Trade-induced Environmental Impacts Connected to a Policy Promoting Agricultural Biofuels in Sweden

A sensitivity analysis on an Agent-based Life Cycle Assessment

FANNY ELFGREN 2023

MVEK12 EXAMENSARBETE FÖR KANDIDATEXAMEN 15 HP
MILJÖVETENSKAP | LUNDS UNIVERSITET

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Lund 2023

Abstract

The demand for biofuels is increasing as a result of increased climate mitigation ambitions aiming to replace the use of fossil fuels. To meet the increasing demand, energy crops grown on agricultural land used to produce biofuels is getting more and more attention. Since agricultural land is a scarce resource, conflicts can arise between food production and biomass for biofuels, making it essential to understand the trade-offs of using agricultural land for biofuel supply such as the demand for import of food crops and outsourced environmental damages. In this study, a sensitivity analysis was conducted looking at the environmental impact from trade in the Agent-based life cycle assessment conducted by López et al. (unpublished). This evaluates and compares the environmental impacts between two scenarios where a policy incentive replacing 25 percent of arable land with grass leys used for biofuel production is either present or absent. The sensitivity analysis in this study focused on evaluating how the environmental impact from trade concerning crop imports in López et al.'s study differs depending on the geographical region where the crops are produced, with the aim of testing the robustness of López et al.'s results. The sensitivity analysis showed that the environmental impacts from crops, measured in kg, vary substantially depending on the geographical location they origin from and which impact assessment method being used. However, when taking into account the volume of crops being imported, the result showed the same result as in López et al´s study, that the presence of the policy incentive has greater environmental performance than the absence of it. Implementing similar policies promoting the production of biofuels on a broader scale needs to be thoughtfully understood due to the conflict-relationship between food security and bioenergy demand as well as the potential of causing indirect-land-use-changes outside of its boarders.

Populärvetenskaplig sammanfattning

Efterfrågan på biobränslen ökar som ett resultat av höjda klimatreducerande ambitioner som syftar till att ersätta användningen av fossila bränslen. För att möta den ökande efterfrågan uppmärksammas alternativet att odla energigrödor på jordbruksmark för produktion av biobränslen allt mer. Eftersom jordbruksmark är en knapp resurs kan konflikter uppstå mellan livsmedelsproduktion och biomassa för biobränslen, vilket gör det viktigt att förstå effekterna av att använda jordbruksmark för biobränsleförsörjning.

För att utvärdera effekten av att tillsatta styrmedel som främjar produktionen av energigrödor på jordbruksmark kan en livscykelanalys utföras som specifikt kollar på miljöpåverkan. På Centrum för miljö-och klimatvetenskap vid Lunds universitet har Raül Losada i López med flera modellerat ett ekonomiskt styrmedel som leder till att bönder i Götalands Södra Slättbygder ersätter en del av deras matproduktion med energigrödor som kan användas till att producera biobränslen. De har även utfört en livscykelanalys som utvärderar och jämför miljökonsekvenserna mellan att introducera detta styrmedel och att inte introducera styrmedlet. Slutsatsen av detta var att närvaron av styrmedlet resulterade i en lägre total miljöpåverkan än scenariot där styrmedlet var frånvarande.

För att testa trovärdigheten av ovannämnd studie, utfördes i denna studie en känslighetsanalys med fokus på den handel som uppstår som ett resultat när produktion av grödor i området förändras. Känslighetsanalysen fokuserade på att utvärdera hur miljöpåverkan från handel avseende import skiljer sig åt beroende på den geografiska region där grödorna produceras. Känslighetsanalysen visade att miljöpåverkan från grödor per kg varierar kraftigt beroende på varifrån de kommer från och vilken konsekvensbedömningsmetod som används. Däremot, när man tar hänsyn till mängden grödor som importeras, visade resultatet samma resultat som i López med fleras studie, att närvaron av styrmedlet har lägre miljöpåverkan än frånvaron av det.

Eftersom ökade klimatambitioner i en region kan resultera i handel och behovet av import, är det viktigt att fortsätta utreda hur effekterna av policys på större skala kan leda till att miljöpåverkan förflyttas till andra länder och regioner. Detta är speciellt viktigt när miljöpåverkan förflyttas till länder med sämre miljölagar och produktionssätt.

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Abbreviations

AB-LCA	Agent Based Life Cycle Assessment
BAU	Business As Usual - Scenario representing the absence of policy
GRASS	GRASS – Scenario representing the presence of policy
GSS	Götalands Södra Slättbygder
DALY	Disability adjusted life year
Species.yr	Species years, describing the unit of disappeared species years
PDF.m2.yr	Potentially Disappeared Fraction of species over one square

1.0 Introduction

Bioenergy is today the largest source of renewable energy globally (Hodgson et al., 2022), and contributes to almost 60% of the renewable energy in the European Union (European Commission, n.d.) Bioenergy contributes to the green transition of the European Union by replacing the use of fossil fuels and mitigating emissions, particularly in the transport sector (European Union, Directive 2009/28/EC). Sweden has a net-zero target by 2045, and a reduction goal to reduce the emissions from domestic transportation by 70% by the year 2030 compared to 2010 emissions levels (Naturvårdsverket, n.d.a). Biofuels are considered an important measure to achieve these goals (Naturvårdsverket, n.d.b).

Producing biofuels requires biomass that can come from both forests, waste, and agriculture (Hodgson et al., 2022). Today, forests contribute with the highest share of biomass in the production of biofuels (World Bioenergy Association 2021). However, with an expected increasing demand for biofuels (OECD & FAO of the United Nations, 2018, Chapter 9), the contribution from agriculture is expected to increase (Tsiropoulos et al., 2022). Energy crops and perennial plants such as grass leys can play an important role in increasing Sweden's production of biofuels within the agricultural sector (Englund et al., 2023; Albizua et al., 2015). Apart from being energy-efficient (Smyth et al., 2009), grass leys can bring co-benefits such as reducing nutrient loss and soil erosion and improving biodiversity on high-productive agricultural land (Englund et al., 2023; Albizua et al., 2015). In addition to this, grass leys can contribute to increasing levels of soil organic carbon (SOC), resulting in increased carbon sequestration and higher yields in the long term (Englund et al., 202; Haney et al., 2010); Qin et al., 2016).

Since agricultural land is a scarce resource, conflicts can arise between food production and biomass for biofuels, making it essential to understand the trade-offs of using agricultural land for biofuel production (Subramaniam et al., 2019; Thomas et al., 2009). One effect of introducing policies that promote the use of biofuels is that it can result in the need of import (Fuchs et al., 2020; European Commission, 2013). Imports may be needed both for raw material that can be used for the production of biofuels or due to displaced food production when land is used in a region for growing biomass to produce biofuels (Tsiropoulos et al., 2022). Since technology, agricultural practices, climate conditions and environmental regulations differs between regions and countries (Fuchs et al., 2020), it becomes crucial to understand the environmental effects of introducing policies resulting in the need for imports.

A life cycle assessment (LCA) consists of four steps and is a tool that evaluates a product's or service's environmental impact (Jolliet et al., 2016). When evaluating the environmental impacts of policy interventions concerning agricultural changes, an LCA can be coupled to an agent-based model (ABM) called an AB-LCA. AgriPoliS is an ABM that has the capacity to study the influence of policies on agricultural change (Iamo, n.d.). The model can consider a large number of individually acting farms and how they respond to a specific policy intervention (Iamo, n.d.). To couple an LCA to an ABM, the ABM is first used to simulate farmers' responses to a policy. These responses can then be fed into the Life cycle inventory phase of the LCA to evaluate the environmental effect of introducing a certain policy.

This thesis will perform a sensitivity analysis on an AB-LCA conducted by Raül Losada I López and his research team at the Centre for Environmental and Climate Science (CEC) at Lund University. The AB-LCA conducted by López et al. (unpublished) aims to contribute to scientific evidence for decision-making concerning the production of biomass for biofuels in the Swedish region Götalands Södra Slättbygder (GSS). The policy incentive that is modeled in the AB-LCA is in the form of a payment that would encourage converting 25 percent of arable land over a 20-year period with grass leys that will be used for biofuel production. The benefit of introducing grass leys in this specific region is that it would solve its SOC depletion problem (López et al., unpublished). The two scenarios compared in the AB-LCA conducted by López et al. (unpublished) which are modeled in AgriPoliS are referred to as business as usual (BAU) and GRASS. The BAU scenario reflects the absence of the policy and the GRASS scenario the presence of it. The modeling of these scenarios not only showed that introducing this policy had greater environmental performance than the absence of it, but also that the production of crops will change in the region, resulting in displaced crop production and imports. The AB-LCA considers trade and displaced food production, however, the AB-LCA modeling setup relies on pre-defined trade scenarios which are not explicitly modeled. The pre-defined trade scenarios are based on a European market average concerning production statistics between countries. To receive a better understanding of the effect of introducing the policy in the GSS region, this thesis will perform a sensitivity analysis where the pre-defined trade scenarios are replaced with available trade data statistics for Swedish crop imports.

1.1 Aim and Research Questions

The purpose of the study is to evaluate how the environmental impact from trade concerning crop imports in López et al.'s study differs depending on the geographical region where the crops are produced. Where the aim is to test the robustness of López et al.´s result by performing a sensitivity analysis on the origins of the imported crops.

Two research questions have been identified:

Does the environmental impact vary depending on the geographical locations that the crops originate from?

Does changing trade origins affect the main conclusions drawn in López et al.´s study, that the presence of the policy resulting in grass leys replacing 25% or arable land in the GSS region has greater environmental performance than the absence of it?

1.2 Ethical Reflection

This study has few ethical concerns and do not include controversial methods. However, the results of this study could contribute to policy decisions which in turn could affect production of crops in the GSS region. It could therefore have an impact on the local communities and farming practices. Moreover, replacing crops with grass leys that would increase carbon sequestration could contribute to mitigating climate change, having beneficial effects for humans and the environment. In addition, replacing crops for the purpose of growing biomass for biofuel production evokes the discussion about what interests we should prioritize. With land being a scarce resource, should we prioritize locally produced food or renewable energy?

2.0 Method

2.1 Functional Unit and Scenarios

The functional unit of the AB-LCA conducted by López et al. (unpublished) is Götalands Södra Slättbygder (GSS) (figure 1), a region with high-productive agricultural land with observed depleted soil organic carbon levels (Brady et al., 2015). Same as in López et al.'s study, this study has a cradle-to-farm-gate perspective focusing only on the environmental impacts related to the GSS region which does not include the user phase of the biofuels that grass leys contributes too.

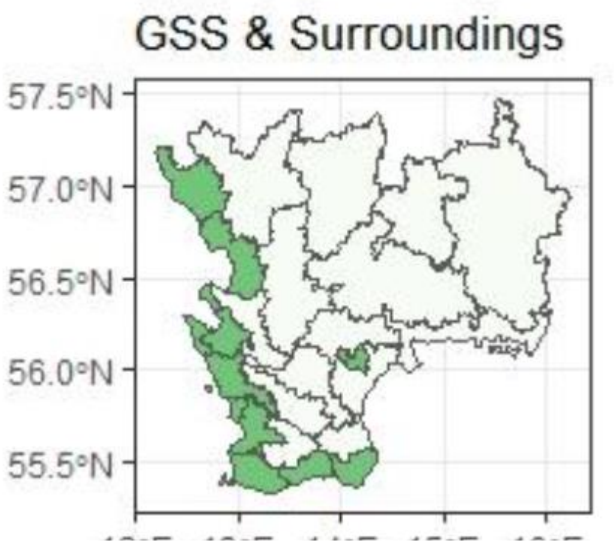


Figure 1. Map over Götalands Södra Slättbygder and surroundings. GSS in green (López et al., unpublished).

As mentioned in the introduction, the 20-year policy intervention simulated in AgriPoliS by López et al. results in changes in crop production in the region. In the GRASS scenario which represent the presence of the policy, production of winter wheat and spring barley will decrease compared to in the business-as-usual scenario (BAU) which represents the absence of the policy (see table 1 below). Meanwhile, winter rapeseed, sugar beet and grass ley will increase in the GRASS scenario compared to the BAU scenario. With the assumption of an unchanged demand for crops, winter wheat and spring barley needs to be imported to secure demand in the GRASS scenario. The increase in production of winter rapeseed and sugar beet in the GRASS scenario will instead replace import that is assumed to otherwise be imported in the 20-year period. Therefore, the import of rapeseed and sugar beet is allocated to the BAU scenario. In addition, import of a fuel mix is required in the absence of the policy (the BAU scenario) to replace the amount of fuel that the grass leys contribute to in the GRASS scenario. This study will cover the environmental impact from the fuel mix, but no sensitivity analysis will be performed on it.

Table 1. Production Volume (1000 t) for each main crop at year 20 of the simulation in BAU and GRASS (López et al., unpublished). Results for GRASS are expressed as the difference from BAU (positive meaning greater than in BAU and negative meaning less than BAU.

Crop	Production Volume (1000 t)	
	BAU	**GRASS**
Winter Wheat	868.57	-36.83
Spring Barley	433.87	-432.80
Winter Rapeseed	129.76	14.33
Sugarbeet	2129.25	4.25
Grass Ley	0.00	510.84

2.2 LCA and sensitivity analysis

To evaluate the robustness of the AB-LCA results conducted by López et al. concerning the environmental impact from the share of crops produced outside of GSS, a sensitivity analysis was performed where their geographical origin was tested. The modeling setup by López et al. (unpublished) relies on a European market average based on production statistics for each country. In this sensitivity analysis, this data was replaced with available trade data statistics for Swedish crop imports.

A life cycle assessment (LCA) consists of four phases and the sensitivity analysis is part of the fourth phase of the LCA called the interpretation phase. When conducting a sensitivity analysis, operations are also made in the second and third phase. Therefore, this next paragraph will explain the theoretical background on how to conduct an LCA.

The first phase of an LCA is the goal and scope definition where the objectives of the study is defined, the functional unit and the system boundaries (Joliet et al., 2016). The second phase is the inventory analysis where environmental impact data is collected and quantified such as emissions and pollution to air and water. The third phase is the impact assessment where the environmental impacts are evaluated. This can be performed by different environmental impact assessment methods such as ReCiPe 2016 and IMPACT World+ which are the impact assessment methods that this study uses. Environmental impacts can be divided into categories and midpoints such as global warming and marine acidification. As a midpoint category, global warming represents the impacts of greenhouse gases. These parameters can in turn be aggregated into damage characterization also referred to as endpoints, representing the damage to areas that we want to protect such as human health and ecosystems which are the two damage characterizations that this study uses. The last step of an LCA is called the interpretation phase where results are interpreted, and uncertainties evaluated. A sensitivity analysis is a part of the interpretation phase with the purpose of testing the robustness of the results. This can be done by identifying the key parameters that influence the results most and changing the input of those parameters to see how that affects the results (Joliet et al., 2016). In this sensitivity analysis, trade is the parameter which inputs are changed for.

2.2.1 Endpoints

As mentioned, this study uses endpoints to present the results of the LCA. The endpoints' units that represent the impact on Human Health are in the impact assessment methods ReCiPe 2016 and IMPACT World+, "DALY" which represents a disability adjusted life year. The unit representing the impact on Ecosystems is in ReCiPe 2016 "species.yr" representing disappeared species years and in IMPACT World+ "PDF.m2.yr" representing a potentially disappeared fraction of species over one square.

2.2.2 Trade data collection

The first step of the sensitivity analysis was to collect trade data for barley, wheat, rapeseed and sugar beet. Origins of import of barley and wheat to Sweden was collected from United Nations Comtrade database (United Nations, 2023.). No data on rapeseed and sugar beet was found in United Nations Comtrade database. Therefore, data for rapeseed and sugar beet was instead collected from the OEC data platform (OEC, n.d.) which visualize data from the data set HS92 1995-2021 from CEPII's BACI database (CEPII, 2023). CEPII is the Center for Prospective Studies and International Information and France's main institute for research and expertise in international economics (CEPII, n.d.b). All data collected represented import origin shares based on value since no available data based on quantity was found. Analyzed trade data showed that exporting countries and their share to Sweden varies between years. Therefore, an average between the years 2017-2021 was calculated, year 2021 being the most recent year of data available. Import origins and their average shares representing more than 2 percent of Swedish imports for each crop between the years 2017-2021 is presented in table 2 below.

The LCA tool used in this study is SimaPro 9.4.0.3, which is a science-based tool that includes a variety of life cycle inventory databases (SimaPro, n.d.). There is a limited array of country-specific data available in the life cycle inventory database Ecoinvent in SimaPro 9.4.0.3. Countries with data available for each crop in SimaPro which are the only countries that can be modelled in this study can be seen below in table 2. The only European countries that Ecoinvent provides data on are Spain, France and Germany. However, as can be seen in table 2, the origin of Swedish imports found in trade data statistics is substantially more diverse. One extreme case is sugar beet where ca 98 percent of Swedish imports origins from other countries than the ones available in SimaPro. This limitation resulted in that the sensitivity analysis could not reflect the complete reality of Swedish import origins for the different crops.

Table 2. Import origins per crop available in SimaPro and import origins contributing to more than 2% of trade based on trade data, representing their average share calculated for the years 2017-2021.

Crop	Countries in SimaPro	Import origins contributing to more than 2% of trade based on available trade data between (2017-2021)
Barley	Germany France Spain	Germany (17.2%), Denmark (50.8%), Finland (11.6%), UK (10.9%), Poland (4.90%) and Lithuania (4.50%).
Wheat	Germany France Spain	Germany (25.2%), France (16.2%), Spain (4.70%), Denmark (17.6%), Lithuania (6.3%), Kazakhstan (5.10%), Latvia (4.40%), Poland (4.20%), Romania (3.50%), Italy (3.30%), Bulgaria (3.10%) and the Russian Federation (3.00%).
Rapeseed	Germany France	Germany (9.50%), France (24.1%), UK (26.1%), Lithuania (11.3%), Denmark (9.70%), Latvia (5.00%) and the Netherlands (3.70%).
Sugar beet	Germany France	France (2.40%), Poland (45.0%), Belgium (41.2%) and the Netherlands (8.3%).

2.2.3 Calculations of country specific shares in Import Scenario

The pre-defiend trade scenario within the AB-LCA is from now on referred to as the Benchmark scenario including Benchmark BAU and Benchmark GRASS. The trade scenario that this thesis compared to the Benchmark scenario based on available trade data statistics is referred to as the Import scenario, including Import BAU and Import GRASS.

To calculate the shares for the Import scenario, the average shares (table 2) which the countries available in SimaPro represented between the years 2017-2021, was added up. The aggregated shares represented a 100 percent of imports. To calculate the new shares for the Import scenario, each countries' share representing more than 2 percent of Swedish imports was then divided by the aggregated share. For example, France and Spain stood for less than 2 percent of imports of barley to Sweden and Germany stood for 17.2 percent. The aggregated share was therefore (0%+0%+17.2%) making Germany's share 100 percent (17.2%/17.2%). These calculations were made for each crop. The Benchmark shares in López et al.'s study and the new shares in the Import Scenario replacing the Benchmark shares is presented in table 3 below.

Table 3. Import origins shares tested for each crop and country. The table shows the pre-defined shares in the Benchmark scenario that was previously simulated in SimaPro in the Benchmark scenario and the Import scenario shares in green that was modelled in this study.

Crop	Benchmark share Germany	Import share Germany	Benchmark share France	Import share France	Benchmark share Spain	Import share Spain
Barley	43.74%	100.0%	38.85%	0%	17.42%	0%
Wheat	36.67%	54.63%	57.09%	35.17%	6.233%	10.20%
Rapeseed	55.60 %	28.27%	44.40%	71.73%	-	-
Sugar beet	43.44%	0%	56.56%	100.0%	-	-

2.2.4 LCA operations

Shares in the system setup in SimaPro 9.4.0.3 were changed to represent the Import scenario shares in table 3 above for each crop. Two impact assessments by the methods ReCiPe 2016 and IMPACT World+ was run. The outputs of the impact assessments provided environmental impact data for production of 1 kg of each crop in form of endpoints. This data was then exported to a spreadsheet. In the spreadsheet, the data was summarized and the endpoint category *Land transformation, biodiversity* was excluded from the analysis for IMPACT World+ since SimaPro generated an unrealistic impact from the category, same as in in the AB-LCA conducted by López et al. The impacts in the Benchmark scenario were then compared to the impacts in the Import scenario.

3.0 Results

3.1 Changes in kg per crop

Overall, the results from both the impact assessment methods showed that changing the import origins´ shares have an impact on the environmental impact per crop in kg (see table 4&5). All the crops' impacts on both Human Health and Ecosystems changed with at least 7 percent compared to the Benchmark scenarios. For some crops, the difference in impact between the Import scenarios and Benchmark scenarios were way larger than 7 percent. The largest difference concerned rapeseed from IMPACT World+ calculations, where the impact on Ecosystems from rapeseed decreased by 74.84 percent and 72.44 percent on Human Health when changing the import origin shares (table 5). Overall, there were also larger differences in impact per crop in the results from IMPACT World+ than in the results from Recipe 2016 (see table 4&5). Similarities in the results from both IMPACT World+ and ReCiPe 2016, was that the impact from wheat increased and the impact from barley decreased compared to the Benchmark scenario. However, concerning the impact on Human Health and Ecosystems from rapeseed, the impact increased in the results from ReCiPe 2016 but decreased in the IMPACT World+ result. For sugar beet, the impact assessment methods also weighed the changes in import shares different, where the impact on Human Health and Ecosystems decreased in ReCiPe 2016 but increased in the IMPACT World+ result.

Table 4. Difference in impact calculated by the ReCiPe 2016 methodology on Human Health and Ecosystems between the Benchmark scenario and Import scenario for each crop per kg. (-) meaning the impact in the Import scenario is larger than in the Benchmark scenario.

	Human Health		**Ecosystems**	
Crop	Δ between Import BAU and Benchmark BAU	Δ between Import GRASS and Benchmark GRASS	Δ between Import BAU and Benchmark BAU	Δ between Import GRASS and Benchmark GRASS
Rapeseed	-13.39%	-	-7.86%	-
Sugar beet	19.53%	-	18.28%	-
Wheat	-	-27.82		-21.61%
Barley	-	29.70%		29.21%

Table 5. Difference in impact calculated by the IMPACT World+ methodology on Human Health and Ecosystems between the Benchmark scenario and Import scenario for each crop per kg. (-) meaning the impact in the Import scenario is larger than in the Benchmark scenario.

	Human Health		**Ecosystems**	
Crop	Δ between Import BAU and Benchmark BAU	Δ between Import GRASS and Benchmark GRASS	Δ between Import BAU and Benchmark BAU	Δ between Import GRASS and Benchmark GRASS
Rapeseed	72.44%	-	74.84%	-
Sugar beet	-15.87%	-	-41.72%	-
Wheat	-	-51.55%	-	-65.48%
Barley	-	21.24%	-	7.80%

3.2 Total impact from trade for each crop

The results from ReCiPe 2016 where the impacts in kg per crop were multiplied with the amount imported in the scenarios (see table 1 method section), showed that Import BAU had a higher total impact than Benchmark BAU on both Human Health and Ecosystems (figure 2). Different from calculations by the Recipe 2016 methodology, IMPACT World+ results showed that Import BAU had a lower total impact than the Benchmark BAU scenario on both Human Health and Ecosystems (figure 3). In the BAU scenarios, impact from sugar beet is almost not visible in the figures. This is due to the small amount of sugar beet being imported (see table 1 in method section).

Concerning the GRASS scenarios, the ReCiPe 2016 results showed that the overall impact from trade is lower in the Import GRASS scenario than in the Benchmark GRASS scenario for both Human Health and Ecosystems (figure 2). Since the amount of barley being imported in the GRASS scenarios is much larger than the amount of wheat imported (see table 1 in method section), the decrease in impact from barley had the biggest influence on the decline of the total impact that is seen in figure 2. The IMPACT World+ results showed that the overall impact from trade is lower in the Import GRASS scenario than in the Benchmark GRASS scenario for both Human Health and Ecosystems (figure 3), which is the same relationship as in figure 2. Even though the difference between the increased impact from wheat per kg is notably higher (65.48%) than the decrease in impact from barley (7.80%) (see table 5), the amount of barley imported is so much larger than the amount of wheat imported (see table 1 in method part) that it still resulted in that the Import GRASS scenario had a lower total impact than the Benchmark GRASS scenario.

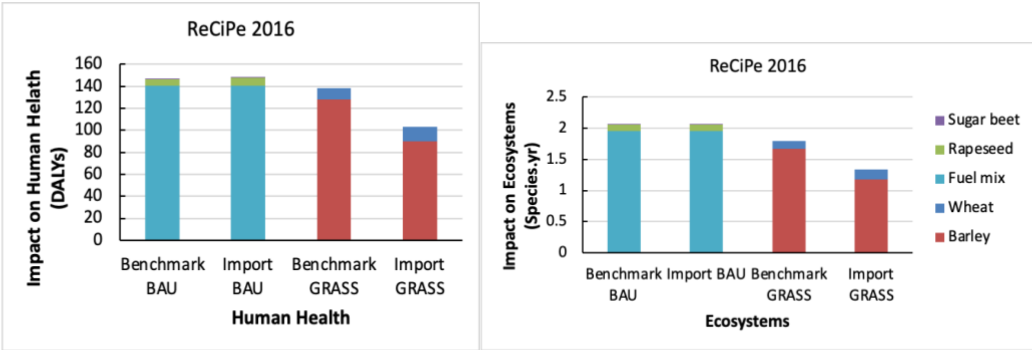


Figure 2. Impact from trade per crop for each scenario on Human Health in DALYS (left) and Ecosystems in Species years (right). Impact from fuel mix is included for the Benchmark and Import BAU scenarios. Impact is calculated by the ReCiPe 2016 methodology.

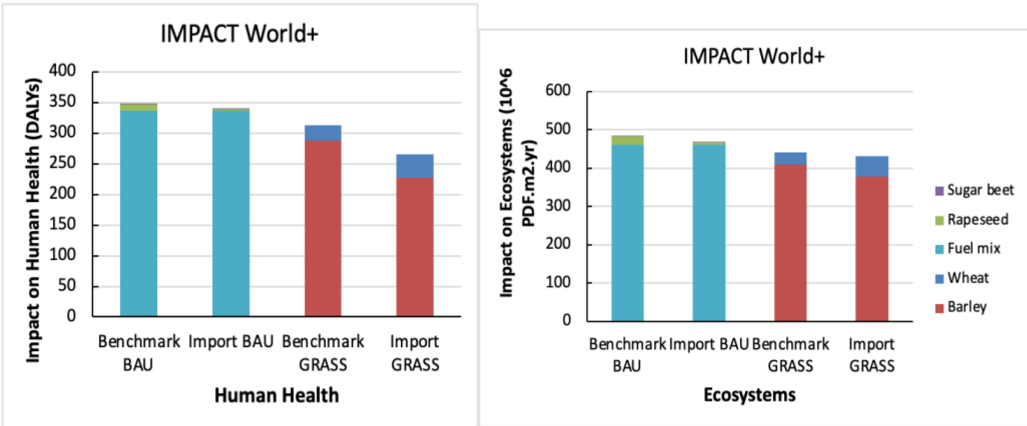


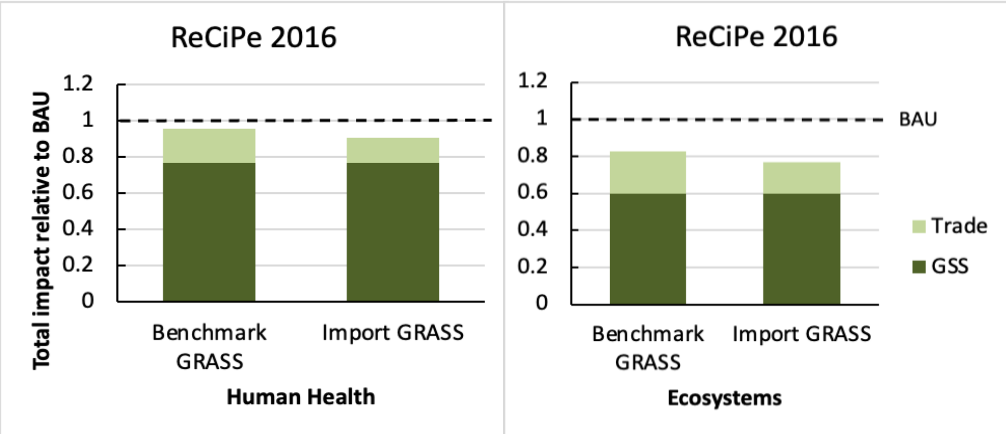
Figure 3. Impact from trade per crop for each scenario on Human Health in DALYS (left) and Ecosystems in PDF.m2.yr (right). Impact from fuel mix is included for the Benchmark and Import BAU scenarios. Impact is calculated by the IMPACT World+ methodology.

3.3 Impact in GRASS scenario relative to BAU scenario

In the Benchmark scenario conducted by López et al. (unpiblished), GRASS has a lower total impact on both Human Health and Ecosystems compared to BAU, which indicates a positive performance of the policy. The results given by ReCiPe 2016 shows the same relationship where the impact in the Import GRASS scenario is lower compared to the Import BAU for both Human Health and Ecosystems (see figure 4a). The result also

shows that the difference between the Import GRASS scenario and the Import BAU scenario is bigger than between the Benchmark scenarios. This difference can be explained by the results showed in figure 2 above due to that the Import BAU scenario has a higher impact than the Benchmark BAU scenario and the Import GRASS scenario has a lower impact than the Benchmark Grass scenario.
IMPACT World+ results showed that the Import GRASS scenario has lower impact on both Human Health (left) and Ecosystems (right) than the Import BAU scenario which is the same as in the Benchmark scenario (figure 4b).

4a.



4b.

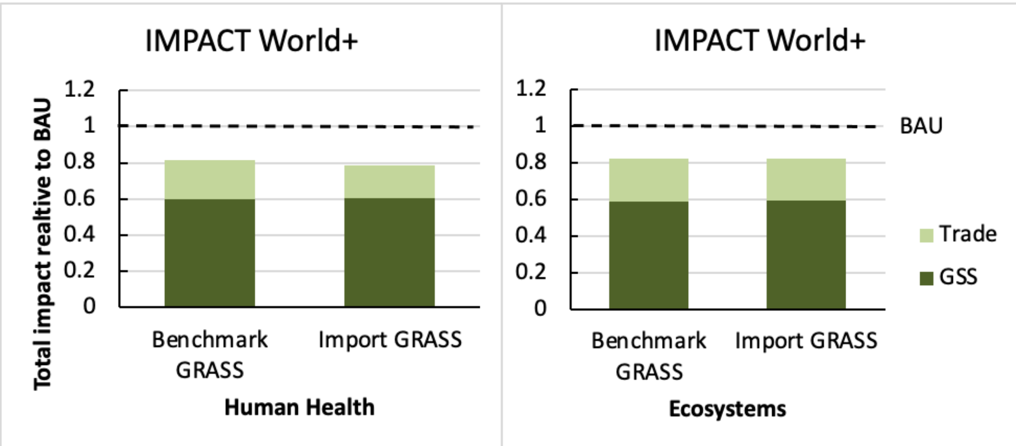


Figure 4a&4b. Total impact on Human Health (left) and Ecosystems (right) in the Benchmark GRASS and Import GRASS scenarios relative to the total impact of their corresponding BAU scenario (Benchmark GRASS/Benchmark BAU), (Import GRASS/Import BAU). The dashed horizontal black line represents the impact from BAU scenarios. Light green represents the impacts connected to trade including the fuel mix and GSS represents the environmental impacts from production of crops in the region. Results calculated by the ReCiPe 2016 methodology at top (4a) and results calculated by IMPACT World+ below (4b).

3.4 Analysis on impact category level

Analysis on an impact category level on Human Health showed that the Import BAU scenario had higher impacts than the Benchmark BAU scenario in all categories except for two (table 6). The two categories that Import BAU scenario had lower impacts in was Human carcinogenetic toxicity and Ozone formation. Concerning impact on Ecosystems, the only impact category that was lower in the Import BAU scenario was Ozone formation, terrestrial ecosystems. Even though the Import BAU scenario had a higher impact than the Benchmark BAU scenario for most categories, the increase in impact was very small (less than 1 DALY respectively PDF.m2.yr per category) and had a marginal effect on the total impact from trade in the BAU scenario as can be seen in figure 2.

The import GRASS scenario had higher impact on Human health than the Benchmark GRASS in only one category; Human carcinogenetic toxicity, and two categories; Freshwater ecotoxicity and Marine eutrophication on Ecosystems.

Table 6. Difference (Δ) in impact between the two GRASS scenarios (Import GRASS- Benchmark GRASS) and BAU scenarios (Import BAU-Benchmark BAU) for each impact category sorted for the two areas of protection Human Health and Ecosystems. Difference represent changes in the unit DALY for Human health and PDF.m2.yr for Ecosystems. Order of impact categories is sorted from largest to lowest influence. Results following the ReCiPe 2016 methodology.

	ReCiPe 2016		
AREA of Protection	**Impact Category**	**GRASS Δ**	**BAU Δ**
Human Health	Fine particulate matter formation	-1.2E+01	5.1E-01
	Global warming, Human health	-3.8E+00	1.9E-01
	Human non-carcinogenic toxicity	-2.3E+00	5.2E-02
	Human carcinogenic toxicity	7.0E-01	-1.2E-02
	Water consumption, Human health	-1.7E+01	1.7E-02
	Stratospheric ozone depletion	-7.4E-02	3.0E-03
	Ozone formation, Human health	-5.0E-03	-4.0E-05
	Ionizing radiation	-3.3E-03	1.6E-04
Ecosystems	Land use	-3.8E-01	4.9E-03
	Terrestrial acidification	-3.3E-02	1.4E-03
	Global warming, Terrestrial ecosystems	-1.1E-02	5.6E-04
	Ozone formation, Terrestrial ecosystems	-7.1E-04	-5.7E-06
	Water consumption, Terrestrial ecosystem	-8.3E-04	3.7E-05
	Freshwater eutrophication	-3.4E-02	3.4E-04
	Terrestrial ecotoxicity	-2.6E-05	4.9E-06
	Freshwater ecotoxicity	4.7E-05	2.8E-06
	Marine eutrophication	1.1E-05	4.7E-07
	Marine ecotoxicity	-2.5E-04	4.8E-06
	Global warming, Freshwater ecosystems	-3.1E-07	1.5E-08
	Water consumption, Aquatic ecosystems	-6.2E-06	2.4E-08

The result from the IMPACT World+ methodology differs from ReCiPe 2016 in that the impacts in Import BAU were lower than in the Benchmark scenario for all impact categories connected to Human health and Ecosystems (table 7).

Between the GRASS scenarios, all impacts were lower in the Import GRASS scenario except for 5 categories; Human toxicity cancer, short term, Freshwater ecotoxicity, long term and short term, Marine acidification, long term, and short term. Four of the five impact categories where the Import GRASS scenario had a larger impact were connected to Ecosystems. The effect of this is reflected in figure 3 where the difference in impact on Ecosystems do not differ as much between the scenarios as it does for Human health.

Table 7. Difference (Δ) in impact between the two GRASS scenarios (Import GRASS-Benchmark GRASS) and BAU scenarios (Import BAU-Benchmark BAU) for each impact category sorted for the two areas of protection Human Health and Ecosystems. Difference represent changes in the unit DALY for Human health and PDF.m2.yr for Ecosystems. Results following the IMPACT World+ methodology. Order of impact categories is sorted from largest to lowest influence.

IMPACT World+			
AREA of Protection	**Impact Category**	**GRASS Δ**	**BAU Δ**
Human Health	Climate change, human health, long term	-1.3E+00	-3.6E+00
	Water availability, human health	-9.5E+00	-4.3E-01
	Particulate matter formation	-9.1E+00	-1.2E+00
	Climate change, human health, short term	-2.3E+00	-1.5E+00
	Human toxicity non-cancer, short term	-2.3E+01	-1.2E+00
	Human toxicity non-cancer, long term	-3.4E+00	-3.6E-01
	Human toxicity cancer, short term	3.1E-01	-3.2E-01
	Human toxicity cancer, long term	-8.0E-02	-1.1E-02
	Ionizing radiation, human health	-6.9E-03	-2.1E-03
	Ozone layer depletion	-1.3E-03	-4.1E-04
	Photochemical oxidant formation	-2.0E-05	-2.9E-04
Ecosystems	Freshwater ecotoxicity, long term	1.9E+07	-9.8E+06
	Land occupation, biodiversity	-2.7E+07	-4.8E+06
	Climate change, ecosystem quality, long	-3.0E+05	-7.8E+05
	Terrestrial acidification	-1.8E+06	-1.9E+05
	Climate change, ecosystem quality, short	-4.9E+05	-3.2E+05
	Marine acidification, long term	7.0E+04	-1.6E+05
	Freshwater acidification	-1.4E+05	-2.1E+04
	Freshwater ecotoxicity, short term	3.3E+04	-1.6E+04
	Marine acidification, short term	7.6E+03	-1.7E+04
	Marine eutrophication	-5.0E+04	-6.9E+03
	Freshwater eutrophication	-2.0E+04	-2.0E+03
	Water availability, terrestrial ecosys.	-5.9E+04	-3.2E+03
	Water availability, freshwater ecosys.	-2.0E+03	-8.8E+01
	Thermally polluted water	-6.7E-01	-2.1E+00
	Ionizing radiation, ecosystem quality	-2.5E-04	-2.0E-04

4.0 Discussion

The results showed the extent to which the geographical origin of crops in Europe has on their environmental impacts. The sensitivity analysis showed that the environmental impacts on Human Health and Ecosystems, vary substantially depending on the import origins of the crops. When replacing the pre-defined trade scenario based on production volumes (Benchmark scenario) with the trade scenario based on trade data on imports to Sweden (Import scenario), the difference in impact in kg where more significant for some crops (see table 4&5), such as for wheat which impacts on Ecosystems increased by 65.48 percent. There were also large differences between the impact on Human Health from rapeseed that decreased by 72.44 percent in the Import scenario (table 5). Moreover, not only did the percentages differ, but there were also differences between what crops' impacts increased and decreased in the Import BAU scenario between the two impact assessment methodologies. That the ReCiPe 2016 methodology and IMPACT World+ methodology results were so different (see table 4 & 5) shows that it exists uncertainties between the methods which Chen et al. (2021) also suggests. It could therefore be argued that using more than one impact assessment method is relevant.

Connecting the impact of crops to the changes in import shares, Recipe 2016 weighs the impact for France concerning the production of rapeseed lower than for Germany since the impact increased when a larger share was imported from Germany. On the other hand, results from IMPACT World+ showed the opposite trend, which weighs the impact from rapeseed production in Germany less compared to France since the impact decreased. Similar differences could be seen for sugar beet. Looking into what caused these differences and how the two impact assessment methodologies weigh and consider different inputs has not been analyzed more in depth due to time constraints.

Even though there were significant differences in the impact in kg per crop, the differences did not affect the relationship in total impact between GRASS and BAU. As shown in figure 4a&b, Import GRASS has a lower environmental impact than Import BAU, same as it had between the Benchmark scenarios. The same conclusion can be drawn in this sensitivity analysis, that implementing the policy promoting the production of biomass for biofuels has better environmental performance than the scenario without the policy implementation. It can therefore be argued that the results in the AB-LCA conducted by López et al. are robust and that changing the import origins and their share did not affect the overall result substantially.

Since the aim of López et al.´s study is to contribute to scientific evidence for policymaking, the sensitivity analysis and its results are important as it tests a sensitive input in López et al.´s study which in turn helps to provide a better decision basis for policies that can reduce negative environmental impact. The sensitivity analysis results support López et al.´s results, that the presence of the policy promoting the growing of grass leys for biofuel production has greater environmental performance than the absence of it. This means that implementing the policy could have a beneficial effect on the environment, creating more sustainable farming practices. Conducting studies that aim to contribute to scientific evidence for policymaking is extremely important as we today face many challenges such as global warming and biodiversity loss. We need policies contributing to a sustainable society where we take responsibility for what our actions have caused. From an ethical perspective, this is essential due to our responsibility for mitigating the suffering of others and ensuring that we utilize our resources today without compromising future generations' needs.

The demand for biofuels is increasing as fossil fuels are being phased out. Tsiropoulos et al. (2022) argue that achieving a large-scale bioenergy deployment to meet EU's ambitious emission reduction goals requires the supply of energy crops and conversion of arable land since the forestry biomass potential is limited. Even though a policy intervention to increase the production of biomass for bioenergy on arable land in Sweden, like the one in this thesis, may not have a large impact on trade on a bigger scale. Implementing similar policies on a broader scale in EU, needs to be thoughtfully understood due to the conflict-relationship between food security and bioenergy demand as well as the potential of causing indirect-land-use-changes outside of its borders. As Fuchs et al. (2020) discuss, the European Union has had a high import demand of crops that has caused the outsourcing of environmental damage. Fuchs et al. (2020) enhance the problem of green policies that result in imports from countries with less strict environmental laws. In a report from the European Commission (2013), the EU demand on import for crops including crops for biofuel production, embodied 1/3 of the world's deforestation due to trade over the period 1990-2008. The fact that trade can outsource environmental damages makes it highly relevant to understand the trade-offs of introducing "green policies" concerning the use of biofuels including the effects of potential outsourced crop production that biomass production for biofuels on agricultural land on a larger scale could bring.

4.1 Uncertainties in the method and further research

An uncertainty in this study is that the trade data for sugar beet and rapeseed could not be found on the United Nations Comtrade database (United Nations, n.d.), and that the data collected for sugar beet and rapeseed was instead collected from the secondary source OEC that visualize data from CEPII's BACI data base (OEC, n.d.). The data was not collected from the BACI database directly because the database provides a file covering data on bilateral trade flows over 20 years for 200 countries and 5000 products, which was too time consuming to sort for the time available.

Important to remember when working with LCAs is that the result of the LCA can only be as good as the data inputted and impact assessment method used (Chen et al., 2021). Therefore, there can be many uncertainties when conducting an LCA and its results should be interpreted carefully (Chen et al., 2021). The original study by López et al. is a comparative LCA specific to alternative configurations for GSS and its results are not designed to be used outside of this comparison.

For further research, performing a sensitivity analysis on the fuel mix that is imported in the BAU scenario would be relevant since the fuel mix contributes with the largest impact from trade which can be seen in figures 2 and 3. Studies have also shown that the environmental impact differs between fuel mixes (Carbrera-Jiménez et al., 2022; Jeswani, 2020), indicating that the fuel mix could be a sensitive input.

5.0 Conclusion

The results of replacing the pre-defined trade scenario in the AB-LCA conducted by López et al. (unpublished) with a scenario that is based on available trade data covering actual import origins to Sweden, showed that the environmental impact per crop in kg vary substantially depending on import origin. However, the sensitivity analysis showed that these differences did not result in a change of the relationship in total impact between the GRASS scenario and the BAU scenario. The same conclusion as in López et al.´s study can be drawn in this sensitivity analysis, that implementing the policy promoting the production of biomass for biofuels has better environmental performance than the scenario without the policy implementation. It can therefore be argued that the AB-LCA result in López et al.'s study is robust and that changing the import origins and their share did not affect the overall result substantially. A conclusion that can be drawn from the results is that uncertainties exist between the two impact assessment methodologies ReCiPe 2016 and IMPACT World+ used in this study, which other sources such as Chen et al. (2021) also suggest. The sensitivity analysis is limited to the data available in SimaPro which did not cover all import origins found from trade data. The sensitivity analysis could therefore not completely reflect the reality of import origins to Sweden concerning the different crops. Since the demand for biofuels is increasing, using agricultural land to grow biomass for biofuels may be necessary to meet the increasing demand. However, land is a scarce resource and conflicts between food production and demand for biofuels can arise. Implementing policies that promote biofuels can also lead to the demand for imports, potentially resulting in outsourced environmental damages. Therefore, it becomes essential to continue evaluating the trade-offs and effects of introducing "green policies" that aims to increase the use of biofuels.

Acknowledgements

First of all, I would like to thank my supervisors Raül López and Katarina Hedlund for their valuable guidance and insights throughout the production of this thesis. I would also like to thank Olof Andersson and Louise Engsmyre for their support and inputs. Lastly, I would like to thank my group supervisor Ullrika Shalin and my supervising group for insights during my thesis.

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