The Dynamics in the Dairy Cattle Sector: Policies on Cow Milk Production Can Reduce Greenhouses Gas Emissions and Land Use

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Abstract. This paper was aimed to understand the key components affecting the dynamics of world milk production and consumption and their effects on CO_2 emissions (CO_2eq) and grassland-use. A model was built on two major balancing loops: world milk demand **(MD)**, and world milk production (**MP**). The MP consists of three balancing loops: cow number (**CN**), cow productivity (**CPr**), and feed cost; they represented the indirect and direct way to change the MP rate in order to meet MD, and the positive relationship between cost and demand of feed, respectively. The model consisted of 6 sub-models: people and milk market; cows; milk production; energy requirements; economics; environment. Simulated scenarios were performed between 2007 and 2052. The structural loops affected the output behavior: when MD>MP farm profitability described goal seeking patterns, while if MP>MD it described constant oscillating patters. Scenarios with low CPr did not meet the MD. Scenarios with greater CPr and policies to improve CPr and cattle efficiency met the MD while reducing the CN and using fewer inputs per kg of milk. The model suggested that CPr and cattle nutritional efficiency were the key factors in mitigating anthropogenic environmental impacts by reducing total demand for energy, grassland-use, and CO_2eq/kg of milk.

Key words: drifting goal archetype; milk demand; milk production; environment.

1. Background Information

Food production and environmental impact are going to represent the most important issues related to animal production in the near future. The increase of world population to over 8 billion people in 2030 will increase the demand of food around the world (FAO, 2006). The livestock sector is expected to partially contribute to the food supply by increasing meat, milk, and processed products. The dairy cow sector provides about 83% and 13% of total world milk and meat production, respectively (FAO, 2009). On the other hand, the livestock sector contributed to about 18% of total anthropological greenhouses gas in terms of carbon dioxide equivalent emissions (CO_2eq) per year. The dairy cows sector emits 22% of total livestock CO_2eq of which 15% is allocated to milk production and remaining 7% 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 correspond to the 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 with milk production higher than 8,500 kg of milk/per year (Rotz et al., 2010).
Furthermore, the environmental impact of livestock is related to energy demand and vegetal biomass use. In fact, vegetal biomass, like cereals grains, can be used both as animal feed or human food or, alternatively to the fossil fuels, as organic substrate to produce heat or power; between those different sectors the competition for the use of the same biomass source could generate a raise of price of grains (Kim, 2009).

In this contest, the main objective of animal scientists is to identify the most viable solutions to improve milk production in the near future while minimizing the environmental impact of the livestock. From this point of view, the main objective of this paper was to model the basal structure of milk production and consumption dynamics in the world as influenced by milk price and farm profitability. A more specific objective was to simulate different future scenarios to highlight the effect of the milk production improvement on greenhouses gas emissions and grassland use of dairy cows.

2. Model Description: Causal Loop Diagram

In the sequent sections of this paper a description of the information flow through the model will be showed as causal loop diagrams of the main variables. Then the details of each sub-model aggregation will be explained during the model building process. Selected simulation scenarios will be described focusing the point of view of each scenario.

The model was built using Vensim® version 5.9PLE (Ventana System, Inc.). The model defined dairy cow milk system as a drifting goal archetype. Following the archetype structure, two important balancing loops were considered: world milk demand (loop 1, market in blue color in Figure 1, **MD,**) and world milk production (loop red 2a and loop green 2b in Figure 1, **MP**), respectively. The MD (kg/year) would represent the desired state of the system, it mainly depends on the number of people in the world (assumed as an external factor), and their annual milk consumption per capita. The MP (kg/year) describes the ways to meet the milk world demand; it uses the number of dairy cows in the world and their annual milk productivity (kg/year). The milk production strongly depends on the farm profitability, which is positively related to the farm investments designed to buy cows or to increase their own milk production level.

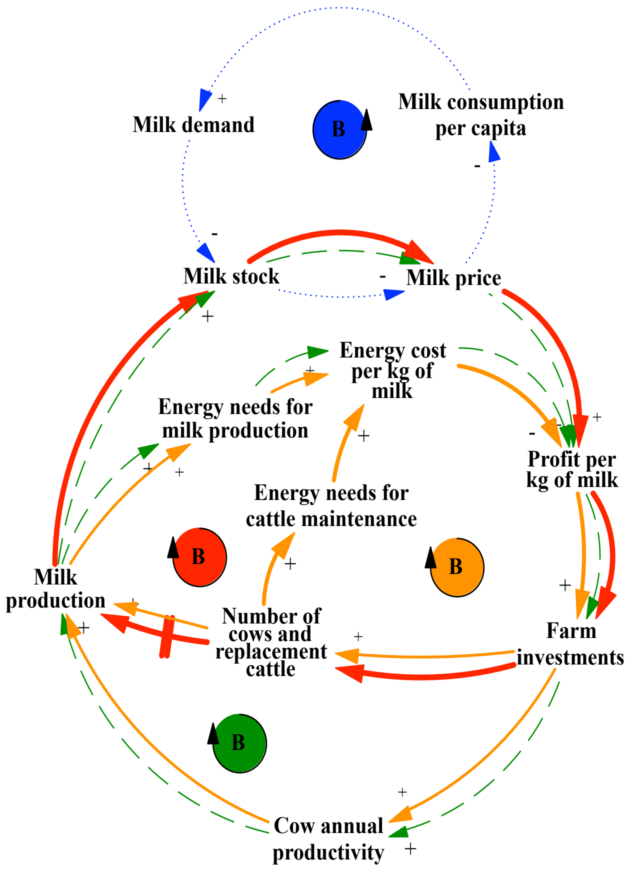

Figure 1. Causal loop diagram of the dairy sector model. Loops are identified by colours and lines: blue dotted (….) for the milk demand loop; red (bold solid line) for cow number in world herd, green dashed (- - -) for annual cow productivity and orange (thin solid line) for feed cost of the milk production loop.

The gap between demand and offer of milk is represented by the difference between MD and MP, it 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 affect positively the farm profitability. In fact, farm profitability is the main variable positively related with farm investments for production increasing, avoiding the diversification of products within the farm.

The MP acts prevalently in two ways in order to change the milk production rate. The first one named cow number (loop red 2a, **CN;** Figure 1) is positively related to milk production rate and represent an indirect way to change the milk production rate in order to meet MD. The second one is named cow productivity (loop green 2b, **CPr;** Figure 1) and it represents a direct way to change the milk production rate in order to meet MD.

Another loop acts inside of the MP loop, named feed cost (loop orange 2c, **FC;** Figure 1), and it involves both CN and CPr. Actually, FC reflects the positive relationship between cost of animal feed and feed demand for animals. Economic and environmental problems are involved in the FC because of the land carrying capacity and the competition for biomass use as human's feed, animal's food, or "clean" energy source. From an energetic point of view, the CN loop is the expensive way and the CPr loop is the least cost way to increase the total amount of milk production. In fact, to increase production by increasing the number of cows the farm should sustain the energy cost of increased number of cattle (cows and replacement cattle) maintenance, and the energy cost of additional milk production; while to increase milk production by increasing the annual CPr, only the energy cost of additional milk production should be sustained. Thus, the CPr loop, causes a decrease of energy expenditure per kg of milk taking advantages from the dilution of maintenance cost in the higher milk productivity.

3. Model Description: Sub-models and Selected Variables

The current model consisted of 6 sub-models: A) human population and milk market B) cow population; C) cow productivity; D) energy and feed requirements; E) economics; and F) environmental impact.

A) Human population and milk market (Figure 2). Includes 3 stocks:

- world human population and relative flows of birth and death rate (Kim, 2009),
- milk demand per capita which varied on change in milk demand per capita, and
- milk market stock and relative flows of milk consumption and production.

Some other auxiliary variables were calculated in order to estimate the milk gap between milk human consumption and animal production. Milk substitute use is also considered to adjust the milk market gap.

B) Cow population (Figure 3). Includes two stocks: number of dairy cows in the world and number of replacement animals and their relative flows of replacement and culled (discarded) cows; the flows are regulated by replacement and culling fractional rates. A delay of 1.5 years was applied to account for growing period of the young cows; this value corresponds to the interval from calving to puberty of as replacement heifer.

C) Cow productivity (Figure 3). Includes a stock, the cow production level in liters per cow per year, which positively varies with the milk production improvement coming from management and breeding.

D) Energy and feed requirements (Figure 3). Includes calculated values of net energy requirements for maintenance, pregnancy, and milk production as recommended by the NRC (2001). Net energy requirement were converted to total gross energy requirements (GEr) in order to estimate the total amount of feed required as forage and concentrate to meet the energy requirements.

E) Economics. Includes the calculation of milk profitability per kg of produced milk, which consists of the difference between costs and revenues of the milk production process at farm level. Milk price was assumed as a function of the milk market gap, while ration cost was assumed a function of cereals and forage demand and their price; non-nutritional costs were calculated as a percentage of total costs.

F) Environmental impact (Figure 4). Includes the estimates of the greenhouses gas emissions, as a sum of CO_2eq from enteric methane (CH_4), methane from waste and nitrous oxide (N_2O) from waste, carbon dioxide (CO_2) from secondary sources, expressed per kg of produced milk. The Tier 2 standards coefficients and equations of IPCC (2006) were used to estimate CO_2eq emissions. This sub-model also includes the estimates of grassland used produce forages for the dairy sector; the animal forage demand was estimated as the percentage of animal energy intake used to cover maintenance requirements.

Values from literature were used as initial values of the variables. Lookup functions were used to estimate the coefficient of conversion of gross energy to net energy and the effect of profitability on replacement fractional rate in the sub-model 4 and 5, respectively. All used variables are descripted in Table 1, with initial setting values and references source. An ”if-then-else” function was used to modulate the effect of farm profitability on milk production improvement. Thus, only if farm profitability is positive farmers should invest their money to improve breeding and management of cows, otherwise only the breeding of cows might allow an increase of cow annual productivity. The milk production improvement was not assumed as a lookup function of milk profit because of the heavy technological limits to cow annual productivity. As a matter of fact, the maximum milk production improvement depends on several external factors not directly related to the farmer choices; thus, farmers just can manage the improvement allowable at the moment.

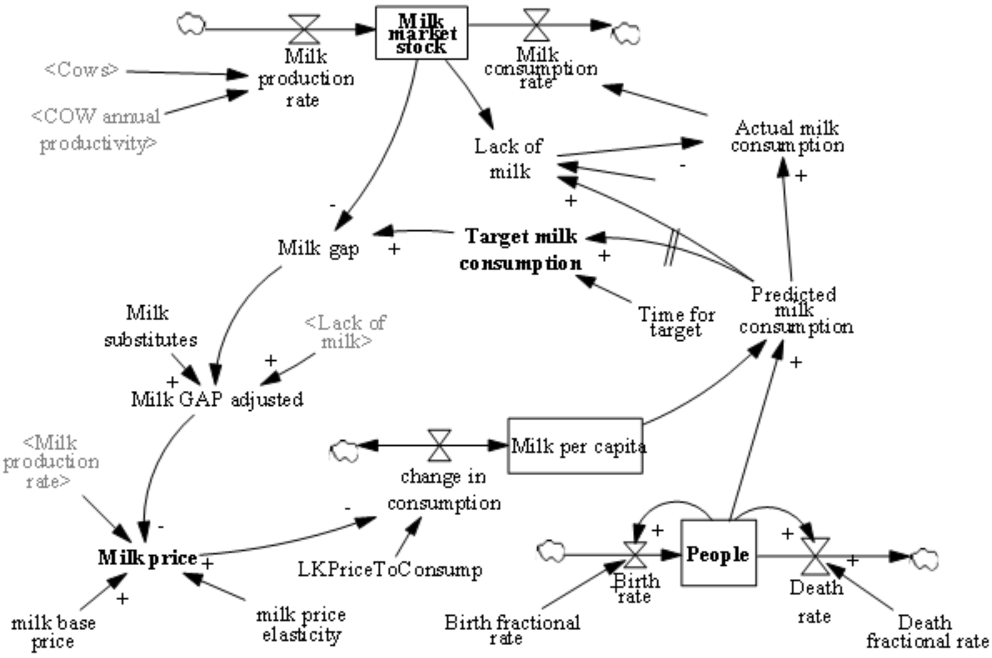

Figure 2. Snapshot of the sub-model A, representing “Human population and milk market”.

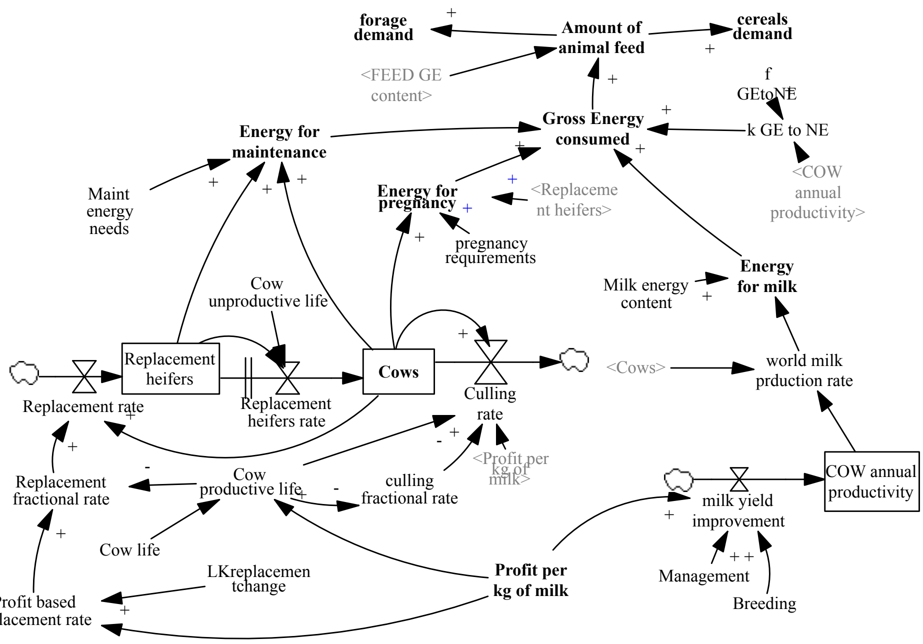

Figure 3. Snapshot of 3 sub-models: B (Cow population), C (Cow productivity), and D (Energy and feed requirements for animals).

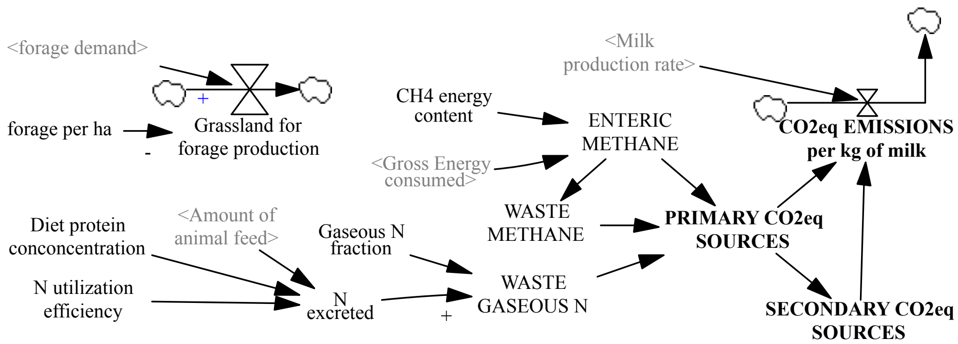

Figure 4. Snapshot of the sub-model F (Environmental impact), it was not included in the loop diagram.

Table 1. Variables used in the model with principal equations, initial values of constant variables and stocks and consulted reference source.

Sub-model	Variable	Type	Unit	Initial value at year 2007	Reference
1	People	Stock	Number	6.88e09	Kim (2009)
1	Milk per capita	Stock	kg/(person x year)	83	FAO (2007)
1	Milk market stock	Stock	Kg	1.00E+10	-
1	Change in consumption	Flow	kg/(person x year)	F(milk price)	
1	Milk consumption rate	Flow	kg/year	Cow annual productivity x cows	
1	Milk production rate	Flow	kg/year	Milk demand per capita x people	
1	Time for target	Delay	Year	0.25	
1	People Birth fractional rate	Auxil.	%	0.162	Kim (2009)
1	People Death fractional rate	Auxil.	%	0.084	Kim (2009)
1	Milk gap	Auxil.	kg/year	Milk stock-predicted milk demand	
1	Predicted milk demand	Auxil.	kg/year	People x milk per capita	
2	Replacement heifers	Stock	Initial number	Cows*0.4	
2	Cows	Stock	Initial number	244.1e+08	FAO (2007)
2	Changes in cow productive life	Lookup	f (profit/kg of milk)	-0.5/+0.5	
2	Milk yield improvement (MYI)	Flow	kg/cow/year/year	Breeding + management	
2	Replacement heifers rate	Flow	cattle/year	Replacement heifers/cow unproductive life	
2	Replacement rate	Flow	cattle/year	Cows x replacement fractional rate	
2	Cows unproductive life	Delay	Years	16/12	
2	Cow productive life	Auxil.	Years	3.5	
2	Culling fractional rate	Auxil.	%	1/cow productive life	
2	Replacement fractional rate	Auxil.	%	Culling rate	
3	Cow annual productivity (CPr)	Stock	kg/cow/year	2333+MYI	FAO (2007)
3	Breeding	Auxil.	kg of milk /year	Depends on simulated scenario	
3	Management	Auxil.	kg/cow/year/year	Depends on simulated scenario	
4	K gross to net energy	Lookup	f (CPr)	(0.2-0.4 % of GE)	
4	Gross Energy Demand (GED)	Auxil.	Mcal/year	Maintenance+pregnancy+milk	
4	Cereal demand	Auxil		GED/FGE x (1-Forage in diet)	
4	Forage in diet	Auxi.	%	Energy for maintenance/GED	
	Forage demand	Auxil	Kg	(GED/FGE) x Forage in diet	
4	Feed energy cost	Auxil.	$/mcal	Ration cost/FGE	
4	Feed gross energy (FGE)	Auxil.	mcal/kg	4.398 Mcal	
4	Maintenance energy needs	Auxil.	mcal/cow/year	3650	
4	Milk energy content	Auxil.	mcal/kg	0.700	
4	Pregnancy requirements	Auxil.	mcal/year	340	
5	Cereal price	Auxil.	$/kg	0.10	
5	Cereals base price	Auxil.	$/kg	0.10	
5	Cost per kg of milk	Auxil.	$/kg of milk	Nutritional+Non-nutritional costs	
5	Forage base price	Auxil.	%/kg	0.05	
5	Forage price elasticity	Auxil.	% of price	0.01	
5	Grain price elasticity	Auxil.	%/%	0.10	
5	Milk base price	Auxil.	$/kg	0.33	
5	Milk price elasticity	Auxil.	% of price	0.2	
5	Total costs	Auxil.	$/year	Nutritional cost/0.85	
5	Nutritional cost	Auxil.	$/year	GED x (ration cost/FGE)	
5	Profit based replacement rate	Lookup	%	F (profit per kg of milk)	
5	Profit per kg	Auxil.	$/kg	Revenues - costs	
5	Ration cost	Auxil.	$/kg	Forage cost+cereals cost	
5	Revenues	Auxil.	$/year	Milk price x milk production rate	
6	CO_2eq. emissions per kg	Flow	kg CO_2eq/kg	(enteric+waste CH_4) + waste N_2O + secondaries	
	Grassland for forage	Flow	Ha/year	Forage demand/forage per ha	
6	Forage production	Auxil.	kg/ha	5000*0.9 kg of DM	

4. Model Simulations

Six different scenarios were simulated in order to enhance the effects on market and environment caused by the different approach used to meet the milk demand. The simulation time horizon was 45 years, between 2007 and 2052; unit for time was years with a time step of 0.015625; and Euler method for integration was used. The simulated scenarios were:

A) cow number increase, no improvement in cow productivity (0 CPr);
B) low milk production improvement, 7.5 kg/cow per year, profit based (7.5 Cpr);
C) medium milk production improvement, 15 kg/cow per year, profit based (15 CPr);
D) high milk production improvement, 30 kg/cow per year, profit based (30 CPr);
E) a change in policy: +5% efficiency of conversion from gross into net energy (15 CPr metabolic efficiency +5%);
F) a change in policy: high milk production improvement, constant (30 CPr constant).

The scenario A assumed that no genetic and management improvement could contribute to increase the cow annual productivity, and only the variation in number of cows could modulate the milk production rate. Actually, this is not a realistic scenario, even a low genetic improvement could be considered such as inertial force generated by the interaction between the replacement rate and the human livestock activity. This is just a hypothetical base scenario used for behavior comparison.

Scenarios B, C, and, D assumed a low, medium, and high level of milk production improvements allowed by the technological sources applicable onto livestock activity both for breeding and management.

Scenario E and F simulated the effect of a change in policy. They assumed the CPr, identified as the direct way to produce milk, is judged an environmental energetic-related issue. The simulated policy act on two ways warranting a well-defined technological goal applied to the dairy sector: E) sustaining a constant medium milk improvement which aimed to a break between the milk production improvement and farm profitability and F) sustaining a 5% increase of efficiency in the metabolic conversion of gross to net energy. The technological goals of these simulated policies were established on the actual state of knowledge and on the past trends of milk production improvement.

5. Results and discussion

Human population was assumed as external input for all scenarios; it started from 6.88 Billions people and constantly grew until 10.37 Billions in the year 2050 (Kim, 2009). The simulation results focus on future trends of milk demand and production variables between different scenarios and their effect on environmental impact of dairy cow sector. Predicted milk demand reflected the growing trend of human population (Table 2). Milk human consumption varied depending on changes in milk consumption per capita; it started at the same level for all scenarios (83 kg/year per capita) and showed, between the scenarios A and F, a difference of 2.3 and 7.7 kg/person x year in 2030 and 2050, respectively (Table 3). This difference was caused by the effects of loops MP and MD, which created the changes in milk prices (Figure 1).

Table 2. Yearly values of human milk consumption, dairy cow number and milk production obtained from simulated data.

Scenario	Year	Milk consumption	Milk demand	Cows	CPr (Cow productivity)	Total milk production
		kg/capita	Billions of kg	Millions of head	kg/cow	Billions of kg
A-0 CPr*	2009	82.7	580	244.9	2333	571
B-75 CPr	2009	82.7	580	245.0	2338	573
C-15 CPr	2009	82.7	580	245.0	2345	574
D-30 CPr	2009	82.7	580	245.0	2360	578
E -15 CPr eff. +5%**	2009	82.8	581	245.7	2360	580
F -30 CPr Constant	2009	82.7	580	240.3	2390	575
A-0 CPr*	2030	79.1	681	248.5	2333	579
B-7.5 CPr	2030	79.3	683	249.8	2465	616
C-15 CPr	2030	79.6	686	251.1	2607	655
D-30 CPr	2030	80.6	694	246.0	2819	694
E -15 CPr eff. +5%**	2030	80.3	692	258.7	2675	692
F -30 CPr Constant	2030	81.4	701	232.1	3020	701
A-0 CPr*	2050	74.6	781	262.4	2333	612
B-7.5 CPr	2050	75.7	792	266.3	2616	697
C-15 CPr	2050	76.6	802	268.4	2907	780
D-30 CPr	2050	80.6	844	249.6	3384	845
E -15 CPr eff. +5%**	2050	78.4	821	276.3	2975	822
F -30 CPr Constant	2050	82.3	863	238.3	3620	863

*** CPr indicated the milk production improvement in kg of milk/cow per year.**
**** Increase by 5% in efficiency of conversion from gross energy to net energy in respect with the other simulations.**

Cows population started at the value of 244 million and differently grew depending on considered scenario: the number of cows linearly increased in scenarios A, B, C, and E, stayed in a stable trend for the scenario D and presented a linear decreasing trend for the scenario F (Table 2).
The number of cows as estimated for the year 2050 ranged between 238 millions of scenario F and 276 millions of the scenario A (Table 2).
Cow number varied based on the replacement rate and culling rate that directly depended on cow productive life. Replacement and culling rates showed linear increasing trends for scenarios A, B, C, and oscillatory trends for scenarios D, E, and F (unreported data); The oscillation pattern was imperceptible in the cow number tendencies and was carried on by the milk profitability that usually drive the farmer decisions in order to increase or decrease the cow productive life.
The oscillatory trends in the profitability per sold milk (Figure 5) were, in turn, generated by the variation in milk price and milk market gap, reflecting the behavior of milk market stock.
Milk market stock, representing the junction between the two main loops of the drifting goal archetype (loops MD and MP; Figure 1), resulted to be the original point of the oscillations in the system, due to the accumulation of the production in the stock.

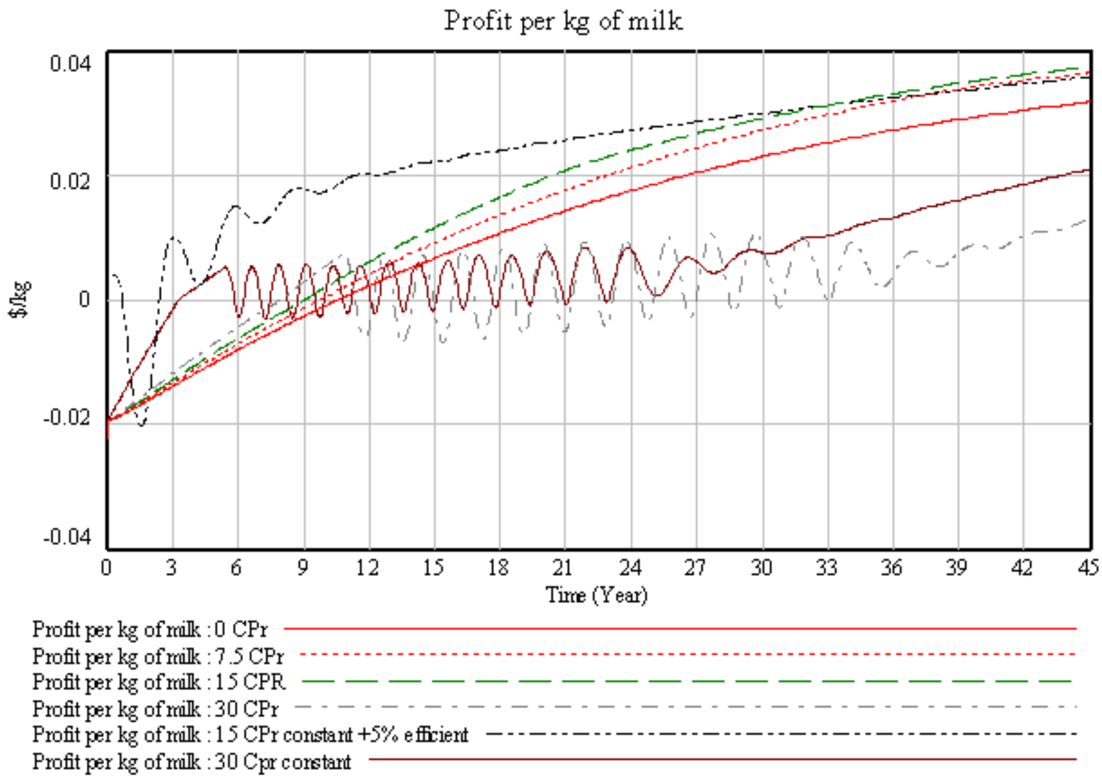

Figure 5. Milk profitability per kg of produced milk as estimated by the dairy sector model for simulated scenario A, B, C, D, E, and F.

The propagation of the oscillatory trend through the model stopped at the cow number stock, where the linear growth trend was restored, probably because both of the inflow and outflow rates (replacement and culling) of the cows stock were affected by the oscillatory trend.
As reported in Figure 5, for the scenarios A, B, and C, a goal seeking pattern of farm profitability was observed; it corresponded to a condition of a negative milk gap (MD>MP) indicating that the desired state of the system dominated the structure, pulling the CN and CPr. While, both in the highest cow productivity and highest efficiency scenarios (D, E, and F), farm profitability described oscillatory trends; it corresponded to a condition of a positive milk gap (MP>MD) indicating that the CN and CPr loops dominated the structure, pushing the milk market and creating product's accumulation. Other delays in the model, such as time to reach the target milk consumption (applied on milk gap; sub-model 1) and time for a young cow to became productive (applied on milk production rate; sub-model 2; Table 1), acted enforcing or reducing the oscillatory behavior originated in milk market stock.
Milk price, assumed equal to 0.33$/kg at the initial time, ranged from 0.39 and 0.27 $/kg between the scenario F and A, respectively (Table 2). It also reflected oscillatory decreasing trends in scenarios D, E, and F, showing a peak every 2 years (unreported data).
On the other hand, linear trends of milk production costs ($/kg of produced milk) did not influence the oscillatory trends of milk profit. Decreasing trends of cost per kg of produced milk, with high differences in slope between scenarios, were observed, except for the scenario A, where the cost of milk production increased. Milk production cost at farm gate started with higher values than milk price and at the year 2050 ranged between 0.36 and 0.25 $/kg of produced milk, for the scenario A and F, respectively.
The most part of the differences between scenarios mainly depended on the CPr, which reflected the values of milk production improvement for management and breeding used as input. CPr presented increasing trends except than for the scenario A, where milk production improvement was assumed equal to 0 (Table 2).
The milk production rate, being a combination of loops CN, CPr and FC, tried to seek the milk production demand, but only the scenarios with the highest milk production improvement (D and F) or the scenario E with improved nutritional efficiency, were able to meet the human milk demand (Table 2). Looking at the Figure 5, the favorable scenarios for the human milk market caused an economic distress for the farms due to profitability oscillation. It could be reduced with adequate policies described by scenario E and F: improve CPr and nutritional efficiency of animals that can helps dairy farms to reduce maintenance and nutritional costs and maintain a positive profitability.
All scenarios with CPr higher than 0 showed as the same milk production rate could be obtained using a few number of cows producing more milk per cow with broad environmental benefits. In particular, gross energy demand increased in scenarios A, B, C, and D, while stayed stable in scenario E and decreased in scenarios F from the initial time to the year 2050 where was in a range between 7028 and 8163 Billions of Mcal/year as estimated for scenario A and F, respectively. The increase in CPr also caused variations in the grassland use to produce

forages destined to the dairy cow sector (Figure 6), it because of the smaller amount of forage needs and the increase of cereals demand. The carbon footprint of milk production, recently estimated by the FAO in 2.4±26% kg of CO_2eq per kg of FPCM (Gerber et al., 2010), was reduced in the model estimates from 2.5 of the year 2007 to 1.5 kg of CO_2eq per kg of FPCM in the scenario F, where a constant increase of production of 30 kg of milk per cow per year drove the milk production rate (Figure 7).

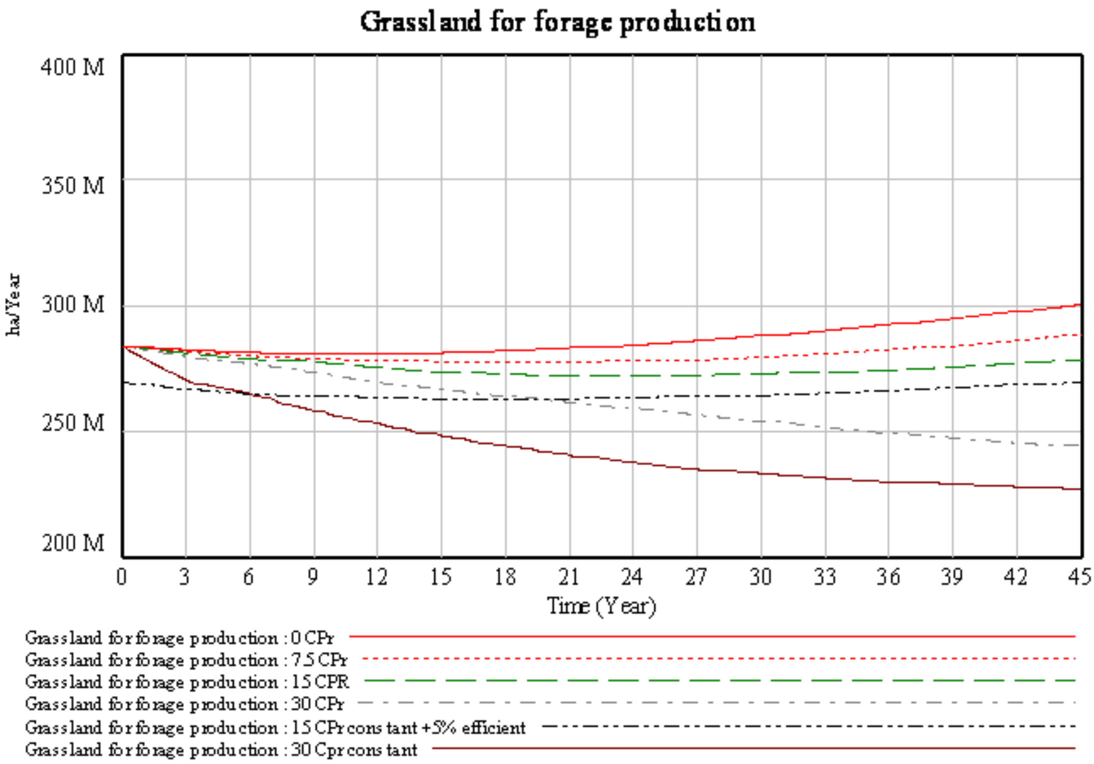

Figure 6. Grassland use to produce forages for animal feeding as estimated by the dairy sector model for simulated scenario A, B, C, D, E, and F.

The model assumed a open world market of dairy product and a cow population producing an average amount of milk per head. Some limitations of the model should be adjusted in order to improve the model structure. As reported by, FAO (2006), Gerber et al, (2010), and IDF (2010) the world milk market should be divided, at least, in two component reflecting the differences about developing countries and developed countries. In fact, those two groups of countries are characterized by differences in production systems (raised breeds, feeding system, cow productivity, specialization and management of livestock) and in the milk market (amount produced and consumed, prices and costs related to the milk production) that should be modeled separately to improve the description of the system and the model accuracy.

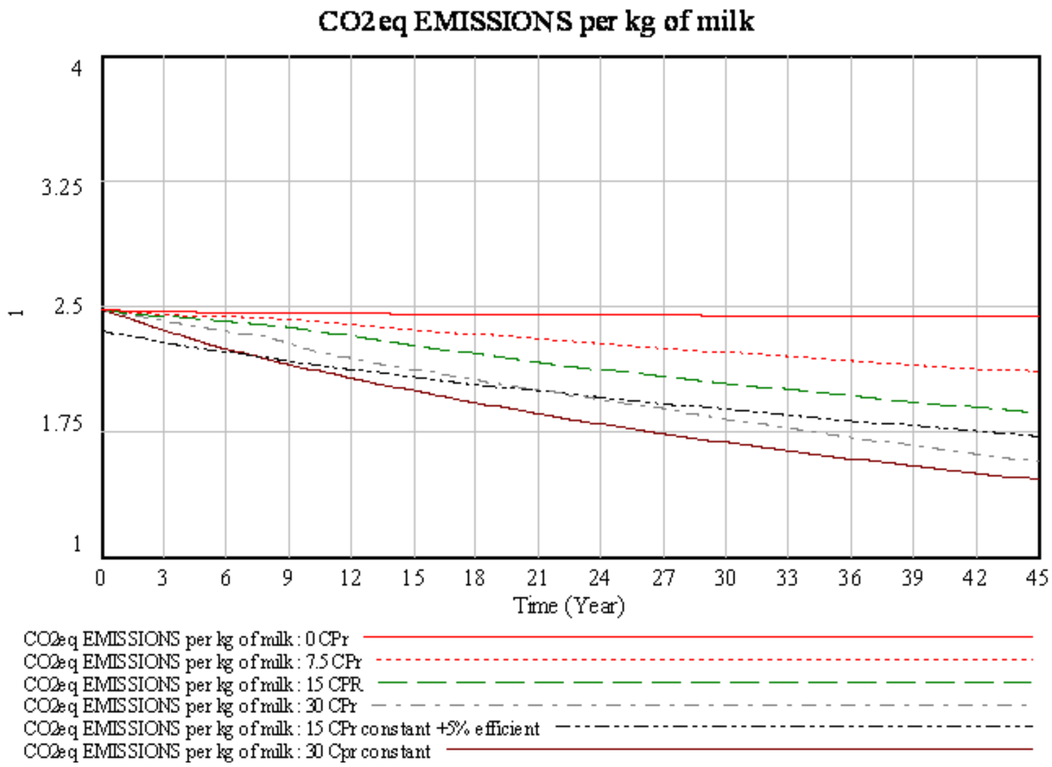

Figure 7. Carbon footprint in kg of CO_2 equivalents emitted per kg of milk as estimated by the dairy sector model for simulated scenario A, B, C, D, E, and F.

6. Model evaluation

Data of FAO from 1999 to 2009 were used to evaluate the model and extrapolate future trends for dairy cow population, annual milk productivity per cow and total milk production. In particular, data from 2007 and 2009 were used to cheek the initial performances of the model. In addition, minimum and maximum values of cow number and milk production over time, in forecasted trends, were estimated from 2010 to 2050 (Table 3). Those forecasted trends were based on the growth rate of the human population (Kim, 2009) and the constant milk consumption of 83 kg of milk per capita per year as observed in FAO (2007 and 2009).

Model Simulated data from 2007 to 2009 for cow population and milk production were assumed consistent with data for the year 2007 and 2009 reported by FAO; the model predicted the observed values of 2009 with an error lower than 2% and also predicted the future trends between the forecasted range of the same trends (Table 3).

Table 3. Model evaluation for the estimates variables. Scenario A and C represented the simulated conditions correspondent to the minimum and maximum forecasted trends of cow milk productivity, cows in the world and total milk production.

Year			2007	2009	2030	2050	07/09	07/50
Scenario							%	%
Min*	Cows in the world	Millions of heads	244.1	247.6	247.6	247.6	1.4	1.4
Scenario A				244.9	248.5	262.4	0.3	7.5
Scenario C				245.0	251.1	268.4	0.4	10.0
Max*				247.6	304.2	369.9	1.4	51.5
Min**	Cow milk productivity	kg × cow	2333	2344	2344	2344	0.5	0.5
Scenario A				2333	2333	2333	0.0	0.0
Scenario C				2345	2607	2907	0.5	24.6
Max**				2344	2685	2990	0.5	28.2
Min*	World milk production	Billions of kg	569	580	665	740	1.9	30.1
Scenario A				571	579	612	0.4	7.6
Scenario C				574	655	780	0.9	37.1
Max*				580	647	867	1.9	52.4

* values for years 2007 and 2009 as reported by FAO (http://faostat.fao.org) while values for years 2030 and 2050 estimated considering the human milk demand (83 kg of per capita per year consumed by the human population reported by Kim, 2009) produced with various combinations of milk productivity and cows number.

** values for years 2007 and 2009 as reported by FAO (http://faostat.fao.org) while values for years 2030 and 2050 were estimated considering that milk cow productivity does not increase (min) or considering an increase of milk production equal to the trend reported by FAO from the years 1999 to 2009 (max).

Reference modes and values of milk price and milk production cost reported in literature were also used to evaluate the model performances in simulated scenarios. In particular, the oscillatory trend of the milk price, predicted by the model in scenarios in D, E, and F, was consistent with the reference mode observed in milk price in US between 1991 and 2009 (Gould, 2011), and the milk price trend reported in different countries around the world (IDF, 2010; Figure 8). Milk production cost at farm gate started with higher values than milk price and at the year 2050 ranged between 0.36 and 0.25 $/kg of produced milk, for the scenario A and F, respectively (Figure 5). The model estimates of the range of milk production cost were very similar to the range 0.27 - 0.37 ($/kg) reported by Gerber et al., (2010) between different production systems around the world. The same authors also reported that, considering the present prices and costs of commodities, only 2% of milk around the world should be produced with a positive profit per kg of milk that is consistent with initial model estimates.

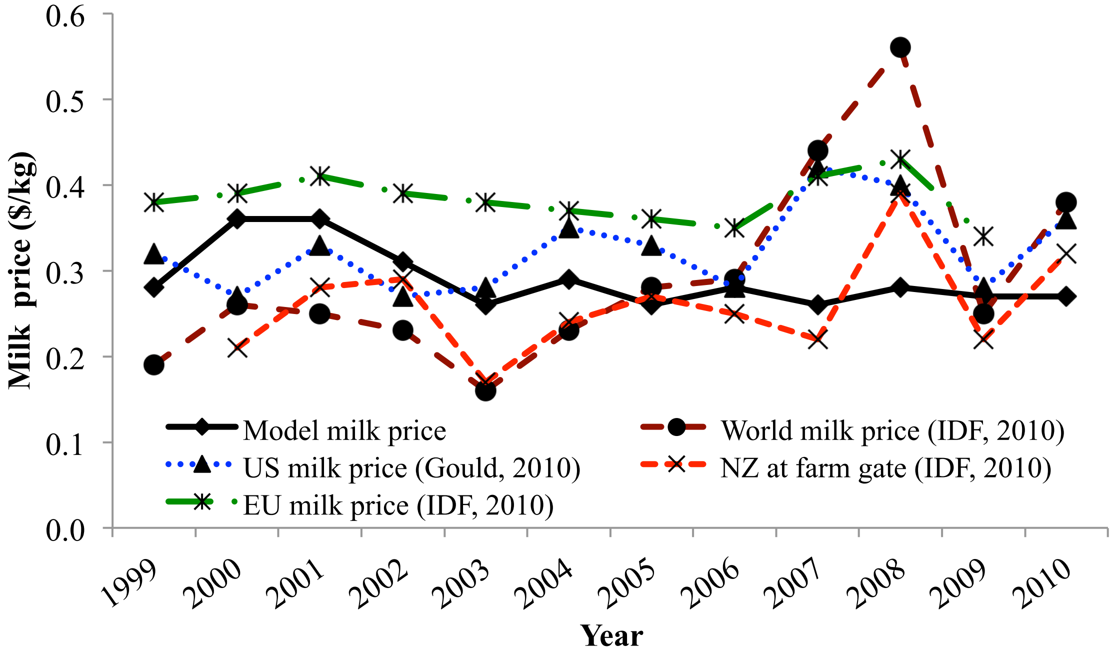

Figure 8. Milk price observed in different countries from 1999 to 2010 and model prediction of the milk price in the same time interval.

7. Conclusion

The dairy sector model was able to forecast the behavior pattern of the cow population, their energy demand, their feed use and their environmental impact in different scenarios. The structural loops affected the output behavior, in particular farm profitability described goal seeking patterns when MD>MP, while described oscillating patters if MP>MD. The scenarios with low cow productivity per year (A, B and C) showed that lower increases in milk productivity would not be able to satisfy the human milk needs, most likely because the increase of number of cows is delayed by the unproductive cow life, thus milk production could not increase as fast as required by the market.

Simulated scenarios D, E, and F showed that the only way to increase the milk production rate to match milk demand were to produce the same amount of milk rate with a reduced number of cattle in the world by improving their productivity and their nutritional efficiency.

The simulation results indicated that milk productivity and nutritional efficiency are the key factors to solve environmental issues related to the Life Cycle Assessment of the dairy sector. In particular, they could help to reduce the total amount of energy demand by the dairy cows and the carbon footprint. In conclusion, the model showed that by selecting more efficient cows, one could reduce the desertification risks because of a lower rate of use of grasslands and assist in the mitigation of greenhouses gas pollution.

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