SEGES INNOVATION
DAKOFO Dansk Korn & Foder

RAPPORT

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LCIA of Danish winter wheat and spring barley

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1 INTRODUCTION

Given the widespread use of the GFLI database, this project aims to generate additional datasets with relevance for Denmark. The datasets are calculated according to the GFLI methodology, but they have not been externally reviewed yet (as required by GFLI for approval in their database).

The selected datasets come from a priority list made after a few meetings between SEGES Innovation P/S, DAKOFO and its members, where a few key Danish “raw feed ingredients” and “processed feed ingredients” were shortlisted. This report focuses on the production of the following cereals (“raw feed ingredients”): spring barley from both conventional and organic agriculture, and winter wheat from conventional agriculture.

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2 WORKFLOW

A brief description of the workflow:

- Primary and improved secondary data on spring barley and winter wheat cultivation in Denmark was collected by representatives from SEGES Innovation, using a broad list of data sources, using the GFLI data collection template for cultivations. Data collection followed the steps described in the project deliveries “Datainput til LCA” (in Danish)
- Primary and improved secondary data from SEGES overwrites the “default” data that is available in Agri-footprint 6.3 (AFP6.3), and missing data was filled in using the AFP6.3/GFLI methodology.
- Emission models describing emissions to air, soil and water are compliant with GFLI/AFP6.3 methodology.
- LCIA impacts of spring barley and winter wheat were generated using ReCiPe 2016 Midpoint (H). See more details about the use of Recipe 2016 Midpoint (H) and EF3.1 in the supplementary material (“SM OpenLCA vs SimaPro”).

3 NOTES ON MODELLING

Key modelling parameters that require further specification (other than the well described AFP6.3 and GFLI methodology):

- The model uses AFP6.3 as the background LCI database.

- Crop residue modelling parameters (unless otherwise specified, the data is based on IPCC (2019), Table 11.1A and 11.2):
  - Spring barley
    Slope and intercept: “barley”
    N contents in ABR: based on the NorFor’s database (http://feedstuffs.norfor.info/), i.e. 0.006936 kg $_N$ / kg (instead of the default value of 0.007 kg $_N$ / kg from IPCC)
    N contents in BGR: “barley”
    Ratio of BGB to AGB: “barley”

  - Winter wheat
    Slope and intercept: "winter wheat"
    N contents in ABR: based on the NorFor's database (http://feedstuffs.norfor.info/), i.e. 0.004488 kg $_N$ / kg (instead of the default value of 0.006 kg $_N$ / kg from IPCC)
    N contents in BGR: "winter wheat"
    Ratio of BGB to AGB: "winter wheat"

- FRACremove (fraction of above-ground residues of crop T removed annually for purposes such as feed, bedding and construction)
  - Spring barley, conv.
    FRACremove = 42.7%. The value is calculated based on the ratio between removed straw and yields reported in Danmarksstatistik (codes: HST77 and HALM1; average value between 2018-2022), which is equal to 51.2%.

  - Spring barley, org.
    FRACremove = 42.9%. The value is calculated based on the ratio between removed straw and yields reported in Danmarksstatistik (codes: HST77 and HALM1; average value between 2018-2022), which is equal to 51.4%.

  - Winter wheat
    FRACremove = 36.8%. The value is calculated based on the ratio between removed straw and yields reported in Danmarksstatistik (codes: HST77 and HALM1; average value between 2018-2022), which is equal to 47.8%.

- Heavy metal uptake by the crop based on Delahaye et al. (2003) (see AFP6.3 methodology, Table 3-10):
  - Spring barley: based on "barley"
  - Winter wheat: based on "wheat"

- Manure application in the cultivation of conventional cereals:
  Given the large pig production of pigs in Denmark, pig manure is the main type of manure used in Danish agriculture, except in the cultivation of roughages where cattle manure is preferred. In line with this observation, the current approach in AFP6.3 assumes that Danish pig and poultry manure is equally spread across all Danish crops, except roughages: 7970 kg pig_manure /ha + 153 kg poultry_manure /ha, which based on the composition of manure in AFP6.3 translates into 61.5 kg N /ha, 17.1 kg P /ha and 41.0 kg K /ha.
  Because of the lack of compositional values for heavy metals in Danish manure, this LCA model assumes a composition of pig and poultry manure equal to the ones in AFP6.3. The specific plant nutrient needs during the cultivation stage are achieved by the application of mineral fertilizers.

- Manure application in the cultivation of organic cereals:
  Optimal N applications in organic barley is in the range of 70-80 kg of plant available N /ha. In Denmark, 80% of the N contained in pig and poultry manure is considered to be plant available (https://lbst.dk/landbrug/goedning/husdyrgoedning-og-anden-organisk-goedning#c92849). Assuming an application rate of 75 kg of plant available N /ha, the

calculated amounts of pig and poultry manure, based on compositions used in AFP6.3 and keeping the same ratios used in conventional agriculture, are 12148 kg and 234 kg, respectively.

- Types of fertilizers: calculated as in the GFLI database, i.e. based on IFAstat consumption data for Denmark over the period 2017-2021

- Multifunctionality (cereal grains // straw)
    - economic allocation: based on Danish average prices (2020-2022)
        - Spring barley conv.: 84.3% // 15.7%
        - Spring barley conv.: 85.5% // 14.5%
        - Winter wheat conv.: 85.9% // 14.1%

    - energy allocation: based on the gross caloric value of the NorFor's database (http://feedstuffs.norfor.info/)
        - Spring barley conv.: 67.7% // 32.3%
        - Spring barley conv.: 67.6% // 32.4%
        - Winter wheat conv.: 68.6% // 31.4%

    - mass allocation: based on the ratio between removed straw and yields reported in Danmarksstatistik
        - Spring barley conv.: 66.1% // 33.9%
        - Spring barley conv.: 66.0% // 34.0%
        - Winter wheat conv.: 67.7% // 32.3%

- Start material modelled as in AFP6.3

- Drying:
    - An 2% drying is assumed, i.e. from 17% to 15%, via the use of natural gas and electricity
    - The drying model accounts for the loss of mass (which is a refinement compared with the AFP6.3 modelling)
    - The drying process occurs at the farm

- Direct land use change impacts (on Climate Change) based on LUC Impact Tool (2023) from Blonk Sustainability
    - Spring barley: based on “barley” (dLUC = 0)
    - Winter wheat: based on “wheat” (dLUC = 0)

- Peat soil oxidation:
    - Given the negligible crop-specific correction factor for Denmark (i.e. between 0.9991 – 1.0024), Danish peat soil oxidation values were modelled by using the country-level average value for all crops (i.e. 987 kg CO_2 /ha and 0 kg CH_4 /ha and 0.616 kg N_2O /ha) as calculated in AFP6.3.

- Modelling of conventional and organic spring barley:
    - The two production systems are modelled using the same methodology.

The main differences between the two systems are in the use of pesticides (no pesticides in the organic system) and mineral fertilizers (no mineral fertilizers in the organic system), which are reflected in the model.

The composition of manure is assumed to be the same in both production systems, and equal to the one used in AFP6.3. While this a limitation, because the manure coming from the organic livestock production is expected to contain less heavy metals, i) the cultivation of organic crops in Denmark use a combination of both conventional and organic manure, and ii) there is a lack of compositional data describing Danish manure, both organic and conventional.

4 LCIA RESULTS

Table 1, Table 2 and Table 3 summarize the LCIA results, using characterized impacts from ReCiPe 2016 Midpoint (H), for Danish spring barley, produced via both conventional and organic agriculture, and winter wheat, produced via conventional agriculture, expressed after economic allocation, energy allocation and mass allocation, respectively. Additional impact categories are added to comply with the GFLI format: climate change impacts from land use and land use change, and climate change impacts from peat oxidation.

The aggregated and weighted DQR of the three cereals is 1.30.

TABLE 1. LCIA results, expressed as characterized impacts, for spring barley (conventional and organic) and winter wheat, after **economic allocation** (calculated via ReCiPe 2016 Midpoint (H)).

		1 tonne Spring barley grain conv., dried, at storage {DK}	1 tonne Spring barley grain org., dried, at storage {DK}	1 tonne winter wheat grain conv., dried, at storage {DK}
yields	kg/ha	5801	4051	7701
DM	-	85.0%	85.0%	85.0%
Global warming - Including LUC & Peat	kg CO2 eq	539.6488	594.1121	455.7473
Global warming - Excluding LUC & peat	kg CO2 eq	361.2498	330.6394	319.4063
Global warming - LUC only	kg CO2 eq	0.0665	0.0846	0.0554
Global warming - Peat only	kg CO2 eq	178.3324	263.3880	136.2856
Stratospheric ozone depletion	kg CFC11 eq	0.0092	0.0089	0.0079
Ionizing radiation	kBq Co-60 eq	4.3720	4.4568	3.8220
Ozone formation, Human health	kg NOx eq	1.1686	1.2728	1.0450
Fine particulate matter formation	kg PM2.5 eq	0.7273	1.0232	0.6239
Ozone formation, Terrestrial ecosystems	kg NOx eq	2.3856	2.3286	2.1432
Terrestrial acidification	kg SO2 eq	4.2096	5.7197	3.6109
Freshwater eutrophication	kg P eq	0.3366	0.6046	0.2900
Marine eutrophication	kg N eq	2.3549	2.1369	2.0265
Terrestrial ecotoxicity	kg 1,4-DCB	549.4760	267.0857	738.4653
Freshwater ecotoxicity	kg 1,4-DCB	9.9966	4.1500	22.4261
Marine ecotoxicity	kg 1,4-DCB	7.3376	5.5049	8.3477
Human carcinogenic toxicity	kg 1,4-DCB	5.8855	7.5766	5.0299
Human non-carcinogenic toxicity	kg 1,4-DCB	94.4990	83.0132	91.4274
Land use	m2a crop eq	1520.6158	2245.4200	1162.1605
Mineral resource scarcity	kg Cu eq	0.4635	0.3060	0.4839
Fossil resource scarcity	kg oil eq	40.8071	33.8329	38.5283
Water consumption	m3	0.5585	0.5586	0.4708

TABLE 2. LCIA results, expressed as characterized impacts, for spring barley (conventional and organic) and winter wheat, after **energy allocation** (calculated via ReCiPe 2016 Midpoint (H)).

		1 tonne Spring barley grain conv., dried, at storage {DK}	1 tonne Spring barley grain org., dried, at storage {DK}	1 tonne winter wheat grain conv., dried, at storage {DK}
yields	kg/ha	5801	4051	7701
DM	-	85.0%	85.0%	85.0%
Global warming - Including LUC & Peat	kg CO2 eq	436.0450	472.4528	366.2494
Global warming - Excluding LUC & peat	kg CO2 eq	292.7104	264.0962	257.4398
Global warming - LUC only	kg CO2 eq	0.0543	0.0678	0.0451
Global warming - Peat only	kg CO2 eq	143.2803	208.2887	108.7645
Stratospheric ozone depletion	kg CFC11 eq	0.0074	0.0070	0.0063
Ionizing radiation	kBq Co-60 eq	3.5846	3.6010	3.1241
Ozone formation, Human health	kg NOx eq	0.9413	1.0090	0.8364
Fine particulate matter formation	kg PM2.5 eq	0.5853	0.8102	0.4989
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.9191	1.8441	1.7129
Terrestrial acidification	kg SO2 eq	3.3846	4.5257	2.8842
Freshwater eutrophication	kg P eq	0.2708	0.4785	0.2318
Marine eutrophication	kg N eq	1.8921	1.6899	1.6173
Terrestrial ecotoxicity	kg 1,4-DCB	443.2549	213.1086	591.1716
Freshwater ecotoxicity	kg 1,4-DCB	8.0902	3.3441	17.9575
Marine ecotoxicity	kg 1,4-DCB	5.9742	4.4372	6.7430
Human carcinogenic toxicity	kg 1,4-DCB	4.8625	6.1340	4.1517
Human non-carcinogenic toxicity	kg 1,4-DCB	76.6097	66.3763	73.6685
Land use	m2a crop eq	1221.7827	1775.7459	927.5299
Mineral resource scarcity	kg Cu eq	0.3807	0.2508	0.3947
Fossil resource scarcity	kg oil eq	33.7200	27.7491	31.7074
Water consumption	m3	0.4620	0.4559	0.3894

TABLE 3. LCIA results, expressed as characterized impacts, for spring barley (conventional and organic) and winter wheat, after **physical allocation** (calculated via ReCiPe 2016 Midpoint (H)).

		1 tonne Spring barley grain conv., dried, at storage {DK}	1 tonne Spring barley grain org., dried, at storage {DK}	1 tonne winter wheat grain conv., dried, at storage {DK}
Yields, grains	kg/ha	5801	4051	7701
DM	-	85.0%	85.0%	85.0%
Global warming - Including LUC & Peat	kg CO2 eq	426.3370	461.8784	361.5094
Global warming - Excluding LUC & peat	kg CO2 eq	286.2881	258.3124	254.1579
Global warming - LUC only	kg CO2 eq	0.0531	0.0664	0.0446
Global warming - Peat only	kg CO2 eq	139.9958	203.4996	107.3069
Stratospheric ozone depletion	kg CFC11 eq	0.0072	0.0069	0.0062
Ionizing radiation	kBq Co-60 eq	3.5108	3.5266	3.0872
Ozone formation, Human health	kg NOx eq	0.9200	0.9861	0.8253
Fine particulate matter formation	kg PM2.5 eq	0.5720	0.7917	0.4923
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.8754	1.8020	1.6901
Terrestrial acidification	kg SO2 eq	3.3072	4.4219	2.8457
Freshwater eutrophication	kg P eq	0.2646	0.4675	0.2287
Marine eutrophication	kg N eq	1.8487	1.6510	1.5956
Terrestrial ecotoxicity	kg 1,4-DCB	433.3016	208.4170	583.3705
Freshwater ecotoxicity	kg 1,4-DCB	7.9115	3.2740	17.7208
Marine ecotoxicity	kg 1,4-DCB	5.8464	4.3444	6.6580
Human carcinogenic toxicity	kg 1,4-DCB	4.7667	6.0087	4.1051
Human non-carcinogenic toxicity	kg 1,4-DCB	74.9334	64.9302	72.7279
Land use	m2a crop eq	1193.7810	1734.9227	915.1033
Mineral resource scarcity	kg Cu eq	0.3729	0.2460	0.3899
Fossil resource scarcity	kg oil eq	33.0559	27.2203	31.3461
Water consumption	m3	0.4530	0.4469	0.3851

5 SUPPLEMENTARY MATERIAL

Restricted access (only to reviewers):

- LCI from OpenLCA (JSON-LD file)
  It is a single product system (with all value chain connections) per each feed ingredient. The LCIA results can be calculated as it follows:
  - mass allocation: it can be calculated directly (after the selection of “physical allocation”)
  - economic and energy allocations: they can be calculated following this procedure:
    1. update the revenue cells (mass of the product multiplied by either the price (€/kg) or the energy content (MJ/kg) in the individual companies,
    2. calculate the new allocation factors in the “allocation” tab, using the “calculate from cost/revenue”
    3. close the process,
    4. open the “product system” and calculate the impacts selecting “economic allocation”.
- LCI used in modelling (Microsoft Excel)
- “SM OpenLCA vs SimaPro” (Microsoft Word and Excel)