Greenhouse gas savings from biofuels in Germany

Certified emissions and ILUC impacts

studio gear up

April 2021

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Date: April 2021

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Summary

Indirect land use change emissions

In 2008, concerns were raised that land use for the production of biofuels feedstock could displace food production and lead to expanding agricultural land elsewhere, outside the control of biofuels supply chains, for instance in high carbon forests and peatland. Such indirect land use change, or ILUC, could lead to carbon emissions that could undo the savings achieved by biofuels replacing fossil fuels.

Global ILUC effects cannot be observed or measured. Therefore, the impacts can only be estimated via modelling of global and local agricultural markets combined with modelling of agricultural cultivation and its expansion patterns.

From 2009 onwards, the Commission launched several modelling studies to examine the indirect impacts from increasing the demand for biofuels. This resulted amongst others in the GLOBIOM 2015 study, published in 2016.[15] The GLOBIOM study informed policies such as the ILUC Directive, the recast of the Renewable Energy Directive and is often cited in debates on ILUC.

After the publication of the GLOBIOM 2015 analysis, in some publications the calculated ILUC emissions were simply added on top of direct emissions and it was concluded that overall savings were limited. This is unfortunately a misconception of the modelling results as explained in detail in Chapter 3. The main reasons are:

- The ILUC emissions calculated by GLOBIOM are only applicable to additional biofuels specifically under the (assumed) market circumstances for the 2010-2020 period. In the 2000-2010 period, EU feedstocks typically had limited ILUC impacts:
    - Much feedstock was developed on set-aside land or compensated for land abandonment elsewhere in the EU, with no ILUC impacts.
    - The demand for biodiesel triggered a significant improvement in rapeseed yields until (at least) 2010, and therefore caused limited ILUC impacts.

  As a result, the composite ILUC impact for all biofuels in the EU market is much smaller than the factors calculated in GLOBIOM 2015.
- GLOBIOM 2015 calculated impact factors based on an arbitrary 1%-point growth shock of each crop-fuel combination (or equal to 123 PJ per fuel). But any increase less than the 1%-point assumed in the model results in lower ILUC impacts per energy unit, because the expansion into high carbon land is non-linear: smaller growth is easier to accommodate within the existing system and leads relatively to less agricultural expansion. In the past decade, the volume of some types of crop biofuels have hardly increased (rapeseed and wheat), while others have increased with still less than 1%-point.

New GLOBIOM modelling (2019) with an improved representation of the current agri-commodity market and land expansion trends finds lower ILUC emissions for important feedstocks for EU biofuels.

The current study aims to clarify how the direct greenhouse gas emission performance of biofuels developed over time, in how far the indirect effects that were predicted have come true, and how these indirect emissions should be accounted to understand the overall greenhouse gas savings.

Greenhouse gas emission savings achieved by biofuels in Germany

For all biofuels in the EU market, the greenhouse gas emission must be certified and reported to the national government. In Germany, the Federal Office of Agriculture and Food (BLE) annually reports on the performance of biofuels sold in the German market (accounted against the German greenhouse gas mandate). That report includes the observed *direct* emissions from biofuels.

If one wants to account for the estimated ***indirect*** emissions, the overall greenhouse gas emission savings from replacing fossil fuels with biofuels are calculated as follows:

Emission savings = **Fossil emissions** (According to regulation EU 2015/652: 93.3 g/MJ for petrol, 95.1 g/MJ for diesel) – **Biofuels direct emissions** (Per biofuel batch calculated with method in RED Annex V) – **ILUC emissions** (Estimated for crop fuel combinations through global modelling of agri-commodity market)

The direct emissions are mainly derived via the calculation methodology given in the Renewable Energy Directive and calculated over the entire supply chain. This is explained in Chapter 2.

The indirect emissions are estimated from combining the GLOBIOM estimations with market dynamics in the past two decades. This is described in detail in Chapter 10 of this report.

Figure 1 shows the resulting emission savings from the most important biofuels in the German market when including the indirect impacts.

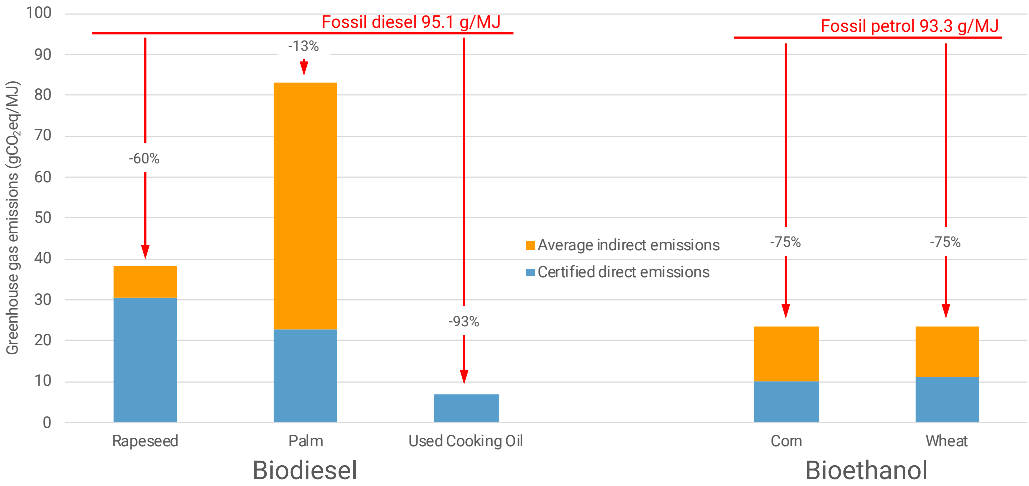

Figure 1. Direct and indirect emissions from the current main biofuels in the German market in 2019, and the resulting savings when these biofuels replace fossil fuels. The five biofuels represent 90% of the energy in biofuels in the German market. Direct emissions are taken as an average of the certified actual emissions in the German market [BLE 2020, German Federal Office for Agriculture and Food, Evaluation and Progress Report 2019]. Indirect emissions follow from the analysis in Chapter 3 of the current report.

Biofuels make already a significant and direct contribution to climate emission reduction in the transport sector. In particular the waste-based biodiesel has very low direct and indirect emissions.

The direct emissions of crop-based biofuels can further decrease by sustainably improving agricultural yields, smarter fertilizer application, use of renewable energy in transport and conversion along the supply chain and carbon sequestration in soils. These opportunities for further improvements exist for most crops, but they require investments that will only materialize if there is sufficient market perspective.

Risk for indirect emissions from biofuels can be further diminished by a focus on low ILUC feedstock production, through sustainable yield increases above the trendlines and additional feedstock production on marginal and degraded lands. Certification of low ILUC risk biofuels is currently being developed by the European Commission. Production of low ILUC risk biofuels will only take place on a significant scale if there is sufficient political support and demand beyond 2030.

1 Introduction

Background to emissions caused by Indirect Land Use Changes

In 2008, concerns were raised over indirect impacts that could be caused by increasing the demand for biofuels. Additional demand for feedstock could trigger land use change outside the control of biofuels supply chains, for instance in high carbon forests and peatland. Such indirect land use change, or ILUC, could lead to carbon emissions that could undo the savings achieved by biofuels replacing fossil fuels.

Several studies explored the topic, but quantification of ILUC remained complex, because the mechanisms underlying ILUC are plentiful and can hardly be observed or measured. Therefore, the impacts can only be estimated via modelling of global and local agricultural markets combined with modelling of agricultural cultivation and its expansion patterns.

In 2016, the GLOBIOM study on the indirect impacts from biofuels was published.[1] It estimated the ILUC impacts of increasing contributions of certain crop-fuel combinations, as well as the impact of several biofuel market growth scenarios. The findings of GLOBIOM (discussed in Chapter 3) greatly impacted the policy development. Most notably, the recast Renewable Energy Directive for the 2021-2030, limits the contribution of food crop-based biofuels to renewable energy in transport to 7%[2] of the total demand for energy in transport. At a wider scale, ILUC concerns are limiting the role that biofuels can play in decreasing the climate emissions from the transport sector.

Now, 5 years after the GLOBIOM study was published, and over a decade since the first Renewable Energy Directive was published, it is useful to understand how the direct greenhouse gas emission performance of biofuels developed over time, in how far the indirect effects that were predicted have come true, and how these indirect emissions should be accounted to understand the overall greenhouse gas savings, and overall: how biofuels can contribute to reducing climate impacts from transport in the coming decades.

Carbon reduction threshold for biofuels on the European transport market

It is important to understand that only biofuels with sufficient emissions savings compared to fossil fuels qualify as renewable fuel for transport. Since the Renewable Energy Directive (RED) was published in 2009, the environmental performance of biofuels in the European market is subject to sustainability certification. For all biofuels in the EU market, among others the direct greenhouse gas emission must be certified and reported. A key requirement for biofuels in the EU market to count as renewable fuel in the frame of the directive, is that the greenhouse gas emission reduction achieved by the biofuel over the fossil fuel it replaces, has to meet a threshold. This threshold has increased over time, from 35% initially, to 50, 60% or 65% from 2021 onwards, depending on the age of the installation that produced the biofuel.[3]

Furthermore, German legislation requires that fuel suppliers reduce the greenhouse gas intensity of the fuels they sell in the German market. This effectively increases the value of better performing biofuels and incentivises the development of better performing biofuels.

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[1] Ecofys, IIASA and E4tech, 2015, The land use change impact of biofuels consumed in the EU, commonly known as the GLOBIOM study. It was effectively published in March 2016.

[2] The formulation in the Renewable Energy Directive is actually complex: The contribution of crop-based biofuels to achieving the target for renewable energy in transport "… shall be no more than one percentage point higher than the share of such fuels in the final consumption of energy in the road and rail transport sectors in 2020 in that Member State, with a maximum of 7 % …" [Renewable Energy Directive EU/2018/2001]

[3] In the first years, this threshold was set at 35% compared to a fossil fuel comparator of 83.8 g/MJ. From 2017 onwards, the threshold was increased to 50%. Biofuels from installations that started production in 2017 or later had to achieve 60% emission reduction from 2018 onwards [EU Renewable Energy Directive 2009/28/EC]. The ILUC Directive in 2015 amended these thresholds and applied the 60% threshold to all installations that started operation after 5 October 2015, i.e. the high threshold was instantly applied to a larger share of the market [EU ILUC Directive EU/2015/1513]. The 2018 recast of the Renewable Energy Directive, for the 2021-2030 period introduces three groups with different thresholds: biofuels produced in installations in operation before 6 October 2015 have to achieve 50%, biofuels from installations that started production between 6 October 2015 and 31 December 2021 have to achieve 60%, and from installations starting operation from 2021 onwards have to achieve 65% emission reduction while the fossil fuel comparator increased to 94 g CO_2eq/MJ (or 95.1 for diesel and 93.3 for gasoline) recognising that exploration and refining of fossil oil has become more complex and energy consuming in the past decade [recast EU Renewable Energy Directive EU/2018/2001].

This current study shows how the greenhouse gas performance of biofuel supply chains is calculated and shows the emission reduction achieved by biofuels in the German market in 2019, with and without ILUC emissions. The study shows that the regulatory requirements and mechanisms have greatly reduced the direct emissions associated with the use of biofuels and, as a consequence, that the emission savings have increased. It concludes with recommendations to further decrease risks on ILUC in biofuel supply chains.

2 How to calculate the direct emissions from biofuels

A decade of measuring the greenhouse gas emissions of biofuels in the EU makes clear that the performance in the real world is better than what is presented as typical in the directive. The typical values were calculated on basis of conservative data. Driven by policy requirements and the market in Germany, the carbon intensity of biofuels continuously improves.

How does a company calculate the direct emissions and savings?

For the calculation of carbon emission reduction achieved by biofuel supply chains, the RED and RED II Directives include default values for the most common crop-fuel combinations that the industry may use, and a calculation methodology to calculate the actual performance. The default values in the Directive are often based on conservative calculations, and most operators choose to have actual values certified using the methodology.

Greenhouse gas emissions from biofuels are calculated over the entire supply chain as shown in Figure 2.

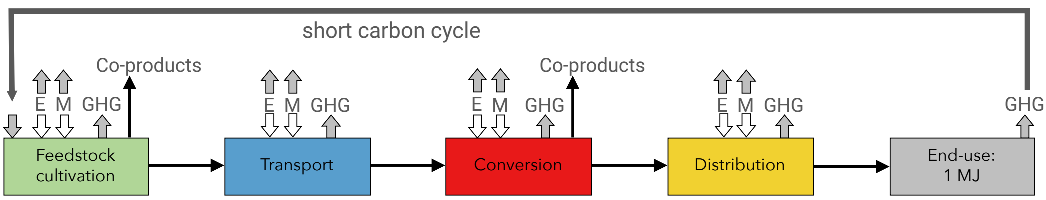

Figure 2. The calculation of greenhouse gas emissions from biofuels in the EU market considers the entire lifecycle. GHG indicates greenhouse gas emissions, E and M indicate Energy and Materials used in the supply chain.

Emissions from each step in the supply chain are accounted:

- All emissions directly produced by the supply chain steps, for example:
  - CO_2 released from diesel use in the tractor on the field, or during transportation of feedstock or product, or when natural gas is being used in a conversion plant
  - N_2O (nitrous oxide) from the application of fertilizer on the fields
  - CH_4 in case of methane slip in an anaerobic digester
- All emissions resulting from the production of the energy and materials along the supply chain, such as emissions in the production of fertilizer or electricity.
- Co-products carry part of the greenhouse gas emission burden via energy allocation.
- Emissions from end-use of biofuels are zero, because the emissions of the fuel (and of the co-products and other biogenic emissions along the supply chain) have previously been absorbed from the atmosphere during crop growth.
- In some cropping systems soil organic carbon increases, so that net carbon is drawn from the atmosphere.

For all biofuels in the EU market, the direct greenhouse gas emissions must be certified and reported. For this purpose, the Directive allows two types of values: default values for common crop-fuel combinations, and a detailed methodology to calculate actual values. The default values are derived from typical values and are by purpose more conservative.[4] Typical values in turn have been calculated on basis of crop production practices and conversion-to-fuel technology of the early 2000s. So, default values are more conservative than typical, which are already more conservative than actual values in most situations.

[4] For common crop-fuel combinations, the Directive includes disaggregated values for three supply chain steps: cultivation (feedstock production), conversion (from feedstock to final fuel) and transport and distribution (of feedstock, intermediary products and final fuel). The *default* values for the conversion step are set 40% more conservative than the *typical* values for this step. For the other two steps the default value is equal to the typical value [Directive EU/2018/2001].

Operators could use the default values as a fallback option, if they would not know the real greenhouse gas performance.

The default values were useful in the early years of the Directive, when most crop-fuel combinations could meet the 35% emission reduction threshold simply by using these default values, and when the experience with certification of real supply chain emissions was still limited.

Today, most operators do not use the default values. For many crop-fuel combinations, the default supply chain emissions are too high to meet the required threshold (which today is 50%, 60% or 65% depending on the age of the installation). Feedstock producers and operators have improved crop yields, decreased fertilizer application, improved conversion efficiencies and reduced the energy inputs in conversion facilities, not only to meet the thresholds of today, but also in anticipation of markets that ask for better performing biofuels.

Therefore, most operators use the methodology prescribed in Annex V of the Directive to calculate the actual greenhouse gas emissions along the supply chain.

Several publications that explored the contribution of biofuels to climate action cite the typical values of the Directive as if these represent the average performance of biofuels. This is not correct. The typical values are conservative by nature and only have a function in the frame of the legislation. The actual performance of biofuels is much better.

Development of actual emissions

Figure 3 shows the development of the greenhouse gas intensity of European biofuels according to several sources that have consistently measured the performance over a longer time. The improvement is caused by two effects: (1) there has been a shift towards more use of fuel types that directly have a better greenhouse gas performance, such as, but not exclusively, waste-based biofuels, and (2) within each crop-fuel combination, the observed performance is continuously improving because of improvements along the supply chain.

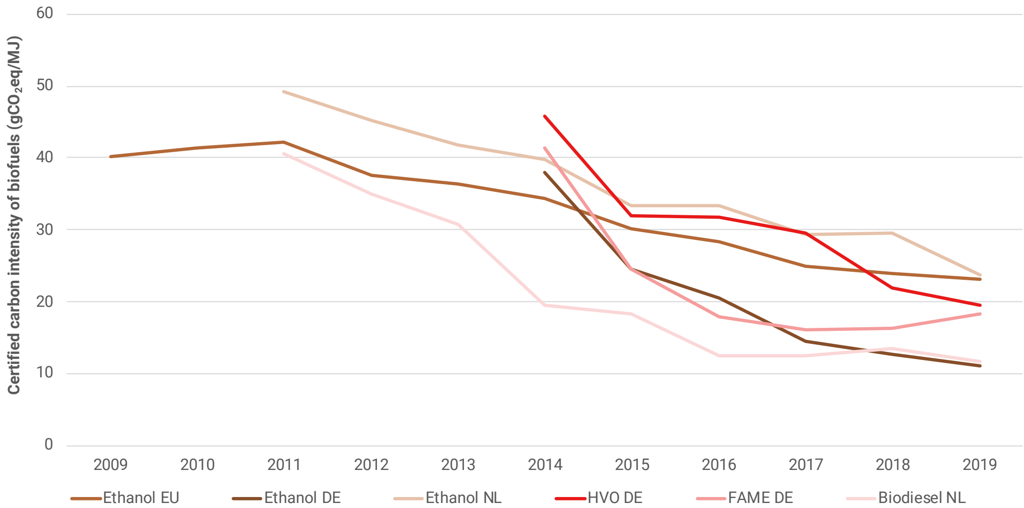

Figure 3. Decrease of direct emissions for bioethanol and biodiesel, produced in the EU (Ethanol EU), or consumed in the German (DE) and Dutch (NL) markets.[5] *FAME and HVO are both types of biodiesel.*

The improvements are triggered by legislation mainly. In order to meet the greenhouse gas emission reduction threshold in 2019, most biofuels had to achieve at least 60%, which implies the maximum emissions would be around 38 g/MJ. As noted, German legislation effectively attaches more value to better performing biofuels. Dutch legislation strongly supports waste-based biofuels.

[5] Data for EU produced ethanol was taken from ePURE [ePURE 2019, Aggregated and audited data of ePURE members]. Data for Germany was combined from the BLE publications for 2016 and 2019 [BLE 2017, German Federal Office for Agriculture and Food, Evaluation and Progress Report 2016; and BLE 2020, German Federal Office for Agriculture and Food, Evaluation and Progress Report 2019]. Data for the Netherlands is reported by NEa [NEA 2020, Rapportage Energie voor Vervoer in Nederland 2019, Trend of reported emissionfactors for gasoline and diesel replacers].

The improvement shown for Germany does not only result from a shift from one feedstock to another, but also from improved performances of some crop-fuel combinations, as is shown in Figure 4. Between 2015 and 2019, especially maize and wheat ethanol showed a strong decrease in supply chain emissions. Compared to the typical emission listed in the Directive, all crops demonstrate that the real emissions are much lower. The typical value for waste-based FAME is close to what is reported today, mainly because the feedstock emissions are zero by definition and thus cannot be further improved.

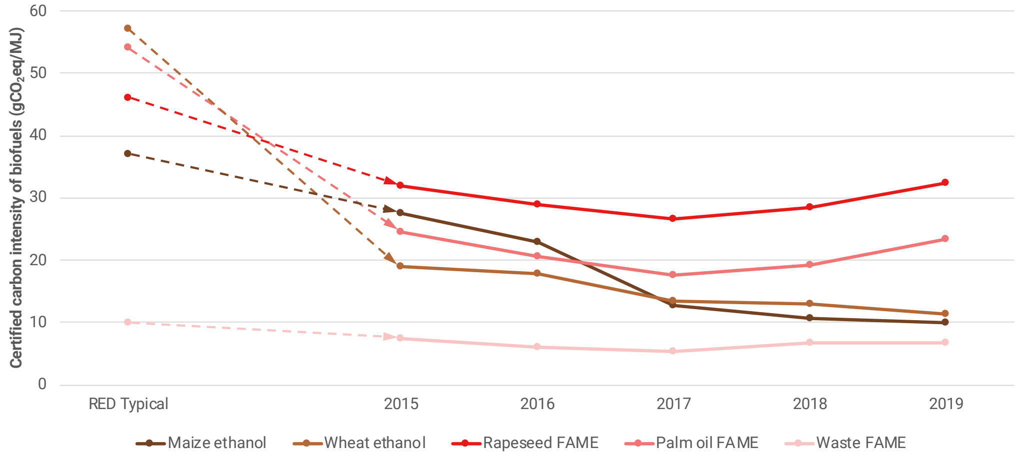

Figure 4. Development of carbon intensity of several crop fuel combinations sold in the German market, compared to the RED typical value.[6]

Further improvements for lower carbon footprint in the coming decade

There is a large potential to increase the production of both biofuels and biofuels feedstock, especially through increasing the yields and redeveloping abandoned agricultural land.

Yields across agriculture are continuously increasing through an introduction of technological and practical innovations. Many of these innovations are relevant for increasing the yields and decreasing the environmental pressure, such as:

- Digitalisation by remote sensing (satellite images), GPS precision farming, drones, real time fertiliser optimisation by nitrogen sensors on tractors.[7]
- Optimisation of the land use, for example by smart rotations and sequential cropping.[8]
- Less invasive cultivation techniques such as strip tillage.[9]
- Improved harvesting practices and harvesting machines reduce the product loss.[10]

Biofuels can actually help to attract investments in agriculture, drive innovations, and spur regional economies. Good performance of crop-based biofuels is possible when demand is accompanied by strict sustainability requirements.[11]

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[6] RED Typical values from the 2009 Renewable Energy Directive. All other values from the BLE publications for 2016 and 2019, see footnote 5.

[7] OECD assessed options and opportunities for digitisation in agriculture, with many case study examples, and analysis on barriers in policies and regulations [OECD 2019 Digital Opportunities for Better Agricultural Policies]. An overview of EU research in digitizing agriculture was published by researchers of the Italian National Research Council [Bacco et al., 2019, Digitisation of agriculture – A survey of research activities on smart farming, Array 3-4].

[8] Valli et al. 2017, Greenhouse gas emissions of electricity and biomethane produced using the Biogasdoneright™ system: four case studies from Italy, Biofuels, Bioprod. Bioref.

[9] Practice and advantages of strip tillage are described in the position paper by CIB for the EC ART Fuels Forum [Wellinger et al., 2018, Biogas done right in transport].

[10] Seed sampling informs the best timing for harvesting, harvesting machines for rapeseed today have advanced headers to reduce seed loss harvesting machine settings are based on crop situation [Terres Inovia, 2020, Quelques règles à respecter pour bien optimiser sa récolte de colza].

[11] Ecofys 2019, 2030 Transport decarbonisation options.

3 ILUC impacts from biofuels

Policy makers and biofuel producers are concerned about ILUC impacts that could result from biofuels, but which take place outside of their span of control. An increasing demand for biofuels could trigger expansion of agricultural land in third countries, and this could lead to releasing CO_2 from carbon stocks. The effect cannot be measured, only modelled. The newest insights show that ILUC impacts in the coming decade are lower than previously estimated. Moreover, historical ILUC is not equally applicable to all the biofuels in the market. Through improvements in agricultural practices, ILUC risks can be reduced.

ILUC explained

The most complex topic related to the sustainability of biofuels is Indirect Land Use Change, or ILUC. This is, simply said, the rippling effect that an increasing demand for biofuels feedstock can have in global agriculture, and which could lead to land expansion and deforestation elsewhere, with the subsequent effect of carbon emissions. When additional biofuels increase demand for the crops grown on existing agricultural land, this additional demand could constrain supply, and thereby increase prices globally for those crops. The prospects of higher crop prices could trigger the clearing of high carbon stock land for additional agriculture. This effect is called ILUC.

Other responses to the increasing demand are increasing productivity (which is estimated to account for 80% of the response[12]), bringing low carbon land into agricultural production, reducing consumption in other end-use sectors, or substituting a different commodity (which in turn, may or may not have ILUC impacts).

ILUC is not measurable as it takes place via complex economic interactions and is manifested only in small variations on the large dynamics of the global agriculture system. ILUC can only be analysed through detailed modelling. The European Commission commissioned the GLOBIOM consortium to assess the ILUC impact from several biofuels policy scenarios.[13] It concluded that the ILUC effect depends amongst others on the type of biofuel crop and the regional land use context.

ILUC factors reported

The main results from the GLOBIOM 2015 study are given in Figure 5. ILUC factors are calculated for increasing volumes of biofuels. They are calculated for a significant demand "shock" (equalling a volume of 123 PJ per fuel), in the 2010-2020 scope of the analysis.[14] They are thus not equally applicable to existing biofuels as we will discuss below.

[12] "The EU ethanol consumption had negligible impact on cereal prices given that the EU share in the global ethanol market did not exceed 7%, and the global cereal market is driven mainly by demand for feed. In the future, the strongest biofuel consumption growth is expected in developing countries, while the increased demand for food and feed for a growing and more affluent population is projected to be mostly met through productivity gains, with yield improvements expected to account for about 80% of the increase in crop output." [European Commission's 2017 Renewable Energy Progress Report].

[13] Ecofys, IIASA and E4Tech 2015, The land use change impact of biofuels consumed in the EU.

[14] For instance, in the 2015 GLOBIOM study, for each crop-fuel combination, the ILUC impact was calculated on the basis of a 1%-point demand "shock", i.e. an increase of the contribution of this crop-fuel combination equivalent to 1% of EU transport sector energy (1%-point equalling to 123 PJ). Note that the ILUC impact is not linear. Lower shocks would lead to lower ILUC values. More importantly, the ILUC value is only calculated for additional volumes after 2010 and are not valid for existing volumes. The consequences of these aspects are further explored in the text.

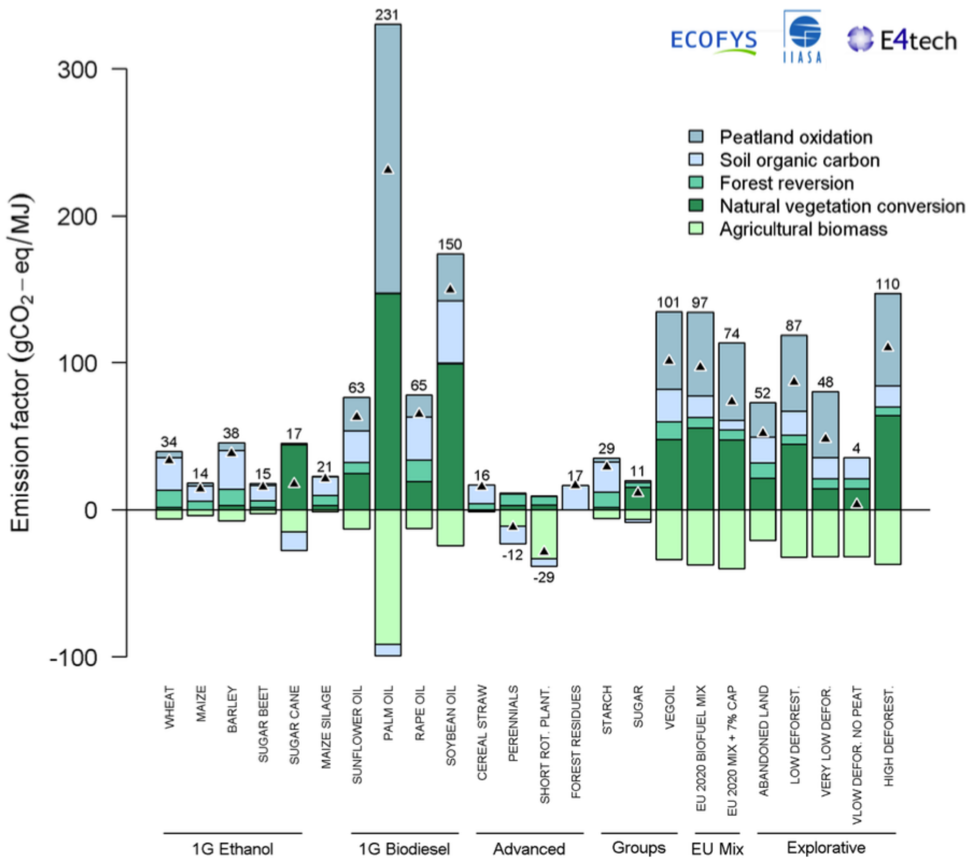

Figure 5. Overview of the modelling results of the GLOBIOM study, with Land Use Change related greenhouse gas emissions per scenario.[15]

The key findings of the GLOBIOM study in 2015 were:

- Low ILUC factors were found for ethanol.
- Moderate ILUC factors were found for biofuels based on European rapeseed and sunflower oil,[16] but ILUC is paid back within a few years by the savings resulting from replacing fossil fuels.
- High ILUC factors were found for soybean and palm oil.
- Low and even below zero ILUC factors are found for advanced biofuels, depending on feedstock land management.

Other studies have also calculated the ILUC impacts from biofuels, summarised for the main crop-fuel combinations in Table 1. As can be seen, new GLOBIOM calculations in the frame of the 2019 ICAO study project significantly lower ILUC impacts. It is difficult to pinpoint the most important reasons for the lower results, but amongst others it is caused by (1) increasing the depreciation period from 20 to 25 years, (2) updated understanding of the agricultural production systems, (3) observations of less expansion of palm oil into peatland and other high carbon land, (4) a different view underlying causes and responsibilities, and (5) less autonomous afforestation of abandoned farmland.[17]

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[15] Ecofys, IIASA and E4tech, 2015, The land use change impact of biofuels consumed in the EU, commonly known as the GLOBIOM study. It was effectively published in March 2016.

[16] GLOBIOM reports that rapeseed biodiesel causes 65 g/MJ ILUC related greenhouse gas emissions, almost entirely because it indirectly increases the demand for palm oil. Other studies give significantly lower results: CARB reports 14.5 g/MJ, IFPRI reports 52 g/MJ.

[17] A complete analysis can be found in [Cerulogy, 2019, Understanding the indirect land use change analysis for CORSIA].

Table 1. ILUC factors for (food) crop-based biofuels found by Mirage 2011,[18] GLOBIOM 2015[19] and ICAO 2019[20] for selected feedstock, all in g CO_2eq/MJ.

	Mirage 2011	***GLOBIOM 2015***	***ICAO 2019 (GLOBIOM) 1)***	***ICAO 2019 (GTAP) 1)***
Rapeseed Biodiesel	54	65	24	18
Palm biodiesel	54	231	53	31
Soy biodiesel 2)	56	150	104	20
Maize ethanol	10	14	15	15
Wheat ethanol	14	34	-	-

1) The 2020 ICAO study reports ILUC factors for HEFA and Alcohol-to-Jet (ATJ) pathways. These are corrected to derive factors for FAME biodiesel and bioethanol, by considering the conversion efficiency from feedstock to final fuel. From the amount of vegetable oil delivering 1 MJ of HEFA, about 1.13 MJ of FAME could be produced. Therefore, the values reported here are slightly lower than the HEFA values in the ICAO study. The conversion efficiency from ethanol to ATJ is 61%[21] which means that the ILUC impact for maize ethanol is 61% of the value reported by ICAO for maize ATJ.

2) Mainly concerns soybean from South America. The ILUC impacts result from the local expansion into tropical forest and the link to palm oil production via international oil market. EU produced soybean would have lower ILUC impacts, but these are not presented in the studies.

Historic ILUC is zero in some cases

The ILUC factors cited above apply to *additional biofuels* and should not be applied to the *whole* biofuels volume, especially because historic biofuels volumes developed partially without ILUC. For instance, EU feedstock for biofuels before the original Renewable Energy Directive was largely developed on set-aside land that could not be used for other activities, and hence this feedstock was produced without negative indirect impacts.

Figure 6 demonstrates for rapeseed biodiesel, how the volume development in the EU market relates to ILUC factors and how this changes over time. Because of the limited growth in biodiesel (FAME and HVO jointly) between 2008 and 2019 (0.6 Mtoe) compared to the preceding decade (3.9 Mtoe), it's resulting ILUC impact at present is low.

The GLOBIOM ILUC factors are based on calculating all ILUC impacts in the first 20 years after a "demand shock", i.e. after an increase in demand (which caused, indirectly but rather instantly the indirect land use change) and dividing all these impacts by the total fuel volume produced in those same 20 years. Most of the impacts take place in the years immediately after the shock, or are most heavily felt in the first decade, and distributing over 20 years is generally accepted. After 20 years these emissions have thus all been accounted for, and one could argue that ILUC becomes zero. In reality, a small ILUC emission remains as an echo of the original demand shock – for detailed explanation of how this works see Footnote (7) under Table 2.

We assume that the growth beyond 2020 must be achieved with low ILUC impacts, as shown by the increasing green area at the top of the graph. This would imply that ILUC "containing" biofuels will gradually disappear, and that the biofuels volume can increase while ILUC impacts decrease. This would of course require strong governance and appropriate policy support measures.

[18] IFPRI, 2011, Assessing the land use change consequences of European biofuel policies (MIRAGE model).

[19] Ecofys, IIASA and E4tech, 2015, The land use change impact of biofuels consumed in the EU.

[20] ICAO, 2019, CORSIA supporting document, CORSIA eligible fuels – Life cycle assessment methodology.

[21] The ICAO calculations for the ATJ pathway are based on the GREET model of Argonne National Laboratories. GREET assumes that 18.1 MJ of ATJ is produced from 29.7 MJ of ethanol [Han et al., 2017, Well-to-wake analysis of ethanol-to-jet and sugar-to-jet pathways].

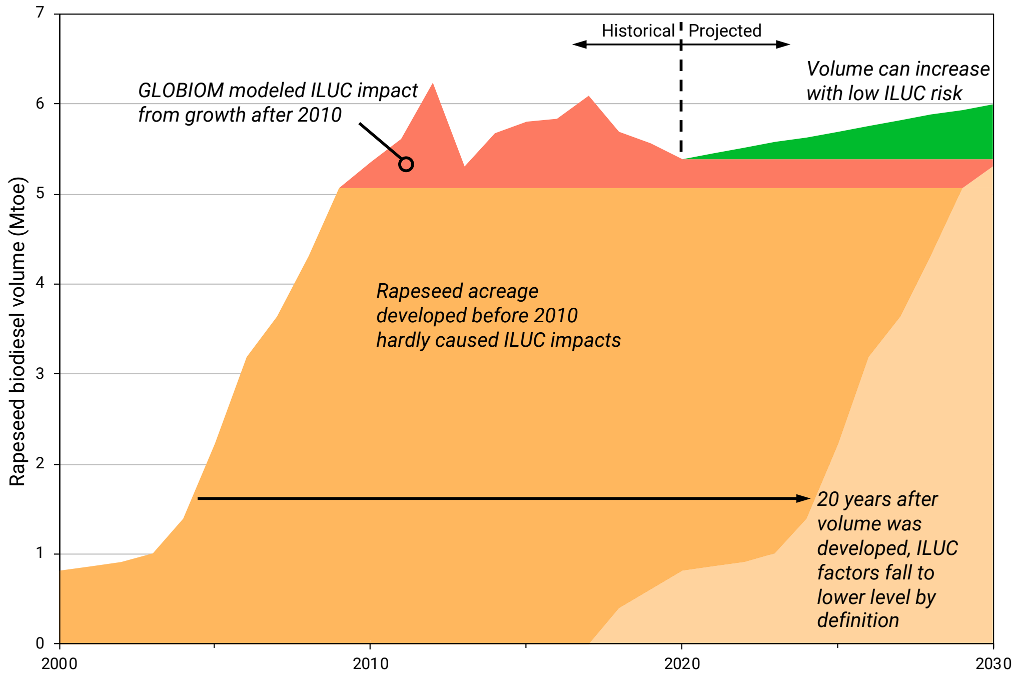

Figure 6. Example of how different ILUC factors apply to biodiesel from EU rapeseed between 2000 and 2030. The rapeseed developed before 2010 has a limited ILUC impact, as it was largely accommodated through yield increases (see Footnote 2 under Table 2), or on set-aside land, which did not incur ILUC impacts,[22] or it delayed agricultural land abandonment in the EU which causes a small ILUC impact.[23] After 2010, the volume of rapeseed biodiesel barely increased. GLOBIOM ILUC factors are calculated as the average over the first 20 years after a "shock" or increase takes place. The impacts in years 21-40 are much smaller than in years 1-20. Growth of the sector after 2020 is assumed to be under low ILUC risk conditions, which would require strong governance [figure based on Ecofys 2019, 2030 Transport decarbonisation options].

For example, rapeseed biodiesel in the current EU market (2020) exists for about 0.8 Mtoe of volume that was added before 2000, more than 20 years ago, and thus has very low ILUC impacts (4 g/MJ); 4.3 Mtoe of volume that was added between 2010 under conditions that we would today describe as low ILUC (between 0 and 7 g/MJ see Table 2), and only for 0.3 Mtoe of ILUC inducing biofuels added between 2010 and now, with an ILUC impact of 24 g/MJ. The composite result of this is 7.6 g CO_2eq/MJ, which is much less than the 65 g/MJ often cited in literature.

Development patterns for the other main crops are different. Corn ethanol increased more between 2010 and 2020 than in the preceding decade and therefore the >2010 ILUC factor has a larger role than the <2010 ILUC factor. On the other hand, the volume of wheat ethanol in the EU market hardly increased since 2010.

For the different shaded areas in the figure, Table 2 presents and explains the ILUC factors.

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[22] During the set-aside period, up to 1.5 million hectares was planted with rapeseed, yielding up to 5.5 Mtonne of rapeseed, or about 2.2 Mtonne of biodiesel.

[23] In the EU, agricultural land has been abandoned massively in the past 3 decades, mainly for farm-economic reasons that relate to overproduction and unattractive markets. Biofuel feedstock crops provide farmers with additional income which delays land abandonment. GLOBIOM projects that some abandoned land can develop into higher carbon forest. Through this lens, pre-RED rapeseed biodiesel has probably avoided some afforestation. This has an ILUC impact of about 7 g/MJ according to GLOBIOM.

Table 2. ILUC factors for four main crop biofuel combinations in different timeframes and different situations, in g CO_2eq/MJ [Based on Ecofys 2019, 2030 Transport decarbonisation options].

	Ethanol (EU corn)	***Ethanol (EU wheat)***	***Biodiesel (EU rapeseed)***	***Biodiesel (palm oil)***
ILUC for the volume in the market before 2010 [1)]	0 g/MJ if feedstock was grown on set-aside land [2)] 0 g/MJ if the additional production was achieved via increasing yields [3)] 7 g/MJ if feedstock was grown on land that otherwise would have been abandoned [4)]			231 g/MJ [5)]
ILUC for additional volumes in the market after 2010 [6)]	15 g/MJ	34 g/MJ	24 g/MJ	53 g/MJ
ILUC factor after 20-year amortisation [7)]	0 g/MJ	2 g/MJ	4 g/MJ	46 g/MJ
ILUC factor for low ILUC risk growth after 2020	Assumed to be 10 g/MJ maximally (primarily from avoided afforestation)			

1) The GLOBIOM 2015 modelling estimated the impacts of increasing the biofuels market between 2010 and 2020. It did not consider the development of biofuels before 2010, which had different dynamics.

2) In the EU, a large share of biofuels feedstock was produced on set-aside land, and by policy definition did not displace food crops and therefore not lead to ILUC. This was the case for part of the corn, wheat and rapeseed.

3) If the additional production is achieved by increasing yields, then this does not lead to ILUC, per the definition in Commission Delegated Regulation (EU)2019/807. This is the case for a large part of the rapeseed biodiesel: Rapeseed yields in the EU strongly increased from 2.75 tonne per hectare in 2002 to 3.61 tonne per hectare in 2015. Comparing the increase of RME over this period (about 5 Mtonne) with the increase of EU produced rapeseed (13 Mtonne), makes clear that RME was probably the single driver for the rapeseed cultivation increase. It can be concluded, that about 45% of the additional RME production was accommodated by yield increase, while the remainder was achieved on "additional" land [Oil World statistics summarized in Nazlin 2017, Competitiveness of the rapeseed industry in the European Union, Oil Palm Industry Economic Journal 17(1): 32-50].

4) When biofuels feedstock is produced on existing crop land this avoids land abandonment (of the same land, or elsewhere in the system) in the EU. Note that about 10 million hectares (net effect) of agricultural land was abandoned in the EU between 2000 and 2015 and that another 5 million hectare net is expected to be abandoned in the period 2015-2030, the bulk of which is likely to remain unused [European Parliament AGRI 2020, The challenge of land abandonment after 2020 and options for mitigating measures], while the total EU cropland used for biofuels was about 3.4 million hectares in 2018 [Navigant, 2020, Technical assistance to 5th report on progress of renewable energy in the EU, Analysis of bioenergy supply and demand in the EU]. According to GLOBIOM 2015, the use of avoided land abandonment causes an ILUC impact of about 7 g/MJ. The reason is that land, if abandoned, could develop partially into forest, which would sequester carbon. In GLOBIOM, this is called foregone sequestration. "Excluding foregone sequestration has a large impact on ethanol feedstocks; the LUC value for wheat for example drops from 34 to 22 gCO_2 e/MJ biofuel consumed and for maize from 14 to 9 gCO_2 e/MJ. The EU 2020 biofuel mix scenario result drops from 97 gCO_2 e/MJ to 90 gCO_2 e/MJ without foregone sequestration". The average impact of foregone sequestration is thus 7 g/MJ.

5) The impact factor for palm oil biodiesel before 2010 is taken from GLOBIOM 2015, since it was largely based on observations of land use change, deforestation and expansion into peatland in the decades before 2010.

6) GLOBIOM 2015 calculates ILUC factors based on a 1% demand "shock", or 2.9 Mtoe per crop-fuel combination, this is more than observed for any of the crops between 2008 and 2019 (rapeseed biodiesel 0.6 Mtoe, palm oil biodiesel 2.2 Mtoe, corn ethanol 1.7 Mtoe, wheat ethanol 0.2 Mtoe). Since the ILUC impact is non-linear, smaller than 1% increases would lead to lower ILUC impacts. However, the extend of this non-linearity is not known. We therefore still apply the GLOBIOM factors. The factors are taken from the GLOBIOM calculations in the 2019 ICAO study, since these are based on improved insights in the dynamics of the agricultural market in the past decade. Factors are corrected for the conversion efficiency to final product (ICAO study presents factors for aviation fuels with more conversion losses than road fuels, therefore our factors are slightly lower).

7) The emission categories considered in the GLOBIOM 2015 study behave as follows: (a) Loss of natural vegetation is instant (within few years, zero thereafter). (b) Soil organic carbon stabilises at a new equilibrium within 20 years, so the carbon flux becomes zero before 20 years. (c) Peatland that is drained will oxidise, continues to do so for at least 50-100 years, although the emission rate decreases, but in the period of 20-40 years after the demand shock is assumed to be still 75% of that in the first 20 years. (d) Carbon in agricultural biomass is continuous if the biomass is removed after harvest; this depends on practice and crop. (e) Forest reversion is assumed to be forever, but the carbon uptake slows down in unmanaged forests. It is assumed that the carbon uptake in the 20-40 years period after the demand shock will have reduced to 40% of that in the first 20 years [Personal communication of Mr. Hamelinck with Mr. Valin, IIASA].

Low ILUC crop production

Solutions are being developed to produce additional feedstock with low ILUC risks, either through expansion into unused land (controlled *direct* land use change) or through increasing the yields in existing crop production. Beyond the targets and definitions of the RED II, significant increases of biofuels deployment can be achieved while limiting ILUC risks, to optimize greenhouse gas emission reduction and to avoid biodiversity impacts.

ILUC can be avoided in several practical ways:

- Produce additional crops on unused low-carbon land, such as abandoned agricultural land or degraded land, where there is no recent history of land use change, so that it does not interfere with existing crop production.
- Yields can be increased above the baseline trends, through better practices, such as better fertilisation, better seeds, irrigation, better timed responses, better agro-chemicals and better machinery. All of these are facilitated by better information and equipment (smart, or precision agriculture).
- Additional crops can be produced on current agricultural land, for instance by double cropping.[24]

[24] Valli et al. 2017, Greenhouse gas emissions of electricity and biomethane produced using the Biogasdoneright™ system: four case studies from Italy, Biofuels, Bioprod. Bioref.

4 Overall result

When considering the observed and certified emissions reported for biofuels in Germany, and the corrected ILUC impacts, it becomes clear that all biofuels in the German market achieve greenhouse gas emission reductions compared to the fossil reference fuels they replace.

This is shown in Figure 7. On the left, the common misinterpretation of total impacts is shown and, on the right, the observed and corrected performance.

As can be derived from Chapters 2 and 3, this is the result of (1) strict thresholds and incentives for renewable fuels with high CO2 savings, and (2) improved insight in the ILUC impacts of biofuels introduced to the market in the past 2 decades.

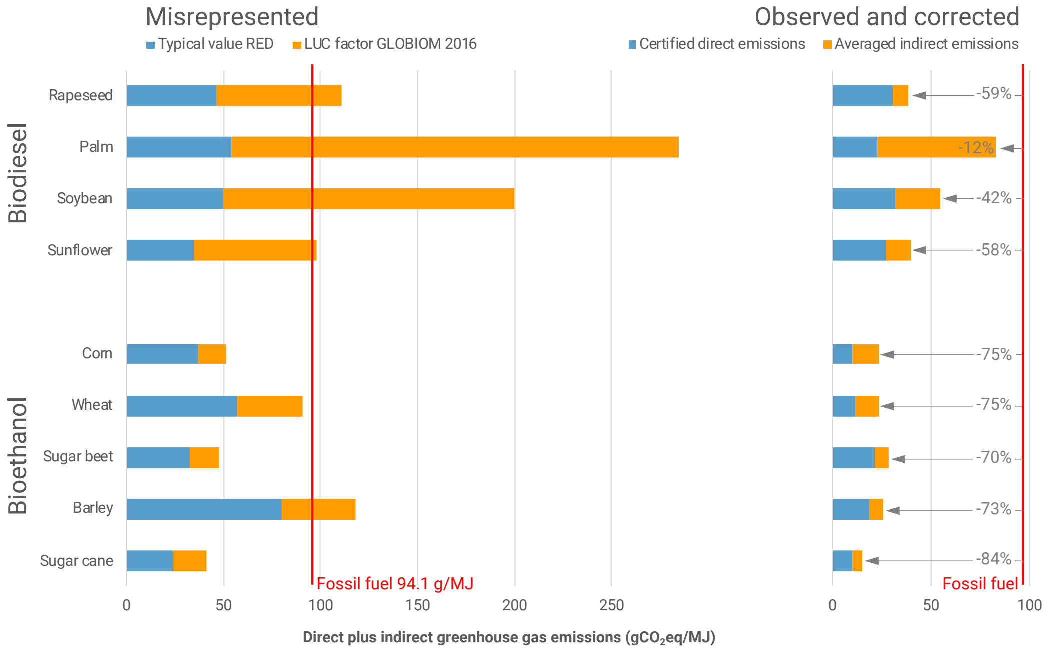

Figure 7. Comparison of representation of total emissions by T&E[25] (left) with observed and corrected values (right). The corrected values for indirect emissions of biofuels are explained in the text and in Table 2. Note that indirect emissions for fossil fuels are unknown (comparator shows only emissions from production and use). In this chart, the biofuels emissions are compared to the generic fossil fuel comparator of 94.1 g/MJ.

In conclusion, biofuels save emissions and therefore can play an important role in climate action in the transport sector. The greenhouse gas performance of biofuels could even be further improved by improving agricultural yields in a smart and sustainable manner, which in itself will also further reduce ILUC risks.

[25] Transport & Environment, 2016, GLOBIOM: the basis for biofuel policy post-2020.

5 Results for the German market

Biofuels accounted against the German greenhouse gas mandate mainly consist of FAME biodiesel and bioethanol and smaller shares of HVO biodiesel and biomethane, as shown in Figure 8. The main feedstocks are waste vegetable oils (26.8% of the total energy in biofuels), rapeseed (24%), palm oil (19.7%), corn (15.9%) and wheat (4.4%), together representing 90.8% of all the energy in biofuels in Germany.

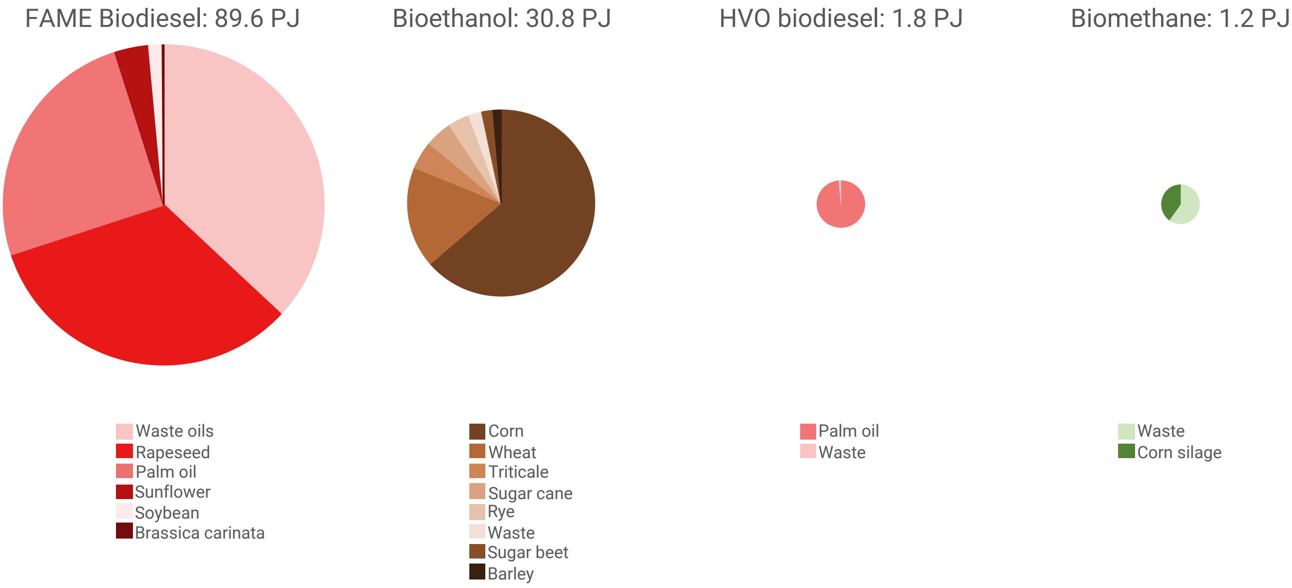

Figure 8. Biofuels in the German market and their feedstocks [BLE 2020].

As was shown in the previous chapter, all these fuels reduce greenhouse gas emissions in comparison with the use of fossil gasoline or diesel, even when accounting for the estimated ILUC impact. The resulting total emission reduction is given in Table 3. The 120 thousand TJ represents about 3.3 million tonne of biofuel. On average 1 tonne of biofuel when replacing fossil fuel, thus saves over 2 tonne of CO_2eq emissions even when including ILUC impacts.

Table 3. Emission reduction achieved by biofuels in the German market in 2019, with and without indirect emissions. Emissions for the "other" feedstock are taken as a weighted average of the other crops within the biodiesel or bioethanol group. Note that BLE reports slightly better total direct savings of 9,662 ktonne CO_2eq for 2019 – the difference can be attributed to generalization of the "other" feedstocks in our calculation.

	Consumption TJ	Reported direct savings (g CO_2eq/MJ)	Reported direct savings (ktonne)	Direct and indirect savings (g CO_2eq/MJ)	Direct and indirect savings (ktonne)
Biodiesel					
Waste vegetable oil	33,139	88.2	2,923	88.2	2,923
Rapeseed	29,600	64.5	1,909	56.9	1,684
Palm oil	22,523	72.3	1,628	12.1	273
Other	4,386	75.8	332	57.2	251
Bioethanol					
Corn	19,623	83.3	1,635	69.9	1,372
Wheat	5,394	82.0	442	69.6	375
Other	5,792	83.0	481	69.8	404
Total	***120,457***		***9,351***		***7,282***

The direct emissions from biofuels can further decrease by sustainably improving agricultural yields, smarter fertilizer application, use of renewable energy in transport and conversion along the supply chain. Opportunities for further improvements exist for most crops, but investments will only be made if there is sufficient market perspective.

The indirect emissions from biofuels can further decrease by a focus on low ILUC feedstock production, through yield increases above the trendlines and additional feedstock production on marginal and degraded lands. Certification of low ILUC risk biofuels is currently being developed by the EC. Actual production of low ILUC risk biofuels will only take place if there is a significant demand beyond 2030.

Biofuels can make a significant and direct contribution to climate emission reduction in the transport sector.