be address as linear since R^2 is 0.7 and it is statistical significant (p= 4.4^10^{-8})



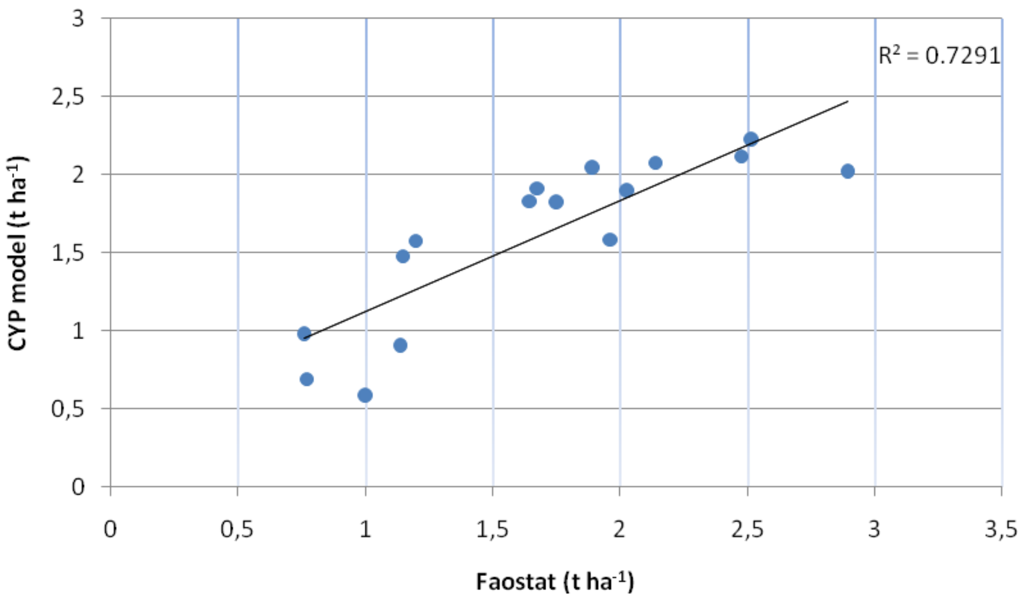
Comparison of model results and Faostat data show that correlation is linear and statistical significant (p= 9.1^10^{-4}).



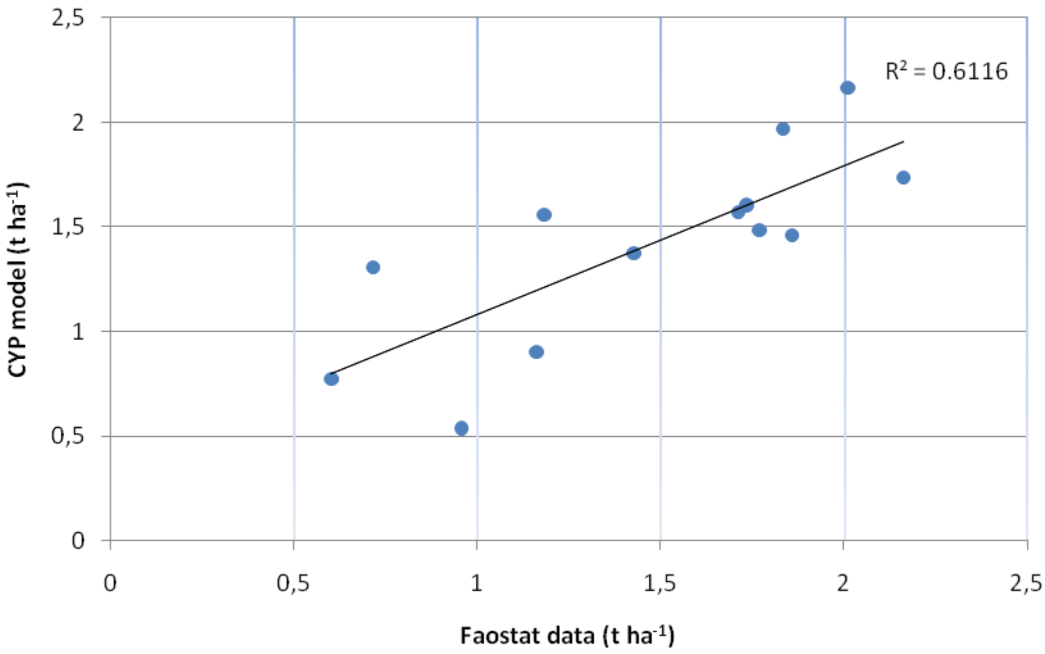
Comparison of model for sugarcane`s yield prediction show statistical significance (p=8.3^10^{-4}) and can be address as linear since the R^2 is 0.6.



Correlation between Faostat data and numerical model is statistical significant, due to linear correlation (R^2=0.7) and is also statistical significant (p=2.5^10^{-5}).



Comparison of model for soybean`s yield prediction show statistical significant (p=1.6^10^{-3}) and can be address as linear since the R^2 is 0.6.



Annex 3: Data on energy and material inventories

Biofuel	Bioethanol	
Feedstock	Corn	
Location	United States of America	
Crop yield	7260	kg $_{(corn)}$ ha^{-1}
Yield conversion factor	0.32	kg(C_2H_5OH) kg$_{(corn)}$$^{-1}$
Pre harvest energy and material input	/	/
N	0.0065	kg$_{(N)}$ kg(C_2H_5OH)$^{-1}$
P	0.0011	kg$_{(P)}$ kg(C_2H_5OH)$^{-1}$
K	0.0029	kg$_{(K)}$ kg(C_2H_5OH)$^{-1}$
CaO	0.0110	kg$_{(CaO)}$ kg(C_2H_5OH)$^{-1}$
Diesel	0.1050	kg$_{(diesel)}$ kg(C_2H_5OH)$^{-1}$
Post harvest energy and material input	/	/
Electricity	0.9340	MJ kg(C_2H_5OH)$^{-1}$
Natural gas	2.1810	MJ kg(C_2H_5OH)$^{-1}$

Renouf et al., 2008; Faostat, 2009.

Biofuel	Bioethanol	
Feedstock	Corn	
Location	Canada	
Crop yield	6486	kg $_{(corn)}$ ha^{-1}
Yield conversion factor	0.32	kg(C_2H_5OH) kg$_{(corn)}$$^{-1}$
Pre harvest energy and material input	/	/
N	0.0265	kg$_{(N)}$ kg(C_2H_5OH)$^{-1}$
P	0.0723	kg$_{(P)}$ kg(C_2H_5OH)$^{-1}$
K	0.0410	kg$_{(K)}$ kg(C_2H_5OH)$^{-1}$
CaO	0.1301	kg$_{(CaO)}$ kg(C_2H_5OH)$^{-1}$
Diesel	0.2146	kg$_{(diesel)}$ kg(C_2H_5OH)$^{-1}$
Post harvest energy and material input	/	/
Electricity	0.3787	MJ kg(C_2H_5OH)$^{-1}$
Diesel	13.1763	MJ kg(C_2H_5OH)$^{-1}$

Barthiaume et al, 2001; Faostat, 2009.

Biofuel	Bioethanol	
Feedstock	Corn	
Location	China	
Crop yield	4220	kg $_{(corn)}$ ha^{-1}
Yield conversion factor	0.32	kg(C_2H_5OH) kg$_{(corn)}$$^{-1}$
Pre harvest energy and material input	/	/
N	0.2332	kg$_{(N)}$ kg(C_2H_5OH)$^{-1}$
P	0.0888	kg$_{(P)}$ kg(C_2H_5OH)$^{-1}$
K	0.3320	kg$_{(K)}$ kg(C_2H_5OH)$^{-1}$
CaO	0.1999	kg$_{(CaO)}$ kg(C_2H_5OH)$^{-1}$
Diesel	0.0414	kg$_{(diesel)}$ kg(C_2H_5OH)$^{-1}$
Post harvest energy and material input	/	/
Electricity	1.0077	MJ kg(C_2H_5OH)$^{-1}$
Coal	16,103	MJ kg(C_2H_5OH)$^{-1}$

Yang et al., 2009; Faostat, 2009.

Biofuel	Bioethanol	
Feedstock	Sugar beet	
Location	Belgium	
Crop yield	59951	$kg_{(s.beet)}\ ha^{-1}$
Yield conversion factor	0.080	$kg(C_2H_5OH)\ kg_{(s.beet)}^{-1}$
Pre harvest energy and material input	/	/
N	0.0300	$kg_{(N)}\ kg(C_2H_5OH)^{-1}$
P_2O_5	0.0154	$kg(P_2O_5)\ kg(C_2H_5OH)^{-1}$
K_2O	0.0154	$kg(K_2O)\ kg(C_2H_5OH)^{-1}$
Diesel	0.021	$kg_{(diesel)}\ kg(C_2H_5OH)^{-1}$
Post harvest energy and material input	/	/
Electricity	0.326	$MJ\ kg(C_2H_5OH)^{-1}$
Natural gas	6.241	$MJ\ kg(C_2H_5OH)^{-1}$

Halleux et al., 2008; Faostat, 2009; Langeveld et al, 2008.

Biofuel	Bioethanol	
Feedstock	Sugar beet	
Location	France	
Crop yield	64334	$kg_{(s.beet)}\ ha^{-1}$
Yield conversion factor	0.080	$kg(C_2H_5OH)\ kg_{(s.beet)}^{-1}$
Pre harvest energy and material input	/	/
N	0.004	$kg_{(N)}\ kg(C_2H_5OH)^{-1}$
P_2O_5	0.0023	$kg(P_2O_5)\ kg(C_2H_5OH)^{-1}$
K_2O	0.0058	$kg(K_2O)\ kg(C_2H_5OH)^{-1}$
Diesel	0.0054	$kg_{(diesel)}\ kg(C_2H_5OH)^{-1}$
Post harvest energy and material input	/	/
Natural gas	6.1278	$MJ\ kg(C_2H_5OH)^{-1}$
Coal	4.0009	$MJ\ kg(C_2H_5OH)^{-1}$
Oil	4.8602	$MJ\ kg(C_2H_5OH)^{-1}$

Malça and Freire, 2006; Faostat, 2009.

Biofuel	Bioethanol	
Feedstock	Sugar beet	
Location	United Kingdom	
Crop yield	45111	$kg_{(s.beet)}\ ha^{-1}$
Yield conversion factor	0.080	$kg(C_2H_5OH)\ kg_{(s.beet)}^{-1}$
Pre harvest energy and material input	/	/
N	0.0310	$kg_{(N)}\ kg(C_2H_5OH)^{-1}$
P	0.0049	$kg_{(P)}\ kg(C_2H_5OH)^{-1}$
K	0.0141	$kg_{(K)}\ kg(C_2H_5OH)^{-1}$
Diesel	0.0516	$kg_{(diesel)}\ kg(C_2H_5OH)^{-1}$
Post harvest energy and material input	/	/
Electricity	0.7400	$MJ\ kg(C_2H_5OH)^{-1}$
Natural gas	2.1860	$MJ\ kg(C_2H_5OH)^{-1}$
Coke	0.334	$MJ\ kg(C_2H_5OH)^{-1}$

Renouf et al., 2008; Faostat, 2009.

Biofuel	Bioethanol	
Feedstock	Sugarcane	
Location	Brazil	
Crop yield	64334	kg $_{(s.cane)}$ ha^{-1}
Yield conversion factor	0.0587	kg(C_2H_5OH) kg$_{(s.cane)}$$^{-1}$
Pre harvest energy and material input	/	/
N	0.0080	kg$_{(N)}$ kg(C_2H_5OH)$^{-1}$
P_2O_5	0.03218	kg(P_2O_5) kg(C_2H_5OH)$^{-1}$
K_2O	0.03218	kg(K_2O) kg(C_2H_5OH)$^{-1}$
Diesel	0.0251	kg$_{(diesel)}$ kg(C_2H_5OH)$^{-1}$
Post harvest energy and material input	/	/
Electricity	0.667	KWh kg(C_2H_5OH)$^{-1}$

Macedo et al, 2008; Faostat, 2009.

Biofuel	Bioethanol	
Feedstock	Sugarcane	
Location	Taiwan	
Crop yield	64500	kg $_{(s.cane)}$ ha^{-1}
Yield conversion factor	0.0587	kg(C_2H_5OH) kg$_{(s.cane)}$$^{-1}$
Pre harvest energy and material input	/	/
N	0.0581	kg$_{(N)}$ kg(C_2H_5OH)$^{-1}$
P	0.0092	kg$_{(P)}$ kg(C_2H_5OH)$^{-1}$
K	0.0184	kg$_{(K)}$ kg(C_2H_5OH)$^{-1}$
Diesel	0.0199	kg$_{(diesel)}$ kg(C_2H_5OH)$^{-1}$
Post harvest energy and material input	/	/
Electricity	0.6111	KWh kg(C_2H_5OH)$^{-1}$

Chiung-Lung and Yuh-Ming, 2009; Faostat, 2009; Fao, 2002.

Biofuel	Bioethanol	
Feedstock	Sugarcane	
Location	Australia	
Crop yield	84173	kg $_{(s.cane)}$ ha^{-1}
Yield conversion factor	0.0587	kg(C_2H_5OH) kg$_{(s.cane)}$$^{-1}$
Pre harvest energy and material input	/	/
N	0.0261	kg$_{(N)}$ kg(C_2H_5OH)$^{-1}$
P	0.0038	kg$_{(P)}$ kg(C_2H_5OH)$^{-1}$
K	0.0134	kg$_{(K)}$ kg(C_2H_5OH)$^{-1}$
Diesel	0.0376	kg$_{(diesel)}$ kg(C_2H_5OH)$^{-1}$
Post harvest energy and material input	/	/
Coal	0.7000	MJ kg(C_2H_5OH)$^{-1}$

Renouf et al., 2008; Faostat, 2009.

Biofuel	Biodiesel	
Feedstock	Rapeseed	
Location	Germany	
Crop yield	2890	$kg_{(rapeseed)}\ ha^{-1}$
Yield conversion factor	0.415	$kg(BD)\ kg_{(rapeseed)}^{-1}$
Pre harvest energy and material input	/	/
N	0.1326	$kg_{(N)}\ kg(BD)^{-1}$
P	0.0200	$kg_{(P)}\ kg(BD)^{-1}$
K	0.0250	$kg_{(K)}\ kg(BD)^{-1}$
CaO	0.0363	$kg_{(CaO)}\ kg(BD)^{-1}$
Diesel	0.03641	$kg_{(diesel)}\ kg(BD)^{-1}$
Post harvest energy and material input	/	/
Electricity	0.4344	$MJ\ kg(BD)^{-1}$
Transport	0.138	$MJ\ kg(BD)^{-1}$

Kaltschmitt et al., 1997; Faostat, 2009.

Biofuel	Biodiesel	
Feedstock	Rapeseed	
Location	Sweden	
Crop yield	2070	$kg_{(rapeseed)}\ ha^{-1}$
Yield conversion factor	0.415	$kg(BD)\ kg_{(rapeseed)}^{-1}$
Pre harvest energy and material input	/	/
N	0.3015	$kg_{(N)}\ kg(BD)^{-1}$
P	0.0838	$kg_{(P)}\ kg(BD)^{-1}$
K	0.1094	$kg_{(K)}\ kg(BD)^{-1}$
CaO	0.2328	$kg_{(CaO)}\ kg(BD)^{-1}$
Diesel	0.0724	$kg_{(diesel)}\ kg(BD)^{-1}$
Post harvest energy and material input	/	/
Electricity	0.9493	$MJ\ kg(BD)^{-1}$
Transport	0.174	$MJ\ kg(BD)^{-1}$

Hovelius and Hansson, 1999; Faostat, 2009.

Biofuel	Biodiesel	
Feedstock	Rapeseed	
Location	United Kingdom	
Crop yield	3000	$kg_{(rapeseed)}\ ha^{-1}$
Yield conversion factor	0.415	$kg(BD)\ kg_{(rapeseed)}^{-1}$
Pre harvest energy and material input	/	/
N	0.1695	$kg_{(N)}\ kg(BD)^{-1}$
P_2O_5	0.0489	$kg(P_2O_5)\ kg(BD)^{-1}$
K_2O	0.0578	$kg(K_2O)\ kg(BD)^{-1}$
CaO	0.1389	$kg_{(CaO)}\ kg(BD)^{-1}$
Diesel	0.0436	$kg_{(diesel)}\ kg(BD)^{-1}$
Post harvest energy and material input	/	/
Electricity	0.1740	$MJ\ kg(BD)^{-1}$
Transport	0.97	$MJ\ kg(BD)^{-1}$

Stephenson et al., 2008; Faostat, 2009.

Biofuel	Biodiesel	
Feedstock	Soybean	
Location	United States of America	
Crop yield	2890	kg $_{(soybean)}$ ha^{-1}
Yield conversion factor	0.1722	kg(BD) kg$_{(soybean)}^{-1}$
Pre harvest energy and material input	/	/
N	0.0074	kg$_{(N)}$ kg(C_2H_5OH)$^{-1}$
P	0.0759	kg$_{(P)}$ kg(C_2H_5OH)$^{-1}$
K	0.0297	kg$_{(K)}$ kg(C_2H_5OH)$^{-1}$
Diesel	0.0654	kg$_{(diesel)}$ kg(C_2H_5OH)$^{-1}$
Post harvest energy and material input	/	/
Electricity	0.2700	KWh kg(C_2H_5OH)$^{-1}$

Pimetel and Patzek, 2008; Faostat, 2009.

Biofuel	Biodiesel	
Feedstock	Soybean	
Location	Taiwan	
Crop yield	2350	kg $_{(soybean)}$ ha^{-1}
Yield conversion factor	0.1722	kg(BD) kg$_{(soybean)}^{-1}$
Pre harvest energy and material input	/	/
N	0.0490	kg$_{(N)}$ kg(BD)$^{-1}$
P	0.0224	kg$_{(P)}$ kg(BD)$^{-1}$
K	0.1853	kg$_{(K)}$ kg(BD)$^{-1}$
Diesel	0.1245	kg$_{(diesel)}$ kg(BD)$^{-1}$
Post harvest energy and material input	/	/
Electricity	0.2823	KWh kg(BD)$^{-1}$

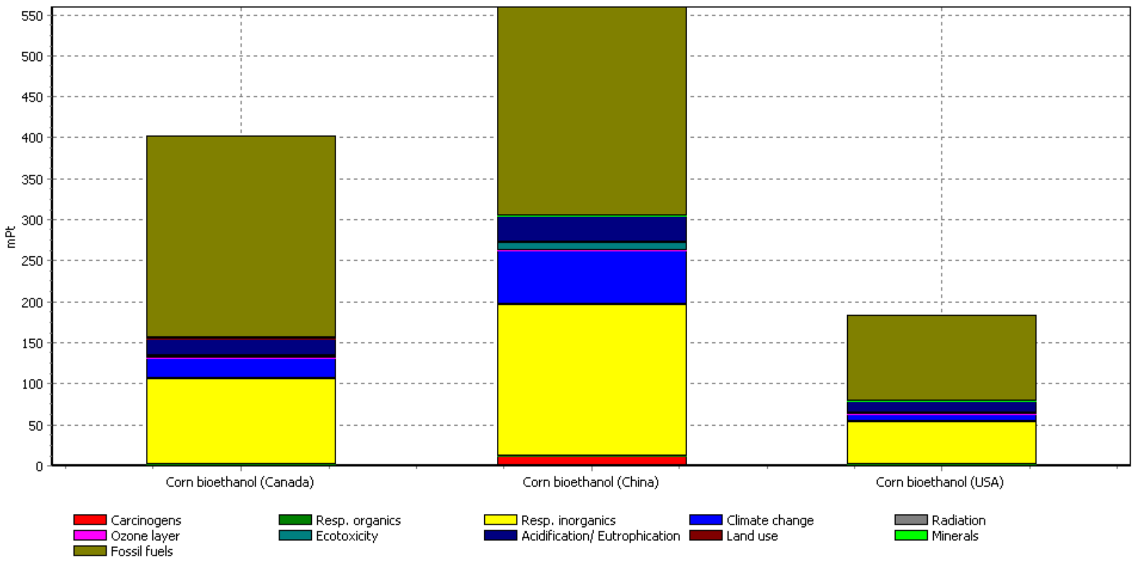
Chiung-Lung and Yuh-Ming, 2009; Faostat, 2009; Fao, 2002.

Biofuel	Biodiesel	
Feedstock	Soybean	
Location	Argentina	
Crop yield	2591	kg $_{(soybean)}$ ha^{-1}
Yield conversion factor	0.1722	kg(BD) kg$_{(soybean)}^{-1}$
Pre harvest energy and material input	/	/
N	0.0112	kg$_{(N)}$ kg(BD)$^{-1}$
P	0.0336	kg$_{(P)}$ kg(BD)$^{-1}$
K	0	kg$_{(K)}$ kg(BD)$^{-1}$
CH_3OH	0.1105	kg kg(BD)$^{-1}$
Diesel	0.1167	kg$_{(diesel)}$ kg(BD)$^{-1}$
Post harvest energy and material input	/	/
Electricity	0.2761	MJ kg(C_2H_5OH)$^{-1}$

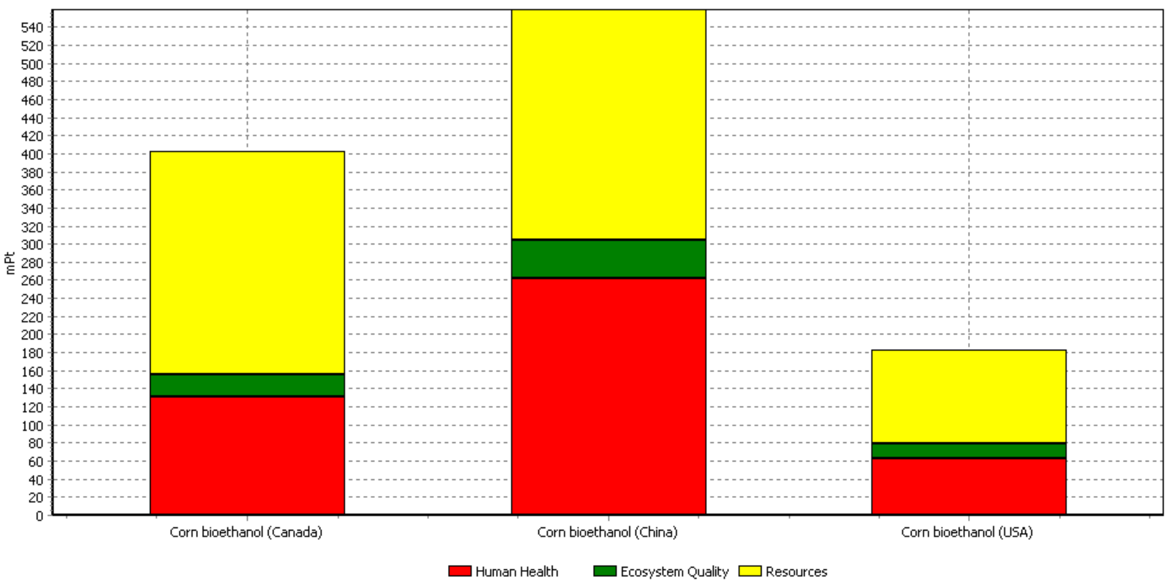
Panichelli et al., 2009; Faostat, 2009.

Annex 4: Total environmental impacts for selected liquid biofuels

Corn

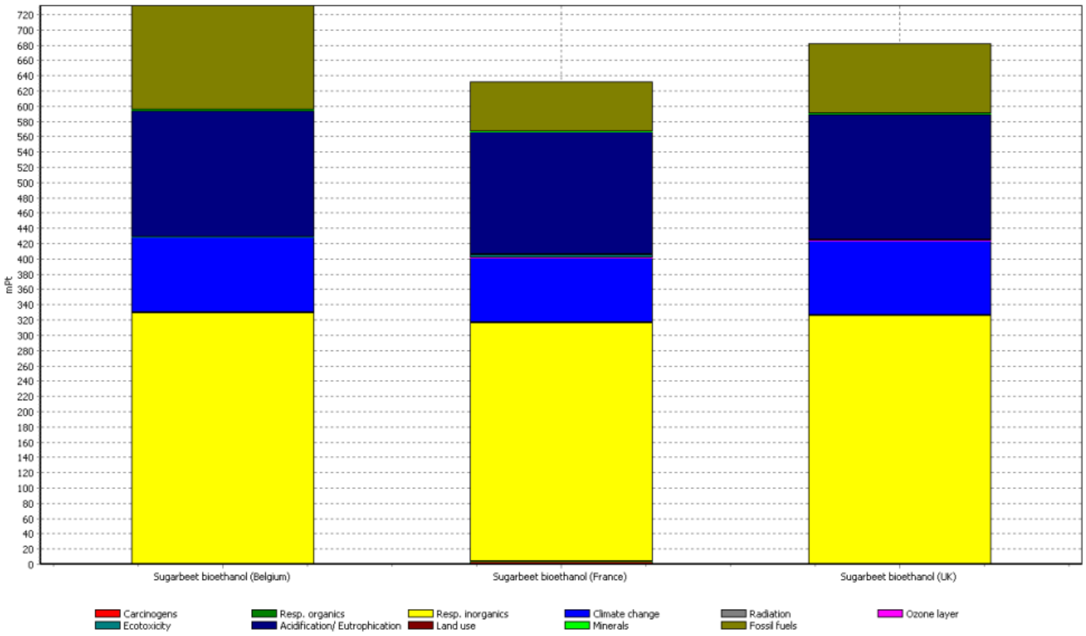


Comparing 1 kg 'Corn bioethanol (Canada)', 1 kg 'Corn bioethanol (China)' and 1 kg 'Corn bioethanol (USA)'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score

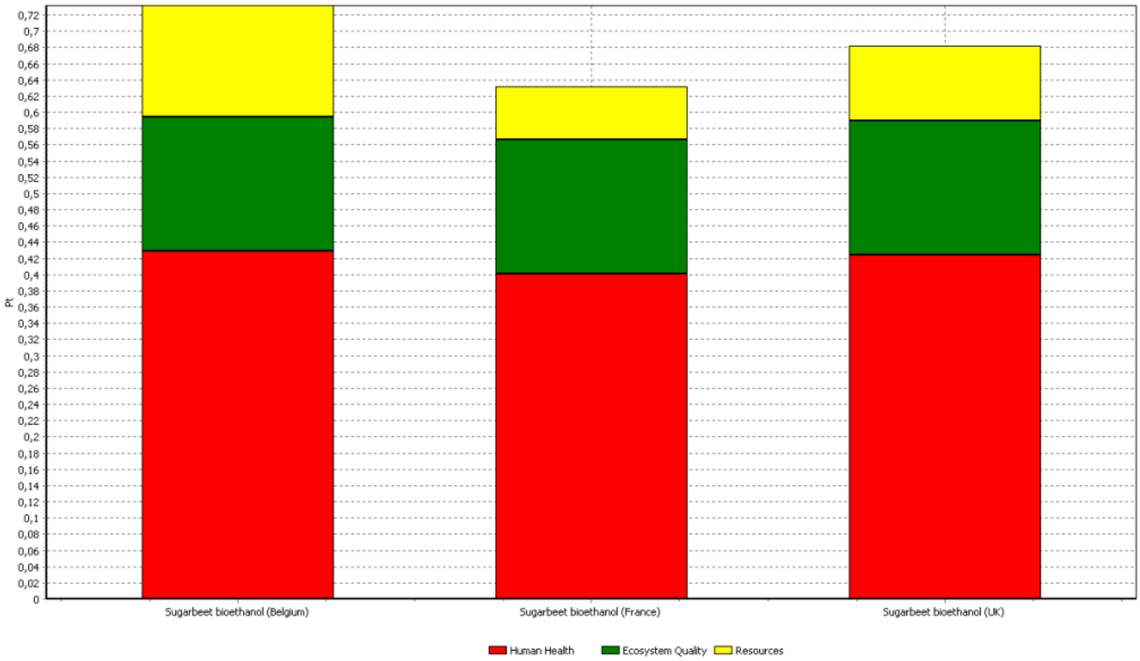


Comparing 1 kg 'Corn bioethanol (Canada)', 1 kg 'Corn bioethanol (China)' and 1 kg 'Corn bioethanol (USA)'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score

Sugar beet

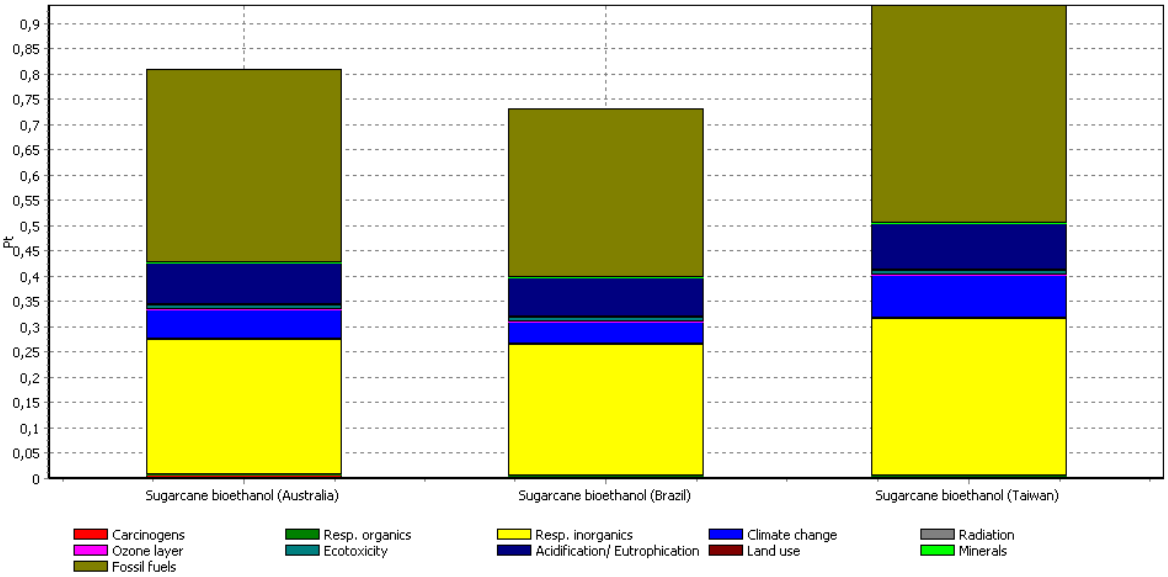


Comparing 1 kg 'Sugarbeet bioethanol (Belgium)', 1 kg 'Sugarbeet bioethanol (France)' and 1 kg 'Sugarbeet bioethanol (UK)'; Method: Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A / single score

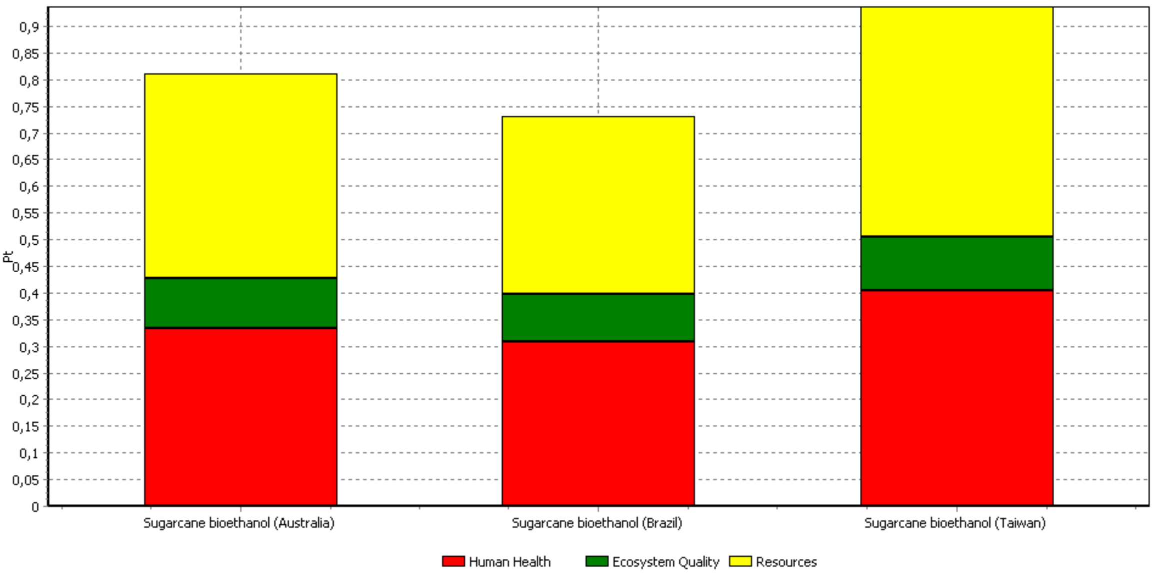


Comparing 1 kg 'Sugarbeet bioethanol (Belgium)', 1 kg 'Sugarbeet bioethanol (France)' and 1 kg 'Sugarbeet bioethanol (UK)'; Method: Eco-indicator 99 (H) V2.03 / Europe EI 99 H/A / single score

Sugarcane

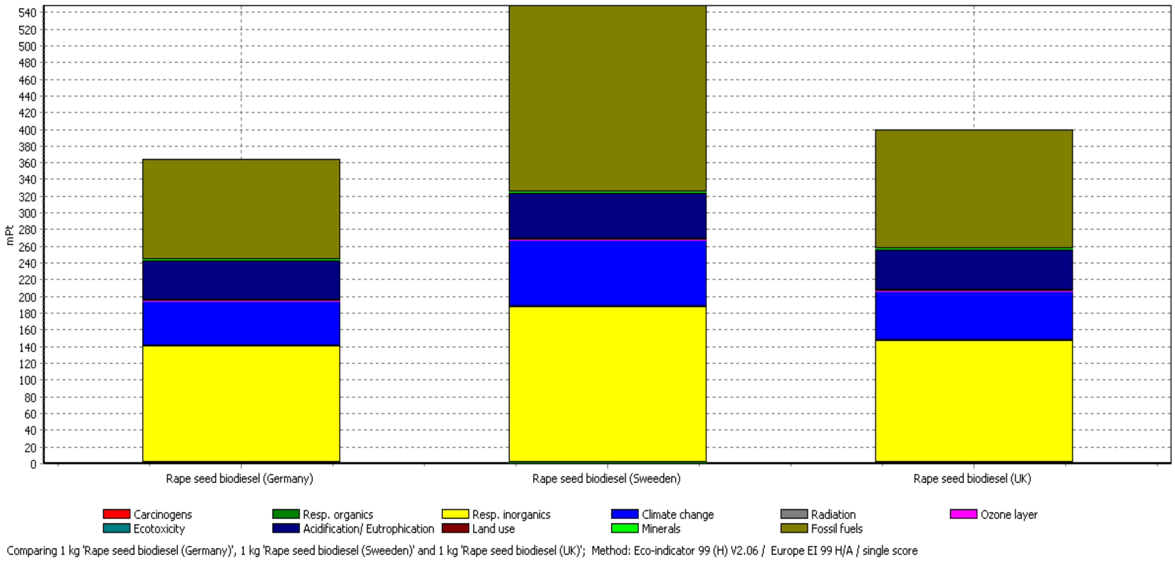


Comparing 1 kg 'Sugarcane bioethanol (Australia)', 1 kg 'Sugarcane bioethanol (Brazil)' and 1 kg 'Sugarcane bioethanol (Taiwan)'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score



Comparing 1 kg 'Sugarcane bioethanol (Australia)', 1 kg 'Sugarcane bioethanol (Brazil)' and 1 kg 'Sugarcane bioethanol (Taiwan)'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score

Rapeseed


mPt
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140
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80
60
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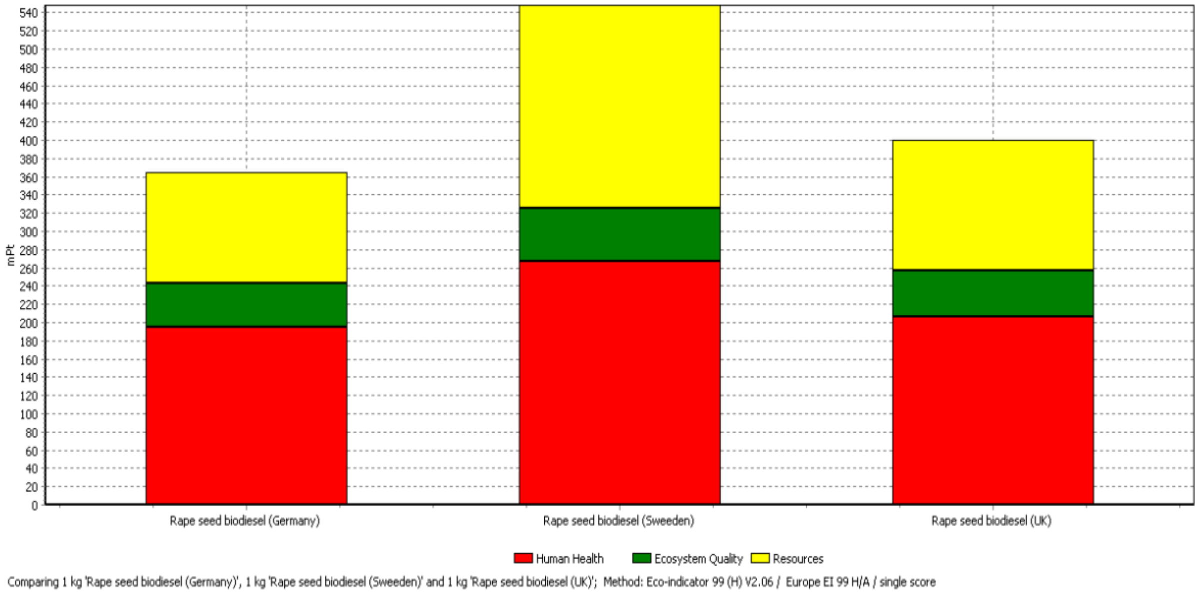
20
0
Rape seed biodiesel (Germany)
Rape seed biodiesel (Sweeden)
Rape seed biodiesel (UK)
Carcinogens
Resp. organics
Resp. inorganics
Climate change
Radiation
Ozone layer
Ecotoxicity
Acidification/ Eutrophication
Land use
Minerals
Fossil fuels
Comparing 1 kg 'Rape seed biodiesel (Germany)', 1 kg 'Rape seed biodiesel (Sweeden)' and 1 kg 'Rape seed biodiesel (UK)'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score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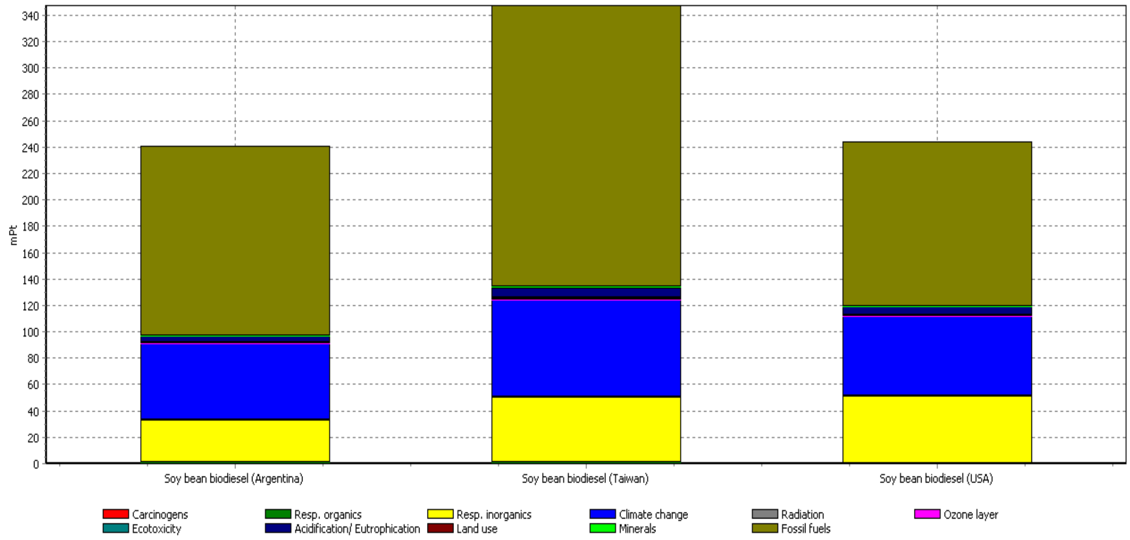
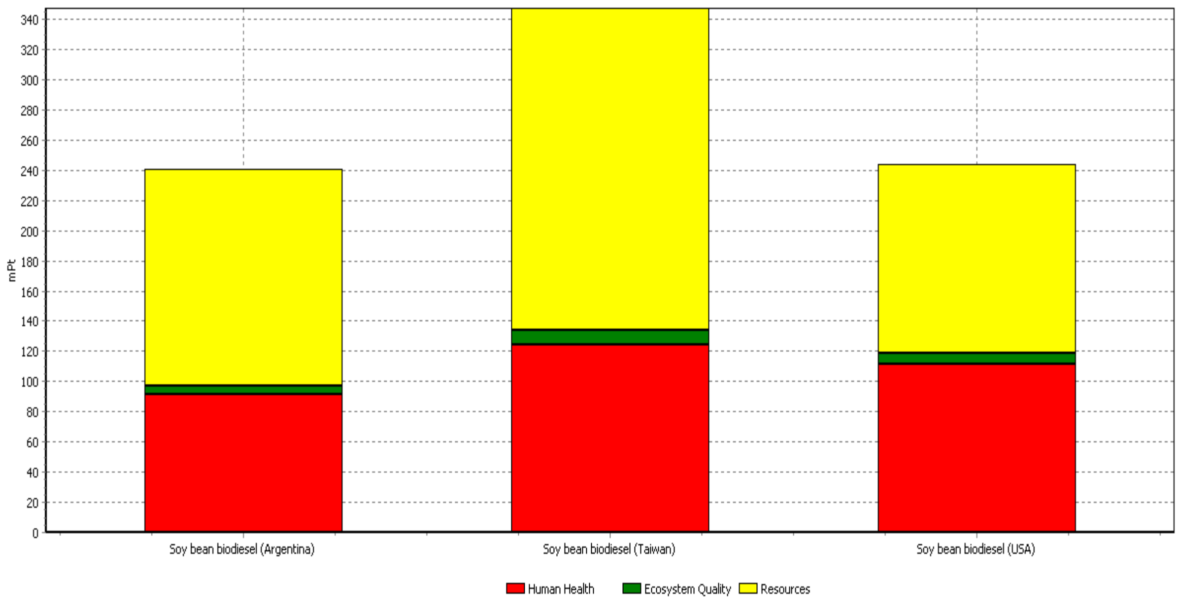
20
0
Rape seed biodiesel (Germany)
Rape seed biodiesel (Sweeden)
Rape seed biodiesel (UK)
Human Health
Ecosystem Quality
Resources
Comparing 1 kg 'Rape seed biodiesel (Germany)', 1 kg 'Rape seed biodiesel (Sweeden)' and 1 kg 'Rape seed biodiesel (UK)'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score

Soybean



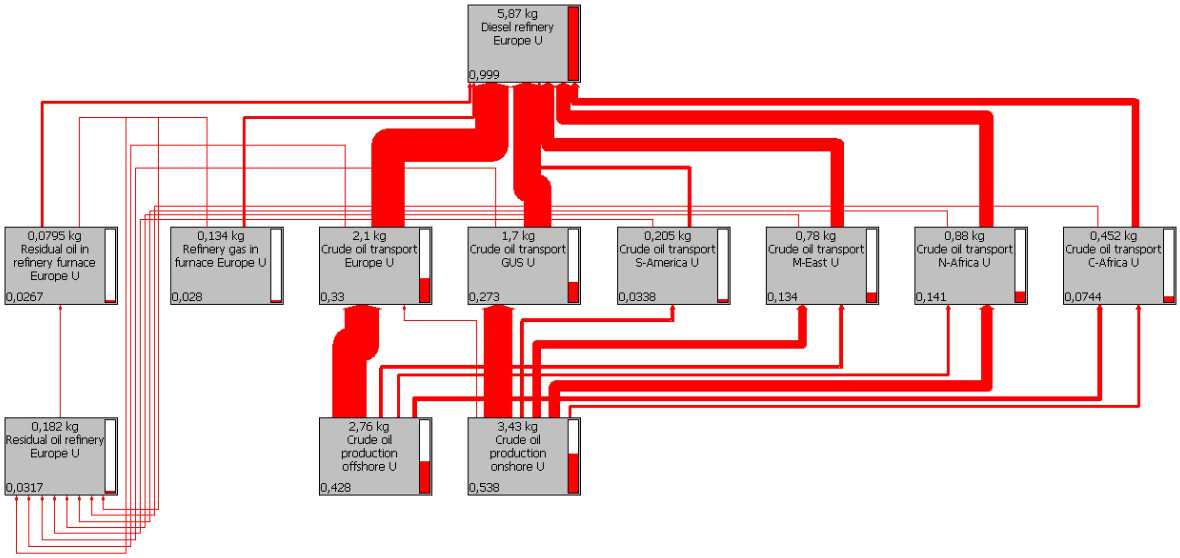
Comparing 1 kg 'Soy bean biodiesel (Argentina)', 1 kg 'Soy bean biodiesel (Taiwan)' and 1 kg 'Soy bean biodiesel (USA)'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score



Comparing 1 kg 'Soy bean biodiesel (Argentina)', 1 kg 'Soy bean biodiesel (Taiwan)' and 1 kg 'Soy bean biodiesel (USA)'; Method: Eco-indicator 99 (H) V2.06 / Europe EI 99 H/A / single score

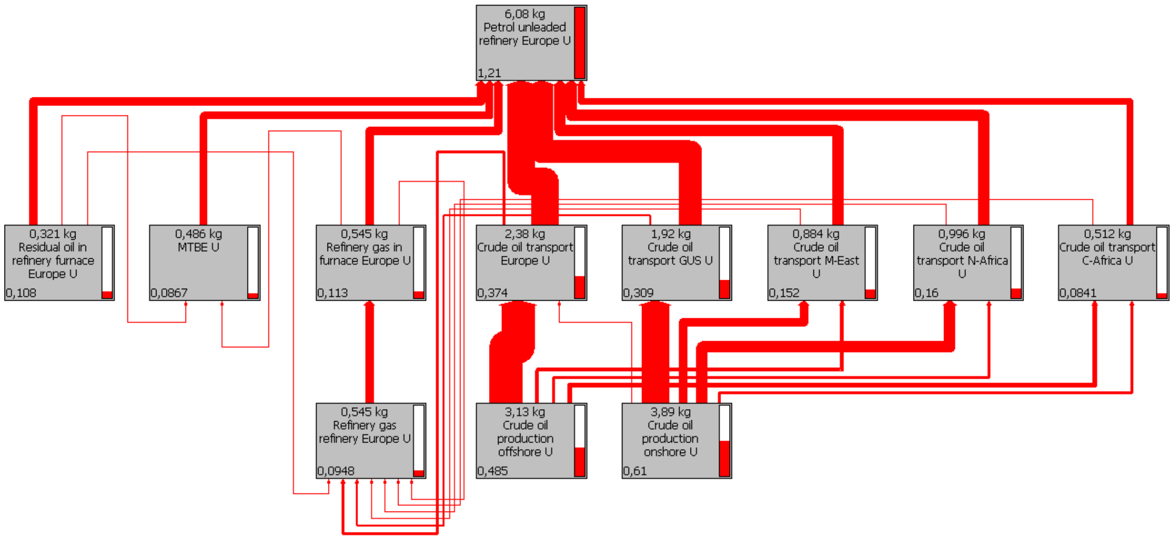
Annex 5: Flowchart diagram for fossil diesel, petrol and electricity production from various sources

Fossil diesel



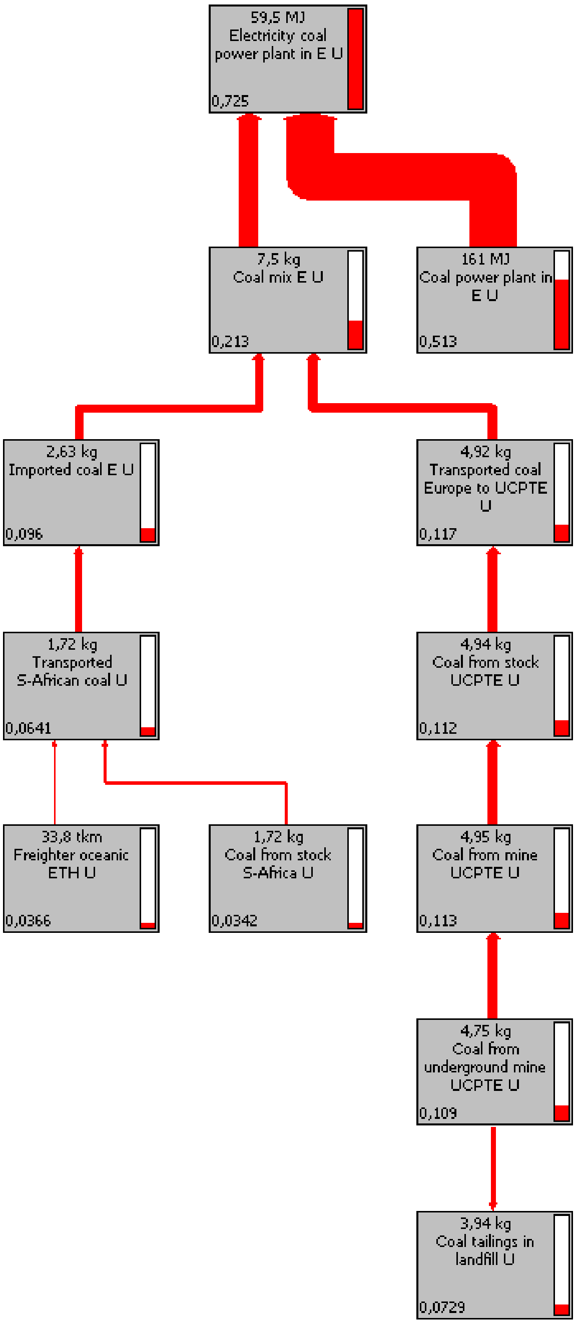
Energy and materials flow of a modern European refinery are analysed for diesel production. Several processes such as distillation or steam reforming are required to produce large variety of oil products. Flowchart show inventories for producing 5.87 kg of fossil diesel which is equivalent of 100 km driven by average European car.

Petrol



Energy and materials flow of a modern European refinery are analysed for petrol production. Several processes such as distillation or steam reforming are required to produce large variety of oil products. Flowchart show inventories for producing 5.08 kg of petrol which is equivalent of 100 km driven by average European car.

Electricity from coal



Electricity from coal power plant is modelled for hard coal power plants. The average lignite and hard coal power plant is calculated based on the production figures. For energy efficiency, the share of installed abatement technology, the amount of ashes, and the emissions of airborne pollutants, country specific information or coal specific composition information are used. The construction of the power plant, land use, the operation of the cooling equipment and water borne pollutants are equally modelled for all European countries.

Electricity from hydro power

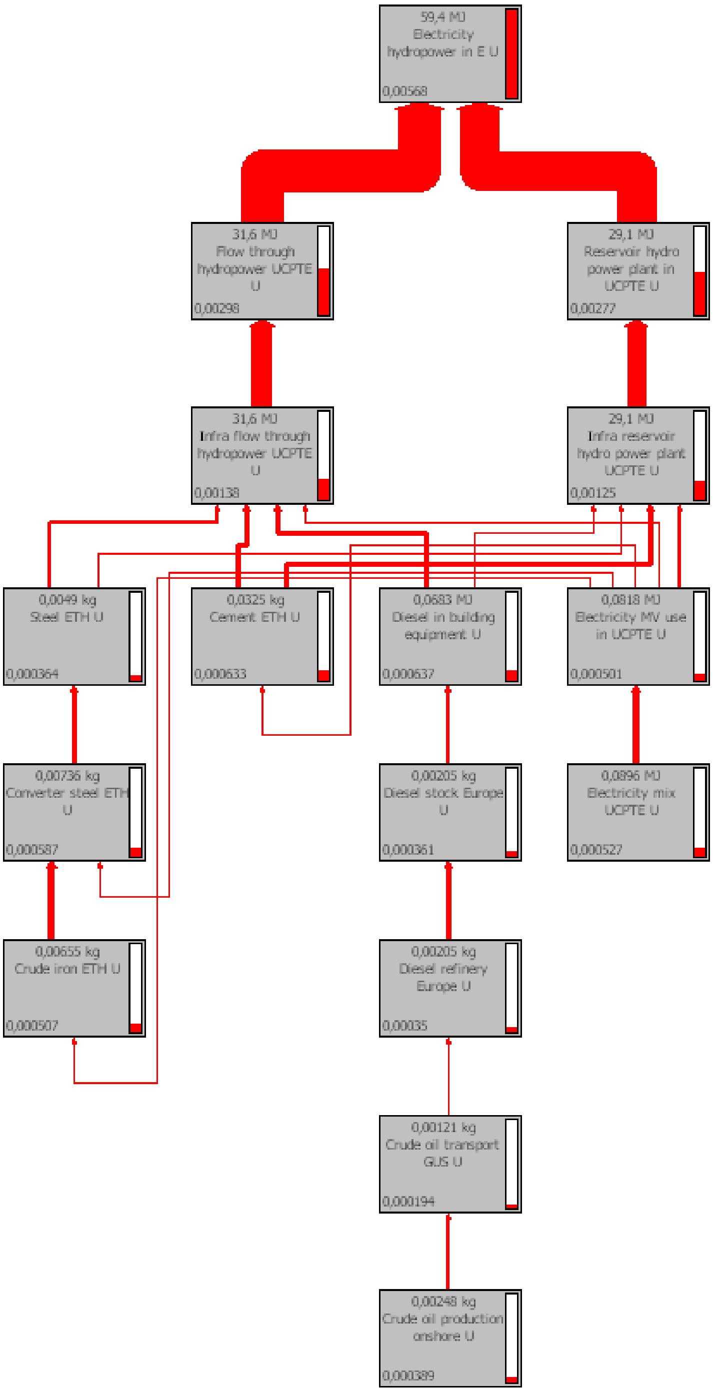
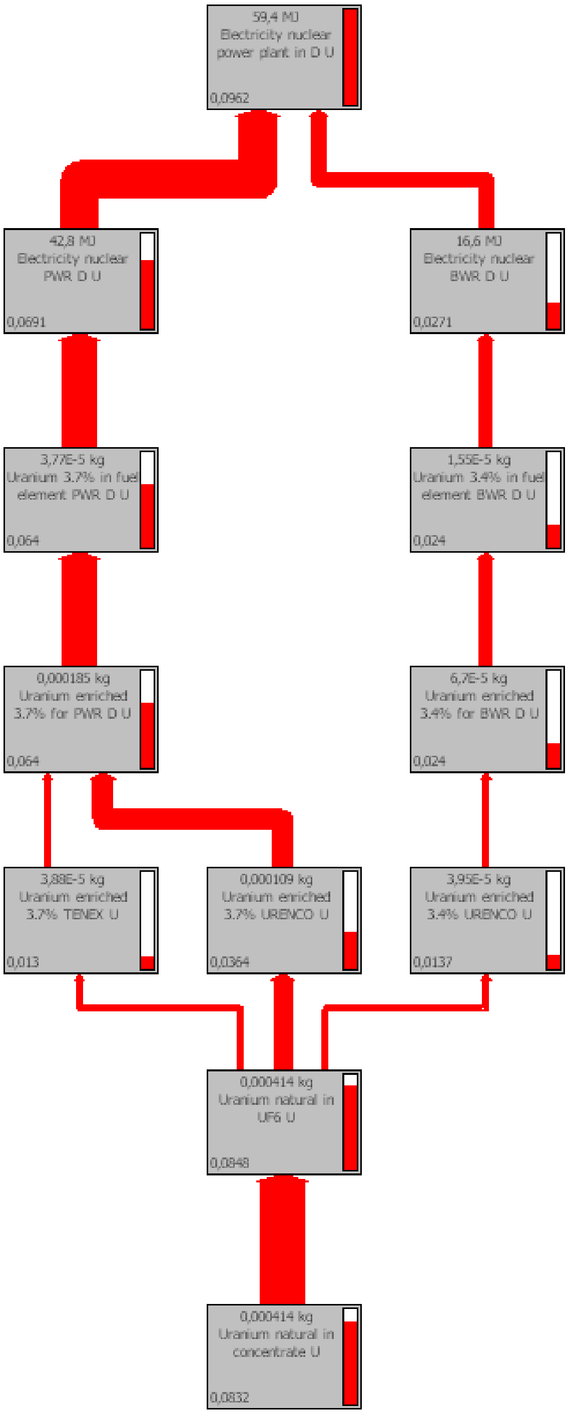


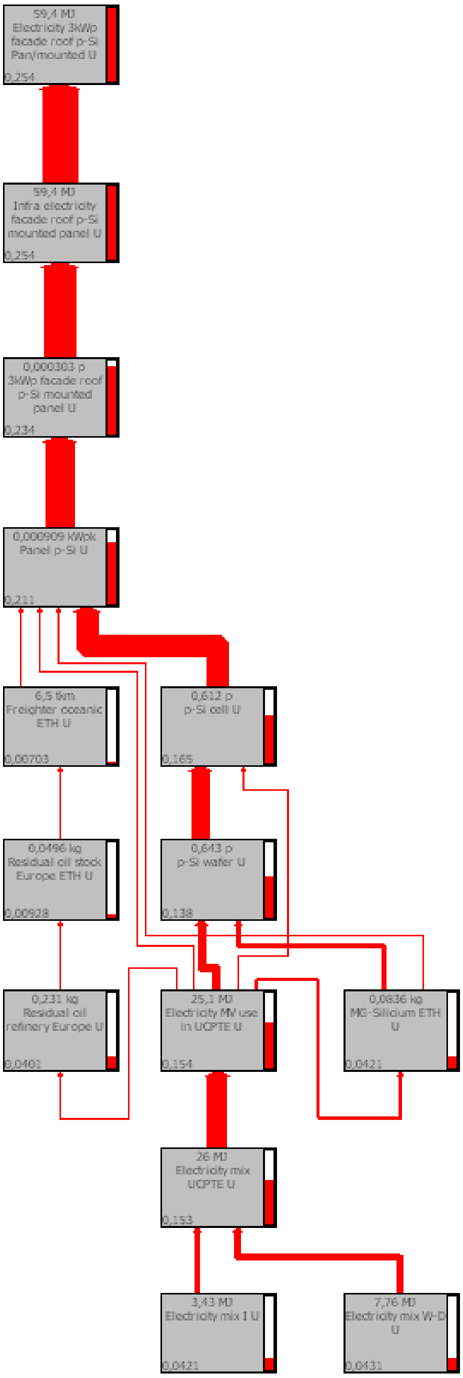
Figure above show modelled electricity production with run of river power plants and water storage plants in Spain.

Electricity from nuclear power



Scenario describing the electricity generation of nuclear plant with pressurized water reactors (72%) and boiling water reactors (38%) in Germany.

Electricity from photovoltaic



Energy and material flow for production of electricity with solar cells installed in Switzerland.

Annex 6: Correlation between air temperature and solar irradiation

Figure show linear correlation between air temperature and solar irradiation. Results of statistical analysis shows that correlation is statistical significant (p=0.007).