The Impact of Climate Change on the Economics of Dairy Farming – a Review and Evaluation

Die ökonomischen Auswirkungen des Klimawandels auf die Milchviehhaltung – Überblick und Bewertung

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Abstract

The impact of climate change has become a major concern within the agricultural profession. While many studies on Climate Change Impact Assessment (CCIA) deal with crop farming, little has been done with regard to livestock farming. This paper aims to shed light on the present state of research in the field of dairy farming, one of the major sectors in agriculture, in a three-fold manner. First, potential climate change impacts in dairy farming are discussed qualitatively. Second, challenges and methodological approaches in economic CCIA are presented, with a closer look at the issue of climate data and farm-level adaptation. Third, an overview and assessment of available studies on economic CCIA in dairy farming along a set of evaluation criteria is provided. The paper concludes with further research opportunities in this field.

Key Words

climate change; dairy farming; economic impacts

Zusammenfassung

Die Auswirkungen des Klimawandels auf die Landwirtschaft sind zu einem zentralen Thema agrarwissenschaftlicher Forschung geworden. Während sich viele Studien zur Klimafolgenforschung auf den Pflanzenbau konzentrieren, hat die Tierhaltung in dem Zusammenhang bisher nur wenig Beachtung gefunden. Der vorliegende Beitrag untersucht den derzeitigen Stand der Forschung im Bereich der Milchviehhaltung, einem zentralen Produktionszweig der Landwirtschaft, in dreierlei Hinsicht. Zunächst werden die potenziellen Folgen des Klimawandels für die Milchviehhaltung diskutiert. Des Weiteren werden verschiedene Herausforderungen und methodische Ansätze der Klimafolgenforschung aufgezeigt, wobei insbesondere auf das Problem der Klimadaten und der Anpassung auf der landwirtschaftlichen Betriebsebene eingegangen wird. Schließlich erfolgt eine Analyse der bestehenden Literatur zur Klimafolgenforschung, die sich mit den ökonomischen Auswirkungen auf die Milchviehhaltung beschäftigt, anhand einer Reihe von Bewertungskriterien. Der Beitrag endet mit Schlussfolgerungen im Hinblick auf neue und sich abzeichnende Forschungsmöglichkeiten.

Schlüsselwörter

Klimawandel; Milchviehhaltung; ökonomische Auswirkungen

1 Introduction

Although the impacts of climate change are an important research area in agricultural economics, the majority of studies concentrate on crop farming and only very few focus on livestock farming, especially dairy farming (see, for a general overview, SONKA, 1991; DARWIN et al., 1995; ADAMS et al., 1998; KURUKULASURIJA and ROSENTHAL, 2003). This is surprising given the multiple impact of climate change on this sector of agriculture. First of all, excessive heat, cold, humidity, wind and radiation influence dairy cows negatively. For example, feed intake, milk performance (milk quality and quantity) and conception rate are reduced, and the cows' immune status and well-being are impaired (BERMAN, 2005; KADZERE et al., 2002; NARDONE et al., 2010; CAVESTANY et al., 1985; WITTMAN and BAYLIS, 2000; WEST, 2003). Some of these effects also apply to heifers and calves. Mitigation measures like barns or specific shelters are only partially effective (see, for example, MAYER et al., 1999).

Indirect impacts on dairy farming also exist as fodder crops are affected by reduced precipitation and rising temperatures, which can cause yield losses (LOBELL and FIELD, 2007). Heavy or long-term precipitation events also constrain harvesting or pasturing and even lead to flooding. Pathogen infections – in plant production as well as in animal husbandry – can increase due to certain climatic conditions, and some new species may appear (ANDERSON et al., 2004; CHAKRABORTY et al., 2000; KADZERE et al., 2002). While bio-physiological reactions of animals and plants are more or less well known, pathogen infections are highly multi-factored and only reveal good results through a complex structural approach with many variables (KOBOURN et al., 2008). Empirical data sets are rare and scientific knowledge is thus still weak (PURSE et al., 2005).

In general, climate as well as topography, infrastructure, policy measures, etc., are external variables that restrict or benefit dairy production at a specific farm. As soon as one of these variables becomes less important, the other variables become relatively more important. For example, SMITH (1968) found that annual milk yields in Great Britain are well forecasted on the basis of rainfall data from April to June. DRAGOVICH (1982) shows that the influence of rainfall on milk production is the highest in "areas where economic incentives to distort climatically-dependent production patterns were less" (ibid.: 263). Thus, the reduction of political constraints or subsidies makes climate a relatively more important location factor. Empirical findings indeed indicate that since milk quota trade became more flexible in Germany a shift occurred within milk production with a move towards pasture-based areas, for instance to the northern coasts of Germany (LASSEN and BUSCH, 2009; BÄURLE and WINDHORST, 2010).[1]

It is against this background that the question becomes how, and to what extent, dairy farming will adapt to climatic change. At the heart of the problem in studies dealing with the assessment of climate change impacts (hereafter, we use the abbreviation CCIA to stand for climate change impact assessment) lies the vulnerability of systems or regions (see also IGLESIAS et al., 1988). Vulnerability is generally defined as a product of the dimension and rate of a stimulus (e.g., drought), the sensitivity of a system (e.g., dependency on rain) and the adaptability of the system (e.g., production alternatives or irrigation availability) (WALKENHORST and STOCK, 2009). It should be noted that with regard to CCIA, sometimes the term "resilience" is used rather than "vulnerability". Resilience points to the importance of a system's or region's ability to return to normal functioning after damage has occurred, and thus emphasizes the aspects of flexibility and recovery.

The problems expected from climate change are relatively complex given the local and regional differences as well as the various farming systems. For example, British and Eastern-Canadian dairy farmers fear wetter and warmer conditions in winter as this would boost feed costs due to a longer housing period, increase the risk of pneumonia and reduce growing rates in calves (HUGHES et al., 2008; REID et al., 2007). Continental European dairy farming, in contrast, is expected to be influenced mainly by a decline in feed production and more heat stress in summer (WALTER and LÖPMEIER, 2010).

Nevertheless, global warming can even be positive for regions where low temperatures have been a problem for dairy production so far. As dairy cows require a significant part of the feeding energy for physiological maintenance during the cold season, they have less energy for milk secretion. Generally, the vegetation period is also shorter in these regions and global warming can increase the quality and quantity of farm-owned feed. Moreover, rising CO_2-levels in the atmosphere are expected to increase crop and grass yields, too, while to some extent reducing drought sensitivity, yield quality and species mixture (for a detailed description of the biological impacts of rising CO_2 enrichment see IDSO and IDSO, 1994; HEBEISEN et al., 1997; KAMMANN et al., 2005; SOUSSANNA and LÜSCHER, 2007; WEIGEL et al., 2006).

From the discussion above it becomes clear that performing CCIA is a rather difficult and multifaceted task. It is striking that studies in this field conclude that there will be gainers and losers from climate change, be it within countries (LIPPERT et al., 2009), across continents (QUIROGA and IGLESIAS, 2007; MARACCHI et al., 2005) or globally (ROSENZWEIG and PARRY, 1994; PARRY et al., 2004; REILLY et al., 1994; DARWIN et al., 1995). Although general equilibrium models often suggest rather minor climate-change-related reductions in global agricultural production, the redistributive and regional effects are large (BOSELLO and ZHANG, 2005; ADAMS et al., 1998; CROSSON, 1989).

[1] The regional relocation of milk production is expected to be aggravated in the course of climate change. This holds true, because north-western Germany will probably be less negatively and, to some extent, even positively impacted by climate change due to the mitigating influence of the proximity to the sea (ZEBISCH et al., 2005). Indeed, high and regular precipitation, as well as low opportunity costs of grassland due to unsuitability for crop farming, enables, in addition to high milk yields out of grass forage, relatively low cost dairy farming.

By reviewing the relevant literature along a set of evaluation criteria, this paper analyses the multiple impacts of climate change on the economics of dairy farming. The next section identifies the challenges in CCIA, while Section 3 classifies the methods developed and applied in order to address these challenges. Section 4 gives an overview of empirical studies that have examined the costs and benefits of climate change for dairy farmers. It describes and compares the various studies and summarizes their main findings. Finally, the paper concludes with Section 5.

2 Challenges in CCIA

One of the two key challenges in CCIA is the climate data itself, which contains a large degree of uncertainty. Although there is a rising demand for improved climate models, significant progress is probably not to be expected in the medium-term. This is due to the large number of uncertainties with regard to future climate, e.g., forecasting greenhouse gas emissions or apparent differences between the projections of the various climate models (HALLEGATTE, 2009: 242). The uncertainties even increase as one moves down the scale from global climate change to the economic impacts for a specific type of farm (MORAN et al., 2009: 21). Typically, a possible range of emission scenarios is estimated in a first step, and a carbon cycle response is developed. Further on, global climate is modelled and the results are projected and downscaled to the regional or local level. Biophysiological reactions are then assessed and finally 'converted' into economic impacts. At every step the scope of possible outcomes increases and, consequently, economic impacts show the largest level of uncertainty. However, highlighting the economic impacts of climate change is obligatory in order to define necessary and efficient adaptation investments. Uncertainty in climate modelling is indeed so large that some argue that the range of potential error far exceeds the range of results (PARRY et al., 2004; QUIROGA and IGLESIAS, 2007). A common method to mitigate these uncertainties is to use several climate models and scenarios and to project a defined range of possible outcomes.

Climate change is, in addition, generally expressed in meteorological average values and mean states, as climate is, by definition, average weather over a large timescale, i.e., typically 30 years (WALKENHORST and STOCK, 2009). However, while meteorological average values (e.g., monthly average temperatures) might explain part of the profitability of dairy farming, climate variability and extremes play an important role, too. In particular as thresholds are crucial in the preservation of a certain type of animal or plant performance (MACDONALD and BELL, 1958). IGONO et al. (1992), for example, report that temperatures below 21 degrees Celsius several hours a day provide a safety margin for cows to regenerate and maintain a certain milk yield performance. So the temperature at night is just as important as the heat peak during the day for evaluating physiological heat stress for dairy cows. Therefore, monthly average temperatures do not show whether the necessary temperature threshold for a cow to regenerate is attained at some point during the day.

Further evidence for the importance of daily or even hourly weather information is provided, among others, by BOHMANOVA et al. (2007). The authors show that milk yields start to decline at a certain temperature threshold, but stay constant before that threshold. Here, a monthly average temperature cannot elicit when and for how long the threshold is exceeded. With regard to the milk yield of cows, it is known that the weather data of the preceding four days has a greater influence than the weather of the test day itself (LINVILL and PARDUE, 1992; WEST et al., 2003). A temperature humidity index (THI) is commonly applied to measure heat stress in dairy cows, which includes a daily minimum as well as a maximum temperature. This has proven to yield more accurate results than daily average temperatures (ST-PIERRE et al., 2003). For plant growth, REID et al. (2007) show for Ontario, Canada, that the moisture balance for the whole growing season stays the same, while the moisture balance for the water-sensitive reproductive period declined. KORNHER et al. (1991) found that a certain period of days with a daily average temperature above 5 degrees Celsius is necessary for grass growth to start. This could not be modelled with only monthly or seasonal averages.

Besides "physiological reasons", many meteorological studies have shown a high probability of an increased intensity and frequency of extreme weather events, which are *per se* an expression of weather variability that can be hidden by average values (MEARNS et al., 1984; SCHÖNWIESE, 2008; KATZ and BROWN, 1992; WEISHEIMER and PALMER, 2005). If the normal distribution moves with time to the right, extreme weather events that are currently relatively rare will become more frequent. Hence, what will be a relatively rare weather event in the future will be farther up the scale, e.g., "hotter" or "wetter", than what has been experienced so far. As a consequence, many researchers recommend integrating extreme weather events into CCIAs (GEIGEL and SUNDQUIST, 1984; HULME et al., 1999).

The second big challenge in CCIA, in addition to the climate data itself, is the farmers' adaptation to climate change (SMIT and SKINNER, 2002). Early studies often neglect the impact of adaptation to climate change, for example adjustments of production systems or in view of technical and biological progress, and assume that farmers are "naive" (KLINEDINST et al., 1993; EASTERLING et al., 1993). It was shown later that such an adaptation, which undoubtedly takes place, influences the results significantly (KAISER et al., 1993; ADAMS et al., 1998; SEGERSON and DIXON, 1999). The inclusion of adaptation in CCIA is therefore one of the most disputed issues among the lines of research in CCIA (MENDELSOHN and NEUMANN, 2001). Furthermore, the question is not only if farmers' adaptation is considered, but also to what extent this adaptation is allowed within the analysis. For example, RISBEY et al. (1999) argue that some assume the farmers to be "clairvoyant", and, therefore, that they "know exactly what the climate/weather outcomes will be and know exactly what the best adaptation strategies are" (ibid.: 144). Such a "perfect" adaptation is however rather unrealistic due to the aforementioned uncertainties with regard to future climate.

Moreover, the way adaptation to climate change is modelled, either in a comparative static or in a dynamic way, has been discussed intensively over the last years. Climate change is indeed not merely about stepping from one climate to another, but about dealing with a continuous process of change. This process involves, among others, transition costs, price and weather variability and changes in variability as well as the complexity of individual decision-making. Hence, it is no wonder that some authors argue in favour of dynamic approaches to analyse the impacts of climate change at the farm level (APFELBECK et al., 2007; SONKA and LAMB, 1987; KAISER et al., 1993; REILLY et al., 1993). Others, in contrast, propose to use comparative static approaches because agricultural activities like crop farming can adapt rather easily in the short-term, e.g., by switching crops. A dynamic adaptation to climate change is therefore seen as more appropriate for long-term activities like forestry and coastal protection (MENDELSOHN and NEUMANN, 2001). But, with regard to intensive livestock farming, investment costs are high and designed for the long-term and farms tend to be extremely specialised in their activity. So if short-term production adjustments are not possible or only at high costs, one must ask what adaptations can and should be made? To address this, research is needed on how farmers adapt to extreme weather events at present. The explicit involvement of stakeholders as opposed to so-called "desktop-research" is one of the recent advances in CCIA (PARRY et al., 2007).

In addition to farmers' adaptation, the projection of an "adapted world", that is, in our case, supply and demand shifts on the market for dairy products, due to technological progress, political constraints or subsidies, population growth, changes in diets, etc., is a difficult but indispensable task (SONKA and LAMB, 1987). This implies the use of global or partial equilibrium models. While almost all studies have up to now assumed current input and output prices (KURUKULASURIYA and ROSENTHAL, 2003), an integration of other exogenous and non-climatic forces often lies far beyond the scope of CCIA. Nevertheless, many studies point out that non-climatic forces can have a far stronger impact on producer, national or global welfare than climate change itself (WALTER and LÖPMEIER, 2010; BOSELLO and ZHANG, 2005). Taking these forces into account and revealing their interactions with climate change can, on the one hand, provide a more realistic description of the scenarios chosen. On the other hand, it can help to reveal the relative importance of climate change among the various "stressors" farmers are exposed to. That is why some authors underline the multifaceted and dynamic character of farm-level adaptation (RISBEY et al., 1999; BELLIVEAU et al., 2006), while simple stress-response approaches (heat - milk loss or drought - reduced grass growth, respectively) can be seen as only one building block in CCIA.

Empirical evidence on the farmers' attitudes, responses and adaptations in view of climate variability and change is rather limited. HUGHES et al. (2008) and REID et al. (2007) found that livestock farmers tend to deal with weather on a short-term basis and specific weather extremes have to occur in at least two consecutive years to stimulate significant adaptation (HUGHES et al., 2008). There are also hints that farmers very well recall specific weather extremes like a severe summer heat, flooding or late frost (HUGHES et al., 2008; CROSS, 1994). In contrast with this, REID et al. (2007) show that Canadian dairy and hog farmers are in general especially unconcerned about climate change. The same holds true for German dairy farmers, who rank so-called "production risks", which include weather extremes, merely in third place, whereas risks with regard to factor markets (here, prices for inputs and land rents) and with regard to political constraints are in first and second place, respectively (WOCKEN et al., 2008). In England and Wales about three quarters of the farmers state that they did not adapt to such weather extremes as prolonged summer drought or intense rainfall (ADAS, 2007). It should be noted that even if a high capacity to adapt exists, this is not necessarily utilised, especially if there are barriers like political constraints to adaptation (MORAN et al., 2009). It is argued that liberalization policies, e.g., the reduction of commodity-specific price support, can foster adaptation, as alternative crops or the implementation of extensive farming systems become more favourable (LEWANDROWSKI and BRAZEE, 1993).

3 Methods in Economic CCIA

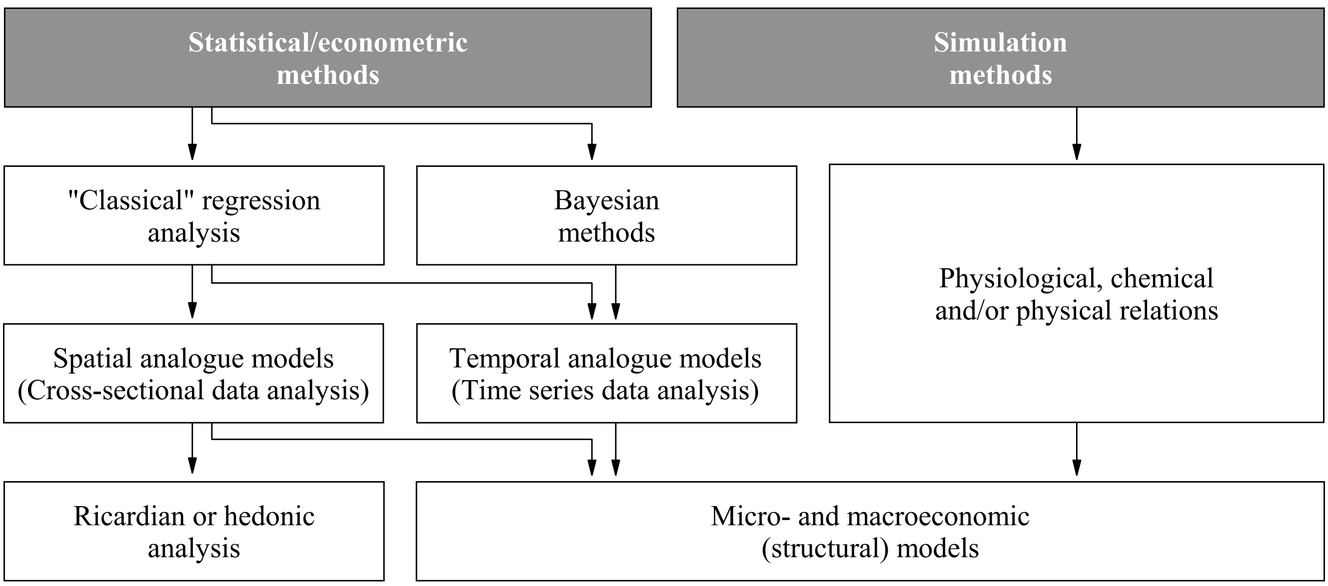
Although analyses of economic CCIA have numerous special characteristics, a variety of methodological approaches has been used from the conventional economic toolbox and substantially refined so far (TOBEY, 1992; ISERMEYER AND THOROE, 1995; KURUKULASURIJA and ROSENTHAL, 2003). According to CARTER et al. (1988) two main branches can be broadly distinguished, namely the simulation and the statistical method (see figure 1).

Simulation methods look at physiological, chemical or physical functions and relations via laboratory and field experiments in order to model the responses of plants and animals to climate. Starting from the definition of vulnerability, the majority of simulation-based CCIA studies for dairy farms examine the sensitivity and the capacity to adapt of crops, animals and the farm as a whole with regard to projected climatic changes. Alternatively, other studies in this field conduct a sensitivity analysis to reveal the limits of resilience through changes in climatic variables for a well-defined farming system (see, for example, HUGHES et al., 2008).

Statistical/econometric methods apply mainly "classical" regression analysis or use other econometric modelling tools like the Bayesian methods (see, for an application, KRAUSE, 2007; MUSANGO and PETER, 2007). The basic idea here is to derive the relationships between changes in climate and plants, animals as well as farmers decisions, respectively, from a sample of empirical data. However, as underlying reasons for (significant) causal relationships often remain hidden, statistical/econometric methods are sometimes referred to as a "black-box approach" (CARTER et al., 1988: 105).

It must be noted that methodological approaches for CCIA in agriculture are sometimes differentiated into structural modelling and spatial analogue models (SCHIMMELPFENNIG et al., 1996; ADAMS, 1999). The first approach builds on a clear definition of the decision problem or objective function of the farmer. Then plant and animal physiological functions and further restrictions are combined with the expected behaviour of farmers, e.g., profit maximization. The second approach relies on observed behaviour of farmers and employs data on production and climate across farms and regions (ibid.). While analyses based on structural

Figure 1. Methodological approaches for CCIA in agriculture



Source: own design

modelling are "inherently interdisciplinary, in that they typically use models from several disciplines" (ADAMS, 1999: 366), spatial analogue models usually apply statistical methods in order to infer "how commercial farmers have responded to different climatic conditions" (SCHIMMELPFENNIG et al., 1996; 3).

Accordingly, structural modelling and spatial analogue models can rather be seen as sub-branches and further developments of simulation and statistical/econometric methods, respectively. A special case in spatial analogue models that has been widely used is the so-called Ricardian or hedonic approach. It examines the impact of changes in climate particularly on land values and farm revenues as these variables implicitly reflect the profit maximising land use. The underlying assumption is that observed land use and farming systems are principally a result of climatic conditions. This approach has received particular attention since the work of MENDELSOHN et al. (1994).

DESCHÊNES and GREENSTONE (2006) further use the terms production function and hedonic approach to classify the research of economic CCIA. Following the authors' distinction, the first relates rather to simulation methods and examines the impact of climatic conditions on crop yield. The latter "attempts to measure directly the effect of climate on land value" (ibid.: 1) and can therefore be treated as synonymous with the aforementioned Ricardian analyses.

In contrast to spatial analogue models, which employ cross-sectional data, it is possible to use time series data for a special region or location in order to assess how farmers respond to changes in climate. This would then refer to "temporal analogue models", which have been used only rarely in CCIA concerning agriculture. This may be attributed to the vast amount of consistent data that is necessary to conduct such analyses. At this point the study by EASTERLING et al. (1993) must be mentioned. They exploit a period of a specific weather extreme in the past to analyse how this extreme would affect current and future farming. The authors take into account technological and economic changes that (might) have taken place as well as rising CO_2-levels and run a crop growth model. Hence, this approach must rather be assigned to the branch of simulation models.

The results of simulation models, e.g., reduced crop or milk yield or higher disease pressure for dairy cows, are typically used as inputs in economic models in order to make an assessment of the costs and/or the benefits of climate change impacts. The same holds true for statistical and econometric exercises as far as the variables under consideration are not directly expressed in economic terms such as land rent, farmer income or profit per cow. Furthermore, partial or economy-wide models can integrate the results of simulation or statistical/econometric-based CCIAs so as to derive how demand, supply and price levels are affected. In that way, the impacts for farmers (PARSONS et al. 2001; TURNPENNY et al., 2001) as well as on the sectoral (SEGERSON and DIXON, 1999), national (REILLY et al., 1993; KANE et al., 1992) and global level (BOSELLO and ZHANG, 2005; FISCHER et al., 2005; REILLY et al., 1994; DARWIN et al., 1995) can be assessed.

Both simulation and statistical/econometric methods have their merits and limitations. For example, the former helps to understand the underlying functions and relations between plant, animal and climate processes. Statistical/econometric methods are usually based on empirical data that contains historic climatic conditions. Thus, if some future climatic conditions are beyond what has been observed so far, conclusions cannot be drawn from past observations. Statistical/econometric methods can therefore only to some extent predict the responses of plants, animals and farmers to expected changes. That is why simulation methods, based on laboratory and (half-) field experiments where specific weather extremes can be studied, may lead to more focused and valuable results. This applies in particular to the detection of bio-physiological thresholds.

Statistical/econometric methods have the advantage of being normally less resource intensive given the use of secondary data. Moreover, these methods regard adaptation to climate change as embedded in the data employed and therefore as endogenous. Identifying the exact physiological, chemical or physical functions and relations as well as adaptation measures is, however, one of the key challenges in simulation-based studies. Apart from that, not all functions and relations can be assessed via laboratory and field experiments, but must be derived on the basis of statistical/econometric methods, too (CARTER et al., 1988).

Statistical/econometric methods are also able to cover large geographical areas, and, hence, results for many farmers can be generated at once (see, for example, SEO and MENDELSOHN, 2008). Nevertheless, these methods, and particularly the Ricardian or hedonic analyses, suffer from the risk of omitting variables, e.g., soil quality (DESCHENES and GREENSTONE, 2006). Another problem with the Ricardian or hedonic analyses is that zero adjustment costs are assumed. Hence, results must be interpreted with care and can only be regarded as "a lower bound estimate of the costs of climate change" (QUIGGIN and HOROWITZ, 1999: 1044) and it is not surprising that statistical/econometric approaches tend to show slightly more advantageous impacts on agriculture (MENDELSOHN and NEUMANN, 1999; TOL, 2006).

It becomes apparent that simulation and statistical/econometric methods are complementary (SCHIMMELPFENNIG et al., 1996) and their application depends on the research question. There are also ways to combine these methods in order to circumvent the limitations that both of them possess (see, for an example, SEGERSON and DIXON, 1999).

4 Overview of Studies on CCIA in Dairy Farming

Given the substantial body of literature on climate change related to dairy farming, we decided to use the following 'filter' for inclusion of studies in the current overview. First, the study should focus on economic impacts on dairy farming. That said, we also include three studies that evaluate dairy-related climate change impacts quantitatively, but not explicitly economically (see the studies of FITZGERALD et al., 2009; PARSONS et al., 2001; TOPP and DOYLE, 1996). Analogously, three studies are included which do not look at climate change, but calculate the impacts of current climatic conditions on the economics of dairy farming (MAYER et al., 1999; IGONO et al., 1987; ST-PIERRE et al., 2003). Studies which examine physiological, chemical or physical responses to environmental conditions, without any relation to climate change and economic impacts, are legion and shall not be included (see, for a comprehensive overview in this field, ST-PIERRE et al., 2003; ADAMS, 1999).

Table 1 presents the studies under consideration. At a first glance, it is striking that CCIAs on dairy farming are restricted to a few countries. The limited geographical scope may be due to the important role that dairy farming plays in these countries and the funding available for agricultural research. In addition, this situation corresponds to what is known as one of the common distortions in risk perception: as (most of) these countries are relatively less familiar with weather extremes like droughts or heat they perceive "global warming" as a major risk (SCHÜTZ and PETERS, 2002). Certainly, there is also a higher awareness of the need to conduct CCIAs due to the role of rising sea level and coastal protection in some of these countries.

Whatever the reasons are, studies are lacking for many climatic zones. For example, in Europe most of the research has been done for western maritime climatic zones (Great Britain and Ireland, see table 1). However, it would be rather interesting to analyse the impacts of climate change in southern, northern and continental Europe, as well as in some Asian, South-American and Oceanic countries, which are of great importance with regard to world dairy markets (e.g., China, India, Brazil, Russia, Australia, New Zealand, see FAOSTAT, 2011).

In view of the methodological approach only MAYER et al. (1999) and SEO and MENDELSOHN (2008) apply statistical/econometric methods. The first study undertakes general nonlinear modelling and identifies the losses in milk yield due to heat loads and the physiological and economic efficiency of heat abatement. The latter estimate a multinominal logit regression with regard to species selection in the line of spatial analogue models and investigate farmers' production decisions and how these affect income. Both of these studies show the importance and value of comprehensive and consistent datasets in order to assess climate change impacts. For example, SEO and MENDELSOHN (2008) employ a sample of more than 5 000 farms in ten African countries, including explanatory variables like temperature, precipitation, soil types and even availability of electricity. MAYER et al. (1999) use time series data on temperature and humidity, as well as data on milk production from farms, dairies and research stations over 30 to 144 days. All other studies presented in table 1 are based on simulation methods. The authors use models to analyse the relationship between grass growth, feed intake, milk yield, etc. and climatic conditions. Then, results are put in the context of contemporary farming and (economic) conclusions are drawn.

While both of the statistical/econometric-based studies draw continent-wide conclusions (Africa, Australia), the majority of the simulation-based studies treat only one country or region (see table 1). This is probably due to the fact that physiological, chemical or physical models are often validated in certain areas. Their geographical reach is therefore inherently restricted. However, ST-PIERRE et al. (2003) and KLINEDINST et al. (1993) also conducted studies based on simulation models where the influence of current climate on livestock and/or dairy farming is calculated separately for all states of the USA, the focus being on heat stress. Simulation methods are

Table 1. Compilation of studies on climate impact on dairy farms, goals and methods applied

No.	Authors	Study area	Objective and methodological approach applied
1	SEO and MENDELSOHN, 2008 (SEO)	African countries	*Objective:* Analysing how African livestock farmers decide under climate change *Method:* Farmers' decisions under specific climatic conditions are examined with a structural equation model using a sample of ten countries and more than 5 000 farms; based on this, impacts on net revenue are derived
2	LEVA et al., 1996 (LEV)	Argentina	*Objective:* Measuring current and potential future milk yield loss due to heat stress *Method:* Using current and expected climatic conditions to calculate the THI and milk loss; reference situation is average milk yield under "normal" climatic conditions without heat stress
3	MAYER et al., 1999 (MAY)	Australia	*Objective:* Assessing the impacts of heat loads on Holstein dairy cows and estimating milk yield loss and costs *Method:* Use of long-term meteorological data to identify weather extremes over space and time; econometric estimation of production losses due to heat loads
4	WALTER and LÖPMEIER, 2010 (WAL)	Germany	*Objective:* Analysing dairy farming in various German regions under rising temperatures due to climate change *Method:* Physiological algorithms and THI-formula based on the literature; one scenario, but results of four climate models used
5	TOPP and DOYLE, 1996 (TOP)	Great Britain	*Objective:* Assessing climate change impacts on milk yields and forage management in Scotland (four different locations) *Method:* Simulation model of a grazing dairy cow and models of grass and grass-white clover swards; two emissions scenarios and two climate scenarios
6	PARSONS et al., 2001 (PAR)	Great Britain	*Objective:* Exploring potential impact of climate change on grazing systems *Method:* Simulation models of grass production, livestock feeding, livestock thermal balance and thermal balance of buildings; stochastic weather generator
7	HOSSELL, 2002 (HOS)	Great Britain	*Objective:* Analysing costs and benefits of climate change impacts on single crops *Method*: Calculation of the net present value of increased milk production assuming that there is an increased grass growth under climate change (source: HOSSELL et al., 2001) and therefore higher stocking rates, measured in cows per hectare
8	HUGHES et al., 2008 (HUG)	Great Britain	*Objective:* Identifying relevant weather extremes under climate change and appropriate adaptation measures in cooperation with farmers *Method:* Sensitivity analysis of investment costs for cattle barn ventilation and incidence of calves' respiratory disease (more likely under climate change)
9	MORAN et al., 2009 (MOR)	Great Britain	*Objective:* Assessing climate change impacts on the British livestock industry *Method:* Several bio-physiological models; assuming current prices; deduction of economic gains and losses
10	FITZGERALD et al., 2009 (FIT)	Ireland	*Objective:* Identifying the adaptation potential of grass-based dairy systems to climate change *Method:* Dairy system simulator including models for herd feed demand, grass production and grass utilisation; climate model data
11	IGONO et al., 1987 (IGO)	USA	*Objective:* Calculating the physiological and economic gains of specific heat reduction measures *Method:* Simulation-based approach to measure heat stress and economic consequences under adaptation measures such as shade, spray and fan systems
12	KLINEDINST et al., 1993 (KLI)	USA (Europe)	*Objective:* Examining the potential economic losses from climate change on milk production and reproduction in the USA and to a smaller extent in Europe *Method:* Physiological algorithms for milk production and conception rate; climate data of three global climate models applied in these algorithms
13	ST-PIERRE et al., 2003 (STP)	USA	*Objective:* Estimating economic losses for livestock industries from heat stress *Method:* Animal responses to heat modelled from literature; use of maximum THI, daily duration of heat stress and heat load index
14	MADER et al., 2009 (MAD)	USA	*Objective:* Assessing the impacts of climate change induced changes in temperature on livestock production, i.e., dairy and beef cattle as well as pigs *Method*: Physiological production/response models for animals; focus on voluntary feed intake; climatic conditions from climate models

Notes: Capital letters in the second column show the abbreviation of each study which will be used later in table 2.
Source: own compilation

thus not *per se* limited to a specific region. But the results must inevitably be interpreted with caution, as they imply the same conditions, for example, with regard to housing systems and genetic predisposition for all locations.

Although they apply different econometric approaches, both MAYER et al. (1999) and SEO and MENDELSOHN (2008) use animal choice or milk yield as a dependent variable instead of as an economic value, e.g., farmers' income. The independent variables are, among others, climatic variables like temperature, precipitation and humidity. Then, in a second step, the authors assess the economic impacts of the resulting changes in animal choice and milk yield. Such a two-step-procedure might be due to an expected marginal impact of climatic variables on dairy farmers' income. The influence of other factors like farm management (seasonal calving, management skills), fodder quality (summer/winter fodder) and market and policy constraints (infrastructure, input and output prices, quotas) on farmers' income is probably more important in relative terms. It, therefore, seems to be a rather difficult task to include all the relevant explanatory variables, besides climatic conditions, in a regression analysis, if the dependent variable is an economic value.

SEO and MENDELSOHN (2008) argue that the statistical/econometric method based on a cross-sectional dataset is particularly suitable for Africa because farmers generally keep their livestock outside, directly exposed to weather factors. Hence, the choice and number of animals must have some relation to climate. According to this argumentation, the same approach applied in Europe or North America may yield insignificant or marginal impacts of climatic conditions on choice and number of animals or farm income as there are more sophisticated and weather-independent housing systems for animals. There has been, to our knowledge, no study which has further explored this issue so far. However, it must be stressed that there is undoubtedly an influence of climate on farmers' income in intensive dairy farming. A time series approach which analyses how milk yield or the amount of grass-based feed interacts with temperature and precipitation over time might reveal these relations.

While MAYER et al. (1999) provide an interesting and illustrative example for the use of statistical/econometric-based CCIA with regard to dairy farming, the authors emphasize the role of climate impacts which are not included in their analysis, i.e., weight loss, raised somatic cell counts and decline in pasture quality and quantity. This again shows the complexity of a comprehensive CCIA which takes the relationships of bio-physiological processes and climatic conditions into account. Table 2 lists all direct and indirect impacts that have been considered in the fourteen studies considered (columns 2 and 3). The first include impacts on milk yield, conception rate, dry matter intake, weight and mortality, and the latter include impacts mainly on feed production. Ten of the fourteen studies concentrate either on one or the other group of impacts. TOPP and DOYLE (1996) as well as PARSONS et al. (2001) and MORAN et al. (2009) are the only studies where both types of impacts are considered. It should be noted that TOPP and DOYLE (1996) merely simulate the growth of grass and, based on these results, they derive the impacts on milk yield and body weight in a second step. In contrast, PARSONS et al. (2001) and MORAN et al. (2009) examine the direct impacts of climate on the dairy cow performance.

It is striking that those studies focusing on Great Britain commonly indicate positive impacts of climate change on feed production. This is due to the expected longer vegetation period, higher temperatures and a higher CO_2-concentration in the atmosphere. As TOPP and DOYLE (1996) model cow performance solely on the basis of the predicted increasing feed production, they infer positive impacts on milk yield. Similarly, HOSSELL (2002), who only models the impact on feed production, identifies large economic benefits for British dairy production. FITZGERALD et al. (2009) calculate the implications of an extended vegetation period and of summer drought for dairy feed production at the farm level. They can thus deduce management recommendations like to produce more conservation feed and to make a break in summer pasture.

As soon as direct impacts of climatic conditions on dairy cows and milk yield are taken into account, however, economic benefits from increased feed production can be offset, among other things by losses in milk yield and higher mortality rates due to heat stress (PARSONS et al., 2001; MORAN et al., 2009). Clearly, the type and number of direct and indirect impacts included in the analysis very much influence the results and conclusions drawn. The study of ST-PIERRE et al. (2003) covers the largest number of direct impacts in the studies under consideration, namely four (i.e., milk yield, mortality, dry matter intake and conception rate).

Table 2. Compilation of studies on climate impact on dairy farms, main characteristics and results

Study	Direct impacts considered	Indirect impacts considered	Involvement of stakeholders	Adaptation to climatic conditions	Calculation of adaptation costs	Number of climate scenarios used	Regionalization of climate data	Main conclusions
SEO	Embedded in the data set used		No	Yes	No	3	No	African farmers will adapt to climate change; while small farmers are able to switch species rather easily, changes come at significant cost for large farms; governments have to assist these adjustment processes
LEV	mi	No	No	No	No	2	No	Current milk yield losses due to heat stress are already significant in Argentina, especially in the northern part; expected climate change will aggravate the corresponding production losses
MAY	mi	No	No	Yes	No	No climate scenario used		THI thresholds vary across the Australian regions, so cows might be adapted differently; production losses are greater for dairy herds with above-average milk yield; "good management" can mitigate these impacts
WAL	mi, cr, dm	No	No	(Yes)	No	4	Yes	The economic benefits of dairy farming (return from milk minus feed costs) will decline significantly in the long-run; German regions will be affected differently; competitiveness of coastal regions will increase
TOP	(mi, we)	Feed	No	(Yes)	No	2	No	Grass and grass-white clover swards respond differently to climate change in Scotland; mean milk yield will probably increase as the total silage yield from the first cut will be higher
PAR	mi, we	Feed	No	Yes	No	3	Yes	Cows will probably adapt to climate change in Great Britain, however shade should be provided in warmer regions; farmers can benefit from increases in grass production through higher stocking rates
HOS	No	Feed	No	Yes	Yes	1	Yes	Generally positive impacts of climate change on grass growth and therefore on dairy farming in England and Wales, given that future economic policies are beneficial to increased milk production
HUG	No	pr	Yes	Yes	Yes	1	(Yes)	Past weather extremes lead to specific adaptation by British farmers, e.g., improved ventilation systems; climate change impacts will increase pneumonia risk and feed costs due to longer periods of housing.
MOR	mi, cr, mo	Feed	(Yes)	No	No	1	Yes	Adaptation to climate change impacts such as increase in grass production, heat stress, exotic diseases is inevitable; the necessary adaptation is generally within the capacity of the British livestock industry
FIT	No	Feed	No	Yes	No	6	Yes	Grass-based dairy production in Ireland is able to adapt to climate change; differences between farms on poorly and well-drained soils; more feed in spring and autumn, but a drop in grass growth in summer
IGO	mi	No	No	Yes	Yes	No climate scenario used		During summer heat, cows in shade plus fan and spray experience less physiological changes and produce more milk compared to shade only; investments in fan and spray under shade will increase net profits
KLI	mi, cr	No	No	No	No	3	No	Declines in milk production and conception rate will be more significant in the USA than in Europe; most affected areas in the USA are major milk producing regions
STP	mi, mo, dm, cr	No	No	No	No	No climate scenario used		Impacts of heat stress, i.e., decreased performance and reproduction, increased mortality, cause significant economic losses; dairy farming is the most negatively affected among major US livestock industries
MAD	mi, dm	No	No	No	No	2	No	Dairy farming in the Great Plains of the USA will experience losses under climate change; milk production will decrease if no adaptation takes place

Notes: Study abbreviations are defined in table 1. "mi" is milk yield, "cr" is conception rate, "dm" is dry matter intake, "we" is weight, "mo" is mortality and "pr" is pneumonia risk.
Source: own compilation

The relationships between climatic conditions and pathology have not yet been fully included in economic CCIAs concerning crop or livestock production. As it is supposed to have a great impact, some argue that results are biased if ignored (AMEDEN and JUST, 2001). The same applies to the performance of heifers and calves which is only examined by ST-PIERRE et al. (2003). The authors find, however, that these impacts are rather marginal. Besides, no study has ever quantitatively analysed warming in winter as potentially beneficial for milk yield in cold climatic zones, since less energy is required to maintain the body warmth. Neither have these climatic zones been considered, nor do bio-physiological models or production functions exist that include milk loss through cold. Beneficial effects for cold climatic zones are often qualitatively discussed. Given these open questions, estimations on global milk production under climate change should be seen as lower bounds.

The minority of the studies under consideration include information gained from stakeholders, like expert interviews with farmers or farm advisors (see table 2, column 4). Such involvement can deliver highly relevant and focused results which help to understand how climate change is perceived from the farmer's point of view and what adaptation measures will be implemented. HUGHES et al. (2008), for example, use survey results that show which specific weather extremes British farmers consider as becoming worse under climate change. The farmers neither mention drought nor heat stress, but sudden changes in temperature which cause calf respiratory disease. Interviews with farmers revealed that this risk concerns dairy farmers. This aspect had not received attention in other CCIAs in Great Britain or Ireland before, where typical and obvious issues like grass growth and heat stress had been explored. This underlines the need for an integration of stakeholders' views and priorities.

On the other hand, this lack of involvement shows the problem for stakeholders, and especially farmers, to work out strategies and adaptation measures for yet unperceived and unknown future challenges under climate change like potential warming in summer or a drought-reduced corn harvest. Indeed, MORAN et al. (2009) show the qualitative results of stakeholder discussions. These give the researchers an idea of how concerned farmers actually are about climate change, namely "very little", and which kind of adaptation measures for certain climate scenarios farmers (will) choose today and until 2020.

The inclusion of adaptation measures in CCIAs has an equally strong influence on the results as the type and number of direct and indirect impacts taken into account. Table 2 (column 5 and 9) shows that almost every study in the present overview finds a positive, or at least not negative, impact of climate change, if adaptation is considered. In contrast, the impacts are generally negative, if no adaptation is assumed (see, for example, LEVA et al., 1996; WALTER and LÖPMEIER, 2010, and MADER et al., 2009).[2] For example, KLINEDINST et al. (2003) and WALTER and LÖPMEIER (2009) calculate milk loss through heat stress, based on physiological functions, for the United States and Germany, respectively. As the authors do not integrate any shade and fan systems, heat resistance through breeding or other measures, they find significant milk production and economic losses. MAYER et al. (1999), on the contrary, show that losses in milk production due to heat can be mitigated to a significant extent.

Although the alleviating effects of adaptation to climatic conditions are analysed in the majority of studies under consideration, only few calculate the accompanying costs of these measures (see column 6). HUGHES et al. (2008) assess the efficiency of barn ventilation to reduce the incidence of respiratory diseases in cattle, especially calves, while IGONO et al. (1987) look at the economic consequences of fan and spray systems in addition to shade. HOSSELL (2002) evaluates grassland irrigation to mitigate drought (not efficient) and enlarging herds as a reaction to more fodder (efficient). It should be noted that WALTER and LÖPMEIER (2010) integrate adaptation into their study to the extent that they show which month is the best for calving in order to mitigate milk yield loss. However, the authors do not make any further economic evaluation.

The regionalisation of climate change scenarios and the reduction of uncertainty by the use of several climate scenarios instead of just one can be seen as the current state-of-the-art method in CCIA. Table 2 (column 7) shows that indeed the majority of the reviewed studies applies more than one climate scenario. Also, the majority of studies based on climate modelling results further regionalize the data in order to more precisely assess changes in temperature or precipitation (column 8). It should be noted here that, interestingly, empirical studies which explicitly address

2 Such an observation has also been made with studies analysing the impacts of climate change on crop farming (KAISER et al., 1993; SEGERSON and DIXON, 1999).

the frequency of specific weather extremes are rare. This can be due to two facts. First of all, there is a general controversy in the meteorological community whether a rising frequency of weather extremes is really being experienced and is part of climate change, or if this is just a subjective perception (MEARNS et al., 1984; SCHÖNWIESE, 2008; KATZ and BROWN, 1992; WEISHEIMER and PALMER, 2005; GEIGEL and SUNDQUIST, 1984; HULME et al., 1999). Second, it is not easy to combine probabilities of weather extremes with bio-physiological models.

The ninth column of table 2 summarizes the main conclusions drawn in the studies under consideration. We deliberately choose to be rather general in this listing as detailed results are hardly comparable. On the one hand, the economic yardstick used to measure and express climate change impacts differs substantially, for example, benefits and losses are expressed per cow, per herd or for the national dairy farming sector as a whole. On the other hand, the studies are characterised by a large variance, among others, in the time horizon considered, climate scenario(s) applied and impacts taken into account.

Cross-country comparisons are possible if several countries or regions are analysed within one study. For example, KLINEDINST et al. (1993) look at the USA and also some European countries. The authors find that milk yield losses due to summer heat in the South of the USA are higher than in Spain and the South of France. Although adaptation is not explicitly considered in the analysis, the authors note that negative impacts might be less important in those regions where dairy farmers are used to dealing with heat, i.e., in the South of the USA, but more problematic for "unprepared" dairy farmers in the North of the USA and Europe.

As far as economic benefits and losses are provided, it is possible to evaluate their significance on the background of a contemporary dairy farm. For example, KLINEDINST et al. (1993) use two "normal levels" of milk production per cow, i.e., 23 and 33 kilogram per day. Assuming a lactation period of 360 days, this amounts to 8 280 and 11 880 kilograms of milk per cow and lactation, respectively. The highest seasonal milk production losses were estimated to be up to 700 and 900 kilograms in the southeastern USA, equalling 8 and 7.5 percent of a cow's milk production, respectively. This is a relatively significant impact for a dairy farm given that milk is most often the only marketable product, apart from some bull calves. MAYER et al. (1999) assume milk production per cow to be at a level of 25 kilogram per day and estimate a loss in milk production for Australian dairy farmers of about 5 percent. ST-PIERRE et al. (2003) estimate milk production losses in the USA ranging from 68 kilograms per cow and year in Wyoming to 2 072 kilograms per cow and year in Louisiana. However, it is not noted on which yield level these calculations are based.

These results demonstrate the large differences in milk production losses depending on the region under study. Also, it must be stressed that MAYER et al. (1999) and ST-PIERRE et al. (2003) use current climatic conditions instead of those expected in the future. Climate change can therefore become a serious problem for dairy farmers in regions which already face hot and humid climatic conditions.

5 Conclusion

This paper has given an overview on studies dealing with economic CCIA in dairy farming. Given the amount of public and academic attention to climate change impacts on agriculture, it is surprising that only a small body of literature exists analyzing the cost and benefits to livestock and especially dairy farming. This can certainly be attributed to the complexity of physiological, chemical, physical and also behavioural functions that have to be considered. The overview shows that existing studies are limited to only a few countries and climatic zones, which in fact do not belong to the areas presumably most affected by climate change.

From a methodological point of view, the use of simulation-based approaches predominates. This seems to be due to the fact that such approaches allow for a more focused assessment of climate change impacts, especially in view of expected conditions. Statistical/econometric methods require comprehensive and consistent data. Also, the extent to which climatic conditions influence dairy farming in sophisticated and (nearly) weather-independent housing systems and whether other variables such as market or policy constraints have much more explanatory power can be discussed. The withdrawal of the EU milk quota system will, without a doubt, enhance the role of climatic location factors. This does not mean, however, that simulation-based methods are *per se* superior to statistical/econometric methods. Both methods must be regarded as supporting and complementing each other.

Besides, the overview indicates that mostly either direct impacts of climate change affecting a dairy cow's performance or the indirect impacts, particularly on feed production, are analysed. While the first tend to be negative, the latter are normally positive for most of the regions under consideration. Hence, the conclusions drawn must be qualified with regard to the type and number of impacts examined. Another important point is to allow for possible and required adaptations of farmers, politicians, etc., to climate change. If these are not taken into account, associated economic losses (benefits) are likely overestimated (underestimated). On the other hand, assuming perfect adaptation shows the opposite case and generally underestimates economic costs (and overestimates benefits), as natural, farming, economic and social limits to adaptation are neglected. This calls for a closer involvement of stakeholders than has been done so far in CCIA, in order to identify and prioritise realistic adaptations.

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