sustainability

Article

Environmental Impacts of Rapeseed and Turnip Rapeseed Grown in Norway, Rape Oil and Press Cake

Erik Svanes [1,*], Wendy Waalen [2] and Anne Kjersti Uhlen [3]

1 Norwegian Institute for Sustainability Research, 1672 Fredrikstad, Norway
2 Norwegian Institute of Bioeconomy Research, 2849 Kapp, Norway; wendy.waalen@nibio.no
3 Faculty of Biosciences, Norwegian University of Life Sciences, 1430 Aas, Norway; anne.uhlen@nmbu.no
* Correspondence: erik@norsus.no; Tel.: +47-9701-6051

Received: 28 October 2020; Accepted: 9 December 2020; Published: 12 December 2020

Abstract: Many Norwegian consumers eat more red meat than is recommended by the Government. Of the protein currently consumed, 75% is of animal origin. Natural conditions in Norway favour the production of meat, dairy and seafood but high-protein plants can also be grown in the country. This study analysed the environmental impact of growing turnip rapeseed (*Brassica rapa*) and rapeseed (*Brassica napus*) and the processing of rapeseed into dietary oil and press cake. The results were then compared with some common animal protein food sources. Impacts were calculated for 24 impact indicators. The climate impact of dried seeds was 1.19 kg CO_2-eq/kg, for rape oil—3.0 kg CO_2-eq/kg and for rapeseed press cake—0.72 kg CO_2-eq/kg. The environmental impact of rapeseed production is higher than in most other countries, predominantly due to lower yields. Press cake from rapeseed could be a valuable source of protein in foods. In Norway, the environmental impacts of this material (climate impact—2.5 kg CO_2-eq/kg protein) are at the same level as other plant protein sources, but far lower than some of the most common animal protein sources (climate impact—16–35 kg CO_2-eq/kg protein). When comparing the impacts while taking nutrient content into account, these differences remained the same. Improvements in the environmental performance of oilseed and its products can be achieved both by improving yields through better agronomic practices and increasing the proportion of winter rapeseed.

Keywords: rapeseed; turnip rapeseed; press cake; rape oil; protein; health; LCA; Norway

1. Introduction

Norway has made a commitment to reduce GHG emissions by 50% by 2030 [1]. In its endeavour to reduce greenhouse gas (GHG) emissions, the Norwegian agriculture sector has agreed to reduce emissions by 5 million tonnes of CO_2-equivalent tonnes in the period 2021–2030 [2].

One possible means of achieving this target is to reduce the production of foods such as meat, which produce high GHG emissions. As meat has a high protein content, it should essentially be replaced by foods with a high protein content. A recent report commissioned by the Norwegian Government [3] showed that by changing the diet of Norwegian consumers, a reduction in GHG emissions of 2.9 million tonnes CO_2-eq could be achieved. Advanced models were created for these calculations. As a basis for this number, Mittenzwei et al. [4] created a total number of eight scenarios with a varying degree of compliance with the governmental dietary guidelines and the level of national self-sufficiency. All diets contained the same pro-capita protein and energy intake as the reference scenario. From these eight scenarios, one was chosen and presented in the principal project [3] to show the potential effect of a dietary change on domestic GHG emissions. The reduction in GHG emissions could, for the most part, be achieved by reducing red meat consumption and increasing the consumption of plant-based foods which have less climate impact.

In addition to the reduction of GHG emissions, which have been a major focus the last decade, considerable efforts have also been made since the 1980s to reduce the run-off of nutrients from agricultural soils. This has reduced the eutrophication of freshwater and the sea and developed Norwegian agriculture in an environmentally sustainable direction. This work is continuing, and it is an important goal alongside that of reducing GHG emissions.

A significant number of studies have shown that the production of plant protein in general has a far lower environmental impact than meat protein. As an example, one Norwegian study [5] calculated the environmental impact of faba beans and peas per kg dried grain and per kg protein using eight impact indicators. A comparison with the results from a study on dairy beef and milk [6] found the average GHG emissions of peas and faba beans to be 14–29 times less than those for dairy beef meat, and 9–15 times lower than for milk, when expressed per kg protein. For all other categories, the picture was the same. In the case of freshwater eutrophication, for example, the corresponding results were 33–51 and 2–3 times lower, respectively, and for terrestrial acidification 84–124 and 700–103 times higher when compared with peas and faba beans.

The difference is even greater when compared with suckler beef produced in Norway [7]. The GHG emissions for suckler beef were 42 and 49 times higher than for peas and faba beans, respectively, and when the comparison was made on the basis of protein content, the results were 43 and 58 times higher. Partially replacing beef and other types of meat with plant protein could thus potentially make a significant reduction in the environmental impact of food production and consumption in Norway.

Seed from rapeseed (*Brassica napus*) and turnip rapeseed (*Brassica rapa*), hereafter referred to as oilseeds, are one possible protein source with a low climate impact. Most of the rapeseed and turnip rapeseed in Norway is grown for use as animal feed, but a proportion of rapeseed is used in oil production. The protein content in the oilseeds is normally 20–22%, a similar level to that of peas, but lower than the protein content of faba beans. Rapeseed and turnip rapeseed can be grown in Norway and can achieve protein contents 2–3 times higher than those of cereals. Oilseeds are unique in having high content of lipids (48–50%), of which 63% are monounsaturated, 7.5% saturated and 29.5% polyunsaturated. The seeds can be used for oil extraction, yielding an edible oil and a press cake with high protein content. The press cake is now widely used in the production of feed concentrates, but has, however, the potential to be used as food for human consumption; as such, it could represent an important source of protein. The term rapeseed press cake is used in this article to denote the remaining fraction after pressing, whereas rape meal is used to denote the remaining fraction after removing oil in two steps: pressing followed by solvent extraction. In Norway, cold pressing is employed in the production of rape oil but in other countries it is frequently carried out with subsequent solvent extraction.

In Norway, rapeseed is generally used for animal feed as an ingredient in feed concentrates [8]. Approximately 1300 tonnes (ibid), out of a total production of 10,000 tonnes (in 2018/19) is cold-pressed, yielding 300,000 litres of oil for human consumption and 10,000 tonnes of press cake which is currently used for feed. At the time of writing, rapeseed is utilised in the production of rapeseed oil in Norway, but it is also technically possible to use turnip rapeseed (*Brassica rapa*) grown in Norway for this. The total amount of rapeseed produced for feed is high, 161,684 tonnes having been utilised in this way in 2019.

Crops and/or press cake from rapeseed can potentially be used for human consumption as a protein source, in Norway and many other countries. There are, however, certain obstacles to their use as such. In the case of rape meal, these include the fact that it contains some antinutritional compounds, an unpleasant taste, poor digestibility, inferior physicochemical properties and an unappealing colour [9]. The compound (Kaempferol 3-O-(2‴-O-Sinapoyl-β-sophoroside) which gives the bitter taste to the rape meal has been identified [10]. This finding opens up possibilities for the development of processing techniques to remove this compound and thus make the rape meal more suitable for human consumption. Commercial products do exist that are made from rape meal, [11,12] and that can be used in foods. The press cake in Norway is the remainder after oil production. Since this processing does not include heating to a high temperature or solvent extraction, the protein structure is unlikely to be much altered. The taste and smell, however, are still challenges to be overcome.

A partial replacement of animal protein products with plant protein products could potentially provide benefits for consumer health. Fifty-five percent of all male consumers and 33% of all female consumers in Norway eat more meat than the recommended maximum amount of 500 g red and processed meat per week [13]. High meat consumption has been linked to diseases such as cardiovascular disease, colorectal cancer and type 2 diabetes [14]. IARC (International Agency for Research on Cancer) has classified red and processed meat as class 1, Carcinogenic to humans.

1.1. Oilseed Cultivation in Norway

Oilseed production in Norway is very limited but there is a considerable potential for increasing it [15]. In 2019 oilseed crops were grown on 3400 ha (ibid), an area representing approximately 1% of the total area of cereal production in Norway. Table 1 shows the area sown with three different oilseed species, average yields and total production, based on the sales of seed and expert knowledge [16]. Winter turnip rapeseed (WTR) is also grown but the level of production is so low that it has been ignored.

Table 1. Area of oilseeds in Norway, production amounts and potential production.

	Average Area Today, ha	Average Yield, t/ha	Average Production Today/t/ha	Potential Area, ha	Potential Production, t
SR	1345	2620	4386		
WR	1662	3500	2068		
STR	355	1772	1046		
Total	3400		10,032		52,000

SR: spring rapeseed, WR: winter rapeseed and STR: Spring turnip rapeseed.

Production is in the main restricted to the higher yielding grain producing regions in the southeast of Norway. This is due both to the topography and to the limited length of the growing season in other regions. Production is primarily based on spring rapeseed (*Brassica napus*) and spring turnip rapeseed (*Brassica rapa*). In recent years, approximately 60–80% of the area has been seeded to spring rapeseed, a market share which has increased with the development of varieties better suited to a short growing season [17]. Spring turnip rapeseed is grown on 20–40% of the oilseed area. It is generally grown in regions which are on the boundary for oilseed production, as it requires a shorter growing season than spring rapeseed. The yield potential of spring turnip rapeseed under Norwegian conditions is approximately 40% lower than spring rapeseed [18]. Furthermore, turnip rapeseed has a higher susceptibility to insect damage. There is growing interest in winter rapeseed production, which, when compared with spring rapeseed, offers a higher yield potential and less risk of insect damage [19]. Production remains, however, very limited and the available area varies from year to year. Successful winter survival necessitates seeding in early August, a demand that can be challenging to meet in years with cooler temperatures and/or difficult harvesting conditions. Winter rapeseed has a poorer winter survival rate than most other autumn sown species such as winter wheat and winter rye. Norwegian winter conditions can be harsh, with ice encasement and deacclimation events during late winter. As such, winter survival is a limiting factor in the expansion of winter rapeseed in Norway [20].

There is significant potential for increasing the production of plant protein in the cereal regions of Norway. In a recent study, scientists [21] calculated a potential production of 52,000 tonnes of oilseeds (8.5 times the current production). Given the existing area of the various oilseed species and the corresponding yields, oilseeds on average produce approximately 400 kg protein per hectare. An increase in winter rapeseed production would expand this protein production significantly, as a result of its higher yield potential.

Oilseeds could become an important protein source in Norway. The press cake contains 28.8% protein and 25% fat [8] following cold pressing. Currently, it is only used as animal feed, but it could potentially be utilised for human consumption. In this study the environmental impact of oilseed press cake as a protein source is compared with other protein sources in Norway. In addition, other products from oilseeds produced in Norway are analysed to gain a picture of the full environmental impact of oilseed production within the country.

1.2. LCA of Oilseeds

Numerous Life Cycle Assessment studies of rapeseed have been carried out, but predominantly on rapeseed used as fuel, and as rapeseed methyl ester. There are several studies on other derived products, on rape oil, but far fewer than on rapeseed methyl ester.

In Norway, Bonesmo et al. [22] studied the carbon footprint of several crops, including oilseeds, and found a total of 1.27 kg CO_2-eq/kg DM. One study [23] found GHG emission results from a number of research projects ranging from 0.20 to 5.9 kg CO_2-eq/kg dried rapeseed (9% water). The average of these results was 1.21 kg CO_2-eq/kg dried rapeseed, equal to 1.26 kg CO_2-eq/kg DM.

Few results are given for other indicators, but Mousavi-Avval et al. [24] and Queiros et al. [25] found acidification potential of [24] 23 and [25] g 9.4–14.6 SO_2-eq/kg dried rapeseed and eutrophication potential of [24] 18 and [25] 2.7–14.7 g PO_4-eq/kg dried rapeseed. Queiros et al. [25] studied winter rapeseed grown in France, Germany and Poland, while Mousavi-Avval [24] looked at winter rapeseed in Iran.

The primary aim of this study was to investigate the environmental impact of oilseeds as a protein source, employing press cake from cold pressing as an example. The study also aimed to quantify the impact of rapeseed oil from the same process, and the environmental impact of rapeseed and turnip rapeseed, which in Norway is primarily used as animal feed.

This project is unique in that there are very few studies on the environmental impact of turnip rapeseed and products derived from cold pressing of rapeseed.

1.3. Research Gaps

The following research gaps have been identified:

1. Environmental assessment of rapeseed grown in a northern climate zone, covering more than carbon footprint.
2. Environmental assessment of turnip rapeseed.
3. Environmental assessment of rapeseed press cake from cold pressing.
4. Comparison of the environmental impact of rapeseed press cake with other food protein sources.

1.4. Research Approach

The following research questions are posed in this study:

1. What is the total environmental impact of rapeseed (spring and winter varieties), spring turnip rapeseed, rape oil and rape press cake produced in Norway?
2. What are the environmental hotspots relating to these products?
3. What possibilities exist for the reduction of environmental impact from these products?
4. How great is the environmental impact of rapeseed press cake as a protein source in food compared with other prominent protein sources on the Norwegian market?

In addition to calculations based on kg product and kg protein, the comparison (in point 4) was also made based on nutrient content.

2. Materials and Methods

The principal method employed in this study was life cycle assessment based on ISO14040–44 [26,27]. LCA is known as a methodology for estimating the environmental impact of a product or a service throughout the value chain from raw material extraction to production, use and waste treatment.

2.1. Goal and Scope

The principal goal of the study is to calculate the environmental impact of rapeseed press cake, from rapeseed produced in Norway, as a possible protein source in food products, and to compare that with the impact of other protein sources. Other objectives include calculating the environmental impact of Norwegian grown rapeseed and turnip rapeseed, as well as rape oil from cold pressing.

Research questions are presented in Section 1.4.

In this article the following products are analysed:

1. winter rapeseed (WR),
2. spring rapeseed (SR),
3. spring turnip rapeseed (STR),
4. rapeseed oil, made from winter and spring rapeseed,
5. rapeseed press cake, made from winter and spring rapeseed.

2.1.1. Functional Unit

The functional units defined in this study are as follows:

1. 1 kg dried oilseed (winter and spring rapeseed, spring turnip rapeseed) after drying is completed, with 8% moisture.
2. 1 kg rapeseed oil after pressing.
3. 1 kg rapeseed press cake after pressing.
4. The amount of rapeseed press cake containing 1 kg protein.

2.1.2. System Boundary

This study includes several products and utilises two different system boundaries:

System 1 includes the growing and drying of oilseeds, and System 2 includes the growing, drying and cold pressing of rapeseed to produce rape oil and rape press cake.

The system boundaries of the products in this study are illustrated in Figure 1. In general, the systems studied are Cradle-to-Gate systems, which do not include the production, distribution and consumption of the food products from these raw materials. The reason for this being that the wide range of processing alternatives make it difficult to select just one. In addition, this is still currently a field for development and little data is available.

Another factor is that the number of vegetarian food products is sharply increasing, and the industry is looking for alternatives to soy as a raw material.

Generally, there is a preference for rapeseed over turnip rapeseed for processing to oil, thus it is assumed that all turnip rapeseed is used for animal feed.

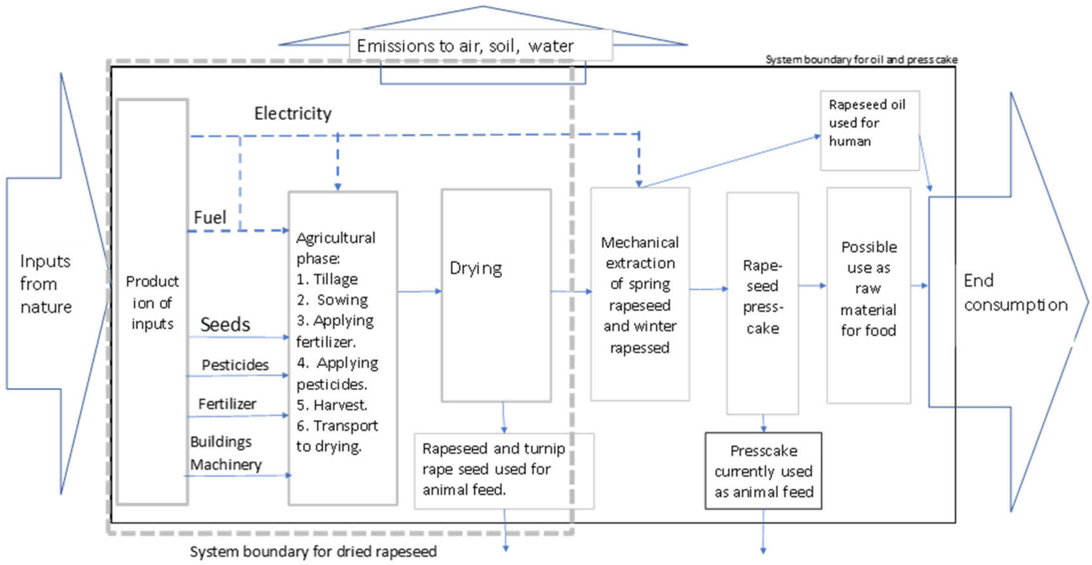

Figure 1. System boundaries. The geographical boundary of the study is Norway. The technological scope is conventional production and the processing is cold pressing without subsequent solvent extraction. The time-related scope is one cycle of production from preparation of the soil, which can take place in the previous season, until the oilseeds are harvested. This winter rapeseed cycle can take more than one year, as field work and seeding often take place in early August and harvesting the following August.

2.1.3. Allocation

There are two primary multiple output processes in the studied system. The agricultural stage produces rapeseeds, plant residues and the benefit of increased crop yields in the subsequent crop, following the cultivation of the oilseeds. Plant residues from rapeseed cultivation are, in Norway, left on the field and ploughed into the ground, and there is therefore no allocation made to them. The benefit for the next crop lies outside the temporal boundary of the rapeseed production system and is thus not included in the LCA.

The rapeseed processing stage produces oil and press cake. According to ISO 14,044 [27], allocation should be avoided by splitting processes, but as all processes in growing and processing are common, this is not possible. The next choice [ibid] is to employ system expansion, either by a multifunctional unit or by substitution. A multifunctional unit is not an option here since the aim is to study the products rape press cake and rape oil separately. Substitution is also not feasible as it is impossible to identify one single product that could represent either of the products. The third option [ibid], the use of a physical factor for the allocation, is possible, but since there is a considerable difference in the value of the products, and thus an incentive to maximise the output of oil, mass allocation has been found to be a poor choice. Energy allocation was not applied. Energy content is an important parameter for animal feeds, but it is assumed as having little importance for humans. The remaining choice is economic allocation.

Economic allocation is employed in partitioning the processing and upstream impacts of the two products.

2.1.4. Data Quality Assessment

Crop yields can vary greatly from year to year, as a result of weather, pests, varieties grown and other external factors. In order to maximise representativity, average data over 5 years were collected and quality checked by agricultural advisors and experts within the field of agricultural research.

Data on farming were collected directly from farmers. The farmers responding (107) to the survey represent 82% of the total area in Norway used for oilseed production.

2.2. Modelling Assumptions

2.2.1. Land Use (LU) and Land Use Change (LUC)

Virtually all agricultural soil in Norway has been cultivated for more than 30 years. Some areas are still being converted to agricultural soil from forest and marshes every year, but these areas are generally not utilised for oilseed production. Consequently, no effect of land use change was included in the study. Indirect land use change was not included. The reason for this being that it is an attributional study, as well as the fact that no direct causal link has been established between land use in other areas internationally and oilseed areas in Norway.

Effects of Land Use include the effects of changes in soil management and the effect of agriculture on soil, when no changes are made either to soil management or crop. In this study, the effect of Soil Carbon Change has been included using results from the ICBM two chamber method.

The area devoted to oilseeds has not expanded in recent years, nor have changes been made to soil management practices.

This study has therefore not encompassed any Land Use Change, but changes in Soil Carbon have been included.

2.2.2. Direct Emissions

Direct field emissions include CO_2, NH_3, NOx and N_2O into air and P and N compounds into water, as nitrate and phosphate. Calculation of emissions of NH3, NOx and N_2O from soil have been carried out according to IPCC; Tier 1 [28]. In this procedure, 10% of added fertiliser N is converted to NH_3 and NOx, without specifying the share of each gas. In this study, the default amount of NOx emitted from soil was used, representing 0.7% of total N [29]. This indicates that the NH3 emission constitutes 9.3% of total fertiliser N added.

The Agricultural Environmental Monitoring Program (JOVA) monitors runoff of nutrients annually on a few selected farms in Norway. The Skuterud catchment is assumed to be the most representative for rapeseed growing in Norway. Rapeseed is grown there every year. The area of rapeseed varies from year to year, but in 2012, spring rapeseed was farmed on 14% of the total area of the catchment. On the basis of the latest report [30], leakage rates of 48 kg nitrogen compounds per ha, as N, and 2.5 kg phosphorus compounds per ha, as P, were assumed.

During cultivation of arable crops, the amount of soil organic matter (SOM) is reduced [31]. During this process, soil organic carbon (SOC) is released as CO_2 and some of the N (in the SOM) is emitted as N_2O. The ICBM model [32] has been developed using long-term monitoring data from Norwegian agricultural areas. In this study, results from a calculation made by Bonesmo et al. [22] were used. The authors of that study employed the ICBM model to calculate emissions of CO_2 from SOC. When SOC is reduced, some N-containing compounds are also released from the soil. A ration of 10:1 of C: N was assumed. The IPCC Tier methodology [28] was used to calculate N_2O emissions from this released amount (Fsom in IPCC terminology).

2.2.3. Alternative FUs

As mentioned in Chapter 2.1.1, protein is used as a basis for one of the functional units. The remaining FUs are based on weight, which do not reflect the function of the product. In order to remediate this, an alternative functional unit has been proposed. This is a unit inspired by the Nutrient Rich Foods 9.3 (NRF9.3) developed by Drewnowsky [33]. The index was expanded by three nutrients which are lacking in the Norwegian diet, according to the Norkost 3 [13] study, among others. These are Vitamin D, iodine and folate.

The result was the NRF12.3 index, as well as another version where the nutrient content was not normalised to 100 kcal of the product, but to 100 g of the product. The latter version is here referred to as NRF12.3mass.

2.3. Life Cycle Inventory (LCI)

The studied system comprises the agricultural stage, drying of harvested seeds and, for rape oil/rape meal, also transport to processing and the processing itself.

2.3.1. Agriculture

The data on which this study is based, was taken from a survey among farmers in 2019.

The rate of response corresponds with 82% of the area, or 2788 ha of a total of 3400 ha [34] for which subsidies were paid. It is assumed that farmers apply for subsidy for the entire area where oilseeds are grown. Respondents were asked to choose one of the three species (the one they regarded as being most important) as the basis for their answers, so that the rate of response could not be 100%. The results were then evaluated by agronomical advisors and scientists. The resulting Life Cycle Inventory is given in Table 1.

2.3.2. Processing

Most rapeseed in Norway is fed directly to animals, but approximately 13% [8] is pressed to produce rape oil and rapeseed press cake. This is achieved by cold pressing, with no subsequent hexane extraction. Inventory data is given in Table 2. In contrast, the most common means of producing rape oil in Europe is via pressing and solvent extraction. The end products of this process are rape oil and rape meal. In this study, results are presented for rape press cake and rape oil from cold pressing.

Table 2. Life Cycle Inventory for the agricultural stage of rapeseed and turnip rapeseed.

Input/Output	Unit	Spring Rapeseed	Winter Rapeseed	Spring Turnip Rapeseed
N fertiliser	kg N/ha	141	178	135
P fertiliser	kg P/ha	19	25	20
K fertiliser	kg K/ha	53	70	45
Runoff, total N	kg N/ha	16	16	16
Runoff, total P	kg P/ha	2.5	2.5	2.5
Fuel for cultivation (diesel)	liters/ha	97	97	97
Insecticides	g/ha	144	48	144
Herbicides	g/ha	82.5	165	82.5
Fungicides	g/ha	150	80	150
Lime	kg/ha	430	450	470
Seed	kg/ha	7.5	3.3	9.4
Yield	kg/ha	2620	3500	1772
Electicity for drying	Wh/kg	65.9		
Diesel for drying	Wh/kg	43.2		
Propane for drying	Wh/kg	5.36		
Biofuel for drying	Wh/kg	13.5		
Light fuel oil for drying	Wh/kg	3.8		

Turnip rapeseed is predominantly used for animal feed in Norway, because the oil content is lower than that of rapeseed [8]. This species was therefore not included in the calculations of impact from rape oil and rape meal.

Data used for calculation allocation factors are given in Table 3. For the allocation, published world market prices were used [35], because of a lack of data from the Norwegian rape oil producer. The allocation factors were based both on these prices and the yields reported by the Norwegian producer.

Table 3. Data for cold pressing of rapeseed.

Cold Pressing	Amount Dried Seeds Pressed	Amount Oil	Amount Press Cake	Source
Mass (g)	500	100	400	Processing plant
Allocation factor		51.5	48.5	van Zeist et al. (2012)
Energy use for pressing	19.2 kWh electricity/100 kg oil produced			Processing plant

2.4. Life Cycle Impact Assessment (LCIA)

The choice of impact categories for this study was based on the results of a number of LCA with different weighting methods including ILCD 2011 Midpoint+ V1.11/EC-JRC Global, equal weighting, EDIP 2003 V1.07, ReCiPe 2016 Endpoint (H) V1.04/World (2010) H/A, Ecological Scarcity 2013 V1.06/Ecological scarcity 2013 and IMPACT 2002+ V2.15/IMPACT 2002+. The results show that the highest impacts were associated with human health, ecotoxicity, global warming and land use. Eutrophication, resource depletion and particulate matter were also mentioned. In addition to these impacts highlighted by the weighting analyses, it was decided to include water consumption and the consumption of fossil resources. The reason for this is that fossil resources are not renewable and are being rapidly depleted, and that the consumption of water is not sustainable in many parts of the world.

Some of these impacts are not covered in CML, and for that reason it was decided to include results using the ReCiPe method (2016 Midpoint (H), version 1.02) in addition to CML.

The principal LCIA method chosen was CML with the following impact categories: global warming potential, acidification potential, eutrophication potential, abiotic depletion potential, elements and abiotic depletion potential, fossil resources and cumulative energy demand. For cumulative energy demand, Cumulative Energy Demand V1.10 by Ecoinvent was employed.

The following impact assessment methods from ReCiPe (2016 Midpoint (H), version 1.02) were utilised: Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Human carcinogenic toxicity, Human non-carcinogenic toxicity, Land use and Water consumption. The analyses were carried out using the SimaPro 8.5.2.0 software which was used together with the Ecoinvent 3.5 database and Agri-Footprint 4.0.

3. Results

3.1. Potential Environmental Impacts of Dried Oilseeds

Table 4 summarises the total LCA results for dried oilseeds. The weighted average of production was calculated on the basis of the following distribution of amounts harvested in Norway: spring rapeseed (SR) 53.5%, winter rapeseed (WR) 33.2%, spring turnip rapeseed (STR) 12.7% and winter turnip rapeseed (WTR) 0.6%. This was calculated from the distribution of production areas for the last three growing seasons, based on data from seed sales of the companies FK Agri and Strand Unikorn and average yields (Table 1). In the calculations, the WTR is ignored because of the small share of production.

In general, WR has the smallest impact, while STR has the highest, with SR being in between.

The weighted values are for many indicators close to those of spring rapeseed, which can thus be said to be the average oilseed cultivated in Norway, in terms of environmental impact.

The differences in impacts between the three different species lie in the region 40–80, expressed as a percentage of the lowest result (WR) by the highest (STR) result. The indicators Land use, Marine ecotoxicity and those for Eutrophication showed the greatest difference, whereas the smallest difference between these two species was found in Freshwater ecotoxicity, Human carcinogenetic toxicity and water consumption. The other indicators lie in between. The same pattern can be seen when comparing WR to SR.

Table 4. Life Cycle Assessment (LCA) results for dried oilseeds.

CML		SR (per kg)	WR (per kg)	STR (per kg)	Weighted Average (pr kg)
Climate change	kg CO_2 eq	1.24	0.96	1.49	1.19
Acidification	g SO_2 eq	14.1	10.5	17.2	13.5
Eutrophication	g PO_4— eq	16.1	10.7	20.3	15.1
ADP elements	kg Sb eq	4.0×10^{-5}	3.7×10^{-5}	4.4×10^{-5}	3.9×10^{-5}
ADP fossil	MJ LHV	7.3	5.5	8.9	7.0
Cumulative energy demand	MJ	9.1	7.0	11.0	8.8
ReCiPe					
Terrestrial ecotoxicity	kg 1,4-DCB	9.7	6.9	12.0	9.2
Freshwater ecotoxicity	kg 1,4-DCB	0.13	0.09	0.16	0.12
Marine ecotoxicity	kg 1,4-DCB	0.59	0.40	0.75	0.56
Human carcinogenic toxicity	kg 1,4-DCB	0.023	0.020	0.025	0.022
Human non-carcinogenic toxicity	kg 1,4-DCB	1.7	1.3	2.0	1.6
Land use	m2a crop eq	4.5	2.9	5.7	4.2
Water consumption	m^3	0.013	0.011	0.016	0.013

WR = Winter rapeseed, SR = spring rapeseed, STR = spring turnip rapeseed.

3.2. *Environmental Hotspots for Dried Oilseeds*

Figure 2 shows the distribution of GHG emissions in the life cycle of dried spring rapeseed, as well as that of five other indicators. The primary hotspot is the emission of nitrous oxide, directly and indirectly from soil. Of these emissions, mineral fertiliser is the most considerable source. The second highest emissions come from the production and transport of fertilisers used. Diesel and soil carbon loss also make major contributions, whereas the production of seed, lime and pesticides have a low impact in comparison. The impact of CO_2 from lime application, from drying and from the production of machines produces intermediate GHG emissions at a level between buildings and soil carbon loss.

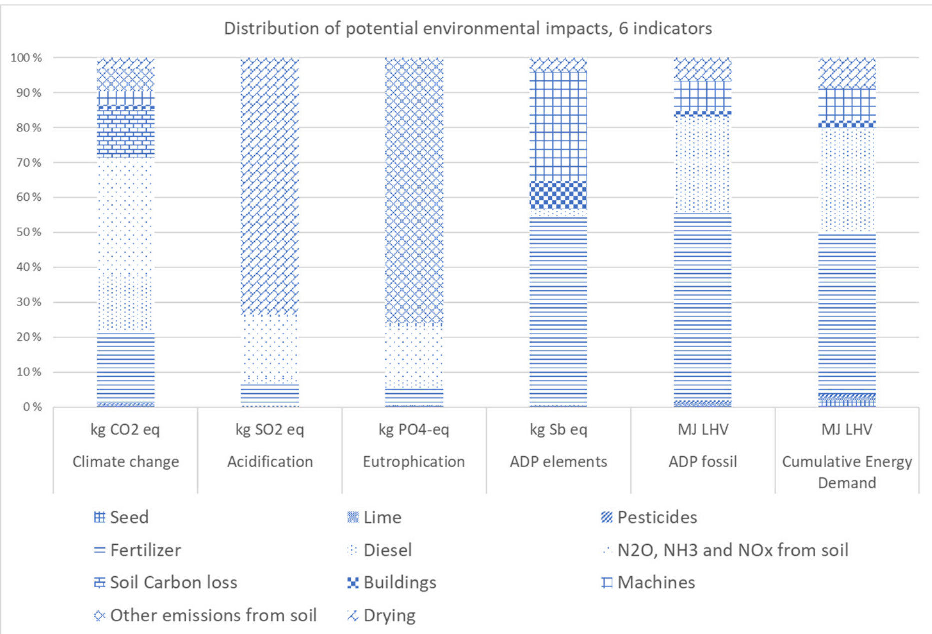

Figure 2. Distribution of potential environmental impacts for growing and drying oilseeds, six CML indicators.

For other impact categories, there are other hotspots. In the case of acidification, for example, the hotspots are drying and emissions to air of NH_3 and NOx from the application of fertilisers.

For eutrophication, the emissions of P and N compounds to water and NH3 to air and water are most important, but production of fertiliser also gives high emissions. The production of machinery and fertiliser plays a major role with regard to the depletion of elements (ADP Elements). These two factors, in addition to fuel use, account for most of the depletion of fossil fuels. For Cumulative Energy Demand (CED), the same hotspots can be seen, with drying in addition.

From ReCiPe, distribution of impacts of some indicators representing toxicity and resource use are shown in Figure 3. Pesticide application dominates all three ecotoxicity indicators, followed by fertiliser production, and to a lesser extent, the production and maintenance of machinery.

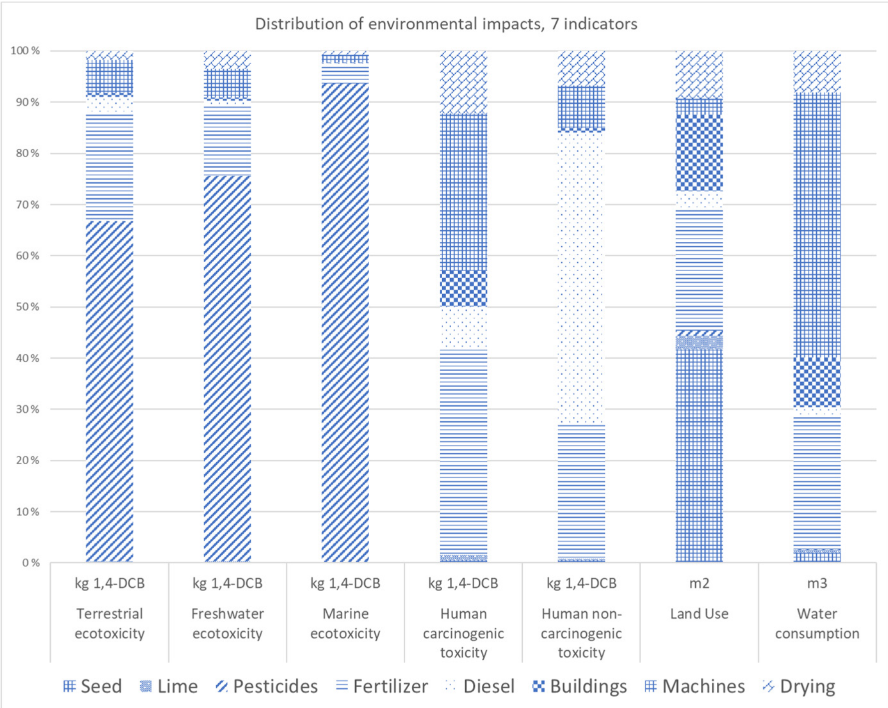

Figure 3. Distribution of environmental impacts of growing and drying oilseeds, eight ReCiPe indicators.

The highest impacts on human toxicity, carcinogenic impacts are created by the production of machinery and fertiliser, followed by drying, fuel production and combustion. For human toxicity, non-cancer related, fuel and fertiliser are most important, followed by machines and drying. Water consumption is shown to be highest for the production of machinery and fertiliser, with lesser contributions from buildings and drying.

3.3. *Environmental Impacts of Rapeseed Processing Products*

In Norway, only rapeseed is used for further processing to rape oil in Norway. The proportion of WR and SR used for making rape oil is not known, hence it is assumed that these raw materials are used in amounts representing their share of national production: 62% SR and 38% WR.

Table 5 gives the results for products from the cold pressing of rapeseed. Rapeseed press cake is also expressed per kg protein in order to enable comparison with other protein sources.

Table 5. LCA results for rapeseed products from cold pressing.

CML	Unit	Rape Oil, per kg	Rapeseed Press Cake, per kg	Rapeseed Press Cake, pr kg Protein
Climate change	kg CO_2 eq	3.0	0.7	2.4
Acidification	g SO_2 eq	33	8	27
Eutrophication	g PO_4— eq	37	9	30
ADP elements	kg Sb eq	1.0×10^{-4}	2.4×10^{-5}	8.2×10^{-5}
ADP fossil	MJ LHV	1.0	0.2	0.8
Cumulative energy demand	MJ	24	6	19
ReCiPe				
Terrestrial ecotoxicity	kg 1,4-DCB	20	5	16
Freshwater ecotoxicity	kg 1,4-DCB	0.23	0.05	0.18
Marine ecotoxicity	kg 1,4-DCB	1.2	0.3	1.0
Human carcinogenic toxicity	kg 1,4-DCB	0.062	0.015	0.050
Human non-carcinogenic toxicity	kg 1,4-DCB	4.0	0.9	3.2
Land use	m2a crop eq	9.2	2.2	7.5
Water consumption	m^3	0.042	0.010	0.034

Rape oil has a higher environmental impact than rape press cake because of the higher price and the fact that economic allocation is applied. The results can be employed when comparing with other sources of protein in feed or food. They can also be used in comparisons with other sources of fats in human diets.

Table 6 shows a comparison between the environmental impact of rapeseed press cake and several other protein sources in food, per kg protein. Even though rapeseed press cake is currently used for animal feed, a comparison is made with food protein sources. This is because this study aims at investigating this product as a possible food protein source. For GHG emissions, eutrophication, acidification, energy consumption and land use, the impact is significantly lower for the rapeseed press cake than for the animal-based protein sources. For GHG emissions from the meat categories, beef from suckler cow has the highest impact and chicken has the lowest. Compared with the other plant-based protein sources, rapeseed press cake has the lowest climate impact per kg protein, slightly lower than faba bean and faba bean concentrate, and significantly lower than peas. Comparing with another study from Norway (results to be published later), rapeseed press cake has a slightly higher climate impact than faba bean concentrates and faba beans, and slightly lower impact than pea protein concentrates and peas. Results given in Table 5 come from studies by Huesala et al. [36] (faba bean concentrate, whey protein, skim milk powder and whole milk powder), Korsaeth and Roer-Hjelkrem [6] (dried faba beans and peas) and Svanes [37] (suckler beef, pork, chicken and cod).

Rape oil from cold pressing is only used for human consumption in Norway. Taking this into consideration, a comparison was made with butter, the primary source of fat in Norwegian diets [13].

Table 6. Comparison of protein sources, per kg protein.

Impacts pr kg Protein	GWP	EP	AP	CED	LU
	kg CO_2-eq/kg	g PO_4-eq/kg	g SO_2-eq/kg	MJ/kg	m^2/kg
Rape seed press cake	2.4	30	27	19	7.5
Faba bean concentrate	2.7				24.0
Faba beans	3.1				
Peas	5.0				
Suckler beef	141				
Pork	16	118	288	71	57
Chicken	13	103	103	93	
Cod	28	34	138	320	
Whey protein	20				
Skim milk powder	23				
Whole milk powder	34.3				

GWP = Global warming potential; EP = Eutrophication potential; AP = Acidification potential; CED = Cumulative Energy Demand; LU = Land Use.

Results are given in Table 7. The calculation of butter impacts was made using an Ecoinvent process but substituting raw milk input with a Norwegian raw milk modelled from data in Roer et al. [6]. The environmental impacts are compared on the basis of energy.

Table 7. Impact of rape oil compared with butter, per MJ gross energy.

	GWP	EP	AP	CED	LU
	kg CO_2-eq/MJ	g PO_4-eq/MJ	g SO_2-eq/MJ	MJ/MJ	m^2/MJ
Butter	2.6	13	18.2	12.2	2.2
Rape oil	0.80	10.0	9.0	6.4	2.5

The climate impact is 221% higher for butter, eutrophication—28% higher, acidification—101% higher, energy demand—92% higher. For land use, however, the opposite is true. Rape oil has an 12% higher impact than butter, but only arable land is included in the comparison.

In a different analysis environmental impact results were balanced with nutrient content.

This was achieved by dividing the results by nutrient density, represented by twelve nutrients and three components, that authorities want to limit the consumption of. Table 8 shows a comparison between rape press cake and four other important protein sources in Norway. In this comparison the GHG emissions per kg are divided by the nutrient content of the foodstuffs, expressed as NRF 12.3 and NFRF 12.3 mass. The comparison shows that the differences between rape press cake and the other protein sources, with the exception of cod, are even higher than when purely comparing impact per kg protein. When comparing rapeseed press cake with cod using NRF12.3 metric, the difference in results (GWP/NRF 12.3) are far smaller, being only a factor of 3. This is largely due to the high energy content of rape press cake and the low energy content of cod. The high content of Vitamin D and iodine and is also of importance, since many Norwegians ingest too little of these nutrients. The results for cod on both indexes are therefore much lower than those of the meat products.

Table 8. Climate gas emissions divided by nutrient density indexes.

	GWP/NRF12.3mass	GWP/NRF12.3
Rape press cake	0.2	0.2
Suckler beef	46.3	1.5
Pork	6.4	1.8
Chicken	6.5	1.5
Cod	2.0	0.6

3.4. Impact at National Level of Replacing Meat and Butter with Rape Press Cake and Oil

The potential volume of rapeseed and turnip rapeseed in Norway has been estimated at 52,000 tonnes yearly [21]. This could potentially be processed by cold pressing to 10,400 tonnes of oil and 41,600 tonnes of press cake [8]. Assuming an average protein content in rapeseed of 21% and a moisture content of 8% [8], the amount of protein from the press cake on the market would be 6028 tonnes. According to the producer of rape oil, 100% of the rapeseed can in fact be deemed suitable for pressing to make press cake [8]. Experts have however commented that a more realistic figure would be somewhere between 80–90%, when the entire production of rapeseed and turnip rape seed in Norway is taken into consideration [16]. In order to make a conservative estimate of the possible effect of expanding oilseed production, it was assumed for this study that 80% of the oilseeds could be used for pressing.

It is difficult to predict which food items would be consumed in smaller amounts as a result of this increased production of oilseeds for use in foods, and for this reason a scenario was developed by the Norwegian Government in the Klimakur project [4] as a basis. In this study red meat consumption was reduced while consumption of seafood, cereals, vegetables, fruits and nuts was increased. The meat consumption showed a reduction of production of suckler beef by 71%, mutton by 38% and pork by 38%. In the scenario in this study, oilseed press cake replaces an equivalent amount (counted as protein) of red meat (see ratios above) and the oil replaces an equivalent amount of butter (counted as energy).

It is assumed that the reduction in meat and butter consumption only results from production in Norway. This assumption is supported by the fact that meat and butter imports into Norway are small.

The total impact of achieving the maximum possible oilseed production and replacing red meat and butter in Norway is given in Table 9. The table contains three indicators relating to emissions and two relating to resource use. The calculations show that a major reduction in climate impact could have been the result, giving a reduction of 655,000 tonnes CO_2-eq/year in total. Significant reductions would also have been noted for other emissions indicators, as well as for the resource indicators.

Table 9. Impact at national level of utilising the total potential for growing oilseeds and substituting meat and butter.

Impact Categories and Units		Decreased Meat Consumption	Increased Production of Press Cake	Decreased Production of Butter	Increased Production of Rape Oil	Total Impact of Substitution
Climate change	tonnes CO_2-eq/year	−654,879	23,519	−65,542	24,974	−671,927
Acidification	tonnes SO_2-eq/year	−5370	264	−439	281	−5264
Eutrophication	tonnes PO_4-eq/year	−1852	293	−318	311	−1567
ADP fossil	GJ/year	−1,415,227	7595	−200,129	8064	−1,599,696
CED	GJ/year	−2,391,187	185,908	−317,809	197,408	−2,325,679

4. Sensitivity Analyses

A sensitivity analysis was conducted to determine the importance of allocation in processing, or, more precisely, the use of mass allocation and varying prices in economic allocation.

Because the prices of rape oil and rape press cake were unknown, there is an uncertainty regarding the allocation factors. In order to test the effect of different allocation factors, another set of allocation factors were calculated, based on World Market Prices [38,39]. These allocation factors are given in Table 10. Rape meal was used as a proxy for rape press cake. The world market price for rape meal relative to rape oil was higher than the price ratio employed by AgriFootprint.

Table 10. Economic allocation factors used in sensitivity analyses.

	AgriFootprint	World Market Prices
Rape oil	52	45
Rape meal	48	55

As a result of using these market prices, there was an increase in impact for rape press cake. For GWP, the increase was 17%, from 0.70 to 0.82 kg CO_2-eq/kg rape press cake. Using mass allocation, the GWP for rape press cake would be 1.17 kg CO_2-eq/kg, an increase of 67%.

It is therefore clear that the effect of allocation on the end result is relatively high.

5. Discussion

5.1. Dried Oilseeds

In a previous study in Norway [22], GHG emissions of 1168 g CO_2-eq pr kg dried rapeseed were calculated to be very close to the GWP result of rapeseed (not turnip rapeseed) in this study, and well within the variation found on Norwegian farms in that [ibid] study.

Looking at results in other countries, Forleo et al. [23] found average GHG emissions of 768 g CO_2-eq pr kg dried rapeseed from six farms in Italy. The same study summarises GHG emissions results from LCA of rapeseed and sunflower seed around the world. The average of the rapeseed results, together with the results from six Italian farms (ibid) was 1210 g CO_2-eq/kg rapeseed. The result in this study is virtually identical to the world average calculated by Bonesmo et al. [22]. When the results from farm 1 in that study were excluded, however, the average was 1014 g CO_2-eq/kg, about 15% less than in this study. Farm 1 represents very small farms in Italy, with small inputs and low yields.

A greater difference in impacts was expected, since yields are low in Norway in comparison with most other countries in Europe. The average yield for 2013–2017 was 1900 kg/ha [18], whereas yields in France and Germany were 3400 and 3810 kg/ha, respectively [40]. The primary reason is that in Norway, a high proportion of spring oilseed is grown, whereas in France and Germany only winter oilseeds are grown.

CO_2 and N_2O emissions originating from soil mineralisation have been included in the Norwegian studies (this study and Bonesmo et al. [22]). In the other studies, soil, mineralisation has apparently not been considered except for Queiros et al. [25] and Brandao et al. [41] The latter study found GHG emissions for rapeseed cultivation in the UK of 1883 g CO_2-eq/kg cradle-to-gate with SOC making up 0.88 kg CO_2-eq. The yield was 2.9 tonnes/ha. The contribution from soil mineralisation in this study was 163 kg CO_2-eq/kg spring rapeseed, when the direct CO_2-emissions and the N_2O emissions from associated N are added together. If these emissions are subtracted, the GWP result for spring rapeseed is 1090 kg CO_2-eq/kg dried product, which is slightly higher than the average mentioned above.

For acidification, the results in this study (10.5–17.2 g SO_2-eq/kg dried oilseed) lie within the range of results reported by Mousavi-Avval et al. [24] and Queiros et al. [25]): 9.4–23.2 g PO4-eq/kg dried oilseed. For eutrophication, the results of this study (10.7–20.3 g PO4-eq/kg dried oilseed) are at the higher end when compared with the results from the two other studies (2.7–18.2 g PO4-eq/kg dried oilseed).

It would thus seem that the environmental impact of oilseed production is, on average, at the same level or slightly higher than that of published studies from other countries.

5.2. Rape Oil and Rape Press Cake

The main production regions for rapeseed in Norway are the same as for faba beans and peas, but if we include turnip rape seed the growing region is more extensive. All these crops can be used in food. It is therefore reasonable to compare the environmental impact of growing and processing these plants. The impact is decidedly higher for rapeseed cultivation, but the consideration that rapeseed can be a source of both fat and protein in the human diet sets it apart from peas and faba beans. The high value of the oil co-product and the application of economic allocation are the reasons for rapeseed press cake having a lower environmental impact than faba beans and peas.

The press cake is currently used in animal feed but utilisation in food would be a more efficient option, as it would eliminate losses by bypassing the animal. Even the most efficient animal or farmed fish production in Norway, such as salmon farming, still has a protein in/protein out factor of about 3 [42] and an energy in feed/energy in edible meat (and milk) factor of about 4 (ibid).

The environmental impact of protein from rape press cake is far less than that of most of the important food protein sources in Norway [37]. The quality of the product must, however, be taken into account. The most important quality parameter is the nutritional content. In this study, the nine nutrients defined by Drewnowsky are supplemented with three nutrients especially important in Norway, so as to make the assessment more relevant to the country. The need to adapt to local conditions has been highlighted in several scientific studies, such as that by Røøs et al. [43].

The results showed that taking nutrition into account does not bridge the gap between animal protein and plant protein products. One exception is the comparison with seafood, where the difference in results of climate impact divided by nutrient density is only a factor of 3 when normalising against energy content. Using nutrient indices based on calorie intake generally gives far lower nutrient scores for energy-rich food raw materials like rapeseed press cake relative to many other protein sources, such as meat, than indices based on mass. The approach of using energy content is questionable because consumers can simply adjust what they eat together with the product. In a meat-based meal, for example, the consumer might include more energy-rich ingredients such as pasta, whereas when eating products based on rapeseed, they might eat less of such ingredients. The results do show, however, that seafood is a much better supplier of some nutrients lacking in the Norwegian diet than rapeseed press cake.

The better environmental sustainability performance as food protein raw material means that there could be a significant environmental benefit in using rapeseed press cake in food products to replace foods such as meat. Of course, the total impacts depend on the volume of oilseeds grown. Table 7 shows that, despite the relatively small area of arable land in Norway and the smaller proportion of that area that can be utilised for growing oilseeds, if the oilseed growing potential were to be exploited in full measure, the impact in Norway could be relatively high

Cold pressing in Norway produces high impacts. The small scale of the production in Norway might be one reason for this, as large-scale production usually makes for higher efficiency.

There are some uncertainties with the results. The chief of these being the assumption that a major proportion could be used in food products that both taste appetising and have other properties, such as being easy to cook, and that this will persuade people to use them instead of meat. The reason for the authors choosing to make this assumption is that commercial rape protein concentrates for food purposes already exist on the market today.

Another uncertainty is that the impacts of processing rape press cake further into a material that can be used in food products are as yet unknown, and thus could not be calculated. Press cake from rapeseed and turnip rapeseed must be processed further before it can be used as raw material for food.

The unpleasant tasting compounds must be removed. Such processing would probably increase the environmental impact of rapeseed protein products. Another factor that must be considered is protein quality. Rapeseed has a lower protein quality than that of foods such as meat. One measure of quality is PDCAAS (protein digestibility corrected amino acid score). Animal proteins often have a PDCAAS of 1 or close to 1 while plant proteins have lower scores. For rapeseed, a value of 0.82 is given [44] and for rapeseed protein isolate a value of 0.86 was found [45]. The protein quality of rapeseed can, however, be improved by adding the amino acids that occur in small amounts or compensate by adding other food ingredients.

Looked at comprehensively, these factors indicate that the comparison with other protein sources might be too favourable for the press cake. On the other hand, the pre-crop effects discussed in Section 5.3 point in the opposite direction because these positive effects of growing rapeseed have not been included.

Even considering the lower protein quality, the difference in environmental impact is still significant.

For the calculation of potential at a national level, the assumption is that 80% of harvested oilseed can be used for food. Even though this is the current reality, it is difficult to know if this would still be the case if the total oilseed production were to be expanded to its full potential. It is also not known if oilseed in the future would be processed by cold pressing, warm pressing or pressing plus solvent extraction. It is known, however, that heat treatment makes it difficult to extract protein in the later processing stages.

Rather than being an accurate account, the results overall should be seen as an indication of the degree of benefit that can be achieved by replacing animal protein and fat products with protein and fat from oilseeds in the Norwegian diet.

The oil gives significantly lower impacts of most indicators per MJ than butter, with the exception of area use (only arable area). The differences are, however, much smaller than the differences between the rapeseed press cake results and the animal protein results, calculated per kg protein. The allocation method and data used in the allocation might partially explain this difference. Both for meat/milk and for press cake/oil, economic allocation is used, but the meat is allocated far higher impacts than milk when compared with oil vs. press cake. Milk contains much more water than the other products, but the same pattern is seen when looking at allocation factors based on dry matter content.

The results of the sensitivity analyses show that the allocation in the processing step is a major source of uncertainty in results for the processing of products. As rape meal, and presumably also rape press cake, will be increasingly used as raw material for food, it is likely that their value will increase and therefore also their environmental impact. Using mass allocation gives considerably higher impacts for the press cake but is not a good alternative since the price difference between the press cake and rape oil is so high.

Another important consideration is the availability of arable land. The arable land area in Norway is very small, only 800,000 ha, or 3% of the total area. 482,000 ha are pasture or grass production areas, and 274,000 ha are used for cereals. Cereals can only be grown on about a third of the arable land area, or 1% of the total land area. Data comes from national statistics [46].

Wild fish is another abundant resource which for the most part is sustainably harvested. This means that the use of proteins from ruminants and wild fish could be more beneficial for national self-sufficiency than expanding plant protein production. Finally, there are several economic factors that should be taken into consideration. One of these is that meat and fish production provides a significant number of jobs in rural areas where there are few other means of employment. Oilseeds, on the other hand, can only be grown in the best soils around the Oslo fjord, where there are already many more job opportunities.

5.3. Benefit of Growing Oilseeds for Subsequent Crops

Growing oilseeds provides a benefit for the subsequent crop. This has been documented in numerous studies. In one study [22], the authors compared a monoculture wheat system with wheat grown following spring rapeseed. They documented increases in crop yield and quality (protein content and grain seed weight). At the same time, a reduction in crop diseases and improvements in soil quality are often observed. In Germany, an increase in wheat yield while keeping N input at the same level as usual was shown by Weiser et al. [47]. The same results have been found in Norway [48].

The mechanisms behind the pre-crop effects are not entirely clear, but Kirkegaard et al. [49] found the following factors: improved soil structure, better weed control and reduced pest pressure. Another study [50] found a high N surplus after oilseeds were grown, which in some cases exceeded 40% of the N applied. In Germany in 2015, regulations recommended a reduction of 10 kg N/ha the year following oilseed cultivation [51]. These were results obtained from experiments, but Abrahamsen [47] confirmed that on commercial farms, wheat yields following the growing of oilseeds were significantly higher than wheat yields from continuous cereal cropping.

The pre-crop benefit, is, however, outside the time boundary of the studied system and is thus allocated to the next year's crop. In some studies, the benefit of a process taking place in one year in a crop rotation is allocated to other crops in the rotation. This is the case with the green manure crop in one study, [52] where the benefit was divided up for all the other crops in the system. The circumstances are, however, different, as green manure is not a product in itself but a fertilisation technique that occurs just once or a few times during the crop rotation, but benefits the entire crop rotation. This could be likened to the application of lime, which gives a benefit for several years but only occurs within the time horizon of one of the crops, in, for example, an eight-year cycle. It is possible to use a scope that includes the whole crop rotation, but this would give a multifunctional unit. Finding the impact of specific products within the rotation could be possible using substitution, but this is a controversial practice and it is not clear what should be employed as the basis for substitution. This ought to include farming in a similar climate, with the soil, cultivar type and all other factors being similar.

5.4. Improvement Possibilities

Several agronomic improvements could potentially increase yield levels and thereby the environmental impact of both spring and winter oilseeds. Optimal plant establishment can create a bottleneck, as oilseeds are a very small seeded crop which is susceptible to soil crusting and incorrect seed placement. Seedlings that are weakened as a result of difficult establishment conditions become more vulnerable to damage from flea beetles. Seedling vigour tests [53] have recently been established in Norway and can be utilised to select high quality seed. Recent findings indicate that early seeding at a shallow depth can reduce the risk of flea beetle damage [54]. Current research is focusing on fertilisation practices that encourage quick seedling emergence as a strategy to reduce flea beetle damage.

Other integrated plant protection (IPM) strategies are necessary for spring rapeseed and turnip rapeseed, because of the large number of insects that can cause severe yield losses. IPM strategies can reduce the use of insecticides, thereby minimising environmental impacts. IPM strategies are also key in avoiding the development of insecticide resistance. Intercropping and catch crops have been tested and are currently being developed for this purpose [55].

Optimal plant density and plant health are necessary for the efficient utilisation of fertiliser. Gains in optimised plant nutrition are possible. Split application of fertiliser, for example, allows producers to more precisely apply the product based on plant requirements, thereby reducing the risk of leaching and denitrification. Sensor technology is becoming more feasible, allowing growers to apply fertiliser according to plant density and nutrient requirements [56].

In addition to agronomic improvements, replacing spring oilseeds with winter rapeseed could potentially significantly improve the environmental performance of oilseed production as a result of higher yields. In addition, winter rapeseed production requires fewer insecticides, thereby improving the environmental performance in relation to, for example, ecotoxicity. The expansion of the winter rapeseed area in Norway is, however, dependent on access to varieties with improved winter hardiness. Varieties which can better tolerate ice encasement, deacclimation events and low temperature stress would reduce the risk of winterkill and thereby the need to re-seed in the spring. A satisfactory plant density in the spring is essential for optimising the use-efficiency of inputs such as fertiliser and pesticides [20]. The risk of having to re-seed should be taken into consideration, along with the environmental/economic impact associated with the extra inputs of time, material and energy.

An extension of the growth season in Norway as a result of climate change is expected to have a considerable impact on cereal and oilseed production [57]. A warmer climate will allow for the use of spring varieties that have a longer growing season requirement as well as higher yield potential. In addition, an extension of the growing season will expand the regions for oilseed production, and a longer autumn period will widen the window for being able to sow winter varieties. Precipitation is also expected to increase in this period, so it will be important to develop time-efficient sowing methods, better able to utilise the window when field work is possible.

5.5. Other Sustainability Impacts

It is important to note that not all sustainability impacts are included in this study. Biodiversity is one example of an environmental impact that has not been considered. Pastures often have a high biodiversity, but this positive effect must be balanced against the negative effect of growing concentrate ingredients. Social effects should also be considered. These effects were outside the scope of this study but ought to be investigated in the future.

6. Conclusions

This study provides an overview of the environmental impact of growing rapeseed and turnip rapeseed in Norway and processing rapeseed into rape oil and a press cake that can potentially be used for food.

In general, the oilseed species can be ranked in decreasing order in terms of their environmental impacts: STR > SR > WR.

The greatest GHG emissions come from N_2O emissions from soil, fuel use, production of fertiliser and soil carbon loss.

The most notable potential for improving the environmental performance of rapeseed and turnip rapeseed in Norway can be achieved by increasing the yield through improved agronomical practices. This includes improving optimal plant establishment, better fertilisation, better suited cultivars and improved plant protection, as well as a shift towards a larger area of winter rapeseed.

Rape press cake is protein-rich and can potentially be used as a protein source in food. The environmental impact of rape press cake is significantly lower than that of other common protein sources in the Norwegian diet, even when balanced against nutrient content.

The amino acid composition and digestibility is favourable compared with peas and faba beans, two other plants with high protein content that can be grown in Norway. Another advantage of using rape press cake in food is that it is a by-product from oil production and its current use as animal feed is inefficient compared with its potential utilisation in food.

The impact of introducing more oilseeds into the Norwegian diet was shown to be relatively major.

Some additional processing is required to turn it into a food ingredient and this will probably increase the environmental impact. Other sustainability impacts such as biodiversity and job creation in rural areas should also be taken into consideration before passing final judgement on the sustainability of oilseed crops as a future food protein source in Norway.

Author Contributions: Conceptualization, E.S., A.K.U. and W.W.; methodology, E.S.; validation, A.K.U. and W.W., formal analysis, E.S.; data collection E.S.; writing—original draft preparation, E.S.; writing—text on agriculture W.W.; review and editing, A.K.U. and W.W.; visualization, E.S.; supervision, W.W.; project administration, A.K.U. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by The Research Council of Norway, grant number 267858.

Acknowledgments: The authors would like to thank oilseeds farmers, farmers associations and the processing company Norsk Matraps for important contributions to this work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Norwegian Government. 2020. Available online: https://www.regjeringen.no/no/tema/klima-og-miljo/innsiktsartikler-klima-miljo/klimaendringer-og-norsk-klimapolitikk/id2636812/ (accessed on 25 March 2020).
2. Norwegian Government. 2019. Available online: https://www.regjeringen.no/no/aktuelt/enighet-om-klimaavtale-mellom-regjeringen-og-jordbruket/id2661309/ (accessed on 25 March 2020).
3. Norwegian Government. *Klimakur 2030: Tiltak og Virkemidler Mot 2030*; Report M-1625; Miljødirektoratet: Trondheim, Norway, 2020. (In Norwegian)
4. Mittenzwei, K.; Walland, F.; Milford, A.B.; Grønlund, A. *Klimakur 2030: Overgang Fra Rødt Kjøtt til Vegetabilsk og Fisk*; NIBIO: Norway, 2020. (In Norwegian)
5. Korsaeth, A.; Roer-Hjelkrem, A.-G. *Livsløpsanalyse (LCA) av Dyrking av Erter og Åkerbønner i Norge*; NIBIO report; NIBIO: Norway, 2016; Volume 2, No 117. (In Norwegian)
6. Roer, A.-G.; Johansen, A.; Bakken, A.K.; Daugstad, K.; Fystro, G.; Strømman, A.H. Environmental impacts of combined milk and meat production in Norway according to a life cycle assessment with expanded system boundaries. *Livest. Sci.* **2013**, *155*, 384–396. [CrossRef]
7. Samsonstuen, S.; Åby, B.A.; Crosson, P.; Beauchemin, K.A.; Bonesmo, H.; Aass, L. Farm scale modelling of greenhouse gas emissions from semi-intensive suckler cow beef production. *Agric. Syst.* **2019**, *176*, 176. [CrossRef]
8. Morten, H.; Norsk, M.; Rape Oil and Press Cake Production Company, Tomter, Norway. Personal Communication, 2020.
9. Tan, S.H.; Mailer, R.J.; Blanchard, C.L.; Agboola, S. Canola Proteins for Human Consumption: Extraction, Profile, and Functional Properties. *J. Food Sci.* **2011**, *76*, R16–R28. [CrossRef] [PubMed]
10. Hald, C.; Dawid, C.; Tressel, R.; Hofmann, T. Kaempferol 3-O-(2‴-O-Sinapoyl-β-sophoroside) Causes the Undesired Bitter Taste of Canola/Rapeseed Protein Isolates. *J. Agric. Food Chem.* **2019**, *67*, 372–378. [CrossRef]
11. CanolaPro. Available online: https://www.dsm.com/corporate/solutions/nutrition-health/canolapro-plant-protein.html (accessed on 30 March 2020).
12. Avena BlackGrain. Available online: https://blackgrain.com/blackgrain/ (accessed on 30 March 2020).
13. Totland, T.H.; Melnæs, B.K.; Lundberg-Hallèn, N.; Helland-Kigen, K.M.; Lund-Blix, N.A.; Myhre, J.B.; Andersen, L.F. *En landsomfattende Kostholdsundersøkelse Blant Men og Kvinner i Norge i Alderen 18–70 år. Norkost 3*; Helsedirektoratet, Oslo: Oslo, Norway, 2012. (In Norwegian)
14. Wolk, A. Potential health hazards of eating red meat. *J. Intern. Med.* **2017**, *281*, 106–122. [CrossRef]
15. Abrahamsen, U. *Sortsforsøk i Vårraps og Vårrybs*; NIBIO: Norway, 2020; Book 6 (1). (In Norwegian)
16. Waalen, W.; Norwegian Institute for Bioeconomy Research, Kapp, Norway. Personal communication, 2020.
17. Abrahamsen, U. Sortsforsøk i vårraps og vårrybs (In Norwegian). *Jord-og Plantekult.* **2019**, *2*, 150–153.
18. Abrahamsen, U.; Brodal, G. *Sortsforsøk i Vårraps*; NIBIO: Norway, 2019; Volume 5, pp. 148–150. (In Norwegian)
19. Waalen, W.; Olsen, A.K.B. *Sorter og Høstgjødsling av Høstraps*; NIBIO: Norway, 2020; Volume 6, pp. 141–143. (In Norwegian)
20. Waalen, W.; Øvergaard, S.; Åssveen, M.; Eltun, R.; Gusta, L. Winter survival of winter rapeseed and winter turnip rapeseed in field trials, as explained by PPLS regression. *Eur. J. Agron.* **2013**, *51*, 81–90. [CrossRef]
21. Abrahamsen, U.; Uhlen, A.K.; Waalen, W.M.; Stabbetorp, H. *Muligheter for Økt Proteinproduksjon på Kornarealene*; NIBIO: Norway, 2019; Volume 5. (In Norwegian)
22. Bonesmo, H.; Skjelvåg, A.O.; Janzen, H.H.; Klakegg, O.; Tveito, O.E. Greenhouse gas emission intensities and economic efficiency in crop production: A systems analysis of 95 farms. *Agric. Syst.* **2012**, *110*, 142–151. [CrossRef]
23. Forleo, M.B.; Palmieri, N.; Suardi, A.; Coaloa, D.; Pari, L. The eco-efficiency of rapeseed and sunflower cultivation in Italy. Joining environmental and economic assessment. *J. Clean. Prod.* **2018**, *172*, 3138–3153. [CrossRef]

24. Mousavi-Avval, S.H.; Rafiee, S.; Sharifi, M.; Hosseinpour, S.; Notarnicola, B.; Tassielli, G.; Renzulli, P.A.; Khanali, M. Use of LCA indicators to assess Iranian rapeseed production systems with different residue management practices. *Ecol. Indic.* **2017**, *80*, 31–39. [CrossRef]
25. Queirós, J.; Malca, J.; Freire, F. Environmental life-cycle assessment of rapeseed produced in Central Europe: Addressing alternative fertilization and management practices. *J. Clean. Prod.* **2015**, *99*, 266–274. [CrossRef]
26. International Standards Organization. *ISO 14040:2006: Environmental Management—Life Cycle Assessment—Principles and Framework*; ISO: Geneva, Switzerland, 2016.
27. International Standards Organization. *ISO 14044:2006—Life Cycle Assessment—Requirements and Guidelines*; ISO: Geneva, Switzerland, 2016.
28. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*; IPCC: Geneva, Switzerland, 2006.
29. EEA. *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016. Technical Guidance to Prepare National Emission Inventories*; EEA Report no 21/2016; European Environment Agency: Copenhagen, Denmark, 2016.
30. Bechmann, M.; Stenrød, M.; Greipsland, I.; Hauken, M.; Deelstra, J.; Eggestad, H.O.; Tveiti, G. *Erosjon og tap av næringsstoffer og plantevernmidler fra jordbruksdominerte nedbørfelt. Sammendragsrapport fra Program for jord- og vannovervåking i landbruket (JOVA) for 1992—2016*; NIBIO Report 3 (71); NIBIO: Norway, 2017. (In Norwegian)
31. Riley, H.; Bakkegard, M. Declines of soil organic matter content under arable cropping in southeast Norway. *Acta Agric. Scand. Sect. Plant Soil Sci.* **2006**, *56*, 217–223. [CrossRef]
32. Andrèn, O.; Kätterer, T. ICBM: The introductory carbon balance model for exploration of soil carbon balances. *Ecol. Appl.* **1997**, *4*, 1226–1236. [CrossRef]
33. Drewnowski, A. The Nutrient Rich Foods Index helps to identify healthy, affordable foods. *Am. J. Clin. Nutr.* **2010**, *91*, 1095S–1101S. [CrossRef]
34. Stabbetorp, H. *Dyrkingsomfang og Avling i Kornproduksjonen.*; NIBIO: Norway, 2019; Book 4 (1). (In Norwegian)
35. Van Zeist, W.J.; Marinussen, M.; Blonk, H.; Broekema, R.; Kool, A.; Ponsioen, T.C. *LCI Data for the Calculation Tool Feedprint for Greenhouse Gas Emissions of Feed Production and Utilization: Dry Milling Industry*; Blonk Consultants: Gouda, The Netherlands, 2012.
36. Heusala, H.; Sinkko, T.; Sözer, N.; Hytönen, E.; Mogensen, L.; Knudsen, M.T.; Heusala, H.; Taija, S.; Nesli, S.; Eemeli, H.; et al. Carbon footprint and land use of oat and faba bean protein concentrates using a life cycle assessment approach. *J. Clean. Prod.* **2020**, *242*, 118376. [CrossRef]
37. Svanes, E. *Life Cycle Assessment of the Existing Protein Consumption in Norway*; Report OR45.19; Ostfold Research: Oslo, Norway, 2019.
38. Index Mundi. Available online: https://www.indexmundi.com/commodities/?commodity=rapeseed-oil (accessed on 12 September 2020).
39. Commodity 3. Available online: https://www.commodity3.com/ (accessed on 12 September 2020).
40. FAOSTAT. Crops. Food and Agriculture Organization of United Nations. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 24 September 2020).
41. Brandão, M.; I Canals, L.M.; Clift, R. Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. *Biomass Bioenergy* **2011**, *35*, 2323–2336. [CrossRef]
42. Bjørkli, J. Protein and Energy Account in Salmon, Chicken, Pig and Lamb]. Master's Thesis, Norwegian University of Life Sciences (UMB), Ås, Norway, 2002.
43. Röös, E.; Karlsson, H.; Witthöft, C.; Sundberg, C. Evaluating the sustainability of diets-combining environmental and nutritional aspects. *Environ. Sci. Policy* **2015**, *47*, 157–166. [CrossRef]
44. Federal Register. True Protein Digestibility Value of Common Foods. *Fed. Regist.* **1993**, *58*, 2193–2195.
45. Fleddermann, M.; Fechner, A.; Rößler, A.; Bähr, M.; Pastor, A.; Liebert, F.; Jahreis, G. Nutritional evaluation of rapeseed protein compared to soy protein for quality, plasma amino acids, and nitrogen balance—A randomized cross-over intervention study in humans. *Clin. Nutr.* **2013**, *32*, 519–526. [CrossRef]
46. National Statistics Agency Agricultural Statistics. Available online: www.ssb.no (accessed on 12 October 2020).
47. Weiser, C.; Fuß, R.; Kage, H.; Flessa, H. Do farmers in Germany exploit the potential yield and nitrogen benefits from preceding oilseed rape in winter wheat cultivation? *Arch. Agron. Soil Sci.* **2018**, *64*, 25–37. [CrossRef]
48. Abrahamsen, U. *Forgrødevirkning av Havre, Oljevekster, Erter og Åkerbønne*; NIBIO: Norway, 2018; Book 4 (1). (In Norwegian)

49. Kirkegaard, J.; Christen, O.; Krupinsky, J.; Layzell, D. Break crop benefits in temperate wheat production. *Field Crop. Res.* **2008**, *107*, 185–195. [CrossRef]
50. Bouchet, A.-S.; Laperche, A.; Bissuel-Belaygue, C.; Snowdon, R.; Nesi, N.; Stahl, A. Nitrogen use efficiency in rapeseed. A review. *Agron. Sustain. Dev.* **2016**, *36*, 38. [CrossRef]
51. BMEL. Verordnungsentwurf Novellierte DüV [Proposal for the New Federal Fertiliser Ordinance]. 2015. Available online: http://www.bmel.de/SharedDocs/Downloads/Service/Rechtsgrundlagen/Entwuerfe/EntwurfDuengeverordnung.html (accessed on 12 October 2020).
52. Knudsen, M.T.; Meyer-Aurich, A.; Olesen, J.E.; Chirinda, N.; Hermansen, J.E. Carbon footprints of crops from organic and conventional arable crop rotations—Using a life cycle assessment approach. *J. Clean. Prod.* **2014**, *64*, 609–618. [CrossRef]
53. Kimen Såvarelaboratoriet AS. Available online: https://www.kimen.no/ (accessed on 26 March 2020).
54. Waalen, W.; Abrahamsen, U. *Jordarbeidingsstrategier og Såmengde ved Etablering av Våroljevekster*; NIBIO: Norway, 2019; Book 5 (1); pp. 151–156. (In Norwegian)
55. Thömming, G.; Solhaug, K.A.; Norli, H.R. Kairomone-assisted trap cropping for protecting spring oilseed rape (brassica Napus) from pollen beetles (Coleoptera: Nitidulidae). *Pest Manag. Sci.* **2020**, *76*, 3253–3263. [CrossRef]
56. YARA. Available online: https://www.yara.no/gjoedsel/hjelpemidler-og-service/n-sensor/ (accessed on 26 March 2020).
57. Seehusen, T.; Waalen, W.; Hoel, B.; Uhlen, A.K.; Persson, T.; Strand, E. *Endret Klima—Effekter og Behov for Tilpasninger i Norsk Kornproduksjon*; NIBIO: Norway, 2016; Volume 2, pp. 14–17. (In Norwegian)