



Embedding animal welfare in sustainability assessment: an indicator approach

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Abstract

In line with growing consumer interest in sustainable food production, a number of farm-level sustainability indicator studies have been published in recent years. Despite the importance of animal welfare, many such frameworks fail to adequately take account of it, mostly due to difficulties in accessing suitable data. This paper demonstrates that it is possible to develop indicators of animal welfare that can be embedded within a wider sustainability framework using a representative farm-level dataset such as the European Union (EU) Farm Accountancy Data Network (FADN) for Ireland, the Teagasc National Farm Survey. The paper presents a set of sustainability indicators for dairy farms in Ireland for the 2014–2017 period and examines the impact of policy reform on sustainability performance. Headline results show that welfare standards on dairy farms in Ireland have remained stable over the period despite the considerable intensification of the dairy sector following EU milk quota removal. Furthermore, dairy farms that have expanded herd size significantly have improved welfare standards more than farms that have not increased production. An analysis of synergies and trade-offs between the various aspects of sustainability reveals that positive correlations exist between welfare standards and economic and environmental performance. The analysis facilitates the identification of win-win farm-level strategies that can be adopted to improve economic, environmental and animal welfare outcomes. The framework developed here presents opportunities for evaluating policy impacts at the farm level on various aspects of sustainability. The use of the FADN demonstrates the capacity to extend such an approach across the EU.

Keywords

Agricultural sustainability • composite welfare indicator • dairy cow welfare • dairy farm expansion • social sustainability

Introduction

The concept of sustainability is at the core of contemporary food and agricultural policy. The goal of the European Union (EU) Common Agricultural Policy (CAP), to continue to foster sustainable food production, is clearly reflected in the recent Green Deal and Farm to Fork strategies, which aim to make food systems fair, healthy and environmentally friendly. Indeed, the latter highlights the importance of the evaluation and revision of existing animal welfare legislation, and the further collection of data to assess the sustainability of farming more broadly. In line with legislation, there is a growing demand for practical and scientifically valid assessments of animal welfare in order to safeguard and address gaps, while satisfying the public's request for increased transparency. Indeed, over 80% of European citizens have cited animal welfare as a serious concern, believing that the welfare of farm animals should be better protected (European Commission, 2016).

Arising from market and political interests, a plethora of indicator-based assessments of the sustainability of food production have emerged (FAO, 2014; Van Asselt *et al.*, 2014; Ryan *et al.*, 2016; Bonisoli *et al.*, 2019; Soldi *et al.*, 2019). Although such studies typically include indicators of the economic, environmental and social performance of farms and/or food production, animal welfare is often inadequately addressed, as highlighted in a recent review by Brennan *et al.* (2020). Those studies that did address animal welfare utilised combinations of various resources and animal-based measures and tended not to be based on nationally representative datasets (Van Calker *et al.*, 2005; Arandia *et al.*, 2011; Lillywhite *et al.*, 2012).

Traditionally, farm animal welfare has been assessed using resource-based measures reflecting welfare standards through management or environmental attributes, such as access to

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water or housing conditions (Battini *et al.*, 2014; Phythian *et al.*, 2019). More recently, animal-based measures, which have the ability to directly measure the welfare status of livestock, have been recognised as a more effective method (Phythian *et al.*, 2019). One of the prominent welfare assessment methodologies to adopt the animal-based approach was the Welfare Quality (WQ) protocol (de Graaf *et al.*, 2017). The WQ protocol outlined four main welfare principles: good feeding, good housing, good health and appropriate behaviour, with associated criteria and animal-based metrics by which to assess them, such as somatic cell count (SCC), mortality rate and body condition score (Blokhus *et al.*, 2010). These four principles have similar objectives to the “Five Freedoms” (FAWC, 2009) and are predominately measured at animal level, and thus are considered a useful guide for the measurement of animal welfare (EFSA, 2012). However, as the collection of such animal-based data is not feasible on a large, nationally representative scale, the utilisation of routinely collected data to assess the quality of herd management and animal welfare on farms has also been explored as a more practical alternative (Nyman *et al.*, 2011; Warner *et al.*, 2020). De Vries *et al.* (2011) identified numerous variables of routine herd data (VRHD), categorised across management, milk production and milk composition categories, and compared these with established welfare indicators (WIs), to identify associations between the two assessments. The VRHD included variables such as milk yield, SCC, fat, protein, mortality, access to pasture and housing systems. De Vries *et al.* (2011) concluded that many routinely collected herd variables had value in estimating dairy cow welfare. De Vries *et al.* (2014) reported that for most WIs, routinely collected herd data can operate as a pre-screening tool for the detection of dairy herds with severe welfare problems. This was further supported by Brouwer *et al.* (2015), who reported that routinely collected data, such as mortality rates and bulk tank SCC, displayed a significant association with animal-based measures such as the general health impression of the dairy cow, including rumen fill and body condition. Brouwer *et al.* (2015) concluded that an objective monitoring system, based on routinely collected data, served as a better diagnostic tool for detecting dairy herds with poor welfare health status than quarterly farm visits by the herd veterinary practitioners. However, ongoing challenges in defining and developing appropriate animal WIs from routinely collected data have contributed to the dearth of animal WIs in broader sustainability studies and variation in the legitimacy of different animal-based measures across welfare assessments (Winckler, 2019).

In the design of appropriate indicators, the multidimensional nature of sustainability and animal welfare is such that multiple variables using different scales may need to be assessed. To simplify interpretation, multidimensional indicators can be aggregated into a single indicator, termed a composite

indicator (CI) (Talukder *et al.*, 2017). Intended to simplify complex information, CIs are now widely implemented within policy analyses and sustainability assessments, combining data on individual measures or indicators into a single index (Nardo *et al.*, 2005). The WQ protocol utilised CIs to develop a welfare index, based upon numerous animal-based measures at the herd level (de Graaf *et al.*, 2017), with a subsequent study developing a composite health indicator (De Vries *et al.*, 2013). In their assessment of herd welfare, Warner *et al.* (2020) devised a CI from routinely collected herd-level data from dairy farms in Canada.

The objective of this paper is to update an existing suite of farm-level sustainability indicators, developed using data from the Irish Farm Accountancy Data Network (FADN), to include a measure of animal welfare on Irish dairy farms, in order to test the relationship between welfare and other aspects of sustainability, and to record welfare changes through time. The analysis was conducted on data over a 4-yr period from 2014 to 2017. This was a period of dramatic structural change in Irish dairy farms, in preparation for and during the aftermath of EU milk quota removal after three decades. Post-quota, milk production has increased by approximately 50% to date, with growth in both herd numbers and milk yield per cow across farms. The sector is therefore an interesting case study in which to explore herd management and assess animal welfare. While animal-based measures are not available through the dataset, existing herd-level data are instead used to identify suitable variables and develop a composite WI, which can act as a diagnostic tool for the detection of dairy herds with poor welfare status and can monitor progress during a period of intensification and expansion.

Previous sustainability assessments at the farm level in Ireland can be found in Dillon *et al.* (2016), Ryan *et al.* (2016) and Dillon *et al.* (2010), although animal welfare is not considered in these studies. This paper aims to fill that gap by investigating animal welfare and herd management on Irish dairy farms during a period of particular structural change, building on and complementing previous work. This approach facilitates an assessment of welfare and how it relates to wider sustainability metrics (economic, environmental and social). This paper addresses a number of research questions: (i) can expert-validated metrics of animal welfare be developed from a routinely collected, nationally representative dataset as part of a wider sustainability framework, (ii) how do measures of animal welfare relate to other indicators of agricultural sustainability and (iii) how does policy reform (i.e. abolition of milk quota) and subsequent production intensification impact the animal welfare standards. The following section of this paper describes the methodological approach used in the development of a CI of animal welfare and the data utilised. There follows an overview of results and a general

discussion of same, the limitations of the study are then discussed and final conclusions drawn.

Materials and methods

An adapted version of the Organisation for Economic Co-operation and Development (OECD, 2008) model for the development of sustainability indicators is used in this paper to identify appropriate variables and to develop a CI of dairy cow welfare. The model for the development of such CIs is presented in Figure 1.

Theoretical model

The theoretical model to inform variable selection is drawn from Warner *et al.* (2020) and De Vries *et al.* (2011) who utilised routinely collected herd data, similar to the data available for this study, in their assessments of farm management and animal welfare. De Vries *et al.* (2011) identified three important dimensions of animal welfare: (i) production intensity, (ii) milk production and composition and (iii) management and facilities, and relevant variables were chosen to reflect these. Such data informed the selection of variables for our purposes. A brief overview is provided in the following paragraphs.

Herd mortality rate, in particular amongst younger animals, is one of the most pertinent methods to assess health status as it provides an insight into potential instances of diseases or insufficient animal husbandry (Ortiz-Pelaez *et al.*, 2008; Seppä-Lassila *et al.*, 2016). For our purposes, calf mortality is identified as the variable most appropriate to represent herd health. While calf mortality rates may be considered a coarse measure of welfare, in herd situations it can reveal the state of animal welfare at a group level (Seppä-Lassila *et al.*, 2016). Common causes of calf deaths include gastrointestinal disorders, which account for 40% of deaths within the first 6 weeks, and pneumonia, which predominately impacts housed

calves (Teagasc, 2017). In addition to their physical housing environment, dairy cow welfare and behaviour can be impacted by stocking rates (Wang *et al.*, 2016). As such, stocking rate is also included as a variable important for the measurement of production intensity and is an interesting metric given the dramatic growth in Irish milk production in recent years.

Access to sufficient clean water and nutritious food is one of the most pertinent components of any animal welfare assessment. While animal-based indicators such as body condition score, conducted through a visual assessment, are optimal, they are not always feasible. As such, routinely collected variables can be used as proxies. Therefore, management-based metrics, such as total milk constituents, can be used to reflect herd nutrition which has a significant impact on milk composition and quality (Markert, 2017). Assessing fluctuations in milk constituents, namely fat and protein, can indirectly inform the farmer about potential metabolic health issues, such as sub-clinical ketosis (Jenkins *et al.*, 2015; Hanuš *et al.*, 2017). Moreover, low milk yields can result from an unbalanced diet, namely one which has low dry matter intake (Teagasc, 2016). The SCC of milk is also a leading indicator of intra-mammary infection as the leukocytes, which comprise the majority of somatic cell material, increase as an immune response to the presence of a mastitis-causing pathogen (Sharma *et al.*, 2011). These variables are taken into consideration in our welfare assessment of Irish dairy herds.

The provision of sufficient animal shelter ensures protection in times of adverse weather conditions. Dry, well-bedded and draught-free housing are important factors for the health of dairy calves (Lorenz *et al.*, 2011), particularly regarding their susceptibility to bovine respiratory disease, namely calf pneumonia (Earley *et al.*, 2004). In Ireland, housing types consist of primarily slatted cubicle houses, followed by straw-bedded sheds, with the former associated with superior health due to the ease of cleanliness afforded by the slatted system. Moreover, the age and quality of animal housing can

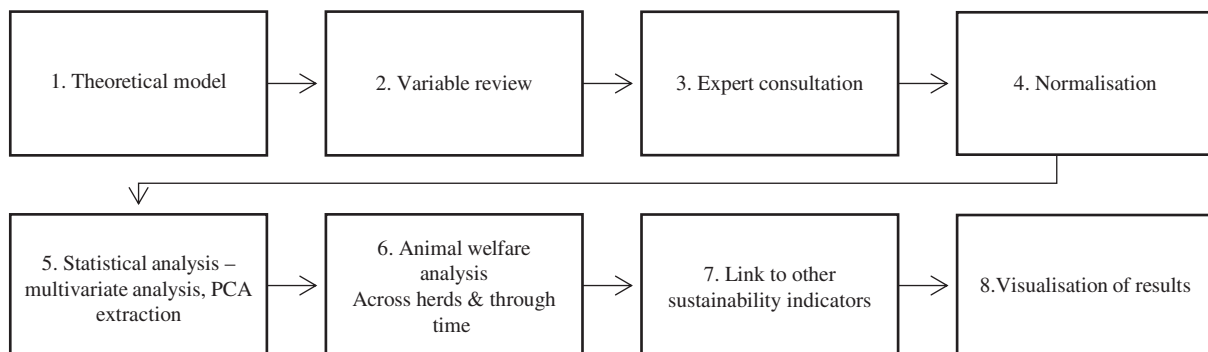


Figure 1. Methodological approach to the development of a composite welfare indicator. Source: Adapted from OECD (2008). PCA = principal component analysis.

be indicative of the comfort level experienced by farm animals (Kelly *et al.*, 2017). Analysing expenditure on dairy cow housing can be revealing of the level of modernisation of the system, and is of particular relevance considering the recent intensification of milk production in Ireland (Teagasc, 2019). The availability of space and the opportunity for animals to graze and express natural behaviours are also imperative for good welfare standards. Pasture-based cows have been shown to exhibit less agonistic behaviour than confined cows (Mee & Boyle, 2020). In this paper, average days at grass is a key indicator of adequate herd management and animal welfare. Access to pasture may also alleviate hoof disorders and lead to less incidences of lameness compared to cattle in a housed system (Olmos *et al.*, 2009). Furthermore, there are several health benefits associated with outdoor grazing: a reduction in observed cases of mastitis, lameness, hoof pathologies and mortality levels compared with cows on continuously housed systems (Arnott *et al.*, 2017; Mee & Boyle, 2020).

Variable review

The Teagasc National Farm Survey (NFS), part of the EU FADN, is the dataset employed to assess dairy cow welfare in this analysis. The survey collects detailed financial and production data from a nationally representative sample of approximately 900 Irish farms on an annual basis. Each farm is assigned a weighting factor to reflect the national farm population using weights from the Central Statistics Office. Primarily utilised to assess the financial situation on farms, the scope of the survey has been broadened over time, to collect data additional to that required in FADN, to develop a sustainability framework encompassing indicators of economic, environmental, social and innovation sustainability (Ryan *et al.*, 2016). Economic indicators available through the survey include the economic return to land, productivity of labour, market orientation and economic viability. The environmental indicators include greenhouse gas (GHG) emissions, nitrogen and phosphorus use, and social indicators include agricultural education of the farmer, the demography of the household, isolation risk and work–life balance. A detailed description of the approach is available most recently in Buckley *et al.* (2019). Due to the constraints of the dataset, the scope of the indicators is limited to the herd level. In line with the approach utilised by Warner *et al.* (2020) and De Vries *et al.* (2011) to assess herd welfare status, the following eight variables were proposed for the indicator development: (i) stocking rate, (ii) dairy calf mortality, (iii) fat-to-protein ratio, (iv) SCC, (v) milk yield, (vi) days at grass, (vii) building investment and (viii) housing type.

Expert consultation

The proposed variables were reviewed by five animal welfare experts employed across Irish and international research

institutes. Experts were asked to evaluate the proposed variables in terms of their suitability to effectively represent dairy cow welfare, and secondly, to propose additional or alternative variables that are available within the dataset. In consensus with the recommendations outlined by Bertocchi *et al.* (2018) and EFSA (2012), three of the five experts noted the absence of animal-based measures; however, they also acknowledged the trade-offs required when attempting to measure animal welfare along with a broader set of sustainability indicators, and the practical alternative provided by routinely collected herd data.

In summary, the expert evaluation identified a number of key factors regarding the proposed welfare variables. Dairy calf mortality and the expansion of the national herd at a sectoral level was identified as a particular welfare challenge impacting the Irish dairy sector at present, in addition to lameness and specifics regarding the age and suitability of animal housing to accommodate expanding herds.

Identifying very low protein or high fat content in milk was confirmed as an acceptable method to indicate potential metabolic risks in dairy cows at a national herd level, in addition to utilising SCC readings as a method to interpret udder health. The provision of appropriate animal bedding was identified as an attribute conducive to heightened welfare levels.

The majority of experts agreed that access to pasture provided an opportunity for animals to express natural behaviours, noting the potential of restricted animal movement to contribute towards the development of pathologies. Issues were raised about investigating antibiotic use on Irish dairy farms; however, the scope of the dataset inhibited the identification of appropriate variables at present. Antibiotic use in agriculture is of particular relevance given the forthcoming EU legislation concerning a move from blanket to selective dry cow therapy. Work is ongoing in terms of collecting data of this nature on farms on a wide scale. This step served as a validation exercise for the variables chosen for this analysis.

Indicator selection

Following the expert consultation, the proposed variables were extracted from a balanced dataset for the period of 2014–2017 and are presented in Table 1. The dataset contains 250 dairy farms (per year) that returned a full set of data for the 4-yr period.

Normalisation

As the variables identified measure different concepts and use different scales, it is necessary to normalise and bring the individual variables to a common scale. Normalisation is performed across the 4-yr period using the MIN–MAX approach (OECD, 2008), whereby the lowest value for each variable is subtracted from the value for a given observation

Table 1: Selected animal welfare variables over balanced NFS dataset, 2014–2017

Variable (n = 1,000)	Unit	2014 Average ¹ (s.d.)	2015 Average ¹ (s.d.)	2016 Average ¹ (s.d.)	2017 Average ¹ (s.d.)	% Change 2014–2017
Stocking rate	Livestock units	2.05	2.01	2.08	2.08	+1.5%
	per hectare	(0.5)	(0.5)	(0.52)	(0.47)	
Calf mortality rate	%	10	11.2	11.8	10.1	+1%
		(12.4)	(13.1)	(11.8)	(11.3)	
Fat-to-protein ratio	%	1.18	1.16	1.19	1.19	+0.8%
		(0.04)	(0.11)	(0.07)	(0.04)	
Milk yield	Litres per cow	5,214	5,489	5,361	5,422	+4%
		(937)	(907)	(938)	(1,015)	
SCC	'000's cells	202	174	168	160	-21%
	per mL	(78.25)	(63.63)	(66.72)	(72.8)	
Investment in housing per cow	€	86	70	67	89	+3.5%
		(245.5)	(211.13)	(243.9)	(289)	
% with slatted housing	%	92.4	92.6	92.6	92.7	+0.3%
		(17.5)	(17.6)	(17.6)	(16)	
Days at grass	Days per year	252	245	247	245	-3%
		(22.3)	(24.7)	(25.1)	(25.8)	

¹Reflects weighted average for population. s.d. is given in parentheses.
NFS = National Farm Survey, SCC = somatic cell count.

and divided by the range of the dataset for that indicator. Indicators are then scaled from 0 to 100, with 0 indicating the poorest performance in the sample for the specific variable in any given year and 100 indicating the best performance.

Statistical analysis

Analysis was conducted on the normalised variables using a multivariate analysis in IBM SPSS Statistics 27.0, with principal component analysis (PCA) utilised as the extraction method. This multivariate statistical procedure allows for trends or patterns within variables to be observed, helping to identify correlations between data points (Eriksson, 2018). Warner *et al.* (2020) utilised the PCA procedure on routinely collected herd data in the development of a composite welfare index for benchmarking dairy farms in Canada.

The primary component derived from the PCA accounts for the maximum volume of total variance in the observed variables, and the second component generated is correlated with some of the observed variables which are not correlated with the first component, and any subsequent components relaying a progressively smaller amount of variance (O'Shea *et al.*, 2018). Applying the PCA, a five-component solution was derived, which contributed cumulatively to the overall variance by 69%, and which contributed individually to the overall explanation of the variance by more than 10%, in line with the standard practice

outlined within the OECD framework (Table 2). Orthogonal rotation was performed to maximise the sum of the squared loadings to better determine how the data correlate with each principal component. An initial test using Promax variation to provide a component correlation matrix determined no value exceeding 0.32, other than the factor correlating with itself. This indicates that the factors in the analysis were uncorrelated, and therefore an orthogonal rotation was utilised. The rotated pattern factor demonstrated the loadings of variables on each component, where a weighting factor of 0.5 or higher constituted loading on a specific component (Table 3).

The first component (PC1) had high loadings of SCC, milk yield and per cow building investment, and the second component had high loadings of days at grass and stocking rate, with fat-to-protein ratio, slatted housing and mortality rate loading on components three, four and five, respectively (Table 3). The Kaiser–Meyer–Olkin measure of sampling adequacy (KMO = 0.540) met the minimum threshold (>0.50) for effective analysis, and the statistical significance of the Bartlett's test of sphericity ($P < 0.001$) indicated that the sample size and the data were adequate for conducting PCA. The weights used for capturing the contribution of each component within the CI were determined by the proportion of variance recovered by each component in the total variance, computed from the results in Tables 2 and 3 (Davidescu, 2017).

Table 2: Empirical results of the principal component analysis

Total variance explained									
Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.42	17.78	17.78	1.42	17.78	17.78	1.25	15.66	15.66
2	1.09	13.66	31.44	1.09	13.66	31.44	1.12	13.97	29.63
3	1.04	13.03	44.47	1.04	13.03	44.47	1.10	13.78	43.41
4	1.00	12.43	56.90	1.00	12.43	56.90	1.03	12.89	56.30
5	0.96	11.96	68.86	0.96	11.96	68.86	1.01	12.56	68.86
6	0.94	11.72	80.58						
7	0.86	10.77	91.36						
8	0.69	8.65	100.00						

Extraction method: principal component analysis.

Eight components generated as eight variables examined (somatic cell count (SCC), milk yield, investment in housing per cow, days at grass, stocking rate, fat to protein ratio, % slatted housing, calf mortality rate). The PCA displays (i) the eigenvalue under the 'Total' column, which is a measure of the variance that is accounted for by the component, (ii) the % of variance explained by the component, and (iii) the cumulative % of variance explained.

Table 3: Rotated component matrix with component loadings

	PC1	PC2	PC3	PC4	PC5
SCC	0.706				
Milk yield	0.585				
Investment in housing per cow	0.611				
Days at grass		-0.622			
Stocking rate		0.756			
Fat-to-protein ratio			0.902		
% with slatted housing				0.905	
Calf mortality rate					0.990

Extraction method: principal component analysis.

Rotation method: Varimax with Kaiser normalisation.

Rotation converged in six iterations.

PC = principal component, SCC = somatic cell count.

Squaring the loadings in Table 3 defined the proportion of the total unit variance which is explained by the principal components, while the aggregation was determined by assigning weights to each of the components equal to the proportion of the explained variance in the dataset (OECD, 2008). For this analysis, the variance explained by the first component over the total variance, 1.25, equates to 0.23 of the total variance, that is, $0.23 = 1.25 / (1.25 + 1.12 + 1.10 + 1.03 + 1.01)$ and so forth for the remaining components. The CI, termed the Dairy Cow Welfare Index (DCWI), was thus determined as: $(PC1 * 0.23) + (PC2 * 0.20) + (PC3 * 0.20) + (PC4 * 0.19) + (PC5 * 0.18)$.

This CI was examined across the balanced farm set ($n = 250$) over the 4-yr period 2014–2017, where each farms' annual DCWI score was compared across the time period. Following this, an analysis of DCWI scores across farms which were categorised by their levels of output increase post-quota was undertaken. According to the dataset, the average increase in milk production in 2017 compared with 2014 was 23%. In order to analyse the impact of this production expansion, farms in the dataset are stratified on the basis of the change in milk production levels over the period. Using the average increase in production (23%) as a reference point, three strata are identified: non-expanders (11% of the sample), those who did not increase production in 2017 compared with output in 2014, moderate expanders (43% of the sample), those who increased production by 23% or less in 2017 compared with output in 2014, and significant expanders (46% of the sample), those who increased production by 24% or more in 2017 compared with 2014 levels.

In addition to analysing dairy cow welfare over time and across farms, it is also interesting to consider how it relates to other aspects of the farm, namely whether any synergies or trade-offs exist between cow welfare and economic or environmental performance of the farm business. In order to interpret this, three established sustainability indicators, two economic (dairy gross margin and income per labour unit) and one environmental (kg of GHG per kg of milk produced, measured in line with the Intergovernmental Panel on Climate Change [IPCC] methodology for the determination of emission indicators across farm systems) (Table 4), were extracted from the Teagasc NFS suite of sustainability

Table 4: Descriptive statistics for selected economic and environmental sustainability indicators

	2014	2015	2016	2017
	Mean (s.d.) n = 250	Mean (s.d.) n = 250	Mean (s.d.) n = 250	Mean (s.d.) n = 250
Dairy gross margin (€)	88,991 (43,095)	83,334 (46,126)	72,504 (42,971)	120,724 (79,353)
Income per labour unit (€)	54,396 (27,597)	52,272 (33,473)	44,316 (29,849)	71,249 (41,435)
Kg of GHG per kg of milk produced	0.76562 (0.12199)	0.72383 (0.11777)	0.7394 (0.12494)	0.72096 (0.11291)

GHG = greenhouse gas.

indicators (Buckley *et al.*, 2019) and a correlation analysis undertaken with the DCWI. While this analysis does not attempt to relay a comprehensive interpretation of any trade-offs existing between dairy cow welfare and overall farm-level sustainability, it may instead provide a cursory overview to any synergies present between welfare levels and different aspects of sustainability. The results of each of these analyses are outlined in the next section.

Results

Generating a CI of welfare (DCWI) from the herd-level variables (SCC, dairy calf mortality rate, stocking rate, milk yield, days at grass, fat-to-protein ratio, investment and slatted housing percentage) permitted an efficient method of analysing dairy cow welfare. In this section, we examine the scores of the DCWI (i) over time, (ii) by milk output expansion in 2017 compared with 2014, and (iii) with additional sustainability indicators, across the balanced farm set. Boxplots were utilised to display the data and to facilitate the visualisation of the statistical distribution of the DCWI scores.¹

Dairy Cow Welfare Index (DCWI) over time

Annual DCWI scores were compared for each of the 250 farms within the balanced dataset over the 4-yr period, 2014–2017,

¹Boxplots divide a dataset into quartiles, with the body of the boxplot representing the interquartile range (25th percentile to 75th percentile) with the median dividing the box. Ends of whiskers represent the maximum and minimum values. Outliers are represented by circles beyond the whiskers, with extreme outliers identified by stars.

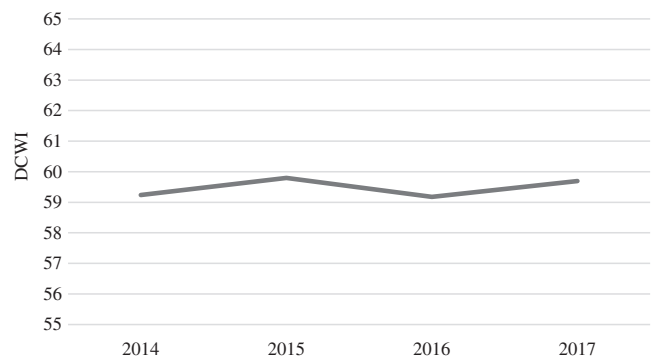


Figure 2. Mean Dairy Cow Welfare Index (DCWI) scores for balanced farm set, 2014–2017.

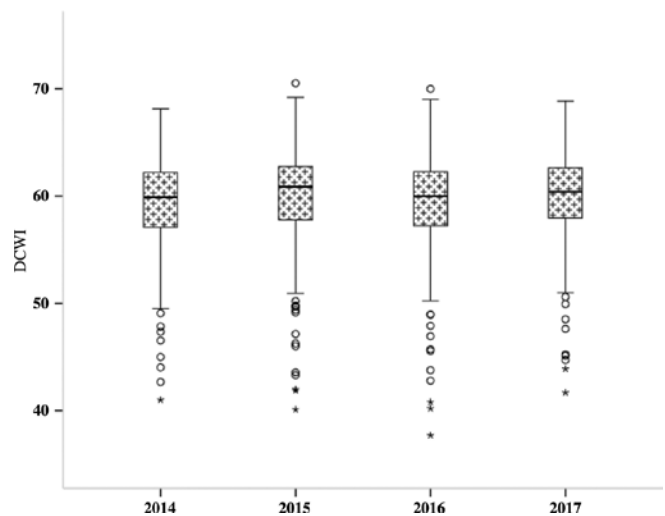


Figure 3. Box and whisker plots of the Dairy Cow Welfare Index (DCWI) for balanced farm set, 2014–2017. See footnote 1 for interpretation of results.

and these scores are visually represented in Figures 2 and 3. Little difference is observed between the DCWI scores over the time period, with marginal fluctuations in average DCWI discernible in Figure 2. The range and distribution of scores have also remained somewhat consistent, as displayed in the boxplots in Figure 3. This result suggests that welfare standards across the balanced farm set have remained relatively static over the time frame.

DCWI by production levels

The dairy cow welfare performance (as defined by a selection of relevant variables) of the three cohorts, non-expanders, moderate expanders and significant expanders, as determined

by their proportion of milk output in 2017 compared with their 2014 output, is visually presented in Figures 4 and 5. There are a number of interesting points of note. Firstly, the significant expanders are starting from a better cow welfare position in terms of their average performance in comparison to the other groups (Figure 4). This cohort records a wider distribution of their DCWI scores in 2017 compared with their 2014 scores, as observed in the boxplots in Figure 5. The non-expanding group demonstrates a marginal decline in mean DCWI scores in 2017 compared with 2014 scores, the only group to record a decrease, while the moderate expanding cohort of farms

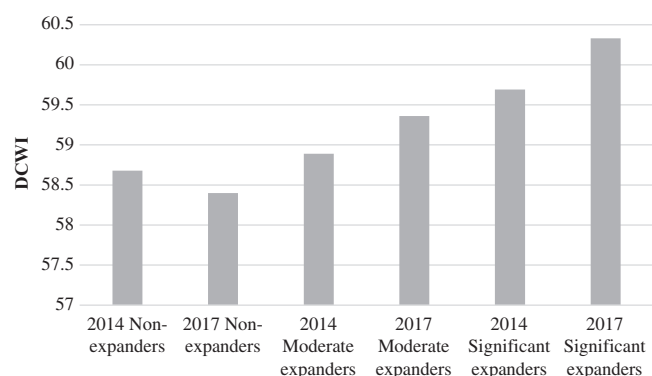


Figure 4. Mean Dairy Cow Welfare Index (DCWI) scores by farm expansion cohort, for the years 2014 and 2017.

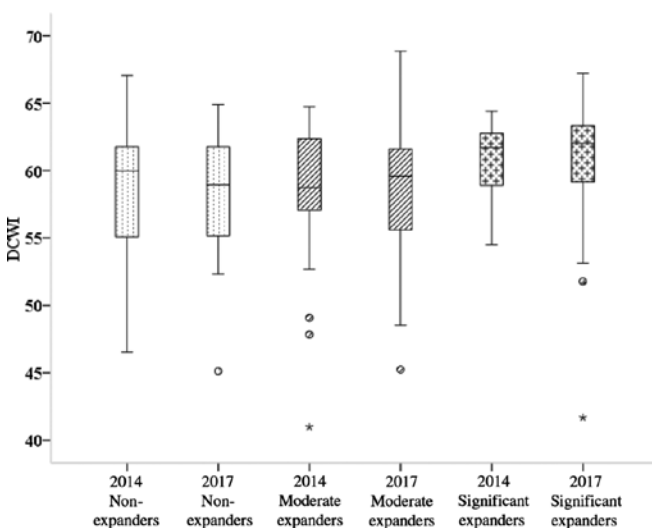


Figure 5. Box and whisker plots of the Dairy Cow Welfare Index (DCWI) by farm expansion cohort, for the years 2014 and 2017. Refer to footnote 1 for interpretation of results.

recorded a small improvement in mean DCWI scores and recorded a wider distribution of scores over the time period. Overall, the evidence suggests that as farms have expanded production, the routinely collected variables used within this composite WI have demonstrated improvement.

Trade-off and synergies with additional indicators

Table 5 demonstrates the results of the correlation analysis between the DCWI, the carbon footprint, measured as kg of GHG emissions per kg of milk solids, and the economic indicators, dairy gross margin and income per labour unit. The coefficients reveal that the relationships are significant and positive in relation to economic performance but negative in relation to environmental performance. In other words, as profitability per hectare and per labour unit increases, higher DCWI scores are recorded. Analysis between GHG emissions and DCWI yielded a significant negative correlation over three of the analysed years, indicating that as the GHG emission intensity of milk production declines, an improvement is observed in welfare levels. This may be indicative of higher technical efficiency on such farms. The evidence suggests that win-win strategies are available to farmers and that through efficient management of resources they can increase farm profit, reduce the carbon footprint of each unit of milk produced and improve cow welfare standards.

The relationship is further examined by comparing the economic and environmental performance in 2017 of the top, middle and bottom performing farms from a dairy cow welfare perspective. The positive relationship between economic performance and dairy cow welfare is evident, with the top performers from a cow welfare perspective also delivering the highest margins, which is graphically demonstrated by the boxplot in Figure 6. This finding is further enforced in Figure 7 where farm income per labour unit is also positively correlated with DCWI scoring, reflecting greater welfare standards.

Finally, the relationship with carbon footprint is negative, suggesting that the top performing farms from a dairy cow welfare perspective also have a lower carbon footprint. This is displayed in the boxplots contained in Figure 8, which demonstrates that the top performing DCWI farms record lower levels of GHG emissions per kg of milk produced compared with the other cohorts. This is a win-win result which suggests that farms can deliver higher farm profits, while protecting animal welfare and reducing their GHG emission intensity of production.

Discussion

This paper presents a number of interesting findings in relation to the impact of milk quota removal on animal welfare performance on dairy farms in Ireland, and provides a

Table 5: Pearson's correlation coefficients with composite indicator – DCWI and sustainability indicators

Variables	DCWI 2014	DCWI 2015	DCWI 2016	DCWI 2017
Dairy gross margin (n = 250)	0.118	0.200 ¹	0.182 ¹	0.232 ¹
Income per labour unit (n = 250)	0.139 ²	0.154 ²	0.094	0.260 ¹
Kg of GHG per kg of milk produced (n = 250)	-0.167 ¹	-0.167 ¹	-0.081	-0.162 ²

¹Correlation is significant at the 0.01 level (two-tailed).

²Correlation is significant at the 0.05 level (two-tailed).

DCWI = Dairy Cow Welfare Index, GHG = greenhouse gas.

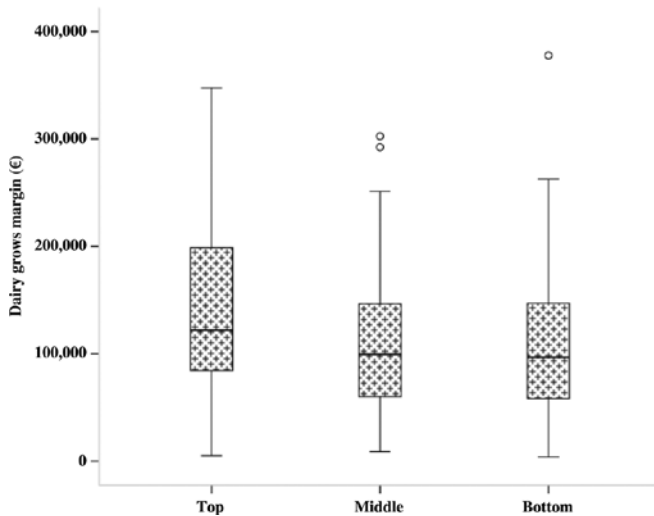


Figure 6. Comparison of top, middle and bottom performing Dairy Cow Welfare Index (DCWI) by dairy gross margin, 2017. Refer to footnote 1 for interpretation of results.

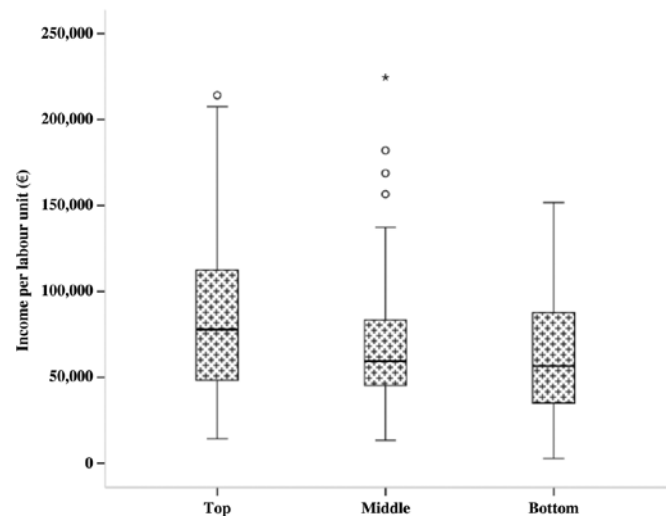


Figure 7. Comparison of top, middle and bottom performing Dairy Cow Welfare Index (DCWI) by farm income per labour unit, 2017. Refer to footnote 1 for interpretation of results.

template investigate the effect of other relevant policy reforms. In anticipation of the milk quota abolition in 2015, many dairy farmers in the preceding years sought to expand their herd, with dairy cow numbers increasing annually, from 1,070,800 in 2010 to 1,432,700 in 2017 (CSO, 2020). This analysis indicates that dairy farms that have significantly expanded production levels since 2014 have recorded improved dairy cow welfare standards on their farms, as supported by the DCWI scores across the different expansion cohorts as seen in Figures 4 and 5. This finding is in keeping with research by Hansen & Østerås (2019), which through the development of a welfare index found a positive association between animal welfare and farm expansion. They report that farmers who opted to expand their production were more satisfied with their income and working day, tended to be more optimistic and determined to continue production, in comparison to non-expanding farmers. They hypothesise that this optimistic

attitude towards expansion has a positive influence on the quality of stockmanship implemented by the farmer, and with the addition of an equitable work–life balance has a positive impact on animal/herd welfare standards.

Our analysis is also indicative of a significant and positive relationship existing between dairy cow welfare and the economic performance of the farm. The results showed that both in the baseline situation and through time, more profitable farms recorded higher composite welfare scores. This finding is in line with Robichaud *et al.* (2019), which reported a positive association between good cow welfare levels and improved productivity and longevity, which was reflected in greater economic margins at the farm level. Robichaud *et al.* (2019) demonstrated that profitability margins per cow were significantly lower in farms with higher incidences of welfare issues, namely knee lesions, while positive associations were established between increased milk yield and reduced

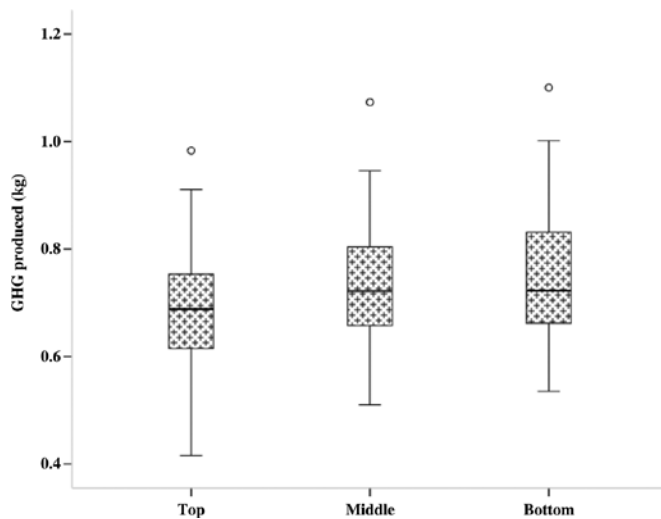


Figure 8. Comparison of top, middle and bottom performing Dairy Cow Welfare Index (DCWI) by kg greenhouse gas (GHG) per kg milk produced, 2017. Refer to footnote 1 for interpretation of results.

prevalence of hoof disorders. This corroborates an earlier study by Barnes *et al.* (2011) which found that farm economic performance improved with reducing levels of lameness, and stipulated that a clear and positive relationship exists between farm animal welfare and technical efficiency. Hansson *et al.* (2011) reported that the most efficient dairy farms were characterised by lower incidences of mastitis, which adversely impacts milk yield and carries considerable remediation costs. Consequently, reducing incidences of mastitis can help advance the economic efficiency of dairy farms, alongside improving overall herd health. This speaks to the advantages of applying routinely collected herd data, such as SCC, in the development of composite WIs, which allows for a cost-effective comparative analysis between welfare and various aspects of sustainability.

On a further positive note, the analysis revealed that the carbon footprint of milk production was significantly and negatively correlated with animal welfare standards, as DCWI scores were higher across farms which generated lower GHG emissions per kg of milk produced, as evident from the correlation analysis in Table 5 and the boxplots in Figure 8. This suggests that win-win farm-level strategies are available to farmers. Through the adoption of appropriate management practices, technologies and investment in farm facilities, farmers can reduce their carbon footprint, improve farm incomes and enhance animal welfare standards. Further analysis of the data presented in this paper would facilitate the identification and quantification of such win-win strategies. A key policy recommendation arising from this analysis is that farmers should be supported in identifying and applying the

appropriate practices and policies for their farms to achieve this optimal outcome. One such practical application includes the adoption of identified technologies under the Teagasc Marginal Abatement Cost Curve (MACC).

Numerous studies exist which assess various aspects of cow welfare on Irish farms, such as the impact of bedding mat types on the welfare of beef cattle (Earley *et al.*, 2017), comparing rubber to concrete pathways on dairy cow hoof health (Boyle *et al.*, 2007) and the effect of space allowance on housed cattle (Keane *et al.*, 2017). These studies provide an in-depth assessment of individual welfare issues, and therefore utilise specifically collected data. This is the first study in an Irish context to utilise routinely collected nationally representative data to address animal welfare.

Limitations on the use of CI

It should be noted that the dairy cow WI developed in this paper is only reflective of the variables used in its construction. While each of the herd-level variables which comprise the DCWI (SCC, dairy calf mortality, stocking rate, milk yield, days at grass, fat-to-protein ratio, investment and slatted housing) provide information on different aspects of herd welfare and management, the lack of animal-based measures limits the ability of the DCWI to provide an all-encompassing assessment of welfare. As many of these variables are efficiency and productivity based, such as milk yield, the positive correlations with economic performance may not be surprising. The use of CIs can provide a herd-level overview of animal welfare (Veerasingam *et al.*, 2011), although the approach is not without criticism (Veissier *et al.*, 2009; Sandøe *et al.*, 2019). In particular, the inclusion of certain variables may not be reflective of overall welfare. If data availability was not a limitation, it would be most insightful to expand the variables used to include other measures of welfare such as lameness and antibiotic use.

The EU's Farm to Fork strategy (2020), which is at the heart of the European Green Deal, aims to accelerate the transition to a sustainable food system. It emphasises the need to reduce GHG emissions, protect biodiversity and ensure high animal welfare standards. To achieve these strategic goals, it is imperative that baseline indicators, based on nationally representative, routinely collected data, are established and that the impact of policy reforms on these key sustainability indicators is monitored and evaluated over time. While many farm-level sustainability assessments exist, our literature review suggests that animal welfare has been somewhat neglected. The sustainability framework developed in this paper has shown that it is possible to develop effective animal WIs using a representative farm dataset such as the FADN. Furthermore, it has been demonstrated that animal welfare standards can be tracked through time and embedded in a broader sustainability framework, thus allowing for the assessment of

synergies and trade-offs with other sustainability indicators. One of the key recommendations arising from this paper is that the FADN should be used to develop a comprehensive assessment of farm-level sustainability including animal welfare. Additional data collection may be required in some countries in order to facilitate this, but as shown for Ireland the richness of the analysis that is possible justifies the activity. Furthermore, the measurement of sustainability will play a key role in the future trajectory of the FADN, as it looks towards its adaptation to the Farm Sustainability Data Network, allowing it to embrace a wider overview of sustainable farming practices across member states.

Conclusion

This study sought to assess welfare levels on Irish dairy farms through the development of a composite WI, utilising routinely collected herd data. Overall, the results of this study indicate that welfare has remained relatively stable across the 2014–2017 period, and that the recent expansion of the sector has not adversely impacted this composite WI. While societal interest regarding the potential effects of intensive farming on welfare standards is welcome, and enquiry is encouraged, it is positive to observe that in this circumstance, expansion of the Irish dairy industry has not impeded standards of animal welfare as measured with routinely collected herd-level variables. Rather, farms that opted to significantly increase milk output demonstrated improved welfare standards over the study period. Furthermore, no adverse compromises were found between farms recording higher DCWI scores and additional sustainability indicators, with top DCWI performing farms recording improvements across economic and carbon footprint indicators.

The development of the composite WI within this study streamlined various health indicators and WIs into a single holistic welfare measure, with the capacity to compare data with additional measures of sustainability. The scope of these WIs comprising the CI, estimated at a herd level, has been dictated by the availability of relevant data. Evolving topical issues, such as antibiotic usage, will necessitate additional variables for inclusion within the FADN. While it is acknowledged that animal-based indicators are more insightful than herd-level indicators, which due to data restriction are more limited, we argue that the insights provided by linking animal WIs to a broader set of sustainability indicators for a sample of representative farms for a prolonged period of time have offset many of the limitations. Furthermore, the utilisation of established herd-level indicators within the CI permits time series analysis across each farm in the survey, facilitating the identification of welfare trends across the different expanders. This

broadens the remit of these indicators beyond individualistic performance measures, and compared with economic and environmental indicators, can help in attaining future agri-food policy objectives, contributing to a more holistic assessment of farm sustainability.

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