Carbon Footprint of Danish vegetables: a gate-to-gate assessment on carrots

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Summary

This report is written as part of the project “Fokus på klima- og bæredygtighedsopgørelser samt virkemidler, der understøtter landbrugsbedriftens grønne omstilling”, and it addresses the feasibility of carrying out carbon footprints of vegetables. Carrots are taken as a case example. The results of this study show that it is possible to calculate the climate change impacts of Danish vegetables, using a “gate-to-gate” assessment. Detailed climate change impacts are presented in the reports, along with the results of sensitivity analyses.

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Abbreviations

d.m.: dry matter; IPCC: Intergovernmental Panel on Climate Change; LCA: life cycle assessment

Aim

The aim of this task is to investigate the feasibility of a model that calculates the impacts on climate change coming from the cultivation of vegetables in Denmark, using a gate-to-gate assessment that exclusively focuses on the emissions occurring during the cultivation process. The case study is a specific Danish farm cultivating carrots, for which we not disclose further information.

Materials and methods

This study is a gate-to-gate assessment on the considered farm. In other words, upstream activities do not contribute to the calculated impacts (with a few practical examples: no impacts from the upstream production of fertilizers, liming materials, electricity, diesel and machineries are included). The functional unit is the production of 1 kg vegetable sold to the market. The functional unit therefore represents the net yields, and not the gross yields where part of the yields is “lost” because of not being sold. In other words, it is only the net yields that carry the impacts from the cultivation stage, because these have the potential to reach to end consumer. Further scenarios are provided in the sensitivity analysis (see Sensitivity analysis section). Direct impacts from the cultivation process are calculated based on the emissions factors presented in IPCC 2019 (“2019 Refinement to the 2006 Guidelines”, v.4, Chapter 11).

Data collection

Farm specific activity data were collected to the extent possible. Part of the data (e.g. NPK applications and field size) was retrieved from MarkOnline, after agreement with the farmer, whereas the rest was retrieved via personal communication. Additional data required for the carbon footprint, was based on available literature, expert judgement and assumptions. The list below presents the type of data collected via the two methods.

Farm specific activity data:

- “types” of carrots
- kg N, P, K applied via manure / ha
- kg N, P, K applied via synthetic fertilizers / ha
- kg liming materials / ha
- diesel consumption
- amounts of above-ground residues
- fate of the above-ground residues
- yields, both gross and net

Expert judgement / assumptions:

- dry matter (needed to calculate the amount of N in the crop residues) (12% as in Agrifootprint 5; van Paassen et al. (2019))
- kg liming materials / ha. In the lack of specific farm data, a fixed application of 198 kg CaCO3 (100% active compound) / ha of soil was used, which is an average value from 2015-2021 based on SEGES Innovation P/S (2022))
- diesel consumption was modelled using the values coming from the "Energy model for crop cultivation" used in Agri-footprint 5 (van Paassen et al. 2019)
- parameters describing crop residues as defined in Equation 11.6 in IPCC 2019, v.4, Chapter 11:
    - "slope" and "intercept" (see Table 1)
    - ratio of below-ground root biomass to above-ground shoot biomass for crop T, kg d.m. ha^{-1} (kg d.m. ha-1)$^{-1}$ ($RS_{(T)}$) (see Table 1)
    - N content of above and below ground residues for crop T, kg N (kg dm)$^{-1}$ ($N_{AG(T)}$ and $N_{BG(T)}$) (see Table 1)
    - fraction of above-ground residues of crop T removed annually ($Frac_{Remove(T)}$) (see Table 1), based on the collected farm-specific data.

Life cycle inventory

Farm specific data were used as input to the model to the extent possible, and Table 1 presents the final life cycle inventory data used in the model. The farmer produces three types of carrots: early carrots (June to July; referred to as "tidlige"), autumn carrots (August to December; referred to as "efterår") and late carrots (December to May; referred to as "halmdækket"). In the baseline scenario, it was assumed that the investigated farm does not cultivate carrots on drained peat soils.

The only parameters for which farm specific data were not used were the diesel consumption and amount of crop residue. The farm-specific diesel consumption data was provided as an average consumption per ha of soil (i.e. ~200 L /ha), rather than per kg product. The carrots fields have rather different yields, and it was therefore preferred to use the results of the "Energy model for crop cultivation" model (as presented in Agri-footprint 5) to model diesel consumption in the model, while using the farm specific data to verify the default values. The farmer provided estimates on the amounts of above-ground residues, but not on the amounts of below-ground residues. From an environmental perspective, it is the combined above- and below-ground residues that contributes to N_2O emissions. The farm-specific data was used as an indication to verify the amounts of crop residues estimated via the "slope" and "intercept" IPCC (2019) method (see volume 4, Chapter 11 in "slope" and "intercept" IPCC (2019) method). The parameters for these formulas were retrieved from the US National Inventory Report for 2018 (US EPA, 2018), which provide Tier 1 data for many vegetables (carrots included).

No farm-specific data could be retrieved for liming materials, so national averages were used as input to the model.

The content of N in the carrots was assumed to be as the generic value presented in the IPCC (2019) guidelines, which was considered acceptable considering that carrots' N contents were reported in the range of 0.0044-0.010 kg N / kg d.m., based on the frida.fooddata.dk database (Technical University of Denmark, 2022).

Table 1. Life cycle inventory describing the inputs to the model. [(*) not disclosed for reasons of anonymization]

		tidlige	efterår	halmdækket	source
gross yield	tonne /ha	50-70	80-120	80-120	HortiAdvice (2022)
gross yield (default)	tonne /ha	60	100	100	
net yield	tonne /ha	45-65	70-85	60-85	HortiAdvice (2022)
net yield (default)	tonne /ha	55	77.5	72.5	
net yield : gross yield	-	92%	78%	73%	
fertilizer (mineral)	kg N /ha	(*)	(*)	(*)	HortiAdvice (2022)
manure	kg N /ha	(*)	(*)	(*)	HortiAdvice (2022)
diesel	L diesel / tonne	2.9	2.9	2.9	"Energy model for crop cultivation" model (as in Agri-footprint 5)
limestone	CaCO3 (100%) / ha	198	198	198	SEGES Innovation P/S (2022)
d.m.	kg d.m. / kg	0.12	0.12	0.12	as in Agrifootprint 5
$N_{AG(T)}$	kg N / kg d.m.	0.008	0.008	0.008	"Generic value for crops not indicated below", (IPCC 2019, table 11.1A)
$N_{BG(T)}$	kg N / kg d.m.	0.009	0.009	0.009	"Generic value for crops not indicated below", (IPCC 2019, table 11.1A)
$RS_{(T)}$	-	0.15	0.15	0.15	US EPA (2018)
Slope	-	0.46	0.46	0.46	US EPA (2018)
Intercept	-	0.02	0.02	0.02	US EPA (2018)
$Frac_{Remove(T)}$		0	0	0	HortiAdvice (2022)

Sensitivity analysis

Drained peat soils are a source of CO_2, CH_4 and N_2O emissions because of their natural degradation. Not all carrots are cultivated on peatland in Denmark. However, in order to estimate the effect of degrading peatland on the results, a sensitivity analysis was carried out. In the new hypothetical set-up (scenario “S.peat”), it was assumed the surface of peatland reflected national averages between cultivated peatland and cultivated cropland (i.e. ~3.4% in 2020, according to the Danish National Inventories (2021); Nielsen et al. (2021)) and that half of this peatland had a carbon content >12% whereas the other half had a carbon content between 6 and 12%.

The difference between gross and net yields is due to the impossibility to sell the entire amounts to the human consumption market. The remaining fraction is primarily used for feed purposes or sent to anaerobic digestors, as communicated by the farmer. While from a consumer perspective the entire impacts from the cultivation processes should be allocated to the carrots that reach the market, from a farmer perspective it would be interesting to know the effect of allocating these impacts to the gross yields (although these values cannot really be used in practice). A sensitivity analysis allocating the entire cultivation impacts to the gross yields was performed, and presented under Scenario “S.gross”.

The baseline scenario calculated the amounts of crop-residues estimated via the “slope” and “intercept” IPCC (2019) method, using some of the Tier 1 parameters presented the US National Inventory Report for 2018 (US EPA, 2018). A sensitivity analysis aiming to test the effect of choosing a different set of parameters was carried out in scenario “S.semigenRes”. In this scenario, it was chosen to use the generic IPCC (2019) value for “ratio of below-ground root biomass to above-ground shoot biomass” (RS(T)) and the tuber-specific IPCC (2019) values for “slope” and “intercept” (see Table 11.A and Table 11.2 in IPCC (2019)).

Results and discussion

Figure 1 presents the climate change impacts (from this gate-to-gate assessment) per ha of soil and per kg carrots, according to all considered scenarios, while presenting the contribution of the main processes. In the case that no peatland is used to cultivate carrots, the climate change impacts for “tidlige”, “efterår” and “halmdækket” carrots are 1.96, 2.27 and 2.01 tonne CO_{2eq} /ha of soil, respectively. However, as the figure shows, the otherwise potential presence of peatland in the field can have a large effect on the climate change impacts. Note that the effect depends on local conditions (e.g. peatland area and content of organic carbon); the hypothetical peatland conditions assumed in the sensitivity analysis (see methodology section) contributed to an additional 1.27 tonne CO_{2eq} /ha of soil.

In general, the main contributors to the climate change impacts were found to be i) the amounts of N applied on the field (via manure and fertilizer), which affect the amounts of N_2O emitted to the atmosphere, ii) the diesel use, which contributes to CO_2 emissions from its combustion, and iii) the amounts of crop-residues, which also affect the amounts of N_2O emitted to the atmosphere.

The “gate-to-gate” climate change impacts per kg carrots in the baseline scenario without peatland cultivation for “tidlige”, “efterår” and “halmdækket” carrots are 35.5, 29.3 and 27.7 kg CO_{2eq} /tonne net yield, respectively. The potential presence of peat soil in the cultivated field can have a large effect on the results: the hypothetical peatland conditions assumed in the sensitivity analysis (see methodology section) showed an increase of ~60% from the aforementioned impacts expressed per tonne net yield.

Scenarios “S.base” and “S.semigenRes” differ on the amounts of crop-residues, and Table 2 presents the amounts of crop residue calculated according to described methods (see methodology section), compared with the estimates provided by the farmer. The results show that the farmer’s data for above-ground residues is between the values calculated for scenarios “S.base” and “S.semigenRes”, suggesting that the farm-specific emissions from crop residues may be in between the considered scenarios. However, this consideration cannot be proven: the amounts of below-ground residues in the considered farm are unknown. Scenario “S.base” is based on Tier 1 parameters that are carrot-specific, although they are not specific for Denmark. In the lack of field specific data describing the amounts below-ground residues, Tier 2 approaches cannot be applied. In this study, the approach used in scenario “S.base” is considered to be more accurate than the arbitrary selection of parameters from Table 11.A and Table 11.2 in IPCC (2019) that aim to match carrots conditions. The quantitative effect of considering different amounts of crop-residues can be seen in Figure 1b and Figure 1d.

The results from Scenario “S.gross”, i.e . the scenario where the carbon footprint is expressed as kg CO_{2eq} /tonne gross yield, are (obviously) lower than the baseline scenario (S.base). The difference in the “gate-to-gate” climate change impacts between the two scenarios is more pronounced in the case of “halmdækket” and “efterår” carrots, because the ratio between net yield and gross yield (see Table 1) is smaller.

Table 2. Amounts of above- and below-ground residues calculated for scenarios “S.base” and “S. semigenRes”, compared with the estimates provided by the farmer.

	S.base		**S.semigenRes**		**Farm-specific**	
	"tidlige"	"efterår" and "halmdæk"	"tidlige"	"efterår" and "halmdæk"	"tidlige"	"efterår" and "halmdæk"
	tonne /ha	tonne /ha	tonne /ha	tonne /ha	tonne /ha	tonne /ha
above-ground residues	28	46	15	19	~22	~30
below-ground residues	13	22	16	26		

Conclusions

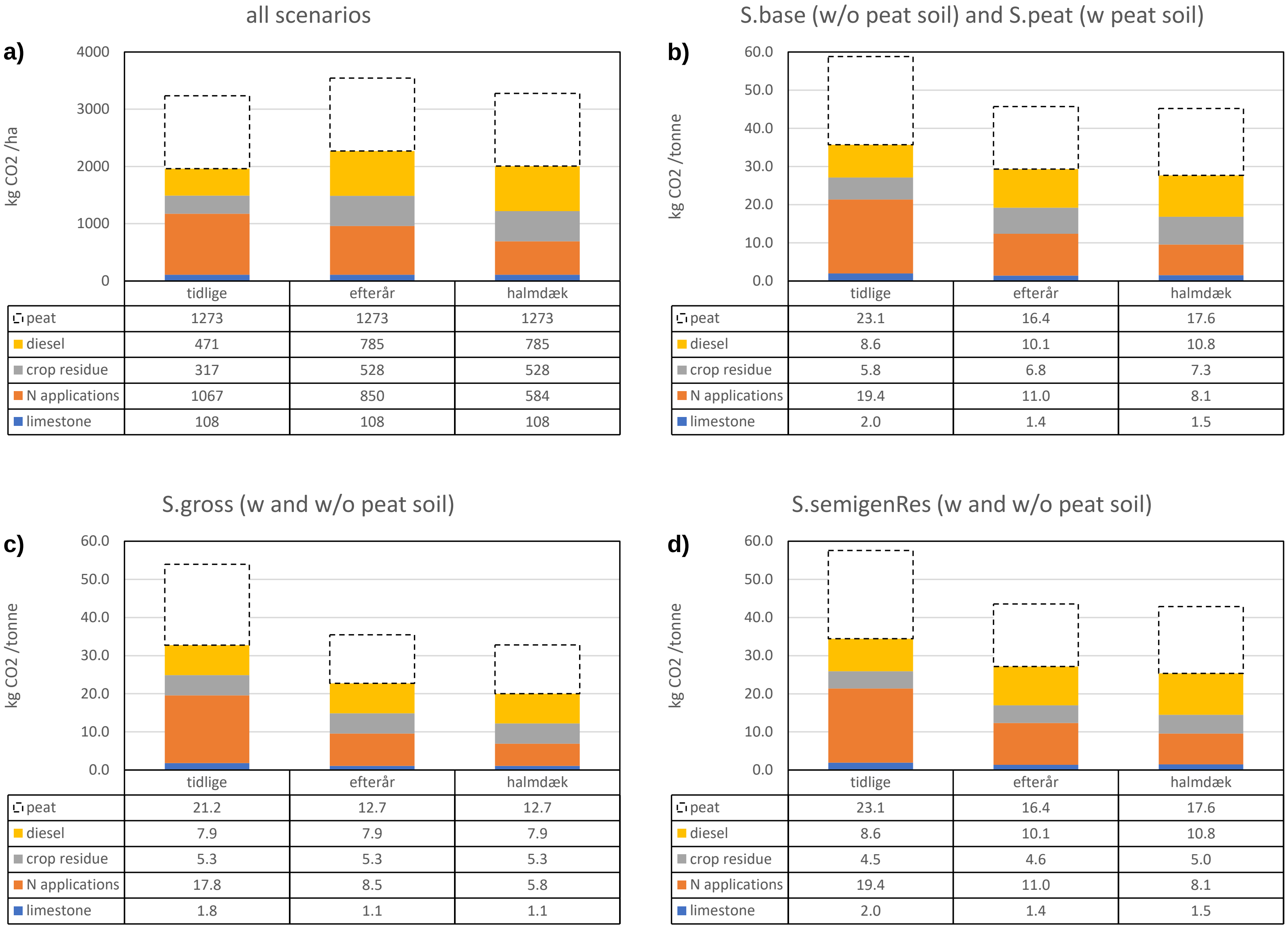
This study demonstrates the feasibility of calculating the carbon footprint of carrots, using a “gate-to-gate” assessment. The calculated climate change impacts assuming no presence of peatland were 35.5, 29.3 and 27.7 kg CO_{2eq} /tonne net yield for “tidlige”, “efterår” and “halmdækket” carrots, respectively. The potential presence of peat soil was shown to have a potentially large effect on the climate change impacts, highlighting the importance of including these emissions as part of the assessment.

In general, the results of this study show that the impacts of Danish vegetables can be assessed. It was however noted that some challenges may arise when estimating the amounts of crop-residues, because of the scarce availability of Tier 1 parameters describing specific vegetables in the IPCC (2019) guideline, and the potentially inaccurate results coming from the use of the generic parameters. In this study, this challenge was overcome by using the Tier 1 parameters presented in the US National Inventory Report (US EPA, 2018), which presents parameters for many vegetables. Further research could focus on generating Danish specific Tier 1 parameters, which would improve the representativeness of Tier 1 carbon footprints.

As mentioned in the methodology, this study represents a “gate-to-gate” assessment, therefore only including the “direct emissions” occurring at the farm. In other words, the presented results do not include impacts from any of the upstream activities (with a few practical examples: no impacts from the upstream production of fertilizers, liming materials, electricity, diesel and machineries have been included).

This is a research study, aiming to assess the feasibility of calculating the carbon footprint of vegetables in the ESGreen tool. The results of this study cannot be used as a product declaration.

Figure 1. Climate change impacts from the “gate-to-gate” assessment in the different scenarios. **a)**: impacts per ha of soil; **b)**: impacts per kg net yields (scenarios “S.base” (without peat soil) and “S.peat” (with peat soil); **c)**: impacts per kg gross yields (scenario “S.gross” (with and without peat soil)); **d)**: impacts per kg net yields, using a different set of parameters to calculate the amounts of crop-residues (scenario “S.semigenRes”). [w/o: without; w: with]



a) all scenarios

	tidlige	efterår	halmdæk
peat	1273	1273	1273
diesel	471	785	785
crop residue	317	528	528
N applications	1067	850	584
limestone	108	108	108

b) S.base (w/o peat soil) and S.peat (w peat soil)

	tidlige	efterår	halmdæk
peat	23.1	16.4	17.6
diesel	8.6	10.1	10.8
crop residue	5.8	6.8	7.3
N applications	19.4	11.0	8.1
limestone	2.0	1.4	1.5

c) S.gross (w and w/o peat soil)

	tidlige	efterår	halmdæk
peat	21.2	12.7	12.7
diesel	7.9	7.9	7.9
crop residue	5.3	5.3	5.3
N applications	17.8	8.5	5.8
limestone	1.8	1.1	1.1

d) S.semigenRes (w and w/o peat soil)

	tidlige	efterår	halmdæk
peat	23.1	16.4	17.6
diesel	8.6	10.1	10.8
crop residue	4.5	4.6	5.0
N applications	19.4	11.0	8.1
limestone	2.0	1.4	1.5

References

HortiAdvice (2022). Personal communication

IPCC (2019). 2019 Refinement to the 2006 Guidelines. https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Nielsen, O.-K., Plejdrup, M.S., Winther, M., Nielsen, M., Gyldenkærne, S., Mikkelsen, M.H., Albrektsen, R., Thomsen, M., Hjelgaard, K., Fauser, P., Bruun, H.G., Johannsen, V.K., Nord-Larsen, T., Vesterdal, L., Stupak, I., Scott-Bentsen, N., Rasmussen, E., Petersen, S.B., Olsen, T. M. & Hansen, M.G. 2021. Denmark's National Inventory Report 2021. Emission Inventories 1990-2019 - Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Aarhus University, DCE – Danish Centre for Environment and Energy, 944 pp. Scientific Report No. 437 http://dce2.au.dk/pub/SR437.pdf

SEGES Innovation P/S (2022). “Årlig statistik for kalkforbruget i landbruget” in Landbrugsinfo

Technical University of Denmark, 2022. Food data (frida.fooddata.dk), version 4.2, 2022, National Food Institute, Technical University of Denmark Food data made available by National Food Institute, Technical University of Denmark (frida.fooddata.dk)

US EPA (2018). United States Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016, Table A-207

van Paassen et al. (2019). Mike van Paassen, Nicolò Braconi, Lody Kuling, Bart Durlinger, Paulina Gual. Agri-footprint 5.0

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