SUSTAINABLE OPERATION OF THE NETWORK OF CHICKEN MEAT AND EGG PRODUCING AND CONSUMING INDUSTRIES VIA MANURE MANAGEMENT

by

Alper Ertürk

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APPROVED BY:

Prof. Dr. Mustafa Özilgen (Thesis Supervisor) ....

Assoc. Prof. Dr. Mahmut Şeker ....

Assist. Prof. Dr. Emrah Nikerel ....

DATE OF APPROVAL: …./…./2016

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ABSTRACT

SUSTAINABLE OPERATION OF THE NETWORK OF CHICKEN MEAT AND EGG PRODUCING AND CONSUMING INDUSTRIES VIA MANURE MANAGEMENT

Thermodynamic analyses of a model network of chicken meat and eggs producing and consuming businesses was carried out to assess the sustainability of the production network under different manure management practices. The model network included a chicken farm, a restaurant, a pet food manufacturing plant, a vegetable garden, an olive garden, a grain field and a manure gasifier. Cumulative degree of perfection (CDP) was referred to as the numerical indicator of the sustainability. When chemical fertilizers were used in the system alone and the poultry manure was discarded, the CDP of the system was 0.66, when poultry manure was used alone to substitute the chemical fertilizers the CDP was 0.67. In the case when poultry manure was used together with bio-fertilizers, the CDP was 0.68. Gasification of the poultry manure increased the CDP to 0.98, and the highest CDP (1.01) was obtained when the poultry manure was gasified and microbial fertilizers were employed in the agriculture.

ÖZET

GÜBRE YÖNETİMİ İLE TAVUK ETİ VE YUMURTA ÜRETİM VE TÜKETİM ENDÜSTİRİSİNDE SÜRDÜRÜLEBİLİR OPERASYON AĞI

Farklı gübre yönetimi uygulamaları altında üretim ağının sürdürülebilirliğini değerlendirmek amacıyla tavuk eti ve yumurta üretim ve tüketim faaliyetleri içeren model ağı termodinamik analizi gerçekleştirilmiştir. Model ağ, tavuk çiftliği, restoran, evcil hayvan yemi fabrikası, sebze bahçesi, zeytin bahçesi, hububat tarlası ve gübre gazifiyer'den oluşturulmuştur. Nümerik sürdürülebilirlik indikatörü için kümülatif mükemmellik derecesi 'ne (CDP) değinilmiştir. Suni gübre tek başına kullanılıp, tavuk gübresi sistemden çıkarıldığında sistem CDP'si 0.66, tavuk gübresi sistem içinde kullanıldığında da CDP 0.67 olarak bulunmuştur. Tavuk gübresi biyolojik gübre ile birlikte kullanıldığında ise CDP 0.68 olarak bulunmuştur. Tavuk gübresi gazifikasyonu CDP değerini 0.98'e yükselmiştir, en yüksek CDP (1.01) ise tavuk gübresi gazifikasyonu ve tarımda biyolojik gübre kullanılması ile elde edilmiştir.

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LIST OF SYMBOLS/ABBREVIATIONS

CCO_2	Cumulative carbon dioxide emission
CDP	Cumulative degree of perfection
CEnC	Cumulative energy consumption
CExC	Cumulative exergy consumption
Ex	Specific exergy (MJ/kg)
In	Input
M	Mass (kg)
Out	Output
Q	Heat (kJ)
T	Temperature (K)
W	Work (kJ)
X	Molar fraction

1. INTRODUCTION

Sustainability is a global development concept giving priority to the satisfaction of human needs while respecting the environment, ecosystem and the animal wellbeing [1]. Developing sustainable processes became a target in many industries in our era. Sustainable production of organic foods and vegetables were among the desired goals [2], [3], [4], [5], [6], [7]. Assessment of the sustainability of production of the eggs had been the focus of numerous studies [8], [9], [10], [11], [12], [13]. Studies regarding sustainable production of chicken and sustainable operation of a chicken restaurant have also appeared in the literature recently [14], [15], [16], [17], [18], [19], [20]. Although "*sustainability*" appears as like a magic word now, there is not any widely accepted numerical criteria yet to assess it.

Life Cycle Assessment (LCA) technique is widely used in order to assess the environmental impact of processes that involves in a product's life (cradle to grave). It provides detailed evaluations of resource use such as energy consumption, water usage and greenhouse gas emission of a system which can be reviewed to understand the performance of a system [9], [10], [14], [19].

Kyoto protocol, an international treaty that aims to reduce emissions of greenhouse gases which cause global warming, was accepted in in 1997. The protocol entered into force in 2005 and approved by Turkish Parliament in 2009. Turkey, classified as an Annex 1 country, agreed to reduce the greenhouse gases of carbon dioxide, nitrous oxide, methane and sulfur hexafluoride [21].

Reducing the detrimental effect of any industry on the environment is a part of the sustainability studies. The poultry industry tries to achieve the maximum meat or egg production while minimizing the greenhouse gas emissions via optimizing the feed composition [9], [10], [22], [23], [24]. Preventing over feeding or decreasing the waste are among the means for lowering the emissions. Energy utilization to produce several food products had been the subject of some studies within this context [21], [25], [26].

In the present study, energy utilization, exergy consumption and carbon dioxide emission of egg production, broiler and spent chicken meat production in a chicken farm furnished with a sustainable restaurant equipped with a vegetable garden, a solar panel system, an oil production facility with olive trees will be evaluated. The feasibility of running a sustainable process will be discussed in terms the numerical values of the total exergy efficiency, CDP and the carbon dioxide emission of the network of egg and broiler producing and consuming industries.

1.1. CONCEPTS OF ENERGY AND EXERGY BALANCE

The first law of thermodynamics, energy balance is most widely used to assess the efficiency of a process or a system by means of energy. The energy balance is unable to provide any information about the work lost (potential) during the energy transformation processes. The exergy (available work) of a system is described as the maximum useful work that brings the system from its initial stage (original state) to the final stage (dead stage) through reversible processes [27], [28]. Exergy is used to indicate and reduce the irreversibilities in processes to improve the process efficiency. The usage of exergy methodology is an important concept to decrease the energy cost and reduce the environmental impact of systems [21].

Exergy efficiency of a process is defined as the total exergy of the products divided by the total exergy of the inputs employed in the manufacturing process [29]:

$$Exergy\ efficiency = \frac{\sum (mCExC)_{products}}{\sum (mCExC)_{\text{raw materials}} + \sum (mCExC)_{\text{fuels}}} \tag{1.1}$$

Cumulative degree of perfection (CDP) is the ratio of the exergy of the products to the sum of the exergies of the input materials and the exergies of the non-renewable fuels [29]:

$$CDP = \frac{\sum (mCExC)_{products}}{\sum (mCExC)_{\text{raw materials}} + \sum (mCExC)_{\text{non-renewablefuels}}} \tag{1.2}$$

Where m is the mass of each stream entering through the system boundaries and CExC is the cumulative exergy utilization for its production. The recent publications by Xu and Flapper (2011), Wu et al. (2013) and Rodriguez-Gonzales et al. (2015) offered recommendations for substituting the less energy efficient steps of food production with the more energy efficient ones representing the general trend towards increasing the energy efficiency by decreasing the energy utilization [30], [31], [32]. Exergy destruction in the individual processing units decreases the overall exergy efficiency of the processes. The process units where exergy destruction is the highest is determined by exergy analysis. Exergy analysis of the entire chains of pork mincemeat, pea-protein based product, and pea soup production processes were determined by Apaiah et al. (2006) as 0.09 per cent, 0.2 per cent, and 0.48 per cent, respectively [29]. Waheed et al. (2008) studied the energy consumption pattern in the orange juice manufacturing industry Nigeria, where the pasteurizer was found to be responsible for more than 90 per cent of the irreversibility [33]. Özilgen and Sorgüven (2011) assessed energy and exergy utilization and carbon dioxide emission during production of soybean, sunflower, and olive oils using farm-to-fork approach [25].

The CExC (cumulative exergy consumption) associated with the production of the olive, sunflower, and soybean oils was found to be 43,050, 17,638, and 45,257 MJ/ton, respectively. In a similar study, Sorgüven and Özilgen (2012) applied the exergy analysis to compute the CExC for assessing the environmental impact of the flavored yogurt production process [26]. The analysis covered three important stages of the yogurt production i.e., agriculture, dairy farming, and industrial processes. The total exergy loss was found to be 75791.6 MJ/ton of flavored yogurt. The results showed that the milk production (dairy farming) had the highest contribution to the total exergy loss, accounting for 53 per cent of the overall exergy loss. Quijera and Labidi (2013) and Yildirim and Genc (2015) carried out exergy analysis to improve the exergy efficiency of the pasteurization of milk by employing solar and thermal energy, respectively [34], [35]. Zisopoulos et al. (2015) employed exergy analysis to compare efficiency of three industrial bread production chains, Degerli et al (2015) employed a similar methodology to calculate the farm to fork exergy efficiency of wheat and rye bread production processes in Turkey and Germany [27], [36]. In another survey, Genc and Hepbasli (2015) assessed the exergetic performance of a potato crisp frying system consisting of a combustor, a heat exchanger, and a fryer [37]. The exergetic efficiencies of the combustor, heat exchanger, and fryer were calculated as 58 per cent, 82 per cent, and 77 per cent, respectively, while the exergy efficiency of the completely frying system was 4 per cent. In a recent review, Zisopoulos et al. (2015) concluded that the exergy-based indicators could lead to the sustainable design of food chains [36].

1.2. POULTRY MEAT AND EGG PRODUCTION

Conventional production of eggs is carried out in two different ways: either with furnished cages or with loose hens on barn floors. The organic egg production requires the hens to be allowed outdoors and given organic feed. They may go outdoors during the day time, and taken indoors at night. KRAV, the main certification organization of organic production in Sweden, requires four m^2 of outdoor area per hen for certification [22]. Laying hens require relatively high protein content and the correct amino acid composition to maintain high egg production rates [9]. A typical process flow diagram of poultry production is represented in Figure 1.1.

Although the organic egg layers eat feed that is much less energy-intensive, they consume more feed and produce fewer eggs then their non-organic counterparts [9], [10], [23]. Table 1.1 and Table 1.2 represent the feed consumption and the number of eggs laid per hen per batch reported from other studies. There is a consensus in the literature that a cage system is more efficient than an organic system since it produces more eggs per kilogram of feed, due to the combination of lower feed input and higher egg output [9], [22], [23]. Consequently, the organic egg production uses 15 per cent more energy, accompanied with 33 per cent larger carbon emission rate in comparison with the caged production [9], [22], [23].

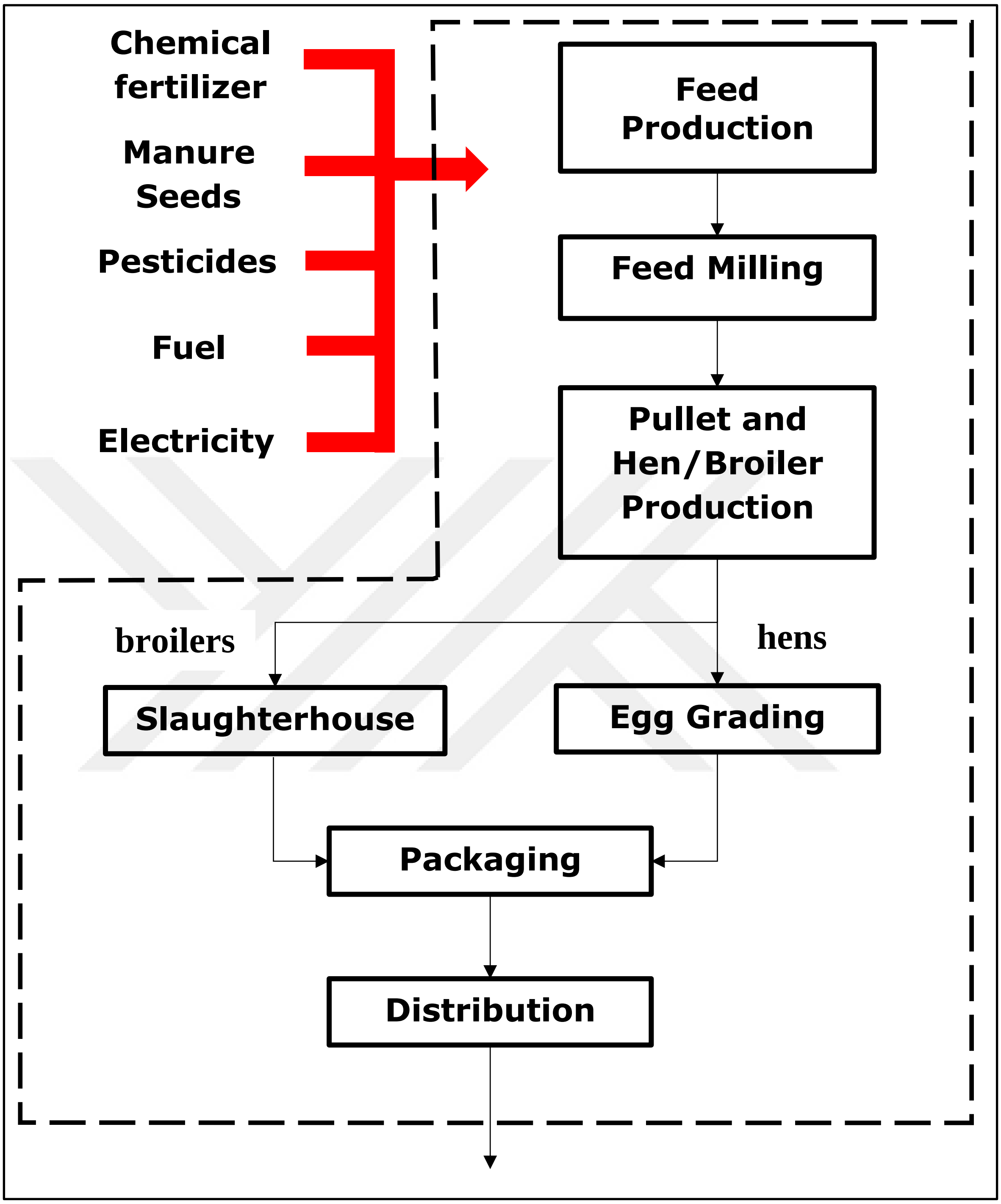

Figure 1.1. Typical process flow diagram of poultry production

Table 1.1. Feed consumption per kg of egg from other studies

Reference Study	Production Type	kg of feed per kg of egg
Dekker et al. 2011 [10]	Cage, Barn, Free Range, Organic	1.99, 2.28, 2.33, 2.59
Wiedemann and McGahan, 2011 [9]	Free Range	2.47
Sonesson et al. 2009 [22]	Cage, Barn, Free Range	2.17, 2.00, 2.20, 2.30
Pelletier et al. 2013 [11]	Barn	2.25
Cederberg et al. 2009 [23]	Cage, Free Range, Organic	2.20 (average)

Table 1.2. Egg production rate, number of eggs per hen from other studies

Reference Study	Production Type	Number of eggs per hen
Dekker et al. 2011 [10]	Cage, Barn, Free Range, Organic	338, 318, 302, 276
Wiedemann and McGahan, 2011 [9]	Free Range	363
Sonesson et al. 2009 [22]	Cage	357
Pelletier et al. 2013 [11]	Barn	429
Cederberg et al. 2009 [23]	Cage, Free Range, Organic	317 (average)

Similar to egg production types, broiler production can also be divided into two groups: organic and conventional production [19, 24]. Compared to conventional production, free-range and organic production appears to have higher mortality rate and lower feed consumption rate [15], [24]. During chicken meat production, producers feed broilers with high protein content concentrates and use different types of amino acid supplements to achieve high body mass gains [15].

Feed production is a significant contributor of the energy demand and produces 55 per cent of the greenhouse gas emissions of the egg production [9]. Chemical fertilizers and poultry manure are among the inputs of feed production. Chemical fertilizers create significant impact on the environment and considered as major pollutants. There are reports that claims and discusses the high level of N_2O emissions (from nitrogen fertilizers) and potential heavy metal pollution due to some being a significant source of heavy metals because of chemical fertilizer usage [38], [39], [40].

Poultry manure is generally rich in nitrogen and phosphorus and used in crop production [41], [42]. It is usually dried before being transported to the fields and applied in low doses, therefore requires little amounts of the spraying equipment use [43], [44], [45]. Poultry manure use in the fields gives rise to considerable ammonia emissions. Ammonia is not a greenhouse gas itself, but converted into nitrous oxide upon oxidation [44], [45], [46]. The excessive amounts of nitrogen use in the feed are avoided to prevent nitrous oxide emission. The optimum ratio of the nitrogen in the eggs to the nitrogen supplied in the feed is about 31 per cent for conventional floor hens and 35 per cent for cage hens and 29 per cent for organic eggs [22]. Poultry manure may be used as an agricultural input during crop production to reduce the chemical fertilizer application or for biogas production to produce energy via turbines [9], [10], [42], [47], [48]. The use of chemical fertilizers in practice is always higher when compared with what the plants actually need, and a good fertilizer management program can reduce the over use, and may lead to about 50 per cent reduction on N_2O emission without causing a decrease in the crop yield [6], [49]. As an alternative method, the soil microorganisms can be used to reduce or eliminate the usage of chemical fertilizers and may have different beneficial effects according to bacterial strains, environmental, plant-crop and soil conditions [50]. In order to identify the most efficient growth-promoting microorganism extensive researches are need to be done as it may affect the results negatively [51], [52], [53].

Apart from the traditional use of manure as fertilizer, poultry manure is also a substrate for biogas production for power generation using gasifier agents such as propane, steam, CO_2 or by induction heat. Biomass gasification can be expressed as the conversion of the biomass material into a gas fuel called as syngas. Syngas then can be used to generate energy by using turbines. Gasifier and turbine properties are also important as the energy generation should yield a positive value when compared to consumption of the process. The process flow diagram of gasification is given in Figure 1.2 [42], [47], [48].

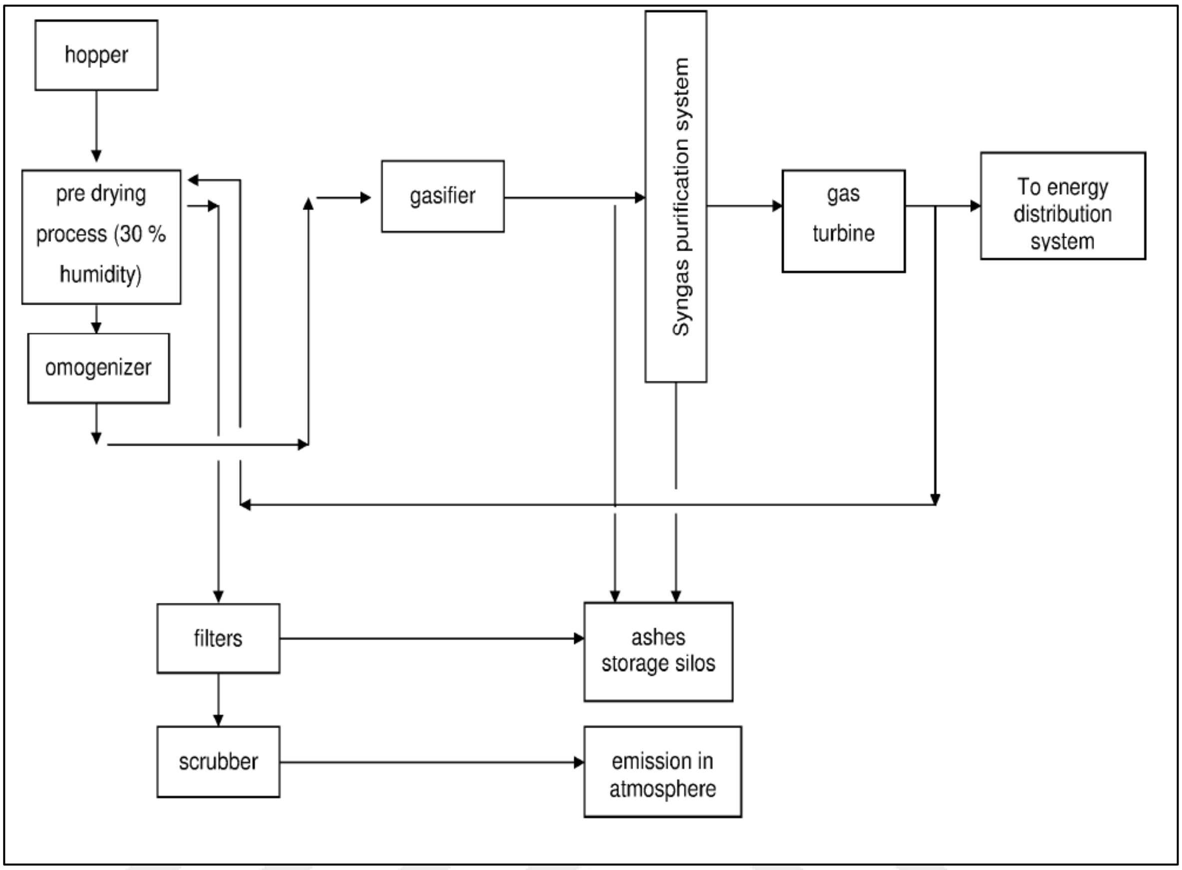

Figure 1.2. Poultry manure gasification process [48]

LDPE, polystyrene, polyethylene, recycled paper and corrugated cardboard are the typical packaging materials used in the poultry industry [15], [19], [54]. Polystyrene is used widely to produce eggcups and trays. Recycled paper was also used for packaging, have less environmental impact in general but causes higher contamination with metals and carcinogenic substances [54].

1.3. VEGETABLE PRODUCTION

Agriculture is one the major sectors in Turkey and has a significant influence Turkey's economy. The vegetable production of tomato, eggplant, cucumber and pepper are among the highest [4], [5], [6]. Among the other vegetable crops, tomato has the highest share in world agriculture production with approximately 126 million tons per annum. In Turkey, the share of tomato production in vegetable agriculture constitutes 38 per cent of the total vegetable production [6], [21]. Production of vegetables can be produced both in open fields or undercover in greenhouses. Greenhouse is a closed structure that the climatic conditions are controlled to produce agricultural plants [4], [5]. Chemical fertilizers, organic manure, agro chemicals, electricity (for irrigation systems), diesel oil (for farm machinery such as tractors) are the main inputs required for the production vegetables [21]. The consumption of energy and chemicals leads to pollution thus it is important to reduce such pollutants. Typical process flow diagram for vegetable production is represented in Figure 1.3.

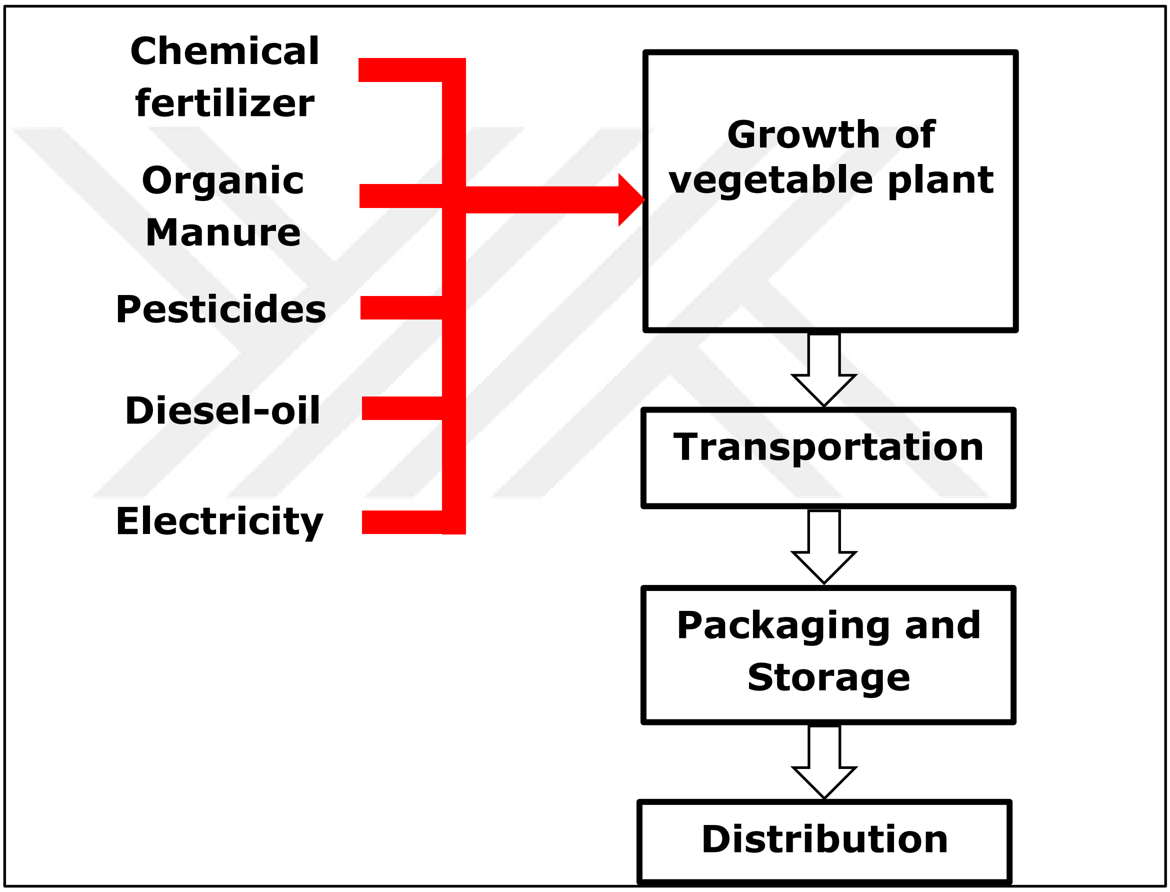

Figure 1.3. Process flow chart of vegetable production

1.4. BIO-FERTILIZERS

Chemical fertilizer usage has a significant impact on the environmental burdens and they are considered as one of the major pollutants in agriculture. There are reports that claims and discusses the high level of N_2O emissions (from nitrogen fertilizers) and potential heavy metal pollution due to some being a significant source of heavy metals because of chemical fertilizer usage [38], [39], [40].

It was reported that the usage of chemical fertilizer is always higher when compared to the needs of soil and fertilizer management can reduce the over usage that will yield approx. 50 per cent reduction on N_2O emission with the same amount of crop yield [6], [49].

Fertilizer usage in poultry industry is important as it is used to produce crops for poultry feed. Wiedemann and McGahan (2011) reported that the feed production is the biggest contributor of the energy demand and produces 55 per cent of the greenhouse gas emissions of the egg production [9].

As an alternative method, the soil microorganisms can be used to reduce or eliminate the usage of chemical fertilizers and may have different beneficial effects according to bacterial strains, environmental, plant-crop and soil conditions [50]. In order to identify the most efficient growth-promoting microorganism extensive researches are need to be done as it may affect the results negatively [51], [52], [53].

Haghighi and Yarmahmodi (2011) reported 21 per cent increase in corn grain yield upon using biological and chemical fertilizers together, in comparison with the case where chemical fertilizers were used alone [55]. According to Janagard et al (2013), after inoculating the soybean seeds with *B. Japonicum* plus phosphate solubilizing bacteria (PSB) the crop yield increased by 1.64 folds while using only 33 per cent of the recommended dose of chemical fertilizers (RDF) [56]. In a study carried out during rapeseed production, the use bio-fertilizer usage improved the yield by 6.7 per cent [57]. Dahmardeh (2013) reported that the utilization of the phosphate bio-fertilizer can reduce the need for chemical phosphate fertilizer by more than 50 per cent; and the combined usage of bio-fertilizers can increase the seed yield (kg per ha) by 32 – 35 per cent with respect to no bio-fertilizer inoculation [58]. Cakmakci et al (2014) reported the grain yield and biomass yield of wheat production as 4.0 t/ha and 13.1 t/ha for chemical fertilizer application and 3.75 t/ha and 11.25 t/ha for mixed bio-fertilizer inoculation [59].

It was reported that the chemical fertilizer usage of tomato production could be reduced by 50 per cent with the synergistic use of *Funneliformis mosseae* and *Bacillus sonorensis* [60]. During agriculture of peppers, 29 per cent increase in yield was reported upon using of bio-fertilizer produced by using *Lumbricus rubellus* [61]. It was also reported that the bio-fertilization with *Azotobacter* could reduce 50 per cent of chemical fertilizer usage and yield similar fruit size, weight and pericarp thickness [62]. Isfahani et al (2013) reported the effect of bio-fertilizer usage on cucumber production [63]. According to results, the highest product yield was obtained by using plant growth promoting rhizobacteria. It was also reported that maximum N, P and Zn concentration could be achieved by using 75 per cent chemical fertilizer + bio-fertilizer. It was reported that inoculation of *Azotobacter* with the combination of PSB could reduce the amount chemical fertilizer usage in eggplant production [64], [65]. When compared to 100 per cent chemical fertilizer treatment, half dose of chemical fertilizer with the combination of bio-fertilizers resulted almost the same amount of fruit yield per plant. According to a bio-fertilization study on cluster beans, bio-fertilizer combination of *Azotobacter*, *Rhizobium*, PSB and *Vesicular – Arbuscular Mycorrizha* (VAM) achieved higher pod yield, pot length and chlorophyll content when compared to inorganic fertilizer usage thus validating the bio-fertilization can replace the chemical fertilizer usage [66]. It was also reported by Ramana et al (2010) that the co-inoculation of bio-fertilizers with 75 per cent recommended dose of chemical fertilizer use improved the seed weight and the pod length by 12 per cent, and pod yield per hectare by 20 per cent, with respect to chemical fertilizer usage alone [67]. For the olive production, Haggag et al (2014) reported that the inoculation of bio-fertilizers with 25 per cent nitrogen, phosphorus, and potassium fertilizers increased the nitrogen, phosphorus and potassium content of the olive seedling with respect to the case carried out with no biological fertilizers [68].

2. METHODOLOGY

In the present study, either chicken meat or the eggs are the main products; manure and spent chicken are the byproducts. Spent hens, broiler slaughter waste and the other by-products (blood, feather, head and intestines) are used for animal feed production, or processed further for human consumption [11], [15], [69].

The chicken meat and eggs producing and consuming network of businesses consisted of a chicken farm, a restaurant, a pet food manufacturing plant, a vegetable garden, an olive garden and a grain field (Figure 2.1). This network was used as a model to simulate the exergy efficiency and the cumulative degree of perfection of the interacting industries under different manure and fertilizer management practices. The cumulative degree of perfection and the exergy efficiency of the total network are employed as the measure of the sustainability of the network.

The data regarding each industry are obtained from the literature and the equipment specifications sheets of the manufacturers. The system and the sub-system boundaries around which the mass, energy and the exergy balances, e.g., equations 2.1 through 2.3, respectively, performed are shown in Figures 2.1 – 2.6:

$$\text{Mass balance: } \sum(m)_{in} - \sum(m)_{out} = 0 \tag{2.1}$$

$$\text{Energy balance: } \sum(mh)_{in} - \sum(mh)_{out} = Q - W \tag{2.2}$$

$$\text{Exergy balance: } \sum(\mathrm{mb})_{in} - \sum(\mathrm{mb})_{out} - \sum_k Q_k \left(1 - \frac{T_0}{T_k}\right) - W = X_{loss} \tag{2.3}$$

Thermodynamic data, which is needed to solve equations 1.3-1.5 are listed in Table 2.1. Exergy is defined as the maximum work that a system can produce, if brought to thermal, mechanical and chemical equilibrium with its surrounding via reversible processes without violating the laws of thermodynamics [25].

Chemical fertilizers, pesticides (agrochemicals), diesel oil, electricity, irrigation water and seed are the main inputs of feed production (Figure 2.2) and vegetable garden. Water used in all processes assumed as fully recycled. For the transportation of broiler and layer feed inputs, calculations are based on 10 toner heavy-duty trucks that utilize 0,287 L/km of diesel with the density of 0.771 kg/L and traveling at speed of 90 km/h [70], [71].

Carbon dioxide emission factors are reported to be 0.85 kg/kg with natural gas, 0.14 MJ/kg with electricity and 0.94 kg/kg with diesel [72], [73]. Hatchery, broiler farms, egg farms, slaughterhouse, olive garden and vegetable garden were assumed as adjacent to the restaurant thus, there would be no environmental impact of transportation considered. The packaging materials needed for the egg production were recycled; therefore, the energy, exergy utilization and carbon dioxide utilization related with these materials are excluded. Specific energy, exergy utilization and carbon dioxide emission factors are collected from the literature and given in Table 2.1.

Energy utilization, exergy utilization carbon dioxide emissions regarding human labor is excluded as it is not possible to collect representative data. Equipment for the production steps includes hatcher, grader and pet food line are selected from web sites-resources and in addition to the equipment, the details related to the energy utilization, exergy utilization and carbon-dioxide emission are selected and calculated.

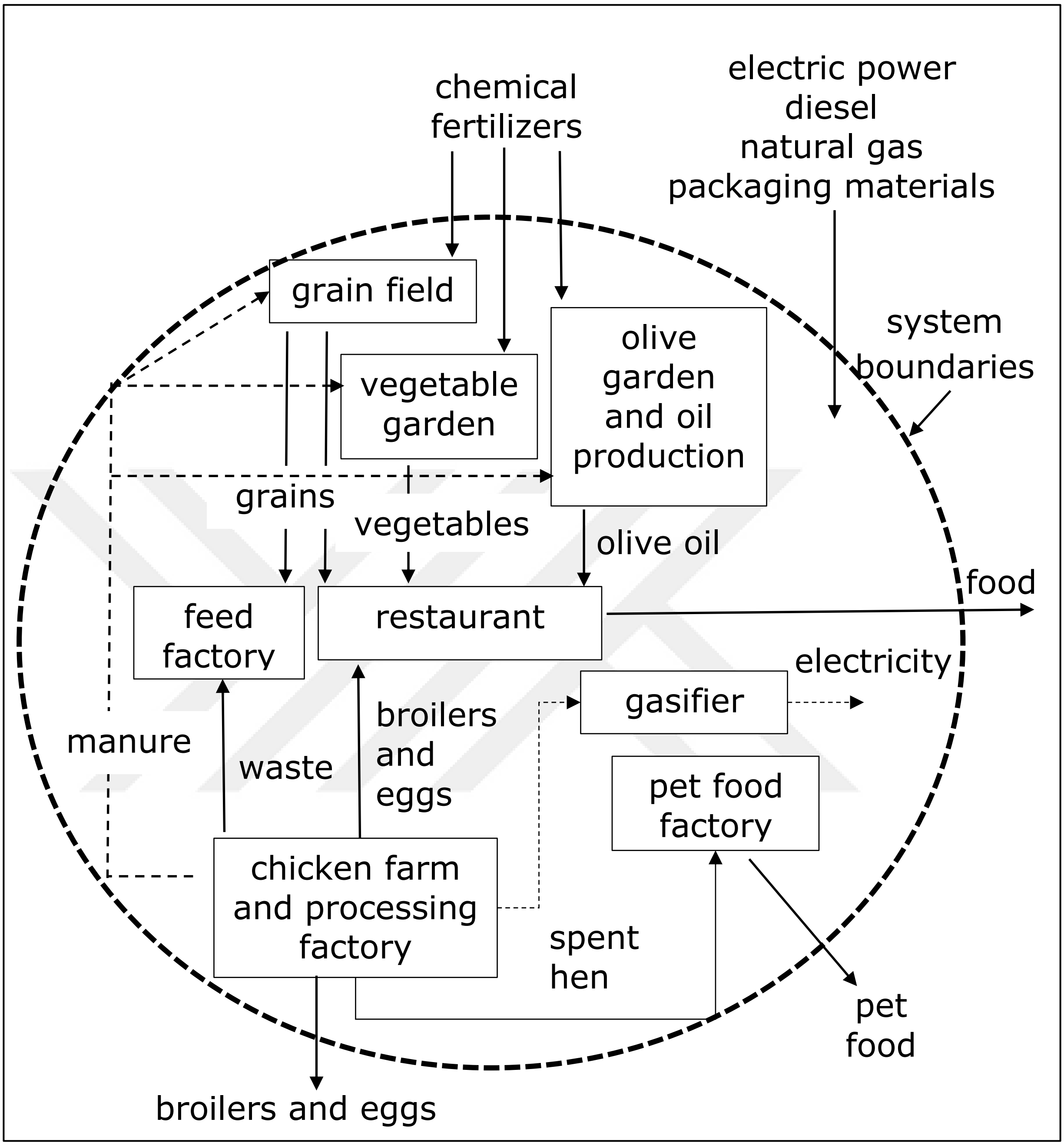

Figure 2.1.Model network of the broiler, egg and manure producing and utilizing businesses

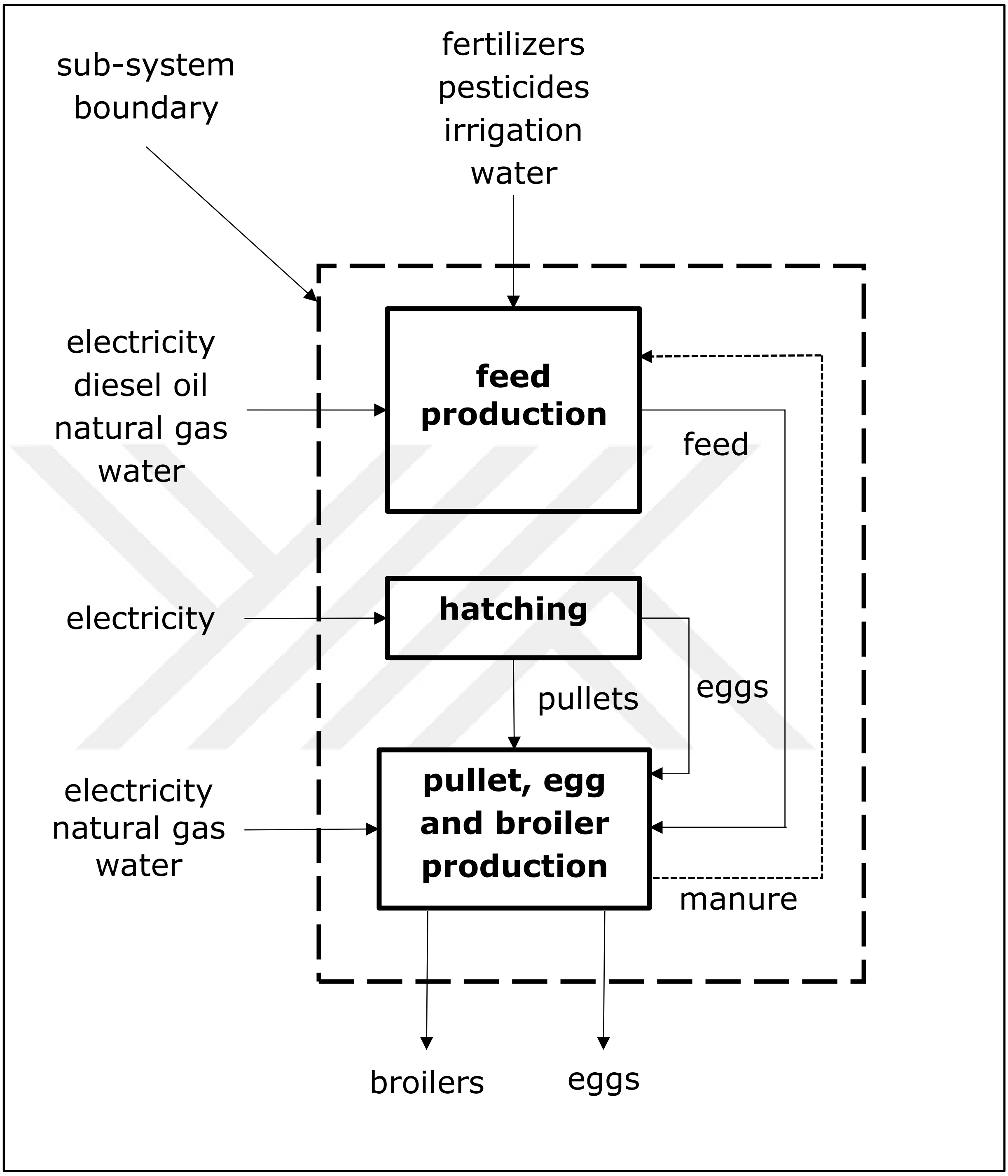

Figure 2.2. System boundaries, inputs and the outputs of the feed production, hatching, eggs, broilers and spent hen production processes. In case of the egg production, spent hens are the byproduct; in case of the broiler production, eggs are the byproduct

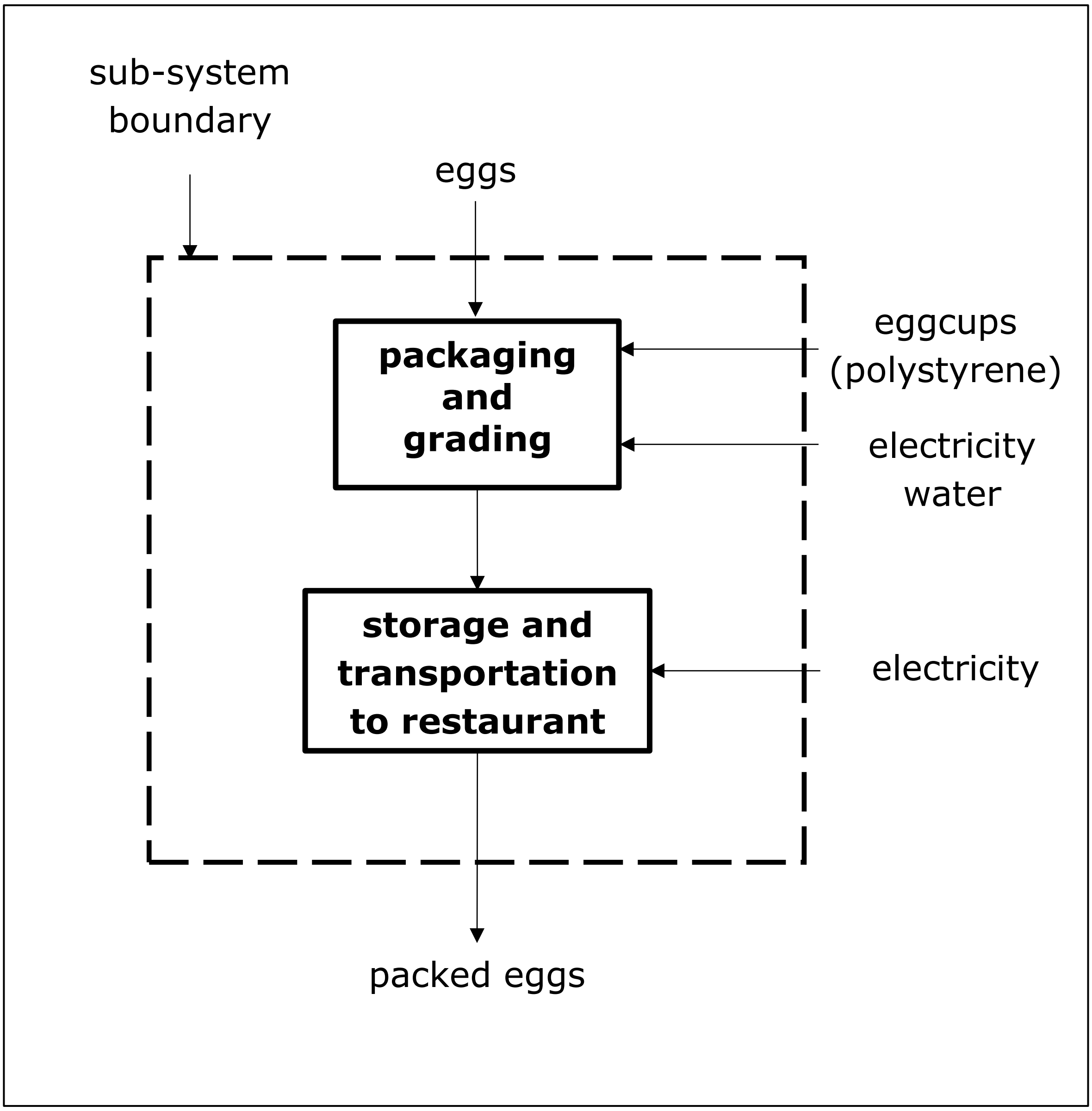

Figure 2.3. System boundaries, inputs and the outputs of the egg packing, storage and transportation processes

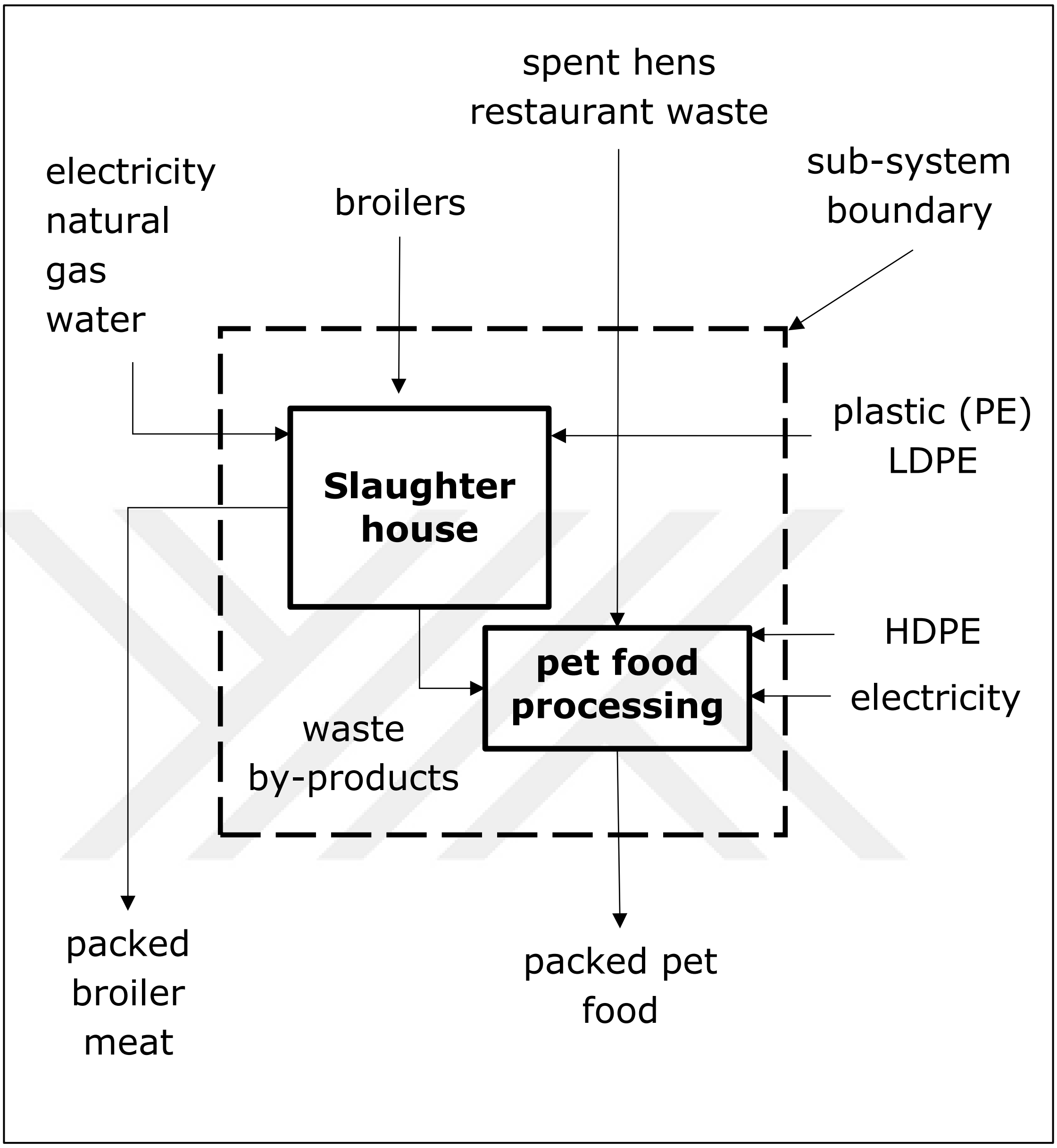

Figure 2.4. System boundaries, inputs and the outputs of the slaughterhouse and pet food units

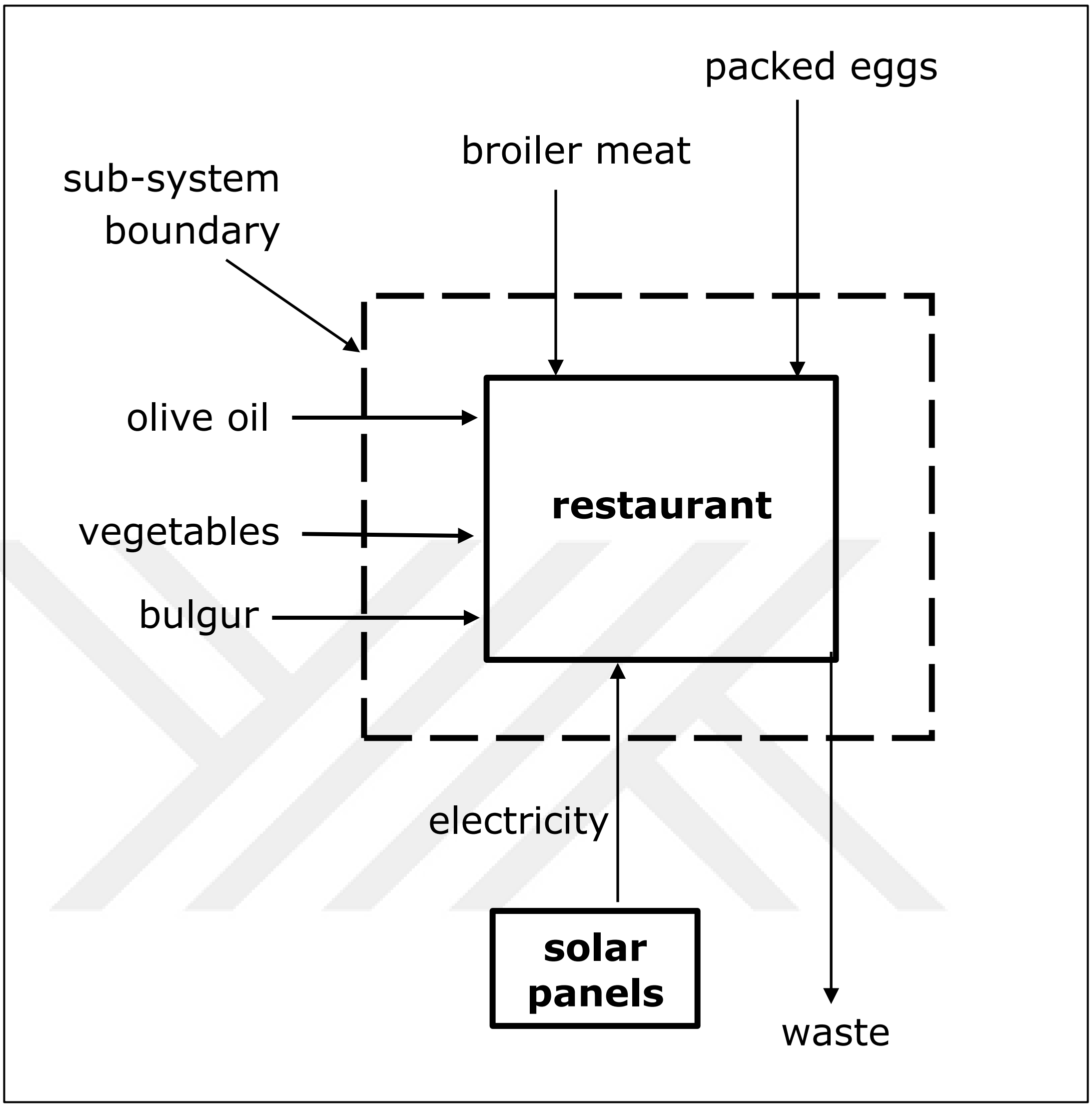

Figure 2.5. System boundaries, inputs and outputs of the restaurant

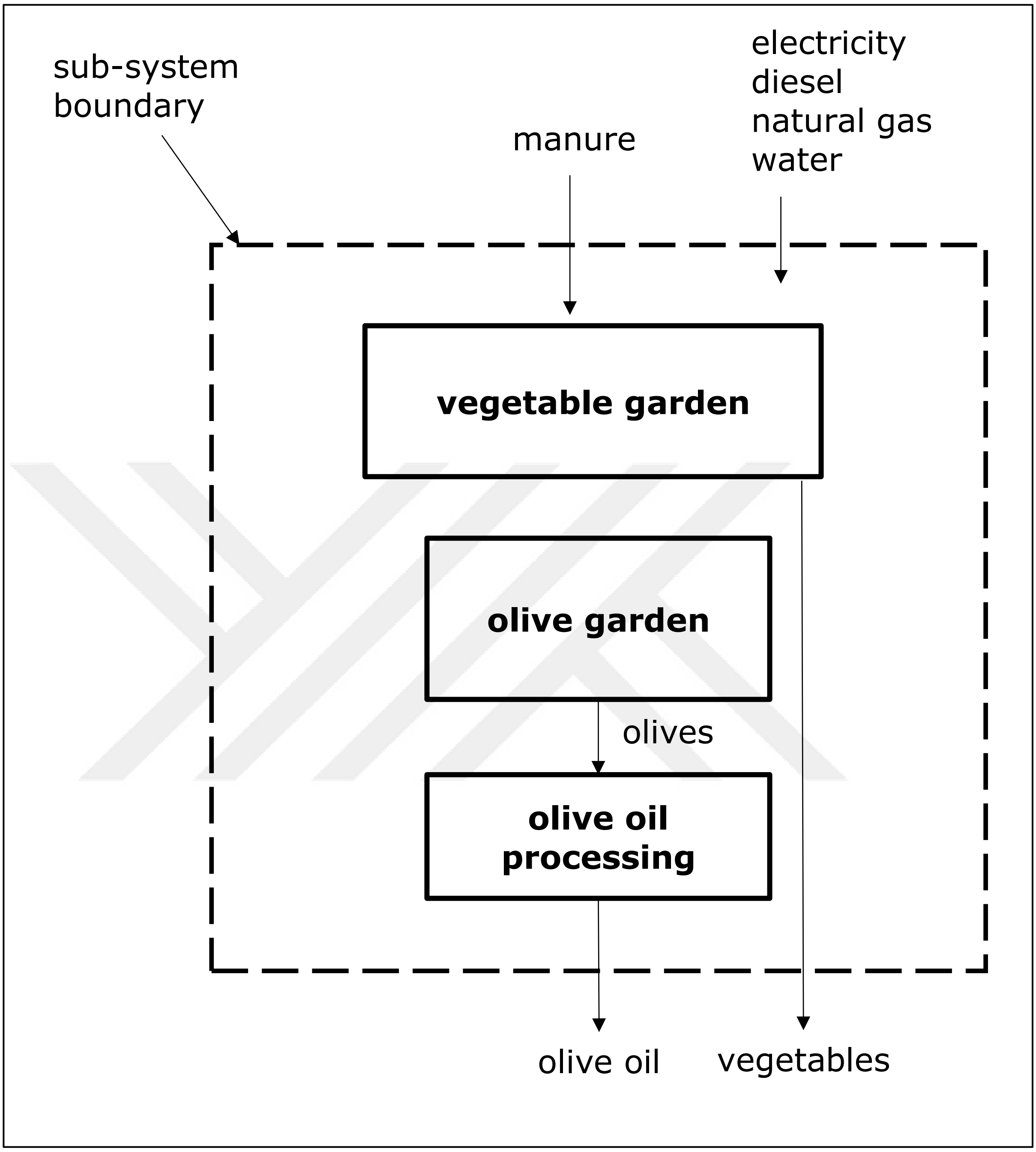

Figure 2.6. System boundaries, inputs and outputs of the provision garden and the olive oil facility

Table 2.1. Thermodynamic data of inputs

Inputs	Units	Specific CEnC/unit	Specific CExC/unit	Specific CO_2/kg
-Energy sources-				
Diesel	L	44.3 [26]	41.0 [29]	0.72 [72]
Electricity	MJ	1.0 [74]	4.2 [29]	0.14 [72]
Natural gas	m^3	38.9 [75]	37.9 [29]	0.85 [72]
-Fertilizers-				
Lime	kg	0.10 [75], [76]	10.0 [25]	0.79 [25]
Nitrogen (N)	kg	78.2 [77]	32.7 [29]	7.1 [78]
Phosphate (P_2O_5)	kg	17.5 [77]	7.5 [79]	2.7 [78]
Potassium (K_2O)	kg	13.8 [77]	4.6 [80]	25.0 [78]
Sulfur [1]	kg	8.9 [81]	37.1 [29]	1.2 [72]
-Agrochemicals-				
Herbicides	kg	198.8 [26]	368.4 [82]	6.3 [27]
Insecticides	kg	198.8 [26]	344.0 [82]	5.1 [27]
Fungicides	kg	198.8 [26]	256.0 [82]	3.9 [27]
-Pack materials-				
HDPE	kg	3.2 [26]	86.0 [26]	0.45 [26]
LDPE	kg	Assumed as recyclable		
Polyethylene	kg	Assumed as recyclable		
Polystyrene	kg	Assumed as recyclable		
-Seed-				
Corn [2]	kg	14.7 [83]	20.5 [25]	0.55 [25]
Rapeseed [2]	kg	29.2 [89]	40.8 [25]	1.1 [25]
Soybean	kg	35.0 [25]	48.9 [25]	1.3 [25]
Wheat	kg	2.8 [84]	18.7 [84]	0.23 [84]
-Water-				
Irrigation	m^3	0.63 [85]	2.6 [29]	0.09 [72]
Other processes	L	0.06 [74]	0.25 [29]	0.01 [86]
-Products (depending on nutrient content)-				
Protein	kg	23.8 [26]	25.4 [26]	-
Fat	kg	39.0 [26]	39.6 [26]	-
Carbohydrate	kg	17.9 [26]	17.5 [26]	-

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[1] Sulfur is assumed as produced with electricity. CEnC and CExC of sulfur calculated accordingly.
[2] CExC and CCO_2 of corn and rapeseed seed is calculated according to those of soybean.
[3] Water is assumed as supplied from water wells. CEnC, CExC and CCO_2 is calculated according to the electricity needs for water pumps.

3. RESULTS AND DISCUSSION

3.1. POULTRY FEED PRODUCTION

Table 3.1 presents a simplified ration employed to produce 1 ton of egg and 1 ton of broiler meat based on the data adapted from the literature [9], [10], [12], [14], [24]. In this study, we assumed input of 2.2 kg of feed consumption per kg of egg production and output of 293 eggs per layer hen. For the broiler production operations, feed conversion ratio (FCR) taken as 1.9 [12]. Using the feed consumption rates, the feed requirement for the broiler production was calculated as 2649 kg (55 per cent) and for the egg production as 2205 kg (45 per cent).

Table 3.1. Ration for the broiler and the layer hens

Feed Ration	**Ration (per cent)**
Corn	65
Soymeal	19
Limestone	7
Rapeseed meal	3
Wheat	2
Soybean oil	1
Rapeseed oil	1
Synthetic amino acids	3
Total	100

The agricultural feed inputs for corn, soy, wheat and rapeseed are collected from the literature and represented in Table 3.2 [12], [27], [81], [89], [90], [91]. It was assumed that the fields received sufficient rainfall, and did not need irrigation. Corn production inputs of LPG and gasoline were substituted with natural gas and diesel in this study. Sulfur fertilizer for corn and soy agriculture was produced with electric power while calculating the energy need and environmental burdens. The pesticide used for the rapeseed production was 0.16 kg/t of Metazachlor (herbicide) and 0.03 kg/t of Esfenvalerate (insecticide) [91], [92]. Soybean and rapeseed yields two important products after extraction, meal and oil. The meal to oil ratio was 83 per cent to 17 per cent for the soybean, and 62 per cent to 38 per cent for rapeseed [12], [27], [81], [89], [90], [91], [93].

Table 3.2. Inputs and outputs of the corn, soy, wheat and rapeseed agriculture

Inputs	**Corn** [12]	**Soy** [81]	**Wheat** [27], [94]	**Rapeseed** [89], [90], [91]
Fertilizer - N (kg)	50.6	2.0	3.2	14.4
Fertilizer - P_2O_5 (kg)	17.4	6.6	2.3	2.3
Fertilizer - K_2O (kg)	17.9	11.0	0.0	0.0
Fertilizer - sulfur (kg)	0.8	0.2	0.0	0.0
Fertilizer - lime (kg)	105	0.0	0.0	0.0
Diesel (L)	14.1	15.9	5.2	10.4
Gas (L)	3.7	0.0	0.0	0.0
LPG (L)	22.0	0.0	0.0	0.0
Electricity (MJ)	49.0	0.0	0.0	6.9
Herbicides (kg)	0.75	1.2	0.0	0.0
Insecticides (kg)	0.0	0.0	0.0	0.0
Fungicides (kg)	0.0	0.0	0.1	0.0
Seed (kg)	6.6	31.3	7.2	0.3
Diesel for transportation (L/km)	0.287	0.287	0.287	0.287
Output				
Crop yield (kg)	3,140	1,124	83	235

The fertilizer used during agriculture was 70.8 kg/t with rapeseed, 66.6 kg/t with wheat, 61.1 kg/t with corn, and 17.6 kg/t with soy. Wheat and soy production requires the highest amount of the pesticide use, e.g., 1.29 kg and 1.06 kg/t of crop, respectively. Diesel utilization was 5.56 L/t with corn, 14.1 L/t with soy, 63.4 L/t with wheat and 44.2 L/t with rapeseed [12], [27], [81], [89].

The natural gas is only used for corn production, calculated as 7.02 m^3/t. Each crop is transported to a feed milling factory 50 km away from the fields. Based on the feed ration, the energy utilization for the crops is calculated as 11,399 MJ, exergy utilization as 9,641 MJ and carbon dioxide emission as 1,510 kg.

Limestone production is adapted from Thuresson (1996), in order to produce 330.07 kg limestone, 69.3 MJ electricity, 0.93 m^3 natural gas and 347 kg water is required [95]. Processed limestone than to be transported to milling facility that is assumed 50 km far from the limestone quarry. With this data, the calculated energy utilization, exergy utilization and carbon dioxide emission are 190 MJ, 470 MJ and 15 kg.

Energy utilization during production of the synthetic amino acids was 86 MJ/kg [9], [96]. It is assumed that 45 per cent of the energy for the amino acid production comes from electricity, 30 per cent from diesel and 25 per cent from natural gas. Addition to these inputs, diesel usage for the transportation to the milling facility based on 50 km distance is calculated. Based on 121 kg of feed ration of energy utilization, exergy utilization and carbon dioxide emission were calculated as 10,500 MJ, 25,080 MJ and 767 kg CO_2.

In order to supply the feed needed for 1 ton of egg and 1 ton of broiler meat production, total energy, exergy utilization and carbon dioxide emission at the gate of milling facility is calculated and represented in Table 3.3 and Table 3.4.

The feed milling facility consists the operation of conveying, cleaning, pressing, grinding, extraction and milling. Equipment except the milling machine is directly adapted from Özilgen and Sorgüven (2011) [25]. Pressing, grinding and extraction processes is only used for soybean and rapeseed to produce soybean meal, soybean oil, rapeseed meal and rapeseed oil.

After the milling operations, feed is transported to the poultry farm that is assumed to be 50 km far from the milling facility. Excess soybean oil and rapeseed oil assumed to be sold out of the system and diesel usage of the trucks calculated according to 50 km distance.
The total energy utilization of agriculture and synthetic amino acid production, feed milling and transportation was 22897 MJ, exergy utilization was 38144 MJ and carbon dioxide emission was 2388 kg (Table 3.5 and Table 3.6).

Table 3.3. Energy and exergy utilization and CO_2 emission during feed agriculture and synthetic amino acid production for egg layers

Input	**CEnC/ton of eggs (MJ/ton)**	**CExC/ton of eggs (MJ/ton)**	**CCO_2/ton of eggs (kg/ton)**
Chemical fertilizers	2,909	1,695	628
Agrochemicals	192	353	6.0
Diesel-oil	2,413	2,233	39
Natural Gas	1,591	1,550	35
Electricity	2,190	9,131	307
Seeds	554	822	21
Process Water	9.4	39	1.3
Transportation to milling facility	173	160	2.8
Total	10,032	15,983	1,041

Table 3.4. Energy and exergy utilization and CO_2 emission during feed agriculture and synthetic amino acid production for broilers

Input	**CEnC/ton of broiler meat (MJ/ton)**	**CExC/ton of broiler meat (MJ/ton)**	**CCO2/ton of broiler meat (kg/ton)**
Chemical fertilizers	3,496	2,037	755
Agrochemicals	231	424	7.2
Diesel-oil	2,900	2,683	47
Natural Gas	1,912	1,862	42
Electricity	2,632	10,974	368
Seeds	666	988	25
Process Water	11	47	1.6
Transportation to milling facility	208	193	3.4
Total	12,056	19,208	1,251

Table 3.5. Energy and exergy utilization and CO_2 emission associated with feed production process for egg layers

Processing step and equipment details	**Energy consumption (MJ/h)**	**CEnC/ton of egg (MJ/ton)**	**CExC/ton of egg (MJ/ton)**	**CCO_2/ton of egg (kg/ton)**
Agriculture of feed and synthetic amino acid production		10,032	15,983	1,041
Conveying (Motovario- V1FD 24 P90)	15	8.5	35	1
Cleaning (TQLZ63 x 100)	0.5	4	17	1
Grinding (Jiadi Machinery LTMJ-4)	67	7	29	1
Pressing (Anyang GEMCO YZS-120)	40	81	340	11
Extraction (Jiadi Machinery D-1688)	11	27	112	4
Milling (Rotex Master YHKJ-250)	79	181	755	25
Transportation to poultry farm, 50 km		29	28	0.5
Transportation of excess rapeseed and soybean oil to 50 km		29	28	0.5
Total		10,399	17,324	1,085

Table 3.6. Energy and exergy utilization and CO_2 emission associated with feed production process for broiler meat (edible fraction for human consumption)

Processing step and equipment details	Energy consumption (MJ/h)	CEnC/ton of broiler meat (MJ/ton)	CExC/ton of broiler meat (MJ/ton)	CCO_2/ton of broiler meat (kg/ton)
Agriculture of feed and synthetic amino acid production		12,056	19,208	1,251
Conveying (Motovario- V1FD 24 P90)	15	10	42	1
Cleaning (TQLZ63 x 100)	0.5	5	21	1
Grinding (Jiadi Machinery LTMJ-4)	67	8	34	1
Pressing (Anyang GEMCO YZS-120)	40	98	408	14
Extraction (Jiadi Machinery D-1688)	11	32	135	5
Milling (Rotex Master YHKJ-250)	79	218	907	30
Transportation to poultry farm, 50 km		35	32	1
Transportation of excess rapeseed and soybean oil to 50 km		35	32	1
Total		12,497	20,820	1,304

3.2. POULTRY EGG PRODUCTION

When the efficiency of egg production was 293 eggs/hen, the mortality rate at the hatchery and farm was 4 per cent, the amount of eggs incubated in the hatcher was be 62 eggs/ton of egg and the incubation period was 21 days. Under these conditions the power requirement and capacity of the egg hatcher (Wei Qian, China) was 0.2 kW and 1,056 eggs/batch, respectively. The energy utilization, exergy utilization and carbon dioxide emission of the hatcher was calculated as 21.6 MJ/t, 88.6 MJ/t and 2.98 kg CO_2/t of eggs.

During the production of the layer hens, electric power utilization in the farm was mainly for ventilation and lightning of the environment. In a Swedish LCA study, farm electricity consumption for barn hens and furnished cages were reported as 260 kWh per ton eggs and 316 kWh per ton eggs [22]. For this study, it is assumed that the electricity consumption would be similar with barn hen production. Before each production batch, the hen house is emptied for cleaning and disinfection. There will be no heating required as the heat generated by chicks is sufficient to maintain optimal temperature range unless the batch production starts during winter [22]. In a LCA study of Dutch egg production systems, farm water usage and manure production were calculated as ~90 L per hen and 20 kg per hen [10]. The water usage in the poultry production was reported to be lower for industrial systems with respect to domestic production as in industrial systems, animals consume more concentrated feed, move less and are bred to grow faster [97]. It was also reported that each hen weighs approx. 1.7 kg at the end of each production cycle [98]. According to these data, the energy utilization, exergy utilization and carbon dioxide emission associated with ventilation, lightning and water usage is calculated as 1,246 MJ, 5,195 MJ and 174 kg (Table 9). The byproducts of the egg production were 1,140 kg of manure and 97 kg of spent hen. The eggs are cleaned by manual labor and graded with AZSMT grading machine (Azeus, China, model 108, capacity 5400 pcs/hour, power requirement 0.5 kW). Eggs were stored in the in cold storage for 5 days before they before they were moved to the restaurant. Electric power requirement of the cold storage was 0.0017 – 0.0009 MJ/kg day [99]. The total energy and, exergy utilization and carbon dioxide emission associated with egg production were calculated as 1,328 MJ/t, 5,535 MJ/t and 186 kg/t of eggs, respectively (Table 3.7).

Table 3.7. Energy utilization, exergy utilization and CO_2 emission of egg farm

Processing Step and Equipment Details	**CEnC per ton of egg (MJ/ton)**	**CExC per ton of egg (MJ/ton)**	**CCO_2 per ton of egg (kg/t)**
Hatching (Wei Qian WQ-1056)	21	89	3
Electricity for lightning and ventilation	938	3,911	131
Water usage	308	1,284	43
Grading (AZSMT-100)	54	224	8
Cold storage for 5 days	7	27	1
Total	1,327	5,534	186

3.3. BROILER MEAT PRODUCTION

For the broiler production, mortality rate of 4 per cent is assumed for both hatchery and farm operations. The hatching machine is assumed as the same machine used for the egg production (Wei Qian WQ-1056). The average live slaughter weight of a broiler was 2.26 kg [14]. The amount of the broiler eggs needed to produce one ton of broiler meat calculated from the given data as 669 egg/t of broiler meat. The energy and exergy utilization and carbon dioxide emission of hatchery was 230 MJ/t, 959 MJ/t and 32 kg CO_2/t of broiler meat, respectively.

In a Swedish LCA study, the total energy requirement of the broiler farm was reported as 0.78 kWh/bird for diesel oil and 0.13 kWh/bird for electricity [100]. Pelletier (2008) reported the farm data of a commercial scale broiler facility according to industry norms as 64.8 kWh for electricity and 80.7 L for LPG (assumed as natural gas) per ton of broiler produced [14]. The water usage and manure production were reported as 7 L per broiler grown and 650 kg per ton of broiler produced [14], [15]. From this data, we can calculate the total water usage and manure production to produce 1 ton of broiler meat as 4,319 L and 906 kg, respectively. Total energy utilization, exergy utilization and carbon dioxide emission of broiler farm is calculated as 2338 MJ, 3560 MJ and 98 kg per ton of broiler meat.

Broilers are moved to slaughterhouse at the end of the production cycle. Slaughterhouse in this study assumed to be a mini slaughterhouse adjacent to the facilities. According to a Danish LCA study, the energy needs in the slaughterhouse reported as 1.06 kWh for electricity and 0.444 MJ for natural gas per broiler processed. It was also reported that 0.138 kWh/broiler of district heat bought in order to supply the energy demand, in this study district heat assumed as natural gas. The energy burdens associated with water usage is also included in the electricity demand and the water assumed to be received from wells. For the packaging, it is reported that 54 g cardboard, 14 g polyethylene and 15 g LDPE was used per broiler. For this study, energy requirements for the packaging materials are excluded as after slaughtering, the product is carried to the restaurant, and the packages can be used more than once. Because of the production of 1-ton broiler meat, 112 kg by-product and 282 kg slaughter waste is produced at slaughterhouse [15]. The calculated energy utilization, exergy utilization and carbon dioxide for the slaughterhouse operation were 2,850 MJ, 10,301 MJ and 340 kg CO_2 per ton of chicken meat (Table 3.8). The broilers are stored for 5 days under the same conditions as eggs after coming out from the slaughterhouse. The total energy and exergy utilization and carbon dioxide emission of the broiler production were 5,425 MJ/t, 14,847 MJ/t and 472 kg/t, respectively (Table 3.8).

Table 3.8. Energy utilization, exergy utilization and CO_2 emission of broiler meat farm

Processing Step and Equipment Details	**CEnC per ton of meat (MJ/ton)**	**CExC per ton of meat (MJ/ton)**	**CCO_2 per ton of meat (kg/t)**
Hatching (Wei Qian WQ-1056)	230	959	32
Electricity and natural gas for farm	2,079	2,479	62
Water usage	259	1,081	36
Slaughterhouse operations	2,850	10,301	340
Cold storage for 5 days	7	27	1
Total	5,425	14,847	472

3.4. VEGETABLE AND OLIVE GARDENS AND BULGUR PRODUCTION

Beans, cucumbers, eggplants and tomatoes are cultivated in the vegetable garden. Data regarding their agricultural inputs are obtained from the literature (Table 3.9). The total use of the pesticide was 0.16 kg/t for tomatoes, 1.64 kg/t for peppers, 1.04/t kg for cucumbers, 1.75 kg/t for the eggplants and 0.21 kg/t for beans [4], [6], [101]. Data regarding the agriculture of tomato agriculture shows that 41 per cent of the agrochemicals used in agriculture were for pesticides, 31 per cent were fungicides and 28 per cent were herbicides. The same ratio was used in our calculations also for peppers, cucumbers and eggplants. Irrigation water is supplied from a water well with the utilization of electric power. Total organic manure and seed use during the agriculture of these plants was 581 kg/t and 0.0038 kg/t. The manure was the byproduct of the egg and broiler production, and the amount of seed was so small that it did not make significant impact on the calculations. Energy, exergy utilization and carbon dioxide emission for the total of agriculture of one ton of each vegetable was 8,184 MJ, 11,491 MJ and 1,715 kg, respectively (Table 3.10).

Bulgur is produced outside the system boundaries and transported to the restaurant. Total energy, exergy utilization and carbon dioxide emission of olive oil production was 39,226 MJ/t, 42,224 MJ/t and 1,280 kg/t, respectively (Table 3.11). For the bulgur production, total energy utilization was reported as 13,668 MJ/t, exergy utilization as 27,723 MJ/t and CO_2 as 1,168 kg/t (Table 3.11).

Table 3.9. Agricultural inputs to the vegetable garden

Inputs	**Agriculture of tomatoes** [6]	**Agriculture of peppers** [4]	**Agriculture of cucumbers** [4]	**Agriculture of eggplants** [4]	**Agriculture of beans** [101]
Fertilizer - N (kg)	3.0	3.6	2.3	3.8	2.1
Fertilizer - P_2O_5 (kg)	3.0	3.6	2.9	6.0	51.0
Fertilizer - K_2O (kg)	1.1	3.1	3.0	4.9	34.0
Diesel (L)	7.5	2.9	8.0	7.3	36.8
Electricity (MJ)	0.0	90.0	76.0	192.0	310.0
Manure (kg)	0.3	0.1	0.4	0.3	580.0
Pesticides (general) (kg)	0.0	0.5	0.3	0.5	0.0
Fungicides (kg)	0.1	0.8	0.5	0.9	0.1
Herbicides (kg)	0.0	0.3	0.2	0.3	0.0
Insecticides (kg)	0.0	0.0	0.0	0.0	0.1
Water for irrigation (m^3)	31.0	6.7	5.3	8.3	1.6
Seeds (kg)	0.0	0.0	0.0	0.0	0.0
Outputs					
Yield (kg)	1,000	1,000	1,000	1,000	1,000

Table 3.10. Energy utilization, exergy utilization and CO_2 emission of vegetable garden

Input	**CEnC/ton of vegetable (MJ/ton)**	**CExC/ton of vegetable (MJ/ton)**	**CO_2 emission/ton of vegetable (kg/ton)**
-Bean production-			
Chemical fertilizers	1,529	609	1,003
Agro chemicals	42	67	1
Diesel-oil	1,633	1,511	27
Electricity	1,115	4,648	156
Water for irrigation	1	4	0.1
Total	4,319	6,839	1,187
-Tomato production-			
Chemical fertilizers	302	126	57
Agro chemicals	31	47	1
Diesel-oil	331	306	5
Water for irrigation	19	81	3
Total	683	560	66
-Pepper production-			
Chemical fertilizers	385	158	113
Agro chemicals	326	497	8
Diesel-oil	129	119	2
Electricity	90	375	13
Water for irrigation	4	18	1
Total	934	1,167	135
-Cucumber production-			
Chemical fertilizers	271	111	99
Agro chemicals	206	314	5
Diesel-oil	354	327	6
Electricity	76	317	11
Water for irrigation	3	14	0.5
Total	911	1,083	121
-Eggplant production-			
Chemical fertilizers	468	191	165
Agro chemicals	347	529	8
Diesel-oil	324	300	5
Electricity	192	800	27
Water for irrigation	5	22	1
Total	1,336	1,842	206
-Total of vegetable garden-			
Total	8,183	11,491	1,716

Table 3.11. Energy utilization, exergy utilization and CO_2 emission during production of olive oil and bulgur production

Input	CEnC/ton of product (MJ/ton)	CExC/ton of product (MJ/ton)	CO_2 emission/ton of product (kg/ton)
-Olive oil production [25]-			
Chemical fertilizers	988	410	110
Agro chemicals	13,268	12,019	194
Diesel-oil	19,635	18,182	321
Water for irrigation	242	1,008	34
Processing and Packaging	5,093	10,605	621
Total	39,226	42,224	1,280
-Bulgur production [84]-			
Chemical Fertilizers	4,011	1,683	400
Agrochemicals	291	451	7
Diesel-oil	4,140	3,830	68
Water for irrigation	4	18	6
Seeds	277	1,851	23
Processing and Packaging	4,881	19,831	663
Transportation to restaurant	64	59	1
Total	13,669	27,724	1,168

3.5. MANURE MANAGEMENT

In this study, multiple manure management scenarios are evaluated and their impact on the total system performance is calculated. In the original system, only a small amount of manure is used in the vegetable garden to provide the organic manure need and the rest of the manure is considered to be sold or discarded from the system without any recycling process. In the second scenario it is considered that the manure is recycled in the system by replacing the amount of fertilizer usage in feed and vegetable production because of its high nitrogen content [9], [15].

Manure sometimes needs to be dried before the transportation and application to the crop fields [22]. In this study, it is assumed that the manure is continuously ventilated and removed to control the moisture content in optimal levels.

Total manure need of vegetable garden was calculated as 581 kg. In order to allocate the manure need for the vegetable garden, 50 per cent of the need is supplied using the manure produced because of egg production and the remaining 50 per cent is supplied by manure yield of broiler meat production. The rest of the manure (859.5 kg from egg production, 625.9 kg from broiler meat production) is sold to poultry feed producers.

Hen manure contains 5.9 per cent nitrogen (N), 2.0 per cent phosphorus (P), 2.1 per cent potassium (K) and 0.5 per cent sulfur (S) [41]. The manure fertilizer replacement or substitution ratio represents the fertilizer value of manure (i.e. If the substitution ratio is 0.5 for nitrogen, it represents that 50 per cent of the chemical nitrogen can be substitute by manure nitrogen content [9]. The fertilizer replacement ratio of the poultry manure is assumed as 0.5, 0.6 and 0.8 for N, P and K, respectively. For sulfur, fertilizer ratio is assumed as 0.6 (average of N/P/K replacement ratio). According to manure yield of 859 kg/t of egg production, 25.1 kg of N-fertilizer, 10.2 kg of P-fertilizer, 14.3 kg of K-fertilizer and 2.5 kg of S-fertilizer can be replaced with the manure during feed production.

One ton of broiler manure may be used to replace 30 kg of nitrogen, 30 kg phosphorus and 20 kg potassium fertilizer during agriculture [14]. Therefore, 626 kg of poultry manure may substitute for 18.5 kg of N-fertilizer, 18.5 kg of P-fertilizer and 12.3 kg of K-fertilizer during production of one ton of broiler meat.

Transportation of the manure to feed production farms is also considered by assuming the diesel usage to 50 km distance. The total manure fertilizer value, energy utilization, exergy utilization and carbon dioxide emission of broiler and egg production including the transportation of manure to crop fields is calculated. The energy utilization of manure management should be considered as a minus value (except transportation) as it should decrease the amount of chemical fertilizer usage, thus decrease the energy need and environmental impacts.

As an alternative to manure management scenario, the manure is used to produce syngas using a gasifier. The syngas then can be used in a generator to generate electricity that can be used in restaurant, poultry farm or vegetable garden. It is reported that various gasification agents such as propane, CO_2, steam or induction heating can be used to supply the heat needed for the gasification [42], [47], [48], [102]. According to a gasification study, poultry manure fed at a rate of 300 kg/h to produce 654 kWh electricity and 40 kg ash using gasifier with induction heating and a turbine with a conversion rate of 29.8 per cent [48]. Koger and Bull (2005) reported that optimizing the temperature of gasifier can reduce the need of gasifier agent for the reaction [47]. Fernandez-Lopez et al (2016) reported that the net energy gains from the gasification process to produce electricity was negative due to energy consumption of drying and gasification processes but from an economical perspective it is more viable due to the high sales price of energy [42].

The energy consumption of the gasification process can be compensated by using solar panels (Suntech STP-285-24) with the dimensions of 1.956 m x 0.992 m and irradiance of 0.8 kW/m^2. If the region that this scenario is applied is getting 5 hours of efficient sun light for 365 days, each panel generates 10,198 MJ/ year of electricity. The total energy consumption of the gasification is calculated as 15,636 MJ assuming same amount of manure that was used for fertilizer replacement scenario therefore 2 solar panels are sufficient enough to supply the energy. By using the same type of turbine as used in the study of Torretta et al (2013), the total energy generation from gasifier is calculated as 11,607 MJ/year [48]. CO_2 emission caused by gasifier is negligible (163 kg) when compared to total emission reduction by electricity generation thus not accounted in the calculations [48].

3.6. INPUTS OF THE RESTAURANT

The restaurant is open to business for 12 hours a day, and serves daily to 27 customers. The calculations were based on the daily consumption of 100 g/day of egg, 100 g/day of chicken meat, 100 g/day bulgur and 100 g/day of each vegetable produced in vegetable garden. The amount of olive oil usage is also assumed as 100 grams per day, to be used for vegetable salad and chicken meat. The required amount of egg, poultry meat, vegetable, olive oil and bulgur production is based on the annual demand of the restaurant (1 ton of each product). In order to calculate the restaurant waste, it is assumed that each customer will consume 90 per cent of their meal and leave 10 per cent as waste. From this input, the total restaurant waste per year is calculated as 900 kg. Food waste is then, to be transported to pet food line as an input of packed pet food.

A typical equipment list is prepared for the restaurant. Data regarding the energy consumption and CO_2 emission of equipment are collected from company websites and calculated as 2,093 GJ/year and 28.7 t/year, respectively (Table 3.12). In order to supply the restaurant energy need, a solar panel system is designed with Suntech “STP-285-24” solar panels. The dimensions and irradiance of the solar panel and region properties are assumed as same as it was used for the gasifier calculations. According to this data, the number of panels needed to support 1-year energy demand of the restaurant is calculated as 205.

Table 3.12. Energy consumption rates of the equipment in the restaurant

Equipment	Time of operation (h/day)	Energy utilization (MJ/year)	CO_2 emission (ton/year)
Oven	5	315,360	4.3
Induction stove	5	141,912	1.9
Conventional stove	5	788,400	10.8
Deep fryer	2	91,980	1.3
Steamer	3	7,884	0.1
Refrigerator	24	75,697	1.0
Heating	12 h for 120 days	59,130	0.9
Cooling	10 h for 100 days	59,130	0.9
Laundry	5	25,920	0.3
Chiller	2	7,490	0.1
Dish washer	12	520,344	7.1
Total		2,093,235	29

3.7. PET FOOD PRODUCTION

Our calculations have shown that during production of one ton of eggs 97 kg of spent hen and 394 kg of waste are produced. Calculations of the pet food production line was based on the specifications of LABH (India) model C247 extruder line (capacity 125 kg/h, power requirement 50 kW).

From these inputs, energy utilization, exergy utilization and carbon dioxide emissions of the production line is calculated as 2,002 MJ, 8,350 MJ and 280 kg. Six grams of HDPE is used for packaging one kg of pet food; fully recyclable plastic pallets, which can make 250 trips, are used in transportation [25].

Dalian Jialin (China) model JT-1200 palletizer with capacity of 1,000 pcs/h and power requirement of 9 kW is employed for pelletizing the pet food, 50 packages of pet food are placed on each pallet, and the pet food is transported to 50 km of distance for distribution.

Total energy utilization, exergy utilization and carbon dioxide emission for the pet food operation is calculated as 2,095 MJ, 9,136 MJ and 285 kg, respectively (Table 3.13).

Table 3.13. Energy utilization, exergy utilization and CO_2 emission during pet food production

Processing Step and Equipment Details	**Energy Consumption (MJ/h)**	**CEnC of pet food (MJ)**	**CExC of pet food (MJ)**	**CO_2 emission of pet food (kg)**
Pet food line (LABH-C247)	180	2,002	8,350	280
Packaging material (HDPE)		27	718	4
Palletizing (Dalian Jian JT-1200)	32	2.3	10	0.3
Transportation to 50 km		64	59	1
Total		2,095	9,136	285

3.8. IMPACT OF THE USE OF BIO-FERTILIZERS

The impact of bio-fertilizer is evaluated according to the amount of reduction that it causes in chemical fertilizer usage. The reduction on the usage is then directly proportioned to energy, exergy utilization and carbon dioxide emission. Since the energy demand and carbon dioxide emission of the bio-fertilizer production is very low, they are not accounted in the calculations.

Table 3.14 shows that 1,813 MJ of energy utilization and 438 kg of CO_2 emission may be avoided in poultry feed agriculture production by using bio-fertilizers in combination with chemical fertilizers. The highest reduction in energy consumption is observed for wheat by 90 per cent and the lowest reduction is recorded for corn (21 per cent)

Total energy utilization and carbon dioxide emission of vegetable garden, olive garden and bulgur production with bio-fertilizer application calculated as 2161 MJ and 890 kg CO_2, respectively (Table 3.15). Bulgur had the highest energy reduction as it is made of wheat, 90 per cent reduction in energy consumption with respect original state while cucumber had the lowest energy reduction with 25 per cent difference with respect to 100 per cent chemical fertilizer usage.

Table 3.14. Energy utilization and CO_2 emission of fertilization with and without bio-fertilizer application to produce the amount of feed required to produce 1 ton of eggs plus 1 ton of broiler meat

Input	Chemical fertilizer application		Combination of chemical and bio-fertilizers	
	CEnC (MJ)	CO_2 emission (kg)	CEnC (MJ)	CO_2 emission (kg)
Corn	4,524	939	3,574	742
Soy	426	307	174	126
Wheat	292	29	29	2.9
Rapeseed	1,163	108	814	76
Total	6,405	1,384	4,592	946

Table 3.15. Energy utilization and CO_2 emission of fertilization with and without bio-fertilizer application of vegetable garden, olive garden and bulgur production

Input	Chemical fertilizer application		Combination of chemical and bio-fertilizers	
	CEnC/ton (MJ/ton)	CO_2 emission/ton (kg/ton)	CEnC/ton (MJ/ton)	CO_2 emission/ton (kg/ton)
Olive oil	988	110	247	28
Bean	1,529	1,003	917	602
Tomato	302	57	151	29
Pepper	385	113	192	56
Cucumber	271	99	204	74
Eggplant	468	165	234	82
Bulgur (wheat)	4,011	400	401	40
Total	7,954	1,946	2,347	911

3.9. PERFORMANCE OF THE TOTAL SYSTEM AND THERMODYNAMIC ASSESSMENT

Total energy utilization, exergy utilization and carbon dioxide emission of the system with different manure management practices are represented in Table 3.16 – 3.18. Compared to base system, manure gasification scenario resulted in a reduction of energy utilization of 13 per cent, exergy utilization of 33 per cent and carbon dioxide emission of 22 per cent. Bio-fertilization scenario is evaluated for manure management scenarios of manure gasification and traditional manure as fertilizer (Tables 3.19 and 3.20). The system with manure gasification and bio-fertilizer inoculation resulted in lowest energy burdens with energy utilization of 73,806 MJ, exergy utilization of 97,240 MJ and carbon dioxide emission of 4,391 kg.

Table 3.16. Total energy utilization, exergy utilization and CO_2 emission of the system with manure discarded from the system

Operation	CEnC (MJ/year)	CExC (MJ/year)	CO_2 emission (kg/year)
Feed for egg and broiler meat production	22,896	38,144	2,388
Poultry egg farm	1,327	5,534	186
Broiler meat farm	5,425	14,847	472
Vegetable garden	8,184	11,491	1,715
Olive garden	39,226	42,224	1,280
Bulgur production	13,669	27,724	1,168
Pet food production	2,095	9,136	285
Manure management	64	59	1
Total	**92,884**	**149,159**	**7,496**

Table 3.17. Total energy utilization, exergy utilization and CO_2 emission of the system with manure treated as fertilizer

Operation	CEnC (MJ/year)	CExC (MJ/year)	CO_2 emission (kg/year)
Feed for egg and broiler meat production	22,896	38,144	2,388
Poultry egg farm	1,327	5,534	186
Broiler meat farm	5,425	14,847	472
Vegetable garden	8,184	11,491	1,715
Olive garden	39,226	42,224	1,280
Bulgur production	13,669	27,724	1,168
Pet food production	2,095	9,136	285
Manure management	-4,355	-1,796	-1,067
Total	**88,466**	**147,304**	**6,428**

Table 3.18. Total energy utilization, exergy utilization and CO_2 emission of the system with manure gasification

Operation	CEnC (MJ/year)	CExC (MJ/year)	CO_2 emission (kg/year)
Feed for egg and broiler meat production	22,896	38,144	2,388
Poultry egg farm	1,327	5,534	186
Broiler meat farm	5,425	14,847	472
Vegetable garden	8,184	11,492	1,715
Olive garden	39,226	42,224	1,280
Bulgur production	13,669	27,724	1,168
Pet food production	2,095	9,136	285
Manure management	-11,594	-48,552	-1,631
Total	**81,227**	**100,548**	**5,864**

Table 3.19. Total energy utilization, exergy utilization and CO_2 emission of the system with manure treated as fertilizer and inoculation of bio-fertilizers

Operation	CEnC (MJ/year)	CExC (MJ/year)	CO_2 emission (kg/year)
Feed for egg and broiler meat production	21,082	37,167	1,951
Poultry egg farm	1,327	5,534	189
Broiler meat farm	5,425	14,847	472
Vegetable garden	6,927	10,982	1,122
Olive garden	38,485	41,917	1,198
Bulgur production	10,059	26,209	808
Pet food production	2,095	9,136	285
Manure management	-4,355	-1,796	-1,067
Total	**81,045**	**143,996**	**4,955**

Table 3.20. Total energy utilization, exergy utilization and CO_2 emission of the system with manure gasification and bio-fertilizer inoculation

Operation	CEnC (MJ/year)	CExC (MJ/year)	CO_2 emission (kg/year)
Feed for egg and broiler meat production	21,082	37,167	1,951
Poultry egg farm	1,327	5,534	186
Broiler meat farm	5,425	14,847	472
Vegetable garden	6,927	10,982	1,122
Olive garden	38,485	41,917	1,198
Bulgur production	10,059	26,209	808
Pet food production	2,095	9,136	285
Manure management	-11,594	-48,552	-1,631
Total	**73,806**	**97,240**	**4,391**

Cumulative energy utilization and cumulative exergy utilization of products are calculated according to nutrient content (protein, fat and carbohydrate) of the products (Table 2.1). The nutrient content of products that are produced in poultry farm, vegetable garden, olive garden and bulgur facility adapted from USDA Nutrient Database Entry [87]. For the pet food production, nutrient content is adapted from Case et al. (2011) [88]. The specific CEnC and CExC of macronutrients are adapted from Özilgen and Sorgüven (2011) [25].

Exergy efficiency is the ratio of the chemical exergy of the product to the chemical exergy of inputs regardless of the energy source is renewable or not while CDP calculation only considers the non-renewable energy inputs as it is used to assess degree of the renewability of processes. In this study, all the energy sources considered as non-renewable therefore, the CDP of the process should be same as the exergy efficiency of the process.

The energy and exergy inflow-outflow and CDP are calculated and represented in Table 3.21 and Table 3.22. The CDP of the original system (manure is discarded) is calculated as 0.66. The scenario with traditional use of manure as fertilizer calculated as 0.67. Manure gasification scenario resulted in CExC reduction of 48,552 MJ/year by the electricity generation from turbine (Table 3.22). This means 48 per cent reduction in CExC of the total system.

Bio-fertilizer inoculation is also another way optimize CDP of the processes involved in the system. Manure gasification increased CDP of processes studied by 46 per cent (0.98) with respect to traditional manure usage as fertilizer. Highest CDP values are calculated for manure gasification plus inoculation of bio-fertilizer to agriculture scenario (1.01).

Table 3.21. CEnC and CExC of products that is produced in the base system

Products	**CEnC (MJ/ton)**	**CExC (MJ/ton)**
-Poultry production-		
Input flow	27,834	57,548
Output flow	17,127	17,770
-Vegetable, olive oil and bulgur-		
Input flow	61,078	81,438
Output flow	62,082	62,572
-Manure and waste management-		
Input flow	2,159	9,195.0
Output flow	17,193	17,866
-Total System-		
Input flow	92,884	149,159
Output flow	96,402	98,208

Table 3.22. Comparison of CDP's calculated for different scenarios

Scenario	**CEnC (MJ/year)**	**CExC (MJ/year)**	**CDP**
-Manure is discarded from the system-			
Input flow	92,884	149,159	0.66
Output flow	96,402	98,208	
-Manure is used as a fertilizer-			
Input flow	88,466	147,304	0.67
Output flow	96,402	98,208	
-Manure used as a fertilizer plus inoculation with bio-fertilizers-			
Input flow	81,045	143,996	0.68
Output flow	96,402	98,208	
-Manure gasification-			
Input flow	81,227	100,548	0.98
Output flow	96,402	98,208	
-Manure gasification plus inoculation with bio-fertilizers-			
Input flow	73,806	97,240	1.01
Output flow	96,402	98,208	

4. CONCLUSION

Energy utilization, exergy utilization and carbon dioxide emission of a sustainable restaurant furnished with a poultry farm that produces egg and broiler meat, a vegetable garden, an olive garden and a pet food line are calculated to assess and reduce the total environmental burden of the system by changing the parameters of inputs. For the original system, the manure produced, because of the poultry production, is considered to be discarded from the system without any recycling. Moreover, scenarios that evaluate the impact of manure gasification to produce energy by turbines and traditional use of manure to reduce chemical fertilizer need in poultry feed production is calculated and compared to the original system.

The olive oil production contributed to the highest impact with the energy utilization of 39,226 MJ, exergy utilization of 42,224 MJ and CO2 emission of 1,714 kg as only 250 kg of olive oil can be produced per ton of olive produced. The poultry system had the second highest contribution for the system and poultry feed production had the most significant contribution by means of energy utilization (76 per cent), exergy utilization (65 per cent) and carbon dioxide emissions (75 per cent) for the poultry system because of the high environmental burdens coming from chemical fertilizer, electricity and fuel usage in agriculture production.

For the chemical fertilizer usage in poultry feed production, it was calculated that rapeseed, wheat and corn require 70.8 kg, 66.6 kg and 61.1 kg per ton of grain produced while soybean production require 17.6 kg/t which is significantly lower compared to others. The environmental impact of the feed ration can be reduced by optimizing the amount of chemical fertilizer usage in crop productions, using feed rations with higher amount of soybean or crops that require lower amount of fertilizer usage [9], [10], [11], [14]. Pelletier et al. (2014) reported that the feed ration range from 10 per cent to 26 per cent for soybean meal and no usage of rapeseed meal [12]. If we substitute the amount of rapeseed usage with soybean, it will reduce the energy utilization by 6 per cent, exergy utilization by 2 per cent and CO2 emission by 3 per cent for the feed production. Diesel usage can be decreased by utilizing biodiesel usage and with good agricultural practices [26]. There was also a study carried to understand the impact of sunflower seed with enzyme and probiotic usage on feed efficiency, egg production and egg weight but the results were negative and no beneficial effect were found when compared to feed prepared with soybean meal [103].

Feed conversion efficiency is also a very critical point for the egg and broiler meat production. As the efficiency increase, the amount of feed consumption to have the same yield of eggs or broiler meat will decrease thus the environmental burdens of feed production will decrease. In order to test the impact, we assumed 10 per cent increase of feed conversion efficiency for both broiler and egg production systems. As a result, the energy utilization, exergy utilization and carbon dioxide emission decreased 9.8 per cent, 9.9 per cent and 10 per cent, respectively. For the egg production, feed conversion efficiency can be increased either by reducing the amount of feed utilized to produce the same amount of eggs or by increasing the number of eggs by using the same amount of feed.

Electricity usage for lightning and ventilation contributes to highest impact in egg farm. Using high efficient light bulbs or annual cleaning of ventilator system can reduce the electricity need of the farm thus reduce the impact [100], [104]. In addition, the electricity can be compensated by increasing the amount of solar panels that is used for the restaurant to produce the energy required for egg and broiler production farms. The broiler meat farm appeared to have a higher contribution with respect to egg farm because of the slaughterhouse operations as in the egg farm we assumed that the packaging is done by manual labor than using a packaging line (except grader). Mortality rate is an important aspect for broiler and egg production. As the mortality increases, the production efficiency will decrease. Thus from a system perspective, the lower mortality is better [22].

In vegetable garden, bean had the highest contribution because of the significantly high usage of fertilizer and electricity. If we stop producing bean and compensate the annual production of the vegetable garden by increasing the amount of other vegetables by 0.25 tons, contribution of vegetable garden will decrease by 41 per cent for energy consumption, 50 per cent for exergy consumption and 62 per cent for carbon dioxide emission.

Manure management is also another important aspect as it is rich in nitrogen and phosphorus [23]. Using manure in feed production reduced 4,355 MJ of energy utilization, 1,796 MJ of exergy utilization and 1,066 kg of CO_2 emission by replacing the chemical fertilizers in feed production. Manure gasification appeared as a better alternative with respect to traditional usage of manure. By using solar panels to supply the energy need of the gasification process, 11,594 MJ/year of energy can be generated from manure and 1,631 kg/year of carbon dioxide reduction can be achieved by using the energy produced from gasification process within the system.

The pet food production is considered as waste management system to utilize by-products and waste of poultry system and restaurant waste. Compared to the total system, it has the least impact to energy utilization (2 per cent), exergy utilization (6 per cent) and CO2 emissions (4 per cent). This impact can be further decreased by decreasing the amount of restaurant waste or utilizing solar panels to compensate the energy requirements of the production line.

Bio-fertilizer usage appears as another alternative strategy to decrease the environmental burdens of chemical fertilization. Inoculation of microorganisms to the soil not only decrease the environmental burdens such as energy consumption and CO2 emissions but also increase the parameters such as product yield and nutrient content. The inoculation of bio-fertilizers and using manure as an input for gasification yielded the lowest energy utilization, exergy utilization and carbon dioxide emission with respect to alternative scenarios studied (Figure A.1 and Figure A.2).

The CDP of products of poultry production processes (egg and broiler meat), vegetable garden outputs, olive oil, bulgur and pet food are calculated. The lowest system CDP is calculated for the original system that the manure is discarded and the highest was obtained when the manure was gasified and microbial fertilizers were employed in the agriculture.

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APPENDIX A: MASS EQUATIONS AND SCENARIO COMPARISON

Table A.1 to A.13 illustrate mass balances that are created to calculate total system expense of energy consumption, exergy utilization and CO_2 emissions. Mass balance calculations are done by using Microsoft Excel functions. Figure A.1 and Figure A.2 show and compare the scenarios that are evaluated in the study.

Table A.1. Mass balance of limestone production

Inputs	**Units**	**Mass balance**
Limestone rock	Kg	373
Electricity	MJ	69
Heat (natural gas)	M^3	0.93
Process water	Kg	347
Diesel for transportation to 50 km	L	1.4
Outputs		
Limestone	Kg	330

Table A.2. Mass balance of synthetic amino acid production

Inputs	**Units**	**Mass balance**
Diesel	L	70.6
Electricity	MJ	4,696
Natural gas	M^3	67.1
Material	Kg	121
Diesel for transportation to 50 km	L	1.4
Outputs		
Lysine, methionine, threonine	Kg	121

Table A.3. Mass balance of feed milling facility

Inputs	**Units**	**Mass balance**
Feed inputs	Kg	5,034
Electricity for conveying	MJ	18.6
Electricity for cleaning	MJ	9.1
Electricity for grinding (soybean and rapeseed)	MJ	15.1
Electricity for pressing (soybean and rapeseed)	MJ	179
Electricity for the extractor (soybean and Rapeseed)	MJ	59.3
Electricity for milling	MJ	399
Diesel for transportation to 50 km	L	1.4
Diesel for transportation off excess material to 50 km	L	1.4
Outputs		
Feed for broiler & hens	kg	4,854
Excess soy oil and rapeseed oil	kg	180

Table A.4. Mass balance of hatching operations

Inputs	**Units**	**Mass balance**
Eggs for incubation	#	731
Electricity	MJ	251
Outputs		
Pullets produced	#	702

Table A.5. Mass balance of egg farm

Inputs	**Units**	**Mass balance**
Pullets (4 per cent mortality)	#	57
Feed required	kg	2,205
Electricity for lightening and ventilation	MJ	938
Natural gas for heating of barn	m^3	0.0
Water usage	L	5,130
Outputs		
Eggs produced	kg	1,002
Spent hens	kg	97
Manure produced	kg	1,140

Table A.6. Mass balance of egg grading process

Inputs	Units	Mass balance
Unprocessed eggs	kg	1,002
Electricity	MJ	5.6
Cleaning water	L	802
Outputs		
Graded eggs	kg	1,002

Table A.7. Mass balance of cold storage of eggs

Inputs	Units	Mass balance
Graded eggs	kg	1,002
Electricity required for cold storage for 5 days	MJ	6.5
Outputs		
Transported eggs (to restaurant)	kg	1,002

Table A.8. Mass balance of pet food production

Inputs	Units	Mass balance
Spent hens + restaurant waste	kg	1,391
HDPE	kg	8.3
Electricity for the production line	MJ	2,002
Electricity for palletizer (Dalian Jian JT-1200, 1200pcs/h, 9kW)	MJ	2.3
Diesel for transportation off excess material to 50 km	L	1.4
Outputs		
Packed pet food	kg	1,391

Table A.9. Mass balance of slaughterhouse operations

Inputs	Units	Mass balance
Broiler	kg	1,394
Electricity	MJ	2,354
Natural Gas	m^3	2.3
District heat (assumed as natural gas)	MJ	10.4
Plastic (polyethylene)	kg	8.6
LDPE foil	kg	9.3
Outputs		
Packaged broiler	kg	1,001
By-products	kg	112
Slaughter waste	kg	282

Table A.10. Mass balance of cold storage of broiler meat

Inputs	Units	Mass balance
Broiler meat	kg	1,001
Electricity required for cold storage for 5 days	MJ	6.5
Outputs		
Transported meat (to restaurant)	kg	1,001

Table A.11. Restaurant solar panel details

Inputs	Units	Mass balance
Dimensions of solar panel	m^2	1.9
Outputs		
Electricity generated	MJ	10,198

Table A.12. Mass balance of manure management (manure as fertilizer)

Inputs	Units	Mass balance
Layer hen manure - vegetable garden	kg	860
Broiler manure - vegetable garden	kg	626
Diesel for transportation of manure to 50 km	L	1.4
Outputs		
N-fertilizer	kg	44.1
P-fertilizer	kg	29.1
K-fertilizer	kg	27.0
S-fertilizer	kg	2.58

Table A.13. Mass balance of manure management (manure gasification)

Inputs	**Units**	**Mass balance**
Layer hen manure	kg	860
Broiler manure	kg	626
Diesel for transportation of ash to 50 km	L	1.4
Outputs		
Electricity	MJ	11,657

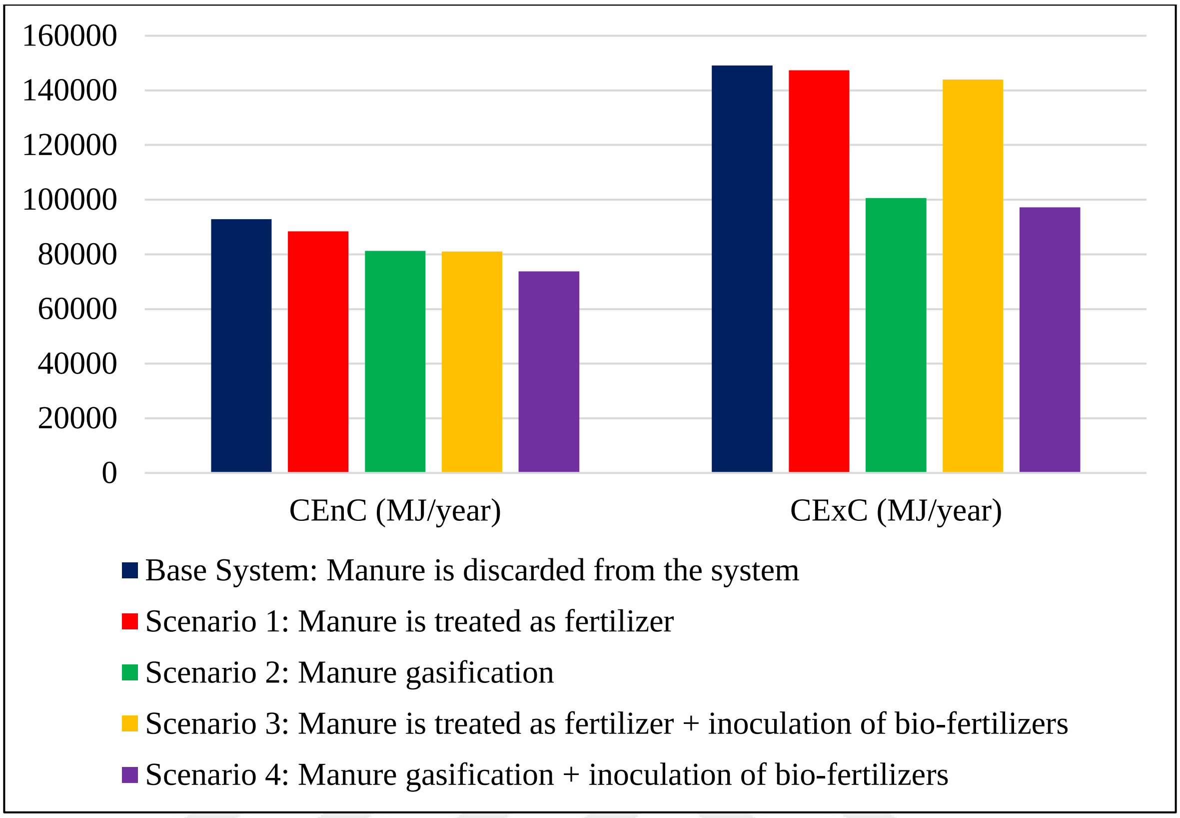

Figure A. 1. Comparison of energy and exergy utilization of different manure management and fertilization scenarios

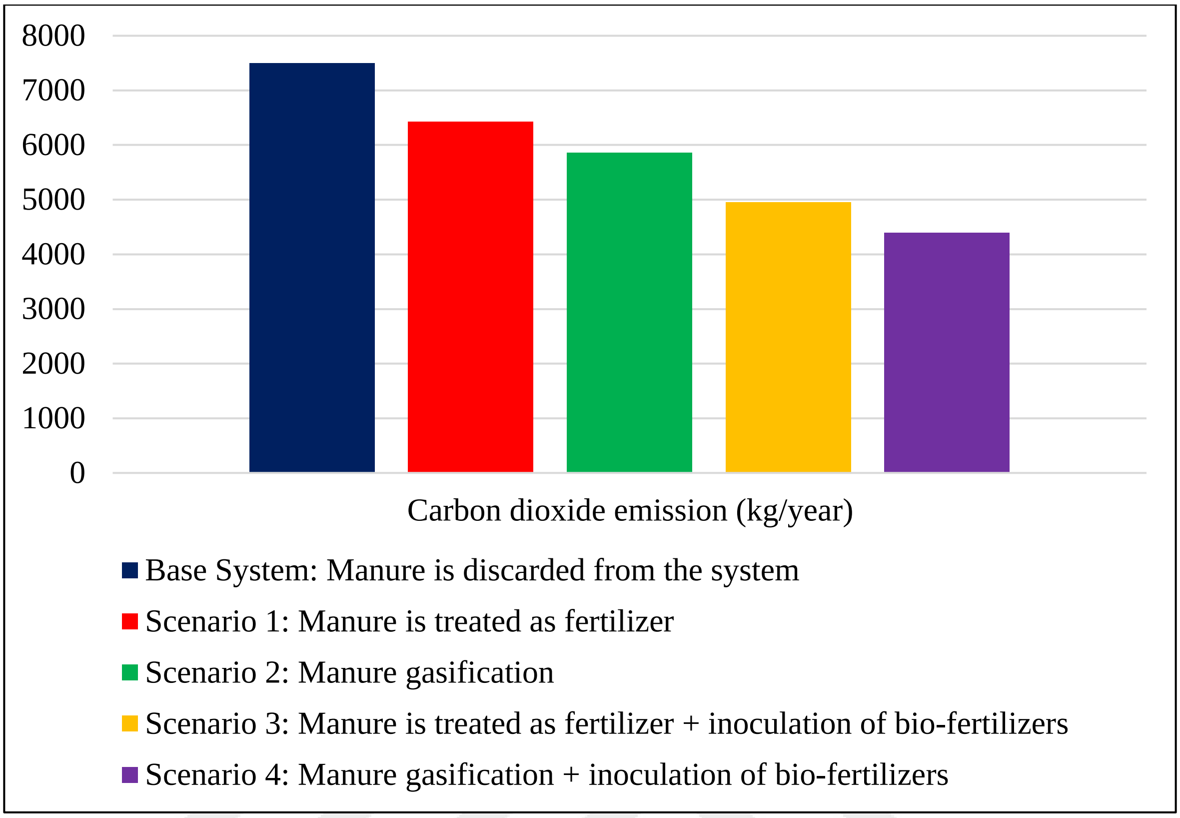

Figure A. 2. Comparison of CO2 emission of different manure management and fertilization scenarios