Climate impact of TPV based on peas and faba beans

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Mindful FOOD solution

This note is a response on the request from Ulrich Kern-Hansen the 20th of May to revise a life cycle assessment from the 10th of February 2021 by Danish TVP on the product *Plant Mate*, a plant based textured protein based on organic peas and faba beans.

Table of Contents

Resume

An overview of the results of the notes is given below in figure 1 and figure 2.

Figure 1. Life cycle inventory of TVP

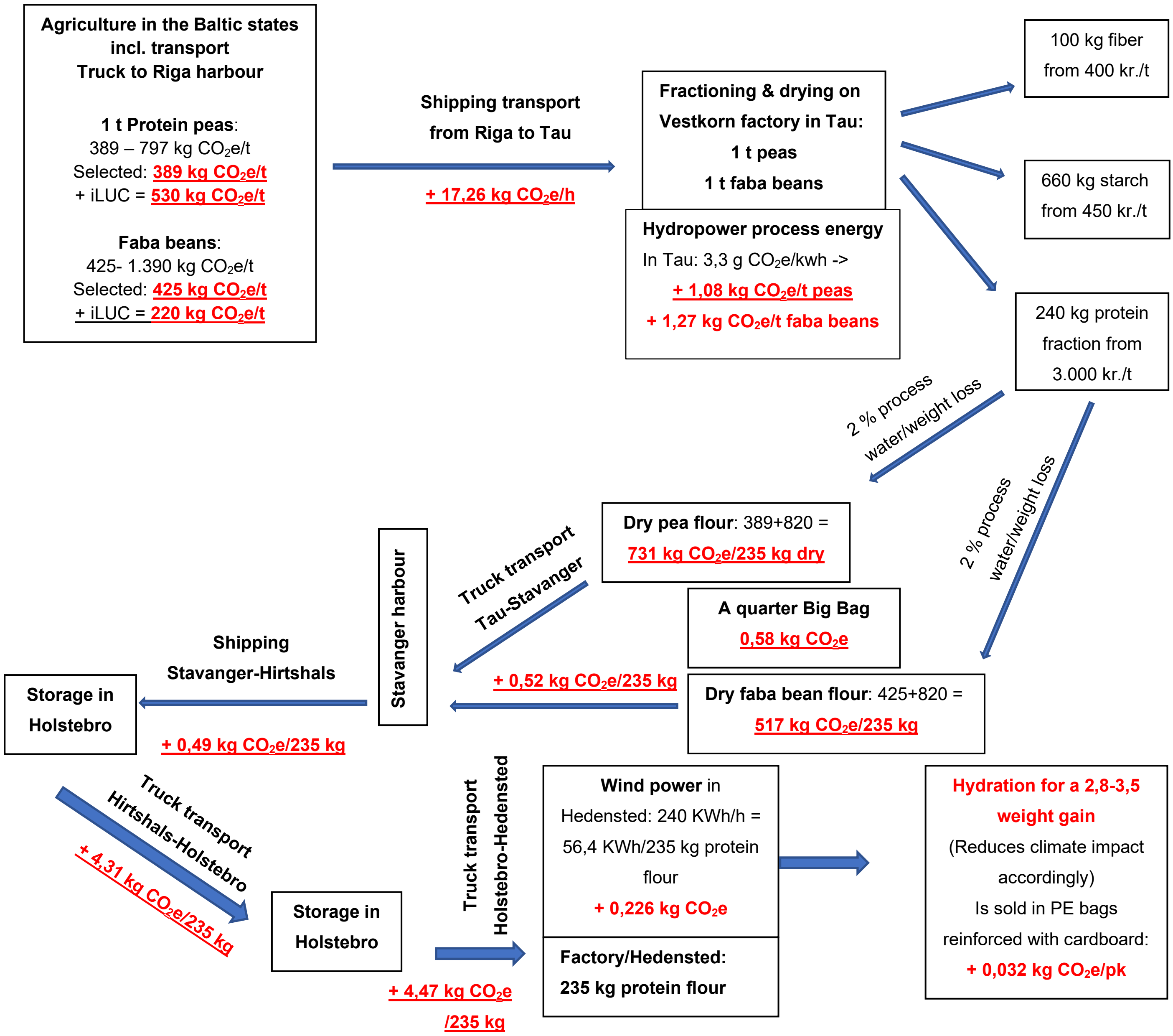
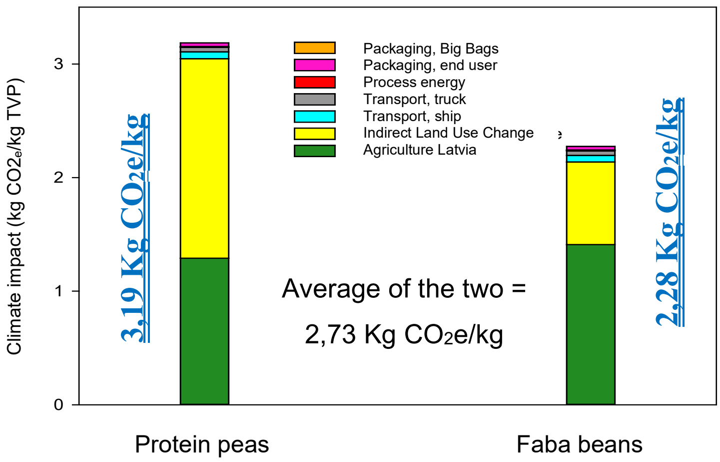


Figure 2. Climate impact of dry TVP granulate

Average climate impact of hydrated TVP:

0,93 Kg CO_2e/kg TVP



1. **Climate impact of plant breeding**

The estimate is that the primary production (activities concerning farming) makes out the biggest climate impact in the production of Textured Vegetable Protein (TVP) from peas and faba beans. Therefore, this factor is important. However, as it is not possible within the framework of this note to make climate impact calculations for the current farms, and, moreover, as production in the following years is to be moved from Latvia to Denmark, data will be gathered from as many reliable and relevant sources as possible. On those grounds, a qualified estimate on the climate impact of the primary production is made. In figure 1, values from Ecoinvent 3 (2020) and Agrifootprint 5 (2020) have been retrieved using the most recent edition of the LCA software, Simapro (2.-0 LCA Consultants 2020a) by means of the latest version of the Stepwise method (2.-0 LCA Consultants 2020b).

Table 1. Data for climate impact of protein peas and faba beans retrieved from Simapro from the largest databases

Ecoinvent 3-database (including infrastructure and long-term emissions)	**Kg. CO_2e/kg vare**
1 kg Protein pea {GLO}|marked for|Conseq, U (Ecoinvent 3 - consequential - unit)	0,41
1 kg Protein pea, Swiss integrated production {GLO}|marked for|Conseq, U (Ecoinvent 3 - consequential - unit)	0,484
1 kg Protein pea, organic {GLO}|marked for|Conseq, U (Ecoinvent 3 - consequential - unit)	0,797
1 kg Fava bean, Swiss integrated production {GLO}|marked for|Conseq, U (Ecoinvent 3 - consequential - unit)	0,568
1 kg Fava bean, organic {GLO}|marked for|Conseq, U (Ecoinvent 3 - consequential - unit)	0,77
Agri-footprint 5-database, peas (including infrastructure and long-term emissions)	
1 kg Peas, dry, market mix, at regional storage/DE Economic (Agri-footprint 5 - economic allocation)	0,486
1 kg Peas, dry, market mix, at regional storage/RER Economic (Agri-footprint 5 - economic allocation)	0,615
1 kg **Peas, dry**, market mix, at regional storage/**NL** Economic (Agri-footprint 5 - economic allocation)	0,634
1 kg Peas, dry, market mix, at regional storage/US Economic (Agri-footprint 5 - economic allocation)	0,776
1 kg Peas, dry, at farm/DK Economic (Agrifootprint 5 – economic allocation) DANMARK!	**0,363**
1 kg Peas, dry, at farm/EE Economic (Agrifootprint 5 – economic allocation) ESTLAND!	0,73
Agri-footprint 5-database, beans (including infrastructure and long-term emissions)	
1 kg Broad beans, market mix, at regional storage/NL Economic (Agri-footprint 5 - economic allocation)	0,601
1 kg Broad Beans, at farm/DE Economic (Agri-footprint 5 - economic allocation)	**0,399**
1 kg Broad Beans, at farm/NL Economic (Agri-footprint 5 - economic allocation)	0,831
1 kg Broad Beans, at farm/FR Economic (Agri-footprint 5 - economic allocation)	1,39
LCA Food database hentet med Simapro 7.3 og Stepwise 1.3, peas (ældre udgaver alle led)	
Grønne ærter, sukkerærter (*pisum sativum*, mangetout), rå, DK (80 % vandindhold – derfor ikke sammenlignelig)	(0,0633)
Gule ærter (pisum sativum), rå, tørre, DK / og ærtemel (1/5,85714 vandindhold)	0,3704

In table 1 above, data is given as '*marked for*' modelled using cLCA (consequence LCA modelling), '*marked mix at regional storage*' and '*at farm*' modelled using aLCA (allocation LCA modelling). Finally, there are a couple of numbers from the older Danish LCA Food database (2007) that complies well with recent data and at the same time points to the importance of the water content when climate impact per kg is to be specified. The climate impact of water is insignificant so that when a product is dried or hydrated, *the climate impact rises and falls in accordance to each weight unit!*

A '*marked for*' dataset gathers all activities with the same product of reference in a specific geographic region – countries, regions or globally. Furthermore, the average transport of this product within the chosen geographical area along with input of the product itself for covering loss in trade and transport is included. In other words, they are consumption mixes of a specific product in a specific geographical region.

In the datasets with '*marked mix at regional storage*', the transport to regional storages from a series of different agricultures (therefore the term 'mix') where the peas and faba beans come from different countries and are transported to a regional storage facility is also included. These values are realistic but not specific to any one country's own production.

Lastly, there is an '*at farm*' dataset that represents the product on the average national plant breeding effort *without transport*. These climate impact numbers will therefore typically be lower than climate impact numbers for '*marked mix*' and '*marked for*' datasets, however, they will likely be more precise. There is a substantial difference in the climate impact of these datasets depending on the country, which we must assume are differences in the plant breeding machinery, the use of excipients, as well as climate and type of soil. For instance, Danish protein peas are attributed a climate impact of 0,73 kg CO_2e/kg – *twice the climate impact as Danish faba beans*! Because we do not know the average distance of transport in Latvia (to Riga) we can only guess at this, since the climate impact of transport over a limited distance means very little (see next section) in comparison to the climate impact of plant breeding in itself. Concerning faba beans, there is neither Danish nor Latvian data in terms of '*at farm*' in the AgriFootprint 5 database. However, here too the country-to-country variation is large as we for instance see in German, Dutch, and French faba beans' climate impact of 0,399 kg CO_2e/kg, 0,831 kg CO_2e/kg, and 1,39 kg CO_2e/kg, respectively. Here, it would make most sense to choose the German numbers in the absence of Latvian and Danish numbers.

Whether choosing modelling in the shape of aLCA (with economic allocation) or cLCA depends on the purpose of the study. aLCA numbers can also employ mass or energy as a base for allocation, but here we are sticking to economic allocation when using aLCA. This is due, among other things, to the process in Norway where peas and beans are fractioned in fibre, starch, and protein fractions that each have a very different economic value.

Concito's rapport 'Klimavenlige madvarer' (Minter, 2019) – mentioned by the requester – contains too diffuse data to make relevant calculations (quoting a Swedish source, Röös 2014: bælgplanter 0,2 – 2,0 kg CO_2e/kg, middelværdi 0,7 kg CO_2e/kg). The 'Store Klimadatabase' ('Big Climate Database') from Concito (2021) has no data on organic peas and faba beans but exclusively an average value on fresh peas sold in Denmark and, as such, no data on faba beans and none for *dried* peas or faba beans. These farming data are therefore not usable in this context.

For this investigation, should we then choose cLCA or aLCA in calculating the climate impact of the product? It all depends on the questions from the manufacturer. Most often, cLCA is the best choice when it comes to comparing products on the global market. The cLCA models environmental impact behind a decision or a suggested alteration in the examined product system (targeting the future) that involves market and economic relations to be taken into account when making a decision. Put in another way, when the market economy is included (Earles and Halog, 2011).

So, in terms of plant breeding which climate numbers should we rely on as the most suitable for this context? Should we choose the same type of modelling for both crops? It is a choice only the manufacturer can make because there is the possibility of choosing to bet more on one crop over the other in terms of economy, climate impact, and probably other things as well.

In this note, climate impact is marked by an *interval* from several numbers in table 1, since '*at farm*' numbers are added in the climate impact of an estimated national transport of 150 km of 0,174 kg CO_2e/t: 0,026 kg CO_2e/kg (see next section).

As is clear from table 1, the climate impact intervals specified in table 1 include both organically and conventionally produced peas and faba beans. There is not a clear-cut connection between organic production versus conventional production and the climate impact of the crops. However, often times the organically produces crops burdens the climate more so than conventionally produced crops (Saxe, 2014), which is supported by data from table 1. In this note, there will be no emphasis on whether protein crops are produced conventionally or organically, this will allow the requester to decide for themselves and put in their own values for the climate impact of plant production.

In addition to the intervals for climate impact of protein peas and faba beans specified in table 1, a *representative value* is selected next by the author as the most realistic estimate from current knowledge. Only a specific LCA for the involved plant breeding efforts can give a completely accurate answer – but this is a much bigger task than what this note seeks to accomplish. Therefore, merely a *representative value* is needed here to plot into the life cycle of figure 1. Values for the intervals of both crops can be calculated if need be.

In terms of protein peas, the climate impact specified as '*at farm*' is selected in Denmark (here chosen instead of Latvia, because henceforth the protein peas are planned to come from Denmark), added in a 150 km average transport with 16-32 t trucks from the plant breeders to Riga (see section on climate impact of freight transport), and we get a value of 0,363 kg CO_2e/kg + 150 km x 0,000174 kg CO_2e/kg km = **0,389 kg CO_2e/kg**. Numbers for Latvia can be calculated if need be.

In terms of faba beans, the '*at farm*' values are selected for Germany added in 150 km of transport: 0,399 kg CO_2e/kg + 150 km x 0,000174 kg CO_2e/kg km = **0,425 kg CO_2e/kg**.

2. Indirect Land Use Change, iLUC

February 1st, Concito published a new database for products sold in Danish supermarkets. Contrary to prior databases (for instance Ecoinvent (2020), which is calculated from the bottom up), Concito's database is a top-down approach using Exiobase (2020), and it focuses on the climate impact of goods sold in Danish stores. The Concito database has neither climate numbers for protein peas nor faba beans from Denmark or any of the Baltic countries but rather contains numbers for raw peas and various beans sorts in fresh weight. Nevertheless, the database divides the climate impact in *farming* + *iLUC* + *processing* + *packaging* + *transport* + *retail*. Among these, only the value of iLUC is useful in this context. LUC = dLUC + iLUC, and dLUC must be assumed to be insignificant.

Here, the values of iLUC from Concito (2021) that typically are 0,12 kg CO_2e/kg fresh peas and 0,05 kg CO_2e/kg fresh beans (Concito 2021) are utilized rather than former selected values (Saxe 2021) from Audsley et al. (2009). In the FRIDA databse (2021), the relation between fresh peas and dried (yellow) peas can be found at 4,44. The iLUC values for fresh legumes are therefore multiplied with this factor to attain iLUC for the dried legumes. iLUC for dried peas is thus considered as 0,53 kg CO_2e/kg and as 0,22 kg CO_2e/kg for dries beans. One should continue to be sceptical of these values as there are many options of iLUC modelling (here we assume to have chosen the most suitable one) and as the conversion of iLUC for fresh produce to iLUC for dried products is a challenge.

3. Climate impact of freight transport

The data for freight transport using bulk carrier and truck is collected using Simapro (2.-0 LCA Colsultants 2020a) and the Stepwise method (2.-0 LCA Consultants 2020b) from the Ecoinvent 3 database (Ecoinvent 2020). The numbers come from consequence modelling, unit process (Conseq, U).

Shipping from Riga harbour to Stavanger harbour (where landing is impossible) consists of 958 nautical miles[1] (1 km = 0,6214 nm) = 1.542 km, to which is added an estimated 13 km extra due to sailing directly to own harbour in Tau. The Ecoinvent database indicates that transport of a relevant sized ocean sailing ship has a climate impact of 0,0111 kg CO_2e/tkm. The impact on the climate of 1 kg peas/faba beans from Riga to Stavanger is therefore 1,555 km x 0,0111 kg CO_2e/tkm = **17,21 kg CO_2e per ton** peas and beans.

The climate impact of *truck transport* depends on the size of the truck rather than the Euro norm level of said truck. It is stated that the cargo transported is 26,4 t (Hirtshals-Holstebro) and 24,4 t (Holstebro-Hedensted). In a geographical delimitation corresponding to the size of Europe (called {RER}), freight transport of 16-42 t Euro norm level 6 trucks has a climate impact of 0,174 kg CO_2e/kg per ton transported km. The transport in Latvia and on to Riga harbour is included in the plant breeding production for the selected '*at farm*' (manually added) and for the other data in table 1 (automatically included in the model).

The *truck transport* in Norway from the factory in Tau to the harbour silo in Stavanger is according to Google Maps 24 km, which means an emission of 0,172 kg CO_2e/tkm x 24 km x (0,235 t protein flour + 0,005 t Big Bag) = 0,972 kg CO_2e/one quarter big bag **protein flour**. However, since the price for transport to and from Norway is asymmetric, since Norway imports more from Denmark than they export, it is possible to choose an economic allocation of transport from Tau to Holstebro. An examination of the prices to/from Norway/Denmark forms the basis for ***a 0,5333 reduction*** of the climate impact in transport from Tau to Holstebro (and not in terms of other routes). The climate impact of Tau-Stavanger therefore ends on **0,518 kg CO_2e/a quarter big bag**.

The shipping transport from Stavanger to Hirtshals in Denmark (truck is led across with a driver or simply a semi-trailer) is 219 nm[3] = 352 km. The climate impact is therefore 0,0111 kg CO_2e/tkm x 352 km x (0,235 t protein flour + 0,0005 t Big Bag) x 0,5333 = **0,49 kg CO_2e/a quarter big bag protein flour**.

The *truck transport* from Hirtshals harbour to the warehouse in Holstebro is according to Google aps 197 km, which means an emission of 0,174 kg CO_2e/tkm x 197 km x (0,235 t protein flour + 0,0005 t Big Bag) x 0,5333 = **8,07 kg CO_2e/a quarter big bag protein flour**.

The *truck transport* from Holstebro to the factory in Hedensted is according to Google Maps 109 km, which means an emission of 109 km x 0,174 kg CO_2e/kg per ton transported km x (0,235 t protein flour + 0,0005 t Big Bag) = **4,47 kg CO_2e/a quarter big bag protein flour**.

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[1] Link til beregning af afstande til havs: http://ports.com/sea-route/#/?a=2905&b=2733&c=Freeport%20of%20Riga,%20Latvia&d=Port%20of%20Stavanger,%20Norway

[1] 1 tkm Transport, freight, sea, transoceanic ship {GLO}|market for|Conseq, U (Ecoinvent 3 - consequential - unit)

4. Norwegian Hydropower

Due to a lack of familiarity with the specific hydropower plant that delivers power to the Norwegian plant, Vestkorn, in Tau near Stavanger, we will assume an average value of **3,3 g CO_2e/kWh** for Norwegian hydropower plants (Raadal, 2020). 96% of all power in Norway in generated by hydropower plants. Their climate impacts come partly from the concrete constructions and the maintenance of them and partly from methane degassing that comes from decomposing organic material in the reservoirs – organic material, which without the flooding in the artificial reservoirs would have decomposed to form CO_2. Methane is a greenhouse gas that is 25 times stronger than CO_2. Furthermore, by establishing large reservoirs it can cause biodiversity to deteriorate along with the living conditions of the locals. The energy consumption for fractioning and drying at the factory in Tau is estimated to be 420,5 kWh/t and 492,3 kWh/t finished protein flour for pea protein and faba bean protein. Therefore, the climate impact is 440,5 kWh/t, 492,3 kWh/t x 3,3 g CO_2e/kWh = 1,388 CO_2e/t peas, 1,625 kg CO_2e/t beans or **1,08 CO_2e/235 kg pea protein fraction and 1,27 CO_2e/235 kg bean protein fraction**.

5. Fractioning and drying in Tau

At the factory in Tau, protein peas and faba beans are dried and fractioned in three fractions: 10% fibres (primarily from legumes) with an estimated market value of 400 kr./100 kg (Henrik Andersen estimated 3-500 kr./100 kg) + 24% protein (Henrik Andersen estimated 23-25%) with an estimated market value of 3.000 kr./100 kg (Henrik Andersen) and 66% starch with an estimated market value of 450 kr./100 kg (Henrik Andersen estimated approximately 70% and 4-500 kr./100 kg) As nothing else has been put forward, it is assumed that these values apply to both protein peas and faba beans.

In financially allocating the climate impact of the protein, we state that the total output of production in Tau is 3.850 kr./t of which the value of the protein is 3.000/3.850% = 88,92% of the value, and through financial allocation, 240 kg protein fraction (24% of 1 t) is therefore attributed to 77,92% of the raw materials' climate impact: 240 kg pea protein fraction have an impact of 0,7792 x (389+530+17,26+1,08) kg CO_2e = 730 kg CO_2e/240 kg pea protein flour. 240 kg bean protein fraction have a climate impact of 0,7792 x (425+220+17,26+1,27) kg CO_2e = 517 kg CO_2e/240 kg pea protein flour. It is informed that the raw material contains 8-10% water while the finished product (flour) contains 6-8% water. There is thus a water loss and therefore a weight loss of approximately 2%. Followingly, the climate impact of the dried flour is corrected to **730 kg CO_2e/<u>235</u> kg pea protein flour** and **517 kg CO_2e/<u>235</u> kg bean protein flour**. This includes the energy consumption for fractioning at the factory in Tau.

6. Big Bags

The typical Big Bag is made from polypropylene (PP, https://www.gleco.dk/gleco-packaging/storsaekke-big-bags). According to Ecoinvent, Norwegian PP has a climate impact of 1,15 kg CO_2e/kg and Danish PP a climate impact of 1,20 kg CO_2e/kg. Assuming the Big Bags used weigh 2 kg (http://www.minibulk.com/en/blog/bid/339710/bulk-bag-economics-102-watch-your-weight) and contain 1 t, it will require an estimated one quarter Big Bag to transport protein flour from 1 t protein peas or faba beans, precisely 235 kg. The climate impact of one quarter Big Bag is therefore 2 kg x 1,15 kg CO_2e/kg x ¼ = **0,58 kg CO_2e/235 kg protein fraction**. For hygienic reasons, it is assumed that Big Bags are not reused when arriving at Hedensted. Incineration gain is not offset as it is estimated to be very low.

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[1] http://ports.com/sea-route/#/?a=2733&b=2996&c=Port%20of%20Stavanger,%20Norway&d=Port%20of%20Hirtshals,%20Denmark

7a. Danish wind power

The climate impact of a new and modern wind turbine is primarily in the production of one – of materials, processing, and production. A large part of the materials in wind turbines are reusable. For instance, it has become possible to reuse the glass fibres from the turbine wings or make use of parts of the material in incinerators. According to Siemens, the reuse minimizes the climate impact in their new wind turbines with 19%. The CO_2-emission from a wind turbine park of 20 Siemens SWT-3.2-113 wind turbines is **4 kg CO_2/kWh** (Viden om vind, 2020).

Certificates for Danish wind power have been purchased with evident information that the power is from new wind turbines. Furthermore, it is informed that 240 kWh/t =56,4 kWh/235 kg is used for granulating the protein flour. The climate impact of this process is therefore 4 g CO_2e/kWh x 56,4 kWh = **0,226 kg CO_2e/235 kg protein fraction**.

7b. Power from the NET as an alternative to wind power

Finding the correct numbers for the climate impact of power from the power grid is no simple task. One distinguishes between environmental declaration and power declaration (Energinet 2019, 2020). The *environmental declaration* is found in what is actually produced, exported, and imported, and the climate impact relates to this. The *power declaration* is found in the purchase and sale of certificates and only accounts for what is physically produced and used in Denmark to the extend that production does not enter into the certificate market (Energinet, 2019). There are still more sustainable energy sources in the Danish power grid.

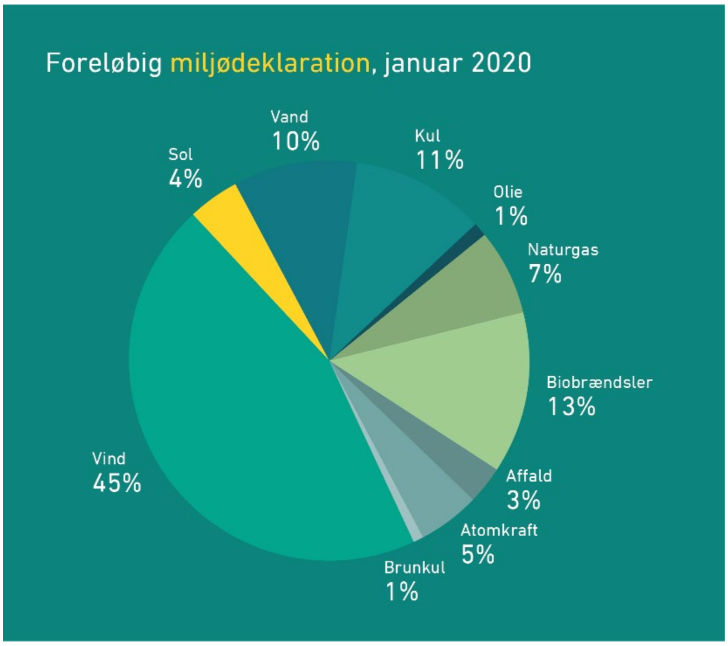

*Figure 3***.** The pie chart shows the composition of an average Danish kilowatt hour from 2019. *The total of Danish power consumption was according to the preliminary environmental declaration in 2019 5,1 million ton CO_2, where in 2010 is was 14,7 million ton.*

Vind = Wind
Sol = Sun
Vand = Water
Kul = Coal
Olie = Oil
Naturgas = Natural Gas
Biobrændsler = Biofuels
Affald = Trash
Atomkraft = Nuclear Power
Brunkul = Brown Coal

Energinet (2019) informs of the development of CO_2e emission from Danish energy consumption from 2010-2019 (figure 4), and on that basis I choose to apply a projection for 2021 that somewhat optimistically is *assumed* to be around **125 g CO_2e/kWh** as there continues to be still more sustainable energy sources.

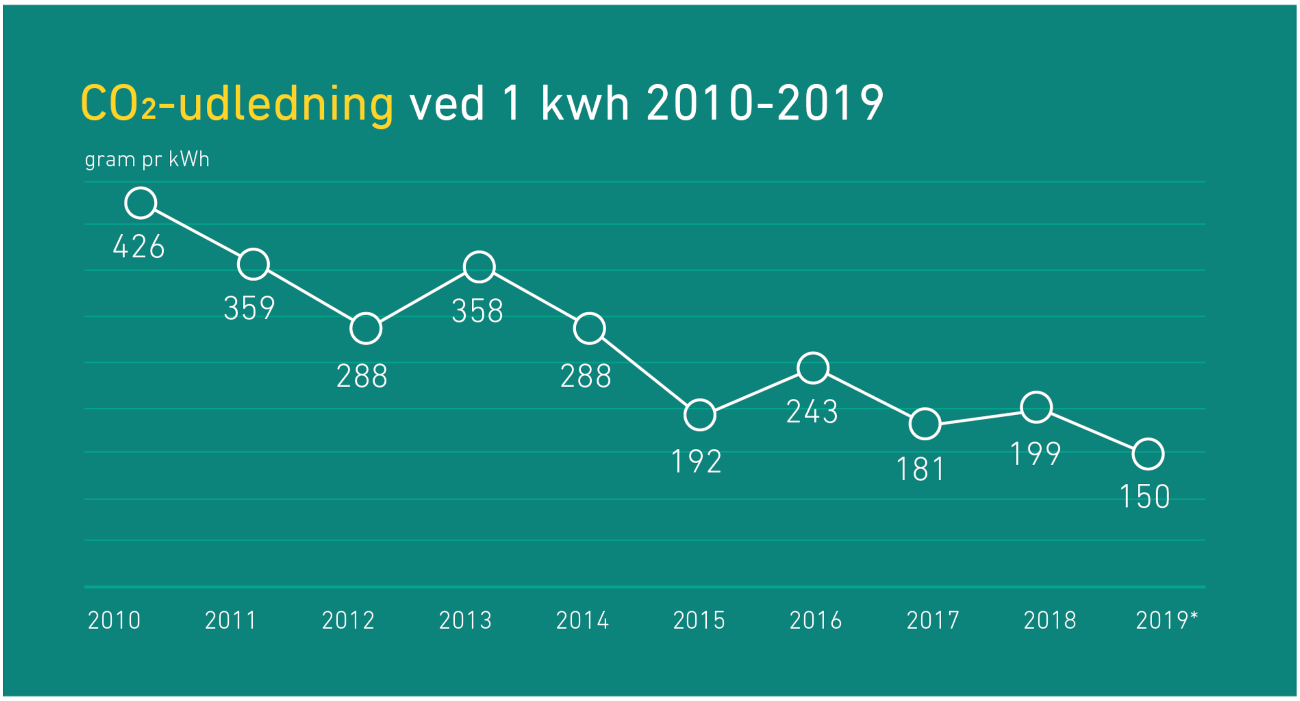

Figure 4. The graph shows CO_2 emission in grans per kWh 2010-2019. The numbers are exclusively distribution loss – for average households, companies, etc., five percent must be added as there is a loss in the power grid before the power reaches the consumers. *The numbers for 2019 are preliminary. (Source: https://energinet.dk/Om-nyheder/Nyheder/2020/01/16/Rekord-lav-CO2udledning-fra-danskernes-elforbrug-i-2019).

If we assume the factory in Hedensted rather than the certified power from the wind turbines that is assumed to emit 4 g CO_2e/kWh, emits 125 g CO_2e/kWh in 2021, the climate impact of the energy consumption of Hedensted's process then increases from 0,226 kg CO_2e/235 kg protein fraction to 125 g CO_2e/kWh x 56,4 kWh/235 kg protein fraction = **7,05 kg CO_2e/235 kg protein fraction**. As such, the share of the total climate impact for the process in Hedensted will **increase from 0,02% to 0,73%** if the power from the wind turbines is replaced for power from the regular power grid.

Therefore, it will mean very little if Plant Mate applies certified wind power in the Hedensted production instead of power from the power grid, and an increase of 0,7 % in climate impact of the already very climate friendly product is quite insignificant. The choice of using certified power from wind turbines must therefore be viewed as an idealistic contribution to the green transition rather than it being conclusive for Plant Mate's total climate impact.

7c. Power from solar cells (pv) as an alternative to wind power

NREL (2012) informs of a climate impact of an average of 46 g CO_2e/kWh from older pv-plants. Muteri (2020) provides an overview of 39 LCA studies of PV-plants and reports of values from 3 to 87 g CO_2e/kWh. Ecoinvent (2020) gives us a climate impact value of 25,5 g CO_2e/kWh in a Belgian low voltage photovoltaic plant. A newer pv-plant can be assumed to have a climate impact of 10-20 CO_2e/kWh depending on where it is located geographically. If that is correct, pv-plants climate impact is somewhere between effective wind power and the average power grid.

8. Sales packaging

Costumers receive the granulates in PE-bags that are assumed to weigh 2 g because they can be quite thin, but when reinforced by cardboard packaging they are assumed to weigh 50 g. Data collected using Simapro shows PE foil's climate impact to be 2,85 kg CO_2e/kg PE, while cardboard has a climate impact of 1,15 kg CO_2e/kg cardboard. The total sales packaging is therefore assumed to impact the climate with 0,063 kg CO_2e/packaging to 2 kg granulate or approximately **0,032 kg CO_2e/packaging to 1 kg granulate**.

9. Hydration by the consumer

At the costumer, the dried pea and bean granulate is hydrated using approximately 180-250 % water before applying it in cooking, meaning *1 kg dried TVP becomes 2,8 to 3,5 kg hydrated product* that can replace meat. As water is assumed to have no climate impact, the final climate impact of *Plant Mate* protein granulate must be divided with 2,8 to 3,5! Unto this the climate impact of the sales packaging above, which is discarded after use, is added. Incineration gain is not set off as this is estimated to be very poor.

10. Overview of results

In this section is an overview of all calculations as illustrated in the resume's figure 2.

Activity	Pea TVP climate impact		Faba beans TVP climate impact	
Only the 77,92% share of protein fraction is stated here	Contribution to climate impact	Climate impact summed up	Contribution to climate impact	Climate impact summed up
Agriculture incl. transport	303 CO_2e/235 kg	303 kg CO_2e/235 kg	331 CO_2e/235 kg	331 CO_2e/235 kg
Land Use Change, LUC	413 CO_2e/235 kg	716 kg CO_2e/235 kg	171 CO_2e/235 kg	503 CO_2e/235 kg
Vessel Riga-Tau	13,4 CO_2e/235 kg	730 kg CO_2e/235 kg	13,4 CO_2e//235 kg	516 kg CO_2e/235 kg
Fractioning/drying, energy	1,08 CO_2e/235 kg	730 kg CO_2e/235 kg	1,27 CO_2e/235 kg	517 kg CO_2e/235 kg
A quarter Big Bag	0,58 kg CO_2e/235 kg	731 kg CO_2e/235 kg	0,58 kg CO_2e/235 kg	518 kg CO_2e/235 kg
Truck Tau-Stavanger	0,52 kg CO_2e	732 kg CO_2e/235 kg	0,52 kg CO_2e	518 kg CO_2e/235 kg
Vessel Stavanger-Hirtshals	0,49 kg CO_2e	732 kg CO_2e/235 kg	0,49 kg CO_2e	519 kg CO_2e/235 kg
Truck Hirtshals-Holstebro	4,31 kg CO_2e	737 kg CO_2e/235 kg	4,31 kg CO_2e	523 kg CO_2e/235 kg
Truck Holstebro-Hedensted	4,47 kg CO_2e	741 kg CO_2e/235 kg	4,47 kg CO_2e	528 kg CO_2e/235 kg
Granulation, wind energy	0,226 kg CO_2e	741,2 kg CO_2e/235 kg	0,226 kg CO_2e	527,9 kg CO_2e/235 kg
The dried granules (grnl.)	No salespackaging	3,154 kg CO_2e/kg grnl.	No salespackaging	2,246 kg CO_2e/kg grnl.
+ Salespackaging	0,032 kg CO_2e	**3,186 CO_2e/kg grnl.**	0,032 kg CO_2e	**2,278 CO_2e/kg grnl.**
Hydrated granules and discarded salespackaging	**0,96 – 1,19 kg CO_2e/kg hydrated granules**		**0,70 – 0,60 kg CO_2e/kg hydrated granules**	

Table 1. Overview of climate impact in the different joints of the life cycle from ground to meat substitute at the consumer, excluded unknown end transport for these. The result of the table is plotted in in figure 2 in the resume.

If *Plant Mate* consists of equal parts pea protein and faba bean protein, sales packaged *Plant Mate* has a climate impact on the mean value of the two intervals at the bottom of table 2: **2,732 kg CO_2e per kg *dried Plant Mate*** *provided that it consists of half and half of each of the two legume plant fractions*. When the product is hydrated, which makes it a product comparable to meat, the climate impact is down to **0,83 – 1,02 kg CO_2e per kg hydrated Plant Mate (on average 0,93 kg CO_2e/kg** – as shown in the resume).

11. Reality check

Conclusively, the climate impact values of protein crops and TVP are compared with the results from other studies of similar products.

The climate impact chosen for protein pea and faba bean from farms in Denmark (for which future deliverances are expected to come from Latvia instead) is in the lower end of the interval shown in table 1. This is fair because there is no transport from a series of different countries to a central storage facility in addition to economically driven import of protein crops from other countries to the same central storage facility. The direct import via Riga and fractioning in Norway supports the choice of 'at farm' values. The Danish values for dried peas (yellow peas) have according to the older Danish database LCA-Food (2007) a climate impact of 0,370 kg CO_2e/kg, which is very close to the value that has been calculated for pea protein in this note. Furthermore, there are numbers for protein peas that are lower, for instance Alberta Peas with a climate impact of 0,183 kg CO_2e/kg 'at farm gate' (Department of Agriculture, 2017). Our World-in-data (2020) show peas climate impact to be 360 g CO_2e/kg. More values are reported by Gonzáles et al (2011) and Knudsen *et al*. (2016).

The climate impact of similar legume protein concentrates and isolates (van Veghel 2018) is well in accordance with the numbers that exist for protein peas and faba beans in this note. Correspondingly, Nette et al. (2016) find that pea protein flour impacts the climate with 0,94 kg CO_2e/kg, a value that also lies very close to the results in this note. Data is from the Ecoinvent database.

12. Conclusions

Plant Mate has a climate impact of **2,732 kg CO_2e per kg *dried Plant Mate*** provided that it consists of half and half of each of the two legume plant fractions. When the product is hydrated, which makes it a product comparable to meat, the climate impact is down to **0,83 – 1,02 kg CO_2e per kg hydrated Plant Mate (on average 0,93 kg CO_2e/kg)**.

Compared to Concito's climate numbers for pork (3,0-3,5 kg CO_2e/kg carvings) and beef (31-152 kg CO_2/kg carvings), *Plant Mate*'s climate impact is 3 to 160 times lower and will help reduce Denmark's total climate impact if animal protein is replaced with this or similar products towards 2030 where the national goal is a 70 % reduction of our climate impact in relation to 1990 – and climate neutrality in 2050.

The most important contributions to TVP's climate impact come from agriculture (green colour in figure 2) and from iLUC (yellow colour in figure 2), such as the cultivation of the legumes' offspring. The applied generic values are deemed responsible and fair to apply here and are well in accordance with the values informed by Veghel (2017). The iLUC values from Concito's 'Store Klimadatabase' now applied are lower than the values applied so far, and therefore the climate impact is considered at a lower value than in the note from February 2021. The choice of agricultural data, iLUC model, and the conversion of iLUC of dried products from fresh products have *absolute crucial impact* on the total result. The choice of an alternative power supplier for the current certified wind turbine power in Hedensted (i.e., the average power grid or pv sollar cells) makes no real difference on the total climate impact of the *Plant Mate* products.

13. Litteratur

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