Policy Modeling for Greenhouses Gas Emissions on Dairy Cattle Sector: the Importance of the Milk Production Improvement

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1. ABSTRACT

More than 14.5 Billion of $ were spent in US by Federal R&D authority for 2011 for Climate Change. Current focus of animal scientists is to identify the most viable solutions to improve farm profitability and milk production while minimizing the environmental impact of livestock. The main objective of this paper was to use the System Dynamics methodology to: 1) model the importance of the milk production improvement to reduce greenhouses emissions in the dairy cattle sector, and 2) focus a viable policy to minimize the dairy environmental impact.

The model consisted of 6 sub-models, as follows: (A) human population and milk market; (B) cow population; (C) milk production; (D) energy and feed requirements by the animals; (E) economics; and (F) potential environmental impacts and government policy; the last sub-model was aimed to encourage and strengthen the reduction of GHG emissions in dairy cattle farms by improving the milk production per cow. Considering the simulated scenarios, the carbon footprint of the milk (expressed as kg of CO_2 equivalents emitted per kg of milk), decreased proportionally to the milk production per cow; while the total amount of emissions was highest in the scenarios with highest milk production rate.

Policies oriented to improve the milk production per cow per year stimulated the milk consumption rate and reduced the carbon footprint of milk. Simulated scenarios showed that to reach environmental goals, governmental policies should be oriented to stimulate dairy farm productivity and taking advantages from minimizing resource utilization and farm inefficiencies

2. BACKGROUND

Food production and environmental impact are going to represent the most important issues related to animal production in the near future (Tedeschi et al., 2011a). In this context, dairy cows acts related the global warming potential of the entire world moreover for the contribution to the greenhouses emissions in the milk production processes. Furthermore, the increase of world population to over 8 billion people in 2030 will increase the demand for food around the world (FAO, 2006). At the moment, the dairy cow sector provides about 83 % and 13 % of total world milk and meat production, respectively (FAO, 2009); in quantitative terms and it is expected to increase its energy demand to partially contribute to the food supply chain by increasing meat, milk, and processed products; in particular, the demand of animal derivate food is expected to growth very fast, especially in the developing countries (FAO, 2006).

Nonetheless, the livestock sector also contributed to about 18% of total anthropological greenhouses gas in terms of CO_2 equivalent emissions (CO_2eq) per year (FAO, 2006). In 2007, the world dairy cow sector emitted 22% of total livestock CO_2eq of which 15% was allocated to milk production and the remaining 7% was assigned to meat production (Gerber et al., 2010). The pollutant effect of dairy cattle, in terms of carbon footprint, was recently estimated in 2.4 ± 26% (varying from 1.3 to 7.5) kg of CO_2eq per kg of fat and protein corrected milk (FPCM; Gerber et al., 2010). The lowest values of emissions were estimated for intensive livestock production systems of the industrialized regions located in North America and Europe; values lower than 1 kg of CO_2eq per kg of FPCM were also estimated for high productive systems where an average cow produces more than 8,500 kg of milk per year (Rotz et al., 2010).

Additionally, the environmental impact of livestock is related to energy demand and vegetal biomass use. The competition for these products could generate a raise of price of grains (Kim 2009). Therefore, the understanding of the interplay between aggregate demand for animal products, production factors, demand, and their relationships to the environment is crucial to guide governmental policy and industrial activity (Tedeschi et al., 2011b). However, because the cost to maintain the herd is between the second or third greatest cost on many dairy farms after feed and labor (De Vries 2005; 2006), milk production improvement has been associated with profitability, with the reduction of resources utilization, and therefore with some environmental benefits (Chase et al., 2003; Capper et al., 2007). The increased productivity of individual animals has decreased the number of dairy cows in the United States from approximately 12.1 million dairy cows in 1970 to 9.1 million cows in 1999 (Cassel, 2001). A big limitation in the increase of productivity is the ability of producers to invest in productivity that is profit related and affected by the commodities and its price in the market demand (Meadows, 1970).

The Kyoto Protocol aimed to reach the reduction of greenhouses gas emissions; is already noticeable a big effort of the governments, business firms and scientific community, in terms of funds and capital resources to understand the keys variables of the global warming control. The Federal R&D authority budget spent in US for 2011 for Climate Change was higher than 14.5 Billion of $ (Higgins, 2012). In this context, the current focus of animal scientists is to identify the most viable solutions to improve farm profitability and milk production while minimizing the environmental impact of the livestock. Without clear priorities between improvement of animal productivity and environmental sustainability a dynamic approach to this issue is needed to understand the possible effects of policy on GHG emission in dairy cattle farms. In particular, system dynamic models could help to focus the eco-sustainability trade-off points, between economic and ecological factors; from this point of view, the variable dynamics driving farmer's investment choices need to be studied and profundized. Simulation modeling developed in conjunction with decision makers and stakeholders can generate credible and relevant assessments of climate change impacts on farming systems (Rivington et al., 2007).

Therefore, the main objective of this paper was to use the system dynamics (SD) methodology to model the milk production and consumption dynamics in the world studying the importance of the milk production per cow improvement to reduce greenhouses emissions in the dairy cattle sector and focus the way pro propose possible policies to minimize the environmental impact of the milk production.

3. MATERIAL AND METHODS

3.1. Development of the model and causal diagram

The model was built using Vensim® version 5.9 DSS (Ventana System, Inc.). The complete model was based on the dairy sector model reported by Atzori et al. (2011). It consisted of 6 sub-models, as follows: (A) human population and milk market; (B) cow population; (C) milk production; (D) energy and feed requirements by the animals; (E) economics; and (F) potential environmental impacts and government policy.

The original model structure was modified substituting the milk market sub model with the basic commodity model structures in Meadows (1970) and Sterman (2001). This structure was integrated with a delay between milk production and milk availability at retail level, to take into account the milk processing into different dairy products consumed at different aging time.

The effect of farm investments on milk production was modeled assuming a direct effect of profit ratio (revenues/cost) on the variation of the herd size (changing the number of replacement or culled cattle) or, alternatively on the destination of part of farm profit to improve breeding and management of producing animals, as previously modeled by Pagel et al. (2002).

The dairy cow milk system was preliminary identified with two important balancing loops, as follows: world milk demand (loop 1; MD; Figure 1) and world milk production (loops B2 and B3,; MP; Figure 1). Loops B2 and B3 in the figure 1, indicate cow number (CN), cow productivity (CPr) while the loop B4 and R6 both indicated the feed cost to produce milk and represented the energy demand due to herd maintenance (FC_{maint}) and energy demand due to milk production (FC_{milk}), respectively.

The MD (kg/year) represents the desired state of the system; it mainly depends on the number of people in the world (assumed as an exogenous variable to our model), and their annual milk consumption per capita that was assumed almost constant in the world as reported in the historical trend from 1970 to 2010 by Rouyer (2011). An increasing trend of milk consumption was assumed to take into account the forecasted trend of milk consumption of developing countries in the near future (FAO, 2006).MP can be varied both changing the CN (indirect way) or the CPr (direct way).

The MP (kg/year) describes the system ways to meet the milk world demand. The MP can be adjusted both varying the CN (indirect way) or the CPr (direct way). It respectively goes throughout the number of dairy cows in the world and their annual milk productivity (kg/cow/year). The gap between demand and offer of milk is represented by the difference between MD and MP. It directly and negatively affects the milk price. Milk price changes can alter the desired state of the system because of the negative relationship with the milk demand per capita and it can also positively affect the farm profitability. The milk production rate strongly depends on the profitability of the production process, which is positively related to the farm investments; they could be used either to expand the number of cows in the herd or to increase their own milk production level. As reported by Weller et al., (2011) the actual genetic gain is 100 kg/cow per year in US; the same authors calculated a nominal economic value of 0.1$ per additional kg of milk productivity improvement per cow on the annual basis; using a conservative assumption the cost of milk production improvement per cow was considered equal to 0.3$ per kg/cow of annual gain; in fact, as reported by Weller et al., (1994), a long term investment in breeding, could be justified if its cost is lower then 3 times the nominal value of gain.

Greenhouses gas (GHG) emissions were modeled using IPCC (2006) assumptions. Methane is produced by the enteric fermentation of organic biomass used for her feeding and by the waste fermentation storage facilities. From storage facilities N_2O and CO_2 were also emitted; other CO_2 emissions comes from secondary sources (IPCC, 2006; Rotz et al., 2010). In the model, emissions of carbon oxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), were considered and then converted in CO_2 equivalents (CO_2eq) as reported by Gerber et al. (2010).

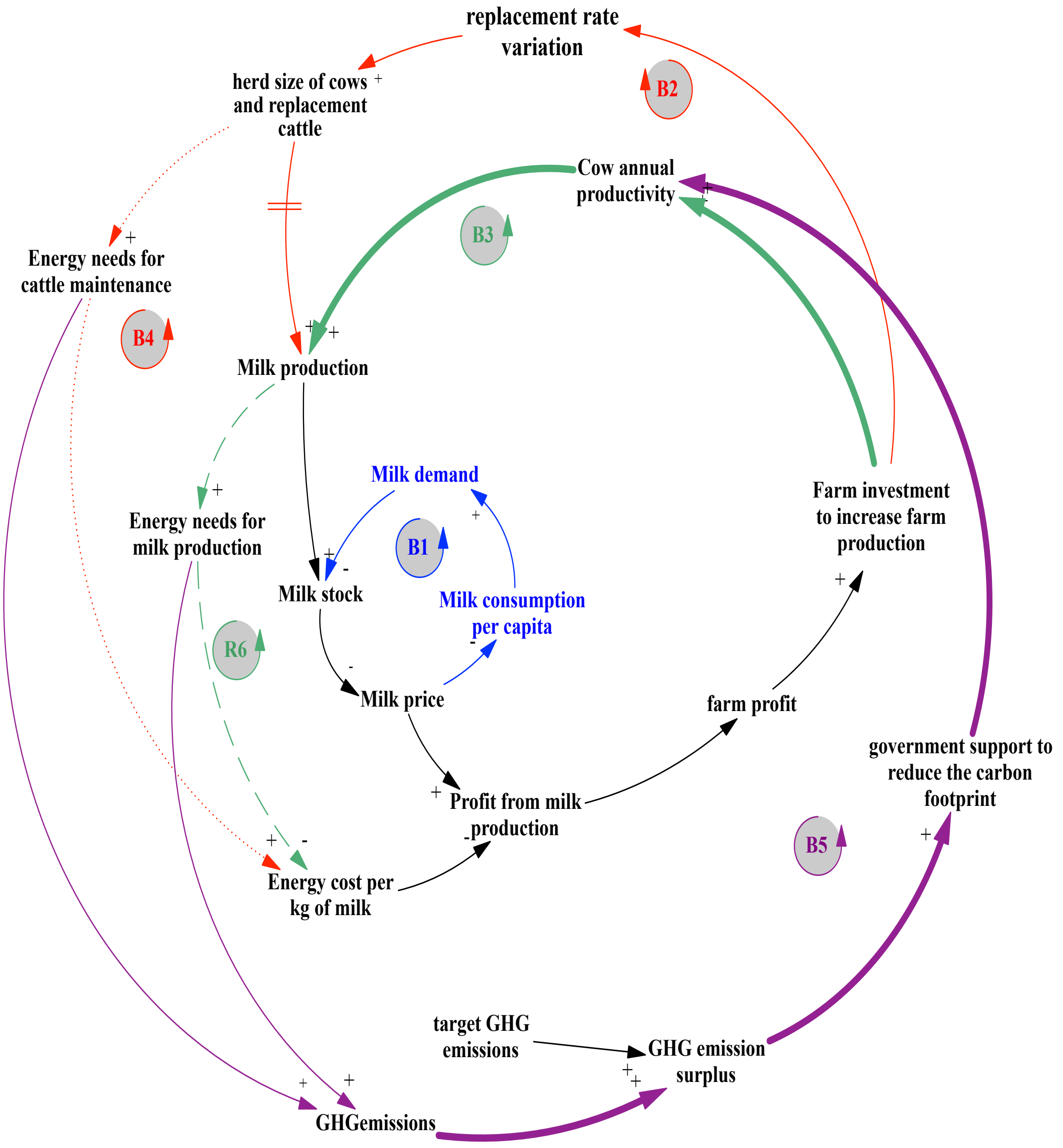

Figure 1. Causal loop diagram of the effect of the milk production improvement on the reduction of greenhouses gas emission:

- world milk demand (desired state of the system, MD; loop B1);
- world milk production (MP; loops B2, B3, B4 and, R6; they indicate cow number (CN), cow productivity (CPr), feed cost to maintain the herd (FC_{maint}) and feed cost to produce milk (FC_{milk}) respectively).
- GHG emissions and government policy in loop B5 (GHG).

Black arrows are involved in > 1 loops while Bold lines indicate a possible policy to stimulate and strengthen the loop effect.

3.2. The dynamic hypothesis

Supposing a constant milk demand in the world, the increase of milk production per cow should cause a reduction of the number of cows and replacement cattle, principally for economical reasons; a reduction of about 2% per year in the US cow number was reported by Capper et al. (2007), in conditions of constant milk production rate, from 1944 to 1980.

Assuming an increasing demand of milk in the world, the farm profit, it could be destined to increase the amount of milk produced by a general farm can be used to increase the number of cows in the herd or to improve their own annual milk production (Figure 1). Looking at the second way of CPr (loop B3 in Figure 1), the investments in breeding programs are unlike other investments, in that the gain are eternal and cumulative (Weller and Ron, 2011); it brings higher environmental and economic benefits. In fact, looking at the Figure 1, more milk is produced by the farms, more milk arrives to the milk market stock; it probably causes a reduction of the milk price, that in turn causes the elimination of a proportional number of cows from the production process. It also generates a proportional reduction of the energetic needs to produce a kg of milk, lowering the maintenance cost of the herd. Energetic needs of milk production are positively related both with the GHG emissions (moreover methane from enteric fermentation) and with the feeding cost. Consequently, the improvement of the annual milk production per cow shall: reduce the carbon footprint of the dairy sector and stimulate the milk consumption.

A policy program based on total GHG emissions of dairy cattle sector was included in this model in addition to the previous version of the model reported by Atzori et al. (2011; Figure 1); a balancing loop of government support to the milk production improvement was simulated in order to encourage and strengthen the reduction of GHG emissions in dairy cattle farms. An environmental policy could also stimulate the effect of the reinforcing loop (R6; Figure 2): in fact if more milk production improvement causes a reduction of the cost of the milk, it will generate more profit and more probability of farm investments to improve the annual milk production per cow.

3.3. Model parameterization and calibration

Values from the literature were used as initial values of the biological auxiliary variables and constants. The initial values of principal stocks were setup using data reported by the Food and Agricultural Organization (FAO; http://faostat.fao.org/default.aspx). Model parameterization and calibration were also performed using data reported by FAO. The FAO provides historical trends and forecasts of human population census and livestock primary production in terms of producing animals, inventories of products, and animal productivity. Model calibration was executed on the lookup functions until the model estimations matches the reported and forecasted FAO trends, from 1999 to 2030, for cow number, cow productivity, and total milk production (Figure 2). The base scenario was simulated considering that 50% of the total annual farm profit was destined to the investments for milk production improvement of the same farm; the investment was then equally divided between increase of farm herd size and improvement of cow annual milk production (Figure 2).

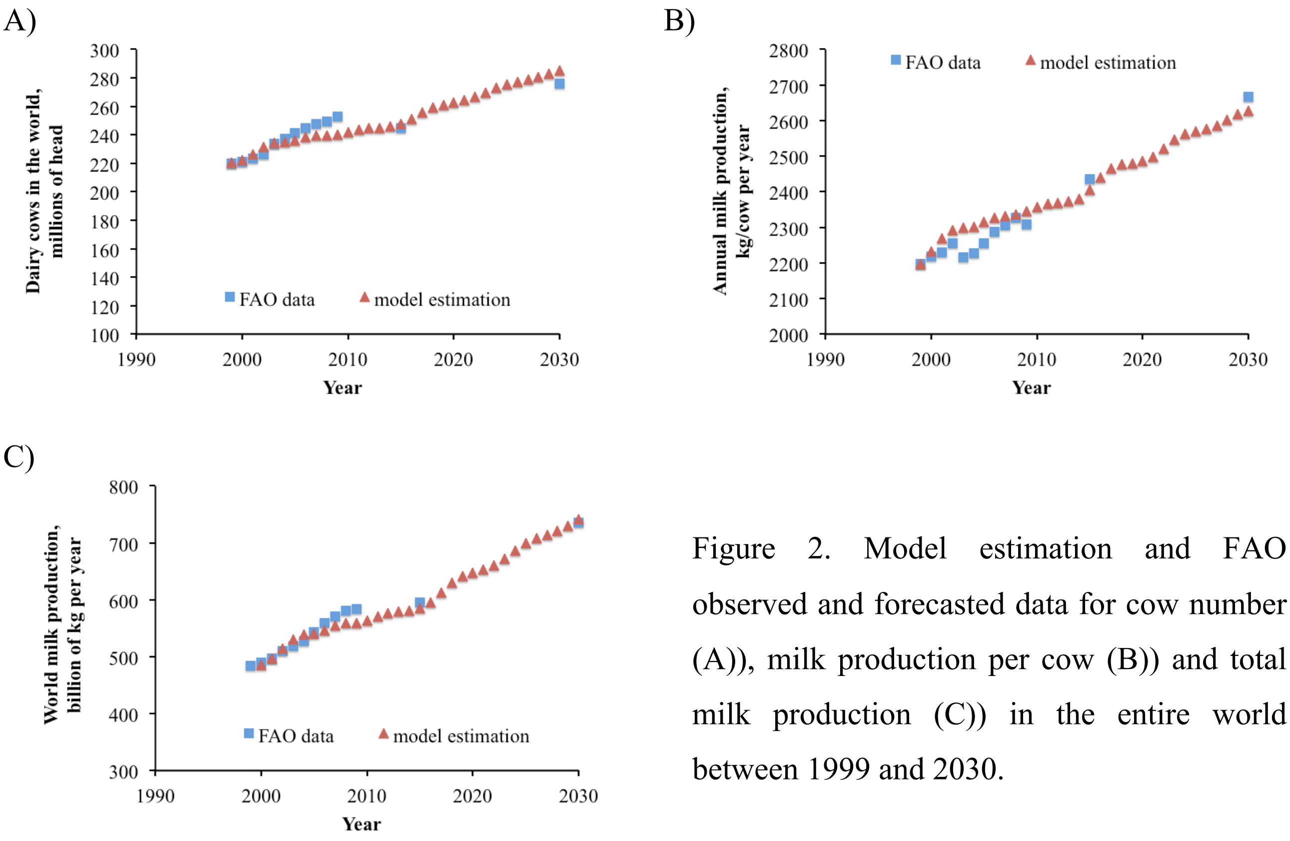

Figure 2. Model estimation and FAO observed and forecasted data for cow number (A)), milk production per cow (B)) and total milk production (C)) in the entire world between 1999 and 2030.

3.4. Model application: simulated case studies

The simulation time horizon was 31 years, between 1999 and 2030; unit for time was years with a time step of 0.0625; the Range-Kutta4 method for integration was used.

Five scenarios with positive profitability were simulated to study the sector dynamics in relationship with GHG emissions;

- 3 scenarios were simulated varying the profit partitioning between herd size (CN) and cow annual productivity improvement:

a) CN0.5: base scenario with 50% of positive profit destined to increase the herd size and 50% to improve cow productivity;
b) CN0.3: scenario with 30% of positive profit destined to increase the herd size and 70% to improve cow productivity;
c) CN0.7: scenario with 70% of positive profit destined to increase the herd size and 30% to improve cow productivity.

2 other scenarios simulated the GHG policy from the year 2014:

d) CN0.5_policy : base scenario + government support to farmers associations in order to reduce GHG emissions; it consisted in 0.0045 \$/kg of milk oriented to improve milk production per cow.
e) CN0.3_policy: government support to farmers associations in order to reduce GHG emissions; it consisted in 0.0045 \$/kg of milk applied to a system already oriented to improve milk production per cow.

4. RESULTS AND DISCUSSIONS

The base scenario described the observed situation of the past years and the forecasted trends reported by FAO. It resulted in a milk production improvement of 15 kg/cow per year (from 2200 to 2400 kg per year from the year 1999 to the 2014; figure 3) it represents the average trend of the milk production improvement for the cows of the world herd size.

The other scenarios reported different increases in milk production per cow, within the range of 2880 kg for the highest production (CN03_GHG policy) and 2486 kg for the lowest (CN07), measured at the year 2030. Considering the comparison between scenarios, the policy had an higher effect on the CN05 scenario with respect to the CN03 scenario (Figure 3).

Relatively to the number of cows (Figure 4) in respect to the milk production per cow (Figure 3) the scenarios were inversely ranked, highlighting the balancing effect of the system structure on the milk production rate. In fact, the total milk production is in equilibrium with human milk demand; consequently, higher production per cow is counterbalanced by lower number of producing animals (Figure 4) as already observed in US (Capper et al., 2007). However the market response to the milk production rate is reflected by the milk availability in the stocks, which causes variations in milk price and, in turn affects the supply chain. The scenario (CN07) with lowest milk production per cow and higher number of cows, also showed the lowest milk production rate between simulated scenarios (Figure 5). CN07 could be considered as the worst scenario for the future of the dairy sector because of its low ability to produce food for humans.

In economical terms, the market structure of this model was developed in order to replicate oscillating patterns of the milk price in the market and at the farm gate, as reported in different countries for fresh milk (IDF, 2011). Was not objective of this model to estimate the milk price variability and volatility. In fact, as reported by Nicholson and Fiddaman (2003), milk price volatility is often caused by a large number of factors than the usual supply-chain explanation, like the behavioral response of industry participants to price and inventory signals, long-term contracting, speculative hoarding, coupled long-term cycles of processing capacity and herd size. A more complex model, as approached by Pagel et al., (2002) accounting for many different variables, such as seasonality of supply, multiple derivate products, minimum price, market premiums, government offers to support prices, international trade policies, etc, must be used to estimate the milk price variability. Moreover, observing that butter, skim powder of milk, cheese and cream are the standard indicators of milk price, the use of the only synthetic price of raw milk for the entire world could be considered an oversimplification of the same commodity market.

As expected, all the scenarios showed oscillating behavior for milk inventory, milk consumption, milk expected consumption rate, inventory coverage, milk price at consumers, total profit. In the base scenario the milk price at consumers varied from 1.1 \$/kg to 0.8 \$/kg showing peaks every 4 years approximately; the oscillation period was very similar to that observed in US milk price between 1990 and 2010 (Gould, 2011). A little variation between scenarios was also observed. Considering the environmental performances of the system in the studied scenarios the total GHG emissions increased proportionally to the milk production rate and the milk annual production per cow (Figure 6). In fact, the carbon footprint of the milk, expressed in kg of emitted CO_2 per kg of milk, decreased proportionally to the milk production per cow (Figure 6) while the total amount of emissions were highest in the scenarios with highest milk production rate (Figure 5).

The scenarios were governmental policies were applied to the system showed that: the public effort on GHG reduction could have a good exit if associated with farm goals of milk production improvement; similar results could be achieved in the farms already managed in order to reach efficiency and productivity; in fact, farm profitability resulted negatively associated with the carbon footprint and the total GHG emissions of the dairy sector. A total reduction of total GHG emissions, was not observed in these ranges of annual milk production improvement per cow; may be a stronger increase of milk yield per cow per year could be helpful to reach these results, as observed by Capper et al., (2007). Thus, the applied policy was not able to change the pattern of behavior of the studied variables, but it was not included in the policy objectives; in fact, the policy was capable to stimulate farmers to produce milk with high level of technical efficiency (i.e increase milk production per livestock unit) and showed as forcing the system trough the B3 and R6 loops it is possible to obtain environmental benefits without significantly change the market conditions.

The model limits model are related to the milk market description and complexity; this model simplified the market structure in order to focus the relationship between the environmental aspect and the farm efficiency. Other models, as the dairy model proposed by Pagel et al., (2002), considered more adapted to study the economic aspect of the milk market, could be integrated with this environmental sub-model in order to better understand the relationships between environmental and economical aspects of the dairy sector.

5. CONCLUSIONS

In environmental terms, the milk production process is a source of emissions of CO_2 and its environmental impact is higher as milk production rate increase in the world. From this point of view, the milk production improvement, could help the dairy sector to fit the main objectives of the sustainability pursued by the Life Cycle Assessment approaches (IPCC, 2006; FAO, 2006): to produce enough food for the growing human population and reducing, at the same time, the environmental cost per unit of products. Simulated scenarios showed that to reach environmental goals, governmental policies should be oriented to stimulate dairy farm productivity and taking advantages from minimizing resource utilization and farm inefficiencies.

6. FIGURES

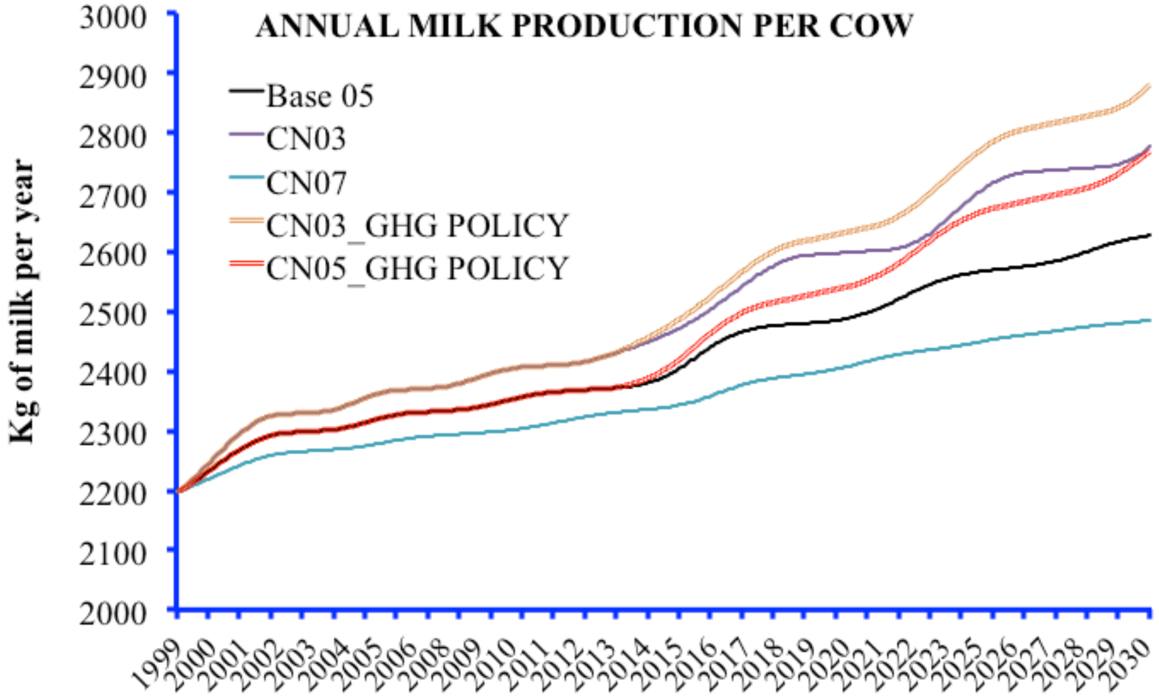

Figure 3. Model estimates of cow annual milk production for the simulated scenarios.

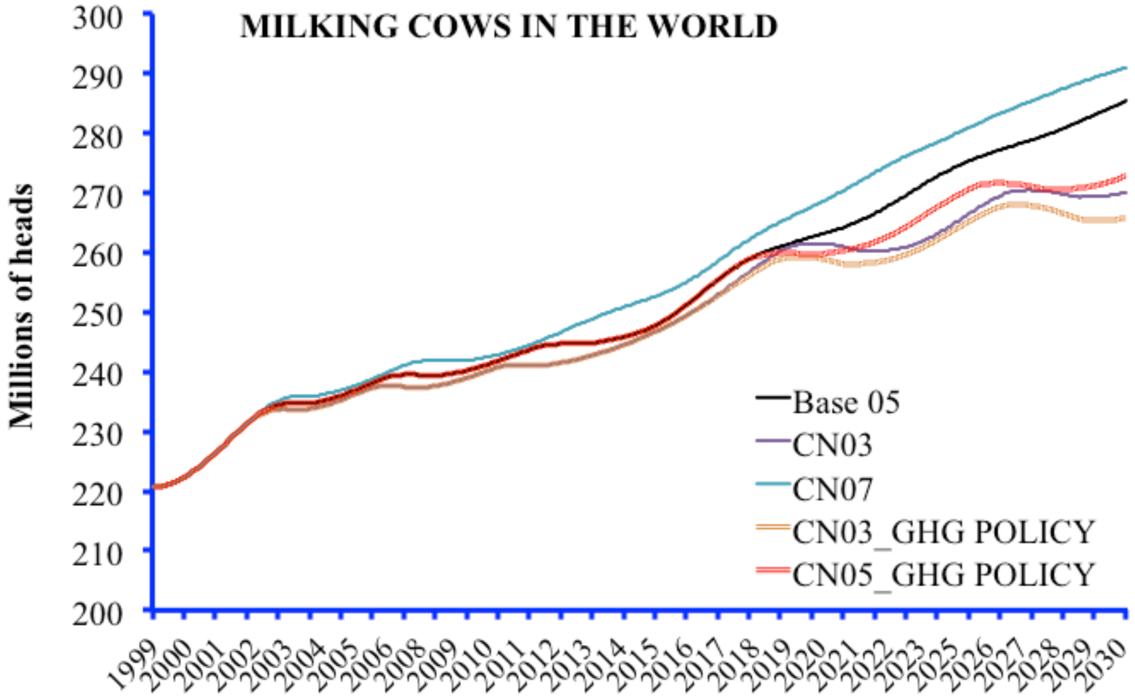

Figure 4. Model estimates of cow number for the simulated scenarios.

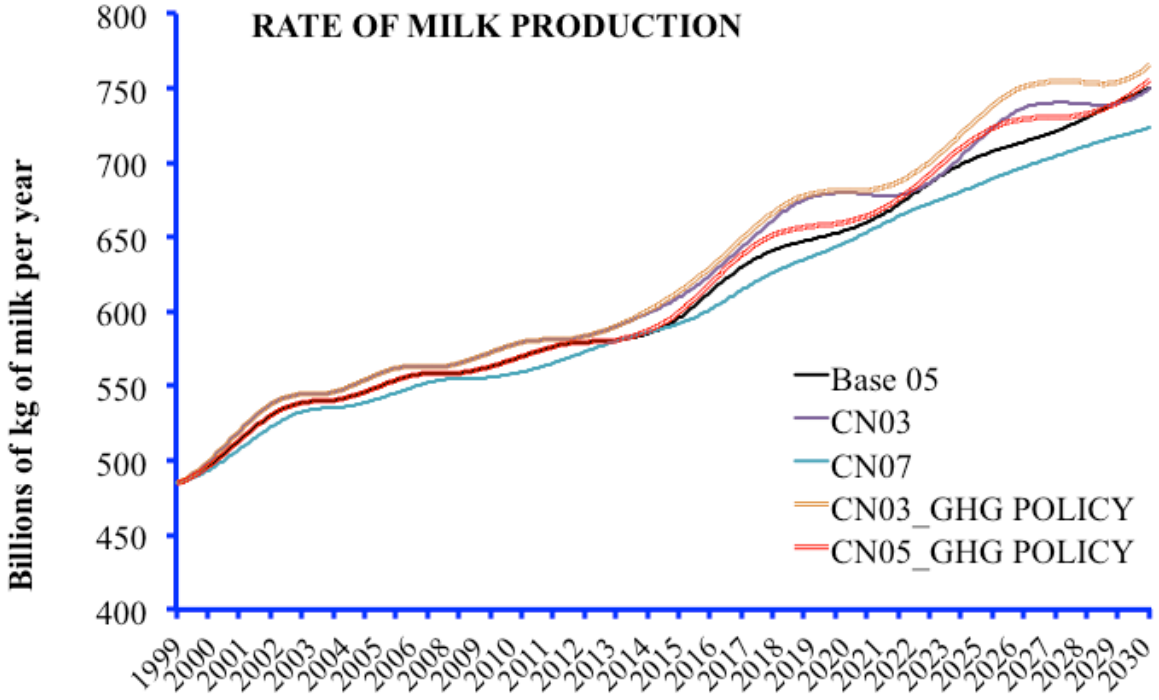

Figure 5. Model estimates of the world milk production rate for the simulated scenarios.

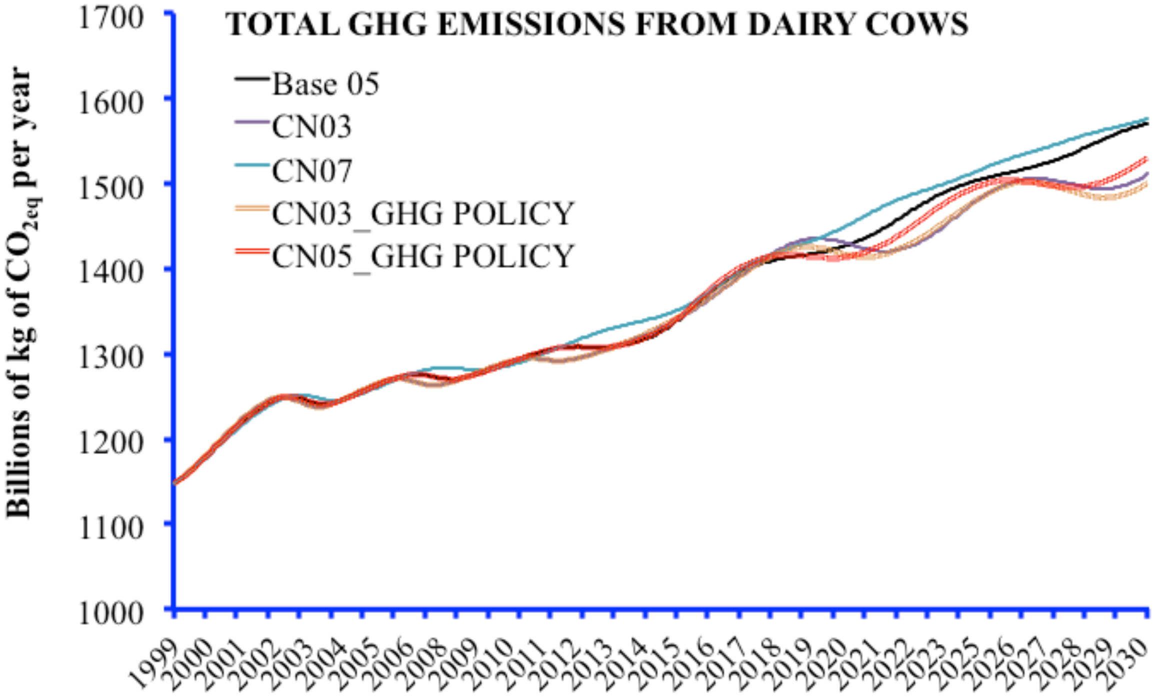

Figure 6. Model estimates of the total GHG emissions for the simulated scenarios.

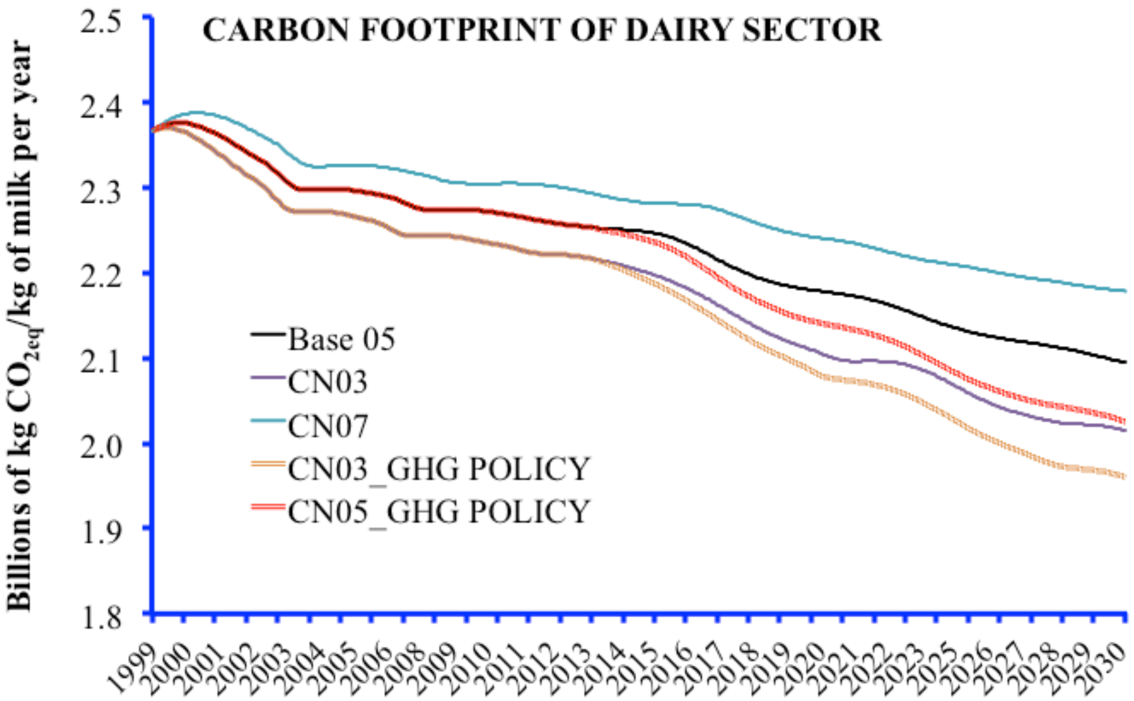

Figure 7. Model estimates of the carbon footprint for the simulated scenarios.

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