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Consumer Impact on Supply Chain Sustainability

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Abstract

Globalization and ever-growing population in the World, inevitably leads to higher demand of products and services. To meet the demand of meat products, farms are expanding and as consequence there is increased negative supply chain (SC) impact on the environment. Thus, to reduce the impact, raising consumer awareness reduced consumption of red meat, can lead to more sustainable meat SCs. The aim of this paper is to show to what extent can the environmental impact be reduced by changing the types of meat consumed. The methodology used in this work is mathematical modelling (optimization), and environmental impacts and total annul meat consumption are objective functions. The result shows that the environmental impact can be significantly reduced by introducing poultry and reducing consumption of red meat.

Keywords: Multi-criteria, Optimization, Supply chain, environmental impacts

Introduction

Nowadays, meat SCs can be divided into several levels (echelons) including: livestock farms, abattoirs, retailers and consumers [1]. However, meat SC networks and logistics involves dealing with conflicting objectives and trade-off solution are often proposed via optimization of several objectives such as: cost minimization, profit maximization, [2] minimization of environmental impact [3] and maximization of social benefits [4].
Livestock production and its SCs sustainability has received attention from scholars and researchers, mainly due to

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the environmental impact [5]. Activities in meat SCs are increasingly polluting air, water and soil, while livestock companies are competing for resources such as: land, water and energy [6]. According to Food and Agriculture Organization [7], livestock sector contributes 14.5 % of all greenhouse gases (GHG) emission, as of 2006. Additionally, they noticed that livestock emission is mostly in form of CO_2, CH_4 and N_2O, which comes from burning fossil fuels, manure and usage of fertilizer.
The objective of this paper is to determine environmental impact of livestock SC, more precisely, GHG emission, water and energy consumption from livestock sector, along the SC. As methodology, optimization is used to minimize the impact of meat SCs on environment. Furthermore, three scenarios are studied to evaluate current environmental impact, and the impact of meat SCs by changing the total annual consumption of meat, while as modelling constrains total calories, protein, fat are used.
The remainder of the paper is organized as follows: Section 2 presents relevant literature in the studied area, Section 3 describes problem and methodology used in the paper, data and findings are given in section 4 and 5, and finally in Section 6 conclusions are presented.

Literature review

Even though, the literature in multi-criteria optimization of SCs from economic and environmental is vast [8], the number of papers dealing with food and meat SCs is somewhat limited [9]. Implementation of best sustainable practices from environmental and social perspective was studied by Pagell and Wu [10], while maintaining economic viability for several case studies. A mixed integer linear model was developed by Rong, et al. [11], where food quality was a decision making objective within SCs production and distribution. Boudahri, et al. [12] developed a model to minimize logistics costs (location and transportation) of poultry SC. Similarly, Paksoy, et al. [13] developed a linear fuzzy multi-objective optimization model for production and distribution of vegetable oils. A multi-objective Bortolini, et al. [14] model for distribution optimization of food SC was proposed, as objective function minimization of economic, environmental and delivery time. A multi-criteria of a three-echelon meat SC Mohammed and Wang [15] is proposed to minimize total costs and maximize consumer satisfaction and products fulfilment.

Problem definition

SCs can be described as follows: there is predefined number of supply units $(i) = 1,2, \dots, N\ supply\ units$, and demand units $(j) = 1,2, \dots, N\ demand\ units$. For every supply and demand there is a defined flow F_i, with environmental impacts: global warming potential GWP_i, water consumption $Wcom_i$, energy consumption $Ecom_i$, and with nutritional values; calories C_i, protein P_i, and fat F_i. Given the information the objective is to determine three scenarios:

I) Annual consumption of meat and its environmental impact.
II) Meat with minimal environmental impact, with same total meat consumption as in first scenario.
III) flows of meat while maintaining total values of calories, protein and fat as in first scenario.

Model formulation

The objective of this work is to determine environmental impact from different types of meat consummated. The problem is formulated as linear programming (LP) problem and was solved through GAMS 24.2.3 and CPLEX 12.6 as solver with intel i7 and 8GB of RAM.
As mentioned, the model is formulated as LP problem and given are following information:

Given is:

- Annual global meat consumption
- Global warming protentional (GWP) along the meat SC

- Water consumption along the meat SC
- Energy consumption along the meat SC
- Global annual calories consumption
- Global annual protein consumption
- Global annual fat consumption

Determine:

- Meat with minimum environmental impact (scenario 2)
- Global meat consumption with same level of calories, protein and fat (scenario 3)

The models for second and third scenarios are listed below, while result for first scenario are obtained from secondary source.

Second scenario:

Objective function describes total environmental impact of meat supply chain, and it is used in scenario 2

Objective function:

$$min\ Z_1 = \sum_i GWP_i\ a_i + \sum_i Wcom_i\ a_i + \sum_i Ecom_i\ a_i \qquad \forall i \tag{1}$$

$$min\ Z_2 = \sum_i GW_i + \sum_i WCO_i \sum_i ECO_i, \qquad \forall i \tag{2}$$

First objective function describes total environmental impact of meat supply chain, and it is used in scenario 2. While the second objective function is used in scenario 3, and likewise minimize environmental impact.

Total meat flow:

$$Fl = \sum_i a_i, \qquad \forall i \tag{3}$$

Total amount of calories consumed is defined by the flow and calories of meat.

Calories consumed per meat:

$$Call = \sum_k C_k\ a_i, \qquad \forall k \tag{4}$$

Total amount of calories consumed is defined by the flow and protein of meat.

Protein consumed per meat:

$$Proo = \sum_k P_k\ a_i, \qquad \forall k \tag{5}$$

Total amount of calories consumed is defined by the flow and protein of meat.

Protein consumed per meat:

$$Fatt = \sum_k F_k\ a_i, \qquad \forall k \tag{6}$$

Total environmental impact is sum of GWP, water and energy usage. Amount of GWP emission is defined by the flow and GWP of meat.

Global warming potential:

$$GW = \sum_i GWP_i\ a_i, \qquad \forall i \tag{7}$$

Amount of annual water usage is defined by the flow and water usage of meat.
Water consumed per meat:

$$Wco = \sum_i Wcom_i \; a_i, \quad \forall i \tag{8}$$

Amount of annual energy usage is defined by the flow and energy usage of meat.
Water consumed per meat:

$$Eco = \sum_i Ecom_i \; a_i, \quad \forall i \tag{9}$$

Data collection

Data collected in this work comes from different sources, most data has been collected from [16], including GWP, water and energy footprints and nutritional values of beef, pork, poultry and sheep meats. In addition to that, global meat consumption is obtained from [17].
In Table 1. GWP, water and energy consumption and global meat consumption are presented.

Table 1. Environmental footprints of meat products as of 2009.

Meat type (per 10^3 kg)	GWP_{100} (10^3 kg of CO_2)	Water consumption ($m^3/(10^3kg)$)	Energy consumption ($GJ/(10^3kg)$)	Global consumption (10^3kg)
Beef	16	15415	28	63835
Pork	6.4	5988	17	105503
Sheep/goat	4.6	8763	12	12763
Chicken	17	4325	23	90664

Note: GWP_{100} (projects global warming potential over timeframe of 100 years)

In Table 2. Values of calories, protein and fat are presented for each type of meat. The nutritional values are for lean beef and pork, while the chicken and sheep/goat are common shelf meats.

Table 2. Nutritional values of different meat types.

Meat type	Nutritional value		
	Calories (cal/kg)	Protein (g/kg)	Fat (g/kg)
Beef	1513	138	101
Pork	2786	105	259
Sheep/goat	2059	139	163
Chicken	1440	127	100

Results

Table 3. presents the obtains results for three scenario studies and presented are total annual meat consumption and total annual environmental impact. In scenario 2 the only chicken as result, since it has lowest environmental impact from the meat.

Table 3. Obtained result for different scenarios

Meat	Scenario 1		Scenario 2		Scenario 3	
	Con	Env	Con	Env	Con	Env
Beef	63835	9.87E+08	-	-	62661	9.69E+08
Pork	105503	6.34E+08	-	-	109328	6.57E+08
Sheep/goat	12763	1.12E+08	-	-	-	-
Chicken	90664	3.96E+08	272765	1.187 E+09	102745	4.47E+08
Total	272765	2.13E+09	272765	1.187 E+09	274734	2.07E+09

Note: Con- consumption, Env- environmental impact

First scenario presents total meat consumption and environmental impact in 2009 [17]. Second scenario determines the meat with minimal environmental impact, while maintaining same total flow of meat as in first scenario. Third scenario evaluates minimal environmental impacts of meats, while maintaining same total consumption of calories, protein and fat as in first scenario.

Limitation and future works

Sustainability of SCs is studied from three different perspectives, namely: economic, environmental and social. However, in this work only environmental aspect is considered. The given model can be expanded to include all three aspects of sustainability of SCs. Additionally, including different food products in the model can greatly improve the whole picture of environmental impact of SCs.

Conclusions

In this paper an optimization model of global meat SC was proposed, based on the annual global meat supply and demand. Three scenario scenarios are examined. First scenario shows global meat in consumption in 2009, and its environmental impacts (Table 1). Second scenario determines the minimum environmental impact of meat, where the impact is reduced by 45% (Table 3) for same meat consumption as in scenario 1. In last scenario total environmental impact is reduced by 3% compared to scenario 1, while the level of calories, protein and fat are set as constrains and are same as in scenario 1. Additionally, the total meat consumed is somewhat higher, which means that the total global meat demand can be same by switching to other types of meat and reducing environmental impact.

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Appendix

Sets:
i, *meat type*

j, *environmental impact*

k, *nutrition*

Parameters:
C, *calories of meat i*

P, *protein of meat i*

F, *fat of meat i*

GWP, *global warming potential of meat i*

$Wcom$, *annual water consumption of meat i*

$Ecom$, *annual nutrition consumption of meat i*

Variables;
ba, *total meat consumption*

a_i, *meat consumption i*

GW, *global warming footprint*

Wco, *annual water footprint*

Eco, *annual energy footprint*

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