ROYAL INSTITUTE
OF TECHNOLOGY

Biodiesel CO2 emissions under Sweden policy scenario and technical constraints

BIOGRACE LABORATORY

CLIMATE CHANGE MITIGATION TOOLS

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1. Introduction

The energy systems present today in European countries rely in a great extent on fossil fuels and non-renewable energy sources although there is a wide range of alternatives to fossil fuels that already are using existing technology and available infrastructure.

The transport sector in Sweden is entirely dependent on fossil fuels, and road transport is the major key player regarding carbon dioxide emissions with an average increase of 0.7% per year since 1990 (1). Although energy efficient improvements in vehicles have been done during the past years, the increase of the car-passenger fleet has caused a continuous increase in carbon dioxide emissions. When compared with the European average, carbon dioxide emissions due to the new car fleet added in the last 10 years are 20-25% higher.

Energy use for transport sector in Sweden is continuously increasing. Besides, the transport sector is the end use that has the greatest difficulty in changing for a different carrier, so it makes this sector one of the main focus for policy challenges.

When the EU decided in 2008 to cut its greenhouse gas emissions to demonstrate that a global commitment could be settled in order to tackle climate change, it settled global targets to be accomplished by each European country.

In order to achieve this commitment, Sweden agreed to reduce by 40% its greenhouse gas emissions from 1990 levels by 2020 (2). Besides, also aims to reach a share of 50% for total energy use from renewable sources while increasing the energy efficiency by 20%.

Furthermore, as the vision for Sweden is not to have any greenhouse gas net emissions into the atmosphere by 2050, the target of 10% of biofuels for the transport sector is a strategic mid-stone to achieve this ambitious goal (1).

In 2005, the domestic road transport itself accounted to be over 90% of total emissions from domestic transport (3); and in 2006, renewable fuels accounted for just the 3% of energy use by transport (3). Under this undesirable basis, Sweden expects to reach by 2030 a car fleet completely independent of fossil fuels.

The promotion of biofuels is a component of the government’s strategy of long-term sustainable development. General economic policy instruments that settle a price for greenhouse gas emissions, together with higher biofuels admixtures in fossil fuels and beneficial conditions for cars with low environmental impact, will lead to decrease the total amount of carbon dioxide emissions in the transport sector.

The use of biofuels has been principally boosted by the fact that since 2004, they have been exempt from the carbon dioxide tax and the energy tax.

In 2010, Swedish government approved to increase the blends of FAME (Fatty-acid methyl ester) in diesel from 5% to 7%. Although the exemption in carbon tax is only present for blends up to 5 % of FAME.

This non-tax exemption for the 2% difference share does not promote the maximum 7% blend of FAME allowed, thus not maximizing carbon dioxide emissions reduction and braking both the 10 % of biofuels for the transport sector and the 40% greenhouse gas emissions target.

2. Objective

The objective of this report is to analyse carbon dioxide emissions reduction comparing fossil fuel based diesel engine vehicles with different FAME percentages of admixtures allowed under the current policy scenario in Sweden. Besides, a percentage of FAME up to 20 % is also considered as it is the maximum FAME admixture possible for diesel engines vehicles without any detriment of engine usability. It represents a good balance of cost, emissions, cold weather performance and materials compatibility (4).

Additionally, a comparison among carbon dioxide emissions of main biofuels (ethanol, biogas and biodiesel) used for the transport sector in Sweden is being made, thus evaluating the role of biodiesel consumption and its greenhouse gas emissions in a broader perspective.

3. Scope and limitations

In order to analyse the implications of carbon dioxide emissions due to biodiesel consumption in the road transport in Sweden, it has been taken into account FAME blends of 5%, 7% and 20%. The two first blend percentages are due to policy constraints in Sweden and the blend up to 20% is considered as the maximum blend acceptable for overall diesel engines without any engine modification.

When calculating carbon dioxide emissions for all three biofuels in Sweden, biodiesel consumption is only measured from 2005 as it is considered the breaking point for the Swedish transport market and previous contributions are considered negligible.

4. Data

In order to compare carbon dioxide emissions for different biodiesel admixtures, it has been necessary to find out carbon dioxide emissions for FAME from rapeseed lifecycle; and for this purpose, BioGrace Greenhouse gas calculation tool was used.

BioGrace values given in the spreadsheet file are based on EU standards. With the aim to have more accurate values, we proceeded into a broad research in order to calculate the carbon dioxide emissions of FAME from rapeseed lifecycle in Sweden with the maximum accuracy.

As mentioned before, the scope of this analysis is national based, all the data entered in BioGrace calculation tool has been extracted from national studies and reports (5), except some data that has been extracted from a rapeseed lifecycle calculation report performed in Denmark (6) when no national data of that particular requirement was found.

Carbon dioxide emissions in BioGrace are divided into the following phases:

- Cultivation of rapeseed
- Rapeseed drying
- Transport of rapeseed
- Extraction of oil
- Allocation over main product and co-product
- Refining of vegetable oil
- Esterification
- Transport of FAME to and from depot.
- Filling station
- Land use change, including bonus for production on non-agriculture or degraded land
- Improved agricultural management
- CO2 carbon and replacement
- CO2 capture and geological storage

Among them, the following phases with the following values were substituted from the EU standard values.

Table 1: FAME from rapeseed parameters when cultivated and produced in Sweden

Cultivation of rapeseed		
Yield		
Rapeseed	3113	kg ha-1 year-1
Moisture content	9	%
Energy consumption		
Diesel	3788	kg ha-1 year-1
Agro chemicals		
N-fertilizer (kg N)	140	kg N ha-1 year-1
K2O-fertiliser (kg K2O)	99	kg K2O ha-1 year-1
Seeding material		
Seeds- rapeseed	5	kg ha-1 year-1
Allocation over main product and co-product		
Main product:Rapeseed oil	1	MJ

Co-prouct: Straw for bedding	0,6326	MJ
Total	1,6326	MJ

After entering all the above mentioned parameters, carbon dioxide emissions for FAME from rapeseed cultivated and proceed in Sweden accounted to be 53.6 g CO_2/MJ $_{FAME}$. When this value was obtained, then was calculated the total carbon dioxide emissions for the different FAME blend admixtures in diesel for a further comparison with greenhouse gas emissions if road transport in Sweden was completely fossil fuel based running with diesel B00.

5. Methodology

Based on biodiesel consumption values (MJ) for road transport from the Swedish Energy Agency, both the share of diesel used and the amount of FAME were also calculated (MJ).

Besides, taking into account the energy and density values for diesel and FAME given in Table 4, the total amount of carbon dioxide emissions (tonnes) for different admixtures was calculated as well.

As mentioned before, it is worth noting that for this analysis was only considered consumption values from 2006 to 2011 due to the fact that in 2005 was the breaking point for biodiesel as it appeared into the Swedish market.

The total emissions (tonnes) for ethanol and biogas for the transport sector in Sweden were calculated as well in order to give an overall perspective for the study. The calculations were made considering a broader period from 2000 to 2011 with the Swedish Energy Agency values.

6. Results

The detailed results for the different phases of FAME cultivation and production are shown in the Table 2 below given in carbon dioxide emissions per energy content of FAME (g CO_2/MJ $_{FAME}$).

Table 3 shows the total carbon dioxide emissions (tonnes) for different admixtures of FAME compared both with carbon dioxide emissions from B00 and the yearly biodiesel consumption (tonnes). In Figure 1 it can be seen the yearly variations of different biodiesel blends related to its consumption.

It is worth noting that for biodiesel 7% the initial value considered is from 2010 when the Swedish Government Directive allowed an increase of FAME blend from 5% to 7%.

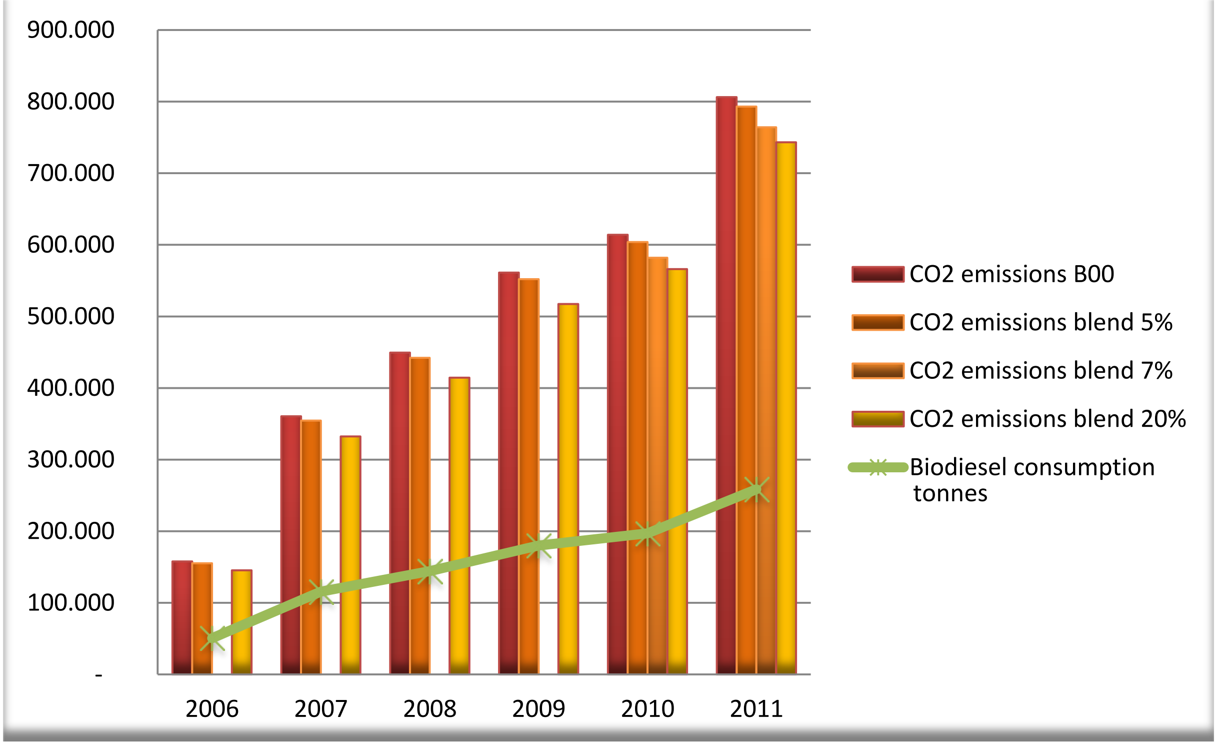
Table 2: Results for the different phases for the cultivation and production of FAME from rapeseed

Results in g CO_2/MJ $_{FAME}$	**Non-allocated results**	**Allocation factor**	**Alloated results**	**Total**
Cultivation e_{ec}				**30,5**
Cultivation of rapeseed	51,31	58,6%	30,06	
Rapeseed drying	0,72	58,6%	0,42	
Processing e_p				**21,7**
Extraction of oil	6,53	58,6%	3,83	
Refining of vegetable oil	1,06	95,7%	1,02	
Esterification	17,61	95,7%	16,84	
Transport e_{td}				**1,4**
Transport of rapeseed	0,29	58,6%	0,17	
Transport of FAME	0,82	100,0%	0,82	
Filling station	0,44	100,0%	0,44	
Land use change e_l	0	58,6%	0	**0**
Bonus (restored degraded land)	0	100,0%	0	**0**
$e_{sca} + e_{ccr} + e_{ccs}$	0	100,0%	0	**0**
Total E	**78,78**		**53,6**	**53,6**

Table 3: Results for the carbon dioxide emissions per different admixture of FAME

Year	**Total CO_2 emissions biodiesel 5% (tonnes)**	**Total CO_2 emissions biodiesel 7% (tonnes)**	**Total CO_2 emissions biodiesel 20% (tonnes)**	**Total CO_2 emissions diesel B00 (tonnes)**
2006	155 228,90	-	145 495,75	157 818
2007	354 630,44	-	332 394,44	360 544
2008	442 102,64	-	414 381,96	449 475
2009	552 026,96	-	517 413,82	561 233
2010	603 957,43	598 908,20	566 088,15	614 029
2011	793 064,68	786 434,46	743 338,02	806 290

Figure 1: Biodiesel consumption and CO_2 emissions per type of admixture (tonnes)



As mentioned before, the results of carbon dioxide emissions were calculated with the resulting value of 53.6 g CO_2/MJ $_{FAME}$ obtained in BioGrace for FAME from rapeseed cultivated and processed in Sweden. Therefore, we have noticed that this value differs with other studies that have calculated as well the value for FAME lifecycle emissions in Sweden and also from the value given by BioGrace according to RED Annex VD that accounts to be 52 g CO_2/MJ $_{FAME.}$

The reason is that although a very exhaustive research has been performed finding cultivation and production parameters for FAME in Sweden, a further and more accurate research should be done with more reliable data sources.

In order not to base this research in a non-reliable value obtained with incomplete information, I have preferred to show a comparison of carbon dioxide reduction emissions considering the FAME emissions' factor obtained for this report and the one obtained by the *Life cycle assessment of Swedish biofuels'* report from the University of Lund in 2010 (7), that stands for 18 g CO_2/MJ $_{FAME}$.

As it can be seen in Figure 2 and Figure 3 below, with an admixture of FAME of 20%, the maximum recommended for blends in diesel engines, total carbon dioxide emissions can be reduced almost by 8% when compared with diesel engines running in B00. This amounts accounts for a total of 62.952 tonnes of carbon dioxide avoided in one single year.

When considered the FAME emission factor calculated by the University of Lund, for an admixture of 20% the reductions can reach 126.462 tonnes of carbon dioxide avoided, equal to almost 16% less than the total emissions released without considering the contribution of the biofuel in the Swedish market.

Figure 2: CO_2 emissions reduction per type of admixture (tonnes) for 2011, calculations based on BioGrace emissions value

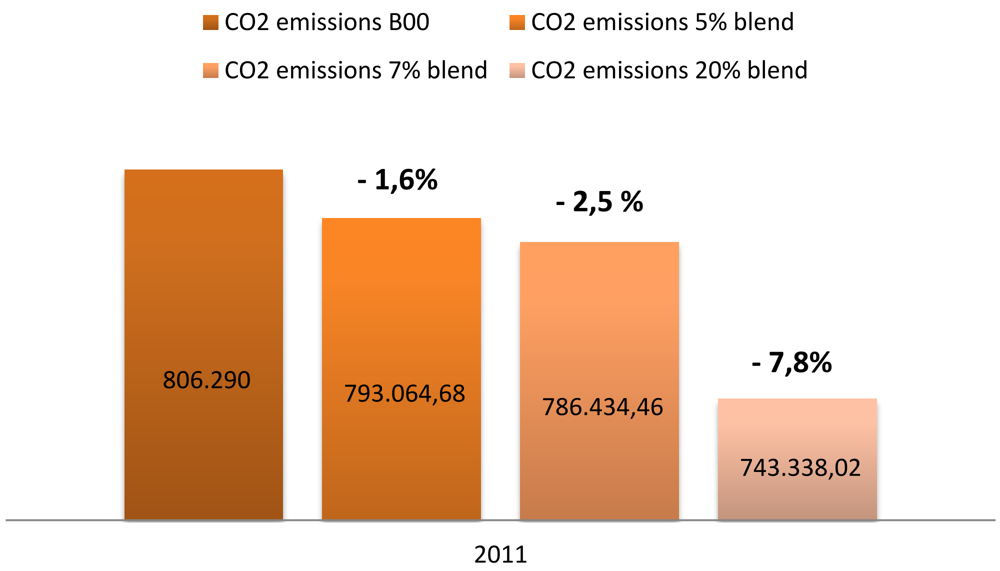
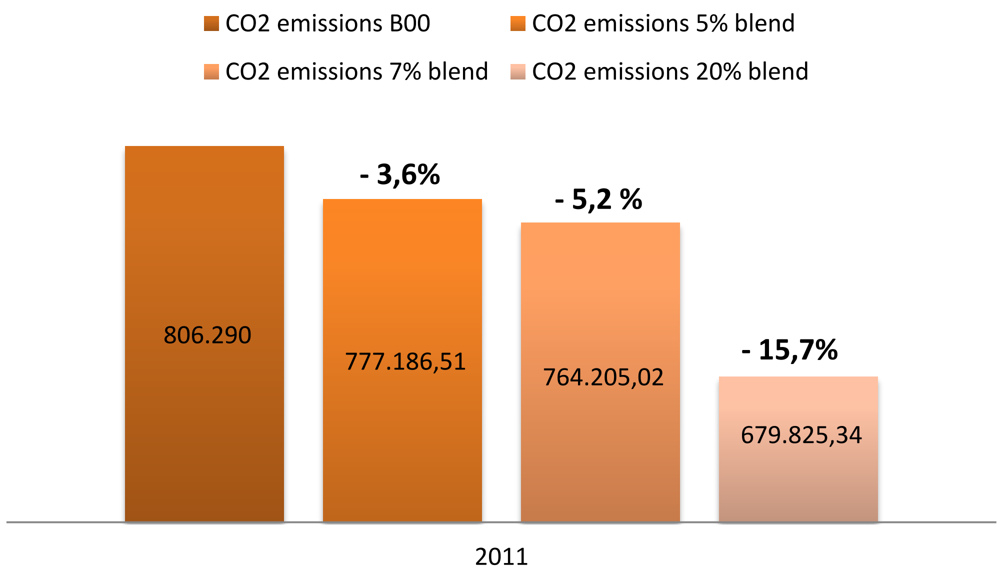


Figure 3: CO_2 emissions per type of admixture (tonnes) for 2011, calculations based on Lund University report emissions value

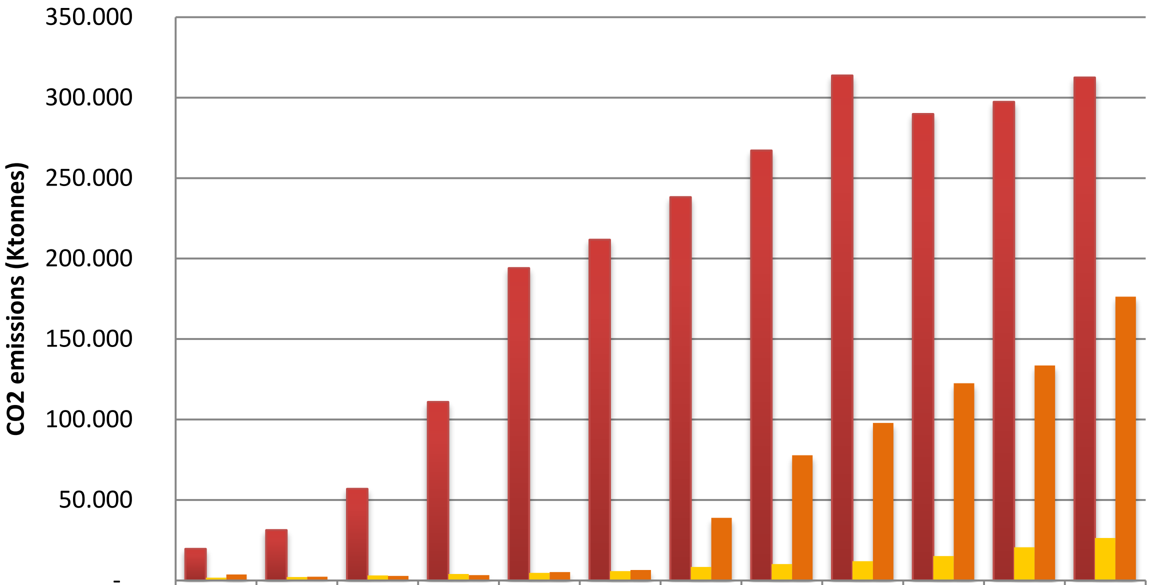


To finalize this study, a general overview of the biofuels' market in Sweden and its related carbon dioxide emissions was performed. To calculate the corresponding carbon dioxide emissions, the emission factors obtained by the University of Lund were used, accounting to be for ethanol 35 gCO_2/MJ, for biogas 10 gCO_2/MJ, and for biodiesel 18 $grCO_2/MJ$.

As it can be seen in Figure 4, biodiesel emissions accounts in a great extension for the total emissions in the road transport sector, given the role of biogas in a residual position; although a continuous and steady increase.

By the other hand, although the energy use (TWh) in 2011 for ethanol and biodiesel was almost the same (8), the carbon dioxide emissions factor for ethanol is higher than for biodiesel, covering a wide amount of the total emissions in the road transport sector.

Figure 4: Evolution of CO2 emissions per type of biofuel by energy use for the Swedish domestic transport (Ktonnes)



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Bioethanol	19.5	31.2	56.8	110.	194.	211.	238.	267.	313.	289.	297.	312.
Biogas	1.62	2.09	3.08	3.96	4.68	5.76	8.28	10.0	11.8	15.1	20.5	26.2
Biodiesel	3.65	2.24	2.80	3.24	5.18	6.48	38.8	77.7	97.8	122.	133.	176.

It is worth mentioning that if the same results were compared with the total emissions released by fossil fuels due to the road transport sector in Sweden, the values of biodiesel and ethanol emissions would represent a minor share. The analysis of total carbon dioxide emissions considering all types of fuels and shares and its relation with the Swedish and European market could be considered in future studies and will need further research.

7. Conclusions

Biofuels for transport are attracting considerable support from the EU in an irregular basis. On one hand, huge investments have been made to promote biogas consumption produced and consumed nationally in Sweden; however the future of biodiesel from rapeseed oil is dependent as well on long-term Swedish government support for its promotion and consumption among all diesel engine vehicle fleet. Besides, we should remember that the diesel engine fleet is in a continuous and steady grow.

The role of governance is fundamental for the future of rapeseed-based biodiesel, it was shown that its net carbon dioxide emissions are much lower than other biofuels, but the complexity of the biofuels industry and the diversity of actors create instability among its producers and consequently among the future in the market.

No further producer investments will be done if governance and policymakers do not settle a long-term and stable basis to promote the production market.

For biodiesel from rapeseed oil producers, it is being more and more costly to produce RME since rapeseed prices have increased significantly from the time that most of the Swedish producers started their production.

Besides, in 2013 biofuels exemption taxes will expire unless the government does not decide the contrary in this short period of time. But according to current trends and to EU possible future decision about limiting biofuel production coming from food crops, it is not likely to happen. On the other hand, the Renewable Energy Directive does not consider the greenhouse gas emissions associated with indirect land-use change, an important factor to take into consideration if, as we have seen in Table 2 when comparing carbon dioxide emissions for the different phases of the cultivation and production of FAME, the release of carbon dioxide emissions during cultivation accounts for an important share.

As we have seen in the report, by increasing current admixture levels of 5% up to the 7% obvious carbon dioxide emissions reduction will be done, but this aspect does not seem to be much attractive for Swedish government as it does not facilitate this goal by promoting as well a tax exemption for this admixture difference. As far as biodiesel price without tax exemption is almost as diesel price, there is no a competitive advantage at all.

Although Sweden has committed itself with more ambitious goals that the ones settled by the EU in the Renewable Energy Directive for all European countries, both with greenhouse gas emissions and energy use share from renewable sources. The target of 10% for biofuels in the transport sector market remained immovable.

8. References

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9. Annex

Table 4: B00 – B5 – B7 – B20 energy and carbon dioxide emission g CO_2/MJ $_{FAME}$

Diesel B00			
LHV diesel	43,1	MJ diesel/Kg	
density	832	Kg/m^3	
Percentage	0,95	0,93	0,8
Emissions	83,8	g CO_2/MJ diesel	

FAME 5%		
LHV fame	37,2	MJ/Kg
density	890	Kg/m3
Percentage	0,05	
Emissions (1)	53,6	g CO_2/MJ fame
Emissions (2)	18	g CO_2/MJ fame

FAME 7%		
LHV fame	37,2	MJ/Kg
density	890	Kg/m3
Percentage	0,07	
Emissions (1)	53,6	g CO_2/MJ fame
Emissions (2)	18	g CO_2/MJ fame

FAME 20%		
LHV fame	37,2	MJ/Kg
density	890	Kg/m3
Percentage	0,2	
Emissions (1)	53,6	g CO_2/MJ fame
Emissions (2)	18	g CO_2/MJ fame

Table 5: Biodiesel B5 – B7 – B20 emissions calculations in kg CO_2/liter biodiesel

Admixture of 5% biodiesel from rapeseed oil

Diesel consumption 95=	34,06624	MJ/liter
FAME-5 consumption=	1,6554	MJ/liter
Disel CO_2 emissions=	2854,750912	g CO_2/liter diesel
FAME-5 CO_2 emissions BioGrace=	88,72944	g CO_2/liter b-d rap
FAME-5 CO_2 emissions Lund=	29,7972	g CO_2/liter b-d rap
TOTAL emissions BioGrace 5%	2 943,48	g CO_2/liter biodiesel
	2,94	kg CO_2/liter biodiesel
TOTAL emissions 5% Lund	2884,548112	g CO_2/liter biodiesel
	2,88	kg CO_2/liter biodiesel

Admixture of 7% biodiesel from rapeseed oil

Diesel consumption 97=	33,349056	MJ/liter
FAME-7 consumption=	2,31756	MJ/liter
Disel CO_2 emissions=	2794,650893	g CO_2/liter diesel
FAME-7 CO_2 emissions BioGrace=	124,221216	g CO_2/liter b-d rap
FAME-5 CO_2 emissions Lund=	41,71608	g CO_2/liter b-d rap
TOTAL emissions BioGrace 7%	2 918,87	g CO_2/liter biodiesel
	2,92	kg CO_2/liter biodiesel
TOTAL emissions 7% Lund	2836,366973	g CO_2/liter biodiesel
	2,84	kg CO_2/liter biodiesel

Admixture of 20% biodiesel from rapeseed oil

Diesel consumption 80=	28,68736	MJ/liter
FAME-20 consumption=	6,6216	MJ/liter
Disel CO_2 emissions=	2404,000768	g CO_2/liter diesel
FAME-7 CO_2 emissions BioGrace=	354,91776	g CO_2/liter b-d rap
FAME-5 CO_2 emissions Lund=	119,1888	g CO_2/liter b-d rap
TOTAL emissions BioGrace 20%	2 758,92	g CO_2/liter biodiesel
	2,76	kg CO_2/liter biodiesel
TOTAL emissions 20% Lund	2523,189568	g CO_2/liter biodiesel
	2,52	kg CO_2/liter biodiesel