Economic impact of investment in animal welfare–enhancing flooring solutions – Implications for promoting sustainable dairy production in Sweden

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Abstract

Purpose – The purpose of this paper was to assess the economic impact of investment in different animal welfare–enhancing flooring solutions in Swedish dairy farming.

This paper forms part of a special section "Promoting Sustainable Food Production: Challenges, Practices, Impacts, and Solutions", guest edited by Wanglin Ma, Hung-Hao Chang, Victor Owusu, Puneet Vatsa and Hery Toiba.

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Design/methodology/approach – The authors developed a bio-economic model and used stochastic partial budgeting approach to simulate the economic consequences of enhancing solid and slatted concrete floors with soft rubber covering.

Findings – The findings highlight that keeping herds on solid and slatted concrete floor surfaces with soft rubber coverings is a profitable solution, compared with keeping herds on solid and slatted concrete floors without a soft covering. The profit per cow when kept on a solid concrete floor with soft rubber covering increased by 13%–16% depending on the breed.

Practical implications – Promoting farm investments such as improvement in flooring solution, which have both economic and animal welfare incentives, is a potential way of promoting sustainable dairy production. Farmers may make investments in improved floors, resulting in enhanced animal welfare and economic outcomes necessary for sustaining dairy production.

Originality/value – This literature review indicated that the economic impact of investment in specific types of floor improvement solutions, investment costs and financial outcomes have received little attention. This study provides insights needed for a more informed decision-making process when selecting optimal flooring solutions for new and renovated barns that improve both animal welfare and ease the burden on farmers and public financial support.

Keywords Animal welfare, Flooring solution, Partial budgeting, Sustainable dairy production

Paper type Research paper

1. Introduction

With increasing consumer awareness and demand for better animal welfare and improved sustainability across the livestock sector, new innovations are emerging that enable farmers to monitor and improve herd animal health, improve productivity and sustain livestock production (Verkuijl *et al.*, 2022). The UN Environment Assembly has tabled a resolution that focuses on animal welfare, the environment and the sustainable development nexus (Stockholm Environment Institute, 2023; Verkuijl *et al.*, 2022). Farm animal welfare influences livestock producers' decision, the entire food production and supply chain (Buller *et al.*, 2018; Cox and Bridgers, 2019; Keeling *et al.*, 2019). The UN Environment acknowledges that animal welfare should be "at the heart of sustainability" (Cox and Bridgers, 2019). Hence, practices that enhance animal welfare should be given attention in the production process.

European dairy farmers are increasingly investing in farm facilities that improve animal welfare (Barkema *et al.*, 2015; Turan *et al.*, 2019), and this is supported by various policy incentives (e.g. Swedish Rural Development Program, 2014–2021). One aspect of farm facilities that receives particular attention from dairy producers is flooring (Magrin *et al.*, 2019; Murphy *et al.*, 2018), and flooring is directly linked to animal welfare due to its effects on animal behaviour and claw and leg health (Murphy *et al.*, 2018). The floor design in alleys and waiting areas is chosen by the individual farmer (Owusu-Sekyere *et al.*, 2021). The farmer's decision to select a particular type of floor is likely dependent not only on the installation cost (Ortega and Wolf, 2018) but also on several factors related to the function of the floors, such as the ability to reduce claw and leg disorders (Rushen and de Passillé, 2006), lameness (Alvåsen *et al.*, 2014), impaired reproduction (Hogeveen *et al.*, 2017; Palmer *et al.*, 2012) and traumatic injuries (Hogeveen *et al.*, 2017; Palmer *et al.*, 2012). While it is likely that these factors are indirectly associated with increased costs, use of inappropriate floors also has more direct economic consequences. For instance, inappropriate floors are associated with reduction in milk output (Huxley, 2013). They can also be linked to premature culling. The mortality rate of cattle is about 5% (Växa Sverige, 2020a). Many of the mortality cases can be linked to claw and leg disorders (Alvåsen *et al.*, 2014). From a policy perspective, it is highly relevant to know if investments to support enhanced animal welfare are profitable at the farm level and whether the farmers themselves can make these investments or if policy support is necessary to stimulate uptake.

There are ranges of different floor design solutions available with a wide variation in effectiveness and costs. One of the most critical properties of walking surfaces is slipperiness (Telezhenko *et al.*, 2008), and this can be improved by installing soft rubber coverings (Rushen and de Passillé, 2006) on top of the concrete surface. Flooring improvements that result in reduced slipperiness, better claw and leg health and increased fertility are expected to improve a farm's financial outcome and therefore contribute to improved competitiveness within the dairy sector (Charfeddine and Pérez-Cabal, 2017; Bruijnis *et al.*, 2010). However, the complex impact of flooring system selection on a farm's economic outcome has not been analysed in previous literature, leaving farmers, advisors and policymakers with insufficient information for economic decisions about flooring types.

A review of the literature shows that only few studies have examined the influence of floor improvements on dairy farm production. Norberg (2012) investigated the effects of rubber alley flooring on lameness and milk yield and found that lameness, which is found to be a significant contributor to economic loses (Herzog *et al.*, 2020; Shearer and Van Amstel, 2019), was significantly lower in dairy cows kept on rubber alley floors than in those on concrete floors. Oskarsson (2008) estimated the average cost of severe sole ulcer, one of the links to lameness, to be €557 [1], which underlines the potential economic effects of floor choice. Rubber mats on alleys are known to increase standing time and decrease lying time. Green *et al.* (2002) found that lameness associated with floor characteristics results in milk losses up to 360 kg per each lame cow per year, corresponding to a significant economic loss. Ettema and Østergaard (2006), using a dynamic, stochastic and mechanistic Monte Carlo model, estimated that installation of rubber mats on alleys would increase the margin per cow-year by €17, based on data from Danish dairy herds.

Notwithstanding the contribution made by the previous literature, specific types of floor improvement solutions, investment costs and financial outcomes have not been thoroughly investigated. Thus, costs estimated from previous studies did not take into account the cost of different floor quality improvements and as such do not provide sufficient information for farmers to make economically optimal decisions regarding floor quality improvement solutions. In addition, previous studies only provide estimates of the marginal increase from reduced lameness due to flooring (Ettema and Østergaard, 2006; Green *et al.*, 2002), while potential direct effects on, for example, fertility and culling were not considered. Accordingly, the aim of this study was to assess the economic impact of improved flooring quality in alleys and waiting areas in free-stall barns. We simulate the effects of soft rubber covering when used to enhance solid concrete floors and concrete slats on farm financial outcome compared with non-enhanced solid concrete and slatted flooring without soft rubber covering as baseline scenarios.

The results of this study provide insights needed for a more informed decision-making process when selecting optimal flooring solutions for new and renovated barns that improve both animal welfare and ease the burden of farmers and public financial support. This study contributes to the debate on the trade-offs between the cost and benefits of different floor quality improvement solutions in dairy farming. We provide evidence on the relationship between floor quality improvements and profitability, which is highly relevant for the sustainability of the dairy industry and for the formulation of efficient agricultural policy. It also contributes to mechanisms that encourage the implementation of more animal friendly floors. Given that the study is based on Swedish dairy farming, the empirical findings are particularly relevant for farmers and policy-making decisions in Sweden; however, the approach used to simulate the financial outcomes is of value to research and policy design beyond the empirical setting used here. The findings indicate that investments in improved floors could be expected without public support in the form of animal welfare improvement incentives for farmers. Furthermore, the study points out that the promotion of farm management practices that have both economic and animal welfare incentives is a possible way of promoting sustainable dairy production.

The rest of this paper is organized as follows: Section 2 presents the materials and methods, which consist of an outline of the economic model, simulation approach and specification of the tornado regression. The following section 3 presents results of the study. Section 4 discusses the simulation and regression results. Finally, Section 5 concludes and discusses the practical and policy implications.

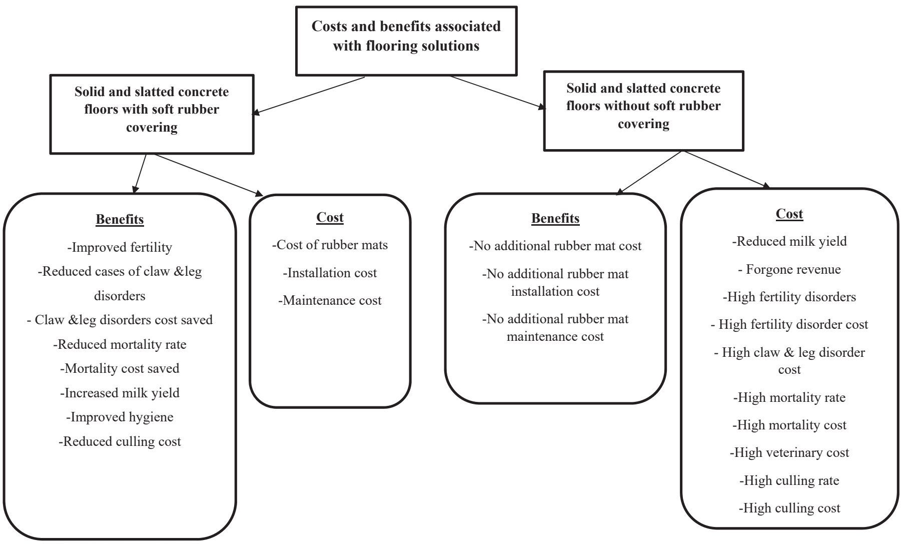
2. Materials and methods

2.1 Outline of the economic model for different flooring solution

The economic model used to assess the impact of investment in flooring solutions is outlined in Figure 1. The model aims to capture decisions by farmers to (1) enhance the solid concrete floor surface with soft rubber covering; (2) enhance slatted concrete floors with soft rubber coverings. Solid concrete and slatted floors without soft rubber covering were used as baseline scenarios. In doing so, we were able to assess how the economic situation on-farm may change if solid concrete floor is covered with soft rubber coverings. In addition, we were able to assess how the economic situation on-farm may change when slatted concrete flooring is enhanced with soft rubber coverings. The benefits and cost parameters used in each model are specified in Figure 1.

For the solid and slatted concrete floors without any quality improvements, the cost parameters of interest include costs associated with reduced milk yield and milk losses in herds with concrete floors compared to herds with soft rubber coverings, as shown in previous studies (Green *et al.*, 2002). Moreover, fertility rates, and claw and leg disorders are considered high in herds kept on solid concrete floors compared to floors with a soft rubber covering (Kremer *et al.*, 2012; Vanegas *et al.*, 2006). These disorders result in significant costs to the farmer (Oskarsson, 2010) and indirectly reduce revenue. Claw and leg disorders are a significantly associated with mortality (Alvåsen *et al.*, 2014), a significant economic losses to the farmer, particularly when animals die or have to be euthanized on farm (Mõtus *et al.*, 2017; Reimus *et al.*, 2020). In terms of the benefits offered by alternative flooring, farms do not incur additional costs for the purchase, installation, and maintenance of soft rubber coverings for solid and slatted concrete floors. Refer to supplementary material (i.e. Table S1 and S2) (Source: Authors work) for details.

For the model on the use of soft rubber covering, the cost parameters of interest included the cost of soft rubber coverings, installation, and maintenance costs. The added benefit due to the use of soft rubber coverings include increased milk yield and reduced milk losses, as



Note(s): Anticipated effects are summarized according to the literature review
Source(s): Authors work

Figure 1.
Outline of the costs and benefits associated with different flooring solutions

shown by Green *et al.* (2002). Herds kept on soft rubber coverings have been shown to have improved fertility and hygiene (Kremer *et al.*, 2012), which also results in lower costs due to fertility disorders. Moreover, herds kept on soft rubber coverings have been shown to have a reduced rate of claw and leg disorders (Bergsten *et al.*, 2015; Norberg, 2012), which reduces costs to the farmer. Lower culling and mortality rates are recorded in herds with soft rubber coverings compared to those with solid concrete flooring (Norberg, 2012). The specific cost and benefit values for each model are discussed in detail in the following sections.

In both economic models, the analysis was performed for one production year, where dairy cows spend 305 days indoors and 60 days on pasture. In addition, the analysis was performed separately for the two main dairy breeds in Sweden, the Swedish Red (SR) and the Swedish Holstein (SH), as milk output, fertility, and returns from these breeds differ. For instance, milk yield differs across breeds with SH yielding 10,790 Kg ECM and SR yielding 9,910 Kg ECM (Växa Sverige, 2020b). Annual return per SH cow is €2,997 [2] and €2,878 per SR cow (Andersson, 2011).

2.2 Simulation approach

We used a farm simulation model for a typical Swedish dairy herd consisting of 100 dairy cows per herd (Agriwise, 2020). The simulation model was built in Microsoft Excel and applied to evaluate the economic impact of improved flooring quality in alleys and waiting areas in free-stall barns. A basic model was constructed using data from a survey, as well as farm and economic data from Agriwise (2019). The net costs and benefits of improvement in floor quality were estimated using a partial budgeting framework. We used the @Risk (Palisade, Ithaca, NY) add-in in Microsoft Excel to perform sensitivity analysis of the stochastic variables relating to floor improvements on farm profitability. We performed multiple regression analysis using @Risk software for the outcome variable (i.e. profitability) and simulated values of the explanatory variables. The floor improvement parameters with significant effects on profitability were identified using a Tornado chart. Tornado charts were drawn in @Risk software with the regression coefficients.

Data used in the simulation were obtained from Agriwise and from farm survey data from 232 Swedish dairy farms preformed at the end of 2019. The farm survey data contains information on housing, floor quality improvements, milking systems, milk production, fertility, and claw and leg health. The Agriwise (2019) database contains data for several dairy production systems in Sweden. Data on housing and milking systems were available for herds with free-stall barns with automatic milking system (AMS), free-stall barns with milking parlours, and rotary and tie-stall barns. In this study, we focus on barns with AMS. The space requirement per cow is 6 m^2 per animal (Swedish Board of Agriculture, 2020). This allowed us to calculate the cost of flooring per animal. The average milk yield per cow for Sweden was 10,417 Kg ECM in 2019/20 (Växa Sverige, 2020b). According to information in the Swedish Dairy Cow Recording Scheme, dairy cows in the case study area were culled on average at an age of 1,884 days with a minimum of 1,069 days and a maximum of 3,769 days.

The farm survey data showed that the majority of the respondents (68%) had made some changes in their flooring and flooring pattern since the original installation. The original floor used in alleys and walkways was cast concrete and/or slatted concrete. Common floor quality improvements were identified from the survey. More than half of the farms had rubber mats on all or parts of the floor in alleys and waiting areas. Surfaces covered with a rubber mat varied between 5 and 100%, with a median of 50%.

2.3 Specification of regression coefficients from tornado graphs

The estimation of the regression estimates from Tornado graph follow a stepwise multiple regression process (Palisade, 2022). Empirically, we specify our Tornado regression as

$$NI = \sum_{i=1}^{I} \gamma AInc + \sum_{n=1}^{N} \gamma Rcost - \sum_{j=1}^{J} \gamma Acost - \sum_{g=1}^{G} \gamma RInc + \varepsilon \tag{1}$$

NI denotes change in net income; $\sum_{i=1}^{I} AInc$ *is* the sum of added income variables; $\sum_{n=1}^{N} \gamma Rcost$ is the sum of reduced cost variables; $\sum_{j=1}^{J} Acost$ denotes the sum of added cost variables; $\sum_{g=1}^{G} RInc$ denotes the sum of reduced income variables. Detail of added income, reduced cost, added cost and reduced income variables are discussed in Sections 2.4 and 2.5. γ is the standardized regression coefficients to be estimated. It is worth noting that the estimated standardized coefficients ($\hat{\gamma}$) are scaled or "normalized" by the standard deviation of the output and the standard deviation of that input (Palisade, 2022). Thus, the standardized regression coefficients are not expressed in terms of actual euros (€) or other units. To get the actual coefficient in terms of units of input and units of output, the estimated standardized coefficients ($\hat{\gamma}$) is multiplied by the standard deviation (SD) of the output and divided by the standard deviation (SD) of the input as specified in equation (2).

$$Actual\ coeff = \left(\hat{\gamma} * SD(output)\right) \Big/ SD(input) \tag{2}$$

Regarding the interpretation of the Tornado Graph, the larger the coefficient (i.e. the longer the bar), the greater the impact of that specific input on the output. For a given variable, a positive coefficient, with bar extending to the right, shows the variable has a positive impact on the output and that an increase in the variable will increase the output Ahmed *et al.* (2021). A negative coefficient, with bar extending to the left, shows the variable has a negative impact on the output and that increasing the variable will reduce the output. McFadden's pseudo R^2 was used to compare different simulated models and to select the best fit.

2.4 Model to evaluate the effects of covering solid concrete flooring with soft rubber coverings on net income per herd per year

Table 1 shows the cost and benefit parameters with the units and distributions used in the model for solid flooring with soft rubber mat (Comfort Mats, 24 MM thickness) covering in alleys and waiting areas. Stochastic variables were modelled using triangular distribution to take into account the lower and upper bound values. The installation of soft rubber coverings on solid concrete floors in alleys and walking areas results in certain costs and benefits.

2.4.1 Added cost. In terms of costs, the farmer incurs additional costs for covering the solid concrete floor with soft rubber coverings. Annual investment costs for soft rubber floors with a 10-year maintenance period was modelled stochastically using triangular distribution with an average cost of €8,105 per herd [3]. It was assumed that the space covered by rubber mats is 6 m^2 per animal (Swedish Board of Agriculture, 2020). In order to obtain overall investment costs, the total number of cows multiplied the average cost per cow. The overall investment cost of rubber mats, installation, and maintenance per herd was obtained by multiplying the average cost per cow by the total number of cows. In addition, our survey data showed that herds kept on rubber mats have a lower proportion of cows with >70 days from calving to first insemination in comparison with herds kept on grooved concrete flooring. The total cost of culling due to fertility disorders was computed by multiplying the reduced cull number by the cost incurred for a culled animal. This value was included in the partial budget as a reduced cost due to change in flooring surface.

2.4.2 Added benefits. In terms of benefits, the survey data showed that herds kept on soft rubber coverings had higher milk yield relative to those kept on solid concrete floor. The total

Variables	Data	Source	Type	Distribution
Investment cost of soft rubber floor[1]	€[2]8,105/herd/year	Survey data (2021)	Stochastic	Triangular [680, 8105, 10,958][3]
Average milk yield SH	11,568 kg/ECM	Survey data (2021)	Deterministic	–
Average milk yield SR	10,406 kg/ECM	Survey data (2021)	Deterministic	–
Increase in milk yield SR	910 kg/ECM/cow	Survey data (2021)	Stochastic	Triangular [750, 910, 950]
Increase in milk yield SH	815 kg/ECM/cow	Survey data (2021)	Stochastic	Triangular [700, 815, 900]
Culling due to fertility problems SR	4 cows/herd/year	Survey data (2021)	Stochastic	Triangular [3, 4, 5]
Culling due to fertility problems SH	5 cows/herd/year	Survey data (2021)	Stochastic	Triangular [4, 5, 6]
Culling due to claw and leg disorder SR	3 cows/herd/year	Survey data (2021)	Stochastic	Triangular [2, 3, 4]
Culling due to claw and leg disorder SH	2 cows/herd/year	Survey data (2021)	Stochastic	Triangular [1, 2, 3]
Mortality rate SR	3 cows/herd/year	Survey data (2021)	Stochastic	Triangular [2, 3, 4]
Mortality rate SH	3 cows/herd/year	Survey data (2021)	Stochastic	Triangular [2, 3, 4]
Mortality cost	€671/cow	Oskarsson (2010)	Stochastic	Triangular [604, 671, 738]
Fertility disorder cost	€31/month	Oskarsson (2010)	Stochastic	Triangular [27, 31, 46]
Claw and leg disease cost	€252/case	Oskarsson (2010)	Stochastic	Triangular [226, 252, 277]
Price of milk	€0.36/kg	Agriwise (2020)	Stochastic	Triangular [0.24, 0.36, 0.39]
Average annual return	€0.19/kg/milk	Agriwise (2020)	Stochastic	Triangular [0.15, 0.19, 0.22]

Note(s): 1 Annuity of 5% discount and 10 years maintenance was used
2 Exchange rates: 2021(€1: SEK10.13), 2020(€1: SEK10.29), 2010(€1: SEK9.54)
3 Values in parenthesis are [lower bound, average, upper bound] values
Source(s): Authors work

Table 1. Variables used in the partial budget model for solid concrete floor with soft rubber covering

value of the increase in milk yield was obtained by multiplying the average yield increase for the different breeds by the average return per kg of milk. The value of the increase in milk yield was included in the partial budget as added income due to change. Fertility is one of the main reasons for culling in Sweden, accounting for 22.9% culling (Växa Sverige, 2019).

The mortality rate on an average Swedish farm is 6% (Växa Sverige, 2019). We calculated the mortality cost saved by multiplying the number of animals saved from death by the mortality cost per cow. Average mortality cost per cow modelled is €671 per cow (Oskarsson, 2010). The total mortality cost saved was included in the partial budget as a reduced cost due to change in flooring surface. In addition, keeping herds on soft rubber coverings reduces cases of claw and leg disorders. Bergsten *et al.* (2015) showed that primiparous cows with rubber mats on top of a slatted floor had significantly less claw and leg lesions than those on concrete slatted floors, and as a result, lower direct costs for veterinarian-treated claw and leg disorders. The reduction in culling due to claw and leg disorders for cows on soft rubber floors was modelled stochastically. The direct cost per reported veterinarian-treated claw and leg disorder is €252 per case. The total claw and leg disorder cost was calculated by multiplying the number of cases by the cost per reported case. This value was added as a reduced cost due to the change in the partial budget.

2.5 Model to evaluate the effects of slatted concrete flooring with soft rubber covering on net income per herd per year

In Table 2, we present the cost and benefit parameters with their units and distributions used in the model for slatted floor with soft rubber covering.

Table 2.
Variables used in the partial budget model for slatted concrete floor with soft rubber covering

Variables	Data	Source	Type	Distribution
Investment cost of rubber mats	€12,803/herd/year	Survey data (2021)	Stochastic	Triangular [11,523, 12,803, 14,083]
Average milk yield SH breed	11,222 Kg ECM	Survey data (2021)	Deterministic	–
Average milk yield SR breed	10,997 Kg ECM	Survey data (2021)	Deterministic	–
Increase in milk yield SR	1044 kg ECM/cow	Survey data (2021)	Stochastic	Triangular [940, 1044, 1148]
Increase in milk yield SH	565 kg ECM/cow	Survey data (2021)	Stochastic	Triangular [509, 565, 622]
Culling due to fertility problems SR	6 cows/herd/year	Survey data (2021)	Stochastic	Triangular [4, 6, 7]
Culling due to fertility problems SH	5 cows/herd/year	Survey data (2021)	Stochastic	Triangular [4, 5, 6]
Culling due to claw and leg disorder SR	2 cows/herd/year	Survey data (2021)	Stochastic	Triangular [1, 2, 4]
Culling due to claw and leg disorder SH	2 cows/herd/year	Survey data (2021)	Stochastic	Triangular [1, 2, 3]
Mortality rate SR	4 cows/herd/year	Survey data (2021)	Stochastic	Triangular [3, 4, 6]
Mortality rate SH	4 cows/herd/year	Survey data (2021)	Stochastic	Triangular [3, 4, 6]
Mortality cost	€671/cow	Oskarsson (2010)	Stochastic	Triangular [604, 671, 738]
Fertility disorder cost	€31/month	Oskarsson (2010)	Stochastic	Triangular [27, 31, 46]
Claw andleg disorder cost	€ 252/case	Oskarsson (2010)	Stochastic	Triangular [226, 252, 277]
Price of milk	€0.36/kg	Agriwise (2020)	Stochastic	Triangular [0.24, 0.36, 0.39]
Average annual return	€0.19/kg/milk	Agriwise (2020)	Stochastic	Triangular [0.15, 0.19, 0.22]

Source(s): Authors work

2.5.1 Added costs. In terms of costs, a farm incurs additional costs for covering slatted floors with soft rubber coverings after the construction of a slatted concrete floor barn. The annual investment costs for slatted floors with soft rubber coverings and a maintenance of period of ten years is €12,803 per herd. The investment costs for soft rubber floors were included in the partial budget as added costs due to change.

2.5.2 Added benefit. In terms of benefits, the field survey data indicated that the milk yield of SR herds on slatted floors with soft rubber coverings was 1,044 kg ECM greater than herds on solid concrete floors. Similarly, milk yield of SH herds on slatted floors with soft rubber coverings was 565 kg ECM greater than herds on solid concrete floors. The value of the increase in milk yield was included in the partial budget as added income due to change. Reduced culling due to fertility problems on slatted floors with soft rubber coverings was modelled stochastically. The total cost of culling due to fertility disorders was computed by multiplying the reduced cull number by the cost incurred for a culled animal. Reduced culling due to claw and leg disorders on slatted floors with soft rubber was modelled stochastically, with an average of one SR cow and two SH cows per herd per year. The cost value for reduced culling due to fertility, and claw and leg disorders was included in the partial budget as a reduced cost due to change in flooring surface.

Based on the survey data, it assumed that mortality on slatted floors with a soft rubber covering was reduced per herd. The calculation of the total mortality costs follows the same procedure for solid concrete floors with soft rubber coverings. The total mortality cost saved was included in the partial budget as a reduced cost due to change in flooring surface.

The total reduced cost due to a reduced number of cows with claw and leg disorders was added as a reduced cost due to the change in the partial budget.

3. Results

3.1 Effects of keeping herds on solid concrete floors covered with soft rubber coverings on net income per herd per year

The results from the partial budgeting model for the scenario where dairy herds are kept on solid concrete floors covered with soft rubber coverings, instead of on bare concrete floors, are provided in Table 3. The results indicate that with the installation of soft rubber coverings on solid concrete floors, the cost for the farm increased by €8,106 per herd per year for both breeds. This amount included costs for soft rubber coverings, installation, and maintenance. However, this increase in cost is offset by a net increase in income (i.e. added income and reduced costs due to the change). The added income due to the change was the result of an increase in milk yield for herds kept on soft rubber surfaces. The cost reduction was observed through the prevention of milk losses, reduction in culling, and lower disease costs (fertility, claw and leg disorders, and mortality costs).

The net change in income associated with SR herds kept on solid concrete floors with soft rubber coverings was found to be €3,664 on average, with a minimum of €469 and a

Added income due to change	Value (€) SR	Value (€) SH	Added costs due to change	Value (€) SR	Value (€) SH
Increase in milk yield	7,364 (43)	6,999 (41)	Investment cost for installation and maintenance of soft rubber coverings	8,106 (86)	8,106 (86)
Total added income	*7,364 (43)*	*6,999 (41)*	*Total added cost*	*8,106 (86)*	*8,106 (86)*
Reduced costs due to change			Reduced income due to change		
Reduced culling cost due to fertility problems	1,161(14)	929 (12)			
Reduced culling cost due to claw and leg disorder	697(6)	464 (3)			
Reduced mortality cost	1,895(14)	1,895 (12)			
Reduced claw and leg disorder veterinary cost	474 (0.3)	711 (0.3)			
Reduced fertility disorder veterinary cost	178 (12)	118 (12)			
Total reduced cost	*4,405(466)*	*4,117 (311)*	*Total reduced income*	*0*	*0*
Increase in net income	11,769 (716)	11,116 (680)	Decrease in net income	8,106 (119)	8,106 (119)
Change in net income SR	3,664 (1,118)				
Change in net income SH		3,012 (1,069)			

Note(s): The values presented are means with standard deviations for stochastic components in parenthesis
Source(s): Authors work

Table 3. Effects of keeping herds on solid concrete floor with soft rubber covering in alleys and walking areas on net income in dairy production

maximum of €5,824 per herd per year. For the SH herd, the net change in income was found to be €3,012 on average, with a minimum and maximum value of €852 and €4,687 per herd per year, respectively. The profit per SR cow increased by €37, and the profit per SH cow increased by €30 if the herd is kept on a solid concrete floor with soft rubber covering.

Figures 2 and 3 present the standardized regression coefficients from the model with solid concrete floors covered with soft rubber coverings for both breeds. This simulated model had pseudo R^2 estimates of 0.32. McFadden (1979) indicated that models with pseudo R^2 ranging from 0.2 to 0.4 have a very good fit. As shown in Figures 2 and 3, investment costs for soft rubber floors, which was assumed stochastic, was the most important variable that negatively affected net farm income as shown by the negative standardized coefficients of −0.81 and −0.86 for SR and SH herds, respectively. Following equation (2), a unit increase in investment cost of soft rubber covering is associated with €10.53 (i.e. (0.81*1118)/86) and €10.69 reduction in net income for SR and SH herds per year, respectively.

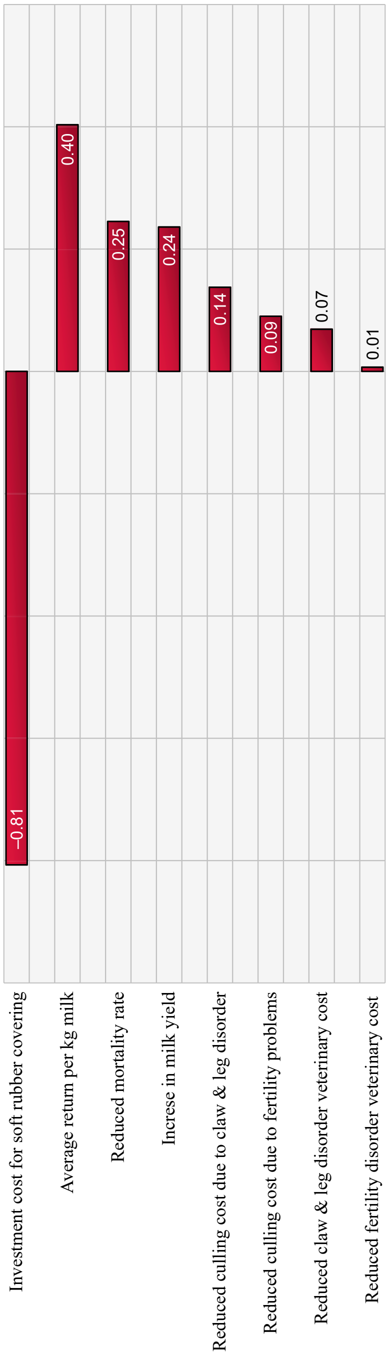
An important variable that positively affects net income was average return per kilogram of milk. For both breeds, a unit increase in average return per kilogram of milk is associated with €27.10 increase in net income per herd per year. For the SR herd, reduced mortality, which was assumed stochastic, was the second most important variable that reduced cost and affected the net income of the farm positively. Specifically, a unit reduction in mortality is associated with €19.96 increase in net income. The next stochastic variable, increased milk yield is associated with €6.24 increase in net income. This was followed by increased fertility and reduced culling costs due to claw and leg disorders. For the SH herd, increase in milk yield, which was assumed to be stochastic, was the second important variable that affected net income positively. Specifically, a unit increase in milk yield is associated with €6.54 increase in net income per herd per year. The next stochastic variable that reduced cost and affected net income positively was reduction in mortality rate. A unit reduction in mortality is associated with €17.82 increase in net income. This is followed by reduced culling costs due to claw and leg disorders, and reduced veterinary costs associated with fertility disorders, respectively. For the sake of brevity, the results of base scenario are presented as supplementary material (see Table S3, Figures S1 and S2).

3.2 Effects of keeping herds on slatted concrete floors covered with soft rubber coverings on net income per herd per year

Table 4 presents the results from the partial budget model for a scenario where dairy herds are kept on slatted concrete floors covered with soft rubber coverings instead of slatted concrete floors without rubber covering. The results indicate that covering the slatted concrete floor with rubber mats increased the farm's costs by €12,803 per herd per year. This amount includes the cost of rubber mats [3], installation and maintenance.

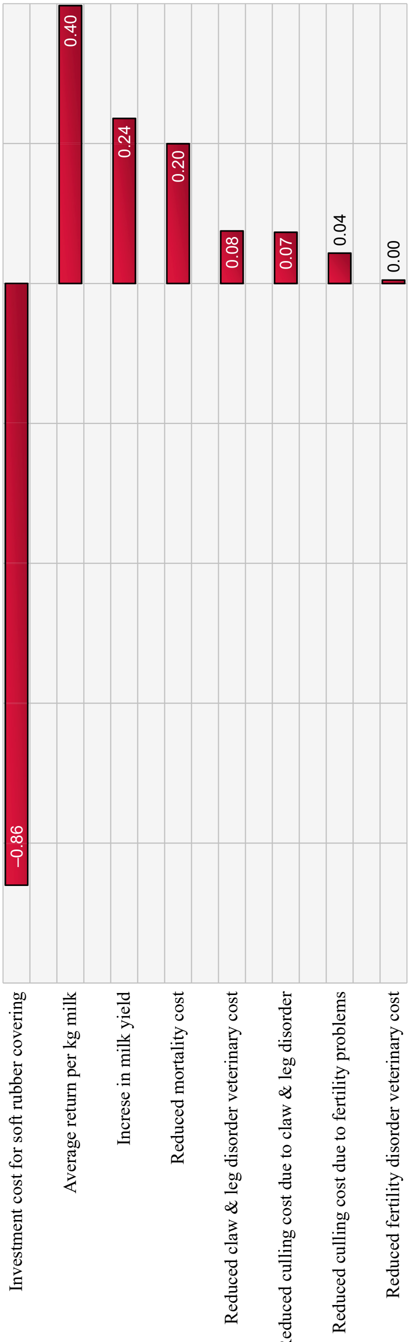
Income was added through an increase in milk yield for herds kept on this type of floor surface. In addition, there was a reduction in costs related to milk losses, culling, mortality, and veterinary expenses. The net change in income associated with SR herds kept on slatted concrete floors with soft rubber coverings was €3,433 on average, with a minimum of €422 and a maximum of €6,766 per year. For the SH herd, the net change in income was €2,687 on average, with minimum and maximum values of €1,120 and €5,360, respectively, per year. The profit per SR cow increased by €34, and the profit per SH dairy cow increased by €27 for herds held on slatted concrete floors with a soft rubber covering.

Figures 4 and 5 present the standardized regression coefficients from the model with slatted concrete floors covered with soft rubber coverings for SR and SH herds, respectively. This model had pseudo R^2 estimates of 0.34. The results in both figures indicate that for both breeds, average return from milk, which was assumed stochastic, was the most important variable that positively affected the net farm income. However, it was observed that the effect



Source(s): Authors work

Figure 2.
Tornado plot with regression coefficients for solid concrete floor with soft rubber covering model for SR



Source(s): Authors work

Figure 3.
Tornado plot with regression coefficients for solid concrete floor with soft rubber covering model for SH

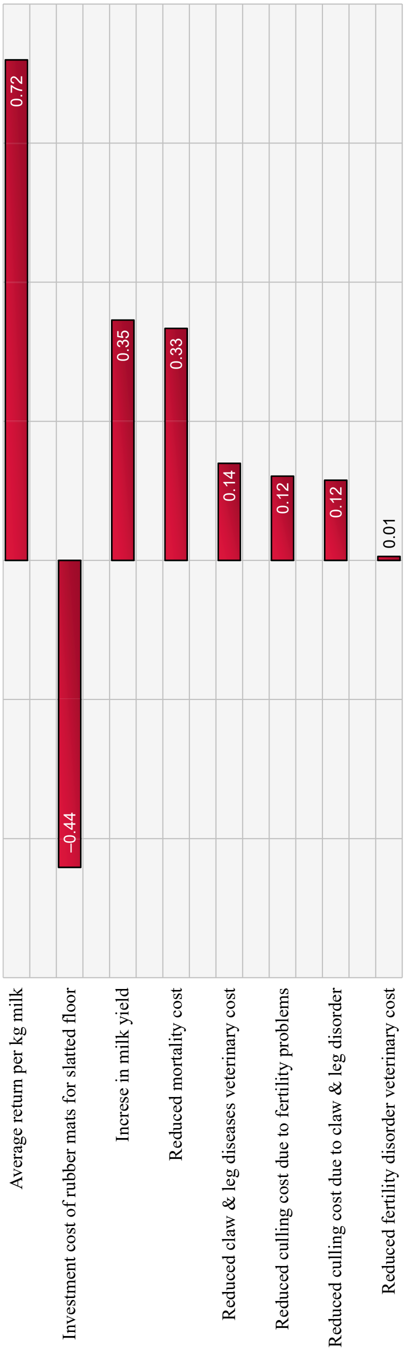
Added income due to change	Value (€) SR	Value (€) SH	Added costs due to change	Value (€) SR	Value (€) SH
Increase in milk yield	11,293(43)	10,010 (23)	Investment cost of installation and maintenance of soft rubber coverings for slatted floor	12,803 (52)	12,803 (52)
Total added income	*11,293(43)*	*10,010 (23)*	*Total added cost*	*12,803 (52)*	*12,803(52)*
Reduced costs due to change			Reduced income due to change		
Reduced culling cost due to fertility problems	1,300 (16)	1,486 (16)			
Reduced culling cost due to claw and leg disorder	464 (6)	511 (6)			
Reduced mortality cost	2,527 (16)	2,654 (17)			
Reduced claw and leg disorder veterinary cost	474 (17)	711 (43)			
Reduced fertility disorder veterinary cost	178 (12)	118 (12)			
Total reduced cost	*4,943 (477)*	*5,480 (483)*	*Total reduced income*	*0*	*0*
Increase in net income	16,236 (1,109)	15,490 (1,000)	Decrease in net income	12,803 (523)	12,803(523)
Change in net income SR	3,433 (1,171)				
Change in net income SH		2,687 (1,065)			

Note(s): The values presented are means with standard deviations for stochastic components in parenthesis
Source(s): Authors work

Table 4. Effects of keeping herds on slatted concrete floor with soft rubber covering in alleys and walking areas on net income in dairy production

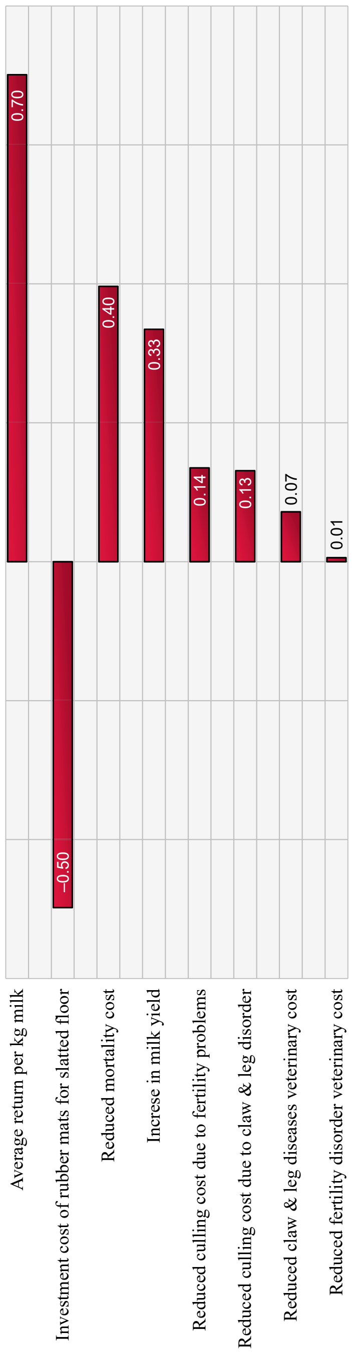
of this variable on net income from the SR model is higher than that of the SH model. In terms of magnitude, a unit increase in average return from milk is associated with €16.21 and €14.34 increase in SR and SH, respectively. For SR model, the second stochastic variable that affected net income positively was increase in milk yield. Specifically, a unit increase in milk yield is associated with €9.53 increase in net income. Next, a unit reduction in mortality is associated with €24.15 increase in net income. In addition, a unit reduction in claw and leg disorder veterinary cost is associated with €9.64 reduction in net income. For SH model, reduced mortality costs was the second stochastic variable that affected net income positively as shown by the standardized coefficient of 0.40. Specifically, a unit reduction in mortality is associated with €25.06 increase in net income. Another stochastic variable that had a positive effect on net income was increase in milk yield, with a unit increase associated with €15.28 increase in net income. Other variables, such as reduced costs from culling due to fertility problems, reduced claw and leg disorders, are associated with increase in net income of the farm.

The results in both figures also show that in both SR and SH herds, investment costs for soft rubber floors, which was assumed to be stochastic, was the most important variable that



Source(s): Authors work

Figure 4.
Tornado plot with regression coefficients for slatted concrete floor with soft rubber covering model for SR



Source(s): Authors work

Figure 5.
Tornado plot with regression coefficients for slatted concrete floor with soft rubber covering model for SH

negatively affected net farm income, as indicated by the negative coefficient estimates of −0.44 and −0.50 for SR and SH, respectively. In term of magnitude, a unit increase in investment cost of soft rubber covering is associated with €9.91 and €10.24 reduction in net income for SR and SH herds, respectively. The baseline results for slatted floor without soft rubber coverings are available in the supplementary file (see Table S4, Figures S3 and S4).

4. Discussion

The present study provides a detailed example of the economic impacts of investments in animal welfare improvement practices, using flooring as an illustration. Our study is highly relevant for farmers' decision-making processes regarding floor types and how the welfare of dairy herd can be improved through adoption of practices that has both animal welfare and economic incentives. In this way, dairy production and supply can be sustained as highlighted by Cox and Bridgers (2019) and Keeling *et al.* (2019) who opined that animal welfare is at the heart of sustainability of the dairy industry. It is also highly relevant for the adoption of sustainable dairy farming practices and effective agricultural policies, as it highlights farm-level economic impacts when farmers move towards flooring systems that can enhance animal welfare. In particular, the present study assessed how the economic situation on dairy farms may change when rubber mats are introduced on top of solid or slatted concrete floors at walking and standing areas. The simulation was performed for a typical Swedish dairy herd consisting of 100 dairy for one production year.

We employed a partial budgeting framework with stochastic elements. The applied framework is a powerful tool for analysing decision-making on the farm and economic effects, particularly in situations where there is lack of detailed empirical data (Ahmed *et al.*, 2021). It allowed us to take into account different 'what if' scenarios in the profitability analysis. It also allowed us to choose the distributional forms that best describe the parameters considered in each model. For instance, each stochastic variable took a triangular distributional form to account for the effect on net income if minimum or maximum values of model parameters are used. The analysis was done with the assumption that there are herds consisting solely of SR and SH cattle. We performed separate analysis for each breed because the two breeds differ in terms of milk output (Bieber *et al.*, 2020; Växa Sverige, 2019; Sverige, Växa, 2020c), veterinary treatment, resistance to disease and disorders (Bieber *et al.*, 2020), and farm returns (Andersson, 2011). In addition, most Swedish farms have a mix of SR and SH cattle. Växa Sverige (2019) and Bieber *et al.* (2020) showed that SH cows generate a higher milk yield compared with SR cows.

The present study revealed that this is only true if herds are kept on soft rubber coverings (See Tables 3 and 4). Our findings indicate that milk yield from SR herds on solid concrete floors is higher than that of SH herds on the same floor surface. The higher milk yield of SR cows in this scenario may be due to their resistance to diseases and disorders. In Sweden, Bieber *et al.* (2020) found that SR cows are more resistant to diseases and disorders and hence had the lowest proportion of general veterinary treatment of all cow breeds. Furthermore, the Comfort Slat Mat (24 MM) used in the scenarios, with its soft rubber covering, is regarded as an expensive alternative compared to the cost of other rubber mats that can be obtained from building companies.

In the first scenario, where dairy herds are kept on solid concrete floors with soft rubber coverings, the findings indicate that the dairy farmer incurs additional costs of €8,105 per herd per year for the purchase of soft rubber coverings (material), installation, and maintenance. However, the findings reveal that the net increase in income offsets the additional cost. The net increase in income was associated with increased milk yield, reduced mortality, reduced culling due to claw and leg disorders or fertility disorders, and lower rate of disease. These findings are contrary to Norberg (2012), who found no significant difference in milk yield between herds kept on soft rubber coverings and solid concrete floors. The Norberg (2012) study did not account for factors such as feeding and other health parameters that influence milk output. In the present study, relevant health and cost parameters that influence net farm returns were included in the model. The increase in milk yield observed for cattle kept on soft floor surfaces is in line with a Swedish study by Bergsten *et al.* (2015) and a Norwegian study by Ruud *et al.* (2010), which showed that soft floors on lying surfaces is associated with high milk output. In addition, Vanegas *et al.* (2006) found that cows kept on soft rubber floors have a lower risk of claw disorders, such as heel horn erosion, compared with cows kept on solid concrete floors. Previous studies support the reduction in disease and culling costs for herds kept on solid concrete floors with soft rubber coverings.

In terms of profitability, the findings suggest that the profit per SR cow could potentially increase by 15.8% and per SH cow by 13.0% if the herd is kept on a solid concrete floor with soft rubber coverings compared to the base scenario. At the herd level, the net change in income associated with SR and SH herds on solid concrete floors with soft rubber coverings is positive. The increase in net income for both breeds is in line with a study by Ettema and Østergaard (2006), who found an increase in margin of 17 Euros per cow per year on soft rubber coverings in Danish dairy herds. This finding lends support to a recent study by Owusu-Sekyere *et al.* (2021) who unveiled that Swedish dairy farmers' have positive preference for soft floors and that their preference are associated with high income from dairy farming. Our simulation results for both breeds affirm that there is a potential increase in the net income of herds that are kept on soft floors.

In the second scenario, where the slatted concrete floor surface was covered with soft rubber coverings, the farmer incurs additional investment costs for soft rubber coverings (Comfort Slat Mat-expensive variant of mats), installation, and maintenance, including the cost of concrete slats. The simulation results for this scenario indicate that the net increase in income from this flooring solution offsets the additional cost. The profitability per SR cow increased by 16.3% and increased by 11.6% per SH cow. At the herd level, the net change in income associated with SR herds kept on this surface is €3,433 and €2,687 per year for SH cows. As explained under the second scenario, the increase in income was associated with higher milk yield, reduced mortality, lower cull rate, and lower disease costs. These findings support the recent call by More *et al.* (2021) for animal welfare programs to maximize efficiencies, as the improved flooring solutions appear to improve farm income. In addition, the potential economic benefits of keeping dairy herds on improved floors (e.g. soft rubber coverings) as found in this study supports a recent study by Owusu-Sekyere *et al.* (2021) who found that Swedish dairy farmers are willing to adopt flooring systems, including soft floors, which improve animal welfare. The authors further found that Swedish dairy farmers attach monetary values to improved flooring attributes such as low-slippery risk and soft floors. Specifically, dairy farmers in Sweden were willing to offer $69 to switch from hard floors to soft floors (Owusu-Sekyere *et al.*, 2021).

For both solid concrete and slatted floors with rubber coverings, the results indicate that there is a variation in net income and profitability for the two breeds considered in this study, with SR cows performing better than SH cows when kept on flooring with a rubber covering. The differences in income observed in this study may be due to the timing of the survey, price levels, and the fact that we considered different parameters in the present study. The differences in income between the two breeds is contrary to what Andersson (2011) found in a comparison between the incomes obtained from SR and SH cows. Andersson (2011) found small differences between the incomes generated by the two breeds, with SH cows obtaining higher income compared with SR cows. It is worth noting that the comparison made by Andersson (2011) did not consider flooring types. The approach developed here can be used for such evaluations, using data from other case study areas. The simulation approach employed allowed us to consider different flooring scenarios.

5. Conclusion and implications

With a growing focus on the importance of adoption of sustainable production practices, and on the sustainable use of agricultural resources, there is also a growing demand for new innovations that enable farmers to monitor and improve herd animal health and welfare, thereby improving productivity and sustainability of livestock production. Animal welfare is a key aspect of the social sustainability of dairy production and is linked to both environmental and economic sustainability (Arvidsson Segerkvist *et al.*, 2020). A central aspect of animal welfare is the housing conditions; as such it is clearly related to two of the five freedoms animals should enjoy (Farm Animal Welfare Council, 2019) as it relates to both freedom from discomfort and freedom from pain, injury or disease. Improving the floors which are used in houses where dairy cows are kept would therefore be a strategy to improve the welfare of the cows and thus to improve the sustainability of dairy productions.

We conclude that investing in flooring may improve animal welfare and enhance economic performance of dairy farms. Giving these benefits, investments in improved floors could be expected without public support in the form of animal welfare improvement incentives for farmers. The study strongly suggests that keeping herds on floor surfaces with soft rubber coverings instead of solid or slatted concrete floors could be a profitable solution for farmers. We can also conclude that SR herds perform better economically than SH herds when kept on solid and slatted floors with rubber coverings. The economic impact of the different floor interventions is highly relevant for Swedish farmers given that the study utilized national data and the specific conditions of Swedish dairy herds in the simulation and modelling. Future research is needed to evaluate the economic impact of improved flooring solutions in dairy farms in other settings.

Our findings, by providing key insights into how animal welfare–friendly flooring solutions relate to the economic situation on the farms, provide insights into farmers' economic incentives to use production approaches that enhance animal welfare and thus the sustainability of dairy production. In particular, the findings are important from the perspective of agricultural policy as they show that farmers have private economic incentives to invest in floors that enhance economic performance and indirectly improve animal welfare. This is interesting also from the perspective of the ongoing debate among stakeholders, which indicates that there is concern about the economic impact of measures to enhance animal welfare. In relation to our results, this discussion points to a lack of information and understanding about how various animal welfare enhancements affect farm economic outcome and underlines the need for in-depth assessments of such effects as a basis for both policy design and information in the dairy sector.

The findings also point to the public and policymakers that animal welfare improvements come with high investment and as such investment support can be provided in scenarios where the returns to investment cannot offset the cost. In order to achieve a sustainable and competitive dairy sector, individual and intergovernmental initiatives must recognize the relevance of investment cost, potential economic outcome, health and ethical considerations in uptake of such initiatives. Giving the high investment cost associated with soft rubber floors installation and maintenance, public policy should continue and improve the investment support for the reconstruction of animal housing as well as support for improved hoof health for dairy cows in Sweden. In this way, we can sustain the dairy sector. The findings also imply that economic incentives could be a feasible way to incentivize uptake of interventions that improve animal welfare and hence sustaining the dairy production in an era where legislations and resolutions are passed for governing how farm animals should be treated.

From farmers' viewpoint, the findings point out how animal welfare enhancing investments may affect the economic outcome of dairy farms. These insights would be useful in guiding farmers in their decision-making about whether or not to invest in improved housing facility (e.g. soft floors) in the dairy herd, considering economic concerns. This would also be useful in informing discussions about cost and ethical considerations related to dairy farming. The findings provide useful insight for farmers and their advisors to make more informed decisions about floor surfaces.

From research viewpoint, the input and output parameters, statistics and the simulated results can act as relevant and very informative basis for future simulations regarding uptake of animal welfare friendly dairy production. The approach used here can also be used to assess the economic effects related with animal health and welfare improvement measures or practices in other types of livestock production to produce knowledge needed to understand the economic consequences of adoption of more sustainable practices.

Notes

1. Average exchange rate 2008 (€1: SEK9.61). Source: Sveriges Riksbank
2. Average exchange rate 2011 (€1: SEK9.03): Source: Sveriges Riksbank
3. Comfort Slat Mat (24 MM)

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Supplementary Material

Table S1. Variables used in partial budget model for solid concrete floor surface (baseline scenario 1)

Variables	Data	Source	Type	Distribution
Average milk yield per cow (all breeds)	10,146 Kg ECM	Survey data (2021)	Deterministic	–
Average milk yield SH	10,657 Kg ECM	Survey data (2021)	Deterministic	–
Average milk yield SR	11,559 Kg ECM	Survey data (2021)	Deterministic	–
Milk losses SR	910 kg ECM/cow	Survey data (2021)	Stochastic	Triangular [750, 910, 950]
Milk losses SH	682 kg ECM/cow	Survey data (2021)	Stochastic	Triangular [600, 682, 815]
Culling due to fertility problems SH	7 cows/herd/yr	Växa Sverige (2019:2020c)	Stochastic	Triangular [3, 7, 8]
Culling due to fertility problems SR	8 cows/herd/yr	Växa Sverige (2019: 2020c)	Stochastic	Triangular [4, 8, 9]
Culling due to claw and leg disorder SH	4 cows/herd/yr	Survey data (2021)	Stochastic	Triangular [3, 4, 6]
Culling due to claw and leg disorder SR	3 cows/herd/yr	Survey data (2021)	Stochastic	Triangular [2, 3, 5]
Fertility disorder cost	€[1]31/month	Oskarsson (2010)	Stochastic	Triangular [27, 31, 46]
Claw/leg disorder cost	€ 252/case	Oskarsson (2010)	Stochastic	Triangular [226, 252, 277]
Mortality rate SRB	5 cows/herd/year	Växa Sverige (2020c)	Stochastic	Triangular [3, 5, 6]
Mortality rate SH	6 cows/herd/year	Växa Sverige (2020c)	Stochastic	Triangular [3, 6, 8]
Mortality cost	€671/cow	Oskarsson (2010)	Stochastic	Triangular [604, 671, 738]
Price of milk	€0.36/kg	Agriwise (2020)	Stochastic	Triangular [0.24, 0.36, 0.39]
Average annual return per kg milk	€0.19/kg/milk	Agriwise (2020)	Stochastic	Triangular [0.15, 0.19, 0.22]

Note(s): 1 Exchange rates: 2021(€1: SEK10.13), 2020(€1: SEK10.29), 2010(€1: SEK9.54)
Values in parenthesis are [lower bound, average, upper bound] values for stochastic variables
Source(s): Authors work

Table S2.
Variables used in the partial budget model for slatted concrete floor surface (baseline scenario 2)

Variables	Data	Source	Type	Distribution
Average milk yield SH	11,102 Kg ECM	Survey data (2021)	Deterministic	–
Average milk yield SR	10,514 Kg ECM	Survey data (2021)	Deterministic	–
Increase in milk yield on slatted floor SR	561 kg ECM/cow	Survey data (2021)	Stochastic	Triangular [505, 561, 570]
Increase in milk yield on slatted floor SH	445 kg ECM/cow	Survey data (2021)	Stochastic	Triangular [400, 445, 490]
Milk losses due to severe sole ulcer SR	500 kg ECM	Oskarsson (2010)	Stochastic	Triangular [450, 500, 550]
Milk losses due to severe sole ulcer SH	550 kg ECM	Oskarsson (2010)	Stochastic	Triangular [450, 550, 605]
Culling due to fertility problems SH	6 cows/herd/year	Survey data (2021)	Stochastic	Triangular [4, 6, 8]
Culling due to fertility problems SR	5 cows/herd/year	Survey data (2021)	Stochastic	Triangular [4, 5, 8]
Culling due to claw and leg disorder SH	2 cows/herd/year	Survey data (2021)	Stochastic	Triangular [1, 2, 3]
Culling due to claw and leg disorder SR	1 cows/herd/year	Survey data (2021)	Stochastic	Triangular [1, 1, 3]
Fertility disorder cost	€31/month	Oskarsson (2010)	Stochastic	Triangular [27, 31, 46]
Claw/leg disorder cost	€ 252/case	Oskarsson (2010)	Stochastic	Triangular [226, 252, 277]
Mortality rate SR	5 cows/herd/year	Survey data (2021)	Stochastic	Triangular [3, 5, 6]
Mortality rate SH	6 cows/herd/year	Survey data (2021)	Stochastic	Triangular [3, 6, 7]
Mortality cost	€671/cow	Oskarsson (2010)	Stochastic	Triangular [604, 671, 738]

Source(s): Authors work

1. Effects of keeping herds on solid concrete floor surfaces on net income in dairy production

The partial budgeting results for a scenario where a dairy herd of 100 cows is kept on a solid concrete floor (base scenario) instead of on soft rubber mats are provided for SR and SH cows (Table S3). The results indicate that the total costs incurred by the farm are reduced due to forgone investments in the installation and maintenance of soft rubber mats. However, this reduction is offset by additional costs arising due to high disease rates, culling (due to fertility problems and claw and leg disorders), and mortality costs, as well as costs related to milk losses on this type of floor.

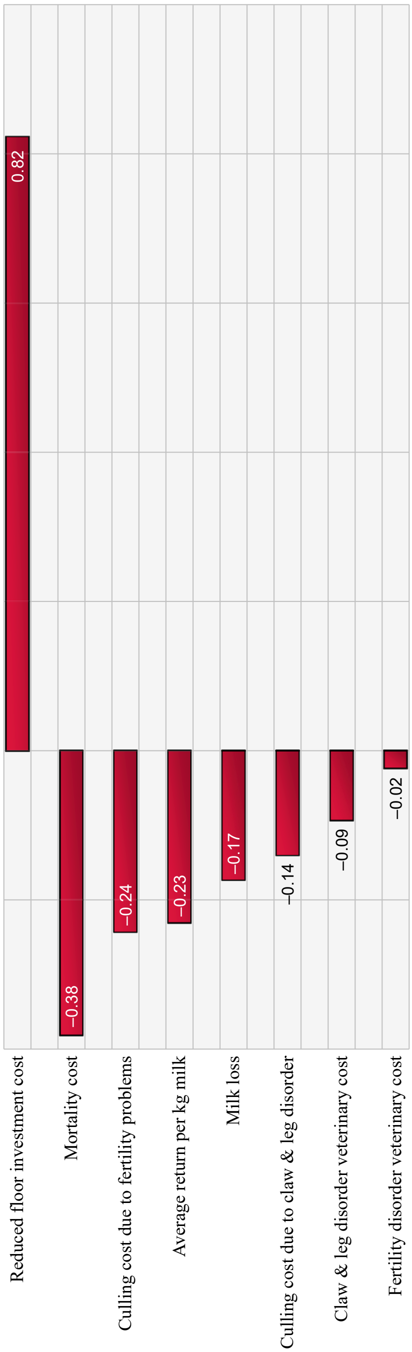
The simulation showed net change in income associated with SR herds on a solid concrete surface to be -€2,110 on average, with a minimum of -€3,554 and a maximum of €2260. Similarly, net change in income for SH herds on a solid concrete surface was found to be -€2,436 per year on average, with a minimum of -€4,152 and a maximum of €2,160. The profit per SR cow, which was €232, is reduced by €21 (i.e. estimated as €2,110/100 = 21) to €211, and the profit per SH cow is reduced by €24 to €208 if the herd is kept on solid concrete surfaces.

The Tornado plots in Figures S1 and S2 show the standardized regression coefficients from the model with solid concrete floors for SR herds and SH herds, respectively. Figures S1 and S2 show that the reduced floor investment cost, which was assumed to be stochastic, was the most important parameter that positively affected the net farm income in both breeds, as indicated by the positive coefficient estimates of 0.82 and 0.74, respectively. However, its contribution effect is higher in the SR model than the SH model. Mortality cost, which was assumed a stochastic variable, was the second most important variable that reduced income and affected the net income of the farm negatively for both the SR and SH plots. However, the effect of mortality cost on net income was higher for SH compared with SR, as indicated by the negative regression coefficients of −0.57 and −0.38, respectively. Besides mortality costs, culling costs due to fertility problems, which was a stochastic variable, was another key variable that reduces income and negatively affects farm income in both SR and SH plots. Other stochastic variables that reduced income and affected the contribution margin negatively include average return per kilogram of milk, milk loses, culling due to claw and leg disorders, and veterinary costs related to fertility, and claw and leg disorders.

Added income due to change[2]	Value (€)[b] SR	Value (€) SH	Added costs due to change	Value (€) SR	Value (€) SH
	–	–	Culling cost due to fertility problems	1,857	1,625
	–	–	Culling cost due to claw and leg disorder	697	929
	–	–	Mortality cost	3,159	3,791
	–	–	Claw and leg disorder veterinary cost	948	948
	–	–	Fertility disorder veterinary cost	592	533
Total added income	*0*	*0*	*Total added cost*	7,253 (496)	7,826(720)
Reduced costs due to change			*Reduced income due to change*		
Reduced investment cost due to forgone installation and maintenance soft rubber mats	8,105	8,105	Milk losses	2,962	2,715
Total reduced cost	*8,105 (119)*	*8,105 (119)*	*Total reduced income*	*2,962 (295)*	*2,715* (261)
Increase in net income	8,105(119)	8,105 (119)	Decrease in net income	10,215 (581)	10,541(760)
Change in net income SR	−2,110(1,021)				
Change in net income SH		−2,436(743)			

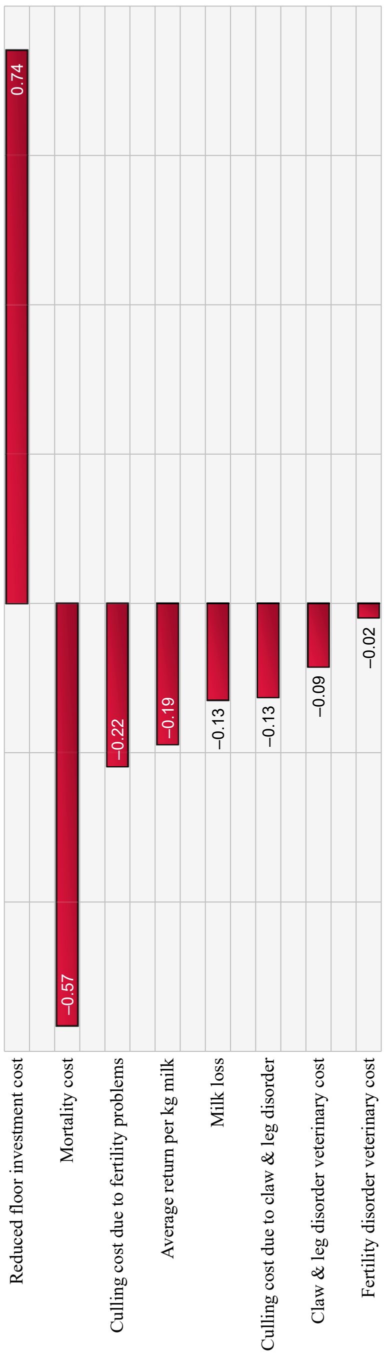
Note(s): The values presented are means with standard deviations for stochastic components in parenthesis
[b] Exchange rates: 2021(€1: SEK10.13)
2 The change refers to the type of floor chosen by the farmer. E.g. added cost due to change refers to the cost parameters added due to using a given chosen floor
Source(s): Authors work

Table S3. Effects of continuing keeping herds on solid concrete floors in alleys and walking areas on net income in dairy production



Source(s): Authors work

Figure S1.
Tornado plot with regression coefficients for solid concrete floor model for SR



Source(s): Authors work

Figure S2. Tornado plot with regression coefficients for solid concrete floor model for S

2. Effects of keeping herds on slatted concrete floor on net income in dairy production

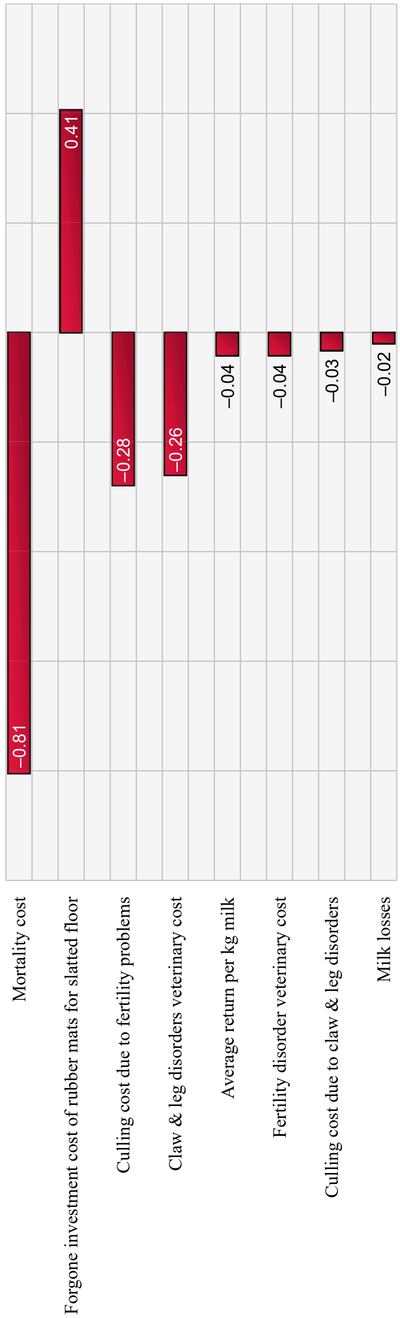
Table S4 presents the results from the partial budget model for a scenario where dairy herds are kept on slatted concrete floors without rubber covering. The results indicate that the farmer forgoes investment costs for installation and maintenance of soft rubber. The farmer saves €5,741 per year due to forgone investment in concrete slats, installation, and maintenance. Despite the forgone investment costs, the costs associated with high disease, culling (decreased fertility, and claw and leg disorders), milk losses, and mortality affected the net income. From the simulation analysis, the net change in income associated with SR herds on slatted concrete surfaces was -€480 on average, with a minimum of -€2,380 and a maximum of €1310. Similarly, net change in income for SH herds on the same floor surface was -€797 per year on average, with a minimum of -€-2,278 and a maximum of €1,065. The profit per SR cow is reduced by €5 to €227, and the profit per SH cow is reduced by €8 to €224, if herds are held on slatted concrete surfaces.

Figures S3 and S4 indicate that for both breeds, the most important variable that positively affected the net farm income was forgone investment costs for concrete slats, installation, and maintenance. This is shown by the positive coefficient estimates of 0.41 for both breeds. The key stochastic variable that affected net income negatively in both breeds was mortality costs, as indicated by the negative coefficient estimates of −0.81 for SR and −0.82 for SH models. The next stochastic variables that affected net income negatively were costs for culling due to fertility problems and veterinary treatment of claw and leg disorders.

Added income due to change	Value (€)[b] SR	Value (€) SH	Added costs due to change	Value (€) SR	Value (€) SH
	–	–	Culling cost due to claw and leg disorders	464	464
	–	–	Culling cost due to fertility problems	1,347	1,393
	–	–	Mortality cost	3,159	3,348
	–	–	Claw and leg disorder veterinary cost	426	474
	–	–	Fertility disorder veterinary cost	529	533
Total added income	0	0	*Total added cost*	*5,925 (400)*	*6,212 (425)*
Reduced costs due to change			*Reduced income due to change*		
Forgone investment cost of rubber mats for slatted floor	5,741	5,741	Milk losses due to severe sole ulcer	296	326
Total reduced cost	5,741 (235)	5,741 (235)	*Total reduced income*	*296 (27)*	*326 (322)*
Increase in net income	5,741 (235)	5,741 (235)	Decrease in net income	6,221 (590)	6,538 (524)
Change in net income SR	−480(351)				
Change in net income SH		−797(585)			

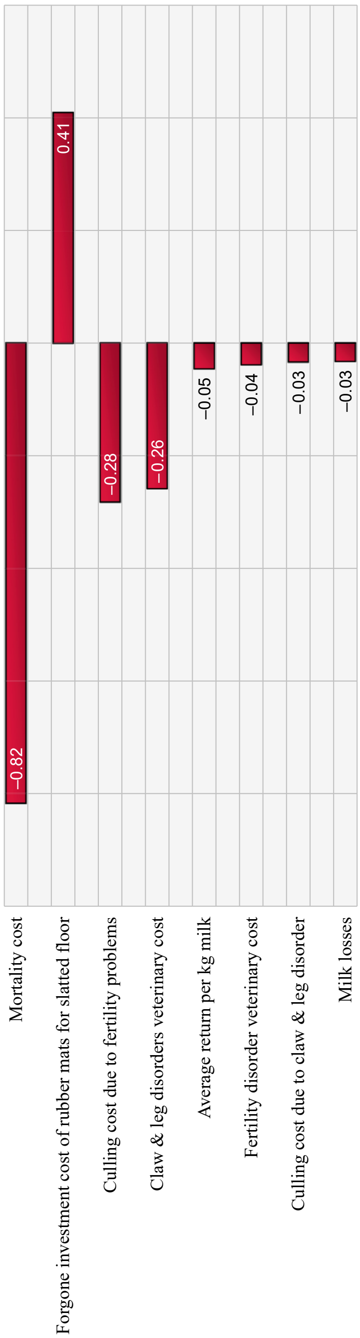
Note(s): The values presented are means with standard deviations for stochastic components in parenthesis
[b] Exchange rates: 2021(€1: SEK10.13)
Source(s): Authors work

Table S4.
Effects of keeping herds on slatted concrete floor in alleys and walking areas on net income in dairy production



Source(s): Authors work

Figure S3. Tornado plot with regression coefficients for slatted concrete floor model for SR



Source(s): Authors work

Figure S4.
Tornado plot with regression coefficients for slatted concrete floor model for SH