Supplements 1: Background to climate emissions estimations given in «Public Willingness to Pay for Crowdfunding Local Agricultural Climate Solutions”

By, Sissel Hansen, Ingvar Kvande, Per Espen Stoknes, Olav B. Soldal, Sylvia Weddegjerde

The below sections describe methods and summarises the estimates of the costs and mitigation potential for the four selected climate measures at local agriculture, that the research paper investigates the willingness to pay for. Each of the four measures are calculated in a separate excel spreadsheet in supplemental materials.

For comparability between the measures, all four measures are assumed to be located on, or closely related to, the same farm. This farm is named “Skaun Økomjølk”, or “Skaun Eco-milk” and lies in the middle of Norway, near the city of Trondheim.

Contents:

1. Solar: Estimated costs and mitigation potential of a solar cell plant

Input about the farm Skaun Eco-milk's energy demand and the infrastructure concerning electricity infrastructure and distribution have been collected from the farmer Jørgen Soknes at Skaun Eco-milk and Per Ivar Solstad at the company Solstad Elektro.

The basis for the evaluation is the roof of the barn, the quality of the distribution grid and the size of the main fuse. In many cases, Norwegian farms use Insulated Terra (IT)-based technologies which again in most cases limit the possible size of a plant. A battery pack is not included in this evaluation as it is considered to be too expensive as of today. The main fuse at the farm is 125 A which limits the size of the production to 50 kW in order to not risk voltage-related problems during feed-in at maximum production. If one adds cable and infrastructure losses and the energy demand at the farm we consider that one can add another 10 kW of panels to the plant. Based on this we have used a 60 kWp plant as basis for the calculations.

The roof is oriented towards the south and the roof angle is 25°. This results in an estimated yearly production of 49 700 kWh based on PVGIS calculations (PVGIS 2020). As the energy demand in the barn is relatively limited, e.g. 110 000 kWh per year (average power demand 9-17 kW) and there is no cooling demand that corresponds to sun irradiation, we have estimated that Skaun Eco-milk - in a best case scenario - could utilize 3/5 of the electricity produced by the solar panels.

The carbon footprint of the solar plant is set to be 20 g CO_2/kWh produced (Louwen et al, 2016). The farmer Jørgen and his family owns an electric vehicle (EV). It is however not present at the farm during daytime (commuting vehicle) and CO_2-mitigation effects of having an EV is thus not included. In the future, with further technology development, EVs and electric tractors could utilize the electricity produced by the solar panels.

The mitigation potential and cost presented in Table 1 of the research paper is estimated using European grid mix in order to make results more general to a European context. These numbers could be scrutinized however, as most of the electricity produced does not fit the daily energy demand in dairy cow farms (of today). Rather than replacing fossil-based electricity in Europe, the effect of the type of solar cell panel solution modelled here could pose capacity challenges with respect to selling the surplus power back the local Norwegian distribution grid. An important note is that if one consideres that the electricity produced replaces electricity defined by the Norwegian grid mix the mitigation measure only corresponds to saving 0,6 tonn of CO_2-eqvuivalents. The near term effect of such an investment could therefore be deemed questionable, while a future combination with other on-farm measures and optimized grid utilisation could prove otherwise.

We collected the solar cell and plant prices from reports from the Norwegian funding body ENOVA and a set of suppliers. The price for electricity utilized at the farm is set to 0.085 EUR/kWh. This correspond to what you «save» from not buying the same electricity. The electricity sold off from the farm is set to 0.04 EUR/kWh. A 60 kW plant is not an economically sound investment based on our estimates.

2. Biogas: Estimated costs and mitigation potential of a biogas plant

2.1 Assumptions and calculations: economics

For these estimates, we applied an economic modelling tool developed by the Swedish Federation of Swedish Farmers (LRF) adapted for Norwegian conditions by the Norwegian Institute for Agricultural Economic Research (NILF) and later by the Norwegian Centre for Organic Agriculture (NORSØK). The spreadsheet model and its results are available in the supplemental materials.

The inputs to the calculations were:

Fertilizer quantity volume: 4730 m3 manure fertilizer with dry matter content of 6.2%

To calculate the potential for biogas, we have used the model's existing, historical figures for decomposition: For the biogas potential, 213 Nm^3 CH_4 / tonne VS (Volatile Solids of the organic material) was applied. We assumed that VS constitutes 80% of TS (Total Solids) and an efficiency of 94%. The methane content of the gas was set at 60% by volume. This gives a potential for Skaun Eco-milk of 459 000 kWh / year. Residence time is set to 30 days which is normal for continuously stirred reactors.

The electricity demand for the biogas plant is set at 5%. Input temperature is set to 7 ^{o}C and operating temperature to 37 ◦C. This gives a heating need including heat loss of 157 114 kWh. When using the gas in a generator with 10% loss, 35% efficiency on electricity. and 55% efficiency on heat, you will then have access to 143 905 kWh or the like. and 78 577 kWh heat for own use and possible resale.

We assumed that the farm Skaun Eco-milk can use 3/5 of self-produced electricity. and that 3/5 of the heat is utilized on the farm. A value of 0.90 NOK/kWh has been set for electricity. and heating for own use at 0.40 NOK/kWh for electricity sold back to the grid. A cash subsidy for the delivery of livestock manure from the Norwegian Directorate of Agriculture to biogas, was estimated to NOK 182 140.

The cost for the facility is set at NOK 6 000 000 based on updated prices from suppliers. Annual operating and maintenance costs are set at 2% of the investment cost. Support from the public agency Innovation Norway has been assumed at 50% of the investment cost and support from the Norwegian Directorate of Agriculture has been calculated on the basis of current rates for delivery of manure / organic fertilizer to biogas plants (Norwegian Directorate of Agriculture 2020)

Given the assumptions above, a biogas plant at Skaun Eco-milk, has a repayment period of 18 years and an internal rate of return of 1.2%. This is not an economically attractive level. This is mainly due to the fact that electricity and heat demand on the farm is relatively limited compared to the production from such a biogas plant.

2.2 Assumptions and calculations: mitigation potential

Our estimates of mitigation potential are made based on a separate setup from the economic LRF-NORSØK model, with most of the GHG emission figures related to storage and spreading of manure and bio-residue gathered from other sources.

The estimates are based on the difference between the farm without biogas and after an assumed successful installation of a biogas plant running at full capacity, as described above.

For the farm *without* a biogas plant, emissions of CH_4 and N_2O from storage have been calculated, as well as emissions of N_2O as a result of the spread of fertilizer and emissions associated with the 110 000 kWh they use of electricity as of today. Figures for emissions from storage and dispersal are taken from Modahl et al (2016). See separate discussion in section 1 for assumptions for calculating emissions associated with the use of electricity from the Norwegian vs. European grid mix.

For the farm *with* a biogas plant, emissions of CH_4 and N_2O from storage have been calculated, as well as emissions of N_2O as a result of the spread of bio-residues, also based on figures from Modahl et al (2016). As referred to above, it is assumed from own experience with similar biogas plants that the farm can manage to utilize 3/5 of its own production of electricity and heat. Emissions associated with materials use and construction of biogas plants (50 g CO_2 / kWh produced) is taken from Budzianowski and Postawa (2017).

3. Manure: Costs and emission reduction potential for drag hose with dribble bars

The farm Skaun Eco-milk is placed on the top of a hillside with many of the fields quite close to the farm. Thus, the farm is well suited for transporting manure slurry with a drag hose.

In the estimates of 7 configurations / scenarios for manure management, we have not included costs or emissions in connection to building of manure storage or emission from storage as these will be the same independent of how the slurry is transported to and spread upon the fields. An exception is a new container for storing slurry built in 2019 that is already set up to make it easier to transport the slurry to the fields with a drag hose. Neither costs nor emissions associated with the production of tractors are included, as the tractors anyway will be on the farm.

3.1 Assumptions and calculations: emissions caused by slurry spreading

The equipment for spreading cattle slurry on Skaun Eco-milk consists of a tractor-driven slurry pump, 2 km with drag hoses and a slurry spreader with dribble bars (Scenario 1). We assume that a drag hose is used on the area of the farm where it is possible to reach with a drag hose, either directly from the manure storage on the farm or via satellite storage. A total of 86 ha are fertilized with cattle slurry.

We also assume that livestock manure is spread when the weather conditions are favourable for fertilization with slurry. With a drag hose, the spreading capacity is large, and it is possible to reach and spread under favourable conditions. In addition, the slurry can be spread under rainy, wet conditions without compacting the soil. We further assumed that the storage capacity is large enough for the farmer to wait to spread slurry until the conditions are favourable. Because the slurry needs to be diluted with water, we assume that the need for storage capacity is larger with drag hose than with a slurry tanker. This assumption is supported by the fact that Skaun Eco-milk is buying a new slurry container to be used as a satellite storage.

A small tractor (70-80 Hp) is used to drive the slurry pump. Estimated diesel consumption is 0.032 litres per cubic meter manure (8 litres diesel per 250 m^3 manure, figures from Jørgen Soknes, May 2019). A tractor with drag hose and dribble bars uses 0.032 litres per m^3. At Skaun Eco-milk, they do use a tractor of 6 tonnes (160 HP) with low air pressure in the tire but they could also have used a smaller tractor of 4.5 tonnes (115 HP).

In the model (and associated spreadsheet available in supplemental materials), we made 7 scenarios to estimate the effects of different situations: Scenario 1 is a reference, baseline-scenario where the slurry is transported and spread with a slurry tanker of 10 m^3 with an conventional slurry spreader driven by a tractor that weighs 7.5 tonnes and has 150 Hp.

In scenarios 2-7 we have estimated the impact on greenhouse gas emissions of using this equipment under different spreading conditions: Scenario 2 – good spreading conditions, Scenario 3 – dry conditions, Scenario 4 – wet, Scenario 5 – wet soil, sun and wind, Scenario 6 is the average for scenario 2-5, Scenario 7 is equal to scenario 6 but with the addition of fertilizer-N as compensation for lost NH_3-N. Scenarios 2-7, for slurry spreading by slurry tanker, are calculated for the same area as scenario 1. The total weight of a full slurry tanker is 13 tonnes. We assume that the diesel consumption per m^3 of fertilizer transported in a slurry tanker is on average 0.5 litres of diesel / m^3 of fertilizer. We have estimated a lower diesel consumption (0.72 litres / tonne slurry) than Bergslid and Ebbesvik (2017) because the farms in their survey had longer driving distances and a unfavourable location of the stable. An average of the estimated nitrous oxide (N_2O) emissions for the scenarios when slurry is spread with a slurry tanker is compared with N_2O emissions when slurry is spread with a drag hose with dribble bars.

We used IPCC (2019) methodology to calculate N_2O emissions and assumed that 1% of nitrogen applied was emitted as N_2O. Nitrogen lost through ammonia volatilization or leached was not withdrawn when the estimated direct N_2O emissions were calculated (IPCC, 2006, Holmengen et al., 2018). Indirect N_2O emissions are calculated as 1% of N lost through NH_3-volatilization and 0.75% of nitrogen leached. We used the N-calculator from NIBIO (https://lmt.nibio.no/husdyrn/) to estimate ammonia-volatilization and nitrogen leaching. Losses of nitrogen as NOx is calculated as a part of nitrogen lost through ammonia volatilization.

We assumed that the slurry was diluted to 3,5% dry matter when spread with drag hose and to 4.5% when spread with slurry tanker. A quantity corresponding to 35 tonnes per ha of slurry with a 3.5% dry matter is spread in the spring and 20 tonnes per ha after the first grass harvest. Because of the higher assumed dry matter content in slurry spread with tanker a lower amount of slurry per ha therefore calculated for slurry spread with tanker (27 and 16 tonnes per ha in spring and after first harvest, respectively). No slurry is spread in the autumn. Estimated wind speed on the Beaufort scale is 3 m/s except in scenarios with sun and wind where the estimated wind speed is 9 m/s (scenarios 3 and 5). Temperature in spring 4 °C, except scenarios 3 and 5 (10 °C). Temperature after first harvest is set to 11 °C, except scenarios 3 and 5 (18 °C). Soil type: Sandy, morainal soils, with annual precipitation 1000 mm.

We assumed a grass yield of 6.5 tonne dry matter/ha based on earlier registrations on this farm (Hansen et al., 2018). We assumed reduced grass yields when slurry is spread with slurry tanker because of soil compaction and NH_3 volatilization. Yield losses due to soil compaction are estimated to 20% in scenarios 4 and 5. The yields in scenario 6 (average of scenarios with slurry tanker) are set to 72% of scenario 1 (drag hose with dribble bars) due to the reduced yields because of NH_3-volatilization (spreadsheet row 150). Grass yields with scenario 7 is assumed to correspond to the same as scenario 1.

3.2 Assumptions and calculations: emission caused by production of equipment

We assumed that the existing slurry storage is used as before regardless of whether the slurry is spread with drag hose spreader or tanker. In addition, investments are being made in new slurry container to increase capacity, and the area that can be spread with a drag hose. Emissions from construction of this slurry container is added to scenario 1. The container is a 500 m^3 steel tank made of 2 mm steel plates coated with aluzinc. http://www.agromiljo.no/produkter/01_am_kum_gjodsellager/01_am_kum/index.shtml

As an estimate of emissions per kg steel plate Norwegian steel constructions coated with zinc is used which gives 2.35 kg CO_{2e}/kg steel plate. (Source: EPD-Norge 2019).

Inside the tank there is a PVC clothing (0.9 kg cloth / m2). GHG emissions per kg PVC are estimated as 1.987 kg CO_{2e}/kg plastic (Eco invent 2.2: Hirscher et al., 2010). Tractor-driven slurry pump (DODA manure pump) and weight 250 kg. AM dribble bars from Agromiljø, weight 900 kg, 2 hose drums one of 300 kg and one of 200 kg. We assumed that an average emission for production of agricultural equipment (Eco Invent 2.2: Hirscher et al., 2010) could be used for slurry pump, hose drums and dribble bars = 3.87 / kg equipment.

Emissions from production of drag hose: Assumed 9 m with suction hose, 1.8 km with supply hose 200 m with drag hose. We assumed the same GHG emissions as with production of PVC. We have not calculated extra for aluminium couplings. If the equipment is used for more than 10 years, estimated emissions from production of the equipment will be lower per year than we have assumed here as we have assumed ten years use.

Emissions from the production of a tanker are not included in the table below, as we assumed that the tanker used was older than 10 years. If emissions from tanker production is to be included 3.4 kgCO_{2e}/ kg tanker can be used (Eco invent 2.2: Hirscher et al., 2010).

3.3 Assumptions and calculations: economics

We assumed price for new for slurry spraying with drag hose with dribble bars NOK 600,000 (Source: Kyrre Vasstveit, 13 May 2019, Agromiljø, personal comm.) and for steel container of 500 m^3 for NOK 190,000. A new slurry tanker with a capacity of 10 tonnes costs around NOK 500,000 (Rose Bergslid, 13 May 2019, personal comm.).

We assumed a 10-year write-down period (personal com. Jørgen Soknes, May 2019). Estimated hours for spreading slurry with drag hose with dribble bars: 100 hours per year, with tanker: 180 hours (personal com. Jørgen Soknes, May 2019). Estimated labour costs per hour are NOK 250 / hour (paid to a replacement for manure driving etc., personal communication with Jørgen Soknes, May 2019). Fertilizer price: NOK 3.5 per kg of fertilizer, duty-free diesel NOK 9.31 / litre diesel (source: Rose Bergslid, 13 May 2019, personal comm.). In calculations of costs, no account has been taken of grants, loan interest or other things than the actual cost of purchasing new equipment. If bought equipment is used, it is used for more than 10 years or is bought in co-operation with neighbours then the investments will be lower than what is assumed in these calculations.

3.4 Summary of results

Table 3.4.1. summarises the main figures in the estimates:

Manure management comparison	Slurry tanker	Hose+ dribble bars	Difference
kg CO_2 eq. / farm and year	50532	38919	11612
Costs in NOK / farm and year	17215	2818	14307

Costs in NOK / kg CO_2 eq.	0.34	0.07	1.23
kg CO_2 eq./ tonne grass dry matter	126	70	
Costs in NOK / tonne grass dry matter	155	191	

Table 3.4.1. Comparison of slurry spreading with drag hose and dribble bars (Hose+dribble bars) with a slurry tanker with a conventional spreader attached to the tractor. Assumes purchase of new equipment for drag hose, dribble bars and extra slurry container, but use of slurry tanker older than 10 years and no new extra slurry container for the scenario with slurry tanker.

Direct and indirect emissions of nitrous oxide (N_2O) during and after the spreading of slurry has a larger impact on the greenhouse gas emissions than CO_2 emissions from the production of equipment and from emissions from diesel through tractor use. Reduced grass yields because of soil compaction and grass damage when driving a tractor with a heavy tanker on wet soil and nitrogen lost due to extra ammonia volatilization has a large impact on the estimated emissions if we convert to greenhouse gas emissions per unit of grass produced (grass dry matter). In the present calculation we have not included greenhouse gas emissions or costs of purchasing grass to compensate for reduced grass yields. In that case, the cost in NOK per CO_2 eq. for replacing a slurry tanker with a drag hose with dribble bars would have been lower.

If spraying with the slurry tanker can be done under ideal conditions, the estimated greenhouse gas emissions (CO_2 equivalents) when fertilizer is spread with a tanker with spreader is only 30% higher per unit of grass produced than for manure spread with a trailing hose. However, it presupposes dry weather before spreading and cold and windless weather during spreading of fertilizer, and light rain during and after spreading. If the farmer manages to do this, it is not economical for the farmer to invest in a drag hose with dribble bars if the old tanker can still be used. If it is relevant to choose between investing in a tanker or a drag hose, it pays to invest in a drag hose when the conditions are as good for it as at Skaun Eco-milk.

There is however a lot of manure to be spread annually, and it is difficult to spread all the manure under favourable conditions. We have assumed that drag hose with dribble bars are not used in sun and wind because the spreading capacity is greater than with a slurry tanker. If the slurry is spread under unfavourable conditions with a tanker with a conventional slurry spreader, the estimated greenhouse gas emissions will be much larger than with slurry spread with drag hose with dribble bars under favourable conditions (almost 3 times as large). Further, it is important to note that Skaun Eco-milk is managed according to organic principles. Thus, they do not use artificial fertilizer and the fertilization level is low. With a higher fertilizer level, the effects on nitrogen losses after spreading livestock manure would be greater.

We acknowledge and give thanks to Jørgen Soknes, Rose Bergslid, Martha Ebbesvik, Kyrre Vasstveit for data, Matthias Koesling for data fra Eco-invent og EPD-Norge, Synnøve Rivedal for comments in the above text in section 3, and Martha Ebbesvik for editing text and associated spreadsheet.

4. Biochar: Estimated costs and mitigation potential of an off-farm biochar plant

The basis for our biochar calculations is to assume a relatively large biochar plant not situated at the farm, but rather assumed to be placed in the valley below. The two main reasons for this framing of the evaluation is the limited heat demand at the farm as well as the biochar technology development at farm-level scale still being in its infancy.

Therefore, in this example, a planned new school as well as other surrounding planned buildings with a considerable heat demand is chosen as the possible receiver of most of the energy although the expected energy demand is not known in detail. A yearly energy demand of 1 GWh providing income through district heating is considered in this case-study. It is also considered that a larger plant would be more efficient and robust for wood chip drying. This is an important element as drying of wood chips is a large consumer of heat as wood chips typically need to have a moisture content limited to 15 % w/w. An alternative with a liquid to water heat pump using 250 000 kWh for providing the same amount of heat is used as basis to calculate CO_2 mitigation with respect to reduced demand for electricity.

The calculations are further performed with numbers collected from a plant that Oplandske Bioenergy will establish at Rudshøgda in Ringsaker Municipitality. This plant will be delivered by the German company Biomacon. With the surrounding infrastructure including facilities for drying wood chips the plant is estimated to cost 19 MNOK. It is further estimated to require a transport volume of 5000-6000 m^3 (uncompressed), which corresponds to about 2200 solid m^3 of wood. We have considered that about 10 farmers/forest owners (Skaun Eco-milk being one of them) could provide wood materials for the plant, the wood to a large extent being a mixture of conifer and deciduous trees. The farmer's motivation is to cut down trees to provide more light for his grass production. The diesel consumption coupled to transport 5500 m^3 of wood chips is about 5000 litres of diesel (Source: Ingvar Torjul 2020, farmer providing wood chips for Tingvoll Flis og Varme AS, pers. comm.).

Emission data related to the materials used in and building of the biochar production plant was not found. We have estimated a number somewhat higher than the on-farm biogas plant, e.g. 40 tonnes of CO_2/year.

The plant is estimated to produce 1400 m^3 of biochar. The biochar is considered as added to soil, but not necessarily in Skaun area or at Skaun Eco-milk as the quality of the soil is already very good in this area and may be better applied to soils with a low content of organic matter. The density of the biochar is set to 0.35 tonnes/m^3 based on (source: Adam O'Toole, pers. comm. 9.9.2020). 62 % of the biochar is considered to be stable and remain as sequestered based on the production temperature and wood as a resource (Budai et al 2016). The atomic ratio between CO_2 and C, 3.67 is used to calculate the amount of CO_2 that one can consider as sequestered.

The price of biochar sold from the plant is set to 3000 NOK/tonne biochar. Support from Innovation Norway is estimated at 7 MNOK: Operation costs (wood chips production, operation and maintenance costs) are set to about 0,05 EUR/kWh. The cost of heat provided for district heating is set to 0.06 EUR/kWh. The lifetime of the plant is set to 20 years and the interest rate to 6 %. The internal rate of return, IRR is thus calculated to be 12.6 % and the payback time 11 years.

We acknowledge and give thanks to Jørgen Soknes and Einar Stuve (Oplandske Bioenergi) for useful data and to Tatiana Rittl (NORSØK) for calculating the impact of carbon sequestration of biochar added to soil.

5. Short explanation to the four spreadsheet models in supplementary materials

For each of the four measures a separate spreadsheet model was made, in order to estimate economics and mitigation potential, when assuming they would take place on the farm Skaun Eco-milk.

For transparency and detail to the interested reader, the spreadsheets are made available as supplemental materials, as-is in the original Norwegian language version. As each measure required its own calculation method, there is no standard setup accross the spreadsheets. Each is custom made for its purpose.

The filenames of the four spreadsheets are:

1) "Supplements Spreadsheet1 - Solar Plant (Norwegian).xlsx"
2) "Supplements Spreadsheet2 - Biogas (Norwegian).xls"
3) "Supplements Spreadsheet3 - drag hose with dribble bars (Norwegian).xlsx"
4) "Supplements Spreadsheet4 - Biochar (Norwegian).xls"

A number of tabs inside each spreadsheet describe the detailed modeling of each mitigation measure.

References:

Budai, A., Rasse, D.P., Lagomarsino, A., Lerch, T.Z., Paruch, L., 2016. Biochar persistence, priming and microbial responses to pyrolysis temperature sereis, Biol. Fertil Soils 52, 749.

Budzianowski, W.M., Postawa, K., 2017. Renewable energy from biogas with reduced carbon dioxide footprint: Implications of applying different plant configurations and operating pressures, Renewable and Sustainable Energy Reviews, Volume 68, Part 2.

Modahl, I.S., Lyng, K-A, Stensgård, A, Saxegård, S.A, Hanssen, O. J., Møller, H., Arnøy, S., Morken, J., Brisied, T., og Sørby, 2016. Biogassproduksjon fra matavfall og møkk fra ku, gris og fjørfe, Status (fase IV) for miljønytte for den norske biogassmodellen BioValueChain. Østfoldforskning rapport 34.16.

Landbruksdirektoratet 2020, https://www.landbruksdirektoratet.no/no/miljo-og-okologisk/jordbruk-og-miljo/husdyrgjodsel-til-biogass/husdyrgj%C3%B8dsel-til-biogass

Bergslid, og Ebbesvik, M. (2017) Samarbeid om spredning av husdyrgjødsel – til beste for bonde, klima og økonomi. NORSØK FAGINFO 4/2017, 6 p. http://orgprints.org/32493/7/NORS%C3%98K%20Faginfo%20nr.%204%202017%20Samarbeid%20om%20spredning%20av%20husdyrgj%C3%B8sel%20Rose%20Bergslid.pdf

Bjønnes,K.L., (ed), 2019. Greenhouse Gas Emissions 1990- 2017, National Inventory Report 2019. Rapport frå Miljødirektoratet, Oslo. M-1271

EPD-Norge, 2019. Environmental Product Declaration: https://www.epd-norge.no/getfile.php/139910-1550570397/EPDer/Byggevarer/St%C3%A5lkonstruksjoner/NEPD-1703-693_CF70.pdf (accessed 1.sep.2020).

Greenhouse gas protocol, 2016. Global Warming Potential Values. https://www.ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20%28Feb%2016%202016%29_1.pdf, (accessed 27. mar 2019).

Hansen, S., Bakke Haavik,T., Bergslid, I.K., Elvatun, H., van Gool, B., Lunnan T., Røthe, G., Walland,F. (2018). Miljø - og klimavennlig melkeproduksjon - Inspirasjon fra seks melkeproduksjonsbruk. NIBIO, NORSØK, NLR. NIBIO rapport, Vol 4, nr 96, 53 pages.

Hischier, R., Weidema, B., Althaus, H.-J., Bauer, C., Doka, G., Dones, R., Frischknecht, R., Hellweg, S., Humbert, S., Jungbluth, N., Kollner, T., Loerincik, Y., Margini, M., Nemecek, T., 2010. Implementation of Life Cycle Impact Assessment Methods. Data v2.2 (2010). Ecoinvent report, Swiss Centre for Life Cycle Inventories.

Holmengen, N. (ed), 2018. Greenhouse Gas Emissions 1990- 2016, National Inventory Report 2018. Rapport frå Miljødirektoratet, Oslo. M-985. http://tema.miljodirektoratet.no/Documents/publikasjoner/M985/M985.pdf

IPCC; Intergovernmental Panel on Climate Change (2006) Revised Guidelines for National Greenhouse Gas Inventories. PCC/OECD/IEA/IGES, Vol 4, Agriculture, Forestry and other land use. http://wwwipcc-nggipigesorjp/public/2006gl/ppdhtm

IPCC; Intergovernmental Panel on Climate Change, (2019) Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use, Appendix 4, Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development.

Yara 2012, Carbon Footprint, Climate impact and mitigation potential of plant nutrition. http://yara.com/doc/29465_Carbon_footprint_En_0604.pdf

Louwen, A., van Sark, W., Faaij, A., 2016. Re-assessment of net energy production and greenhouse gas emissions avoidance after 40 years of photovoltaics development. Nat Commun 7, 13728.

PVGIS 2020, https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP.