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Embodied and operational energy in buildings on 20 Norwegian dairy farms – Introducing the building construction approach to agriculture

Matthias Koesling[a,b,*], Gesa Ruge[c], Gustav Fystro[d], Torfinn Torp[e], Sissel Hansen[a]

[a] Bioforsk – Norwegian Institute for Agricultural and Environmental Research, Organic Food and Farming Division, Gunnars veg 6, 6630 Tingvoll, Norway
[b] Institute of Organic Farming, 23847 Westerau, Germany
[c] University of Canberra, School of Management, Canberra ACT 2601, Australia
[d] Bioforsk – Norwegian Institute for Agricultural and Environmental Research, Løken, 2940 Heggenes, Norway
[e] Bioforsk – Norwegian Institute for Agricultural and Environmental Research, Frederik A. Dahls vei 20, 1430 Ås, Norway

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ABSTRACT

Embodied energy in barns is found to contribute to about 10–30% of total energy use on dairy farms. Nevertheless, research on sustainability of dairy farming has largely excluded consideration of embodied energy. The main objectives of this study were to apply an established model from the residential and commercial building sector and estimate the amount of embodied energy in the building envelopes on 20 dairy farms in Norway. Construction techniques varied across the buildings and our results showed that the variables which contributed most significantly to levels of embodied energy were the area per cow-place, use of concrete in walls and insulation in concrete walls. Our findings are in contrast to the assumption that buildings are similar and would show no significant differences. We conclude that the methodology is sufficiently flexible to accommodate different building design and use of materials, and allows for an efficient means of estimating embodied energy reducing the work compared to a mass material calculation. Choosing a design that requires less material or materials with a low amount of embodied energy, can significantly reduce the amount of embodied energy in buildings.

1. Introduction

The efficient and sustainable use of resources is increasingly important for developments in farming operation and management globally. The focus of early 20th century farming was on the efficient use of land, equipment and workers. This changed with the oil crisis in the 1970s, when the use of non-renewable resources such as oil, gas and coal became a conscious part of farming operational decision making [2] and attention shifted to increasing food production with reduced negative environmental impacts [3]. Worldwide, more than 40% of all energy use is linked to buildings and they produce one third of greenhouse gas emissions during their entire life cycle [4]. In the European Union, the energy consumption of buildings is around 37% of the primary energy consumption [5] and expected to grow [6].

Dairy milk production is probably the food type for which most Life Cycle Assessment (LCA) or carbon footprint analysis has been published [7] and there are various publications on sustainability in dairy farming (for example Dalgaard et al. [8], van Calker et al. [9]). Nevertheless, even in comprehensive LCA studies the embodied energy in buildings is often not included (for example Gerber et al. [10], Meul et al. [11], Yan et al. [12]; exceptions are Smith et al. [13] and Gaudino [14]), or if it is, this is not made explicit (for example Vries and Boer [15]). Out of 13 studies on milk production analyzed by Yan et al. [12], only one (van der Werf et al. [16]) included machinery, and none included buildings. The role of buildings is also omitted from many studies on greenhouse gas emissions from dairy production, as listed by Crosson et al. [17]. There are recurring arguments around why embodied energy is not included in such studies [18]. These encompass the following: small influence on overall results [19], the inclusion of embodied energy is time consuming, there is a lack of data, and that buildings are generally similar and no differences are expected [20,21].

Buildings demand energy both directly and indirectly. Direct energy use occurs during the construction, operating (operational energy), rehabilitation and demolition processes across a building's life cycle. Primary energy is the energy needed to produce the operational energy, including extraction, transformation and distribution losses. Indirect or embodied energy arises from the production of materials and technical installations the buildings

* Corresponding author at: Bioforsk – Norwegian Institute for Agricultural and Environmental Research, Organic Food and Farming Division, Gunnars veg 6, 6630 Tingvoll, Norway.
E-mail address: matthias.koesling@nibio.no (M. Koesling).

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are made of [22]. Of these various uses of energy, operational and embodied energy are the most significant, the other energy demand for construction, rehabilitation and demolition is negligible (about 1%) [22].

With specific reference to farming, energy consumption in the construction and operation of farm buildings is a notable contributor to overall energy consumption. For example, in Denmark, about 10% of the overall farm energy consumption was related to buildings for dairy and cattle production [23], while for swine production in Iowa, embodied energy in buildings and operational energy accounted for 14–27% of the total energy use [24]. Similarly, a study of 50 dairy farms in Switzerland identified that approximately 32% of overall energy use was linked to farm buildings [25]. These results demonstrate that energy efficient buildings, in regard to both embodied and operational energy, should be considered as an important part of sustainable farming practice locally and globally. Research and literature on embodied energy in buildings has to date largely focused on the residential housing and commercial building sector. The research and analysis of agricultural buildings and the subsequent impact on the agricultural business sector has not been developed to the same degree. In this paper the building constructions approach is used to estimate energy. While there are some limitations with the approach, we consider it to be more practical and to require less work than a mass material calculation. With exception for the mass material approach, we consider that it is more precise than other approaches, when buildings differ in age, materials and appearance.

1.1. Approaches to estimating embodied energy in buildings

The amount of embodied energy of a building is estimated for the building's entire lifetime. Usually, it is not known how many years a building will be used and thus the embodied energy of a building is divided by the expected lifetime. Accordingly, the expected lifetime of a building strongly influences the calculations of the annual amount of embodied energy. In the available literature generally, the expected service life of a building is estimated to range from 20 years [26,27] to 80 years [28]. A frequently used assumption is a 50 year expected service life of a building [29–32]. Irrespective of whether a building is assumed to have a short or long service life, improved knowledge and decision making in relation to the design, construction, and operation of farm buildings will become more important in the future. This is not only in relation to achieving efficient embodied energy within the building envelope for dairy farms, but also in terms of achieving reduced long term operational energy demand and improved functional use.

The analysis of embodied energy in buildings can be done utilizing a Life Cycle Analysis (LCA). Either a 'top down' calculation, which breaks down larger components into smaller parts or a 'bottom up' calculation, which builds up the individual parts to the total building, can be utilized. In some instances a combination of both calculation types has also been applied [33]. The 'bottom-up' approach, while well suited for the comparison of individual building materials, can lead to an underestimation of embodied energy compared to a top-down approach, because "transport, construction activity, production of machines and service sectors" are not included [33]. Additionally, comparisons between individual projects and their calculations are often difficult due to the variability between materials and buildings, or lack of detailed assumptions [30].

Of the limited research and literature on embodied energy in farm buildings available to date, the 'bottom up' approach is more frequently used [34], particularly in relation to farm barns (see for example [26,28,29,35]). Existing literature frequently combines the calculation of the embodied energy for equipment and buildings with the number of animals or the amount of meat or milk produced. However, this is considered as problematic, especially where the calculation details and assumptions are not clearly articulated [30], making it difficult to compare or to adapt the approach to other buildings.

Within the available literature, different bottom-up approaches have been used to estimate the amount of embodied energy in buildings for machinery and livestock. The approaches can be divided into five groups and a summary of key aspects and publications for dairy farming are presented in Table 1.

1.1.1. Mass material calculation

The amount of total embodied energy is calculated as the sum of the mass of main different construction materials multiplied with the corresponding amount of embodied energy per mass unit. In the studies for Danish dairy production, the amount of the materials needed to replace the actual barns for all cattle production in the entire country is used [26,27,36]. While for Germany, the amount is calculated for possible future barns [35]. The mass material approach is most precise of the approaches presented and fundamental for all other type of approaches. However, it is demanding [37]. To reduce the workload for calculating the embodied energy, other approaches have been developed.

1.1.2. Different building constructions

Based on the building analyzed, different building constructions are defined (see for example Adalberth [38] and Kohler [39]) and used to calculate the amount of embodied energy for the materials found per square metre floor, wall or roof [39]. The amount of embodied energy for the different building constructions per square metre are then multiplied by the total area of each building construction to derive the overall value of embodied energy for a building. Using Kohler's values for industrial buildings, Audsley et al. [40] present an 'upper limit' for embodied energy for agricultural buildings in different countries, expecting that the value of embodied energy for agricultural buildings is lower than this. Calculating embodied energy of buildings using different building constructions reduces the workload compared to the mass material calculation, but presupposes that the building constructions used for calculations are representative for the buildings analyzed.

1.1.3. Square metre ground-floor

Using square metre ground-floor, Williams et al. [28] calculated the lowest estimate of embodied energy per cow. The longest building lifetime, 80 years was assumed and their calculations were based on the amount of embodied energy per square metre ground-floor from Audsley et al. [40]. Audsley refers back to Kohler [39], who calculated embodied energy for 100 buildings (houses, service and industrial buildings) in Switzerland. Based on materials and values from life cycle inventories for industrial buildings and the actual age of the buildings, Rossier and Gaillard [25] calculated in 2004 for 35 existing dairy farms in Switzerland the highest value of embodied energy per cow (12,400 MJ) and litre milk (2.1) compared to all other studies found (see Table 1). Based on the results from Rossier and Gaillard, embodied energy in dairy housing accounts for nearly one third of all non-renewable energy use in dairy production. The approach is easy to conduct but the results assume that the buildings analyzed are comparable to those used to calculate the amount of embodied energy per square metre ground-floor.

1.1.4. Embodied energy per cow-place

Under this approach, the material masses were multiplied with the amount of embodied energy found in the ecoinvent database [41] to calculate an annual amount of embodied energy per cow-place (bedding place for a cow) which can then be used as a functional unit. Both Schader [42], Nemecek and Kägi [29], present