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# Replacing fossil energy for organic milk production – potential biomass sources and greenhouse gas emission reductions

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There is a growing awareness of the climate impact of agricultural production, not least from cattle farms. Major sources of GHG emissions from milk production are enteric fermentation followed by fossil fuel use and manure/soil management systems. This study analyzes the potential to eliminate fossil fuel use from milk production farms in Sweden, by using residual farm resources of biomass to obtain self-sufficiency in fuel, heat and electricity. The change from a fossil-based energy system to a renewable system based on A) Biogas based on manure and straw and B) Biogas based on manure + RME were analyzed with consequential life cycle assessment (CLCA) methodology. Focus was energy use and GHG emissions and the functional unit was 1 kg of energy-corrected milk (ECM). The results show that organic milk producers can become self-sufficient in energy and reduce total GHG emissions from milk production by 46% in the Biogas system, or 32% in the Biogas + RME system compared to the Fossil system.



## 1. Introduction

This study analyzes the climate impact of implementing self-sufficiency systems at organic dairy farms, by utilizing the farms' own residual biomass for heat, power and fuel production. There is an increasing awareness of environmental, health-related and climate issues associated with our current dairy production processes in Europe, and more and more farms are becoming certified for organic production, eliminating chemicals and artificial fertilizers and with increased focus on animal welfare. It is however only recently that organic labels have become concerned with energy efficiency or energy sources used at the farms. The agricultural industry in Sweden uses 3 TWh of diesel per year, and still a substantial amount of oil for heating (SCB, 2012). Still, environmental system analyses and the general debate of climate impact from meat and milk production are often focusing on the methane emissions from enteric fermentation in cows, and the manure management systems. Life cycle assessments (LCA) of dairy products, such as milk and cheese, typically identifies methane production by enteric fermentation as the largest contributor to greenhouse gases (Flysjoe et al., 2011; Cederberg et al., 2007; Berlin, 2002).

However, while methane production through enteric fermentation is an intrinsic property of the cow, and an inevitable part of the dairy production system, fossil fuels can be replaced with renewable energy sources to reduce climate impact. For example, straw boilers are today rather common at farms in Denmark and Sweden, and heat and electricity can be produced simultaneously in plants with capacity under 1 MW, fueled by solid, liquid or gasified biomass. There are numerous examples in Finland of farm-scale biogas production for heat and combined heat and power (CHP) production, even claiming self-sufficiency on heat and power (Okkonen and Suhonen, 2010). Biogas is a mixture of methane and carbon dioxide that can be produced in a relatively simple digestion process using sewage sludge, manure, or crops as substrate, and the raw gas can be upgraded to 97–98% methane which means classification as vehicle fuel. There is also potential to produce for example biodiesel, ethanol or pyrolysis oil/gas from grains, vegetable oil or other biomass, that with the right adaptations and infrastructural investments can be used in tractors for field operations and for transporting farm products to the markets they are aimed for. Fuel production often requires large-scale production sites; but there are exceptions, such as RME (rape methyl ester) that can be produced on-site at the farm in a fairly simple process.

Moreover, while large power plants and distribution technologies adapted to large-scale production (few point sources in the power production system) were built in the 20th century, today the

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trend is in the opposite direction. Decentralized energy systems and smart grids for efficient power production and distribution enable individuals or industries to simultaneously be producers and consumers of energy ("prosumers") by for example adding solar panels to roof tops. For dairy farmers, becoming self-sufficient in energy would reduce cost of fuel, heat and electricity (although, obviously, with an investment cost) and might also convey additional income from sales of surplus energy, in particular heat. Many farmers today struggle to survive in the harsh economic reality of the agricultural industry, and fewer and fewer are full-time farmers (SCB, 2012). That means that there are potential man-hours available to operate fuel production or CHP systems on the side of the regular farm business, and perhaps a need to diversify the business in order to increase economic stability.

Studies have shown that arable farms, i.e. grain-producers, can utilize their own residual products for producing tractor fuel to cover the farm need (Fredriksson et al., 2006; Hansson et al., 2007; Ahlgren et al., 2008). The study at hand was preceded by an analysis of the potential for an arable farm to reduce its climate impact by changing from a fossil-based energy system to a biomass-based energy self-sufficiency system (Kimming et al., 2011).

This study has been conducted as a consequential LCA (CLCA) with focus on greenhouse gas (GHG) emissions resulting from the change from fossil energy for an organic milk production system to a biomass-based system for production of tractor fuel, heat and electricity. Two biomass systems were analyzed, both utilizing the biogas potential in the manure from dairy cows, supplemented with straw or rapeseed oil, to produce its entire need for energy. The amount of GHG released in each system was calculated partly based on the IPCC methodology for estimating emissions of nitrous oxide and methane from agriculture. The effect of removing straw from the fields, in order to use for combustion or digestion, was calculated based on simulations in the ICBM model (Andrén et al., 2004). The farm is assumed to be located in Southwestern Sweden and has been modeled based on typical data for organic agricultural production in that region. The systems for alternative energy production are based on commercially available technologies. Functional unit is 1 L of energy-corrected milk.

## 2. Material and methods

### 2.1. Organic milk production

The farm studied is a virtual farm, designed to represent a typical organic milk-producing farm in Southwestern Sweden regarding size and farm activities. For simplicity it was assumed that the farm had a dairy herd of 100 cows, with 25% recruitment rate. In accordance with organic principles, it was assumed to be self-sufficient in organically produced forage, of which 50% consists of silage and grazing according to KRAV (Swedish organic label) requirements. The need for forage was calculated from Olrog et al. (2002) and the crop rotations on the farm, as well as the assumed area, were dimensioned for self-sufficiency of feed and forage. There are two crop rotations at the farm; crop rotation 1 is cultivated over 7 × 40 ha and crop rotation 2 over 7 × 14 ha. The crops are produced in the order shown in Table 1. On the first field of 40 ha, the first year spring barley is grown, followed by three years of ley, rapeseed and finally wheat. On the second 40 ha-field the rotation starts with ley and ends with spring barley, and the 7th field starts with broad beans. According to the same principle, crop rotation 2 starts on the first 14 ha-field with spring barley, followed by 5 years of grazing and finally broad beans while the second 14 ha-field starts with 5 years of graze land. Crop yields are based on Swedish statistics for the county of Västra Götaland in Southwestern Sweden (SCB, 2012).

**Table 1**
Crop rotations with yields.

| Crop rotation 1 | Yield (kg/ha yr) | DM content | Crop rotation 2 | Yield (kg/ha yr) | DM content |
|---|---|---|---|---|---|
| Spring barley | 2440 | 86% | Spring barley | 2350 | 86% |
| Ley 1 | 6000 | 29% | Grazing | 6000 | – |
| Ley 2 | 6000 | 29% | Grazing | 6000 | – |
| Ley 3 | 6000 | 29% | Grazing | 6000 | – |
| Rapeseed | 1693 | 91% | Grazing | 6000 | – |
| Wheat | 3228 | 87% | Grazing | 6000 | – |
| Broad beans | 2026 | 85% | Broad beans | 2026 | 85% |

Self-sufficiency in feed and forage implies no external inputs to the dairy farm apart from fossil energy sources. Outputs from the farm include, in addition to milk, by-products in the form of meat, rapeseed oil. Straw and manure are by-products used in a circular system; straw is plowed back into the soil after the harvest of grains and manure collected in the stables is used as fertilizer on the cropland. Each dairy cow produces 1 calf/year, and 25 milk cows, 25 heifers and 50 calves are assumed to be sent to slaughter every year, which contributes to meat production (Cederberg and Nilsson, 2004). Manure is a mixture of feces, urine, bedding material (straw), water and precipitation, collected from stables to an open storage site at the farm. The grazing period in Sweden is 5 months for cows and 6.6 months for heifers and calves (SCB, 2012), and manure produced in this period is not collected. Table 2 summarizes the outputs at the farm with respective annual production rate.

Rapeseed oil is produced from rapeseed, with an oil content of approx. 45% of dry weight. The oil is extracted and leaves a residual product in the form of a protein-rich rapeseed cake. The rapeseed cake is utilized as feed at the farm whereas the rapeseed oil is sold on the vegetable oil market.

The energy requirement for each specific farm activity in the reference scenario is shown in Table 3. Data on electricity use is shown as total energy use during one year (Hörndahl, 2008). Specific energy consumption for grain drying is 5 MJ/kg water. Truck load capacity for fertilization (manure spreading) is assumed to be 15 tonnes, and specific diesel use 0.9 l/ha during spreading and 0.5 and 0.3 l/km during transport to/from the field, respectively (Ahlgren et al., 2010). Average distance to the fields was assumed to be 1.6 km. Manure management includes mucking, stirring and pumping.

### 2.2. Energy supply systems

Two alternative scenarios for how to supply the milk production with energy were considered in this study. In the reference system,

**Table 2**
Farm products and production rates.

| | | |
|---|---|---|
| **Milk** | | |
| Production rate | 6720 | kg ECM/MPU[a]/yr |
| **Feed** | | |
| Forage | 7059 | kg/MPU/yr |
| Grazing | 7500 | kg/MPU/yr |
| Grains | 1550 | kg/MPU/yr |
| Beans | 1100 | kg/MPU/yr |
| Rapeseed cake | 500 | kg/MPU/yr |
| **By-products** | | |
| Meat | 15,950 | kg/yr |
| Rapeseed oil | 18,900 | kg/yr |
| Manure prod. (cow) | 16,771 | kg/yr |
| Manure prod. (heifer >1yr) | 5834 | kg/yr |
| Manure prod. (heifer <1yr) | 6904 | kg/yr |

[a] Milk-producing unit (cow + recruitment).