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Abstract

Fossil fuels make up 80% of the primary energy consumed in the world, from which 58% alone is consumed by the transportation sector. They have a major contribution in greenhouse gas (GHG) emissions by their combustion and consumption which leads to many negative effects including climate change and global warming. In order to tackle these problems in the transportation sector, the biofuels industry has been growing in the previous years. This study analyzes the most relevant environmental impacts that are measured with the life cycle assessment (LCA) methodology and the interaction of LCA with the set of policy instruments that hinder or encourage the production of biofuels in the transportation sector in Germany. The systematic approach used in the methodological design of this research incorporates the LCA methodology, qualitative and quantitative techniques (SWOT matrix) to describe the current situation of biofuels production and consumption in Germany. Although the country has been producing biofuels for more than two decades for the transportation sector and it is the worldwide leader of biodiesel production and consumption, the results indicate that a route towards a sustainable production of biofuels is quite far from a simple way in which only benefits can be addressed. Biofuels production, trade and usage are accompanied by complex processes. There are several contradictions regarding its environmental benefits, discrepancy in the impacts measurements and uncertainty regarding the energy share that they could reach in the future in the transportation sector. The evidence shows that the solution to tackle climate change in the transportation sector is not going to fall solely on the incorporation of biofuels in this sector. Different renewable sources and technologies will have to be introduced. An initial assessment of the current situation of Germany´s biofuels production and consumption and a state of the art of the LCA´s used in policy instruments as a tool to measure environmental impacts are some of the particular contributions provided in this research study. Further conclusions and significant recommendations concerning the existing biofuels industry in Germany, implications about its future development and trends as well as the methodological design have also been drawn.

Key Words: Transportation, biofuels, biodiesel, bioethanol, life cycle assessment (LCA), policies, environmental impacts.

Resumen

Los combustibles fósiles constituyen el 80% de la energía primaria consumida en el mundo, de este porcentaje el 58% es consumido solamente por el sector del transporte, su combustión contribuye significativamente a la generación de gases de efecto invernadero (GEI) lo que conlleva a diversos efectos negativos como el cambio climático y el calentamiento global. Una de las estrategias utilizadas para hacer frente a estos problemas en dicho sector es la producción de biocombustibles. El propósito de este estudio es analizar los impactos ambientales más relevantes que se miden a través del análisis de ciclo de vida (ACV) así como su interacción con las políticas que obstaculizan o favorecen su producción y su consumo en Alemania. El enfoque sistémico utilizado en el diseño metodológico que incorpora el ACV, análisis cualitativo y cuantitativo para la construcción de la matriz FODA, describen la situación actual de la producción y consumo de biocombustibles en Alemania. Los resultados de este estudio indican que a pesar que este país ha producido y utilizado biocombustibles desde hace más de dos décadas, siendo además líder mundial en la producción de biodiesel, se encuentra aún lejos de lograr de una forma sencilla, una producción y consumo sostenible de ellos, en donde sólo beneficios puedan ser atribuidos a estos. La producción, el comercio y el uso de biocombustibles son acompañados de de procesos complejos. Los beneficios ambientales que tienen, la diferencia entre las mediciones y los resultados de sus impactos, la incertidumbre respecto a la cuota máxima que puedan alcanzar en la matriz energética del sector transporte son algunos de los puntos que generan mayores contradicciones. De igual forma los resultados muestran que la solución para combatir el cambio climático en el sector del transporte no va a recaer únicamente en la incorporación de biocombustibles en este sector. Diferentes fuentes de energías renovables así como tecnologías para su producción deberán ser incluidas en él. La evaluación de la situación actual de la producción y consumo de biocombustibles de Alemania así como el estado del arte del ACV utilizado como herramienta en instrumentos legislativos para la medición y control de los impactos ambientales son las contribuciones más sobresalientes provistas en este estudio. Otras conclusiones y recomendaciones importantes en relación con la industria de los biocombustibles existente, las consecuencias sobre su desarrollo y las tendencias de futuro, así como recomendaciones en el diseño metodológico también se incluyen en este trabajo.

Palabras clave: Transporte, biocombustibles, biodiesel, ethanol, análisis de ciclo de vida (ACV), políticas, impactos ambientales.

Zusammenfassung

80% des weltweiten Primärenergieverbrauchs wird durch fossile Brennstoffe gedeckt, wobei 58% davon allein im Verkehrssektor verbraucht werden. Die Verbrennung und der Verbrauch fossiler Brennstoffe tragen zu einem hohen Anteil zu Treibhausgas(THG)-Emissionen bei, was die Auswirkungen des Klimawandels verstärkt und zu globaler Erwärmung führt. Um diesen negativen Effekten entgegenzuwirken, ist die Biokraftstoff-Industrie in den vergangenen Jahren stark gewachsen. In der vorliegenden Arbeit werden die wichtigsten Umweltauswirkungen fossiler Brennstoffe analysiert. Diese werden durch Anwendung der Life-Cycle-Assessment(LCA)-Methode,sowie durchdie Nutzung der LCA-Methodein Verbindung mit politischen Instrumenten gemessen, welche zur Förderung oder zur Verhinderung von fossilen Brennstoffen im deutschen Verkehrssektor eingesetzt werden. Die aktuelle Situation der Produktion von Biokraftstoffen und deren Nutzung wird in der vorliegenden Arbeit durch Anwendung der LCA-Methode sowie durch die Nutzung qualitativer und quantitativer Techniken (SWOT-Matrix) beschrieben. Obwohl Deutschland seit mehr als zwei Jahrzehnten Biokraftstoffe für den Verkehrssektor produziert und der weltweit führende Anbieter und Verbraucher von Biodiesel ist, zeigen die Ergebnisse der vorliegenden Arbeit, dass der Weg zu einer einfachen und nachhaltigen Produktion, in welcher die Vorteile die Nachteile überwiegen, noch lang ist. Die Produktion, der Handel sowie die Nutzung von Biokraftstoffen werden immer noch durch komplexe Prozesse erschwert, welche sich unter anderem im Landnutzungswandel oder im Erhalt der Biodiversität ergeben. Des Weiteren verlangsamen Widersprüche in Bezug auf Vorteile für die Umwelt, Diskrepanzen in den Messungen zu Auswirkungen und Unsicherheiten in Bezug auf den prozentualen Anteil, den Biokraftstoffe zukünftig am Verkehrssektor einnehmen könnten, den derzeitigen Entwicklungsprozess. Die Ergebnisse zeigen, dass die Markteinführung von Biokraftstoffen im Verkehrssektor nicht die alleinige Lösung sein kann, um dem Klimawandel entgegenzuwirken. Hierfür müssen verschiedene Arten an erneuerbaren Energien und Technologien eingeführt werden. Die vorliegende Arbeit führt zunächst eine Bewertung der derzeitigen Situation der Produktion und des Verbrauchs von Biokraftstoffen in Deutschland durch. Des Weiteren wird der Stand der Technik der LCA-Methode, als Instrument und Werkzeug zur Messung von Umweltauswirkungen, vorgestellt. Schlussfolgerungen und Empfehlungen in Bezug auf die Biokraftstoffindustrie in Deutschland sowie ein Ausblick auf zukünftige Entwicklungen, Trends und auf die methodische Gestaltung, schließen die Arbeit ab.

Schlüsselbegriffe: Verkehr, Biobrenntstoffe, Biodiesel, Bioethanol, Ökobilanz (LCA), Gesetz, Umweltauswirkungen.

CONTENT

Abstract-- i
Resumen--- ii
Zusammenfassung--iii
List of Figures --vii
List of Tables -- viii
List of Graphics --- viii
List of Abbreviations --ix
Chapter 1 INTRODUCTION -- 1
1.0 Introduction and Problem statement -- 1
1.1 Objectives-- 2
1.1.1 General Objectives --- 2
1.1.2 Specific Objectives-- 2
1.2 Reading guide-- 3
Chapter 2 CONCEPTUAL FRAMEWORK--- 5
2.0 Introduction --- 5
2.1 Overview -- 5
2.1 Biofuels --- 6
2.2 Biofuels for transportation --- 9
2.2.1 Ethanol ---10
2.2.2 Pure plant oil (PPO) ---11
2.2.3 Biodiesel---11
2.3 Biofuels supply chain --13
2.4 Life Cycle Assessment (LCA) ---13
2.4.1 LCA steps ---14
2.4.2 Goal and Scope definition ---14
2.4.2.1 Well-to-wheel for Fuels ---15
2.4.3 Life cycle inventory analysis --15
2.4.4 Life Cycle Impact Assessment --16
2.4.5 Interpretation--18
2.5 Life cycle costs--18
2.6 Biofuels GHG reductions --19

2.7 Land use ---------- 19
Chapter 3 BIOFUELS POLICIES ---------- 21
3.0 Introduction ---------- 21
3.1 GHG as a Policy Driver ---------- 21
3.2 Policy category and mechanisms ---------- 23
3.2.1 Command and control instruments ---------- 24
3.2.2 Economic & fiscal Instruments and incentive-based instruments ---------- 25
3.2.3 Voluntary and information Instruments ---------- 25
3.3 Allocation of policies in the biofuel supply chain ---------- 25
3.4 EU Energy biofuels policies ---------- 28
3.4.1 European Renewable Energy Directive- RED Biofuels part (2009/28/EC) ---------- 29
3.5 Other countries ---------- 30
3.5.1 United States ---------- 31
3.5.2 Brazil ---------- 31
3.5.3 China ---------- 32
Chapter 4. METHODOLOGY ---------- 33
4.0 Introduction ---------- 33
4.1 Data Collection ---------- 34
4.2. Data analysis ---------- 36
4.2 Scope of this study ---------- 36
4.3.1 Constraints on secondary data collection ---------- 36
4.3.3 Constraints of the environmental assessment ---------- 37
Chapter 5. POLICIES AND LIFE CYCLE ASSESSMENT FOR THE PRODUCTION OF BIOFUELS IN GERMANY. RESULTS AND DISCUSSION. ---------- 38
5.1 Case Study ---------- 38
5.1.1 Land use in Germany ---------- 38
5.1.2 Oil Dependency Imports/Exports ---------- 40
5.1.2.1 Oil Companies in Germany ---------- 41
5.1.2.2 Oil Demand in transportation sector ---------- 41
5.1.3 Biofuels in the transportation sector ---------- 41
5.1.3.1 Biodiesel Consumption and capacity ---------- 42
5.1.3.2 Biodiesel trade ---------- 44

5.1.3.3 Ethanol Consumption ---45
5.1.3.4 Ethanol trade --47
5.1.4 Biofuels Sustainability ---47
5.1.5 Actors in the transportation sector (Biofuels) ---48
5.1.5.1 Feedstock’s Producers --49
5.1.5.2 Biofuel producers and biofuel suppliers --49
5.1.5.3 Government ---50
5.1.5.4 Automotive industries/ Vehicle manufacturers ---51
5.1.5.5 End Users ---52
5.1.5.6 Non Governmental institutes --52
5.1.5.7 Research Institutes ---52
5.1.6 Germany´s biofuels policy development --53
5.1.7 Certificate schemes ---58
5.1.8 SWOT ANALYSIS ---58
5.1.9 Discussion of the current situation of biofuels production in Germany -----------------------60
5.2 Environmental assessment --61
5.2.1 Goal and Scope definition --61
5.2.1 Functional unit (FU) --61
5.2.2 Life cycle inventory analysis ---62
5.2.3 Interpretation ---64
5.2.3.1 Distance travelled per vehicle basis (vehicle-km) ---64
5.2.3.2 Allocation of co-products --65
5.2.3.3 Direct and indirect land use change --65
5.2.3.4 Constraints of the comparison in regards to CO2eq/vehicle-km ------------------------------67
5.2.3.5 Agricultural area category --67
5.2.3.6 Allocation Method ---67
5.2.3.7 Constraints when comparing different authors with land cultivation ------------------------68
5.2.4 Spatial differentiation of impact categories --69
5.2.5 RME Energy performance --70
5.2.6 Discussion of the LCA for environmental impacts --72
CHAPTER 6 GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES-------------74
6.0 Conclusions --74

6.1 Recommendations for further research ---78
REFERENCES--80
Annex A. EXPERTS CONSULTATION--90
Annex B. LAND USE IN GERMANY (NUTS and LUCAS)---92
Annex C. BIOFUEL INDUSTRY IN GERMANY---96
Annex D. ENVIRONMENTAL IMPACTS --98
Annex D 2. QUALITATIVE ANALYSIS --99
Annex E. DIAGRAM FLOW expressed in the Renewable Energy Directive RED 2009/28/EC--------102
Annex F. DISTANCE TRAVELED PER VEHICLE (vehicle-km)---103
Annex F2. AGRICULTURAL CATEGORY (ha)--105
Annex G. ENVIRONMENTAL DATA BASES FOR RME PRODUCTION IN GERMANY ---------------------107

List of Figures

Figure 1 Biofuels classification --- 7
Figure 2 Classification of advanced and conventional biofuels --- 9
Figure 3 Different feedstock sources for biofuels production --10
Figure 4 Conversion of agricultural feedstock's into liquid biofuels --12
Figure 5 Biofuels supply value chain --13
Figure 6 Steps on a LCA ---14
Figure 7 Well to tank and tank to wheels analysis ---15
Figure 8 Elements of the impact assessment---16
Figure 9 Spatial differentiation impact categories ---17
Figure 10 Types of production and environmental costs and their visibility -----------------------------18
Figure 11 Economical, social and environmental impacts ---22
Figure 12 Policy instruments provided at different point in the biofuel supply chain-------------------26
Figure 13 Steps on a LCA adapted to this study ---35
Figure 14 Location of Germany---38
Figure 15 Cultivation of renewable resources in Germany---40
Figure 16 Trade of biodiesel 2010---45
Figure 17 Trade of bioethanol 2010---47
Figure 18 Actors and stakeholders groups in the supply chain--49
Figure 19 German ministries and their function in the Biofuels promotion--------------------------------51
Figure 20 Spatial differentiation impact categories and its indicators applied to the case study----69

List of Tables

Table 1 Production and application of a variety of transport biofuels 8
Table 2 Impact Categories and Possible indicators proposal of Udo de Haes et al........................ 17
Table 3 Policy category and Instruments 24
Table 4 Biofuel supply chain and the policy instruments.. 27
Table 5 Policies, standards, directives, amendments in regards to biofuels 28
Table 6 Code, directive and description of EU directives included in the renewable energy package 30
Table 7 Research methodology 33
Table 8 Cultivation of raw materials and energy crops 39
Table 9 Key oil data.. 40
Table 10 Major legislation and policies regarding German´s liquid biofuel development EU level 54
Table 11 Major legislation and policies regarding German´s liquid biofuel development (Continuation)... 55
Table 12 Overview of the main measures related to biofuels in Germany 57
Table 13 International standards that cover the requirements of the Renewable Energy Directive (2009/28/EC) 58
Table 14 SWOT analysis of the production and usage of biofuels in Germany.............................. 59
Table 15 Changes during different period times in the PE consumption 71

List of Graphics

Graphic 1 Motor fuel supply renewable energies in Germany since 2004. 42
Graphic 2 Consumption, domestic production and production capacity of biodiesel in Germany. 43
Graphic 3 Biodiesel consumption 44
Graphic 4 Consumption and domestic production of Ethanol in Germany. 46
Graphic 5 Ethanol consumption 46
Graphic 6 Common GHG emissions for different biofuels. 48
Graphic 7 g CO2 eq/ vehicle-km 66
Graphic 8 Kg CO2 eq/ ha-y emissions. In a WtT approach 68
Graphic 9 Total Primary energy consumed in Rapeseed production, oil production, transesterification process and total PE with and without co-products allocation in [MJ/tRME] ... 71
Graphic 10 GHG emissions in [kg CO2 eq/tRME] for rapeseed production, oil rapeseed production, esterification and total RME with co-products allocation 72

List of Abbreviations

ASTM	American Society for Testing Materials
B05	Admixture of 95% petroleum diesel and 5% biodiesel
B100	Neat biodiesel
B85	Admixture of 5% petroleum diesel and 85% biodiesel
Biokraft-NachV	Biokraftstoff-Nachhaltigkeitsverordnung / Biofuels Sustainability Ordinance
BSO	Biofuels sustainability ordinance
BTL	Biomass to liquid
Concawe	Oil companies' European association for environment, health and safety in refining and distribution
DDGS	Dried Distillers Grains with Solubles
dLUC	direct Land Use Change
E05	Admixture of 95% petroleum diesel and 5% ethanol
EU	European Union
EUC	European Union Comission
FQD	Fuel Quality Directive
FU	Functional Unit
GEI	Gases de Efecto Invernadero
GHG	Greenhouse Gases
GJ	Giga Joule
Ha	Hectare
HTP	Human Toxicity Potential
IEA	International Energy Agency
iLUC	Indirect Land Use Change
LCA	Life Cycle Assessment
NUTS	Nomenclature of territorial units for statistics
PE	Primary Energy
R&D	Research and Development
RED	Renewable Energy Directive
RME	Rape Methyl Ester
TFC	Total Final Consumption
TPES	Total Primary Energy Supply
UNEP	United Nations Environment Programme

Chapter 1 INTRODUCTION

1.0 Introduction and Problem statement

Fossil fuels have transformed the world since their discovery; they had played the most important role in the transportation sector during the twentieth century. Nowadays they make up 80% of the primary energy consumed in the world from which 57.7 % is used in the transportation sector (Silva Lora, Escobar Palacio, Rocha, Grillo Renó, Venturini, & Almazán del Olmo, 2011). Even though when they initially were developed, their environmental impacts were not assessed. Nowadays it is well known that their combustion is a big contributor of increasing the level of CO_2 into the atmosphere, taking into account that over 20% of all anthropogenic Green House Gases (GHG) emissions are originated in transportation sector (Chouinard-Dussault, Bradt, Ponce-Ortega, & El-Halwagi, 2010; IEA, 2009; Singh-Nigam & Singh, 2011). As a result, this situation has generated high expectations in the liquid biofuels industry among different countries around the world as a source that could potentially mitigate the GHG releases and at the same time can contribute to energy security and support agricultural producers (FAO, 2008).

Due to the increasing release of GHG to the atmosphere caused by the combustion of fossil fuels, some countries have already established goals in order to decrease their CO_2 emissions, however even if the expanding biofuels production can be seen as a good way to mitigate climate change in regards to transportation, it depends on the type of biofuels. Some biofuels have good net GHG emissions savings while others depend on whether and how the effects of cultivation, feedstock, production processes are taken into account (Sorda, Banse, & Kemfert, 2010) and they have already set targets for the use of biofuels, either for use as pure fuel or blended with conventional fuel. In more than ten countries, oil companies are required to add a certain percentage of biofuels to the regular fuel in order to sell it.

The European Union (EU) set in 2003 the basis for the promotion of the use of renewable energy in transportation sector adopting legislative instruments in order to promote the use of biofuels among its member states. Even if the legislation has change during the subsequent years the specific target is to achieve 10% shares of renewable energies on the total road transport demand by 2020. Renewable energies stand for different technologies that use renewable sources (sun, wind, water etc.) due to the common physical and chemical characteristics with their counterparts, and because engines can be run without changes using low blends of biofuels , they are seen as the most feasible fuels to be developed in order to achieve the target (Wiesenthal et al., 2009).

Germany is one of the few EU countries that have promoted biofuels production, encouraging their use even before the EU mandated a target to obey; this situation had located Germany as a leader in biodiesel production and consumption. The main drivers to promote biofuels development in the country are: The need to reduce its oil dependence, the oil import dependency of the country is 95 to 98%; the stimulation of rural economies and the contribution to mitigate climate change (Dautzenberg & Hanf, 2008; IEA, 2012).

Biodiesel in Germany is mainly derived from rapeseed and is called Rape methyl ester (RME) while bioethanol has been only recently produced (2005) in Germany. Its domestic feedstock crops are mainly wheat, rye and sugar beets (Bomb et al., 2007)

Despite the years of development of biofuels industry, they are not yet economically viable fuels for transportation purposes. They have been encouraged by a support tax regime (that in 2013 will be withdrawn), incentives and subsidies along its supply chain value (Haupt, Bockey, & Wilharm, 2010).

Nowadays EU and Germany have controversial debates in regards to the environmental, economical and social impacts of biofuels production, usage and its common renewable energy target. Even if the EU has clear guidelines based on LCA methodology that explain how to measure the GHG emissions, there are some features that haven´t been taken into account (e.g. Direct and indirect land use change, loss of biodiversity, labor conditions, economical incentives, biofuels users' acceptance among others) (EU, 2010).

The importance to study and analyze the environmental impacts, the policies and the lessons learned from the countries that have already introduced biofuels into their markets lies in understanding the advantages and disadvantages that conjugated with other factors can or cannot make the biofuels production and usage the best and most suitable option for transportation purposes to be developed and encouraged.

Also the interaction that policy instruments have with the production and the environment protection can encourage or hinder the biofuels industry.

Germany has been chosen as the case study due to its experience in producing biofuels. Until now it is the leader producer and consumer of biodiesel. It has also used several policy instruments to achieve its goals and the common goal with the EU in reducing GHG emissions in the transportation sector.

1.1 Objectives

1.1.1 General Objectives

The general objective of this study is:

- To analyze the environmental impacts and governmental policies for the production and usage of liquid biofuels in Germany.

1.1.2 Specific Objectives

- To describe and analyze the actual situation regarding biofuels production and usage in Germany.
- To assess the environmental impacts based on life cycle analysis methodology.
- To analyze the governmental policies that are supporting or hindering the markets focused on the main actors regarding biofuels production and usage.

- To put forward some recommendations about the kind, usage and methodological advances of biofuels based on environmental analysis and governmental policies regarding the biofuels production and usage.

The expected results and information obtained from this investigation attempt to answer a series of questions including the following:

Regarding the production and usage of biofuels in Germany

- What is the current situation of biofuels production in Germany?
- Does the domestic crops cultivation (energy purposes crops) guarantee the demand of biofuels in order to achieve the biofuels target?
- Which are the environmental impacts regarding biofuels production and usage that are assessed in Germany and in the EU? Which methodology is followed in order to assess the environmental impacts?
- Which are the differences among the different LCA studies that are provided in the EU and German context?
- Which are the measures that are implemented in order to avoid environmental impacts in other countries? (Third countries that cultivate energetic purposes crops in order to fulfill the demand of countries like Germany that has a biofuel quota).
- What are the challenges and opportunities as well as future prospects of biofuels production and consumption in Germany?

Regarding the policy instruments of biofuels production and consumption

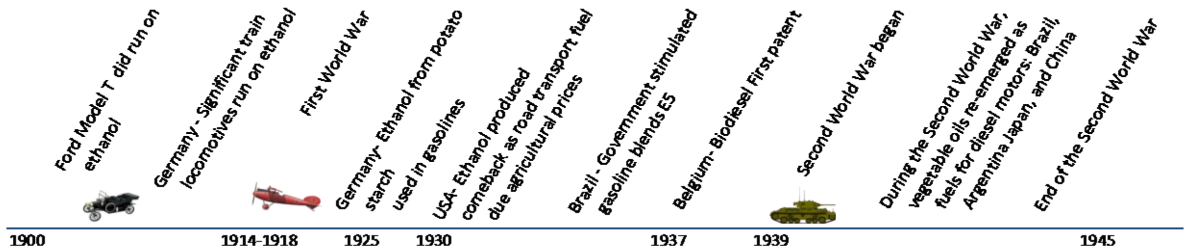
- Which are the policy instruments used worldwide in order to encourage biofuels production and consumption?
- Which policy instruments are used in order to fulfill the sustainability criteria of the RED directive 2009/28/EC [1]in Germany?
- How do the policy instruments interact, control and mitigate the environmental impacts of biofuels usage and production?

1.2 Reading guide

• Chapter 2 is concerned with the conceptual framework. It provides the development of biofuel production and usage since the 1800, giving also the main classification of biofuels for transportation purposes, its characteristics, supply value chain and also describes the life cycle assessment methodology as a technique for evaluating the total environmental impacts of a product or a service over its defined life. The well to wheel concept for fuels in the transport sector is also explained.
• Chapter 3 aims to explain the main policy instruments along the biofuels supply value chain used to encourage the biofuels industry. It also provides some key facts of different countries that have already strong policy mechanisms in regards to biofuels production and consumption.

[1]The RED Directive 2009/28/EC is a legislation which mandates the use of renewable energy in the European Union member's states(EU, 2009).

• Chapter 4 explains the methodology used in this work, describes the data needed and the process to collect it, as well as the scope of the work.
• Chapter 5 is divided in two parts. The first presents the case study (Germany) facts, the biofuels share in the energy transportation mix; it also describes the actors identified and the policy instruments used along the supply value chain in order to encourage biofuels production and consumption in Germany. The second part discusses the principal differences and analysis of the existing scientific available literature that uses a LCA methodology that evaluates the environmental impacts of biofuels for transportation purposes mainly in Germany and in the European Union.
• Chapter 6 is dedicated to the conclusions of this work and also provides recommendations for further research work.



Chapter 2 CONCEPTUAL FRAMEWORK

2.0 Introduction

Nowadays fossil fuels make up 80% of the primary energy consumed in the world, the transport sector already accounts for over half of global oil consumption (IEA, 2011a).The sources of these fossil fuels have the major contribution in GHG emissions by their combustion and consumption which leads to different negative effects including climate change and global warming (Chouinard-Dussault et al. 2010; Singh-Nigam et al. 2011).

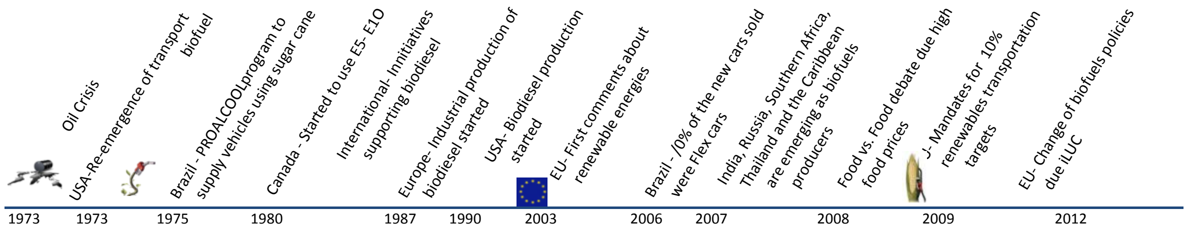
Furthermore the intergovernmental panel on climate change (IPCC) advices that in order to avoid the worst impacts from climate change, global CO_2 emission must be cut by at least 50% by 2050 in order to decrease these emissions, transport sector will play a significant role (IEA, 2009). Transport continues to rely primarily on oil, shifting it away is forecasted to be a slow and difficult process (IEA, 2009).

2.1 Overview

Biofuels began to be produced in the 1800 when ethanol was derived from corn and Rudolf Diesel's first engine ran on biogenic fuel (peanut oil) (IEA, 2011b) also the prototype of the Otto motor, which is currently used (gasoline cars) was developed for burning ethanol. One of the first Ford models ran on ethanol. During the early twentieth century, a significant part of train locomotives in Germany were powered by ethanol, until the 1940s, in those decades they were seen as an available transport fuel but due to a falling fossil fuel prices the development of biofuels were stopped and the fossil fuels were developed (Lucas Reijnders & Huijbregts, 2009a).

Biofuels were used in different countries as emergency fuels during the Second World War e.g. Brazil, Argentina, Japan and China.

It is generally known that vegetable oils re-emerge as available fuel option in the transportation sector with the oil crisis of 1973, when the petroleum prices increased. During this period some



countries like Brazil and USA decided to reduce their dependence on mineral oils establishing different programs and subsidies to support the newborn biofuel industry (Lucas Reijnders & Huijbregts, 2009a).

Other initiatives to promote biofuels were announced in Germany, South Africa, New Zealand and Austria in the 1980´s. In most parts of the world, in the last 10 years there were a fastest growth in biofuel production, some governments support with different policies instruments the biofuels industry development (IEA, 2011b).

The discussion about the biofuels benefits (global climate change mitigation, energy security and agricultural producers support) have controversial debates, in 2008 the marginal benefits of biofuels were brought into view by the high food prices in 2008, which have been linked to increasing transport biofuel production (FAO, 2008).

Worldwide the governments create policies to support biofuels industry in order to decrease the oil dependence (energy security concerns) followed by the support to the rural economy (agricultural support) and more recently with the purpose to reduce CO_2 emissions in the transport sector (climate change mitigation) which has become one of the most important driver for biofuels promotion (IEA, 2011b).

2.1 Biofuels

The term biofuel refers to those liquid, solid or gaseous fuels that store the energy predominantly derived from biomass (FAO, 2008). Different sources of biomass are used to produce bioenergy in different forms e.g. food, wood, residues from the industry, municipal wastes, energy crops, agricultural wastes, residues from forestry etc. **Figure** 1 shows the biofuels classification.

Wood fuels	Direct woodfuels -	Wood from forests, shrubs and other trees used as fuel		
	Indirect woodfuels -	Mainly solid biofuels produced from wood processing activities		
	Recovered woodfuels -	Wood used directly or indirectly as fuel, derived from socio-economic activities outside the forest sector		
	Wood-based fuels -	Mainly liquid and gaseous biofuels produced from woody biomass		
Agrofuels	Fuel crops -	Growing plants for the production of biofuels	Sugar/ starch crops -	Crops planted basically for the production of ethyl alcohol as fuel mainly used in transport (pure or blended)
			Oil Crops -	Oleaginous plants planted for direct energy use of vegetable oil extracted for further conversion into a diesel substitute
			Other energy - Crops	Include plants and specialized crops more recently consideres for energy use.
	Agricultural by - products	Mainly by products from crop harvesting and other kinds of by-products from agricultural activities left in the field		
	Animal by-products -	Primarly excreta from cattle, horses, pigs and poultry		
	Agro-industrial by - products	Several kinds of biomass materials produced chiefly in food and fibre processing industries, such as bagasse and rice husks		
Animal by-products →		Several kinds solid and liquid municipal biomass materials produced in urban societies		

Figure 1 Biofuels classification. Source: Author based on (FAO, 2004)

The use of biofuels is wide however in the past years it has had a faster growth in their production for transportation purposes due to the compatibility with the vehicles engines. Several strategies had been experimented for their application to this sector since the 1980s. Biofuels are mainly produced using agricultural crops as feedstocks. The most significant are ethanol and biodiesel which are currently produced on an industrial scale. (Russo, Dassisti et al. 2012) and widely applied in means of transport. Ethanol obtained from starch or sugar by fermentation and biodiesel based on lipids from terrestrial plants are currently the main transport biofuels. **Table** 1 illustrates the production and the application of biofuels in the transport sector.

Table 1 Production and application of a variety of transport biofuels. Source: (Lucas Reijnders & Huijbregts, 2009b)

Industrial Scale production and applied in Otto and diesel motors	**Production**	**Application**
Ethanol	By fermentation from starch or sucrose	Mostly in Otto motors, pure or as blend
ETB (Ter-butylether of ethanol)	Ethanol produced by fermentation from starch or sucrose	In Otto engines, as blend
Biodiesel (ethyl-or more often methylester from long chain fatty acids	Fatty acid ester from biogenic lipids by transesterfication	In diesel motors, pure or as blend
Industrial Scale production but hardly applied in Otto or Diesel motors	**Production**	**Application**
Methane	By anaerobic conversion from a wide variety of biomass types	Combined use with gasoline or diesel in Otto or diesel engines
Vegetable lipids (oils), e.g. palm oil, coconut oil.	Extraction from oil crops	Currently limited application in diesel motors
Turpentine	Co-product from wood processing (e.g. paper production)	May be mixed into gasoline and diesel
Ethanol	By fermentation from wood hydrolysis containing sugars	Mostly in Otto motors

There are different ways to classify biofuels for transportation purposes, nevertheless one of the most used is based on the feedstock for production and the technologies used to convert that feedstock into fuel, biofuel technologies can be classified into two groups: first-and second biofuels generations or, conventional and advanced biofuels **Figure** 2. Technologies that normally use the sugar or starch portion of plants (e.g., sugarcane, sugar beet and some cereals) as feedstock's to produce ethanol and those that use oilseed crops (e.g., rapeseed, sunflower, soybean, palm oil etc.) to produce biodiesel are better known as first-generation biofuels (Russo et al., 2012). While the second generation biofuels uses technologies that convert lignocellulosic biomass (e.g., agricultural and forest residues) or uses advanced feedstock (e.g., jatropha and micro-algae). It can be understood that second generation is better that the first generation but most of the technologies and feedstock's of this second generation are in a research and pilot plants stages (Sims et al., 2010), also it is not known if this second generation could be used for large scale replacement of biofuels from sugar, starch and edible vegetable oil before 2020 (OECD, 2008; Lucas Reijnders & Huijbregts, 2009a).

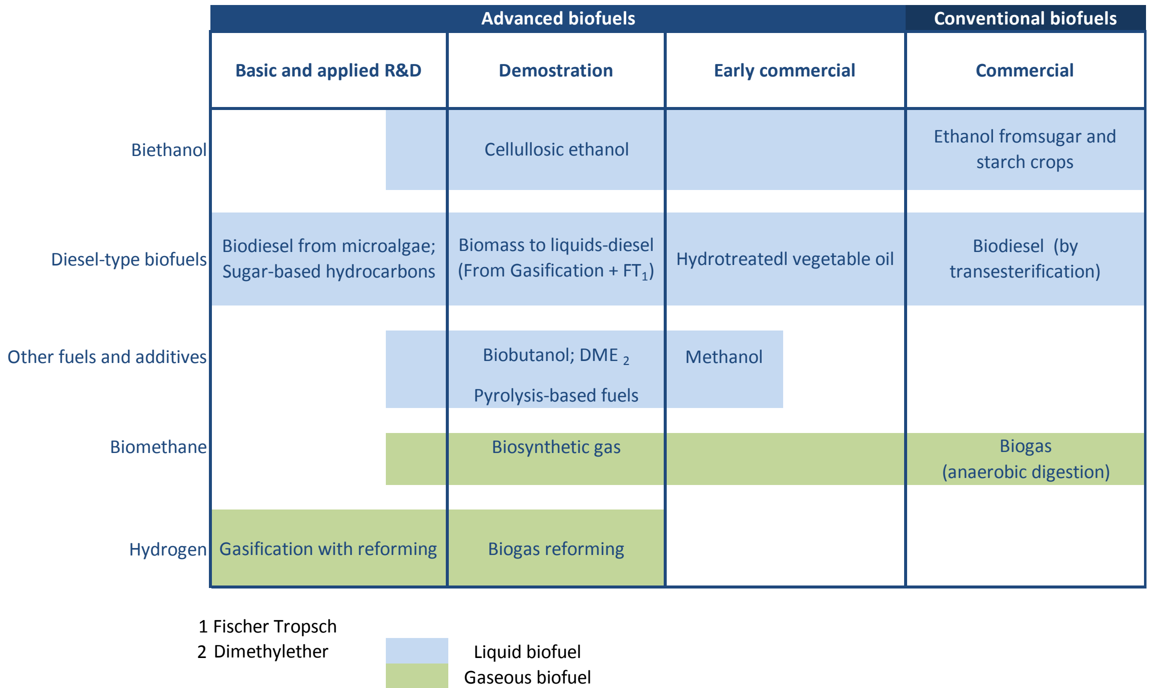


Figure 2 Classification of advanced and conventional biofuels. Source: (IEA, 2011b).

Currently the production of biofuels corresponds only to 1% of total fuel requirements; it is expected to reach 7% in 2030 and ethanol is the most promising fuel among them. Today 1% of the world arable land is used for biofuel production and by 2030 it is expected to reach 2-3.5%. (Acaroglu & Aydogan, 2012).

2.2 Biofuels for transportation

Biofuels for transportation made from plants are often called 'climate neutral' or 'carbon neutral' because the participation of plants in the biogeochemical Carbon cycle. Plants take up CO_2 from the atmosphere and convert this into biomass, and because biofuels are made from biomass when they are burned the CO_2 result as the combustion reaction is returned to the atmosphere (Lucas Reijnders & Huijbregts, 2009b).

As it is shown in **Figure** 3 different biomass feedstock sources can be used for ethanol production and lipids for biodiesel production (Rutz et al., 2007). And **Figure** 4 provides the classification according their production process.

Some authors classify two types of fuels that are based on lipids sources: Pure plant oil (PPO) and biodiesel. The feedstock production and oil extraction are same process stages for both fuels classification. However for the final production of PPO additional purification steps are necessary and biodiesel is obtained through the transesterification. Both end products (PPO and biodiesel) have completely different properties.

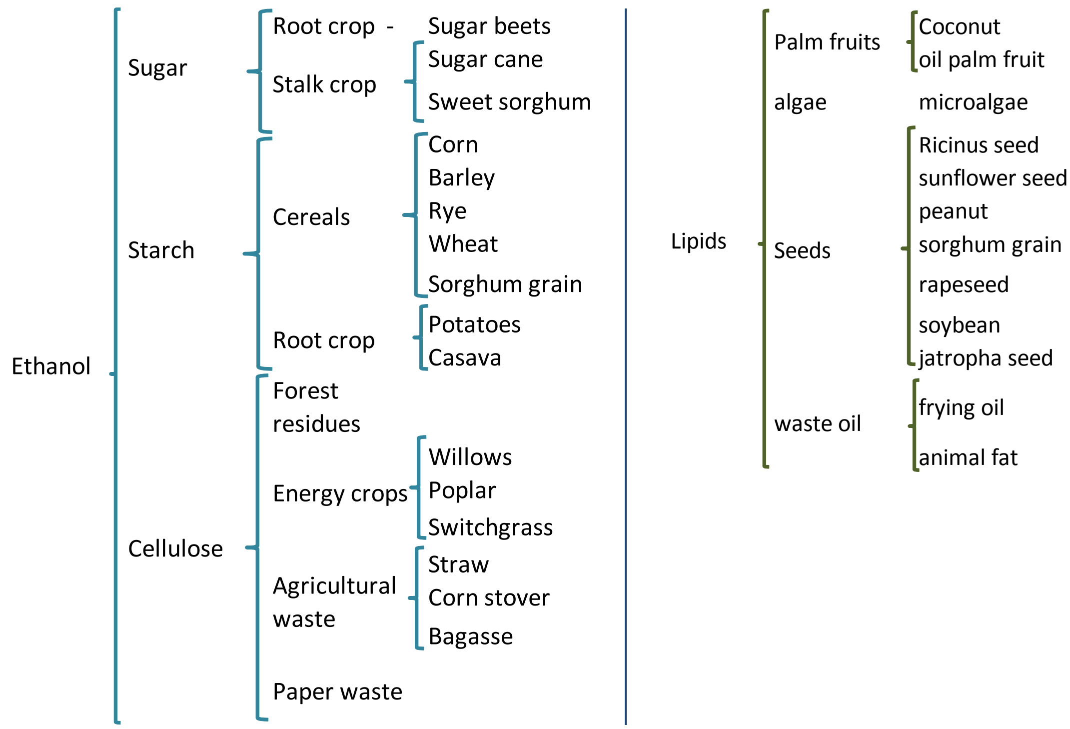


Figure 3 Different feedstock sources for biofuels production. Source: Author modified from(Rutz et al., 2007)

2.2.1 Ethanol

Ethanol, also known as "ethyl alcohol" or "grade alcohol" is colorless chemical compound. Ethanol can be produced from the fractionation of crude oil, but is more commonly produced as a product of the fermentation of biomass; when ethanol is derived from this pathway it is commonly known as 'bioethanol' (Bielaczyc et al., 2013).

Ethanol available in today´s biofuel market is mainly based on either sugar or starch plants. The biomass that contains sugar can be directly fermented to ethanol resulting the simplest way to produce ethanol. Tropical countries produce ethanol using sugar cane as feedstock e.g. Brazil. While European countries produce it from starch components of cereals which represents a very small percentage of the total mass of the plant, the cellulose and lignin which composes a great percentage of the plant, can be processed and converted to alcohol but this process is more difficult than the one of starch, there are different investigations regarding different conversion processes of cellulose and lignin to ethanol nowadays (FAO, 2008).

The two largest global markets of bioethanol as biofuel are the USA in which dominates corn as the feedstock and Brazil that uses mainly sugar-cane (Bielaczyc et al., 2013).

Ethanol can be blended with gasoline; these blends improve the combustion in vehicles, or it can be used in its pure physical state with only some modifications in the engines of the vehicles. In the market these blends are identified by an "E" followed by the volumetric percentage of ethanol in the mixture (e.g. E5, E10, and E85 are the most common blends. In 2007 almost 40 percent of all the gasoline that was sold in the USA contained ethanol; blends of E10 are permitted for sale in the European Union (Bielaczyc et al., 2013).

One liter of ethanol contains almost 70 percent of the energy that a liter of petrol gives; it has also a higher octane level when ethanol is compared with petrol, it contains only trace of sulphur which means less sulphur emissions into the atmosphere when it is burned (Rutz et al., 2007).

Nevertheless the ethanol biofuels production presents different problems from the agricultural plantations which require large amounts of cultivable land, fertile soils and water (Rutz et al., 2007), in storage and distribution ethanol-gasoline blends should be in different pipelines in order to avoid phases separation due to ethanol hygroscopic property. Highest blends are possible but require some adaptations in the vehicles engines, leading with this to the development of flex fuel vehicles that will be able to run on blends with higher percentages of ethanol and also on conventional gasoline (Lucas Reijnders & Huijbregts, 2009a).

2.2.2 Pure plant oil (PPO)

Pure plant oils also known as common vegetable oils belong to the lipid derived oils category in which biodiesel is either found, due to the similar primary processes that both fuels have, for example feedstock production and oil extraction, they can be obtained from a wide variety of oil crops such as rapeseed, sunflower, soybean, castor, some fruits e.g. coconut palms, olive trees or seeds of plants that are grown for textile purposes e.g. cotton also used oils from restaurants having the advantage that can be obtained easily because it is waste raw material, and fat from food processing can be used for the production of both PPO and biodiesel for transportation purposes (FAO, 2008; Russo et al., 2012). The differences stand in the process after the extraction. PPO needs some additional purification steps while to obtain biodiesel the oil goes through a transesterification process.

2.2.3 Biodiesel

Biodiesel is defined by ASTM International as a fuel composed of monoalkyl esters of long-chain fatty acids derived from vegetable oils or animal fats (ASTM, 2013). It is produced mixing the oilseed with alcohol and a catalyst, through transesterification process (Moser, 2009).
Biodiesel can be extracted from a wide variety of oil crops. In Europe the most common source is rapeseed, nearly 85 percent of biodiesel production is made from this crop followed by the sunflower seed oil, soybean (mainly in Brazil and the United States of America) while in tropical and subtropical countries, it is produced from palm oil, coconut and jatropha oils. Also animal fat can be used (FAO, 2008). Furthermore Biodiesel raw materials are easy to transport rather than are fossil crude oil and fuels (Haupt et al., 2010).

The biodiesel transesterification production process has two by-products (1)“crops meal” from the crops crush, which can be used for feed animals and (2) glycerin (Glycerol; 1,2,3-propanetriol) which is used as a chemical raw material in the production of polyurethanes, polyesters, polyethers also used in lubricants, foods, drugs, cosmetics and other material (Moser, 2009). Due to the different feedstock to produce biodiesel, the end product has different physical properties e.g. Viscosity, cumbustility etc (FAO, 2008).

Biodiesel and diesel are not chemically similar; biodiesel is composed of long chains of fatty acid alkyl esters while diesel is a mixture of aliphatic and aromatic hydrocarbons that contain approximately 10 to 15 carbons. When they are mixed the blend shows different properties because of each differences however it is possible to blend biodiesel into diesel in any proportion due its miscible physical properties with diesel (Moser, 2009) or it can be burned in its pure form in almost all diesel engines under certain conditions (Haupt et al., 2010). Nowadays ASTM D975 and D7467 only allow up to 5 (lower blend) and 20 vol. % biodiesel, respectively. Biodiesel-diesel blends are identified by a B followed by the volumetric percentage of biodiesel in the blend.

Lower blends are the most common used due to the energy content of biodiesel. Low blends of biodiesel with diesel maintain the energy content of the fuel (Silitonga et al., 2013), one liter of biodiesel contains 88 to 90 percent of the energy that a liter of diesel gives. The higher oxygen content in biodiesel helps the combustion of the fuel reducing emissions (FAO, 2008).

B5 Biodiesel is permitted within the EN590 mineral diesel specification across Europe (Bioroute, 2007). Furthermore according to the automotive industry a 7 percent admixture represent the highest possible blend that the engines can tolerate (Haupt et al., 2010).

Some problems in regards to the biodiesel usage appear at low fuel temperature, the viscosity of biodiesel changes and some solid formation precipitate and can be seen as engine deposits, this is associated to the presence of plant derived sterol glucosides. Also, there may be more cold starting problems. Another problem occurs with the presence of water in order to avoid the growth of micro-organisms (Lucas Reijnders & Huijbregts, 2009a).

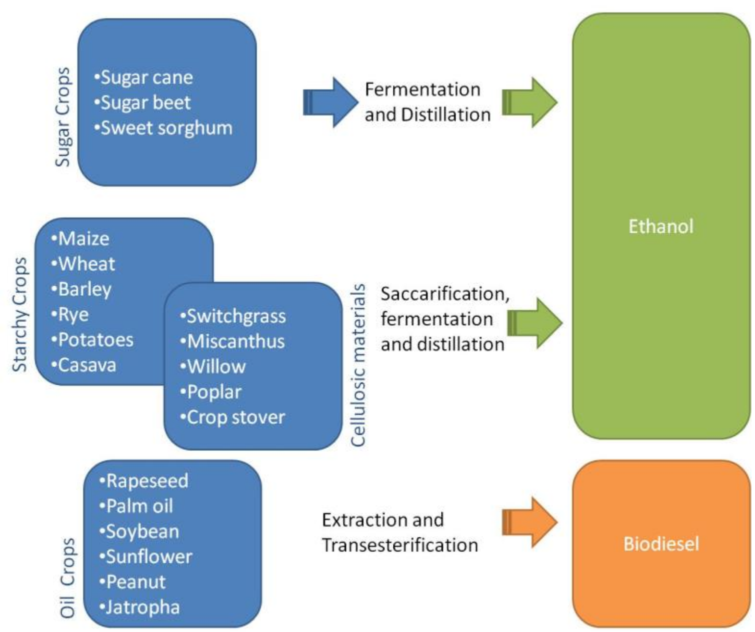


Figure 4 . Conversion of agricultural feedstock's into liquid biofuels. Source: Author modified from (FAO, 2008)

2.3 Biofuels supply chain

Supply chain, value chain or supply chain networks are some of the names that are used to describe the interactions between different independent enterprises (Dautzenberg & Hanf, 2008).

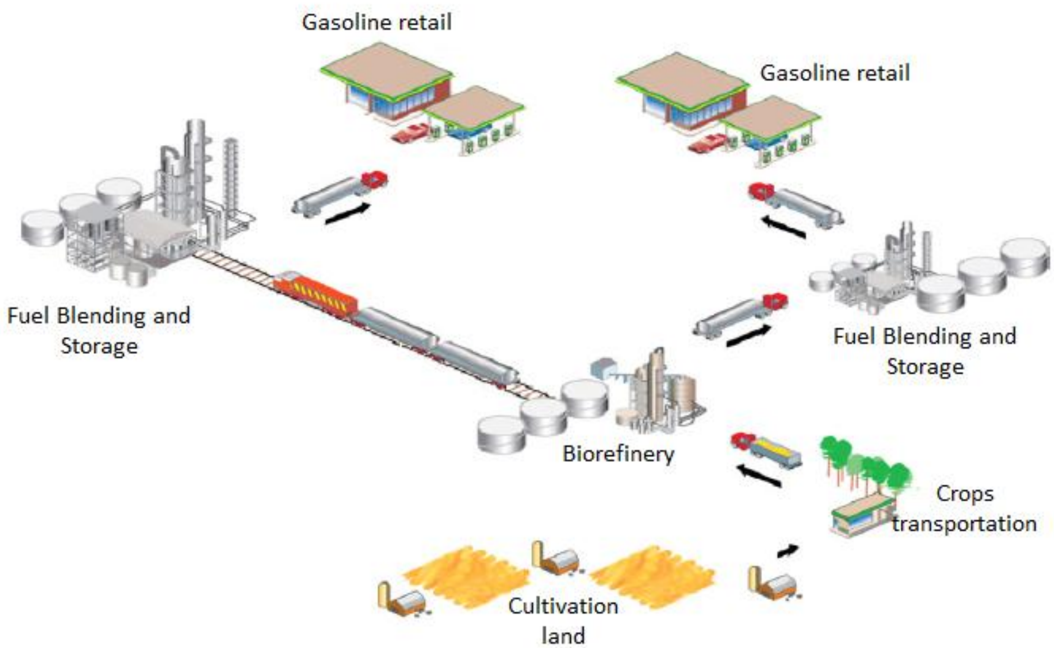


Figure 5 Biofuels supply value chain. Source: Modified from (Awudu & Zhang, 2012).

The major elements in the biofuel supply chain are described as in **Figure** 5 1) Cultivation areas, 2) Storage and transportation of crops 3) biorefinery plants, 4) Blending facilities, 5) distribution facilities and 6) Transportation / end users (Awudu & Zhang, 2012).

Generally the feedstock (biomass raw materials) is transported by trucks from different neighboring cultivation lands to the biofuel refinery plant where biomass raw materials are converted into finished goods (e.g. Ethanol, biodiesel). This finished product is transported via trucks to terminals for blending. Blends are carried out so that the biofuel product can be used for fuel purposes only. The blends are subsequently sent to the gasoline retail outlets, where they are sold together with other types of fuel (Awudu & Zhang, 2012).

2.4 Life Cycle Assessment (LCA)

Life cycle analysis or assessment (LCA) is an international renowned methodology for the evaluation of the global environmental performance of a specific product, the process or the pathway along its partial or entire life cycle. This methodology considers the impacts produced over the entire period of its life from the extraction of the raw materials from which it is made, through the manufacturing, packaging and marketing processes, and the use, re-use and maintenance of the product, on to its eventual recycling or disposal as waste at the end of its useful life (Gnansounou et al. 2009; Kiwjaroun et al. 2009). In the beginning the methodology was mainly dedicated to industrial products. Although the ISO 14040-series provides the standard for LCA, which defines LCA as "the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" and provides the principles for LCA (ISO, 2006). It has been applied in a variety of ways and thus often leads to diverging results, especially in the case of biofuels. LCA of biofuels is often limited to the assessment of energy and, or GHG balances (Gnansounou et al., 2009).

2.4.1 LCA steps

The standard also provides the steps that have to be followed to perform a LCA **Figure** 6 shows these steps. LCA is an iterative process. There are different levels of detail (from screening LCA to full LCA) (CADIS, 2012). Also LCA studies can be used to assure that all relevant environmental information is considered. Because of LCA's restriction to potential impacts, the results should be complemented with data from other tools (Sonnemann et al. 2004).

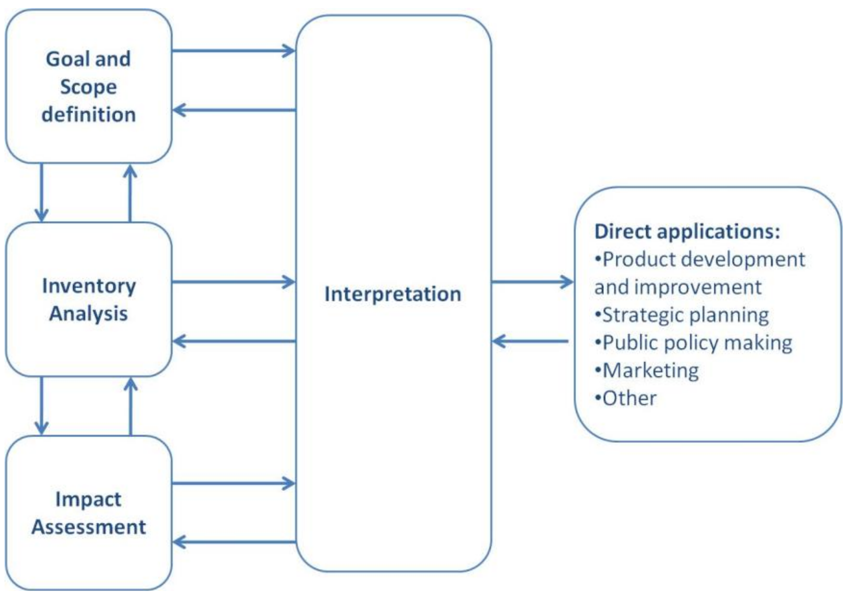


Figure 6 Steps on a LCA. Source: (ISO, 2006)

These four phases are distributed within ISO along patterns: ISO14040 (2006) provides the general framework for an LCA. ISO 14041 (1998) provides guidance for determining the goal and scope of an LCA study and for conducting a life cycle inventory (LCI). ISO 14042 (2000) deals with the life-cycle impact assessment (LCIA) step and ISO 14043 (2002) provides statements for the interpretation of results produced by an LCA. Moreover, technical guidelines illustrate how to apply the standards (Sonnemann et al., 2004).

2.4.2 Goal and Scope definition

Goal and the scope definition is the first and most important step of the methodology because it will be developed according all the decisions that are made in this step e.g. description of the purpose of the study, the expected product of the study, the system boundaries (Illustrated by an input/output flow diagram), the functional unit (FU) and all the assumptions (Poritosh et al., 2009).

The purpose of the FU is to give a reference unit to standardize the inventory data. The definition of FU depends on the environmental impact category and aims of the research The functional unit is often based on the mass of the product under study but energetic and economic values of products or land areas can be used either (Poritosh et al., 2009).

2.4.2.1 Well-to-wheel for Fuels

Well-to-wheels the most popular way to entitle the scope and boundaries when performing an LCA for transport fuels and vehicles, it also can be described as well-to-station, well-to-tank, station-to-wheel or well- to-tank depending on the components of the value chain that are incorporated in the LCA assessment and the purposes of the assessment **Figure** 7. Illustrates this concept. The well-to-wheel LCA is commonly used to assess total energy consumption, the energy conversion efficiency and emissions impact of the fuels used in different transport modes (motor vehicles, aircrafts and marine vessels) (Brinkman, 2006).

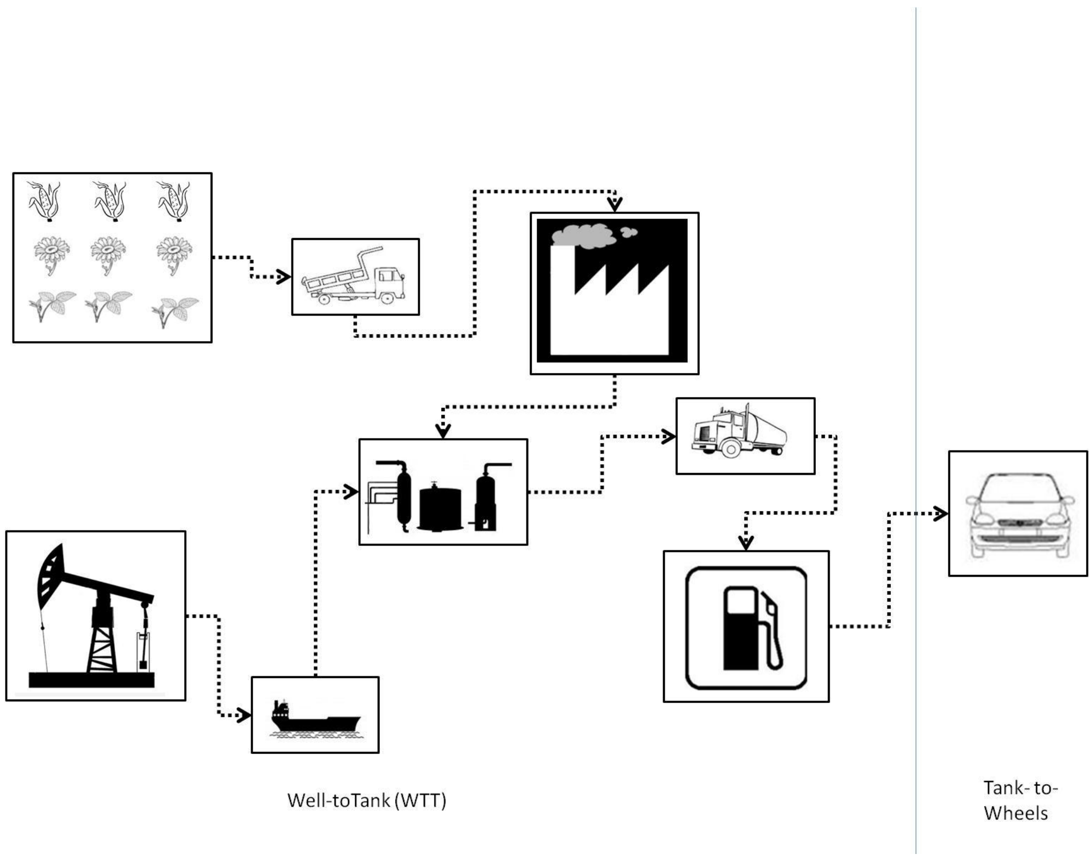


Figure 7 . Well to tank and tank to wheels analysis. Source: Author.

2.4.3 Life cycle inventory analysis

This step of the work is the most intensive and detailed of the LCA because of the data collection. This collection will depend on the information available; the ways to obtain it and the databases that exists. Data from databases can be used for different processes that are not specific for the product under investigation, such as general data on the production of electricity (Poritosh et al., 2009). However for specific products, site-specific data is required. The data should include all inputs and outputs of the different processes. Inputs could be energy (renewable and non-renewable), water, raw materials, etc. while outputs are the products and co-products, and emission to air, water and soil and solid waste generation (Poritosh et al., 2009).

2.4.4 Life Cycle Impact Assessment

The purpose of this step is to understand and to assess the environmental impacts based on the inventory analysis. In this step an impact category is given to the results of the inventory. The impact assessment in LCA generally consists of the following elements represented in the **Figure** 8.

Impact Assesment	Classification -	Is the process of assignment and initial aggregation of impacts data into common impact groups.
	Characterization -	Is the assessment of the magnitude of potential impacts of each inventory flow into its corresponding environmental impact (e.g., modeling the potential impact of carbon dioxide and methane on global warming).
	Normalization -	It expresses potential impacts in ways that can be compared (e.g. comparing global warming impact of carbon dioxide and methane)
	Valuation -	Is the assessment of environmental weight identified in the classification, characterization, and normalization stages by assigning them weighting which allows them to be compared or aggregated.

Figure 8 Elements of the impact assessment. Source: Author modified from (Poritosh et al., 2009).

An impact category is defined as a class representing environmental issues of concern into which life-cycle inventory results may be assigned (Sonnemann et al., 2004). Impact categories as represented in **Table** 2 include global effects for example global warming, ozone depletion; regional effects such as acidification, eutrophication, photo-oxidant formation; and local effects like nuisance, working conditions, effects of hazardous waste, effects of solid waste (UNEP, 2003).

Table 2. **Impact Categories and Possible indicators proposal of Udo de Haes et al. Source: Author modified from** (Sonnemann et al., 2004)**.**

Impact Categories	**Possible indicator**
	Input-related categories
Extraction of abiotic resources	Resource depletion rate
Extratction of biotic resources	Replenishment rate
Land use	Increase of land competition, degradation of life support functions and biodiversity degradation
	Output-related categories
Climate change	Kg CO_2 as equivalence unit for GWP
Stratospheric ozone depletion	Kg CFC-11 as equivalence unit for ODP
Human toxicity	HTP
Eco-Toxicity	Aquatic eco-toxicity potential (AETP)
Photo-oxidant formation	Kg ethene as equivalence unit for photochemical ozone creation potential (POCP)
Acidification	Release of H+ as equivalence unit for AP
Nutrification	Stoichiometric sum of macronutrients as equivalence unit for the nutrification potential (NP)

Impacts of the different categories have consequences on the environment and human welfare on different spatial scales that is important to differentiate. Since the economic processes are spread worldwide, local impacts have a global extension. Using as an example the climate change which affects the whole planet even if not all the regions of the world have the same need and exploit in the same way the biotic resources (UNEP, 2003). **Figure** 9 shows the differentiation in the fate and exposure analysis in different categories.

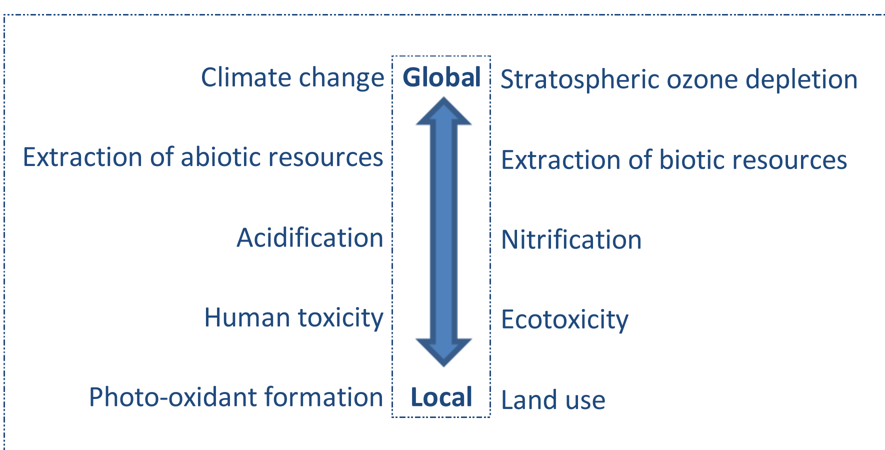


Figure 9 Spatial differentiation impact categories. Source: (UNEP, 2003)

There are different weighting methods in the impact assessment to obtain a single index; they can be distinguished according five concepts, the most used indexes are: Sustainable process index, Material intensity per-service unit (MIPS), Eco-scarcity, Eco-indicador 95, EDIP, Eco-indicador 99 and Multicriteria evaluation (MCE) (Sonnemann et al., 2004).

2.4.5 Interpretation

The objective of this step is to evaluate the results from the impact assessment and compare them with the goal of the study defined in the first phase. In this step the identification of the most important results, some conclusions, recommendations and reports are done. As it was said before the LCA is an iterative methodology, sometimes the results of the interpretation may lead to a new iteration round of the study in one of the previous steps (Sonnemann et al., 2004).

Several LCA studies in regards to biofuels have been completed with various frameworks, scopes, accuracy, transparency, regional specificities and consistency levels making it difficult to compare the results on a rational basis, even when addressing the same biofuel pathway it varies from one country to another (Panichelli, Dauriat, & Gnansounou, 2009).

2.5 Life cycle costs

For producers, there are two types of costs. First the costs paid by them and second the external costs or externalities (Pigou 1920). External costs are not reflected in the actual prices, these costs are associated with negative environmental impacts (e.g. air pollution, water pollution etc.) and the future availability of natural resources (Lucas Reijnders & Huijbregts, 2009a).

Figure 10 shows an overview of all the costs generated in the life cycle of a product and its visibility. The total costs are divided into two main types: Production and environmental. The costs with a lot of visibility are the direct ones of the producer included in the selling price to the client and generated in the phases from extraction to distribution

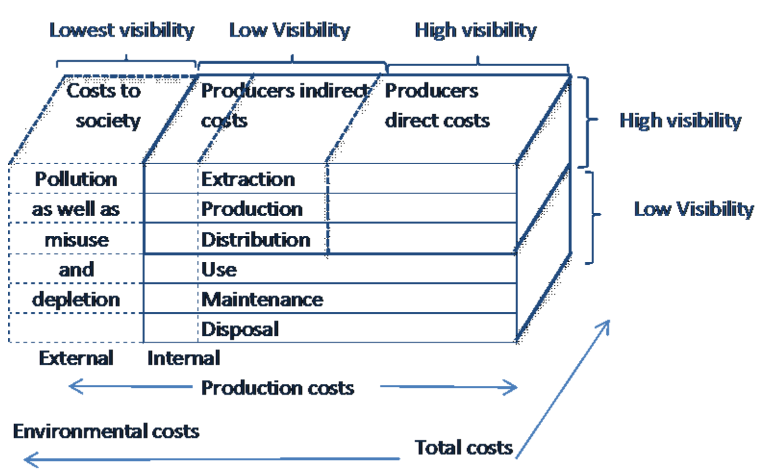


Figure 10 . Types of production and environmental costs and their visibility. Source: (Sonnemann et al., 2004)

The cost of biofuels has been discussed for long periods of time until now, especially in relation to the costs of competing fossil fuels. Two types of costs are involved: the costs of producing biofuels and costs that users have in adapting to biofuels. The latter costs are highly variable (Lucas Reijnders & Huijbregts, 2009b) and will be described in the next chapter.

2.6 Biofuels GHG reductions

Environmental concerns have become important for the development of transport biofuels. Many LCA have been done, assessing the performance of biofuels focusing only in GHG emissions. The mitigation of climate change is often mentioned as the main reason for expanding the production and use of biofuels, CO_2 is liberated when the biomass is burned, then it is supposed to be captured again by the re-growth of the biomass, but fossil fuels are still used for powering biofuel production (Lucas Reijnders & Huijbregts, 2009b).

But depending on the boundaries of the LCA study the GHG emissions can be counted. There are studies that have shown that not often are substantial improvements over current fossil transport fuels or do even worse the explanations for the contradictory results regarding the GHG emissions of biofuels are often due to differences in local conditions and the design of specific production systems, but most of them agree that a great percentage of the impact tends to come from 1) the land that is used for cultivation and the alternative land use, 2) the efficiency in nitrogen fertilization and how the fertilizers are produced, 3) whether the biofuel plant uses fossil fuels or biomass, and 4) how efficiently byproducts are utilized(Börjesson, 2009).

2.7 Land use

Soils contain organic matter which duplicates the amount of carbon that is located in the atmosphere, mainly as CO_2 (BMELV, 2007), furthermore cultivated biomass store carbon too. Because these pools of carbon are so large, even relatively small increases or decreases in their size can be of global significance. The amount of carbon stored (or sequestered) in plants, debris and soils changes as land use is altered, including when biomass is grown and harvested can result in large releases of carbon from soil and existing biomass. This situation can twirl the benefits of biofuels or their carbon neutral advantage. The most properly definition and categorization of land use is provided by the intergovernmental panel on climate change (IPCC) in his good practice guidance for land use, land use change and forestry where define land use as the kind of activity that is carried out on a unit of land and it gives also six land categories: Forestland, cropland, grassland, wetlands, settlements and other (IPCC, 2006).

Indirect land use change (iLUC) effects are not specific to biofuels or bioenergy, but to all incremental land use however when talking about biofuels production iLUC effects have an imporant impact on GHG balance of bioenergy in general, and biofuels in particular. iLUC could also negatively affect biodiversity (Fritsche et al., 2011) however there is no reliable, scientific methodology available today to include iLUC aspects in LCAs (Börjesson, 2009).

The growth of biofuel production and usage for transportation has been and is the subject of different debates. Thanks to these debates several countries have been modifying their energy, climate change and agricultural policies, the review of the main policies in regards to biofuel production and usage and the incentives that are applied nowadays in this sector will be discussed in the next chapter. Despite the last paragraphs try to describe the key issues and facts in regards to biofuels.

Chapter 3 BIOFUELS POLICIES

3.0 Introduction

Governments worldwide have fostered the development of different biofuels programs through various mechanisms of support, trying to cover sustainability concerns; however as most of the different results of LCA show, they are ineffective when talking about controlling land use change; direct land use change (dLUC) and indirect land use change (iLUC).

They also encourage the biofuels production through targets and quotas of biofuels and blends aided by support mechanisms such as mandates, subsidies and tax exemptions (Howarth & Bringezu, 2009).

Mandates for blending biofuels for vehicles fuels have been public made in at least 17 countries at a national level by 2006 (Stefan Bringezu et al., 2009). Most mandates specify a blending of 10–20% ethanol with gasoline or a blending 2–20 % biodiesel with petroleum diesel.

It is important to mention that there are some institutions such as the international standards organization (ISO) working on developing biofuels international standards that would help the broad development of biofuels worldwide with a sustainability criteria for production including inventory of initiatives, verification and auditing mechanisms among others in order to make uniform the sustainability conception in regards to biofuels cultivation, productive processes and usage (Gadonneix et al., 2010).

3.1 GHG as a Policy Driver

The substitution or blends of fossil fuels with biofuels has generated high expectations in the liquid biofuels industry as a source that could potentially mitigate the GHG releases and at the same time can contribute to energy security and support agricultural producers (FAO, 2008; Ryan, Convery, & Ferreira, 2006)

Regarding the reduction of GHG emissions, the theory explains that plants and crops that are used for biofuels purposes are based on the ability of photosynthetic organisms to use solar radiation for the conversion of CO_2 into glucose ($C_6H_{12}O_6$) and subsequently into biomass, so that the plant material effectively is the storage of solar energy and a carbon sink. The energy stored in the plant can be liberated when the biofuel is burnt which also returns the CO_2 to the atmosphere and like a perfect cycle it is supposed to be captured again by the re-growth of the biomass (Lucas Reijnders & Huijbregts, 2009a). However in the practice this circle is not closed at all. There are many inputs e.g. diesel fuel used to drive the machinery that harvest the biofuels plantations, the production process itself to convert biomass in biofuels etc. As result not all the biofuels systems can be considered equal when it comes to considering the key policy objective of reducing GHG emissions. According to this, the methodology to evaluate the GHG reduction is under discussion.

The key driver of biofuels production is the need to reduce global emissions in response to the threat of climate change. In a global scale, this is controlled by the United Nations Environment

Program (UNEP) via the United Nations Framework Convention on Climate Change (UNFCC) in which countries worldwide have the commitment to achieve different levels of GHG reductions, these match with the global target that aims to mitigate climate change (Thornley, 2012).

LCA is the most common methodology used to evaluate the GHG savings of biofuels. This takes into consideration all the energy and the material flows in and out of the system. The inputs always depend on natural variations due to soil types, human interfaces, climate conditions etc (Thornley, 2012). However there exist a wide range of calculation methodologies to measure the emissions, it depends on the policy objective, the calculation methodologies that will be developed.

Even if GHG reduction is the principal driver to create policies world wide as a strategy to mitigate climate change, it is not the only impact that must be taken into account **Figure** 11 shows some of the impacts that may be considered relevant for different biofuels production value chains. Not all of these will be relevant for all the systems. It depends on the feedstock, the processing techniques and the geographic locations of producing and the usage of the biofuels. The challenge that most of the governments have is to create policies and standards that apply to different social, cultural and geographic contexts trying to minimize the negative impacts in environmental, social and economical spheres and maximize the potentials of bioenergy.

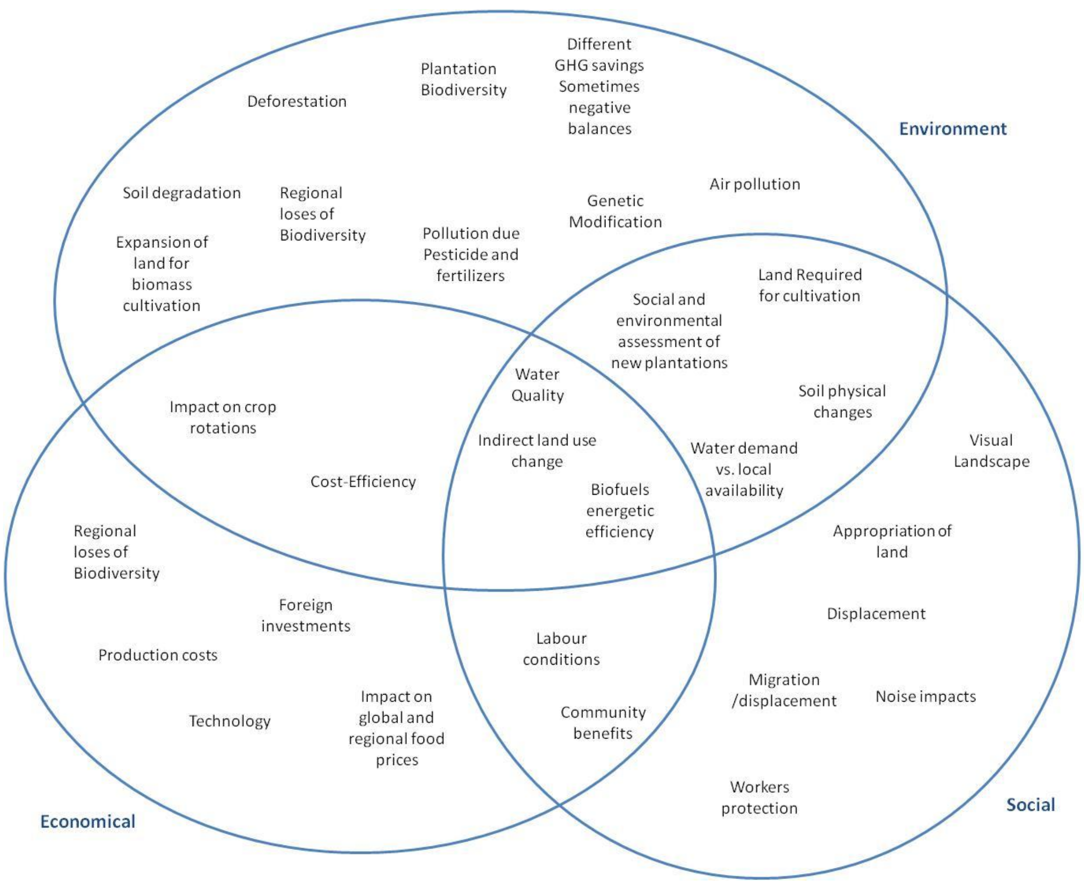


Figure 11 Economical, social and environmental impacts. Source: Author based on (Charles et al., 2007; Janssen et al., 2011; Markevicius, Katinas et al., 2010; Silva Lora et al., 2011; Thornley, 2012)

3.2 Policy category and mechanisms

From a GHG emissions perspective the most common way in which externalities associated with fossil fuel-based energy systems can be addressed and the cost could be brought into the market calculation is to penalize fossil fuel energy suppliers, this will result in an decrease of fossil fuels. The ultimate objective is to change the energy provision usage practices, fostering a behavior change of the supply companies and/or the consumers. This generally is achieved if either:

- The change is enforced by rule mandates or laws or
- There is a perceived economic advantage in making the change by different mechanisms (Thornley, 2012).

There is a wide variety of measures such as command and control instruments, economic instruments, self instruments and communication and diffusion instruments, which can be pointed at various stages of the fuel value chain. **Table** 3 summarizes some policy categories, mechanisms and instruments that have been reviewed on the topics of biofuels policies that promote the production and usage of biofuels. Furthermore the following paragraphs summarize important facts of the policy categories.

Table 3 Policy category and Instruments. Source: Author based on (FAO, 2008)

Policy category	**Instruments**
Command and control	Mandatory blending rates Tariffs on imports Certification Specifications for fuels for transportation sector/ Standards Quotas
Economic and fiscal instruments	Tax exemptions Tax reductions Different subsidies along the supply chain
Incentive economic based instruments	Incentives for the consumption Support for consumption and distribution Funding for filling stations Loans Support for Research and development
Voluntary and communication Instruments	Campaigns International and national standards for liquid Biofuels Certificate schemes

3.2.1 Command and control instruments

Command and control instruments involve a government issuing a command, which sets a standard and then controlling performance by monitoring and requiring adherence to that standard. It is most commonly applied to pollution issues, where a command might be that a facility will emit more than 'z' units of pollutant per measured output unit or measure. In the case of reducing GHG emissions and promoting biofuels the pollutants of concern would be GHGs, the command and control approach would therefore equate to setting a maximum limit on the amount of GHG emissions per unit of energy produced (Thornley, 2012). If a maximum GHG limit were applied, it would be easy to determine whether fossil fuel based plants meet the standard or not because most of the GHG emissions are related to the fuel burn. However, as discussed earlier for biomass, the CO_2 emissions that are difficult to be considered are those involved in harvesting, producing, processing and transporting, which require complex calculations with many uncertainties. These uncertainties are often because of the lack of knowledge of all the steps of the biofuels value chain (e.g. which fertilizer is used or how far materials are transported etc.).

3.2.2 Economic & fiscal Instruments and incentive-based instruments

Economic and fiscal Instruments consist of energy or carbon taxes, tax exemptions and reductions, capital subsidies and grants that stimulate and protect domestic producers.

Incentive based instruments encourage the use of bioenergy from lower carbon intensity sources compared to those with higher carbon intensities. This should result in a financial incentive for the consumer that chooses the low carbon energy supply source. However, in some cases, it is insufficient to narrow the gap between a higher cost, low carbon energy form, and a fossil fuel equivalent (Thornley, 2012).

3.2.3 Voluntary and information Instruments

Voluntary instruments in this context describe activities that lead towards a reduction of negative environmental impacts; these are introduced and implemented by organizations or governments based on a free (voluntary) decision and also try to go beyond the requirements of legislation, that try to contribute a sustainable production and consumption. Some examples are different campaigns for promoting the usage of gasoline blends, some certification schemes that prove the sustainable production of different crops for biofuels and biofuels etc.

3.3 Allocation of policies in the biofuel supply chain

A wide variety of instruments to support the production and usage of biofuels have been stated in the different stages of the supply value chain as it is shown in the **Figure** 12 and organized in **Table** 4.

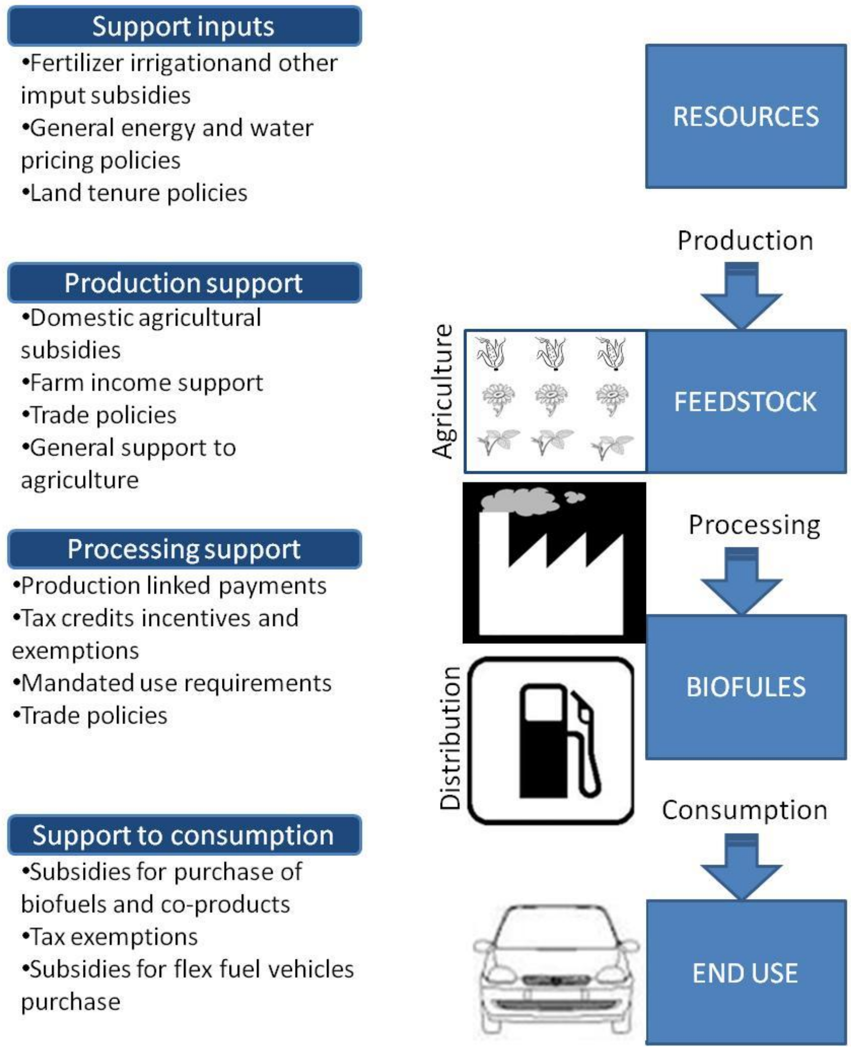


Figure 12 Policy instruments provided at different point in the biofuel supply chain. Source: Author based on (FAO, 2008)

Table 4 Biofuel supply chain and the policy instruments. Source: Author based on (FAO, 2008; Pelkmans, Govaerts, & Kessels, 2008; Thornley, 2012).

Supply value chain	Command and Control Instruments	Economic and Fiscal Instruments	Incentive based instruments	Voluntary and communication instruments
Agriculture	• Regulations and legal issues on the use of waste products for biofuel production • Sustainability requirements for the production of feedstock (mainly growth of energy crops) for biofuels	• Direct subsidies • Subsidies for sustainable energy crops in the frame of regional development. • Support to use waste land for energy crops • Pricing policies for feedstock	• Funding o Research and development for applicability of energy crops and crop yield o Set-up collections systems for waste products and residues	• Networking between farmers associations and the fuel sector • Partnerships and contracts of farmers and biofuel producers • Information campaigns towards the farmers on energy crops • Information campaigns to increase public awareness on collection of residues and waste streams and their value as feedstock for biofuels
Biofuel production	• Fuel quality standards for biofuels and control system • Sustainability requirements for biofuels • Quota system for biofuel producers, linked to tax reductions • Regulations concerning import of biofuels (quota, import tariffs, etc.)	• Direct investment and subsidies for biofuel production facilities • Tax incentives to biofuel producers to lower the production cost of biofuels	• Financing schemes for biofuel production facilities • Funding of research and development for more efficient biofuel production and new biofuel feedstock (e.g. waste products, cellulose)	-
Distribution	• Standards o Fuel quality standards for biofuels o Fuel standards of fossil fuels (allowing certain proportion of biofuels) o Labeling of fuels with a level of biofuel • Mandates of biofuel blending, certain share of blending of fossil fuels with biofuels is obligatory. • Biofuels obligation: A fuel supplier has to ensure that certain share of sold fuels is biofuels. • Mandates for fueling stations to offer biofuels	• Tax reduction or exemptions for biofuels to get competitive with fossil fuels • Direct investment and subsidies for infrastructure adjustments (or new infrastructure)	-	• Voluntary agreement with fuel distributors for the uptake of biofuels in their fuel sales. • Voluntary agreement with fuel distributors to apply sustainability certification for the biofuels they purchase. • Information campaigns towards fuel distributors on the technical implications of the use of biofuels in their infrastructures
Market and end users	• Mandates for vehicle manufacturers to produce and sell biofuel compatible vehicles models • Adapt fuel standards to higher biofuel blends • Type approval regulations for new technologies • Labeling of biofuel compatible vehicles • Exemptions from certain restrictive regulations (exemptions from parking and driving restrictions)	• Subsidies for the purchase of biofuels-compatible vehicles on for conversion costs • Tax incentives for biofuel-compatible vehicles (e.b. yearly vehicle tax) • Tax reduction or exemption for biofuels to get competitive with fossil fuels • Tax incentives for biofuel compatible vehicles (yearly vehicle tax) • Subsidies for the purchase of biofuels compatible vehicles or for conversion costs	• Funding of research and technology development for application of high biofuel blends in vehicles • Demonstrations efforts for application of high biofuel blends in vehicles • Pricing policies o Road pricing o Parking fees	• External information and awareness campaigns o Establish clarity on the advantages and disadvantages of biofuels o Public educational efforts • Marketing focusing on the advantages of alternative motor fuels • Vehicles buyers guides and vehicle labeling • Leadership by example. Governments, public transport companies, or private companies include environmentally friendly vehicles in their fleets to serve as example for other potential users

3.4 EU Energy biofuels policies

The introduction of biofuels as energy source began in the early 1990 **Table** 5 shows an overview of the main documents on European level related to biofuels usage.

Table 5. Policies, standards, directives, amendments in regards to biofuels. Source: Author modified from (Pelkmans et al., 2008)

Year	Documents
1992	Common Agricultural Policy (CAP) Bioenergy crops on set aside
1997	White paper on renewable energies
2000	Green paper on energy supply security
2001	Communication on alternative fuels for road transport
2003	Biofuels directive (indicative targets 2% by 2005, 5.75% by 2010)
2005	Biomass action plan
2006	EU biofuels strategy
2007	Renewable Roadmap & revision of the biofuels directive. Draft revision fuel quality Directive (up to 10% ethanol blending; transport fuel GHG reduction 1% per year between 2010 and 2020)
2008	Draft renewable energy directive (binding target of 10% of renewable fuels in total gasoline/diesel sales by 2020, sustainability criteria for biofuels)
2009	(2009/28/EC) Directive on the promotion of the use of energy from renewable sources. It contains regulations, requirements and guidelines in order to demonstrate sustainability criteria in all the value chain of the biofuel for transportation purposes.
2012	Proposal to modify the directives: Fuel Quality directive (98/70/EC) Renewable energy directive (2009/28/EC)

Even if the production began in 1990 in 2000 biofuels production in Europe has grown significantly thanks to considerable investments. The two main purposes identified of this expansion of biofuels were that they had seen as an a striver to relieve climate change and to provide fuels for the transportation sector due to the rising petroleum prices that creates scarcity of conventional fossil sources. The European Commission set in 2003 the basis for the promotion of the use of renewable energy in the transportation adopting legislative in order to promote the use of biofuels among its member states (Lindberg & Steenblik, 2007).

This legislative act was entitled "Directive on the Promotion of the use of biofuels and other renewable fuels for transport Directive (2003/30/EC)" it laid down indicative targets for biofuels use in transport in the European Union from 2005 up to 2011, indicative means that the targets were not mandatory for the member states (Gadonneix et al., 2010; Lindberg et al., 2007).

Because most of the EU member states were very slow in promoting renewable energies for transport purposes. In 2005, the European Union Commission (EUC), analyzed the situation and figured out that that only 1.4% of the fuels consumed in the transportation sector of the EU, were from renewable sources (biofuels). This finding was completely different from the increment on biofuels consumption that was expected. For this reason the EUC, in January 2008, submitted a proposal as part of the EU's climate protection and renewable energies regulations package in which the voluntary targets would become obligatory targets for all member states (Haupt et al., 2010) . This background defined the development of the EU biofuels sector during the coming years.

3.4.1 European Renewable Energy Directive- RED Biofuels part (2009/28/EC)

As mentioned before, in 2008 the EUC presented the proposal of a directive for the promotion of renewable energies in the energy matrix of the EU members (Renewable Energy Directive, 2009/28/EU). This proposal had been extensively discussed in the Trilog, which consists of the European Council, the EUC and the European Parliament.

One of the most discussed points was regarding the sustainability criteria of biomass for bioenergy cultivation and the corresponding regulations to ensure it, because during that time period the market price of crude oil increase and in an domino effect the crops for food increased too. The consequence of this oil crisis was the debate "food versus fuel". The European Parliament determined a directive which includes specific regulations with the purpose to ensure a sustainable biomass production in the EU and in third countries that export biofuels or biomass for biofuels feedstock´s to the EU (Haupt et al., 2010).

The "Directive on the promotion of the use of energy from renewable sources RED (2009/28/EC)" was published in the Official Journal of the EU in June 2009. This directive contains regulations, requirements and guidelines in order to demonstrate certain level of sustainability when talking about biomass for bioenergy (biofuels) that contemplate the origin, cultivation and GHG balance of biofuels (Haupt et al., 2010). After the publication of the directive (2009/28/EU) the member states were asked to introduce the directive in their respectively national laws within a time framework of eighteen months.

To favor the sustainable production and usage in a domestic and international trade of biofuels is the basis of the RED biofuels part, the directive contains a set of environmental criteria that have to be met by liquid biofuels (Thornley, 2012).

These criteria are based on seven key principles:

- Preservation of biodiversity lands
- Loss carbon in soil consideration
- Wetlands and of forest protection
- Compliance with the EC agriculture requirements
- Encouragement of voluntary agreements on environmental and social issues
- monitoring the environmental impacts
- Support for wastes, nonfood, and no irrigated crops for biofuels feedstock´s (second generation

Furthermore these criteria should be considered over the entire supply chain, beginning with the crops cultivation and its transport, through the production process of the biofuels. It was expected that with the implementation of this directive biofuels could save at least 35% GHG and meet other sustainability criteria along the entire production and supply chain in 2011, 50% from 2017 and 60 % from 2018 (Naumann & Majer, 2012).

Also other directives that are Included in the renewable energies package are the energy taxation directive (2003/96/EC) and the new directive on the quality of petrol and diesel fuels (2009/30/EC) and some facts of these directives are summarized in **Table** 6

Table 6 Code, directive and description of EU directives included in the renewable energy package. Source: Author based on (Gadonneix et al., 2010; Jung, Dörrenberg, Rauch, & Thöne, 2010**; Naumann & Majer, 2012**)

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Code	**Directive**	**Description**
(2003/96/EC)	*ENERGY TAXATION DIRECTIVE*	The EU introduced this Directive in order to compensate for the higher costs of producing biofuels. The main points are: ✓ Energy taxation to be imposed. ✓ Member States are allowed to reduce or exempt excise duties to promote the use and production of biofuels. ✓ Exemption must be proportionate to biofuel blending levels. ✓ The exemptions may apply for a maximum period of 10 years.
(98/70/EC)	*THE FUEL QUAILITY DIRECTIVE*	This directive sets limits to the share of biofuels in blended fossil fuels (5%). The limit was established taking into account the potential for increased pollutant emissions with higher proportions of oxygenates in the petrol and reviewing the compatibility problems of ethanol with fuels system components
2009/30/EC	*AMMENDMENTS TO THE 98/70/EC FUEL QUALITY DIRECTIVE*	The most considerable amendments: ✓ The maximum increase share of ethanol in blended petrol fuels to 10 per cent. ✓ Any diesel fuels with fatty acid methyl ester (FAME, diesel) content up to 7 per cent may be placed on the market, independent of other requirements for diesel fuels.

3.5 Other countries

Biofuels are now in the process of passing from an initial pioneering stage to a mature market in some regions of the world such as the EU member states, USA or Brazil. A wide range of technologies and policy measures are available in these countries that try to reduce the impacts that the biofuels industry has. It is also important to review the different histories of biofuel introduction and the policy instruments that these countries use to support or hinder the usage of biofuels. The factors that most of the countries have in common to support the biofuels industry are: The GHG savings and the reduction of oil imports

The next sections present a summary of some of the largest producing nations in regards to biofuels.

3.5.1 United States

Historically, the USA biofuel policies have focused on the research of alternatives for petroleum fuels with high interest during world wars I and II and the energy crisis of the 1970´s when the oil supply was interrupted, most of the time the attention was attracted by the ethanol industry (Sorda et al., 2010). In 1978 the Energy Tax Act established tax credits for ethanol blenders.

Legislation such as the clean air act amendments (CAAA) and the energy policy of 1992 opened the markets for alternative fuels that can be produced from US domestic resources and give an environmental support advantage over petroleum based fuels. Renewable fuel standards of 2005 and 2007 fostered biofuel production in the USA. The main feedstock over the years had been corn; however research is and has been conducted to create ethanol from cellulose (Pelkmans et al., 2008).

Since the1970s all gasoline powered vehicles sold in the US can run on E10. It also has a long ethanol history, which is mainly focused on blends up to 10% (gasohol) Biodiesel is expanding rapidly; however its production level is still 10 times lower than ethanol (Sorda et al., 2010).

3.5.2 Brazil

Brazil has the most developed and integrated biofuels program in the world, it is the country that has gone further in regards to large scale production and usage of biofuels in the transportation sector. The development of the biofuel industry took place on the oil crisis of the 1970´s. This led to create a National Alcohol Program "Proaclcool" this program was a response to high oil prices, sugar low prices and an excess production of sugarcane production. The objective of the program was to provide a stable demand for the excess production of sugarcane. The government also made agreements with the automotive manufacturers in order to develop a market for flex fuel automobile; with these actions in 1985 the 96% of automobiles sold in Brazil were ethanol powered achieving a successful commercialization of biofuels (Pelkmans et al., 2008).

The "Proalcool program" was formed of two phases. Phase one (1979-1979) the policies dictated by the government looked forward to facilitate industry expansion and higher conversion rates (mixtures gasoline-alcohol)The Brazilian experience with mixed fuel showed that conventional gasoline engines could efficiently operate using a mixture of up to 20% of anhydrous ethanol.

During the second phase (1980- Onwards) the Brazilian government introduced the use of ethanol fuelled cars. The technology for these cars was primarily developed at public research centers and then passed to the private sector.

The Brazilian case shows the importance of integrative policies, promoting the market of renewable energies but also capturing the attention of the private sector (Sorda et al., 2010).

3.5.3 China

China like other countries, is promoting the development of liquid biofuel for transportation (ethanol and biodiesel) however in contrast to other countries China has an impressive economic growth, that led also to increase the energy consumption, and also it has become the number one when talking about GHG release. Due to these facts, China is under great pressure to take actions to tackle the emission issue (Qiu et al., 2012).

In terms of liquid biofuel production, China is now the fourth largest producer in the world after the United States, Brazil, and the EU. Five large-scale bio-ethanol plants were constructed between 2001 and 2007, which had a combined annual production capacity of 1.87 million tons in 2008 accounting for 79 percent of the total bio-ethanol production in China.

Since 1980´s China has been supporting biofuel development trough investments in research and development and biofuel technologies. In 2002 there were pilots programs of ethanol-gasoline blends E10 for automobiles in 5 cities, two years later (2004) the pilot program entered to its second phase in which it incorporated 27 cities for expanding the testing of the blends. During 2004-2007 different command and control, and fiscal policy instruments were incorporated to foster the R&D, production and usage of biofuels in the transport sector (Qiu et al., 2012)

Chapter 4. METHODOLOGY

4.0 Introduction

In order to respond the main and the specific objectives of this work, different data and different analysis were needed. They were chosen from a series of different methods; the theory of the methodology used was explained in chapter 2 and 3. **Table** 7 summarizes the methodological features of this work. The data collection, the data analysis and the scope of this research are explained in this chapter.

Table 7 . Research methodology. * Three concerning tags sent to experts on the field in order to corroborate and retrieve data. Source: Author.

Specific objective and keywords	Data sets	Kind of data	Retrieval methods	Analysis and interpretation
S. objective 1. Analysis and description of the current situation	Theory on Biofuels in Germany	Qualitative/ Quantitative	Literature Review	By relevance and up-to-date quality
S. objective 2. Analysis of the Environmental Impacts	Theory on life cycle analysis, life cycle analysis reports	Qualitative/ Quantitative	Literature Review Experts Consultation*	Qualitative and quantitative data analysis according to its relevance
S. objective 3. Analysis of the Governmental policies along LCA	Reports, laws, decrees, mandates, etc	Qualitative	Literature Review Experts Consultation	Qualitative and quantitative data analysis according to its relevance
S. objective 4. Methodological advances	Findings processed and analyzed information	Qualitative	Research development	Analysis and Interpretation of the data and (SWOT matrix)

4.1 Data Collection

Information can be obtained from secondary or primary research. Secondary research means taking the information from material that already exists; these can be reports that reflect the results of previous studies carried out by governments, published statistics, available academic reports and available studies However when the information needed is not available, new data has to be generated and collected by different methods (e.g. Experts consultation, observations, simulations, etc.) This quest is called primary research, depending on the kind of research which is performed to obtain the data; the data can be called primary or secondary data (WestBerlshire, 2010.

In this work the research methods to collect the data are based mainly on secondary data), and in some cases it was either obtained or crosschecked with expert consultation in order to ensure the most accurate results.

The expert’s consultation was made in order to gather enough information (specific research data, general research data or a specific point of view) to form a perspective about the incentives, barriers and impacts regarding biofuels production and consumption in Germany with the purpose to generate ideas to mitigate those impacts. **Annex** A. EXPERTS CONSULTATIONprovides more information regarding this part of the data collection.

Due to the large amount of literature available in the topic, the information was classified in three categories that are described below:

<u>Policy instruments</u>
Laws, directives, mandates and guidelines were collected from secondary research method mainly from the European Commission platform (EUC, 2013) which provides different sets of links with the EU member’s current legislation in different fields (e.g. agriculture, energy, economics, etc.)

<u>Case study.- Specific data on biofuels value chain</u>
The cultivation area, production volumes of biofuels feedstock’s (rapeseed, wheat), consumption (blends or pure oils) and the imports & exports, were taken from the Federal statistical office in Germany (Statisches Bundesamt) (DEStatis, 2013) for 1995 to 2011 and then crosschecked with the EU statistic data bases(EU, 2013).

<u>Case study.- Environmental data and energy of biofuels value chain.</u>
The first LCA studies about German biofuels pathways appeared in 1990´s. An interesting finding is that these studies incorporate topics which are today´s hotspots such as direct land use and co-products allocation methods. Other feature is the way in which they collect the primary data, most of them use other press publications or make assumptions over assumptions already made by other authors which makes it complex to analyze the current and real situation.
All these studies are classified as shown below and further information about them can be seen in the **Annex** D 2. QUALITATIVE ANALYSIS

- Studies that review and synthesize others’ LCA-related work on biofuels
- Original LCA studies comparing biofuel with fossil fuels
- Studies that develop LCAs in detail for biodiesel and bioethanol
- Studies focusing on LCA of alternative biomass production systems and FT

The collection, classification and analysis of the data were done according to the steps on a LCA in which the interaction among the goal, the data inventory, the impacts assessment, the interpretation and the public policy making analyze and describe in a comprehensive way the biofuels production and consumption in Germany. **Figure** 13.

This thesis identifies policy instruments not only as a direct application of the LCA methodology but as the tools used by governments to achieve a desire objective in an iterative process. This work does not aim to assess biofuels sustainability; however it is important to notice that features of the social and economic spheres have to be included in further works in order to obtain a complete panorama of the biofuels current situation and the policy making process in Germany.

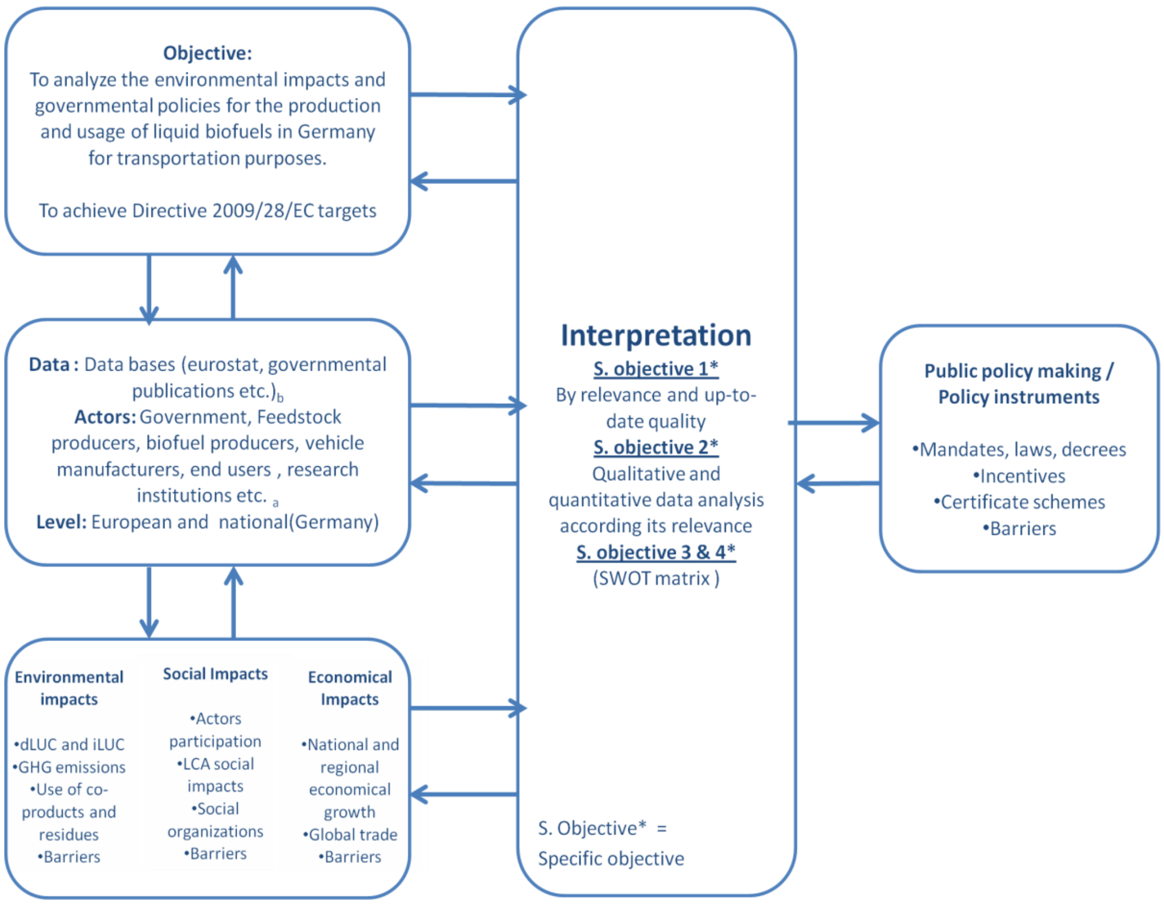

Figure 13 Steps on a LCA adapted to this study (ISO, 2006). Source: Author. a) Actors are described in chapter 5.1 Case Study, b) the data bases used were eurostat and are explained in chapter 5.1 Case study, c) data from available LCA reports in regards to biofuels explained in Chapter 5.2 Environmental assessment, d) Policy instruments explained in chapter 5.1 Case study.

4.2. Data analysis

The data analysis was performed in two parts, the first part corresponds to the case study analysis in which its characteristics regarding fuel and biofuels production and consumption are described and the second part is dedicated to the environmental impacts analysis.

The current focus on the quantitative measurement of environmental impacts based on the LCA methodology is on GHG emissions. Other important environmental impacts are being addressed in biofuels policy in a mixture of actions including quantitative targets such as minimum net GHG emissions savings, and exclusion clauses such as rules which specify that biofuels cannot be derived from biomass feedstock´s grown on certain types of land (rain forest, grasslands, recently natural forest, etc.). Because this work aims to link the LCA methodology to with the policy analysis, the environmental impacts with a strong focus on the quantitative measurement of GHG emissions were chosen in order to describe and analyze the situation in regards to biofuels production and usage in Germany assessing its environmental performance based on the available LCA studies.

The tool used to analyze the current situation in terms of challenges and opportunities for the production and usage of biofuels in Germany is a SWOT-matrix. SWOT stands for strength, weaknesses, opportunities and threats; it is an analytical method to analyze internal strengths and weakness and its opportunities and threats in the external environment. This tool was chosen in order to facilitate the writer to provide its opinion about the current situation in regards to the production and consumption of biofuels in Germany. This analysis is made exclusively based on the literature review and some information was retrieved by mail communication from some experts in the biofuels and policy field.

4.2 Scope of this study

In order to describe and analyze the current situation in regards to biofuels production and usage in Germany some interactions were identified and reported in **Figure** 13, however the social and economical features are not described in this work.

4.3.1 Constraints on secondary data collection

Most countries in the European Union have biofuels websites platforms that show the advance of each country in the biofuels field in order to achieve the targets of the Directive 2009/28/EC. However Germany does not have this kind of platforms, the available information is spread in different data bases and depends on the position and the function of the respective ministry in regards to the energy policy.

Scientific research is available, although most of the studies in regards to biofuels for transportation in Germany use or are referred to the same database (Ökobilanz 2000). One of the reasons to this is that no further changes are realized in recent years.

Information about the certificate schemes (reports and results) that assess the sustainability of the biofuels supply value chains in compliance with the sustainability criteria of the DIRECTIVE 2009/28/EC is not provided in this study due to the fact that it belongs to private enterprises that by law are not required to provide this.

4.3.3 Constraints of the environmental assessment

The large differences that were found in the literature review makes it difficult to harmonize, compare and report the results. The reports reviewed were grouped and reported according some of their characteristics (GHG emissions, climate change potential, acidification and Eutrophication). The differences found in the reports were highlighted and discussed in order to provide some recommendations to further work on the field.

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Chapter 5. POLICIES AND LIFE CYCLE ASSESSMENT FOR THE PRODUCTION OF BIOFUELS IN GERMANY. RESULTS AND DISCUSSION.

5.1 Case Study

Germany is the major economy in Europe and the second most populated nation (after Russia) with 81,147,265 inhabitants. It is located in central Europe, bordering with the Baltic Sea, North Sea, Denmark, Austria, Belgium, Czech Republic, France, Luxemburg, Netherlands, Poland and Switzerland as can be seen in **Figure** 14. The geographic coordinates are 51 00 N, 9 00 E with a land extension of 357,022 sq km (CIA, 2013), with an administrative division of 16 states (Naumann et al., 2012).

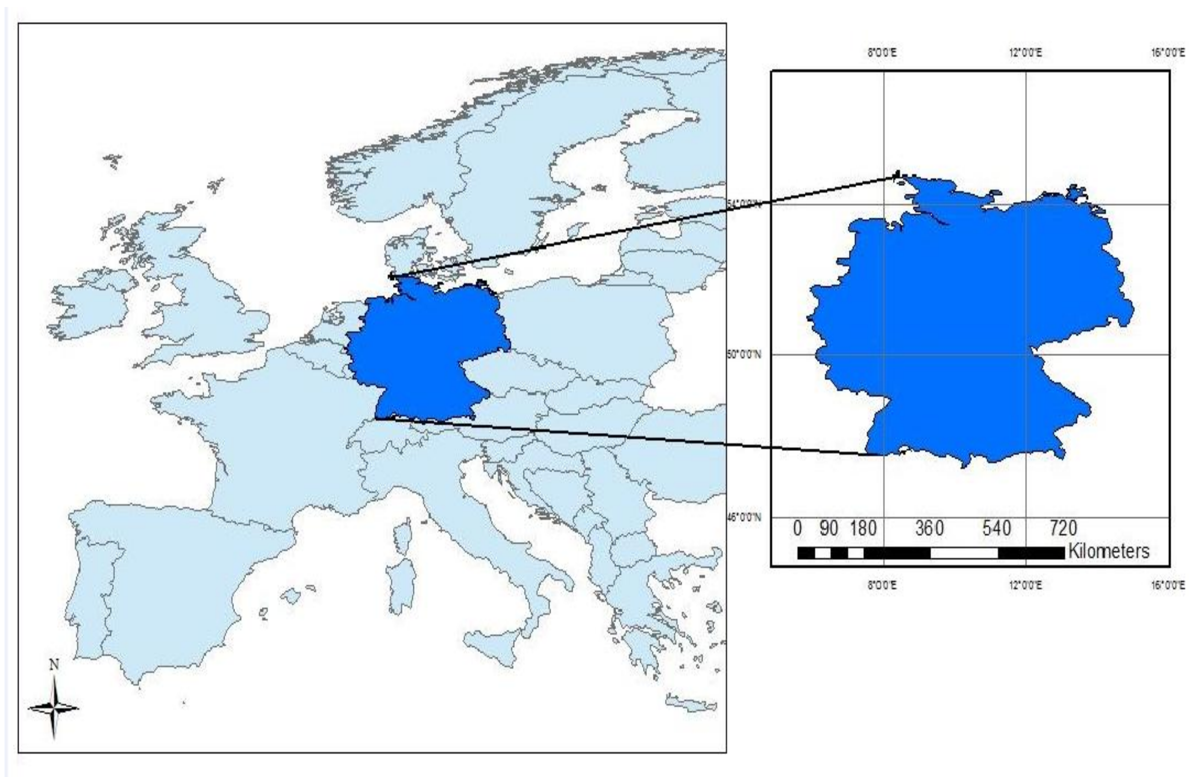


Figure 14 Location of Germany. Source: Author.

5.1.1 Land use in Germany

Germany has a land extension of 357,022 sq km (35.7 million ha), despite its dense population almost half of the land area (47%; 16.7 million ha) is used for agriculture purposes e.g. Arable land and permanent crops: 34% of 12.1 million ha (1% vineyards, orchards, tree nurseries) and grassland: 13% 4.6 million ha. Forest made up 30% of the land with 10.8 million ha. There exist nearly 272,000 farms that supply different goods and energy crops (BMELV, 2013).

Table 8 shows the cultivation of different resources grouped into goods for industrial use and crops for biofuels.

Table 8 Cultivation of raw materials and energy crops. * Estimated data. Source: (BMELV, 2012a).

Plants	Commodities	2011	2012*
Industrial use	Industrial use	160000	245000
	Sugar industry	10000	12000
	Rapeseed oil	120000	120000
	Sunflower oil	8500	8500
	Linseed oil	2500	2500
	Fiber plants	500	500
	Medical plants	10000	13000
	Total	311500	401500
Crops for biofuels	Rapeseed for biodiesel and vegetable oil	910000	913000
	Crops for ethanol	240000	243000
	Crops for Biogas	900000	962000
	Crops for solid biofuels	6000	6500
	Total	2056000	2124500
Total		2367500	2526000

As can be seen in **Figure** 15, since 2003 the cultivation of renewable feedstock has increased enormously in Germany. However, there is a limited amount of agricultural area that is not in use. In 2011 the area dedicated to cultivate biofuel feedstock equaled 2,056,000 ha which is the 5.75 % of the territory.

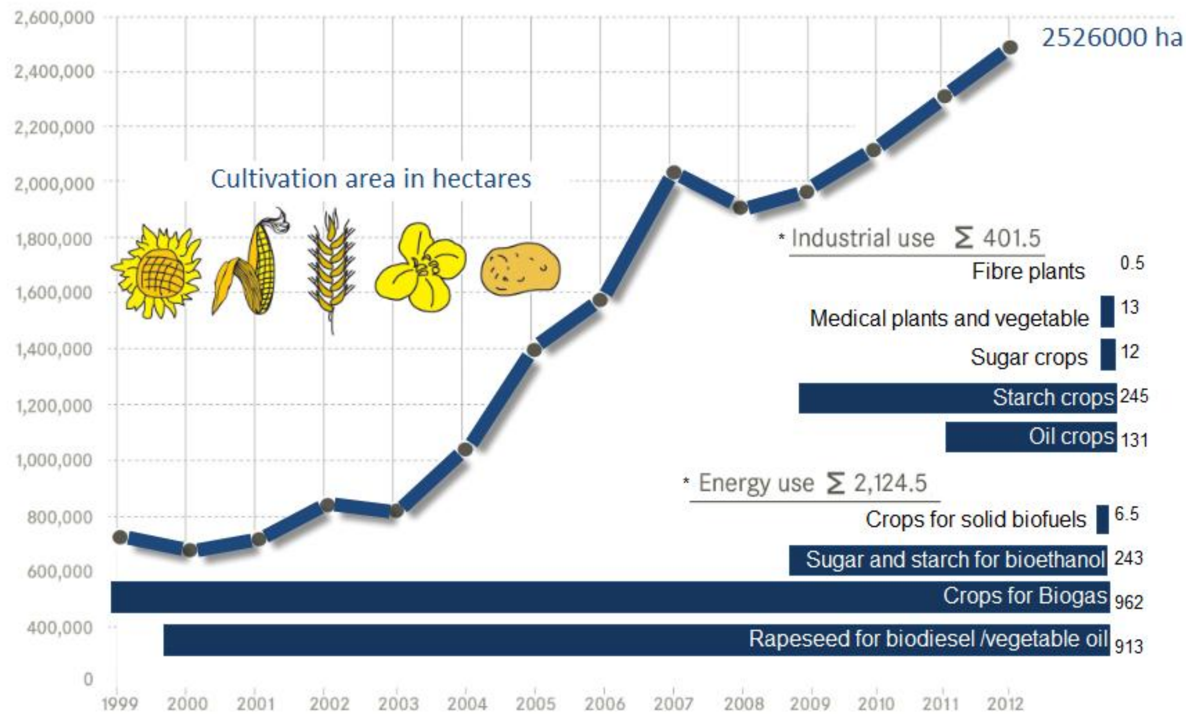


Figure 15 Cultivation of renewable resources in Germany. Numbers given in 1000 Ha; *2012 Forecast data. Source: Author modified from (BMWi, 2013).

The EU territory is under an economic territorial classification system called NUTS (Nomenclature of territorial units for statistics) which is a system for dividing the territory in order to collect, develop and harmonize the EU regional statistics, and as Germany is part of the EU it has the same classification which facilitates the measurement of land uses of its territory (EUC, 2012). **Annex** B. LAND USE IN GERMANY (NUTS and LUCAS)provides more details regarding the NUTS classification.

5.1.2 Oil Dependency Imports/Exports

The domestic oil production in Germany is equivalent to around 2 % of its oil demand leading the country to rely in major percentage (95-97%) on oil imports as it can be seen in **Table** 9. It has well diversified oil supply infrastructure, which consists of crude and oil product import terminals (IEA, 2012).

Table 9 Key oil data. Source: (IEA, 2012).

Key oil Data	1985	1990	1995	2000	2005	2009	2010	2011
Production (Kb/d)	130	102.7	76.3	85.8	113.2	90.8	76.1	79.9
Demand (Kb/d)	2650.6	2681.8	2882.2	2766.8	2620.7	2452.8	2469.6	2400.1
Motor gasoline	606.8	724	697.6	655.1	542.4	473.2	454.3	453.7
Gas/ diesel oil	1150.6	1107.8	1257.1	1163.1	1110	1065.9	1096.1	1050.4
Residual fuel oil	299.1	212.9	195	168.1	175.5	159	147.5	142.8
Others	594	637	732.5	770.5	792.4	754.7	771.7	753.2
Net imports (Kb/d)	2520.6	2579.1	2805.9	2681	1507.5	2362	2393.5	2320.2
Import dependency (%)	95.1	96.2	97.4	96.9	95.7	96.3	96.9	96.7
Refining capacity (kb/d)	2172	1507	2317	2275	2323	2418	2466	2466

Kb/d = killobarrels (of oil) per day

Crude oil is imported through four cross-border pipelines which transport oil from Russia, the Netherlands, France and Italy and four main sea ports. With regards to the sea ports, three are on the North Sea (Wilhelmshaven, Brunsbuttel and Hamburg), and one other (Rostock) is on the Baltic Sea. The most important oil port for Germany is Wilhelmshaven (IEA, 2012).

5.1.2.1 Oil Companies in Germany

There are many international companies operating in the German oil sector, upstream, midstream and downstream. A fundamental difference from other countries is that the German government does not participate in the operation of any of these companies.

In the upstream sector, which consists of exploration, perforation and extraction processes, there is a small number of companies conducting these activities or producing oil in Germany, Wintershall Holding, RWE Dea, GDF Suez E&P Deutschland, and BEB Erdgas und Erdöl (IEA, 2012).

In the downstream sector mainly refining (14 refineries), several international companies have a share in the German refining capacity, Shell Deutschland Oil with a 25.6% share, ConocoPhillips Germany 13.9% and Ruhr Oel (with BP) 9.8% (IEA, 2012).

In the distribution and sales there are more than 14,300 roadside filling stations in Germany, and another 350 filling stations on the autobahns. Aral (BP) and Shell have the highest market shares (22.5% and 21% of fuel sales respectively), followed by Jet (ConocoPhillips Germany) with 10.5% and ESSO with 7.5% (IEA, 2012).

5.1.2.2 Oil Demand in transportation sector

The transportation sector is the largest consumer of oil in Germany consuming approx. 49% of total oil supply in 2010, which also means that 29% of primary German´s energy consumption is attributable to this sector (BMU, 2011). Due to this proportion of oil consumption in the transport sector it is not a surprise that the German government has a target to reduce the final energy consumption by 10% in the period 2005-2020, and by 40% in the period 2005-2050 oil (IEA, 2012).

Some key factors influencing the reduction target are:

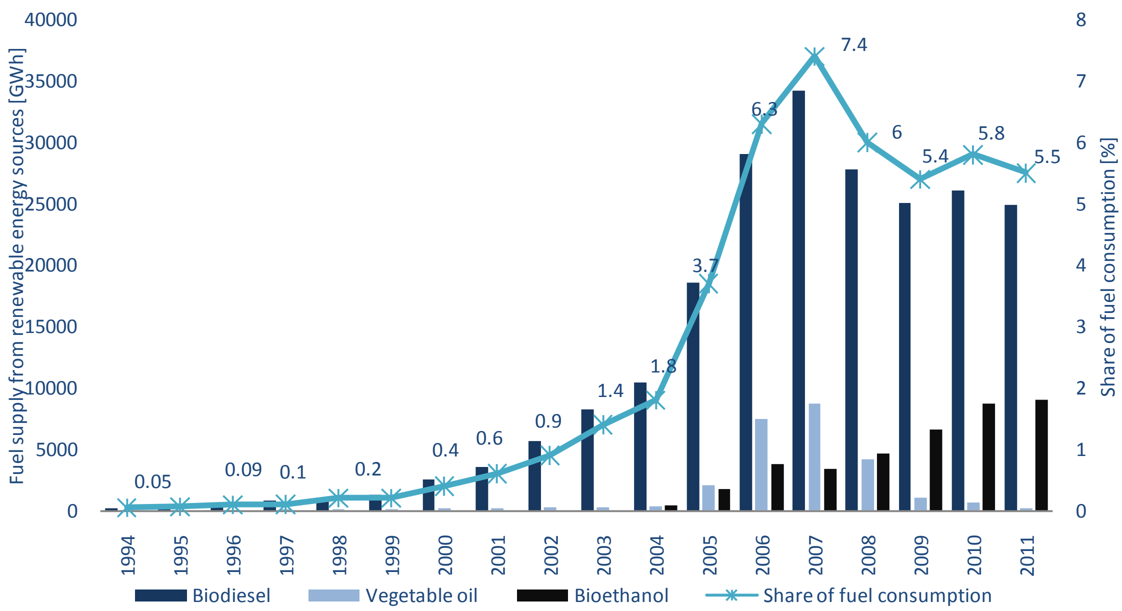
- The promotion of biofuels and alternative fuels in the transportation sector
- The energy taxation level for renewable and fossil energies
- Efficiency standards for designing and manufacturing buildings and cars.

5.1.3 Biofuels in the transportation sector

The dependence on imports of petroleum products and climate change mitigation are the two principal drivers promoting biofuels production in Germany. Biofuels offer an opportunity to partially replace mineral oil as an energy carrier in the transport sector.

Germany is Europe's largest biofuels producer, mainly biodiesel. The best known liquid biofuels in Germany are vegetable oils made from domestic rapeseed and sunflower seeds, and the processed form of vegetable oil called biodiesel (rapeseed oil methyl ester /RME). Bioethanol from sugar beet, grain or sugar cane is added to petrol. Also there is great attention in the Research and Development (R&D) of fuels made from woody biomass, such as biomass to liquid (BTL) fuels that will be important liquid biofuels for the future (BMU, 2011).

Biomass is the only renewable energy carrier with any real significance for transport sector. The country has experienced a faster growth in production capacity of biofuels between 2000 and 2007. This growth has been incentivized by a government tax exemption for pure biofuels. The tax exemption expired at the end of 2012 following the adoption of a duty on the petroleum industry to bring into circulation a minimum percentage of biofuels (IEA, 2012). Other feature that can be seen in **Graphic** 1 is the fast growth to almost 8% by energy content in the transportation sector when the biofuels quota in 2007 was introduced. Biofuels supplied 5.5 percent of Germany's demand of fuel consumed in the transportation sector in 2011; the largest share came from biodiesel (BMELV, 2012b).

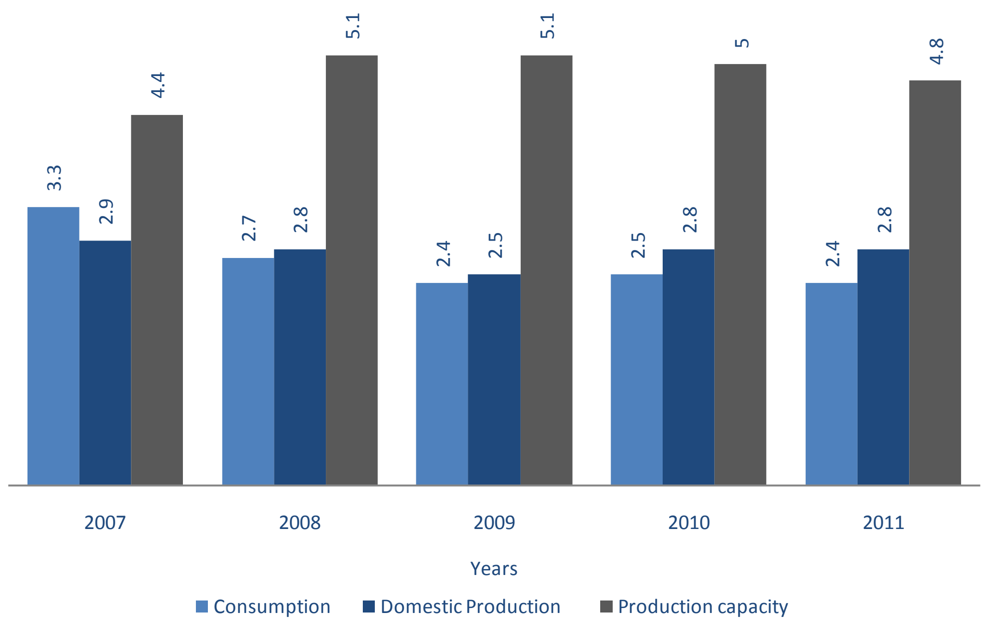


Graphic 1 Motor fuel supply renewable energies in Germany since 2004 Source: (BMU, 2012).

5.1.3.1 Biodiesel Consumption and capacity

Germany is Europe's leading biodiesel producer. In 2011, Germany supplied 30 % of the EU's biodiesel production, (STATISTA, 2012) although it was only using around 58 % of its installed production capacity. **Graphic** 2 presents the consumption, domestic production and production capacity of biodiesel from 2007 to 2011.

The average usage of the capacity production is about 60% some reasons given by different official reports indicate that the cost for import biodiesel is cheaper than to produce it. Furthermore the installed capacity is higher that the consumption in the German market. It can be also seen in the **Graphic** 2 that the quantities of consumption and domestic production are roughly well balanced (Naumann et al., 2012).

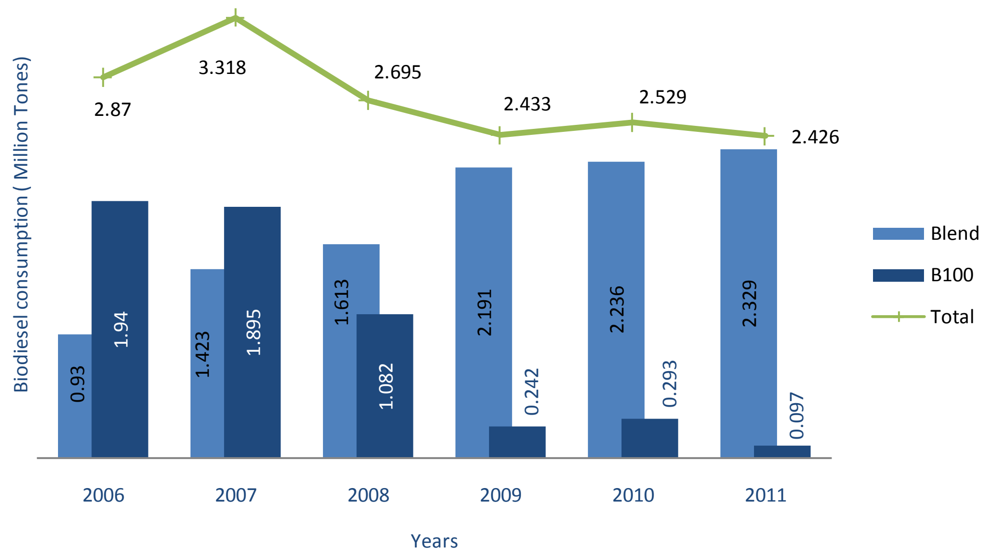


Graphic 2. Consumption, domestic production and production capacity of biodiesel in Germany (million tons) Source: (BMELV, 2012b; STATISTA, 2012)**.**

In Germany, biodiesel can either be used in pure form or blended with normal diesel. **Graphic** 3 presents the biodiesel consumption in pure and blends forms from 2006 to 2011. Until 2004, biodiesel was only used as B100 by some car users. In 2004 the blend B5 (5%v of biodiesel 95%v diesel) was authorized (Bomb et al., 2007).

Since February 2009 a higher B7 blend (7%v of biodiesel, 93%v diesel) was introduced. All diesel engine cars can run on B7 according to the standard fuel for diesel-engine cars (Norm DIN 51628) (BMU, 2009a).

The Fuel Quality Directive 2009/30/EC foster the creation of high levels of biodiesel blends standard. The European Committee for Standardization (CEN) is responsible to develop a standard for B10 use biodiesel (Rauch & Thöne, 2012)**.**



Graphic 3. Biodiesel consumption (Million tons) Source: (BMELV, 2012b; Rauch & Thöne, 2012).

The main Feedstock in percentages for biofuel production in Germany are rapeseed with 87.3%, soybean with 2.5%, palm oil with 0.5%, used cooking oil with 5.10%, animal fat with 2.2% (VDB, 2012). The processing of rapeseed into RME in Germany occurs at different levels, from small-scale farms to industrial-sized biodiesel plants (Berghout, 2008).

The land that could potentially be used for the cultivation of non-food rapeseed is limited due to crop rotation and previously authorized land uses. The federal government indicates that a maximum of around 2 million tones of biodiesel per year can be produced from domestic rapeseed feedstock. Most of the biodiesel sold in Germany is produced domestically. However, some amounts of biodiesel are imported and exported. Detailed statistics on import and export flows are not available; however it is suggested that the amount of biodiesel exported is roughly equal to the amount imported (BMU, 2011).

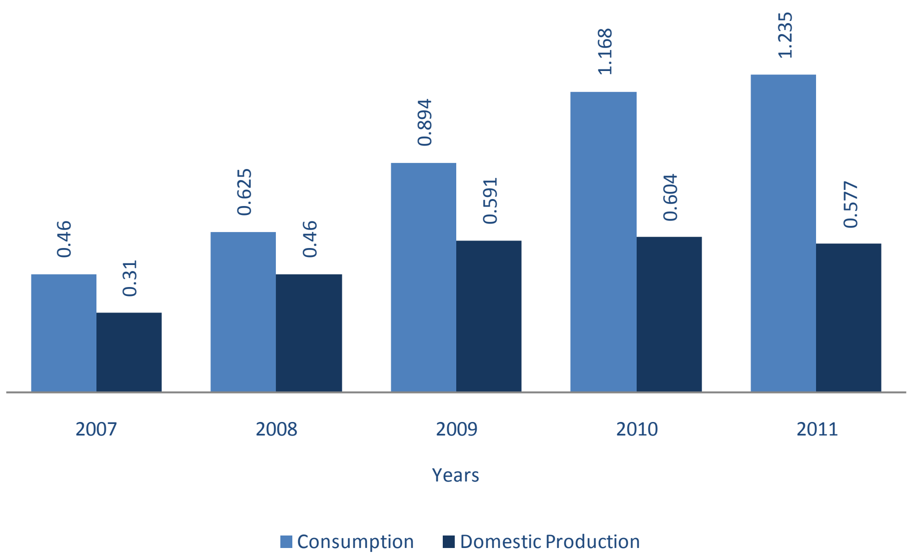
5.1.3.2 Biodiesel trade

The IEA provides the total amount of biodiesel exported and imported in 2010: 992,000 tons of biodiesel have been imported and 918,000 tons have been exported. The main trading partner is the Netherlands from where over 80% of the total is imported. Most of the traded biodiesel is processed through the Amsterdam-Rotterdam-Antwerp port, the largest deep sea port in Europe. Countries of origin are mainly Argentina and Indonesia. Further significant import amounts come from Belgium. Poland, the Netherlands, Belgium and France are the main receiving countries **Figure** 16

Figure 16 Trade of biodiesel 2010, Export and Imports in 1000 t/a Source: Author modified from (Thrän, Fritsche, Hennig, Rensberg, & Krautz, 2012)**.**

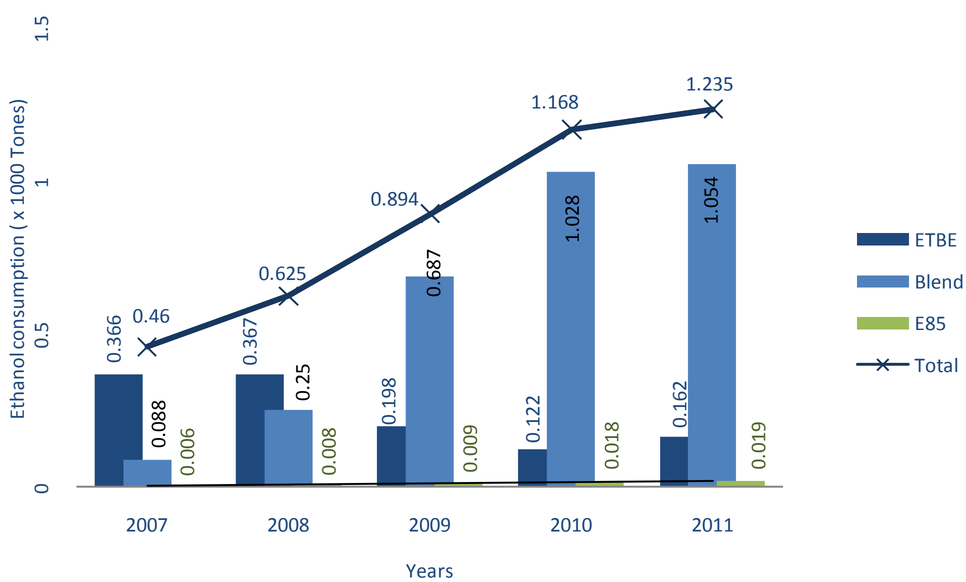
5.1.3.3 Ethanol Consumption

Ethanol was first used in the transport sector in 2004 but it was until 2005 that ethanol has been produced industrially in Germany (Bomb et al., 2007). During 2009 Germany was behind France as the second largest fuel ethanol producer in Europe and one of the top six ethanol-consuming European countries. **Graphic** 4 shows the consumption and the domestic production of Ethanol in Germany from 2007 to 2011. In the past 4 years ethanol consumption in Germany exceeded the amount produced domestically, as a consequence, ethanol has to be imported. The net ethanol imports for 2009 came to 311,000 tons while the quantity of ethanol imports was doubled in 2011(Bundestag, 2010).



Graphic 4. Consumption and domestic production of Ethanol in Germany (million tons) Source: (BMELV, 2012b)**.**

In 2009 ethanol accounted for only 20 % of the biofuels used in Germany's transport sector, while biodiesel accounted for 77 %. Since December 2010 all the filling stations in Germany sell gasoline with a blend of 10%v ethanol. These fuels are referred as E10 (BMU, 2011). In the transport sector Ethanol can be either a compound of Ethyl tert-butyl ether (ETBE), low-blend ethanol petrol (E5 and E10) or high-blend ethanol petrol (E85). The ethanol industry is relatively new in Germany. **Graphic** 5 shows the Ethanol consumption a ETBE, Blends and E85 from the year 2007 to 2011.



Graphic 5. Ethanol consumption (Million Tons) Source: (BMELV, 2012b; Rauch & Thöne, 2012)**.**

The common domestic ethanol feedstock crops are wheat, rye and sugar beets. Other more advanced techniques using lignocelluloses processes, which rely on wood as a feedstock, are still at the pilot stages (Bundestag, 2010).

5.1.3.4 Ethanol trade

In 2010 about 1.34 million tons of bioethanol were imported from which ca. 25% are used as fuel. The main trading partners are the Netherlands, Belgium, France and Poland as seen in **Figure** 17**.** The majority of the traded ethanol is processed through the Amsterdam-Rotterdam-Antwerp port. The origin of the imported ethanol is mainly the USA (Thrän et al., 2012).

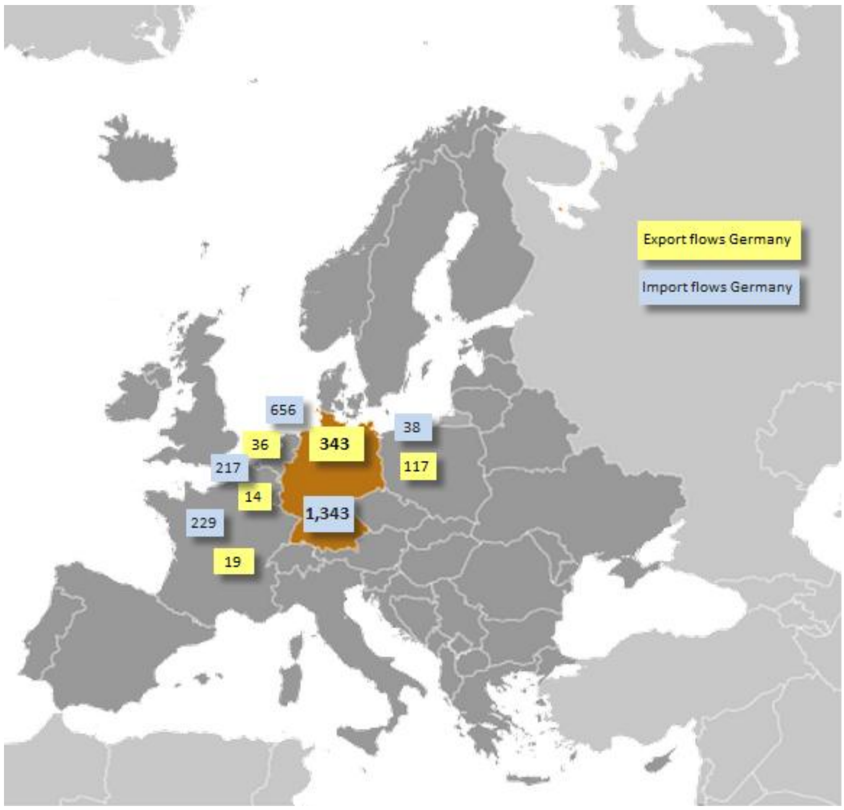
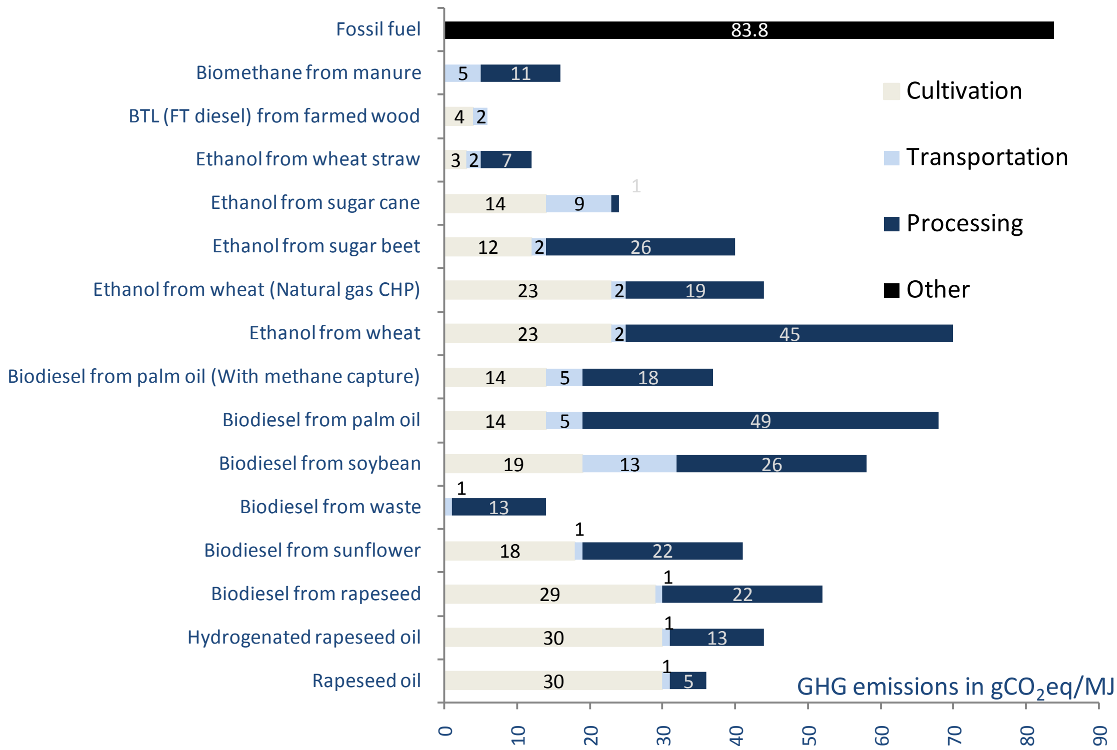


Figure 17. Trade of bioethanol 2010, Export and Imports in 1000 t/a Source: Author modified from (Thrän et al., 2012)**.**

5.1.4 Biofuels Sustainability

Since January 2011 there are some requirements in regards to the sustainability of biofuels that have to be achieved, as an example, biofuels must save at least 35% of GHG emissions along the entire value chain production compared with fossil fuel in the period of 2011-2013 and at least 50% in 2013-2017. **Graphic** 6 shows the common GHG emissions of different biofuels according the Directive EU 2009/28/C.



Graphic 6. Common GHG emissions for different biofuels Source: (BMELV, 2012b) **after UFOP after Directive EU 2009/28/EC.**

In 2012 the draft for some amendments to the Renewable Energy Directive (EU 2009/28/EC) was presented in order to expand the sustainability criteria to foster the so called second generation biofuels, which are non food-crops based. However the criteria to cover indirect land use change which completely modify the GHG balances and the impact in the loss of biodiversity are not defined yet (Bundesregierung, 2013).

Land use change due to biofuel production can occur in two ways, (1) directly, when uncultivated land, pasture etc is converted to produce energy crops (e.g. grassland is used instead to cultivate cereals for bioethanol), or (2) indirectly, through displacement of food and feed crop production to new land areas previously not used for cultivation. From a LCA perspective, direct land use changes are often straightforward and easy to include in the assessment (Miyake et al., 2012)

5.1.5 Actors in the transportation sector (Biofuels)

Actors are people who have an interest, financial or otherwise, in the consequences of any decision taken (ULB, 2007). The actors in Biofuels for the transportation sector in Germany were identified according to its supply value chain. **Figure** 18 shows the main groups of actors.

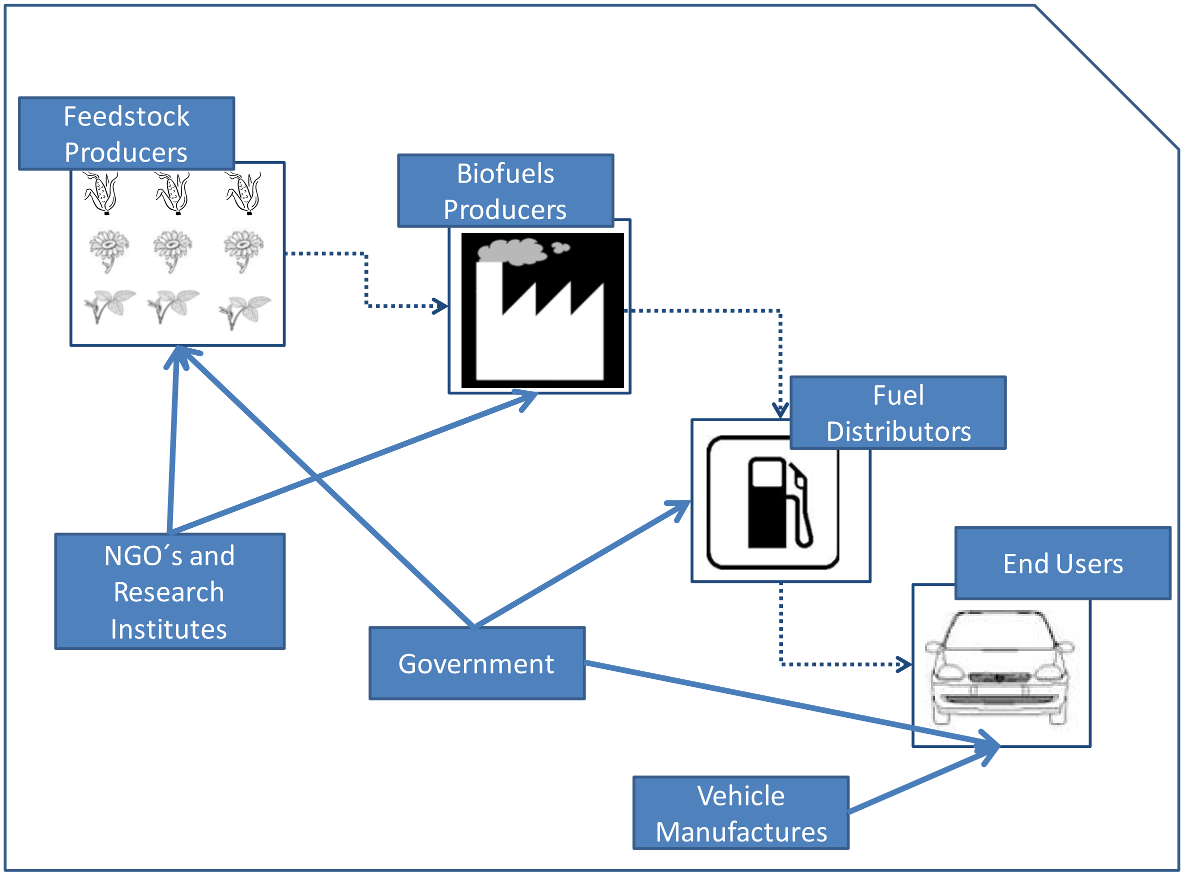


Figure 18.Actors and stakeholders groups in the supply chain. Source: Author.

5.1.5.1 Feedstock's Producers

"Feedstock´s producers" is the tag that groups, the farmers that produce energy crops for first generation biofuels and the people that produce the raw materials for second generation biofuels.

In regards to farmers, they are often grouped on local, regional or national farmer´s organizations (agricultural producer's organizations). In Germany the main association that represents the German agriculture and forestry is the German Farmers´Asssociation (Deutscher Bauernverband, DBV). Its members are the 16 federal states in Germany, farmer´s associations where about 90% of the 380000 German farmers are grouped. The main objective of the DBV is to represent the interest of German farmers in agricultural, economic, environmental, legal, fiscal, educational and social issues related to their activities (DBV, 2013).

However for feedstock to produce ethanol, according to its domestic production capacity, Germany has to outsource feedstock production from developing countries (Huay Lee, 2011).

5.1.5.2 Biofuel producers and biofuel suppliers

There are many biofuels producers and suppliers in Germany. Most of them are grouped in associations that safeguard the member's interests. For the biofuels producers two main organizations were identified. The European Biodiesel Board (EBB) which promotes the use of biodiesel in the European Union, at the same time groups the major EU biodiesel producers (EBB, 2013). Some of its members are ADM, Cargill GmbH, Verbio Diesel Bitterfeld, Natural energy West, Petrotec, Biopetrol Industries AG, EcoMotion GmbH , Mannheim Bio Fuel, Vesta Biofuels, Verband Deutscher Biodieselhersteller e.V. The other organization, VDB represents the interests of the German biofuel industry (70% of the German biodiesel industry and 30% of the ethanol industry are members) at a national and continental level (VDB, 2012).

Another association is the Petroleum Industry Association (Mineralölwirtschaftsverband e. V; MWV) which is composed of the oil companies that are based in Germany, that process crude oil. The main objective of the MWW is to represent the oil industry in legal subjects (MWV, 2013).

5.1.5.3 Government

There are several government agencies that manage and supervise the various policy instruments regulating road transport issues and the biofuel industry. The federal government of Germany has been promoting biofuels since the early 1990´s because Bioenergy is viewed as an important energy carrier for the transport sector; furthermore it supports agricultural industry and regional development (Bundesregierung, 2013).

Multiple government ministries play an important role in the promotion and policy of bioenergy. **Figure** 19 summarizes the main federal ministries and their function in bioenergy policy promotion.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU) Responsible for renewable energy policy, including the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG), the Market Incentives Programs and R&D.
Federal Ministry of Food, Agriculture and Consumer Protection	The Federal Ministry for Food, Agriculture and Consumer Protection (Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft, BMELV) Responsible to manage biofuels and parts of the biomass policy.
Federal Ministry of Transport, Building and Urban Development	The Federal Ministry for Transport, Building and Urban Affairs (Bundesministerium für Verkehr, Bau und Stadtentwicklung, BMVBS) Is in charge of the national fuel strategy.
Bundesministerium der Finanzen	The Federal Ministry of Finance (Bundesministerium der Finanzen, BMF) Handles energy taxation, particularly of biofuels.
Federal Ministry of Economics and Technology	The Federal Ministry of Economics and Technology (Bundesministerium für Wirtschaft und Technologie, BMWi) Responsible for the overall energy policy.

Figure 19.German ministries and their function in the Biofuels promotion. Source: Author based on (IEA, 2012; Rauch & Thöne, 2012)**.**

Other government agencies that participate in the energy policy are: The Federal Office for Agriculture and Food (BLE) that approves and supervises the certification systems and the bodies that administer them. The biofuel quota body—which belongs to the main custom office in Frankfurt (Oder)—is responsible for supervising companies' compliance with the biofuel quota. The main custom offices are responsible for administering the tax relief policies for biofuel producers. The Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe; FNR) is in charge of research projects related to the use of renewable resources. The FNR generates and provides information on renewable energy for academics, the public, politicians, the media and the biofuels industry (Rauch & Thöne, 2012).

5.1.5.4 Automotive industries/ Vehicle manufacturers

The vehicle manufactures group those companies that design, develop, manufacture, put into the market and sell the different motor- fuel vehicles used in the transport sector. In Germany the vehicle manufacturers are associated in the German Automobile Industry Association (Verband der Automobilindustrie, VDA) (Bomb et al., 2007). This association consists of about 600 member companies in the automotive sector. The objective of this association is to lead a lively dialogue between the industry, the public (end users of automobile vehicles), and politicians (decision makers) (VDA, 2008).

As an example of its participation, in 2010 this VDA has declared support for blending bioethanol at E10 after testing compatibility with all models of cars (Bomb et al., 2007).

5.1.5.5 End Users

End user is a person or a group of people who decide to use a certain product, in this work, “end users” refers to the consumers that choose to buy biofuels blends instead of petrol fuels to feed their automotive vehicle tanks. According to some studies in regards to biofuels perception some of the criteria that biofuels end users have to purchase or not biofuels are: The prices of the biofuels vs. fuel, the total cost of ownership (price of flex fuel car + price of biofuel and their increments), the technical compatibility and the green image that they want to show up (Savvanidou et al., 2010; Wiesenthal et al., 2009) the fear to damage the car´s engine, unethical perception to use biofuels when food sources are scarce and unknown long-term consequences (Rauch & Thöne, 2012).

5.1.5.6 Non Governmental institutes

Non-governmental organizations (NGO´s) are organisms that work independently from the government. These organisms can be national or international and they play an important role when talking about biofuels production and expansion. Most of these groups argue and present different constrains for the usage of biofuels to mitigate climate change through reducing the CO_2 emissions in the transport sector. Some of the critical issues that they discuss are: impacts of large-scale biomass production on current agricultural structures (crops, biodiversity, etc.), soil health and maintenance (e.g. erosion, nutrient balance, etc) indirect land use, food vs. biofuels. Friends of the earth Germany and Greenpeace Germany are two NGO´s that provide different reports and data to the debate (Rauch & Thöne, 2012).

5.1.5.7 Research Institutes

Policy and decision makers base their decisions primary on the project results assigned to different research institutes.

Three research institutes were identified in Germany that provide reports for different ministries in order to have solid basis to take actions in bioenergy policy. The German Biomass research Institute (Deutsches Biomasseforschungzentrum; DBFZ) is working in Bioenergy systems, biochemical conversion, thermo chemical conversion and biorefineries areas (DBFZ, 2013). The Institute for Energy and Environmental Research (Institut für Energie und Umweltforschung Heidelberg GmbH ; IFEU) is a research institute that delivers to the federal government different reports of GHG emissions and GHG savings of biofuels (IFEU, 2013) and finally the Agency of Renewable Resources (Fachagentur Nachwachsende Rohstoffe; FNR) is the central coordinating institution for research, development and demonstration projects in the field of renewable resources (FNR, 2011).

5.1.6 Germany´s biofuels policy development

Renewable energy had the attention of German policy maker since the 1973 oil crisis. One of the first attempts to lower the dependency on oil imports was the support to R&D for domestic energy sources, including renewable energy (Laird & Stefes, 2009).

However the production and promotion of biofuels took place in a framework created by the German and the European climate, energy and agricultural policies, the main goal of climate policy is to reduce the use of fossil energies and thus CO_2 emissions. One strategy that would contribute to the reduction of CO_2 emissions is the promotion of biofuels. Another driver for the production of biofuels is the Common Agricultural Policy (CAP) (Henkea et al., 2005).

Table 10 and **Table** 11 present the main policy documents and the main points identified in regards to biofuels for the transportation sector.

Table 10. Major legislation and policies regarding German´s liquid biofuel development EU level. Source: Author based on (EU, 2003, 2009, 2012).

Level	Policy Documents	Main Points of the policies	Source
EU	Common Agricultural Policy (CAP).- The agricultural policy of the European Union	The CAP supports the production of agricultural products by market regulations and market interventions. The CAP partially shapes the domestic production of the energy feedstock. In 2004 a reform that approved Germany to introduce the Single payment scheme (SPS subsidies)	(EU, 2012)
EU	Directive 2003/30/EC (2003)	It aims to increase the use of biofuels in the Union in order to achieve objectives such as climate change commitments, security of supply and to promote renewable energy sources. Indicative targets 2% by 2005, 5.75% by 2010)	(EU, 2003)
EU	Renewable Energy Directive, 2009/28/EU (RED) / 2009	Provides specific regulations to ensure a sustainable biomass production not only within the European Union (EU) but also in third countries exporting biofuels or biomass to the European Union with the purpose to produce biofuels. Specific targets: In the transport sector a 10% share of renewable has to be achieved.	(EU, 2009)
EU	Directive 2009/28/EC (RED Article 17) / 2009	Prohibits the use of biofuels and bio-liquids to meet the directive's renewable energy targets, national renewable energy obligations and their eligibility for financial support, if they do not meet specified sustainability criteria relating to greenhouse gas saving emissions and biodiversity. The directive introduces sustainability criteria for biofuels and bio-liquids.	(EU, 2009)
EU	Directive 2009/28/EC (RED Article 18) / 2009	Provides a model for the verification of compliance with the criteria mentioned in article 17.	(EU, 2009)
EU	Directive 2009/28/EC (RED Article 19) / 2009	Provides a calculation tool for establishing the greenhouse gas impact of biofuels	(EU, 2009)

Table 11. Major legislation and policies regarding German´s liquid biofuel development (Continuation) National Level. Source: Author based on (BMU, 2009b; Dunkelberg, Lehnert, & Neumann, n.d.; Fritsche, 2007; Lindberg & Steenblik, 2007; Pelkmans et al., 2008)**.**

Level	Policy Documents / Mandates	Main Points of the policies	Source
Germany	Ecological Tax Reform (1999)	Stepwise increase of mineral oil tax. Full exemption of pure biodiesel remains. Pure biofuels exemptions from mineral oil tax. Different amendments Amendment to the Mineral Oil Duty.	(Pelkmans et al., 2008)
Germany	Biofuel Quota Act (BioKraftQuG) / 2006	Legislative measure. - Fixed quota for biodiesel; Stepwise increasing quota for bioethanol; Stepwise increasing quota for sum of biofuels. With different amendments. To follow mandatory biofuel blending target for the mineral oil industry. The regulatory provision largely replaced the use of tax exemptions	(BMU, 2009b)
Germany	Germany's national renewable energy action plan (NREAP) /2009	Provides the estimated volumes of biodiesel and ethanol required to meet the mandate	(Lindberg & Steenblik, 2007)
Germany	Biofuel Sustainability Ordinance (BSO) /	Supports the sustainability criteria stated in the RED into German law	(Fritsche, 2007)
Germany	Directive on the Properties and Labeling of the Quality of Fuels (10th BImSchV) /2010	Describe the properties and labeling in the retrials and distribution stores with the goal to introduce E10 blend.	(Lindberg & Steenblik, 2007)
Germany	Energy tax Act Amendments /2012	Biofuel quota act: mandate for fuel distributors to include specific quota of biofuels from 2007 (fully taxed). Penalties in the case of non-compliance. *Extended subsidies for2nd generation biofuels + tax exemption until 2015. E 85 regarded as 2nd generation biofuel (Biofuel part not taxed).	(Pelkmans et al., 2008)
Germany	Draft to amend the Renewable Energy Directive (2009/28/EC)-COM (2012) and the Fuel Quality directive amendments (98/70/EC) / 2012	Specify the target of the RED directive. Further target: 10% RE in transport, of this max. 5% biofuels from cultivated biomass and Reporting of the member states including iLUC factors for biofuels from cultivated biomass.	(Naumann & Majer, 2012)

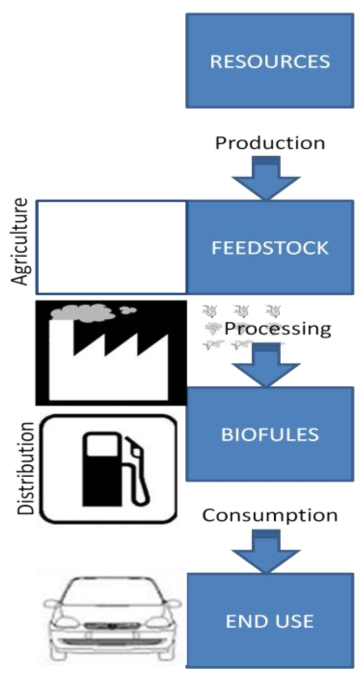
The transport fuels strategy and excise duty exemption in Germany are the main regulatory frameworks supporting the biofuels industry. The national government in collaboration with oil companies and automobile manufacturers, as well as research institutes in Germany, has formulated a transport fuels strategy, it states that biodiesel and bioethanol are important for blends but potentials are limited by land availability. From 2004 to 2006 biofuels, both in pure form and blends were covered by an excise duty exemption, which makes biofuels price competitive with diesel and petrol on a volume basis and energy basis (Bomb et al., 2007; Pelkmans et al., 2008).

In 2006 Germany´s government reviewed the tax situation on biofuels and the adopted measure was the tax incentive mandate: Energy tax law form 2006 that was applicable in 2007. It establishes:

- A specific quota of biofuels for fuel distributors with penalties in case of non-compliance (e.g. mineral oil companies were asked to ensure that 4.4% of diesel sales are made of biodiesel)
- The introduction of a tax on pure biodiesel and pure plant oil with a yearly increase up to 2012.
- Extended subsidies for second generation fuels, and tax exemptions until 2015 (Dautzenberg & Hanf, 2008).

By 2015, the biofuels quota in Germany requires 8% of all transport fuels to be biofuels, with specific quotas for bioethanol and biodiesel with an increase of 12-15% by 2020 (S Bringezu et al., 2009).

5.6.2 Allocation of policy instruments in the Germany´s biofuel supply chain



As it was mentioned in chapter 3 different policy instruments are allocated along the value chain (from the production of the feedstock up to the end use) in order to support biofuels production and usage. **Table** 12 indicates the main measures and policy instruments that Germany has been taking into account order to introduce the usage of biofuels to meet the targets to reduce GHG emissions. It is ordered from the feedstock production point in the chain to the last link concerning the end user.

Table 12 Overview of the main measures related to biofuels in Germany. Source: Author based on (Fritsche et al., 2011; Lindberg & Steenblik, 2007; Pelkmans et al., 2008; Rauch & Thöne, 2012; Scarlat & Dallemand, 2011; Wiesenthal et al., 2009)**.**

Period	Policy Category	Name	Allocation on Value chain	Purposes
2005-Onwards	Economic and fiscal instruments	Subsidies - Single Payment Scheme (SPS)	Feedstock producers	SPS payments decrease the costs of producing biofuel feedstock and the costs of producing crops for the food market
2010-Onwards	Command and control	Certification - International Sustainability and Carbon Certification (ISCC)	All the value chain	Comprises 6 principles and corresponding 3 criteria. In regards with biomass cultivation, management and labor conditions
2011 onwards	Command and control	Certification- Gesellschaft zur Zertifizierung nachhaltig erzeugter Biomasse mbH (REDcert)	All the value chain	Comprises 6 principles and corresponding 3 criteria. In regards with biomass cultivation, management and labor conditions
Different periods	Incentive economic based instruments	"Renewable Resources" Grants funding for R&D	All the value chain	Different funding programs to support R&D for biofuels production, usage etc.
1993-2003	Economic and fiscal instruments	Mineral Oil Tax	Oil companies, distributors, end consumers	Pure biofuels were exempt from mineral oil tax
1999-2003	Economic and fiscal instruments	Ecological Tax Reform	Oil companies, distributors, end consumers	Stepwise increase of mineral oil tax. Remaining pure biofuels.
2004-2009	Economic and fiscal instruments	Amendment of the Mineral Oil Tax Act	Oil companies, distributors, end user	Biofuels and blends exempted from the excise tax on mineral oils
2007 - 2015	Command and control	Biofuel Quota Act	Oil companies and/or third parties which places biofuels into the market	Obliges mineral oil companies to distribute a rising minimum share of biofuels through mandatory blending quotas for biofuel with fossil fuel

5.1.7 Certificate schemes

It is also important to mention that there are some certificate schemes that have been approved by the European commission in compliance with the sustainability criteria (Articles 17 and 18) of the Renewable Energy Directive (DIRECTIVE 2009/28/EC). These certificate schemes can cover some or all the processes mentioned in the flow diagram (Crop producers, farmlands, biofuel processing, biofuel distribution etc.)

The most common certificates schemes and the impacts that are covered are given in the **Table** 13**.** Even if the certificate schemes meet the DIRECTIVE 2009/28/EC sustainability criteria and use a LCA methodology to evaluate the environmental impacts, the report and its results are concealed information because they belong to private companies. Neither the European commission nor the Germany´s government gives public access to the information.

Table 13. International standards that cover the requirements of the Renewable Energy Directive (2009/28/EC) Source: Author modified from (Hamelinck et al., 2008)**.**

Certificate Scheme	Countries involved	Impacts measured							
		GHG	Biodiversity	Carbon stock	soil	air	water	Land rights	labor conditions
International sustainability and carbon cerification (ISCC)	Germany and 3d. Countries	X	X	X	X	X	X	X	
Round table on sustainable palm oil (RSPO)	Germany	X	X	X	X	X	X	X	X
PEFC	Germany		X	X	X	X	X	X	X
RTRS (Latin America)	3d. Countries	X	X	X	X	X	X	X	X
Bonsucro	3d. Countries	X	X	X	X	X	X	X	X

5.1.8 SWOT ANALYSIS

The following SWOT-Analysis in **Table** 14 represents the main benefits and limitations that were found in the description of the current situation of biofuels production and consumption in Germany. The most important points regarding environmental impacts and different features of the LCA as the methodology to measure these impacts are discussed in the next chapter based on literature review and experts consultation.

Table 14 SWOT analysis of the production and usage of biofuels in Germany. Source: Author.

Strengths

→ Germany is the major producer of the EU member of biodiesel with a mature and well-developed German biodiesel industry.
→Excellent data bases that measure all the economic and mass flows regarding biofuels produced domestically or in the EU.
→Classification of all the land uses at an EU and national level, avoiding with this dLUC.
→ No changes in the patterns of certain agricultural crops, sufficient knowledge of the land, yield and productivity.
→ Policy instruments that incorporate sustainability criteria (Not too wide).
→ Research and development, dedicated research centers to develop technology on crops, biorefinery etc.
→ Currently research & development on second generation biofuels (micro-algae, lignocelluloses biorefineries, vegetable oils) in Germany
→ First pilot and demonstration plants from lignocellulosic biorefineries are in operation or under construction in Germany
→Different actors are well involved in the production chain of bofuels.

Weakness

→High dependence on oil imports for transportation fuels.
→ Lack of information to evaluate the iLUC when buying feedstock's from tropical and subtropical countries.
→ Climate conditions are not optimal for the cultivation of certain crops of first generation biofuels and certain second generation biofuels (microalgae) in Germany
→ Technologies for second generation biofuels and biorefineries under demonstration, not into an industrial scale.
→Not well developed bioethanol processing plants.

Opportunities

→Provide themselves with domestic crops or second generation feedstock´s to avoid importing oil or feedstock´s from third countries.
→ Export opportunities for German technology chemicals process, machinery for vegetable oils processing.
→ Research and development of new sources of biomass that can be produced independently from arable land.
→Research and development of new sources of energy for vehicles without great changes in their engines.

Threats /Risks

→For first generation biofuels, cultivation land (area) is the most restricting factor for producing biofuels from agriculture (1^{st} generation biofuels) both in Europe and in Germany.
→ Raw material shortage by increasing biofuels demand.
→ With feedstock's coming from different locations around the world and to cover the demand, difficult to measure the impacts. (Mostly iLUC from tropical and subtropical countries).
→ Not competitive German sugar and starch industry, Germany is displaced by other countries (Brazil, USA, and South East Asia). /It is hard to measure these impacts.
→Germany is geographically in disadvantage compared to other global locations for crops of the first generation and of the second generation (algues) too.
→ Strong, competitive R&D from second generation biofuels (lignocellulosic biomass, multiple feedstocks, algues) outside of Germany.

5.1.9 Discussion of the current situation of biofuels production in Germany

In 2009 the EU enacted the directive 2009/28/EC RED which mandates the use of renewable energies in the EU. It includes a 10% share of renewable energy mandatory target for the EU members to be achieved by 2020 in regards to the transportation sector; this target could by complied using any renewable energy even if biofuels are not specified as the renewable source to be used in the transportation sector. Most of the EU members wanted to fulfill it with the use of biofuels due to the facts that the blends with fossil fuels can be burned in diesel or Otto engines respectively with little or no modifications. This assessment was the result of one of the requisites of the directive which stated that each member had to produce a national action plan with certain own proposals to reach the target. The findings were that most of the EU members wanted to achieve this transportation goal with the production and usage of biofuel (mainly biodiesel and bioethanol) this posture leads to several problems, the most outstanding is that if second generation biofuels are under demonstration stages, the feedstock's are produced from the first generation biofuels which in the case of the EU the limitation would be the land for cultivation, causing with this land use changes in other countries.

In order to face this and other environmental issues which were envisaged in those years (with a clear limitation in water requirements and pollution and indirect land use change) this directive also provides a sustainability criteria reflected also in the FQD to ensure a sustainable domestically and third countries feedstock production that have the purpose to produce biofuels. Both directives (RED and FQD) emphasize the emissions savings of biofuels vs. their fossil fuels counterparts based on a LCA methodology, which on one hand is used to take into account only energy flows and on the other hand it is a good methodology due to the complete analysis and panorama that can be retrieved from the value supply chain. It is also very sensitive to assumptions ant there are different key issues and features that have to be improved.

In order to align their objectives with the EU objectives, Germany has taken two measures to fulfill both RED and FQD requirements, the biofuels quota act and the biofuels sustainability ordinance. The first mandates a 6.25% biofuel petroleum blend by 2014 and the second requires meeting a registered sustainability scheme valid from 2011 which must at minimum include the mandatory sustainability criteria from the RED/FQD (e.g. less carbon intensive biofuels compared with fossil fuels). In 2011 Germany had a 5.5% share of biofuels in transportation fuels, since the 6.25% target was first set.

it is true that the quota act mandates the supply side to produce and sell certain fuels products with admixtures of biofuels, however consumers have not been fully sensitized and encouraged to purchase these fuels, some debates such as food vs. fuel in 2008, the current regarding deforestation of rainforests to lead biofuels crops cultivation and the regrettable labor conditions of the workers in crops cultivation for feedstock's production play an important role in the perception of people to purchase them. Most of these situations occur in third countries where biofuels are not used in the transportation sector at all. This picture hassled and contributed to a series of revisions and amendments to the legislation regarding biofuels production domestically and in third countries.

5.2 Environmental assessment

5.2.1 Goal and Scope definition

Biofuels policy measures in the European Union and in Germany are likely to consist of a mixture of factors including quantitative targets such as minimum GHG emissions savings, and exclusion clauses, such as rules which specify that biofuels cannot be derived from biomass feedstock's grown on certain types of land (peatlands, grasslands, recently cleared natural forests, etc.), trying with this last action, to avoid other environmental impacts such as iLUC.

Furthermore the production and consumption of biofuels are seen as as viable renewable energy strategy in the transportation sector, which aim to tackle climate change and to reduce oil imports. The combination of these purposes puts the current focus on a quantitative measurement of GHG emissions and fossil energy savings.

This chapter focuses on the impacts that production and use of such biofuels might have on emissions of greenhouse gases (GHGs) compared with the emissions from conventional petroleum-based transportation fuels. It also notices the trends and differences of the existing scientific available data contained in scientific papers, governmental reports provided by the corresponding governmental agencies and websites platforms that were also crosschecked with the statistical databases, which use the LCA methodology, or a problem-oriented life cycle assessment perspective to evaluate the environmental impacts of biofuels for transportation purposes mainly in Germany.

These reviewed reports do not include the complete literature of bifouels LCA´s, but they represent the most complete, reliable, public and available reports that have been performed for the case study (Germany) in 15 years' time period (1996-2011). **Annex** D. ENVIRONMENTAL IMPACTS and **Annex** D 2. QUALITATIVE ANALYSIS provide the detailed information for the analysis. The results discussed in the following section are derived from an interpretation and critical assessment of these tables.

The approach used to evaluate the LCA of biofuels is the Well to Wheel (WtW) analysis, as well as a Well to Tank (WtT) approach which doesn´t consider the end-use, the reason for this consideration is justified due to the fact that biofuels are used in existing motor vehicles and their efficiency will not change when operated on biofuel blends or on pure biofuels or fossil fuels.

5.2.1 Functional unit (FU)

The purpose of the functional unit is to provide a reference unit to which the inventory data are normalized and the final results will be shown (Cherubini et al., 2009; Roy et al., 2009).

Concerning LCA of biofuels for transportation purposes, results were expected to be expressed in terms of the same functional unit, to ensure that the comparison is based on the same magnitude of a physical quantity. However, differences were found with respect to the functional unit, which makes impossible to compare and assess the real situation regarding biofuels production and consumption pathways in Germany and the EU.

Reporting results on a distance traveled by certain vehicle (vehicle-kilometer basis) is the simple basis to compare the performance of biofuels vs. their fossil counterparts in a distance traveled (Brinkman, 2006; Edwards, Larivé, & Beziat, 2011a, 2011b, 2011c, 2011d; Edwards R., Larivé J-F., & Beziat, 2011; Fleming, Habibi, & MacLean, 2006; Gärtner & Reinhardt, 2003; SenterNovem, 2008; van Vliet, Faaij, & Turkenburg, 2009; Zulka, Lichtblau, Pölz, Stix, & Winter, 2012).

Another way to express the results of a LCA is on an area basis (hectare) due to the crops cultivation area is the first major limitation for the production of first generation biofuels when trying to avoid impacts regarding dLUC and iLUC (Borken, Patyk, & Reinhardt, 2000; Brauer & Müller-langer, 2008; Kaltschmitt, Reinhardt, & Stelzer, 1997; Quirin, Gärtner, Pehnt, & Reinhardt, 2004; Reinhardt & von Falkenstein, 2011).

Independently from land limitation or distance traveled the results in mass or energy input output is the way that some part of the scientific group and policy makers present results (Cherubini & Jungmeier, 2009; Luo, van der Voet, & Huppes, 2009;Reijnders & Huijbregts, 2008)

This last way to set the FU (per energy input-output) in order to normalize the results of the LCA is the units used by the EU Directive 2009/28/EC.

According to this classification of functional units, the GHG emissions results have been grouped and compared in order to provide to this study a better assessment of the environmental impacts and to provide the main constraints when assessing environmental impacts through LCA methodology, however as it can be seen from this moment of the research there are challenges with the complete application of LCA to biofuels (such as the diversity of impacts and the difficulties of some actors in attempting to take them all into account), the attention is clearly focused on the prominent environmental impacts (GHG emissions, fossil energy consumption), which is a very limited scope for the LCA methodology.

Despite the relevant differences regarding FU most of the LCAs results reported a significant net reduction in GHG emissions when comparing with their fossil fuels competitors.

5.2.2 Life cycle inventory analysis

Regarding environmental impacts, this step of the work has been the most intensive and detailed because it has depended on the information available, the databases, expert's consultation and information crosscheck. The following features were the most important found during the analysis.

The biomass source (feedstock's)
The biomass sources selected to study were rapeseed for biodiesel, sugar beet, winter wheat and potatoes for ethanol, ethanol from lignocelluloses and diesel from FT process which are the main biomass sources used in Germany for the production of biofuels. Most of the retrieved studies used the Borken et al., 2000; Gärtner & Reinhardt, 2003 data bases for Germany. However the variations regarding the cultivation paths impact directly in the GHG emissions balance.

dLUC and iLUC

In the biofuels production, direct land use change (dLUC) occurs when crops for energy purposes displace a previous land use (e.g. forestland, food cropland etc.) This generates changes in the carbon stock of the previous land, nevertheless changes in the carbon content of the soil can take place even if a land use change does not occur (Long term croplands).

However the life-cycle GHG impact of energy crops ultimately depends upon what these crops are replacing. If they replace natural grasslands or forests, GHG emissions will probably increase; if, on the other hand, energy crops are planted on unproductive or arid land where conventional crops cannot grow, or in place of annual crops (e.g. in place of corn grown for ethanol, or rapeseed for biodiesel), they have the potential to significantly reduce associated emissions (BMELV, 2007).

In the information obtained, an obvious path was that the land use impacts had not been taken into consideration, in domestic crops cultivation. This situation can be linked with the Directive 2009/28/EC which prohibits to cultivate crops for energy purposes in lands that have the classification that is given in its guidelines, furthermore each year the EU launches a land use/cover area frame survey (LUCAS) in order to assess change pattern of the land use situation in the EU and estimates crops production. This survey provides policy makers with information regarding the changes and the characteristics of the soil in order to use it properly[2]. However in order to fulfill the biofuels supply to comply with the bioenergy fuel quotas extra crops have to be cultivated or new feedstock's different from agricultural products must be used. Displacement of current land use to produce biofuels can generate a land use change elsewhere (third countries) making it complicated to measure. The displacement of a previous activity or use of biomass inducing land use changes on other lands is called indirect land use change (iLUC).

Fertilizer application

Another evident feature in the information retrieved regarding crops for first generation biofuels is that the agriculture practice is the main source of GHG emissions associated with biofuels production because of emissions of nitrous oxide (N_2O) which evolves from nitrogen fertilizer application and organic matter decomposition in soil. These emissions are not very large in terms of mass but due to the very high global warming potential (greenhouse effect) of this gas which is about 298- 300 times more than CO_2, make their environmental impact significant. N_2O emissions from farming are dominated by two sources: nitrogen fertilizer production and fertilizer application on the field (SenterNovem, 2008).

The fertilizer requirements and crop yield vary widely, these have to be with the climate and soil conditions. The report provided by Quirin et al. (2004) ranges of fertilizer from 53 to 196 Kg N/ha for rapeseed in winter conditions, and the variations of the energy content are between 42 to 70 MJ/kg N applied.

Allocation of co-products

[2]German photos of the land use cover provided by the European Union are showed in Annex B. LAND USE IN GERMANY (NUTS and LUCAS)

Co-products allocation regarding biofuels in simple words means to provide the corresponding value of the total impact or benefit to each product generated (main product or by-products).

There are different calculation methodologies to allocate co-products in the LCA of biofuels, the treatment to account the emissions of co-products that are generated in the production process is important because as they are used in other industry field such as cosmetic purposes, animal feed, generation of electricity, etc. they should share the GHG emissions that are produced in the LCA of biofuels. Mortimer (2012) explains the variation of the different methodologies used for these purposes; the most relevant methodologies can be described as credits substitution which implies to identify the product displaced by the biofuels and evaluate their total GHG emissions in order to discount or subtract these emissions from the biofuel total emissions. This methodology is criticized because extra analysis of co-products supply value chain is needed and the results vary over the time and location. Other allocation methods consist in identifying an attribute that can be the energy content (calorific or heating value multiplied by the respective mass), by price (contribution of the total economic value) or by mass (mainly agricultural yield). In simple words this method consists in dividing the total GHG emissions of a process on a percentage basis of the share of co-products and biofuels.

5.2.3 Interpretation

The objective of this step is to evaluate the results and compare them with the goal of the study defined in the first phase. In this step the identification of the most important results of the impact assessment, the evaluation, the outcomes and some conclusions, recommendations and reports are done. As it was mentioned before the LCA is an iterative methodology, sometimes the results of the interpretation may lead to a new iteration round of the study in one of the previous steps (Sonnemann et al., 2004).

Several LCA studies regarding biofuels from rapeseed, wheat, potatoes and lignocelluloses feedstocks have been completed in the German and European context with various frameworks, scopes, accuracy, transparency, regional specificities and consistency levels making it difficult to compare the results on the same basis. For this reason, this work reports the results based on two functional units (per area cultivated and per km distance traveled). None of these functional units are used to report the GHG in the directive 2009/28/EC. However according to the limits that the EU has regarding land use and the objectives to reduce the consumption of fossil fuels, these functional units are seen as the most suitable and viable units to report GHG emissions and savings.

5.2.3.1 Distance travelled per vehicle basis (vehicle-km)

The results regarding the CO_2eq emissions released related the distance that one car travels (vehicle-km) in a WtT approach are seen in **Graphic** 7

The variation of the results depend on the different features that are incorporated, such as combining different methods to allocate co-products, the introduction of dLUC and iLUC factors (Zulka et al., 2012), new use for the co-products (honey and biogas generation from rapeseed meal) (Gärtner & Reinhardt, 2003), assumptions over assumptions like a cocktail to fix different results from different literature sources (van Vliet et al., 2009), the scope when trying to involve different stakeholders in a complete LCA, or simply the feedstock source production from different locations over the world (SenterNovem, 2008).

5.2.3.2 Allocation of co-products

For biodiesel the reported values are 144 gCO_{2eq}/vehicle-Km without allocation, 78 gCO_{2eq}/vehicle-Km, with an energy allocation of 42.7% for feed meal and 2.84% for glycerin and using a credits substitution the GHG emissions decrease to 25 gCO_{2eq}/vehicle-Km (Zulka et al., 2012).

The results for bioethanol from wheat as feedstock are among 212 gCO_{2eq}/vehicle-Km without allocation, with an energy allocation of 33% for DDGS the results decrease to 48 gCO_{2eq}/vehicle-Km and increase to 194 gCO_{2eq}/vehicle-Km when a credits substitution method is used (Zulka et al., 2012). For the same pathway but using an economic allocation (animal feed and straw) the results are 142 gCO_{2eq}/vehicle-Km (SenterNovem, 2008).

It is evident that the results and the allocation methods lead to different results even if the same pathway is used. Co-products of biofuels value chain do not have the same economic or energetic value. This situation is exemplified with the GHG emissions of bioethanol´s supply value chain. It seems that using an energy allocation is better when Dried Distillers Grains with Solubles (DDGS) are generated as co-products because when electricity can be generated from co-products the fossil fuel extraction and consumption is reduced too.

However the biofuels pathways are different and it results impossible to use the better method according to the co-product generated to calculate the total GHG emissions. Furthermore the new co-products uses that have been recently studied such as the production of honey from the rape meal (Gärtner & Reinhardt, 2003) expand the options to allocate in a best way the co-products changing the GHG emissions too.

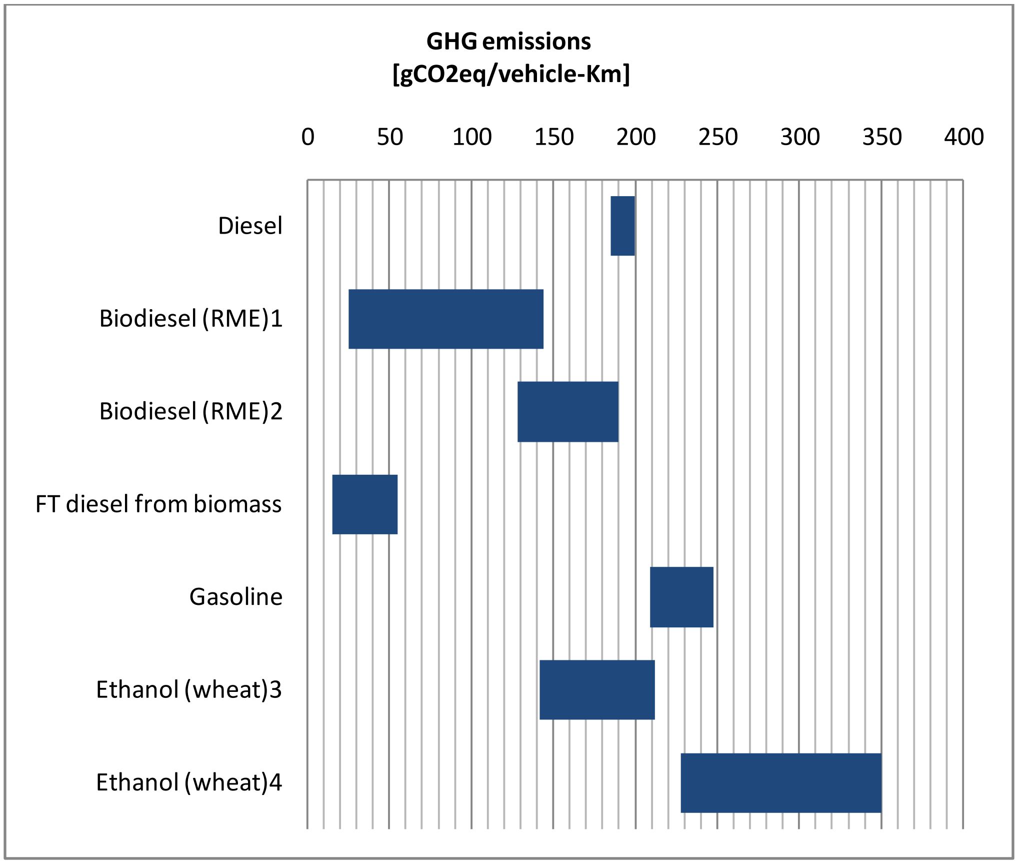
5.2.3.3 Direct and indirect land use change

The incorporation of dLUC and iLUC impacts in the LCA of domestic biofuels in countries of the EU such as Germany seems to make no sense, as each area unit use had been carefully assessed and planned for specific purposes (crops cultivation). However when these factors are included in the LCA the results can have more disadvantages than advantages for biofuels.

Graphic 7 also presents the variation of results when these factors are included. For biodiesel the emissions increased 44% compared with the emissions provided with an energy allocation of co-products (78 gCO_{2eq}/vehicle-Km) while for ethanol it increased in a 79%. However when they are compared with their fossil fuels counterparts (diesel and gasoline), they still have emissions savings.

As for biodiesel the emissions savings are about 36% and for ethanol are 8%. Notwithstanding, when talking about iLUC, only biodiesel continues to have GHG savings (5%) meanwhile for ethanol there are only losses (-41%). These results agree with different studies that made simulations in regards to the conversion of tropical forest to croplands which conclude that the

GHG emissions of most biofuels pathways with an iLUC are higher than those of fossil reference (Zulka et al., 2012).



Graphic 7. g CO2 eq/ vehicle-km. Source: Author based on the results from (Gärtner & Reinhardt, 2003; SenterNovem, 2008; van Vliet et al., 2009; Zulka et al., 2012). (RME)1 and Ethanol (wheat)3= GHG emissions without allocation, with energy allocation and with substitution of credits allocation of co- products. (RME)2 and Ethanol (wheat)4= GHG emissions from RME biodiesel with dLUC factor, low and medium iLUC factors. Methodological details are provided in Annex F.

On the one hand when comparing biofuels with their fossil counterparts and calculating the emissions saved, biodiesel (RME) taking into account only the allocation method, the savings are 87 – 28% depending on whether an allocation method is used or not and if it is used which method is used (e.g. energy, mass, economic allocation or a substitution of co- products credits). When features as dLUC or iLUC factors are incorporated in the methodology the emissions saved for biodiesel (RME) decrease to 31- 5 % vs. the fossil diesel. These represent a decrease of almost 40% of emissions savings from those reports that do not take into account land use change even If they use an allocation method. FT diesel is the best emissions saver (91-72.5%) when compared to fossil diesel; however the economic features can be decisive in order to produce FT diesel instead of crop´s biodiesel.

On the other hand the emissions that are saved from wheat bioethanol are less than those of biodiesel compared with their respective fossil fuel counterpart. An important characteristic of most of the studies that is important to notice is that when land use changes are incorporated to the LCA (dlUC or iLUC factors) there can be reduced emissions savings or even worst the use of these biofuels produces more emissions than their fossil fuel counterparts.

5.2.3.4 Constraints of the comparison in regards to CO2eq/vehicle-km

- The studies where the environmental performance data were obtained were mainly cases studies of Germany, however some of them calculated their parameters (data bases) under global information about land use and practices, process parameters which use different primary energy to feed the process (e.g. coal, natural gas, electricity, oil etc.) The variation of the energy source of the process provides different GHG emissions for each biofuels pathway.
- The aim and scope are completely different which leads to different results, each study wants to achieve a different target, provide different scenarios under the current agricultural practices (Zulka et al., 2012), introduce new co-products uses (Gärtner & Reinhardt, 2003) or involve different stakeholders in the LCA process, (SenterNovem, 2008).
- Different feedstock´s location sources and different carriers provided different results of GHG emissions regarding the transportation of raw material to the process plant and the transportation of the biofuel as final product to the fuel retail impacts directly in the results. It is not the same assumed that ¼ of the rapeseed is imported from third countries and transported by ship (SenterNovem, 2008) while only use domestic feedstock´s with a cultivation land with a 100 km distance from the process factory and another 100 km from the refinery to the retail stations (Zulka et al., 2012).

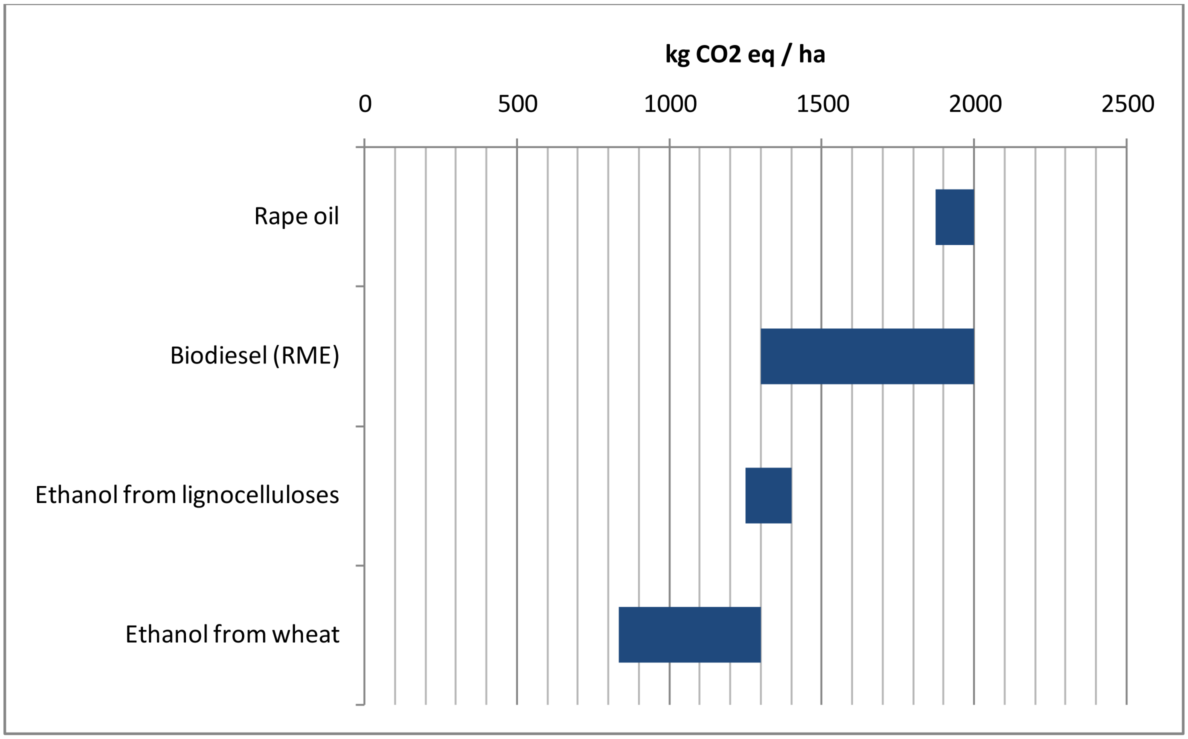
5.2.3.5 Agricultural area category

As it was mentioned before, in both Germany and the EU, land is the first constraint for the production of first generation biofuels which are nowadays totally commercial and for some second generation feedstock's of biofuels. Because this situation the following section expresses the results in a ratio of area of land cultivated.

The oldest data source for environmental impact of RME biodiesel under German context is reported by Kaltschmitt et al. (1997). However different sources around the world have collected different biodiesel RME, pure plant oil, bioethanol from wheat and potatoes pathways (Brauer & Müller-langer, 2008; Quirin et al., 2004; Reinhardt & von Falkenstein, 2011). The primary reasons for the contrasting results are the different assumptions about cultivation, and conversion or valuation of co-products. This thesis study takes the biofuels pathways of RME biodiesel, ethanol from wheat under German conditions and Rape oil, Biodiesel (RME), BTL form lignocelluloses and ethanol from cellulose pathways under EU conditions (Armstrong et al., 2002; Brauer & Müller-langer, 2008).

5.2.3.6 Allocation Method

As in the previous case, the co-products allocation vary from energy allocation in two phases, the oil extraction which 40% of the total energy expenditure until this stage is allocated to rape straw and rapeseed as co-products and a 4% of the total expenditure to glycerin produced as in the refining and esterification process (Kaltschmitt et al., 1997). A substitution of credits for bioenergy from chips and from slop from the sugar extraction and ethanol production is used by Armstrong et al. (2002); Reinhardt & von Falkenstein (2011) studies; and an economic allocation for the co-products generated in the different phases of the biofuels value chain (e.g. rapeseed press cake, raw glycerin and straw to generate electricity) according the prices in the market in 2008 is used in Brauer & Müller-langer (2008) report.



Graphic 8 Kg CO2 eq/ ha-y emissions. In a WtT approach. Source: Author based on (Armstrong et al., 2002; Brauer & Müller-langer, 2008; Kaltschmitt et al., 1997; Quirin et al., 2004; Reinhard & Zah, 2011)**. Methodological details are provided in Annex F2. PER-AREA AGRICULTURAL CATEGORY (HA)**

It is visible in **Graphic** 8 that the wide ranges of the emissions of pure rape oil, biodiesel (RME), BTL and ethanol from lignocelluloses and wheat differ according the authors and their given assumptions. These assumptions provide benefits to the ethanol from lignocelluloses and wheat.

5.2.3.7 Constraints when comparing different authors with land cultivation

- Boundaries of the reports.- This set of studies were complicated to compare and assess due to the boundaries of each study.
- Different studies use different premises and methodologies, so a direct comparison is not always possible. The single major source of differences between studies is the type and use of co-products. When it comes to the potential of biofuels in absolute terms, the crop yield per hectare is also a source of variation, as yields can vary significantly between regions and according to the assumed agricultural practices.
- Different scopes of the reports: Energy balances, global warming, energy efficiency.
- Even if the stages of the biofuels value chain are the same cultivation, transportation of feedstock, biofuel process, transportation of fuel, distribution and fuel use, the pattern

according location, inputs and distance from cultivation land to refinery and the difference of transporting biofuels final products to the stations retails is different in each study reviewed making it hard to group.

5.2.4 Spatial differentiation of impact categories

The current situation regarding biofuels policy instruments only takes into account the most noticeable environmental impact (global warming) which according to the classification of impacts provided by the UNEP global warming it is considered to be in a global category. Due to this situation most of the scientific studies, governmental reports and policy instruments regarding biofuels in the EU attempts to tackle global effects, directly; regional effects such as acidification, Eutrophication or Ecotoxicity with legislative measures, however these measures do not specify the calculation methods or the units to calculate this impacts and local effects as land use are tackled by prohibiting the use of certain land uses, and by supporting certificate schemes such as the international sustainability and carbon certification, the round table on sustainable palm oil, etc. which measure labor conditions, land rights and other impacts **Figure** 20.

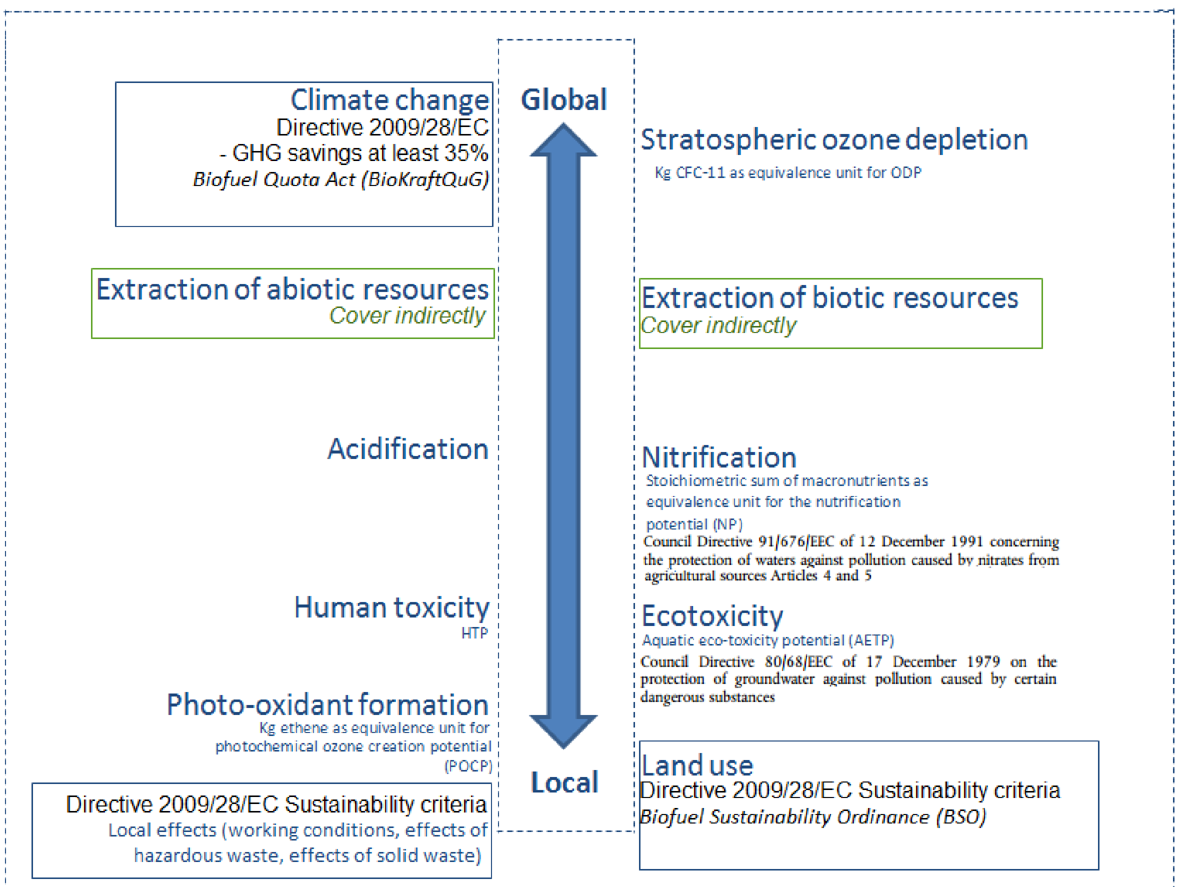


Figure 20 Spatial differentiation impact categories and its indicators applied to the case study. Source: Author based on (UNEP, 2003).

5.2.5 RME Energy performance

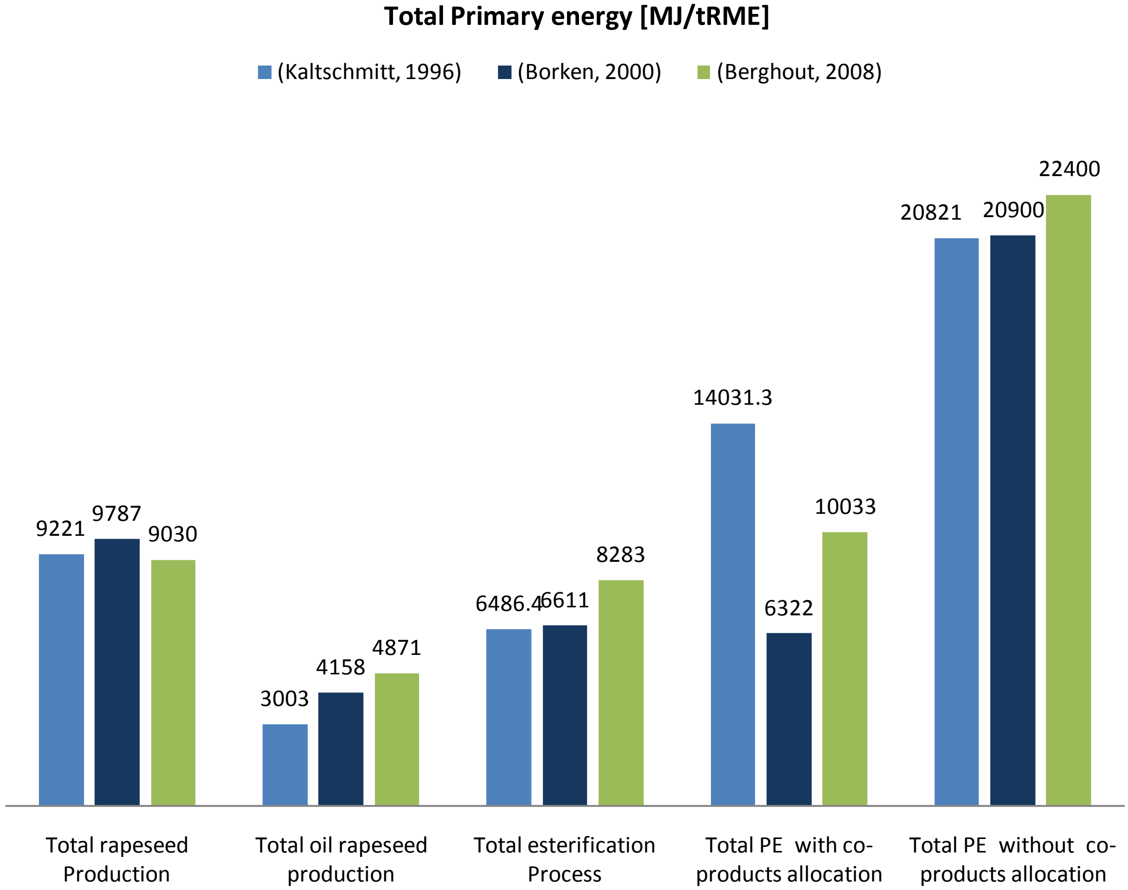
As it is explained in the objectives of this work, the main purpose of this thesis is to assess the policy instruments that are promoting biofuels and to analyze the interaction that these policy instruments have regarding the environmental impacts and the tools that measure those impacts, more specifically the life cycle assessment methodology for biofuels. However differences regarding primary energy consumption and GHG emissions were highlighted for the RME in different years.

As it was described before according to the statistics of production and consumption of biofuels in the European Union and worldwide, Germany has a leader position regarding biodiesel production. Due to this situation three data bases were chosen in order to compare the inputs, and outputs and find out the possible causes of the behavior of primary energy consumption and GHG emissions (Berghout, 2008; Borken et al., 2000; Kaltschmitt et al., 1997).

In order to construct the **Graphic** 9 four processes of the RME value chain in Germany were taken into account.

The PE required for the rapeseed production consists in the tillage, sowing, fertilizing, production and spraying of chemicals (different fertilizers), the harvesting and the transportation of the feedstocks to the oil rapeseed extraction. The oil rapeseed production represents the PE used in the oil extraction & refining, the transesterification process includes the heating of the process and finally the total primary energy reported as total PE is the corresponding after the allocation of co-products. The results are presented in MJ/tRME.

To obtain the total values that are presented in **Graphic** 9 the energy flows of each category (PE rapeseed production, PE oil rapeseed extraction, PE transesterification and total PE with products allocation) are described in **Annex** G. ENVIRONMENTAL DATA BASES FOR RME PRODUCTION IN GERMANY



Graphic 9. Total Primary energy consumed in Rapeseed production, oil production, transesterification process and total PE with and without co-products allocation in [MJ/tRME]. Source: Author based on data bases from (Berghout, 2008; Borken et al., 2000; Kaltschmitt et al., 1997)**.**

Graphic 9 is a comparison between three Biodiesel RME databases for Germany in three different years, 1996, 2000 and 2007. It can be seen that there have been slights variations in the PE consumed in the different selected process, even if the data are provided for different time periods they maintain a positive trend, the only exception is the total PE used with co-products allocation.

Table 15 Changes during different period times in the PE consumption. Units. Percentages [%].

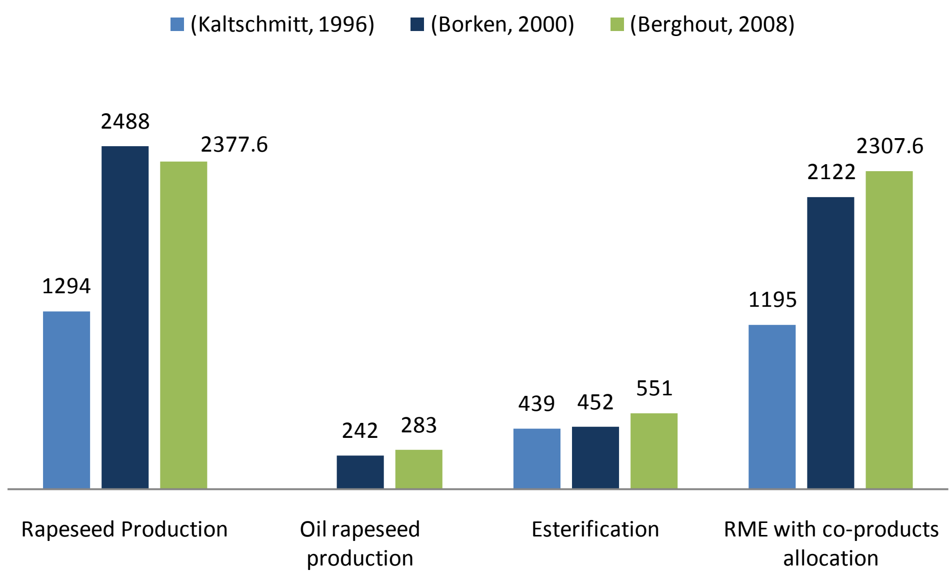
Total	(Kaltschmitt, 1996) vs. (Borken, 2000)	(Borken, 2000) vs. (Berghout, 2008)	(Kaltschmitt, 1996) vs (Berghout, 2008)
Total rapeseed Production	6.14	-7.73	-2.07
total oil rapeseed production	38.46	17.15	62.20
Total esterification Process	1.92	25.29	27.70
Total PE with co-products allocation	-54.94	58.70	-28.50
Total PE without co-products allocation	0.38	7.18	7.58

The values from the **Table** 15 are obtained comparing and subtracting the results provided on **Graphic** 9. The values with a negative sign represent a decrease in PE consumption while the positive represent an increment in PE consumption.

The total PE with co-products allocation exemplifies the differences and the variation when different methods are used to allocate co-products.

The same comparison and analysis described before from the same three data bases was made regarding the GHG emissions expresed in kg CO_2-eq/tRME, however in the specific case of GHG emissions it is notable that the method used to allocate the co-products, the assumptions and the way in with the emissions were calculated influence the results **Graphic** 10 represents the variations among the different studies. However an statement that is clear is that in a Well to Tank analysis the cultivation process provides the major part of the GHG emission released to the atmosphere. The energy flows used to construct it are provided in the **Annex** G. ENVIRONMENTAL DATA BASES FOR RME PRODUCTION IN GERMANY

Total GHG emissions [Kg CO2eq /tRME]



Graphic 10 GHG emissions in [kg CO2 eq/tRME] for rapeseed production, oil rapeseed production, esterification and total RME with co-products allocation. Source: Author based on databases from (Berghout, 2008; Borken et al., 2000; Kaltschmitt et al., 1997)**.**

5.2.6 Discussion of the LCA for environmental impacts

Environmental impacts assessed with the LCA methodology and policy instruments used to encourage the production and usage of biofuels cannot be seen as isolated concepts. The European Commission's Renewable Energy Directive (DIRECTIVE 2009/28/EC RED part biofuels) mandates the member states to report the total GHG emissions of biofuels using the LCA methodology to assess the environmental impacts (GHG emission reduction). The LCA methodology is most clear and complete methodology to determine the relative environmental advantages or disadvantages of biofuels. The RED Directive´s calculation method provides annexes with ranges of values to calculate the GHG emission reduction, where four production stages can be identified: crop production, transport of materials, processing and end-use, the diagram flow can be seen in **Annex** E. DIAGRAM FLOW expressed in the Renewable Energy Directive RED

2009/28/ECAlso these stages are the same stages that are used in the Well to Wheel (WtW) approach.

Due to the differences of data inputs and assumptions that each author uses and makes, the results are difficult to compare even if a WtW life cycle analysis is used. Nevertheless the results given (even they have different functional units) lead to a wide range of GHG reductions of biofuels when compared with their fossil fuels counterparts.

In order to normalize the GHG calculations of the member states, there are some tools that have been developed. These use in the different biofuel production pathways that are indicated in the DIRECTIVE 2009/28/EC notwithstanding some authors (Hennecke et al., 2013; Miller & Theis, 2008) indicate that the results that these tools provide have some differences.

Although the LCA is the most often used methodology to measure the environmental impacts of serveral products, regarding biofuels sector the approach is limited, because the studies focus in the measurement of energy flows and GHG balances, leaving aside other environmental impacts such as ecotoxicity, acidifiaction, eutriphication etc. However the selection of GHG or energy balances measures are linked directly with the policy objectives, in most cases reduction of GHG and reduction in the consumption of fossil fuels.

It has been shown that there are many factors that can influence the assessment of total GHG emissions and net savings for biofuels. These can cause small or large differences in results. They can also be combined to generate a considerable range of results for any particular biofuel pathway. The two main features that can lead to very different results are the allocation of co-products and the functional unit chosen in which the results have to be provided. As an observation, the LCA results of biofuels from cultivation crops produced in Germany should be expressed on a per hectare basis, since the available land for production of feedstocks is the biggest limitation to its future development.

The kind of energy, renewable or fossil that is used during the value chain (e.g. to fuel the process, to transport the feedstock and the final products) has consequences in the calculation both in energy balance and GHG emissions. However a general statement can be made: “The more fossil fuel input a certain biofuel pathway requires, the less energetically desirable it will become”. According to this situation some production value chains are more desirable than others, it depends on the crop´s yield, the amount of pesticides and fertilizers, the energy for irrigation water required, the feedstock processing requirements, the process energy requirements and the distance traveled in the transportation of the feedstock or the final product.

Regarding the allocation of co-products each co-product has a different economic, energetic, mass value, in some cases the productio of certain co-product will be sold in markets which contribute to increase the value chain of this specific product leading to a decrease in raw material, which makes it considerably difficult to provide a generic method to allocate co-products.

CHAPTER 6 GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES

6.0 Conclusions

Biofuels are seen as a renewable energy source for the transportation sector, even though it is a dynamic sector. Biofuels are used strategically to decrease both, oil consumption and GHG emissions. In the last decade more than ten countries in the world have published policies in order to assure the production and consumption in their countries with the aim of tackling three principal issues: oil dependence, agricultural support and climate change.

This research study aims to provide a complete overview of the environmental impacts that are measured with the LCA methodology and controlled through different policy instruments that can either hinder or encourage their production and consumption and the interaction that exists between these two elements (environmental impacts and policy instruments) in Germany as a case study.

The specific objectives of this work were established to guide the steps needed to complete and answer the main objective, in this way the specific objectives were leading the requirements for the assessment of policies and environmental impacts in the case study of Germany. The following conclusions were structured according to each specific objective.

The literature review, secondary data analysis and expert's consultation with local and international researchers revealed numerous works and information related to the study area and the European Union in different fields regarding biofuels for the transportation sector. From these data it was possible to provide the general policy organizational structure, legislative framework, land use , environmental impacts caused by the usage of biofuels in the country, the European Union and third countries where feedstock´s are grown, as well as the key methodological features of the LCA when it is applied to assess biofuels. The conclusions obtained in relation to the study area characterization are the following:

Related to the biofuels production in Germany.

- *Germany is a country that is largely dependent on oil imports from the total PE used in Germany, 52% of the total is destined to the transportation sector.* This situation fostered the biofuels production and usage in the country as a strategy to decrease the fossil fuels consumption.
- *Land extension and land availability to produce first generation biofuels is one of the main constraints to develop biofuels industry in Germany.* From the 357,022 sq km extension land half of the land area (47%; 16.7 million ha) is used for agriculture purposes, from which 12% (2,056,000 ha) is dedicated to cultivate biofuels feedstocks. The principal crops used in Germany to domestically produce biofuels are rapeseed and soy bean for biodiesel while wheat, rye and potatoes are the main feedstock's to produce ethanol. Meanwhile, domestic production of ethanol has been carried out since 2005.

Related to the biofuels consumption in Germany.

- *Biofuels consumption in Germany changes according to internal (Laws enactment) and external (international debates about the relative benefits of biofuels) factors, which influence directly the consumption patterns*. Since the early 90's PPO and biodiesel had a stake of 0.05% on the share of motor fuel consumption, which has been increasing in the subsequent years. The largest increment took place in 2007 when the biofuels quota act was enacted; however global debates such as food vs. fuel in 2008 have lead to a decrement in its share on motor fuel consumption from 7.4% to 5.4%. This last share percentage has remained until the last statistical balance on 2011. Current debates regarding the deforestation of rainforests to lead biofuels crops cultivation and the regrettable labor conditions of the workers in crops cultivation for feedstock's production on third countries play an important role on the consumption side.

Related to the policies that hinder or encourage the biofuels industry focused on the main actors.

- *German national plans and laws regarding renewable energies for the transportation sector have to fulfill and comply the changing legislative measures in two different spatial scales national and European Union.* This situation creates a loop between objectives/targets and plans to achieve and measure those objectives. Amendments have to be done every time that a relevant finding is obtained. Germany as a member of the EU has to align its legislative measures and targets regarding renewable energies in the transportation sector with those enacted by the EU. The transportation sector renewable energy directive (RED) and the fuel quality directive (FQD), enacted by the EUC, are the legal basis for all EU member states, regarding the production, consumption and development of biofuels in the transportation sector.

- *From the different set of policy instruments that can be used to foster the biofuels production and consumption in Germany, only two categories; Command and control instruments and economic and fiscal instruments had been enacted with the purpose to meet the RED and FQD.* The Biofuels Quota Act, which is a volume that mandates a 6.25% biofuel-petroleum blend by 2014 and the Biofuels Sustainability Ordinance (BSO), in effect since January 2011, requires biofuels to meet a BSO registered sustainability scheme, which must at minimum include the mandatory sustainability criteria from the RED/FQD (e.g. biofuels to be 35% less carbon intensive than petroleum in 2011, 50% in 2017, and 60% in 2018).

- *Targets and drivers are clear and specific regarding the share of biofuels in both European Union and German transportation sector, whereby different actors play important roles in both the development of the policy and the industrial production & consumption*. While the government performs its regulatory role among the feedstock´s producers, the biofuels producers and the oil companies, some other actors such as the scientific community and NGO´s, influence the biofuels public acceptance. Debates such as food vs. fuel, rainforest deforestation or biofuels water footprint have led a number of amendments in the policy instruments in both European Union and national levels. The clear example of this situation is the comments and summary of the European

Commission´s proposal to modify the EU biofuel policies of the 17th October 2012. In which a series of amendments were proposed to the fuel quality directive (98/70/EC) and the renewable energy directive (2009/28/EC) regarding biofuels production and modification to the general biofuels share target.

Related to the environmental impacts assessed with the LCA methodology.

- *Although LCA is the most often used methodology to measure the environmental performance of serveral products along their entire value chain, regarding biofuels the approach is very limited*. At least there are 10 environemtnal impact categories proposed by the UNEP and well accepted in the scientific field, however the aim to tackle climate change and reduce fossil fuels consumption, sets the current focus of biofuels LCA on energy flows and GHG balances. Very few studies focus on other environmental impacts such as ecotoxicity, acidification, eutrophication etc.
- *LCA methodology is very sensitive to data sources and assumptions in the different processes of the value chain, which leads to a wide range of results even when the same biofuels production pathway is used.* It has been shown that there are many factors that can influence the assessment of total GHG emissions and net savings for biofuels. These can cause small or even large differences in results. The two main features that can lead to very different results are the allocation of co-products and the functional unit chosen in which the results have to be provided. As an observation, the LCA results of biofuels from cultivation crops produced in Germany should be expressed on a per hectare basis, since the available land for production of feedstock´s is the biggest limitation to its future development.
- *Each biofuel pathway produces a series of co-products that, depending on the national context have a different value*. Regarding the allocation of co-products each of them has a different economic, energetic and mass value. In some cases the production of certain co-product will be sold in markets wich contribute to increase the value chain of this specific product leading to a raw material reduction, which makes consideably difficult to provide a generic method to allocate co-products.
- *The kind of energy, renewable or fossil that is used during the different processes in the biofuels value chain (e.g. to fuel the process, to transport the feedstock and the final products) has consequences in the calculation both in the energy balance and the GHG emissions.* However a general statement can be made. “The more fossil fuel input a certain biofuel pathway requires, the less energetically desirable it will become”. According to this situation some production value chains are more desirable than others, it depends on the crop´s yield, the amount of pesticides and fertilizers used, the energy for irrigation water required, the feedstock processing requirements, the process energy requirements, the distance traveled in the transportation of the feedstock and the final product.

Related to the interactions between the environmental impacts measured with an LCA methodology and the policy instruments.

- *Neither the environmental impacts assessed with the LCA methodology nor the policy instruments used to encourage the production and usage of biofuels in the EU and Germany can be seen as isolated concepts.* The European Commission's Renewable Energy Directive (DIRECTIVE 2009/28/EC RED part biofuels) mandates the member states to report the total GHG emissions of biofuels using the LCA methodology. However it is clear that biofuel policy instruments are likely to consist of a mixture of actions including quantitative targets, such as minimum net GHG emissions savings measured with the LCA methodology, and exclusion clauses, such as rules which specify that biofuels cannot be derived from biomass feedstock´s grown on certain types of land (peat lands, grasslands, recently cleared natural forests, etc.)

- *For domestic production of biofuels, the exclusion clauses regarding where to cultivate crops for energy purposes in order to avoid land use changes meet their purpose, however several improvements have to be reviewed and achieved when crops for biofuels are cultivated in third countries.* The European Union and the case study member (Germany) have well identified the strengths, opportunities and constraints regarding the production of first generation biofuels. They have assessed each hectare of land dedicated to cultivate feedstock´s for first generation biofuels, and they know how much savings they can expect.

- *Regarding the spatial scale (global and local) of the impact categories, provided by the UNEP, only one global impact category, global warming, is well specified and energy balances are linked directly with the policy objective.* Other impacts are tried to be tackled by several clauses and referring some points in other legislative instruments however no evidence was found regarding the methodologies used to measure those impacts.

A route towards a sustainable production of biofuels is quite far from a simple way in which only benefits can be addressed; production, trade and usage of biofuels are accompanied by a complexity, contradiction regarding their benefits, discrepancy in the measurements of impacts (which impacts to measure and where the impacts are measured), uncertainty regarding the energy share that it could have in the transportation sector and many challenges that have to be overcome in both scales the countries that use biofuels (Germany) and the third countries where the feedstock are produced and then imported.

6.1 Recommendations for further research

Different sectors such as electricity, heat and cooling had found renewable energy sources, however it seems that the transportation sector remains far from a renewable energy source. Many expectations had been placed on biofuels, but a series of debates about their sustainability, their relative benefits and the amendments that have been done in the policy instruments, indicate that the current methodologies used (LCA) have challenges to overcome in the future years.

Even when the results of this study have raised more questions than answers as many of the findings indicated more need for analysis, the following section is a set of recommendations categorized in three parts, recommendations for further research, recommendations about the LCA methodology and finally recommendation to policy makers.

From the theoretical and methodological perspective from which the case study was assessed the interactions and integration of environmental impacts measured using the LCA methodology regarding the different policy instruments that foster the biofuels production and consumption. In this sense, the integration of different conceptual features try to achieve a systematic approach, which is seen as the ability to study and analyze a whole from different perspectives, in order to solve a problem in an integrative way, knowing who and when could help according the expertise level required.

Future research regarding the policy analysis and LCA assessment for the production of biofuels in Germany can address any of the following topics:

- The life cycle costs.- Environmental costs and their visibility, the externalities caused by biofuels industry (production and consumption of biofuels)
- The socio-economic analysis.- The interactions between economy, society and policy instruments regarding biofuels production and consumption taking into account the dynamics and overall trajectory of feedstock´s in both the case study and the countries which export raw material for biofuels industry in the EU and Germany.
- The implications for using biofuels in a worldwide context. If the flex fuel cars technology will be exported to other countries the need to create blends in countries in which biofuels are not used will create a series of impacts that have to be foretold and assessed.

Even if the LCA is an international renowned and well accepted methodology in both the policy makers side and scientific side, for the evaluation of the environmental performance of a specific product along its partial or entire life cycle, there are some issues that this methodology does not take into account.

- Environmental and economic performances are well covered, and the guidelines to perform a complete LCA are clear and specific, however the social part is still put aside from this methodology which makes quite complicated to systematically assess the real performance of a product.

- Regarding biofuels production assessed through the LCA methodology. Key features in the impact inventory have to be more specific and clear in order to avoid the different methodological assumptions, conversion processes, different feedstock´s that turn LCA in a very complex methodology.

Finally for the people those are responsible for designing guidelines in the transportation energy sector.

- The current situation regarding biofuels production and consumption in the EU and Germany is not an exemption. It reveals that land is the first limitation that these countries have in order to produce biofuels, hence the need to express the environmental performance on a per area basis instead of the currently used, energy input-output basis which tries to avoid the debate regarding land availability.
- The integration of different key conceptual features such as anticipatory key competences in order to predict future events and anticipate problems avoiding short term-amendments and with this a series of changes in the production and consumption pathways.

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Annex A. EXPERTS CONSULTATION

Concerns to this research work.

- *Specific research data (SRD)*
- *General research data (GRD)*
- *An specific opinion (SO)*

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Tobias Ziep	Biograce tool www.biograce.ne tobias.ziep@htw-berlin.de	Specific research data (SRD)

Annex B. LAND USE IN GERMANY (NUTS and LUCAS)

The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU for the purpose of:

- The collection, development and harmonization of EU regional statistics.
- Socio-economic analyses of the regions.

NUTS 1: major socio-economic regions
NUTS 2: basic regions for the application of regional policies
NUTS 3: small regions for specific diagnoses

The article 19(2) of Directive 2009/28/EC mandates member states to submit to the Commission a report including a list of those areas on their territory classified as level 2 in the NUTS, where the typical greenhouse gas emissions from cultivation of agricultural raw materials can be expected to be lower than or equal to the emissions reported under the heading 'Disaggregated default values for cultivation' in part D of Annex V.

Germany reported the following areas

The regions are as follows:
Schleswig-Holstein, Hamburg, Braunschweig, Hannover, Lüneburg, Weser-Ems, Bremen, Düsseldorf, Cologne, Münster, Detmold, Arnsberg, Darmstadt, Gießen, Kassel, Koblenz, Trier, Rheinhessen-Pfalz, Stuttgart, Karlsruhe, Freiburg, Tübingen, Upper Bavaria, Lower Bavaria, Oberpfalz, Oberfranken, Mittelfranken, Unterfranken, Swabia, Saarland, Berlin, Mecklenburg-Western Pomerania, Chemnitz, Dresden, Leipzig, Saxony-Anhalt, Thuringia, North-East Brandenburg, South-West Brandenburg

European Union Commission 2012.
ID: 40923108N, 40923108S, 40923108E, 40923108W
GPS_Y_LAT: 51.0372
GPS_X_LONG 6.73399

LC1- B11: Common Wheat
LU1: U111 Agricultural Production
LU2:U210 Energy Production

/

European Union Commission, 2012.
ID: 41043064N, 41043064S, 41043064E, 41043064W
GPS_Y_LAT: 50.6468
GPS_X_LONG 6.93107

LC1- B14: Rye
LU1: U111 Agricultural Production
LU2:U210 Energy Production

European Union Commission 2012.
ID: 45743384N, 45743384S, 45743384E, 45743384W
GPS_Y_LAT: 53.50385
GPS_X_LONG 13.81455

LC1- B32: Rape and turnip rape
LU1: U111 Agricultural Production
LU2:U210 Energy Production

Annex C. BIOFUEL INDUSTRY IN GERMANY

BIODIESEL PLANTS IN GERMANY IN 2010

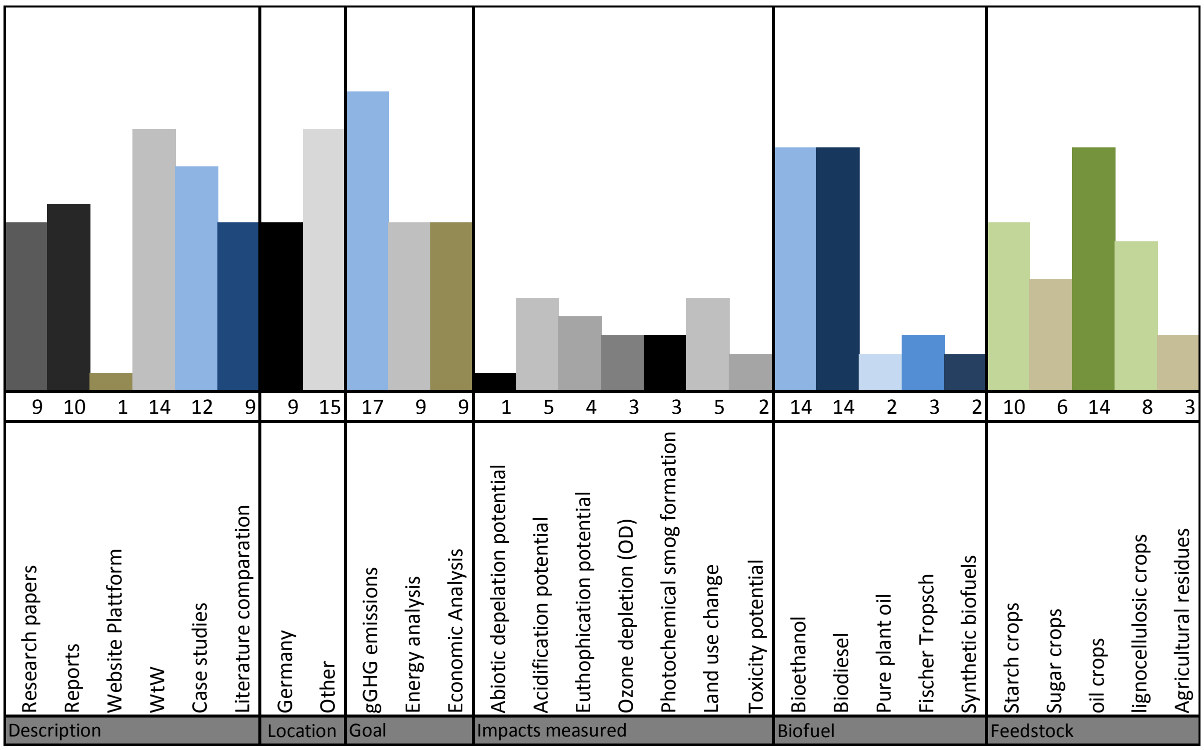
Company	Location	Capacity (tonnes per year)
ADM Hamburg AG - plant in Hamburg	Hamburg	580,000
Cargill GmbH	Frankfurt/Main	300,000
ADM Mainz GmbH	Mainz	275,000
NEW Natural Energie West GmbH	Neuss	260,000
Bio-Ölwerk Magdeburg GmbH	Magdeburg	255,000
Verbio Diesel Schwedt GmbH & Co. KG (NUW)	Schwedt	250,000
ecoMotion GmbH	Lünen	212,000
BIOPETROL ROSTOCK GmbH	Rostock	200,000
Louis Dreyfus commodities Wittenberg GmbH	Lutherstadt Wittenberg	200,000
Verbio Diesel Bitterfeld GmbH & Co. KG (MUW)	Greppin	190,000
BIOPETROL SCHWARZHEIDE GmbH (former Biodiesel Schwarzheide)	Schwarzheide	150,000
Rheinische Bioester GmbH	Neuss	150,000
Vesta Biofuels Brunsbüttel GmbH & Co. KG	Brunsbüttel	150,000
EOP Biodiesel AG	Falkenhagen	130,000
ADM Hamburg AG - plant in Leer	Leer	120,000
BIO-Diesel Wittenberge GmbH	Wittenberge	120,000
KL Biodiesel GmbH & Co. KG	Lülsdorf	120,000
MBF Mannheim Biofuel GmbH	Mannheim	100,000
Südstärke GmbH	Schrobenhausen	100,000
Vital Fettrecycling GmbH - plant in Emden	Emden	100,000
DBE Biowerk GmbH	Tangermünde/Regensburg	99,000
Emerald Biodiesel Ebeleben GmbH	Ebeleben	90,000
Petrotec GmbH	Südlohn	85,000
Bioeton Kyritz GmbH	Kyritz	80,000
TECOSOL GmbH	Ochsenfurt	75,000
LubminOil	Lubmin	60,000
G.A.T.E. Global Atern. Energy GmbH	Halle	58,000
EAI Thüringer Methylesterwerke GmbH (TME)	Harth-Pöllnitz	55,000
Biowerk Oberlausitz GmbH	Sohland	50,000
Biowerk Sohland GmbH	Sohland	50,000
ecodasa GmbH	Burg	50,000
Emerald Biodiesel Neubrandenburg GmbH	Neubrandenburg	40,000
Rapsveredelung Vorpommern	Malchin	38,000
BKN Biokraftstoff Nord AG (former Biodiesel Bokel)	Bokel	35,000
Ullrich Biodiesel GmbH/IFBI	Kaufungen	35,000
Nehlsen GmbH	Grimmen	33,000
KFS-Biodiesel GmbH	Cloppenburg	30,000
HHV Hallertauer Hopfenveredelungs- gesellschaft mbH	Mainburg	7,500
Rapsol GmbH	Lübz	6,000
LPV Landwirtschaftliche Produkt- Verarbeitungs GmbH	Henningsleben	5,500
BKK Biodiesel GmbH	Rudolstadt	4,000
Delitzscher Rapsöl GmbH & Co. KG	Wiedemar	4,000
Osterländer Biodiesel GmbH & Co. KG	Schmölln	4,000
SüBio GmbH	Themar	4,000
Vogtland Bio-Diesel GmbH	Großfriesen	2,000
Total 2010		**4,962,000**

ETHANOL PLANTS IN GERMANY IN 2010

	Company	Production capacity (tonnes per year)	Feedstock
1	CropEnergies AG (Zeitz)	284,040	Cereals, sugar juice
2	Verbio AG (Schwedt)	181,470	Cereals, sugar juice
3	Fuel 21 (Klein Wanzleben)	102,570	Sugar juice
4	Verbio AG (Zörbig)	98,625	Cereals
5	Prokon (Stade)	94,680	Wheat
6	SASOL (Herne)	59,964	Raw alcohol
7	Danisco (Anklam)	44,184	Sugar juice
8	KWST (Hannover)	31,560	Raw alcohol
9	Wabio	9,468	-
10	Müllermilch (Leppersdorf)	7,890	Diary products
	Total production – Germany	**914,451**	

Annex D. ENVIRONMENTAL IMPACTS

The following graphic provides an overview of the total number of reviewed studies selected from scientific papers, governmental reports provided by the corresponding governmental agencies and websites platforms. The studies were selected according to the case study location (Germany), studies from other countries of the European union were also selected due to the similarities in feedstock´s cultivation that they present.



Annex D 2. QUALITATIVE ANALYSIS

Abbreviations list

Location

DE	Germany
EU	European Union
GB	Global
NS	Not Specified
AU	Austria
BZ	Brazil

System boundaries

NS	Not specified
wtw	well to wheel
wtt	well to tank

Goal and Scope

GW	Global warming
GHG	Green house gas analysis
EA	Energy analysis
EcA	Economical analysis

Impacts measured

AD	Abiotic depeletion potential
AP	Acidification Potential
EP	Eutrophication potential
OD	Ozone depletion
PF	Photochemical smog formation
LU	Land use
TP	Toxicity potential

Reference system

FF	Fossil fuel

Transportation biofuels

BE	Bioethanol
RME	Rapemethyl ester / biodiesel
BD	Biodiesel
FT	Fischer Tropsch
SB	Synthetic biofuels

Functional Unit

HA	Agricultural land
IO	Input-output
D	Distance
E	Energy

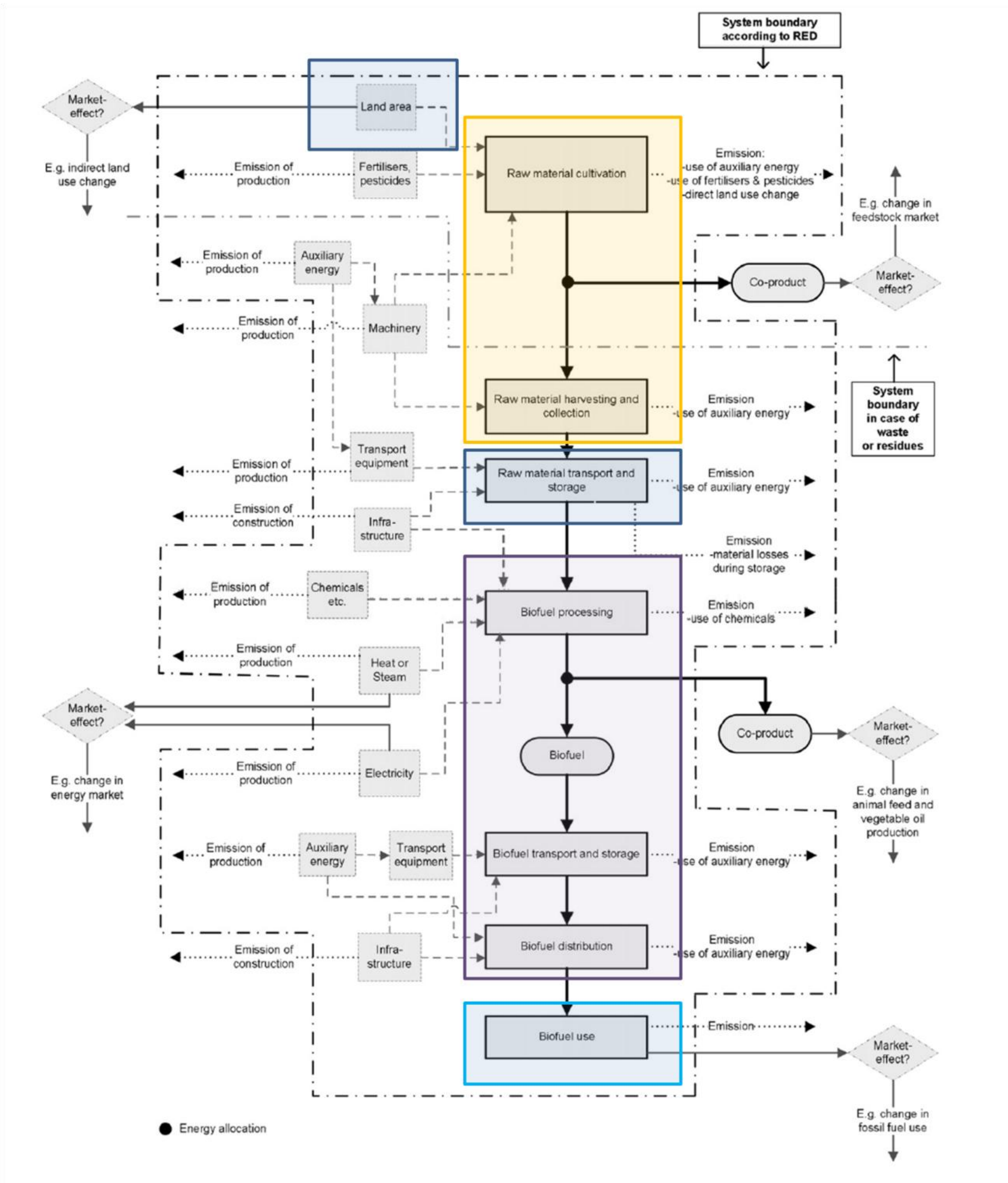
Feedstock´s

SC	Sugar crops
OC	Oil crops
LC	Lignocellulosic crops
AR	Agricultural residues
O	Other
WR	Wood residues

Report	Source	Location	Temporal scale	Data base	System boundaries	Goal and Scope	Impacts	Biofuel	Functional Unit	Reference system	Feedstocks
Life cycle analysis of biofuels under different environmental aspects	(Kaltshmitt, 1996)	DE	1996	NS	wtw	GW, GHG, EA	AP	RME	HA	FF	OC, LC
An energy analysis of ethanol from cellulosic feedstock–Corn stover	(Luo, 2009)	NS	NS	Eco-invent	wtt	EcA	NO	BE, SB	IO	FF	AR
Environmental impacts of a lignocellulose feedstock biorefinery system: An assessment	(Uihlein, 2009)	DE	NS	Eco-indicador 99	wtt	GW	AD, AP, EP, OD, PF, TP, LU	BE	IO	FF	AR
Life cycle assessment of biodiesel Update and New Aspects	(Gärtner, 2003)	DE	2000-2005	Different sources compendium	wtw	GW, GHG	AP, OD, PF	RME	IO	FF	OC
LCA of a biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass	(Cherubini, 2010)	AU	NS	SIMA PRO	wtw	GW, GHG	AD, AP, EP, OD, PF, TP, LU	BE	IO	FF	LC
Ökobilanzen ausgewählter Biotreibstoffe / Biodiesel aus Raps	(Umweltbundesamt, 2012)	DE, AU	NS	GEMIS Austria (Version 4.5)	wtt	GHG, EA	LU	RME	D	FF	OC
Ökobilanzen ausgewählter Biotreibstoffe / Bioethanol aus Weizen	(Umweltbundesamt, 2012)	DE, AU	NS	GEMIS Austria (Version 4.5)	wtt	GHG, EA	LU	BE	D	FF	SC
Investigating the sustainability of lignocellulose-derived fuels for light-duty vehicles	(Fleming,2006)	GB	2012, 2005, 2010	Greet 2006, version 1.6	wtw	GW, GHG	NO	FT	D	FF	LC, WR
Biogenic greenhouse gas emissions linked to the life cycles of biodiesel derived from European rapeseed and Brazilian soybeans.	(Reijnders, 2008)	EU, BZ	2002-2007	Eco invent	wtw	GHG	LU	BD	IO	FF	OC
CO2-neutrale Wege zukünftiger Mobilität durch Biokraftstoffe: Eine Bestandsaufnahme	(Höpfner, 2004)	DE, EU	2000- 2012	NS	wtt	GHG, EA, EcA	NO	BE,BD	E	FF	OC, SC
Environmental assessment of biofuels for transport and the aspects of land use Competition	(Reinhardt, 2011)	GB	NS	NS	wtw	GHG, EA, EcA	NO	BE,BD	HA	FF	SC, OC, LC

Report	Source	Location	Temporal scale	Data base	System boundaries	Goal and Scope	Impacts	Biofuel	Functional Unit	Reference system	Feedstocks
CO2 Mitigation through Biofuels in the transport sector Status and Perspectives	(Quirin, 2004)	EU, DE	NS	NS	wtw	GHG, EA, EcA	NO	BE,BD	HA	FF	SC, OC, LC
Participative LCA on Biofuels (Full report)	(SenterNovem,2008)	EU	NS	Eco invent	wtw	GW	AD, AP	BE	D	FF	OT
Participative LCA on Biofuels (Full report)	(SenterNovem,2008)	EU	NS	Eco invent	wtw	GW	AP, EP	BD	D	FF	OC
The GHG balance of biofuels taking into account land use change	(Lange, 2011)	EU	NS	IPCC and EU guidelines	wtw	GHG	NO	BE,BD	E	FF	NS
Basisdaten für Ökologische Bilanzierungen	(Borken, 1999)	DE	1999	IFEU data base	wtt	GHG	NO	RME	IO	FF	OC, SC
Technological learning in the German Biodiesel Industry	(Berghout, 2008)	DE	2008	Eco invent e IFEU data base	wtw	GHG	NO	BD	IO	FF	OC
Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context	(Edwards, 2011)	EU	2003	ADVISOR modified to EU requirements	wtw	GHG, EA, EcA	NO	BD, RME, BE	D	FF	OC,SC,LC,WR
Cost and life cycle analysis of biofuels (long version)	(UFOP, 2008)	EU	2008	Different sources compendium	wtw	GHG, EA, EcA	NO	BE, BD	D	FF	SC, OC
Energy and greenhouse gas balance of biofuels for europe - an update	(Armstrong, 2002)	EU	2002	Different sources compendium	wtt	GHG, EA	NO	BE, BD	HA	FF	SC, OC

Annex E. DIAGRAM FLOW expressed in the Renewable Energy Directive RED 2009/28/EC



Annex F. DISTANCE TRAVELED PER VEHICLE BASIS (VEHICLE-KM)

The first group consists in a comparison of results from Gärtner & Reinhardt (2003); SenterNovem (2008); van Vliet et al. (2009); Zulka et al. (2012) regarding the CO_2eq emissions released by a vehicle each kilometer traveled (vehicle-km).

All the studies compared the performance of GHG emissions with their conventional fossil fuels counterparts; biodiesel is compared with diesel while ethanol is compared with gasoline.

Zulka et al. (2012) are the authors of the study performed by the Austrian Government that aims with a Well to Tank approach to assess the GHG emissions and to show the variation ranges of GHG modifying the allocation of co-products methods and introducing the direct land use change (dLUC) and indirect land use change (iLUC) features in the methodology.

Gärtner & Reinhardt (2003) reported on the study performed by the IFEU (Institute for energy and environmental research) which make an update and provide new co-products (honey and biogas generation from rapeseed meal) and provide their results in liters of biofuel used instead fossil fuels on a distance of 100 km. They also provide research questions in regards to acidification, nutrient inputs and ozone depletion which they conclude has a disadvantage for biofuels and few studies focuses on these impact categories which have negative impacts and are not asked to measure or control in the EU sustainability criteria of the 2009/28/EC criteria.

The study performed by Van Vliet et al. (2009) calculated a carbon and an energy balance of 14 different Fischer-Tropsch (FT) fuel production with different assumptions that results in a complicated cocktail of studies when trying to fix specific cases form the literature.

The study performed by a consultant in behalf of the Swiss government SenterNovem (2008) is a study that tried to communicate the environmental impacts of biofuels from crops and to involve the stakeholders in the complete LCA project to provide the input parameters. For the case of biodiesel they divided the feedstock as following: 1/2 from crops of Western Europe, ¼ for Easter Europe and ¼ from third countries.

Report	Source	Location	Data base used (eco-inventor etc.)	System boundaries	Products and byproducts	eq CO2 emissions		Units	Comments
Ökobilanzen ausgewählter Biotreibstoffe / Biodiesel aus Raps	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Rapsmethylester (RME) 55%, Presskuchen 42%, Glycerin 3%	200		geq CO2/ vehicle km	Diesel
Ökobilanzen ausgewählter Biotreibstoffe / Biodiesel aus Raps	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Rapsmethylester (RME) 55%, Presskuchen 42%, Glycerin 3%	25	144	geq CO2/ vehicle km	Biodiesel allocation (25 credits , 78 energy allocation)
Ökobilanzen ausgewählter Biotreibstoffe / Biodiesel aus Raps	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Rapsmethylester (RME) 55%, Presskuchen 42%, Glycerin 3%	128		geq CO2/ vehicle km	Biodiesel LUC
Ökobilanzen ausgewählter Biotreibstoffe / Biodiesel aus Raps	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Rapsmethylester (RME) 55%, Presskuchen 42%, Glycerin 3%	128	190	geq CO2/ vehicle km	Biodiesel iLUC (low 140 medium 190)
Ökobilanzen ausgewählter Biotreibstoffe / Bioethanol aus Weizen	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Ethanol 67%, Stillage (DDGS) 33%	248		geq CO2/ vehicle km	Gasoline
Ökobilanzen ausgewählter Biotreibstoffe / Bioethanol aus Weizen	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Ethanol 67%, Stillage (DDGS) 33%	212		geq CO2/ vehicle km	Bioethanol
Ökobilanzen ausgewählter Biotreibstoffe / Bioethanol aus Weizen	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Ethanol 67%, Stillage (DDGS) 33%	148	194	geq CO2/ vehicle km	Bioethanol allocation (194 credits, 148 energy allocation)
Ökobilanzen ausgewählter Biotreibstoffe / Bioethanol aus Weizen	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Ethanol 67%, Stillage (DDGS) 33%	228		geq CO2/ vehicle km	Bioethanol LUC
Ökobilanzen ausgewählter Biotreibstoffe / Bioethanol aus Weizen	(Umweltbundesamt, 2012)	DE, AU	GEMIS Austria (Version 4.5)	wtt	Ethanol 67%, Stillage (DDGS) 33%	250	350	geq CO2/ vehicle km	Bioethanol iLUC

Annex F2. PER-AREA AGRICULTURAL CATEGORY (HA)

As it was mentioned before, land could be a limit for the production of first generation biofuels which are nowadays totally commercial and for some second generation feedstock's of biofuels. Because this situation some authors prefer to express their results in per area of land cultivated and this study grouped these reports in an agricultural area category

The oldest data for environmental impact of RME biodiesel under German circumstances reported by Kaltschmitt et al. (1997). They also apply the same methodology to other biofuels pathways that were debated in that time in Germany due to the relative advantages that they could have in different environmental impacts such as N_2O emissions, SO_2 equivalents and NOx emissions. In order to compare with the other authors reports, the case study (RME diesel) was the only data taken into account for this thesis purposes.

Other study that also assess the environmental advantages and disadvantages of biodiesel (RME), rapeseed pure oil, ethanol from wheat and potatoes among others is the study performed by Reinhardt & von Falkenstein, (2011)which apply a Well to Wheels approach. However the authors collected and compared different international publications that contain also different assumptions regarding cultivation patterns (fertilizer production and application), the calculation of the energy used in the process to generate biofuels and different methodologies to obtain other extra data in order to provide the same data to have a similar basis to compare.

Other collection of international biofuels pathways is the study performed by Quirin et al.,(2004) that reviewed more than 800 studies and analyzed 69 of them in detail, the primary reasons for differing results are different assumptions made about cultivation, and conversion or valuation of co-products. This thesis study only takes the biofuels pathways of RME biodiesel, ethanol from wheat that are reported in Quirin et al. (2004) report under German conditions.

Rape oil, Biodiesel (RME), BTL form lignocelluloses and ethanol from cellulose fuels pathways are taken from the report provided by the report of Brauer & Müller-langer (2008) which performed a cost and life cycle of biofuels of the European Union and grouped in the per area cultivated group.

Armstrong et al. (2002) compared different biofuels pathways in Europe using a Well to Tank approach. This review is limited to the production of biofuels and does not consider the end-use. It also provides a case study for Germany´s RME and as the other reports it mentions that in order to compare the different studies from an energy point of view a calculation of some common parameters that were not included in previous studies (e.g. energy balances in some process in order to compare under the same basis) was done.

Report	Source	Location	System boundaries	Products	eq CO2		Units
Life cycle analysis of biofuels under different environmental aspects	(Kaltshmitt, 1996)	DE	wtw	Biodiesl (RME)	1422.4 and 1593		kgCO2eq/ha
Life cycle analysis of biofuels under different environmental aspects	(Kaltshmitt, 1996)	DE	wtw	Rapeseed oil	-2400		KgCO2eq/ ha
Life cycle analysis of biofuels under different environmental aspects	(Kaltshmitt, 1996)	DE	wtw	Ethanol wheat	-2000		KgCO2eq/ ha
Life cycle analysis of biofuels under different environmental aspects	(Kaltshmitt, 1996)	DE	wtw	Ethanol potatoes	-2350		KgCO2eq/ ha
Environmental assessment of biofuels for transport and the aspects of land use Competition	(Reinhardt, 2011)	GB	wtw	Biodiesel (RME)	-250	-2500	KgCO2eq/ ha
Environmental assessment of biofuels for transport and the aspects of land use Competition	(Reinhardt, 2011)	GB	wtw	Rapeseed oil	-2500	-3750	KgCO2eq/ ha
Environmental assessment of biofuels for transport and the aspects of land use Competition	(Reinhardt, 2011)	GB	wtw	Ethanol wheat	-1000	-3500	KgCO2eq/ ha
Environmental assessment of biofuels for transport and the aspects of land use Competition	(Reinhardt, 2011)	GB	wtw	Ethanol potatoes	-830	-3330	KgCO2eq/ ha
Cost and life cycle analysis of biofuels (long version)	(UFOP, 2008)	EU	wtt	Rape oil	1875	2000	kg CO2eq/ ha
Cost and life cycle analysis of biofuels (long version)	(UFOP, 2008)	EU	wtt	Biodiesel (RME)	1666	1875	kg CO2eq/ ha
Cost and life cycle analysis of biofuels (long version)	(UFOP, 2008)	EU	wtt	BTL from lignocelluloses	3333	7500	kg CO2eq/ ha
Cost and life cycle analysis of biofuels (long version)	(UFOP, 2008)	EU	wtt	Ethanol from lignocelluloses	1250	1400	kg CO2eq/ ha
Cost and life cycle analysis of biofuels (long version)	(UFOP, 2008)	EU	wtt	Ethanol from wheat	833	1300	kg CO2eq/ ha
Energy and greenhouse gas balance of biofuels for europe - an update	(Armstrong, 2002)	DE	wtt	Diesel RME	3120		kg CO2eq/ ha

Annex G. ENVIRONMENTAL DATA BASES FOR RME PRODUCTION IN GERMANY

Environmental data bases	2000 (Basisdaten für ökologische Bilanzierungen)				2007 (Ecoinvent)			
	Quantity per tRME	MJp/tRME	kgCO2-eq/tRME	g N2O /tRME	Quantity per tRME	MJp/tRME	kg CO2eq/tRME	g N2O /tRME
Rapeseed production								
Tillage and Sowing					30.6 L diesel	1214	88.7	2.8
Fertilizing					4.6 L diesel	183	13.3	0.4
Spraying of Chemicals	40.1 L diesel	1591	116	4	6.3 L diesel	251	18.3	0.6
Harvesting and Transport	15 L diesel	596	44	1	13.4 L diesel	530	38.9	1.2
Drying of rapeseed	50.7 KWh+18.25 kg oil	1625	95	1	28.3 KWh+23.9 kg oil	1723	99.2	0.8
Emissions from field		0	1459	4928		0	1452.1	4905
Sum Direct Processes		*3812*	*1713*	*4934*		*3901*	*1710.5*	4910.8
Seed	2.5 kg	10	2	4	3.74 kg	14	3	7
Fertilizer N	122 kg	4549	682	1428	104.6 kg	3901	585	944
Fertilizer P2O5	45.3 kg	820	56	2	18.7 kg	338	23	1
Fertilizer K2O	25.1 kg	272	17	1	61.3 kg	664	43	3
Fertilizer CaO	15.9 kg	37	5	0	15.9 kg	37	5	0
Chemicals production	1.03 kg	287	13	2	0.63 kg	175	8.1	1
Sum indirect process		*5975*	*775*	*1438*		5129	667.1	956
Total rapeseed production		***9787***	***2488***	***6372***		**9030**	**2377.6**	**5866.8**
Oil Extraction								
Transport to oil mill	70% ship; 15% train; 15% lorry	348	26	3	70% ship; 15% train; 15% lorry	348	26	3
oil extraction	88 kWh+ 717 kg steam	3050	177	2	120 KWh+769kg steam	3575	208	3
oil refining	6KWh+148 kg steam	501	29	0	steam	656	38	1
Sum Direct Processes		*3899*	*232*	*5*		*4579*	*272*	6
Hexane	1.0 kg	134	1	0	1.2 kg	161	1.7	0.05
Other chemicals		125	9	0		131.6	9.3	0.4
Sum indirect process		*259*	*10*	*0*		*292.6*	*11*	0
Total rapseed oil production		***4158***	***242***	***6***		***4871.6***	***283***	***7***
Esterification								
Esterification	46 KWh+647.4 kg steam	2411	139	1	108 kWh+727 kg steam	4083	239	1
Sum Direct Processes		*2411*	*139*	*1*		*4083*	*239*	1
Methanol	109.1	4099	305	2	109.1 kg	4099	305	2
Other chemicals	6.3	101	7	0	6.3	101	7	0
Sum indirect process		*4200*	*313*	*2*		*4200*	*312*	2
Total esterification		**6611**	**452**	**3**		**8283**	**551**	**3**
Distribution	150 km	186	14	1	150 km	186	14	1
Total RME (without credits)		***20742***	***3196***	***6382***		**22370.6**	**3225.6**	***5879***
Soy meal (fodder usage)	1621 kg	5477	416	101	1369 kg	4629	351	85
Glycerin (synthetic)	117 kg	8943	658	17	100 kg	7709	567	15
Sum credits		***14420***	***1074***	***118***		12338	918	100
Total RME (with credits)		***6322***	***2122***	***6264***		**10032.6**	**2307.6**	***5779***

Yield	***1143***	***kg RME/ha y***	(Kaltshmitt, 1996)			
Environmental data bases	**PE (MJ)/ha year**	**Kg CO2 eq /ha y**	**Noxg/ha year**	**PE (MJ)/ tRME**	**Kg CO2 eq /t RME**	**Noxg/t RME**
Plant production: cropping of energy producing plants						
Ploughing	646	49	493	565.2	43	431
Stubble cultivation	493	38	377	431.3	33	330
Sowing	213	16	155	186.4	14	136
Fertilizing	83	6	58	72.6	5	51
Plant protection	98	7	85	85.7	6	74
Nitrogen fertilizer	6843	858	1700	5986.9	751	1487
Phosphorus fertilizer	840	61	555	734.9	53	486
Potassium fertilizer	276	17	26	241.5	15	23
Calcium fertilizer	40	5	6	35.0	4	5
Seed+plant material	23	2	7	20.1	2	6
Pesticide	333	16	20	291.3	14	17
Plant production: rotation fallow						
Sowing	-213	-16	-155	-186.4	-14	-136
Mowing	-137	-11	-99	-119.9	-10	-87
Seed+plant material	-536	-68	-249	-468.9	-59	-218
D (fiels emissions)		135	-			
Harvest	616	47	466	538.9	41	408
Transport	36	3	23	31.5	3	20
Storage	1379	101	81	1206.5	88	71
Transport to oil mill	408	31	422	357.0	27	369
Oil extraction	3178	182	269	2780.4	159	235
Subtotal (ST I)	***14619***	***1479***	***4240***	**12790.0**	**1294**	**3710**
Share of ST I (60%)	*8771.4*	887.4	2544	7674.0	776	2226
Refining	521	33	45	455.8	29	39
Esterification	7414	502	495	6486.4	439	433
Subtotal (ST II)	***16706***	***1422.4***	***3084***	14615.9	1244	2698
share of ST II (96%)	*16037.8*	*1365.5*	2960.6	14031.3	1195	2590
Final Report	166	13	146	145.2	11	128
use in car	0	215	11165	0.0	188	9768
Total	***16204***	***1593.5***	14271.6	14176.7	1394	12486
Fossil life cycle						
Pre chain	4566	374	1527	3994.8	327	1336
Energy content diesel fuel	42530	3378	11165	37209.1	2955	9768
Total	**47096**	**3752**	**12692**	**41203.8**	3283	11104
Difference (Biogenic-Fossil)	-30892	-2158.5	1579.6	-27027.1	-1888	1382