INVESTIGATION OF ENERGY CONSUMPTION AND CO_2 EMMISSION FOR HAMBURGER MENU PRODUCTION

by

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INVESTIGATION OF ENERGY CONSUMPTION AND CO_2 EMMISSION FOR HAMBURGER MENU PRODUCTION

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ABSTRACT

INVESTIGATION OF ENERGY CONSUMPTION AND CO_2 EMMISSION FOR HAMBURGER MENU PRODUCTION

Energy utilization and CO_2 emission assessed during farm-to fork fast food production by referring to hamburger menu production with the data collected from the Turkish manufacturers. Energy intensity associated with the production of the ingredients were found consistently in the lower end of the international range, implying that machinery was at least partially substituted with labor in some production lines. Meanwhile, CO_2 emission was at the higher end of the international range, emphasizing the use of relatively inefficient technology and pointing the need for improvement of mechanization and the level of the technology employed. Energy utilization for the entire menu in Turkey was 40,844 MJ/t accompanied with 15,399 kg/t of CO_2 emission. The waste from the fast food industry was assessed for possible electric generation via combustion in Rankine cycle with regeneration and found to have a potential for generation of 3.5 GW/t of waste.

Big Mac®, signature hamburger of the international fast food chain McDonald’s, establishes a “*basket*” for the practical economic indicator “*Big Mac index”*. This concept has been improved and a “*basket*”, was defined by extending the coverage to the entire hamburger menu. The energy indicator of the proposed index when calculated with the data collected from the Turkish manufacturers was 40,884±3,126 MJ/t accompanied with 15,399±858 kg /t of CO_2 emission. When the waste from the menu is combusted for electric power production in Rankine cycle, 17,472 MJ/t hamburger menu of energy may be recovered. The proposed index has been tested for the variations in the amounts of the constituents of the menu and found sensitive enough for practical use.

ÖZET

HAMBURGER MENÜSÜNÜN ÜRETİMİNİN ENERJİ KULLANIMI VE KARBONDİOKSİT EMİSYONUNUN ARAŞTIRILMASI

Türk üreticilerden alınan verilerle hamburger menü üretimi ele alınarak, üreticiden tüketiciye hızlı yiyecek üretimi sırasındaki enerji kullanımı ve CO_2 emisyonu değerlendirildi. Bileşenlerin üretimi ile ilişkili enerji yoğunluğu, tutarlı bir şekilde uluslararası aralığın alt ucunda bulunup; makinelerin bazı üretim hatlarında en azından kısmen işçilikle ikame edildiğini göstermiştir. Bu arada, CO_2 emisyonu, nispeten verimsiz teknolojinin kullanımını vurgulayan ve mekanizasyonun iyileştirilmesi ihtiyacını ve kullanılan teknolojinin seviyesini işaret eden uluslararası aralığın daha üst ucundaydı. Türkiye'deki tüm menü için enerji kullanımı 15.399 kg / T olup CO_2 emisyonu ile birlikte 40,844 MJ/t bulundu. Hızlı yiyecek endüstrisinden gelen atık, rejenerasyon ile Rankine döngüsünde yanma yoluyla olası elektrik üretimi için değerlendirildi ve 3,5 GW / ton atık üretme potansiyeline sahip olduğu bulundu.

Uluslararası hızlı yiyecek zinciri Mcdonald's'ın imzası olan big Mac®, pratik ekonomik bir gösterge olan Big Mac Endeksi' için bir 'sepet' kurar. Bu konsept geliştirildi ve kapsama alanı tüm hamburger menüsüne genişletilerek bir "sepet" tanımlandı. Türk üreticilerden alınan verilerle hesaplanan önerilen endeksin enerji göstergesi 40,884±3,126 MJ/t, 15,399±858 kg /T CO_2 emisyonu ile birlikte 40.884 ± 3.126 MJ / t idi. Menüden çıkan atıklar Rankine döngüsünde elektrik üretimi için yakıldığında, 17.472 MJ / t hamburger menüsü enerjisi geri kazanılabilir. Önerilen indeks, menü bileşenlerinin miktarlarındaki değişimler için test edilmiş ve pratik kullanım için yeterince hassas bulunmuştur.

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LIST OF SYMBOLS/ABBREVIATIONS

Cp	Heat capacity
Ex	Specific exergy
g	Gibbs energy
h	Enthalpy
k	Specific heat ratio
k	Heat source index
m	Mass
N	Number of atomic groups of the elements in molecules
P	Pressure
Q	Heat
R	Universal gas constant
r	Rankine
s	Entropy
T	Temperature
W	Work
w	Specific humidity
x	Mol fraction
y	Mass fraction
ΔG	Gibbs energy increment of an atomic group
ΔH	Enthalpy increment of an atomic group
μ	Chemical potential
ΔS	Entropy change
0	Dead state
ϕ	Specific humidity
CCO_2E	Cumulative carbon dioxide emission
CEnC	Cumulative energy consumption
CexC	Cumulative exergy consumption

ch	Chemical
d	Drying
dest	Destroyed
e	Element
f	Formation
FW	Food waste
ha	Humid air
i	Element, atomic or molecular group
in	Input
LDPE	Low density polyethylene
out	Output
ph	Physical
PW	Packaging waste
sat	Saturation
u	Universal
v	Vacuum
vp	Vacuum pump
w	Water
liq	Liquid
vap	Vaporization
o	Standard

1. INTRODUCTION

Food is a one of the most major human demand, and thus plays a key role for life cycle. Therefore, it brings out to find novel and sustainable ways for consuming food in varying patterns by the outcomes of modern city life that are the difficulties of transportation or limitations of time and differentiation of working conditions [1, 2]. Especially, the style of nutrition has essentially been shaded off to ‘fast-food’ system by the demand for the arrangement of lunch during the working hours and these sort of enterprises that deal with fast-food products become an abundant sector and such a commercial industry [3, 4].

Fast-food industry meets the basic rules of assembly line of the factory to a commercial kitchen. In this sector, the position of fast-food restaurants have crucial positions by providing quick and easy food and beverage to their consumers [2]. This industry brings significant volume of production capacity expeditiously and offers the possibility of sale for the products at a low price scale [5].

In many countries of Europe, especially after the 1950s, there have been significant increases of nutrition habits for eating outside, and there have been changes in people's food consumption patterns. The demand for fast food establishments has also increased steadily.

Indexes are synthetic indicators measuring the relative changes in an observed property over time and space based on a “*basket*” of constituents. The choice of the constituents of the basket should be wide-ranging enough to represent the industry, be sensitive to the dynamic changes and available consistently over the time range in the proposed geographical region. An “*index*” is a representative of a portfolio. The portfolio may characterize an industry, a group of products, price of certain commodities, etc., to give some idea about how the industry changes over time in the same geographical location or with geographical location in the same time period. In the food industry, “*Glycemic* ***index”*** aims ranking of carbohydrate in **foods** according to how they affect blood glucose levels; “*insulin index”* assesses the increase in the insulin level in the blood two-hours after ingesting the food. “*Healthy eating index”* assesses the conformance of the diet with the dietary guidelines. “*FAO food price index*” [6] evaluates the food prices, “*Global food security index*” assesses the affordability, availability, and quality of the foods internationally. "*Food sustainability index"* ranks the countries on sustainability of their food systems in terms of food loss and waste, sustainable agriculture, and nutritional challenges by considering the environmental, societal, and economic performance indicators. Almost all the food related indexes referred here are focusing on either health, or price related issues, but there is no index available yet to assess energy utilization and CO_2 emission in the food industry.

Consumer price indexes may be used for a wide variety of purposes, including measurement of inflation, indexation of commercial contracts, wages, social protection benefits or calculating changes in national consumption or standards of living [7]. The U.S. Bureau of Labor Statistics (BLS) published an index of prices for food consumption at home for the first time in 1903 [8]. The BLS index and its basket had been subject to major updates many times to keep it valid with the changing consumer preferences [9].

Additionally, fast-food restaurants are defined as economic restaurants for a limited food and drink (coke, juice, sandwich, hamburger, toast) where self-service is often practiced, and consumers can take away the packaged processed products with them. It is such an industry that hamburgers constitute 14 percent of all restaurant orders in 2007, which is equivalent to 8.7 billion of servings [10-12].

Considering the concept of index with respect to fast-food industry, hamburger menu is suggested to be used as a global index as well. Globally published weekly journal "The Economist", suggested the use of the price of Big Mac®, signature hamburger of the international food chain McDonald's, as a basis of the "*Big Mac Index*" in 1998 [13]. Big Mac index inspired the other practical indices, such as "*Tall Latte Index*" based on the sale price of the signature product of international coffee chain Starbucks [14]. Big Mac® is produced with the same formulation all around the world, therefore establishes an appropriate "*basket*" for use as an international economic indicator. Big Mac Index is used to compare economic issues occurring in different countries, including affordability of cataract surgery [15], integration of the international markets [16], comparison of the real academic salaries [17] and medical earnings [18-19] measured the stable carbon and nitrogen isotopes of Big Mac ® patties from 26 countries to compare the attributes of the local factors in to this global food and reported significant local influence.

Energy indexes are employed to assess the change in the energy industry. RENIXX World (Renewable Energy Industrial Index) assesses the performance of the renewable energy industry companies based on their market capitalization. The ALTEX Global tracks the companies focusing on transition to diversified lower-emissions energy infrastructure. Ardour global alternative energy index tracks the clean energy technology companies.

Basically, a hamburger menu consists of hamburger patty, bun, mayonnaise, pickles, lettuce onions, fried potatoes, ketchup and a carbonated drink.

Schematic representation of hamburger menu that contains the ingredient and the cycle is revealed in Figure 1.1.

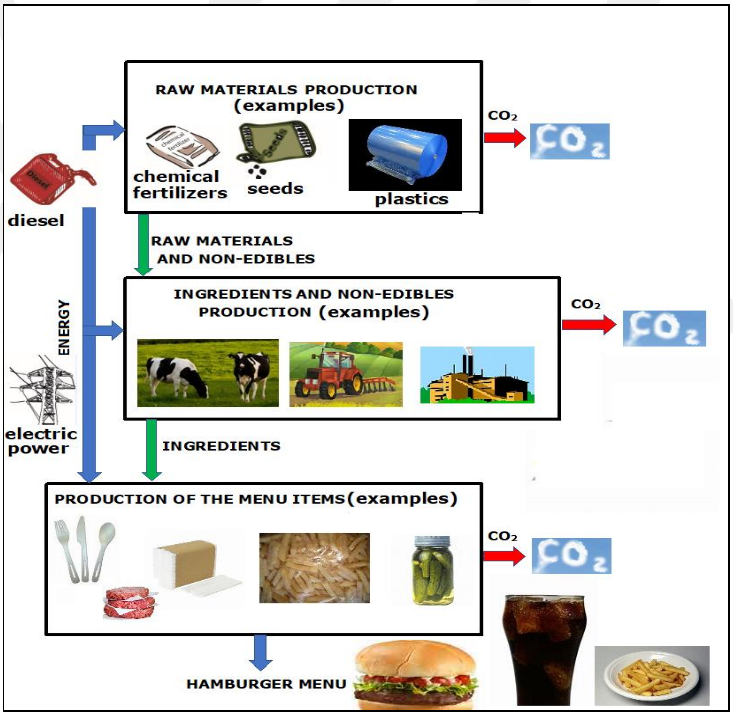


Figure 1.1. Schematic representation of a hamburger menu comprised of the ingredients

In the point of energy, studies on the energy calculation and efficiency for the food and most other industries entered into the late 1970s, and the leading the returns practicable in the early 1980s [20]. These studies had usually been promising, e.g., consumption of energy in factories of modern chemical fertilizer diminished within the years and get closer to the theoretical values [21, 22]. Ramirez et al. [23] demonstrated that the efficiency of energy was developing about 1 percent each year in the Dutch food industry between 2006 and 2010. Another study declined that the ratio of the units of the energy occupied in the Taiwanese food industry for the gross domestic production of the country revealed a consistent decrease [24]. Energy usage for the food production generally consists a considerable part of the total energy usage in a country, e.g., because of the middle of the 21st century, 20 percent of the total energy usage was distributed to sector of the food in Sweden [25]. Freezing, cooling and refrigeration which are the cold chains of food processing and preservation, depend nearly on the usage of electricity; drying (50 percent) and cooking (25 percent) operations are conducted by using directly natural gas [26]. Almost 5-15 percent of the energy availed at each stage of food processing is wasted [26]. For instance, American bakery industry spends more than $ 870 million annually for the energy owing to the very high cost of the energy utilization [27]. There are meticulous searches in the food industry to bring solutions for decrease the energy utilization [28, 29].

Bread is an essential food in many countries. Additionally, hamburgers are basic materials produced among the foods. The fast food industry carries out the precepts of the factory assembly line to a commercial kitchen to enhance the speed, reduce the prices and raise the volume of the sales [5]. Energy usage is attended the emission of the greenhouse gases [30-32]. Therefore, any improvement of the energy efficiency related to their production will not only decrease the budget of the energy, but also reduce the cost of environment.

The first law of thermodynamics, that is to say energy balance, is the widely used one during the assessment of the energy efficiency of a plant or process. Nevertheless, energy balances do not supply data about the prospective loss of work in the energy transformation processes [33].

Assuming the great amount of the fast food and baking food industries, the assessment of the energy efficiency and the contribution to the environmental pollution deserves an important attention. Information in detail about the present technology related to the bakery industry is available in detail in the literature [34-38].

Energy efficiency and CO_2 emission, as a result of energy utilization, are among the factors determining the sustainability of a food production processes. Emission of the greenhouse gasses is an inevitable consequence of the energy utilization as explained previously by

Foster et al., CIAA and Carlsson - Kanyama and Faist [39-41] to convince the public to adapt sustainable methods. During electric power generation from natural gas CO_2 accounts for 99 percent of all the emissions by weight. In a recent study Viesia et al. [42] argued that energy efficiency is not regarded as a top priority in the small and medium enterprises in Central Europe due to the lack of good quality energy use data. There is also no practical index like, Big Mac ® index, available for the assessment of energy efficiency yet. The size of the fast food market is large enough to convince the public about the validity of such an index in 2007 with 8.7 portions of hamburgers were sold in the fast food restaurants, constituting 14 percent of all restaurant orders [43]. This study aims to expand the basket of the Big Mac ® index to use it as an energy efficiency and CO_2 emission indicator.

The constituents of the hamburger menu will be calculated with the data collected in Turkey and then compared with those calculated in varying parts of the world, with the inspiration coming from the Big Mac® Index. In such a comparison, observing meaningful energy intensity and CO_2 emission trends may imply that the basket considered, and the index offered may prove to be useful in such analysis.

Hamburgers are the most common fast food, some of the international fast food restaurants produce almost the same hamburgers, or their menu almost everywhere in the world with similar formulations. Its edible and inedible ingredients are provided from large number of sectors including the products of the plastics, metal, wood and agricultural industries. This study aims to assess energy consumption and CO_2 emission in Turkey through production of the hamburger menu and its constituents. Then the results will be compared with those obtained elsewhere to observe the level of the technology employed in the Turkish fast food industry.

On the other hand, the term “waste valorization” refers to industrial activities which aim reusing or converting the waste into energy or useful products [44]. If the food waste should not be separated at its source, it may be collected together with the ordinary municipal waste. Recent global municipal levels of waste generation are around $1.3x10^9$ t/year and are intended to rise about $2.2 \ x10^9$ t/year by 2025, representing an expressive arise in per capita waste generation rate, from 1.2 to 1.42 kg / (per person in a day) in the next fifteen years [45]. 766 kg of non-food items, including 533 kg of paper, 158 kg of cardboard and 75 kg of low density polyethylene (LDPE), are consumed as service items and for the primary and secondary packaging, in parallel with 1 t of edible and almost all of these non-edible constituents of the hamburger menu (Table 2.1). In Turkey, households produce approximately 1 kg/ (person day) of waste [46]. Sustainable waste management is recommended to be implemented in a hierarchical primacy order of blocking, reuse, recycling, recovery of energy and final removal [47]. Blocking and reuse are implemented mainly with economic preferences, but the achievements usually fall short of the expectations mainly because of the labor cost of sorting. In Finland, e.g. one of the most environment sensitive countries in the world, while 93 percent of the packaging waste of the fast food restaurants could be theoretically recycled, the actual recycle rate was only 29 percent [48]. Getting the waste sorted by the households with monetary incentives may be an option to increase the recycling rate [49]. One of the choices to valorize the unsorted waste is combustion with the purpose of electric power production. In 2015, municipal government was producing 50 MW electricity/ day in Istanbul [46]. Production of the electric power from the fast food restaurant waste appears as a viable option while fighting against the municipal waste.

Moreover, one of the choices to valorize the unsorted waste is combustion with the purpose of electric power production. In 2015, municipal government was producing 50 MW electricity/ day in Istanbul [46].

The modern combustion technology, generally reduces the volume of the waste approximately by 90 percent [50]. Non-combustible ingredients of the municipal solid waste become bottom ash. The particulate matter emitted with the combustion gases (called as fly ash) is generally kept by air pollution control apparatus. These flue gases may contain acidic entities, like hydrogen chloride, sulfur dioxide and nitrogen oxides. Calcium oxide or calcium hydroxide is generally used to neutralize those acidic gases [51]. All of the restaurant food waste constituents described in the following section fighting against the municipal waste.

Impact of the municipal waste combustion on public health and environmental creates concern. Nanometer-sized emissions from the municipal waste incinerators may deposit in the deepest parts of the lungs, cross into the bloodstream and affect different parts of the body [52]. Mercury vapor, originating from the incinerators may find its way to the diet of the inhabitants of the area [53]. Within 4 km of radius of an incinerator pregnant ladies have higher risk of miscarriage because of the exposure to the emissions [54]. The ash from these incinerators may be stabilized with cement [55] and this mixture may be used as light weight filling substance in varying structures, like bund and road construction [56].

A major part of the recent energy research aims finding good use for the previously neglected or unused energy resources. Most low-temperature waste heat from the industrial processes is directly discharged into the environment. Linking the conventionally discarded low-temperature heat sources, such as those of the refrigeration cycle to an organic Rankine cycle [57] using a supercritical carbon dioxide Rankine cycle for waste heat recycle from a gas turbine [58] or using the solar energy [59], geothermal energy [60] and biomass [61] as the heat source are among the subjects being actively researched. Although the health and environmental impact of the municipal waste incinerators are being extensively studied, their use for work performance in Rankine cycle has not been assessed yet, which will be assessed in the present study.

Additionally, exergy efficiency is the ratio of the exergy of the product to the total of the exergies of the raw substances and the fuels, nevertheless if the fuels are renewable or not.

In the current study, exhaustive thermodynamic analysis for the wheat and hamburger bun production in Turkey will be submitted by referring to the energy balance and carbon dioxide emission. Also, energy consumption to produce number of foods had been in the scope of some previous studies.

This study will provide a unique approach, where the energy consumption, the carbon dioxide emission is measured for hamburger menu such as bread (bun), potatoes, pickles, lettuce etc. starting with agriculture and ending with the transfer of the final product to the market.

2. METHODS

2.1. CALCULATION OF ENERGY UTILIZATION, CARBONDIOXIDE EMMISSION DURING PRODUCTION OF HAMBURGER MENU

Hamburgers are made of buns, patties, mayonnaise, onions, lettuce and pickle slices; 1 ton of hamburgers make 5,263 servings. Fast-food restaurants purchase mass produced frozen patties and partially fried frozen potato chips and cook or refry them upon order of the customers. "*Hamburger menu*" is comprised of a hamburger, potato chips and soft drink, additional servings of salt and ketchup are also provided (Table 2.1). Determination of the energy consumption and CO_2 emission during production of the buns was discussed elsewhere [25].

Additionally, amounts of the edible and the non-edible constituents of a hamburger menu are presented in Table 2.1 respectively.

The overall hamburger menu of the flow chart for the production, contains the boundaries, inputs and outputs is supplied in Figure 2.1

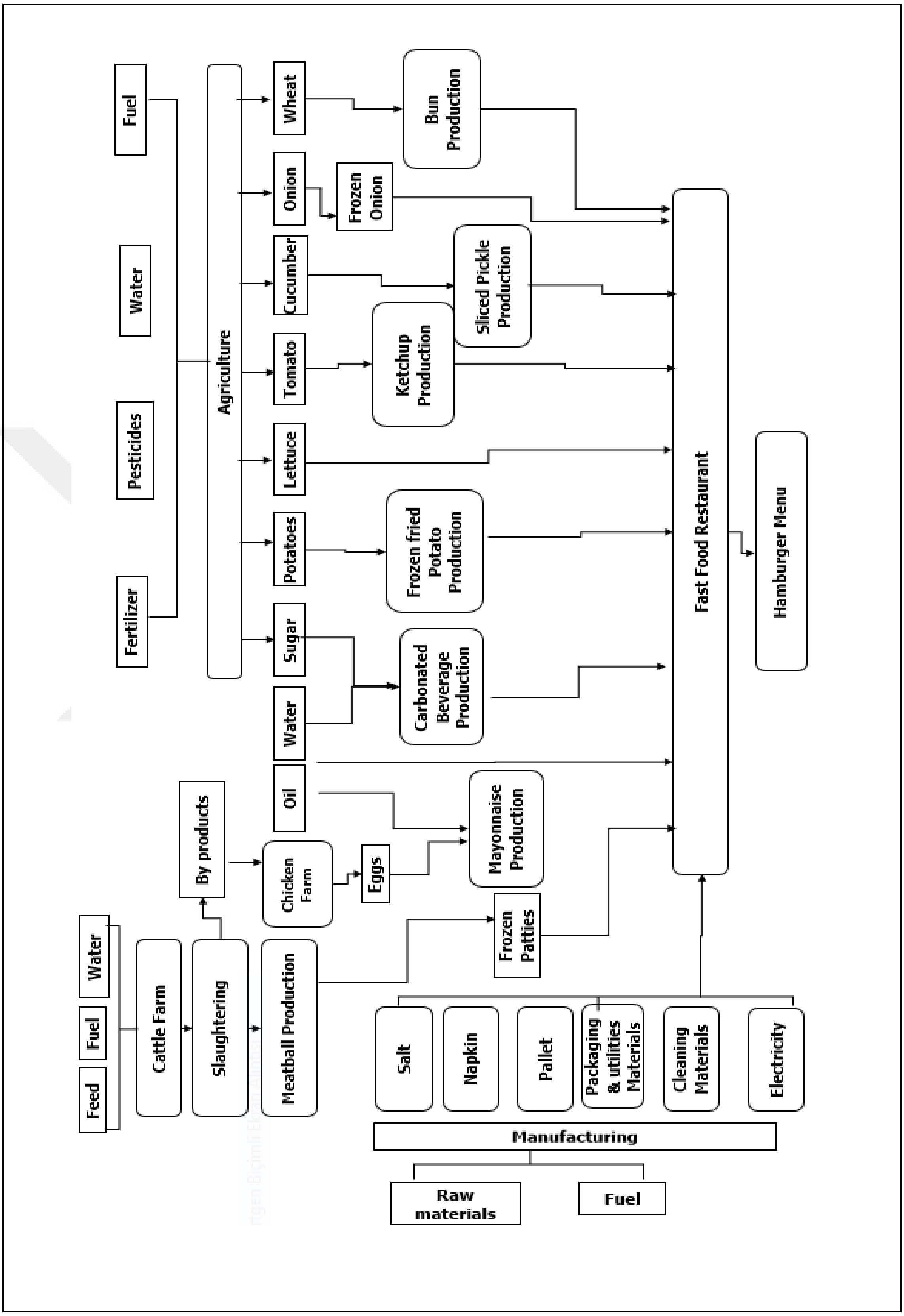


Figure 2.1. Schematic diagram of the hamburger menu production process

Data were collected either by communicating directly with the industrial practitioners or from the equipment specification sheets. If no other information is provided, all the calculations were based on transportation of the commodities in 10 tons capacity heavy-duty trucks, which utilize 0.287 L/km of fuel while traveling at 90 km/h [62]; refrigerated trucks were assumed to be utilizing 20 percent more energy than the others [63]. Density, energy and CO_2 emission factor of diesel were 0.832 kg/L, 57.45 MJ/L and 0.94 kg CO_2/kg, respectively [64].

Table 2.1. Edible and the non-edible constituents of the hamburger menu

Constituent	**(kg/t hamburger)**
Hamburgers	
Hamburger bun	395
Patty	368
Mayonnaise	53
Pickles	26
Lettuce	105
Onions	53
Hamburger total	1,000
Other servings	
Fried potatoes	526
Ketchup	53
Salt	16
Carbonated drink	2,183
Hamburger menu total	3,778
Items made of paper	
Hamburger wraps	10.5

Table 2.1. Edible and the non-edible constituents of the hamburger menu (continued)

Hamburger box	68.4
Glasses for 400 mL/serving of soft drink	52.6
Straw cover for 1,000 servings	1.4
Potato chips holder	31.6
Tray cover	21.1
Credit card slips and receipt	5.3
Bags for the take away menus (3 bags/menu)	311
Total	502
Napkins	
Paper napkins (each customer uses four napkins)	31.6
LDPE for packaging paper napkins	9.5
Cardboard box for 4,000 napkins	3.2
Cardboard boxes	
Hamburger boxes	147.4
Box for glasses	4.0
Box for the lids	2.1
Box for the straws, 25 packages/box	0.8
Corrugated board (19 cm x 29 cm x 19 cm) for secondary packaging of the LDPE garbage disposal bags (173 g each, 30 bags/box)	0.9
Total	155
LDPE packaging material	
Bag for packaging the hamburger boxes	17.6
Packaging for glasses	6.3
Lids for glasses	7.9

Table 2.1. Edible and the non-edible constituents of the hamburger menu (continued)

Wrap for the lids	3.2
Packaging for the straws, 40 straws per package	0.3
Ketchup and mayonnaise pouches	10.5
Garbage disposal bag (65 cm x 80 cm, capacity 20 kg, 8.3 g each)	15.8
Straws	3.7
Total	65

Flow diagrams of the production of the hamburger menu and its constituents are given in Figures 2.2-2.5.

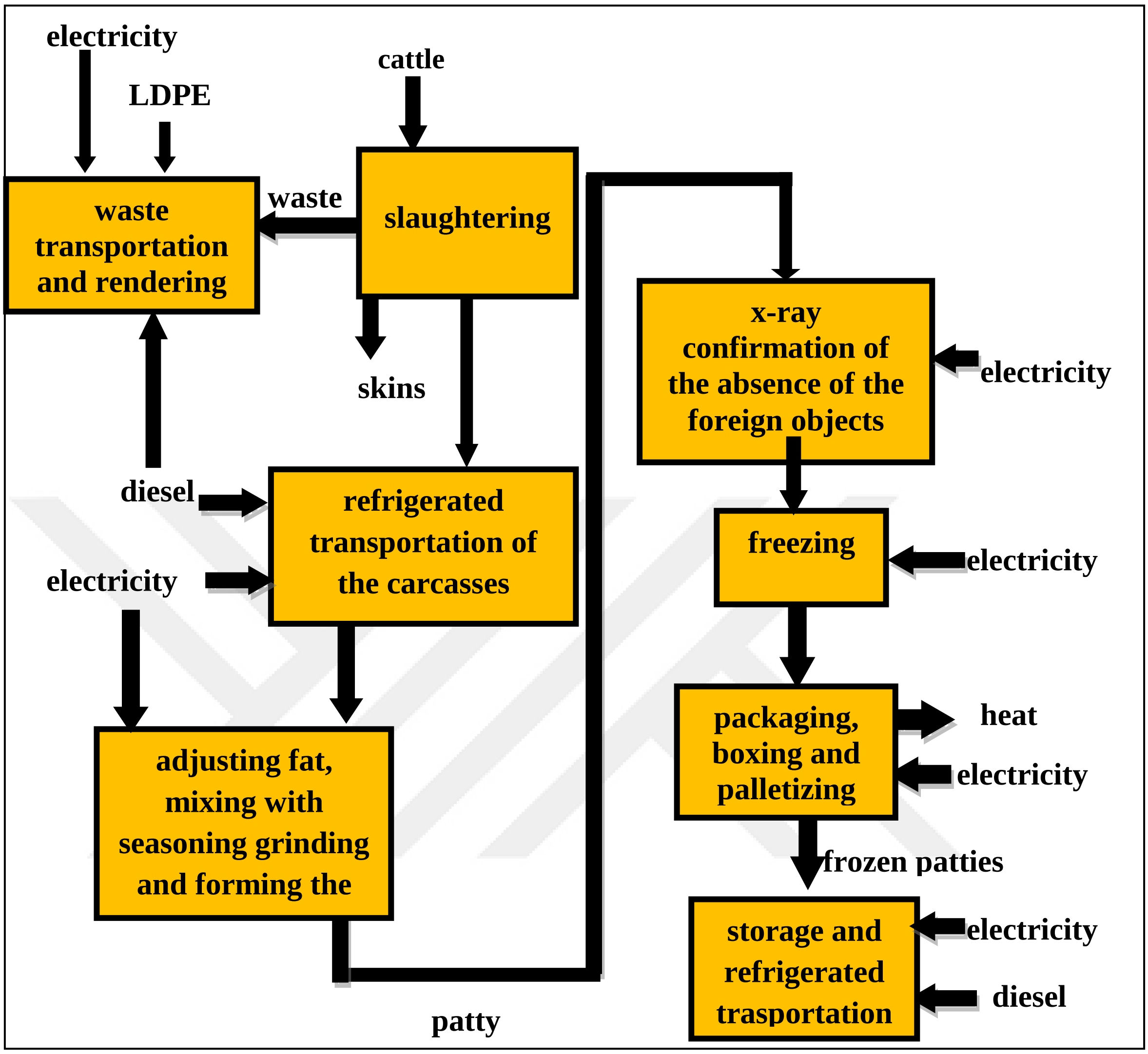


Figure 2.2. Flowchart of the frozen patty production process

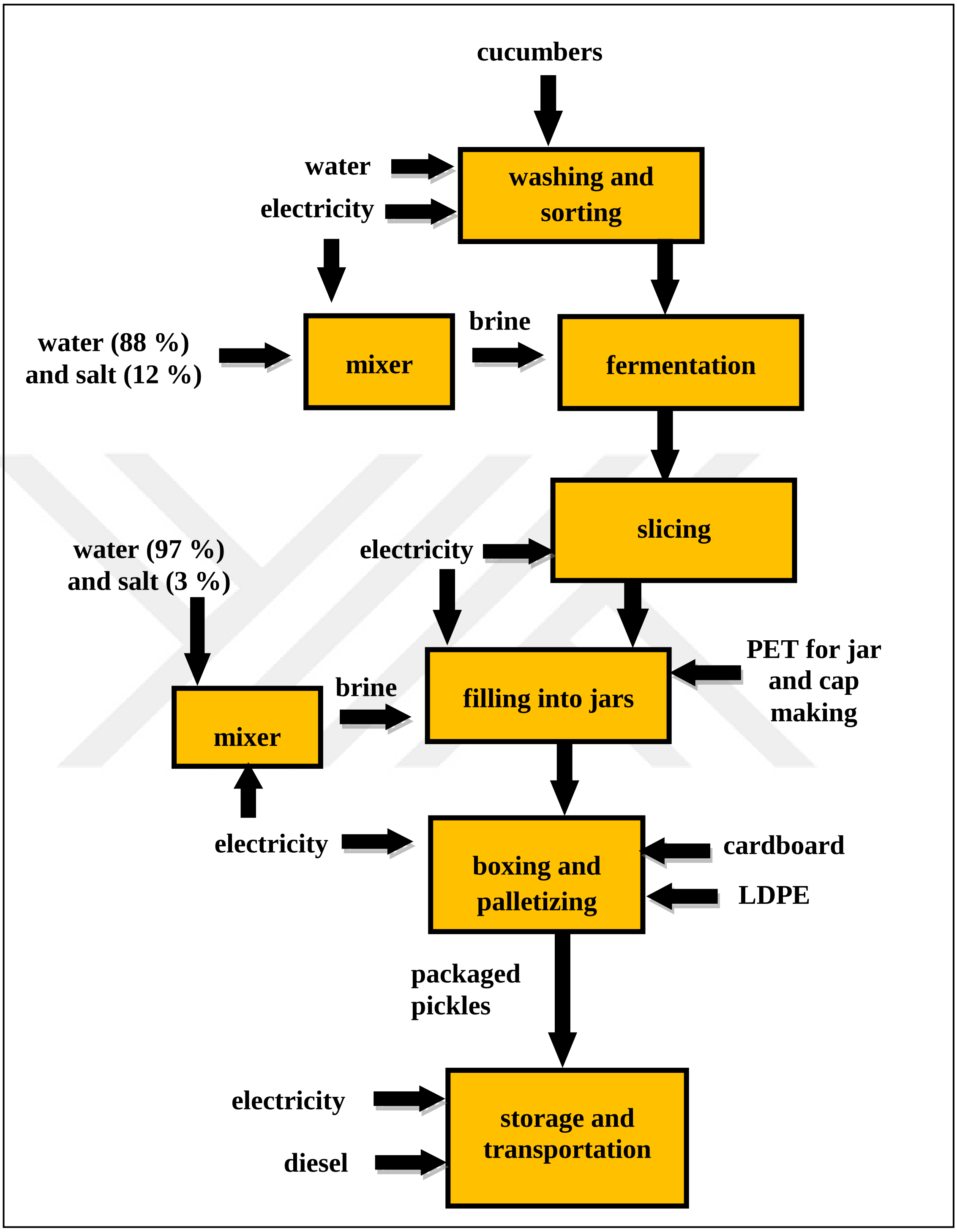


Figure 2.3. Flowchart of the sliced pickles production process

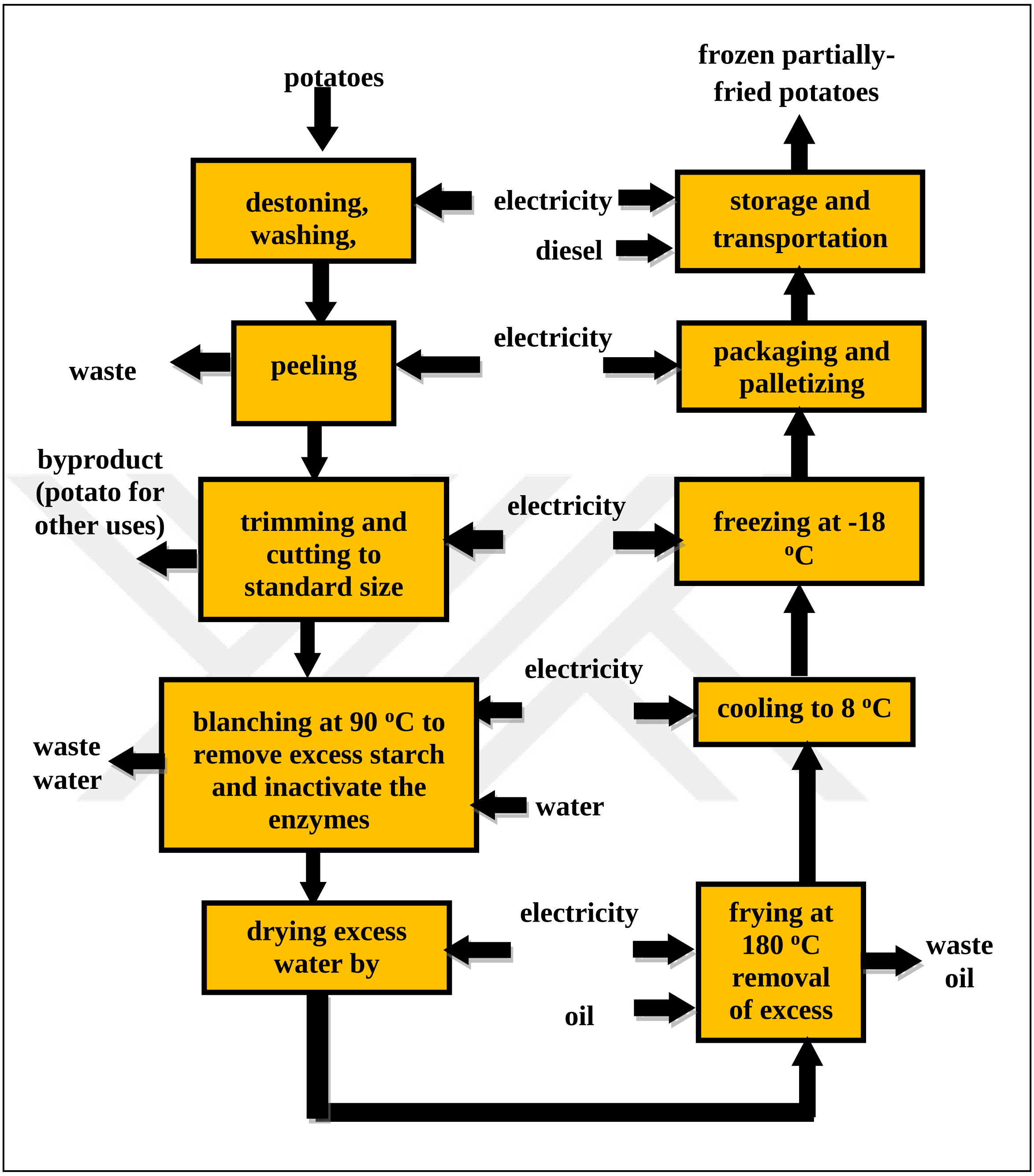


Figure 2.4. Flowchart of the partially-fried frozen potato chips production process

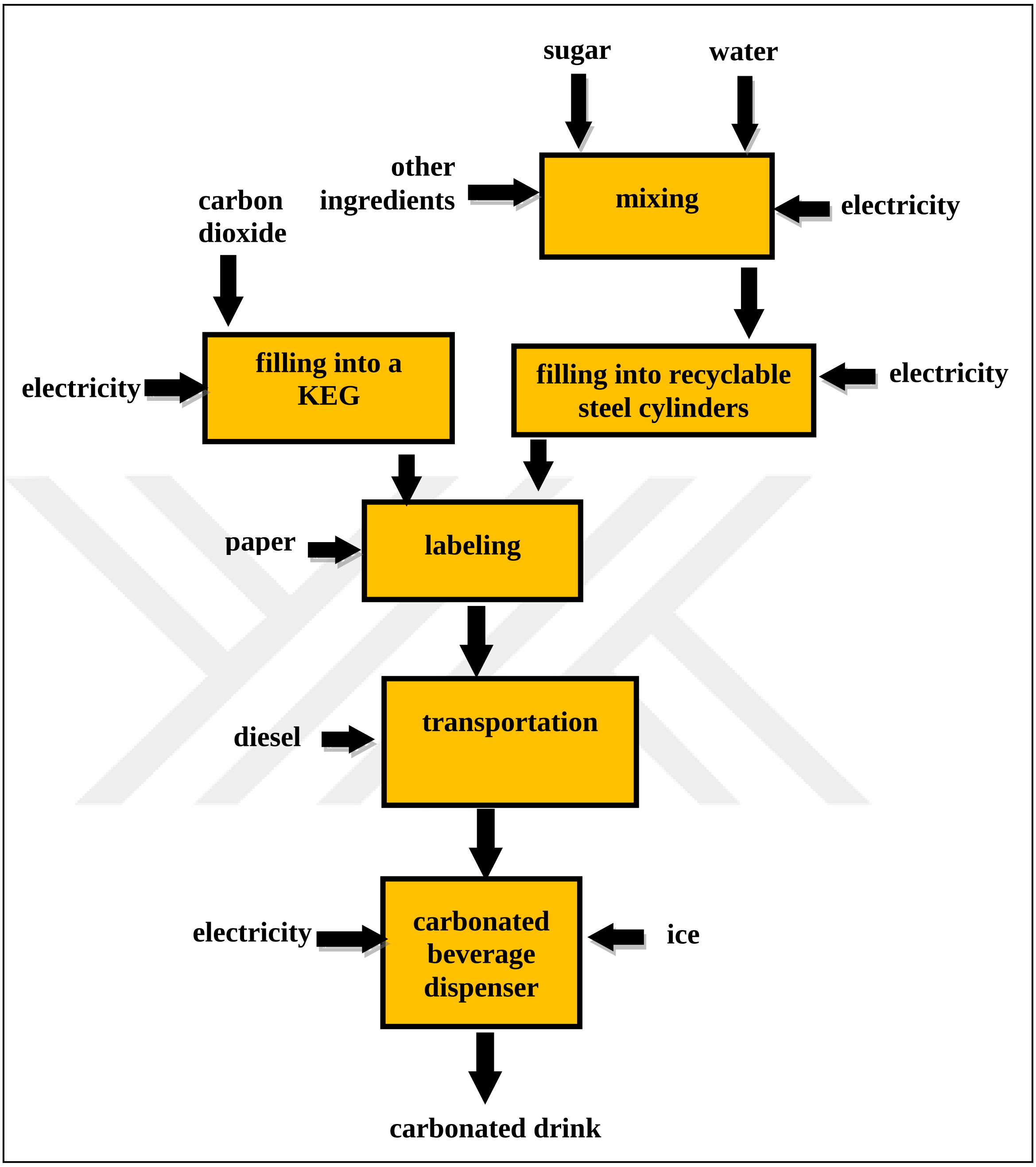


Figure 2.5. Flowchart of carbonated drink production process

Flow diagrams of the production of the hamburger bun and its constituents are given in Figures 2.6. Processes consisting within the system boundaries contain agriculture of wheat and flour production (cleaning and milling), dough preparation, dividing, fermentation, baking, cooling, slicing, packaging and the transportation of breads to the market.

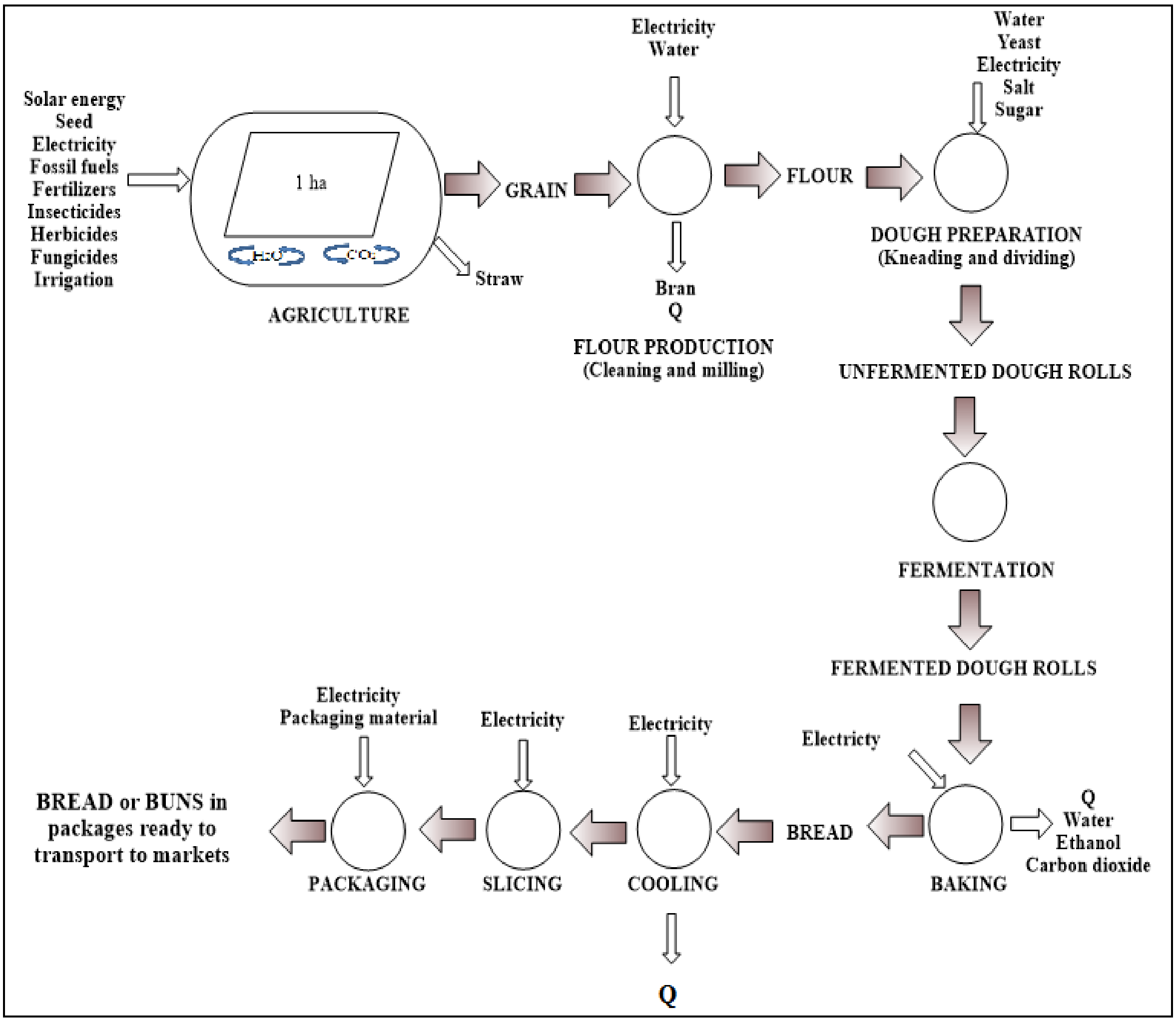


Figure 2.6. Flowchart of hamburger bun production process [25]

Fertilizers and pesticides expended along the agriculture are non-renewable chemicals, and the environmental cost for these ingredients is considered. Electricity used through all the production steps is used from fossil fuels. The energy consumed due to human labor is neglected, since it is practically relatively difficult to pick up representative information. Transportation of the goods is considered; the trucks of the products are taken in to account to be having only one-way trip. The capacities of heavy-duty trucks are 10 tons while the velocity of them is 90 km/h. In the manner of transportation, the distance of factory to factory and factory to market was regarded to be 550 km. The data regarding to the energy consumption and the processing rates of the instruments are obtained from the web sites of manufacturers. Data of the agriculture of wheat is obtained from the literature to calculate energy consumption and carbon dioxide emission. Lal [65] as given in Table 2.2. It was clarified that the carbon dioxide emission of the diesel oil is 0.94 kg CO_2/kg of diesel oil. Bread is accounted to be marketed in packages made of biodegradable [66] polylactic acid (4 g each).

Table 2.2. Inputs and outputs of the wheat agriculture in Turkey

Amount of Agriculture of wheat in Turkey (t)	
Inputs	
Diesel oil (L/ha)	165.6 [67]
Nitrogen fertilizer (kg/ha)	101.88 [68]
Phosphorus fertilizer (kg/ha)	72.2 [68]
Potassium fertilizer (kg/ha)	-
Herbicide (kg/ha)	1.12 [69]
Insecticide (kg/ha)	0.56 [70]
Fungicide (kg/ha)	1.69 [71]
Seed (kg/ha)	227.7 [68]
Irrigation water (kg/ha)	1195 [72]
Transportation (L diesel /km)	0.287 [62]
Outputs	
Grain (kg/ha)	2388.5 [68]
Straw (kg/ha)	223.6 [68]

The non-renewable inputs are chemical fertilizers, water, seed and carbon dioxide, and the outputs are grain and straw, are simulated within the agriculture as a continuous process [67, 68, 73]. It was assumed that all the trucks consumed 0.287 L diesel oil/km [62]. Furthermore, 165.6 L diesel/ha [67] is used in wheat agriculture [74]. The density of diesel oil is approximately 0.771 kg/L [25] the energy equivalency of it is 45.7 MJ/L [67]. Table 2.2 clarify that diesel oil for transportation; seeds production and the chemical fertilizers are the widest energy consumers in agriculture. The total energy input and output for during production of one ton of hamburger menu are calculated with unsteady-state flow system Equations here below.

Mass balance;

$$m_{system} = \sum m_{in} - \sum m_{out} \tag{2.1}$$

Energy balance;

$$\Delta E_{system} = \sum (mh)_{in} - \sum (mh)_{out} + \sum_{k} Q_k - W \tag{2.2}$$

Energy consumption and CO_2 emission during production of the ingredients are collected from the literature as listed in Table 2.3. Energy utilization and CO_2 emission during production of glucose syrup were calculated for the process described by Zhang et al [75].

Table 2.3. Specific cumulative energy consumption and CO_2 emission along production of the inputs and the outputs of the hamburger menu production processes

	Specific CEnC (MJ/kg)	**Specific CCO$_2$C (kg/kg)**
	Agricultural inputs	
Nitrogenous fertilizer (NH_4NO_3)	78.2 [76]	7.11 [22]
Phosphorus fertilizer (P_2O_5)	17.5 [76]	2.7 Kongshaug [22]
Potassium fertilizer (K_2O)	13.8 [76]	25.0 [22]
Pesticides	198.8 [77]	27.8 (measured with the data presented by Banaeian et al [77])
Herbicides		6.3±2.7 [64]
Insecticides	82.5 (calculated from Brehmer [78])	5.1±3.0 [64]
Fungicides		3.9±2.2 [64]
Organic manure	0.30 [79]	

Table 2.3. Specific cumulative energy consumption and CO_2 emission along production of the inputs and the outputs of the hamburger menu production processes (continued)

Animal feed	2.8 [80]	0.23 [1]
Packaging materials		
LDPE	48 [81]	2.1 [82]
HDPE	3.2 [83]	0.45 [83]
PP	1.8 [83]	0.25 [83]
PS	0.9 [83]	0.12 [83]
PLA	54.0 [66]	1.8 [66]
PVC	57 [84]	1.8 [85]
PET	4.8 [81]	0.21 (accounted with the data provided by Saygin et al [81])
Card board	43.3 (accounted based on the data from Chow et al. [86])	1.17 (accounted based on the data from Chow et al. [86])
Paper	16.5 [87]	1.88 [88]
Food ingredients		
Sunflower oil	7.80 [30]	0.49 [30]
Starch	13.77 [89]	3.66 (accounted within the data from Özilgen [89])
Glucose syrup [4]	14.06	4.06
Tomato paste	1.44 [90]	0.20 (measured from Özilgen and Karakaya [90])
Eggs	10.04 [91]	1.04 [91]
Lemon juice	2.66 [92]	1.98 [92]
Vinegar	5.24 [93]	1.94 – 2.54 [94]

Table 2.3. Specific cumulative energy consumption and CO_2 emission along production of the inputs and the outputs of the hamburger menu production processes (continued)

Energy sources and water		
Coal	25 [95]	2.93 [96]
Natural gas	50.0 [95]	$5.83x10^{-3}$ kg/MJ [89]
Electricity	1.0 kJ/kJ [95]	0.14 kg/MJ [97]
Diesel	57.5 [77])	$16x10^{-3}$ [64]
Water treatment	0.07 kJ/L [98]	$9.8x10^{-3}$ kg/L (accounted from PGE data [98]for wide plant 100 MG/day energy consumption for surface water treatment)

[1] Calculated estimating that 45 percent of the energy for the feed production results from electricity, 30 percent from diesel oil and 25 percent from natural gas

The thermodynamic properties of hand sanitizer which contains triclosan, betaine, cocomide dea and sodium lauryl sulfate were accounted via the group estimation methods. The chemical exergy of each ingredients of hand sanitizer is calculated with the sum of Gibbs free energy of each compound and the values of the chemical exergy of its constituent chemical elements. by following as Szargut et al [95] and Jankowski [99] (Table 2.4) . The SMCE may be written as follows:

$$X_{chn} = \Delta G_f + \sum\nolimits_e n_j X_{chne} \qquad (2.3)$$

where X_{chn} is the standard chemical exergy of the compound, ΔG_f is the Gibbs energy of formation, j is the number of moles of the element, *e* and X_{chne} standard chemical exergy of the element, respectively.

Table 2.4. Group contributions for standard chemical exergy of inorganic substance and Gibbs free energy of organic compounds

Atomic Group/Substance	**ΔG_f (kcal/mol)**	**Atomic Group/Substance**	**X_{chn}(kj/mol)**
-CI	-10.2 [99]	Cl	87.1 [95]
-OH	-41.5 [99]	H	331.3 [95]
$>\underset{\mid}{C}=$	6.95 [99]	C	410.26 [95]
=CH-	8.46 [99]	O	233.7 [95]
-O-	-23.2 [99]	N_2	0.72 [95]
$-COO^{1-}$	-83.1 [99]	S	609.6 [95]
$-CH_3$	-3.65 [99]	Na	336.6 [95]
$> CH_2$	1.62 [99]		
>N+< *	-21.7 [99]		
>C=O	-28.4 [99]		
>N-	24.4 [99]		
$*-OSO^{1}{}_{3}^{-}*$	-156 [99]		

2.2. DRYING AND COMBUSTION OF THE FAST FOOD RESTAURANT WASTE

Amounts of wastes for food and packaging were collected from a typical fast food restaurant which has 247 shops in Istanbul. Wastes of 30 customers were weighed and normalized for 1000 kg waste. Food waste is generally too moist to be ignited without preliminary drying. Calculations regarding combustion of the fast food restaurant waste were based on the consideration that the waste was transported in small trucks for 50 km to a municipal solid waste incinerator, where it was subjected to initial water removal (Figure 2.7) by atmospheric drying. T refers to turbine, B is the boiler while OFWH is ‘open feed water heater’ and C is condenser in Figure 2.7.

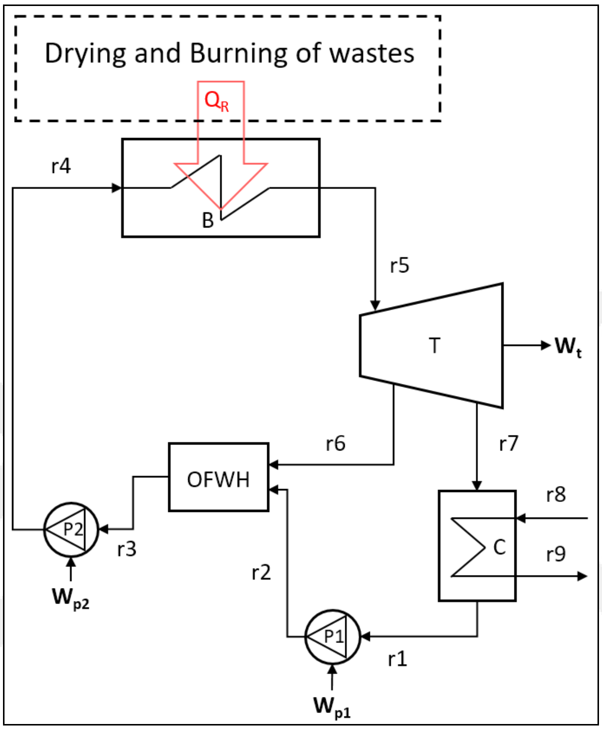


Figure 2.7. Simple schematic of the steady flow Rankine cycle with regeneration [60]

During atmospheric drying, a certain part of the packaging waste was combusted to provide heat to remove the water from the food waste. The remaining packaging and the dried food waste were combusted subsequently in the combustion chamber to provide heat to the Rankine cycle. Calculations were repeated for atmospheric drying before combustion by considering the air leaves the dryer has the temperature and relative humidity varying from 30 °C to 50 °C and from 70 percent to 90 percent, respectively.

Drying is a sophisticated phenomenon including both heat and mass transfer for the materials being dried and the drying environment. Besides, since every material has different molecular structure, the heat and mass transfer mechanisms differ. When a material storing moisture within its porous structure exposed to humid environment, the water movement differs. This is defined in the literature as “water activity” and is very significant in food drying applications. In this study, the complicated mechanisms of drying, especially heat and mass transfer properties of the food waste were neglected.

2.2.1. Work Performance via Rankine Cycle

In this case, calculations were repeated for different drying-combustion temperatures ranging between 590°C-750°C. During the atmospheric drying, a certain part of the packaging waste was combusted which provides necessary heat to remove present water within the food waste. The remaining packaging waste and the dried food waste were incinerated subsequently in the combustion chamber to provide heat to the Rankine cycle.

Calculations were carried out for the combustion of the leftover food, accompanying serving items and the packaging waste with the stoichiometric amount of dry air to heat the working fluid (water) of the Rankine cycle which includes an open feed water heater, and operates under the steady state conditions as described in Figure 2.7. Heating rates were calculated for the combustion temperatures between 590 to 750°C, with 20°C of increments. Heat loss with conduction through the tube walls was neglected. Calculations were done with the assumptions that:

- The Rankine cycle was adiabatic and operating under the steady state conditions.
- Heating in the boiler and heat rejection in the condenser were at constant rates.
- It was operating at a constant pressure at 1.0×10^5 Pa (1 atm) and at a constant temperature.
- The pumps and the turbine had isentropic efficiencies of 85 percent and 80 percent, respectively.
- The turbine inlet temperatures were assumed to be 50°C above the temperature of the combustion products.
- Calculations were repeated for early steam extraction from turbine (or steam directed towards open feed water heater) for pressures from 1 MPa to 4 MPa with 1 MPa increments.
- For every turbine inlet temperature, calculations were repeated for turbine inlet pressures from 14 MPa to 20 MPa with 2 MPa increments.

- During the calculation of exergy destruction, average of the operating temperatures and the environmental temperature were used.

2.2.2. Estimation of Thermodynamic Properties

Organic waste had very high water content, therefore assumed noncombustible before drying. Inorganic waste assumed to have zero water content as declined in Table 2.5.

Table 2.5. Constituents of the waste and their water contents

		Contribution to the Waste (%)	**Water Content (weight %)**
Organic constituents (Food waste)			
	Bun (32.1 kg)	3.2	35.7
	Patty (7.2 kg)	0.7	59.1
	Fried potatoes (14.9 kg)	1.5	39.8
	Ketchup (1.6 kg)	0.2	69.1
	Mayonnaise (2.6 kg)	0.3	21.4
	Mustard (0.7 kg)	0.1	69.8
	Hot Sauce (0.9 kg)	0.1	93.9
	Pickled cucumbers (8.8 kg)	0.9	91.7
	Lettuce (3.1 kg)	0.3	95.4
	Carbonated drink (260.2 kg)	26.0	90.3
	Diet carbonated drink (32.7 kg)	3.2	100.0
Inorganic constituents (Packaging waste)			
	Cellulose (428.5 kg)	42.9	
	Low density polyethylene (41.4 kg)	4.1	

Table 2.5. Constituents of the waste and their water contents (continued)

	Polyethylene terephthalate (1.1 kg)	0.1	
	Polypropylene (117.5 kg)	11.7	
	Polystyrene (46.8 kg)	4.7	

Nutrients, which were not listed in the database, were obtained from the recipe of the food. For example, the hot sauce is produced almost entirely, except for water, from red chili pepper. Therefore, the macronutrients of the hot sauce were assumed to be the same as those of the red chili pepper. For each food macronutrient included in the recipe and packaging materials, thermodynamic properties were calculated from group contribution estimates, so eventually, the thermodynamic properties of the foods and packaging wastes were calculated.

Combining the data from Table 2.5, the constituents of the fast food were calculated referring to the Table 2.6 relevant data base [100].

Table 2.6. Mass concentrations of macronutrients, water, and ash in foods (weight %) [100]

Name	**Hamburger bun**	**Fried potatoes**	**Patty**	**Ketchup**	**Mayonnaise**	**Mustard**	**Hot sauce**	**Pickled cucumbes**	**Lettuce**
Amino acids (wt %)									
Alanine	0.41	0.12	1.61	0.06	0.65		0.04	0.02	0.06
Arginine	0.52	0.18	1.66	0.04	0.85		0.04	0.04	0.07
Aspartic acid	0.59	0.77	2.27	0.29	1.20		0.13	0.04	0.14
Cystine	0.26	0.03	0.26	0.01	0.21		0.02	0.004	0.02
Glutamic acid	3.47	0.59	3.76	0.84	1.53		0.12	0.18	0.18

Table 2.6. Mass concentrations of macronutrients, water, and ash in foods (weight %) [100] (continued)

Glycine	0.44	0.10	1.81	0.04	0.38		0.03	0.02	0.06
Histidine	0.25	0.07	0.81	0.03	0.32		0.02	0.01	0.02
Hydroxyproline			0.42					0.02	
Isoleucine	0.44	0.12	1.12	0.04	0.67		0.03	0.03	0.08
Leucine	0.78	0.19	1.97	0.05	1.09		0.05	0.03	0.08
Lysine	0.36	0.23	2.08	0.05	0.95		0.04	0.01	0.08
Methionine	0.18	0.06	0.64	0.01	0.29		0.01	0.02	0.02
Phenylalanine	0.53	0.21	0.99	0.05	0.53		0.03	0.01	0.06
Proline	1.15	0.13	1.34	0.03	0.50		0.04	0.02	0.05
Serine	0.52	0.13	1.02	0.04	1.03		0.04	0.02	0.04
Threonine	0.35	0.12	0.97	0.08	0.53		0.03	0.01	0.06
Tryptophan	0.16	0.04	0.12	0.01	0.14		0.01	0.01	0.01
Tyrosine	0.28	0.09	0.77	0.03	0.53		0.02	0.02	0.03
Valine	0.52	0.18	1.24	0.03	0.74		0.04	0.02	0.07
Fatty Acids									
Caprylic acid					0.01				
Capric acid					0.01				
Lauric acid			0.01		0.01				
Myristic acid	0.01	0.02	0.40		0.09			0.003	
Pentadecanoic acid			0.07		0.01			0.003	
Palmitic acid	0.46	2.01	3.02	0.03	5.85		0.01	0.07	0.02
Margaric acid	0.001	0.02	0.15		0.04				
Stearic acid	0.36	1.78	1.68	0.01	2.32		0.00	0.01	0.002

Table 2.6. Mass concentrations of macronutrients, water, and ash in foods (weight %) [100] (continued)

Arachidic acid	0.01	0.08	0.01		0.06				
Behenic acid	0.01	0.06			0.13				
Lignoceric acid		0.03			0.01				
Myristoleic acid			0.11		0.02				
Palmitoleic acid		0.01	0.52	0.00	0.72		0.00		0.002
Heptadecenoic acid			0.10						
Oleic acid	0.02	9.93	5.40	0.05	15.3		0.07	0.005	0.01
Gadoleic acid	0.85	0.02	0.04		0.09				
Erucic acid					0.01				
Linoleic acid	1.37	1.85	0.32	0.12	6.30		0.01	0.05	0.02
Linolenic acid	0.14	0.17	0.05	0.00	0.08		0.00	0.07	0.03
Alpha-linolenic acid			0.04						
Gamma-linolenic acid			0.01						
Arachidonic acid			0.04		0.34			0.04	
Timnodonic acid					0.01				
Docosahexaenoic acid					0.09				
Carbohydrates									
Fructose		0.05		9.53	0.06	0.1	0.00	0.65	0.43
Glucose	4.77	0.16		12.1	0.32	13		1.29	0.36
Lactose									
Maltose				1.77					

Table 2.6. Mass concentrations of macronutrients, water, and ash in foods (weight %) [100] (continued)

Sucrose		0.20				16			
Starch	33.5	33.8			0.55				
Dietary Fiber	7.99	3.52			0.00	1.6	0.73	1.21	1.31
Water	37.03	40.0	62.0	70.8	54.1	70	97.5	92.67	96.1
Ash	2.28	1.91	1.15	3.80	1.35		0.73	3.44	0.60

The following describes the route followed during estimation of thermodynamic properties. The total exergy of a substance was expressed as;

$$ex = ex_k + ex_p + ex_{ph} + ex_{ch} \tag{2.4}$$

where ex_k was the potential exergy, ex_p was the physical exergy and ex_{ph} was the chemical exergy, ex_{ch} [101]. The kinetic exergy, which is equal to the kinetic energy and can be calculated by considering the velocity of the stream relative to the surface of the earth and the potential exergy, which is equal to the potential energy related to the elevation of the stream from the surface of the earth [101], are neglected due to their small amounts, and then equation (2.4) is simplified as

$$ex = ex_{ph} + ex_{ch} \tag{2.5}$$

Exergy of a stream depends on both thermodynamic state specified by temperature, pressure, and composition and its chemical structure [102]. The physical exergy was calculated according to equation (2.5);

$$ex_{ph} = b - b_0 = (h - h_0) - T_0(s - s_0) \tag{2.6}$$

where, b is the flow availability; subscript 0 denotes the restricted dead state where the system does not have work potential and usually chosen as T_0 = 298.15 K and P_0 = 1 atm. The chemical exergy of a substance is the sum of the Gibbs free energy of formation and the chemical exergy of the elements making the compound [95];

$$ex_{ch}^{0} = g_f^0 + \sum_{i=1}^{n} N_i(ex_{ch_i}^{0}) \tag{2.7}$$

The terms h and s of equations 2.8-2.9 are defined as;

$$h = \sum_i x_i(h_{f,i}^0 + c_{p,i}\Delta T) \tag{2.8}$$

$$s = \sum_i x_i\left(s_i^0 + c_{p,i}ln\frac{T}{T_0} - R_u ln\frac{x_i}{x_i^0}\right) \tag{2.9}$$

where, superscript 0 denotes the true dead state which refers to the state and all the components within the system are reduced in a reversible way parameters x_i and x_i^0 are the mole fractions of the species i in the mixture and their ratio, $\frac{x_i}{x_i^0} = \mu$, is the chemical potential [102] and [103] which is equal to the mole fraction x_i since the chemical potential of a substance at true dead state, x_i^0, is 1. Mole fraction of the ingredients in atmospheric air is 20.35 percent O_2, 0.03 percent CO_2, 75.67 percent N_2 and 3.03 percent H_2O [102-104]. Approximate value of the heat capacity of a chemical substance was estimated from the Kopp's rule [105] by adding up the specific heats of the constituting atoms of the compounds;

$$c_p = \sum_i^n N_i\Delta_{E_i} \tag{2.10}$$

The terms $h_{f,i}^0$ and s_i^0 of equations (2.8) and (2.9) are enthalpy of formation and absolute entropy of the substances, and their approximate values calculated with the group contribution method. This method provides approximate values of the thermodynamic properties which are enthalpy of formation, Gibbs free energy of formation, and absolute entropy of a chemical structure based on the bond energies [102]. In other words, the molecular structure of compound is decomposed in a set of smaller molecular substructures [99] and each of these molecular substructures have a numeric value for different thermodynamic properties. By adding these numeric values in accordance with the number of molecular substructure involved in the molecular formula of the substance, the thermodynamic properties can be calculated.

The ideal gas enthalpy of formation of a chemical compound is the energy subtracted or extracted during the chemical reaction through which the compound is formed under constant pressure and can be calculated by using Joback's group contribution method [106];

$$\Delta h_f^0 = 68.29 + \sum_{i=1}^{n} N_i \Delta_{Hi} \tag{2.11}$$

Ideal gas Gibbs free energy of formation is the free energy comes out when a substance is formed from its constituent elements and can be calculated similar to enthalpy of formation [106];

$$\Delta g_f^0 = 53.88 + \sum_{i=1}^{n} N_i \Delta_{Gi} \tag{2.12}$$

Numerical values of Δ_{Hi} and Δ_{Gi} for bonds (Table 2.7) depend both on the elements contained in the substructure and its form (linear–non-ring structure and cyclic–ring structure). The difference of the numerical values with respect to elements contained in a substructure was evaluated from the substructure and the extended chemical formula of the substances.

Table 2.7. Atomic group contribution values employed to estimate Δh_f^0 and Δg_f^0 [106]

Bond	**Type**	Δ_{H_i} **kJ/mol**	Δ_{G_i} **kJ/mol**
$-NH_2$	Nitrogen increments	-22.02	14.07
$HN=$	Nitrogen increments	93.70	119.66
$>NH$	Nitrogen increments (non-ring)	53.47	89.39
$>NH$	Nitrogen increments (ring)	31.65	75.61
$-N=$	Nitrogen increments (ring)	55.52	79.93
$-CH_3$	non-ring increments	-76.45	-43.96
$H_2C=$	non-ring increments	-9.63	3.77
$>CH_2$	non-ring increments	-20.64	8.42
$>C=$	non-ring increments	83.99	92.36
$-HC=$	non-ring increments	37.97	48.53
$>CH-$	non-ring increments	29.89	58.36
$>C<$	non-ring increments	82.23	116.02
$-O-$	non-ring increments	-132.22	-105.00
$O=$	Oxygen increments	-247.61	-250.83
$-OH$	Oxygen increments (alcohol)	-208.04	-189.20
$>C=O$	Oxygen increments (non-ring)	-133.22	-120.50
$-O-$	Oxygen increments (ring)	-138.16	-98.22
$>CH_2$	ring increments	-26.80	-3.68
$>CH-$	ring increments	8.67	40.99
$-HC=$	ring increments	2.09	11.30
$>C=$	ring increments	46.43	54.05
$>C<$	ring increments	79.72	87.88
$-S-$	Sulphur increments (non-ring)	41.87	33.12

2.2.3. Thermodynamic Analyses

The valorization method of the fast food waste is analyzed thermodynamically by performing mass, energy, and exergy balances. The governing equations for a steady-flow system are represented here below. For mass balance;

Mass balance:

$$\sum(\dot{m})_{in} - \sum(\dot{m})_{out} = 0 \tag{2.13}$$

Energy balance:

$$\sum(\dot{m}_i h_i)_{in} - \sum(\dot{m}_i h_i)_{out} + \dot{Q}_k - \dot{W} = 0 \tag{2.14}$$

Exergy balance:

$$\sum(\dot{m}_i ex_i)_{in} - \sum(\dot{m}_i ex_i)_{out} + \sum_k \left(1 - \frac{T_0}{T_k}\right)\dot{Q}_k - \dot{W} - \dot{E}x_{dest} = 0 \tag{2.15}$$

where, k is the number of mediums that system interact with in terms of heat transfer. Saturation pressure of water $P_{sat@T_d}$was obtained from thermodynamic property tables of water, and then the partial pressure of the water vapor was calculated from;

$$P_v = \phi P_{sat@T_d} \tag{2.16}$$

Partial pressure of air was the difference between the atmospheric pressure of air and the partial pressure of water:

$$P_{air} = P_{atm} - P_v \tag{2.17}$$

specific humidity of the humid air at given relative humidity, temperature and pressure was

$$w = \frac{0.622 P_v}{P_{air}} \tag{2.18}$$

Amount of the dry air, which should be supplied to achieve a specified drying temperature and relative humidity of the combustion gases at the outlet of the incinerator were calculated from

$$\dot{m}_{dry,air} = \frac{\dot{m}_{water,FW}}{w} \tag{2.19}$$

where, $\dot{m}_{water,FW}$ is the moisture contained in the waste.

All the calculations were performed using Matlab software. Relevant scripts were given in Appendix A.

3. RESULTS AND DISCUSSION

3.1. HAMBURGER MENU

Hamburgers are made of buns, patties, mayonnaise, onions, lettuce, pickle slices, tomatoes and ketchup; 1 ton of hamburgers make 5,263 servings. Fast-food restaurants purchase mass produced frozen patties and partially fried frozen potato chips and cooks or refries them upon order of the customers. Energy consumption and CO_2 emission during production of the constituents of the hamburger menu were calculated (Table 3.1).

Table 3.1. Energy consumption and CO_2 emission along production of the hamburger menu and the accompanying consumables

Menu Item	**Mass Flow (kg)**	**CEnC (MJ/t hamburger)**	**CCO_2E (kg/t hamburger)**
Hamburger			
Bun	395	5,372 ± 270	435 ± 23
Patty	368	5,825 ± 291	12,392± 620
Lettuce	105	3,373 ± 500	5 ± 0.75
Onions	53	85 ± 13	84 ± 13
Pickles	26	500 ± 75	21 ± 3
Mayonnaise	53	483 ± 24	46 ± 2
Hamburgers total	1,000	15,638 ± 1,173	12,983 ± 662
Chips, soft drink, ketchup, salt			
Chips	526	5,938 ± 270	520 ± 26
Soft drink	2,183	4,851 ± 240	450 ± 23

Table 3.1. Energy consumption and CO_2 emission along production of the hamburger menu and the accompanying consumables (continued)

Ketchup	53	829 ± 42	123 ± 6
Salt	16	165 ±8	7 ± 1
Chips, soft drink, ketchup, salt total	2,778	11,783 ± 560	1,100 ± 64
Non-edible constituents of the menu			
Napkins and palletizing			
Napkins	31.6	587,0	23,0
Palletizing (0.5 pallet is replaced in each shipment)	8.5	11,0	1,1
Unaccounted items from Table 2.1.			
Paper production	502	8263	943
Paperware making (average machine power 5 kW, estimated processing time 30 min)	502	47,4	6,9
LDPE production	65	3286	100
LDPE shaping (average machine power 5 kW, estimated processing time 30 min)	65	47,4	6,8
Cardboard box production and labeling with Shanghai Liu Xiang (China) carton maker, 250 cartons/min, 135 kW containing dryer, estimated processing time 30 min	155	21,1	3,2
Cleaning material (disinfectants)	26.3	1,662	231
Non-edible constituents total	1,355	13,926 ± 1,393	1,316 ± 132
Hamburger menu + non-edibles total	5,133	40,844 ± 3,126	15,399 ± 858

3.1.1. The Bun Production Process

The preliminary steps of the bun production consist of the flour production from the grains, kneading and dividing the dough. Milling is the process of breaking the grain and releasing the starchy core. Milling processes receive the grains from the trucks and afterwards clean and quickly dry them. The rough outer layers of the grains are removed and utilize for other purposes, e.g., bran is consumed for breakfast as cereals for human health or animal feed [107]. The cleaning of grains is assumed to utilize 0.6 kWh/ton of energy [108]. The level of moisture in the grains was taken as 15 percent. The moisture of the grains was accepted as 15 percent. Before milling, the grains need to be moisturized and the moisture was accepted as 16 percent follows moisturizing. The moisture content reduces to 12 percent following the milling step [66, 109]. The plant employed in this study the capacity of milling of the plant is 60 tons of grains in 24 h with the consumption of 263 kW of electric power. A general flour production plant consumes 50 percent electric power for milling and grinding, 30 percent for pneumatic conveying and 11 percent for mechanical conveying [110].

Water added to the grains to obtain their water content to 16 percent. The details of the energy consumption and CO_2 emission of the hamburger bun production processes are presented in Table 3.2.

Table 3.2. Energy utilization and CO_2 emission during production of one ton of hamburger buns [25]

Stages of Processing	**CEnC (MJ/t)**	**CCO_2E (kg/t)**
Agriculture		
Diesel	3,092	51
Irrigation	30	43
Electricity Cleaning of the grains (0.6 kWh) [111]	228	32

Table 3.2. Energy utilization and CO_2 emission during production of one ton of hamburger buns [25] (continued)

Agriculture total	3,350	126
Bun making and packaging		
Flour making (Grain 935 kg) (Water 8.0 kg) Flour milling plant in Africa, 60 t/24h, 263 kW,	3,780	297
Dough making (Flour 749 kg) (Water 487 kg) (Yeast 29 kg) (Salt 10 kg) (Sugar 88 kg) (Margarine 36 kg) Dough preparation with Meiying (China), model HWY75, dough kneading machine capacity 450 kg/h, power 2.20 kWs Dough dividing with Haidier (China), model HDR-2000, power 1.5 kW, dividing rate 7s/piece, each piece weighs 50-850 g	4,200	242
Fermentation (Unfermented dough 1400 kg) Fermentation in Berg (China), model XF-16FC, bread proofer equipped with 16 trays in 620 mm x 970 mm x 2100 mm dimensions power 0.85 Kw	68	11

Table 3.2. Energy utilization and CO_2 emission during production of one ton of hamburger buns [25] (continued)

Baking (Dough 1400 kg) Baking in Zhengzhou Ditai (China), model 239-YXDF60 oven, capacity 60 kg/h, power 10.8 kW	910	133
Cooling (Bun 1000 kg) Cooling in Hebei Aocno (China), model ACN-C 1000 bread cooler, operating at cooling capacity of 500 kg/20 min, power 15 kW	41	6
Slicing (Bun 1000 kg) Slicing with Atlas slicer (Taiwan), slicing capacity 1800 loaves/h, slicing thickness 12 mm, power 2.4 kW	0.00	0.00
Packaging (Bun 1000 kg) (Polylactic acid 5 kg) Packaging with Dachuan, model DF-450W packaging capacity 1 bag/s, power 3.6 kW)	270	11
Transportation	910	156
Bun total	13,529	982

The capacity of the kneading machine was 450 kg/h and using 2.2 kW of electric power. The major stages of the dough preparation and dividing are clarified in detail by Cauvain and Young [112].

The capacity of dough divider for cutting and rounding was 50-850 g of pieces of dough in 7 s by assessing 1.5 kW of energy (Table 3.2). A 65 g hamburger bun was estimated to be produced with 58.0 g of wheat flour. The weight of the dough for producing one roll of hamburger bun was 108 g.

Carbon dioxide and ethanol were produced after mixing of all ingredients, regarding to the utilization of glucose by the yeast. When 1 kg of dough is fermented for one hour, yeast consumes 1.86 g of glucose and reveals 0.95 g of ethanol and 0.91 g of carbon dioxide [113]. The energy utilization along fermentation is 68.0 MJ/ton of for hamburger bun dough.

The weight loss was estimated as 40 percent in hamburger buns [32]. The baked loaves were cooled on the racks that air circulates around them, thus prevent the crusts to be soggy. In this study the capacity of the cooling machine was 1000 kg/h and utilized 15 kW of power. 41 MJ of energy was consumed for cooling of 1 ton of hamburger bun (Table 3.2). Hamburger bun is consisted of 53.5 percent wheat flour, 34.8 percent water, 2.1 percent yeast, 0.7 percent salt, 6.3 percent sugar and 2.6 percent margarine [114, 115]. The hamburgers are cut horizontally in a single stroke, into two slices at the middle of the bun [114]. The capacity of slicing machine was 1800 loaves/hour and consumed 2.4 kW of power. Before shipping the buns to the restaurants, eight of them were packaged together. The power of the packaging machine operated at the rate of 1 bag/s was 3.6 kW; and the packaging material was chosen as 4 g per package. The hamburger bun packs had the cumulative energy consumption of 270 MJ/ton.

Totally, hamburger bun production has the maximum energy consumption regarding to the higher weight loss in baking.

The data of the transported grains to the flour factory was accounted in the agriculture as 51 MJ/ton bread and the farm and flour factory was assumed as 50 km far from each other [30]. Therefore, total energy consumption for the transportation is 910 MJ/ton hamburger buns resulted in Table 3.2.

3.1.2. Beef and Patty Production

The steps of the patty production process are described in Table 3.3 and Figure 2.2. Average weight of the cattle was 500 kg, 10 percent of it was fat and 19.7 percent was protein.The cows were fed 9.4 kg/day of concentrate and 3.1 kg/day of roughage for 210 days, and then slaughtered [116, 117]. Eleven cows were transported in one truck for 300 km while going to the slaughter house. The slaughtering plant had the capacity of processing 400 cows/day, operating 300 days/year, 2–15 m^3 water/t of live carcass is used in the slaughterhouse [118]. In the present study, calculations were based on 4 m^3 of water utiliation/t of live carcass. The carcasses are kept in a refrigerated storehouse (power requirement 5 - 25.5 MJ/kg meat [1] for 24 to 36 hours to reduce the moisture loss and the remaining metabolic activity. The carcasses are transported to the meat processing facility for 390 km at 2^{o}C in refrigerated heavy-duty trucks (capacity 22 ton, utilizing 0.40 L of diesel/km). The carcasses are cut with electric saws in the refrigerated work environment at 12°C with the energy utilization of 2.5-15.5 MJ/kg meat [1]. Energy utilization during grinding of the meat was calculated for the use of CFS AutoGrind industrial grinder (Netherlands, model U280, capacity 4-22 kg/h, engine power 74 kW, duration of grinding 10 minutes); 6.5 kg of ground meat is placed in a LDPE package, and then in a carton, 30 cartons are placed on a pallet; for the secondary packaging of 1 t of frozen patty 165 corrugated cartons and 5.2 pallets are needed. The patties were made of 90.7 percent ground meat and 9.3 percent seasonings, fat content of the ground meat is adjusted to 25 percent. The formulation is kneaded in CFS CombiGrind mixer (Netherlands, model 225, engine power 50 kW) for 20 minutes and the patties are formed in Formax Ultra 26 (Netherlands, capacity 455 kg/h, engine power 36 kW) patty maker and then inspected with LOMA (UK, power requirement 2.6 kW) X-ray equipment to assure that there is no contamination by foreign objects. The patties were individually quick frozen in Frigoscandia (USA, model 600) conveyor freezer (engine power 24.5 kW, baseload 121,220 kJ/h, capacity 2,000 kg/h, freezing temperature -23.3 to -28 ^{o}C), and then 6.5 kg of them were put first in a LDPE bag (weight of the bag is 150 g) and in a (38.5 cm x 25.7 cm x 20.4 cm) corrugated cardboard carton (weight of a carton is 500 g), 30 boxes are placed on a pallet. The storage facility (Friterm, Turkey, model dT 6K) had enough space for 135 pallets (volume = 1208 m^3) and operating at -24 ^{o}C. It was running to provide 18 hours/day of cooling and 2 hours/day defrosting. The patties were stored in Mellcon (India) model HCRU 1.5 (5.0 m x 4.0 m x 3.0 m, 1.4 kW) cold room, for 2 days in the restaurant and then cooked on Nieco model mpbr 94 cooking machine (US, capacity 48 pieces/min, power 20 kW). Table 3.3 describes energy consumption and CO_2 emission along frozen patty production.

Table 3.3. Energy consumption and CO_2 emission along frozen patty production

Stages of Processing	**CEnC (MJ/t)**	**CCO_2E (kg/t)**
Producing the meat [127]	1,500	33,000
Patty making and packaging		
Transportation to the meat processing factory	426	7
Cutting the carcasses with electric saw	54	8
Grinding the meat	88	12
Adjusting the fat content	98	17
Forming the patties	78	12
Individually quick freezing of the patties	52	8
Packaging with RMF patty stacker (USA), power 5 kW, capacity 100 strokes/min	12.1	2
LDPE packaging material	2,014	49
Cardboard packaging material	3,341	90
Inspection of the patties	9.7	1
Frozen storage	574	80
Transportation to the restaurants	1.3	0.02
Frozen storage in the restaurant	52	7.3
Cooking and frying at the restaurants	556	325
Hamburger patty total	8,856	33,618

Table 3.3. Energy consumption and CO_2 emission along frozen patty production (continued)

Waste removal and recycling (rendering)		
Electricity	344	48
Natural gas	6,578	8
Water	0.02	-
Transportation of the products to a poultry feed production factory	53	1
Patty total	15,831	33,675

Energy cost and CO_2 emission associated with beef production is considerably variable depending on the technology employed. If all the other parameter will remain the same, when we employ the maximum energy utilization data as presented by de Vries and de Boer [146] 53.00 MJ/kg meat and the corresponding CO_2 emission data as 33.00 kg CO_2/kg meat, the index will be 42,243 MJ/t menu, and 15,399 kg CO_2/t menu. When we compare these numbers with the index vales calculated with those for Turkey, we will see that energy utilization will be 3.3 percent higher, while the CO_2 emission remains the same. On the other hand, when we employ the minimum energy utilization data as presented by de Vries and de Boer [146] 34.00 MJ/kg meat and the corresponding CO_2 emission data as 15.00 kg CO_2/kg meat, the index will be 41,544 MJ/t menu, and 8,822 kg CO_2/t menu. When we compare these numbers with the index vales calculated with those calculated for the conditions prevailing in Turkey, we will see that energy utilization will be 1.6 percent higher, whereas the CO_2 emission will be 42.7 percent less.

3.1.2.1. Treatment of the Waste of Beef Production

On the average the carcass of the cattle accounts for 53 percent of the live weight, the skins are used for leather or hide production, and the rest is used for rendering [119]. The rendering products are among the raw materials of the chicken feed industry. An average rendering meal consists of about 31 percent bone and fat, 32 percent protein and 37 percent moisture; 16 to 18 percent of the total rendering proteins comes from the blood [120]. Rendering data were collected from a slaughtering and meat processing factory, located in Izmir. The rendering facility was selling its products to a poultry feed producing factory. The average distance between the rendering and poultry feed factories was 80 km.

3.1.3. Lettuce, Onions, Tomatoes and Pickles

Data regarding tomatoes, lettuce, onions and cucumbers agriculture were presented in Table 3.4. Energy consumption along agricultural production of the fresh onions with conventional methods was adapted from Moore [121] as 1.58 MJ/kg. It is estimated that used natural gas, electricity and diesel were equivalent, and 15 percent of the onions were lost along manual sorting and peeling, equal amounts of natural gas, electricity and diesel were used in agriculture.

Table 3.4. Energy consumption and CO_2 emission along production of fresh tomatoes, lettuce, onions and cucumbers

Stages of Processing	**Energy Utilization (MJ/t)**	**CO_2 Emission (kg/t)**
Fresh tomatoes (data is adapted from Karakaya and Özilgen [90])		
Chemical fertilizers	302.2	57.3
Chemical pesticides	23.5	0.7
Diesel for transportation	420.2	5.8
Water for irrigation	19.4	2.7
Recycling the waste tomatoes	164.7	22.8
Total	930	89.3
Onions (data is adapted from Moore [121])		
Onion agriculture	1,603	84

Table 3.4. Energy consumption and CO_2 emission along production of fresh tomatoes, lettuce, onions and cucumbers (continued)

Winter lettuce production in a heated greenhouse (data are adapted from Djevic and Dimitrijevic [122])		
Fuel oil (has the same properties as diesel)	24,857	71
Fungicides	271	0.2
N fertilizer	960	72
P_2O_5 fertilizer	25	0.1
K_2O fertilizer	51	0.1
Seeding sprays	35	5
Boxes	4,637	146
Seed and blocking compost	1,286	7.5
Total	32,122	302
Cucumbers production (data was adapted from Abdi et al. [123])		
Seeds (0.15 kg/ha)	0.002	0.00
Chemical fertilizers (NH_4NO_3, 0.4%, P_2O_5 56.3%, K_2O 43.4%)	128	81.3
Chemicals (herbicides 25%, fungicides 34 %, insecticides 41%)	20	1
Organic manure (14,200 kg/ha)	49	-
Water (1,769 m^3/ha)	0.02	-
Diesel oil used for agriculture (1,165 L/ha)	744.3	12.4
Electricity (2,056 kWh/ha)	23	3.3
PVC (525x365x200 mm)	14,842	468.7
Total	15,807	570

Summary of the pickles production process is presented in Table 3.5 and Figure 2.3.

Table 3.5. Energy consumption and CO_2 emission along pickles production

Stages of Processing	**Energy Utilization (MJ/t)**	**CO_2 Emission (kg/t)**
Pickles production		
Cucumber agriculture (5 % of the cucumbers is not appropriate for pickling)	16,597	599
Transportation	117	2.0
Receiving and separation	36.1	5.1
Sorting and washing in Bigtem, Turkey, washing and sorting machine, power 10 kW	29	4.1
Brine preparation and pasteurization	1,347	23.6
Fermentation of the cucumbers in brine	155	21.8
Slicing	17	2.4
Replacing brine	21	102.6
Packaging and transportation of the pickles		
PET for jar making	504	22
Washing the PET bottles	44.3	2.03
Filling the jars	2.1	0.3
Capping the jars	4.2	0.6
Packaging (Technochem) engine power 2.3 kW	3.2	0.45
Corrugated board for tray making	101	2.73
Polypropylene for wrapping the jars on a tray	2.4	0.1
Palletizing	36	5

Table 3.5. Energy consumption and CO_2 emission along pickles production(continued)

Storage and transportation to a distance of 250 km at ambient temperature	232	5.83
Pickles total	19,248	800

The pickles factory was 200 kms away from the cucumber fields. After arriving to the factory the cucumbers were conveyed and separated by size on a conveyor belt (Yavuz Makine, Turkey, power =15 kW), 8 percent of the cucumbers were wasted before fermentation. Nine t of cucumbers were fermented anaerobically at 25^{o}C in nine t of brine (made of 87.1 percent water, 12 percent salt, 0.5 percent acetic acid, 0.2 percent calcium chloride, 0.1 percent sodium benzoate and 0.1 percent potassium sorbate) with occasional mixing (power of the mixer=18 kW) and in a fermentation tank (Technochem, India). The fermented cucumbers were sliced by a slicing machine (Bigtem, Turkey, model GM 12 OV, capacity=1.5 t/h, and engine power=8 kW), an additional 1.5 percent of the pickles were wasted during slicing. The brine was replaced with water (pump power=8 kW, duration 60 min) after slicing the pickles to reduce the salt content to 5 percent. The pickles were filled in to the PET jars (filling capacity = 3 kg, jar weight = 315 g) with filling machine (Technochem, India, power requirement = 1.5 kW). The PET jars were washed in Bigtem washing machine (model GWECJ.01, power requirement= 7.5 kW) with steam (steam utilization rate=1.5 m^3/h). The jars were capped with Technochem (India, engine power = 3 kW, capacity 120 jars/min) capping machine. Six jars were placed on a tray made of 42 g of cardboard and then wrapped with 30 g of polypropylene. 60 jars of pickles are placed on a wooden pallet and palletized with Formaksan (Turkey) palletizing machine (capacity 1 pallet/min, engine power 21.45 kW) and then transported to a distance of 250 km at ambient temperature for storage and distribution.

3.1.4. Mayonnaise, Ketchup and Salt Production

Mayonnaise and ketchup are produced by blending the ingredients, both products are packaged. Data regarding the ingredients and energy consumption along production of mayonnaise, ketchup and salt are presented in Table 3.6.

Table 3.6 Energy consumption and CO_2 emission along mayonnaise, ketchup and salt production

Stages of Processing	**Energy Utilization (MJ/t)**	**CO_2 Emission (kg/t)**
Mayonnaise production		
Inputs of mayonnaise		
Sunflower oil (719 kg)	5,608	491
Egg yolk (113.8 kg)	1,173	119
Lemon juice (5 kg)	133	99
Glucose syrup (10.7 kg)	150	43
Vinegar (124.2 kg)	0.65	0.3
Salt (27.5 kg)	8	0.5
Unpackaged mayonnaise total (1000 kg)	7,073	753
Packaging materials of the mayonnaise		
LDPE (28.1 kg)	1,348	59
PP (4.6 kg)	0.8	0.1
HDPE (0.20 kg)	0.6	0.1
Electric power utilization for homogenizing, packaging and other equipment (industrial data)	300	42
Utilization of diesel for transportation	390	6.4
Packaged mayonnaise total (1,029 kg)	9,112	861

Table 3.6 Energy consumption and CO_2 emission along mayonnaise, ketchup and salt production (continued)

Ketchup production			
Raw materials (energy utilization and CO_2 emission data are adapted from Özilgen, submitted)			
	Tomato paste (408 kg)	588	81,6
	Starch (81.6 kg)	1,124	299
	Sugar (112.2 kg)	1,100	66
	Glucose syrup (120 kg)	1,752	487
	Vinegar (105 kg)	550	242
	Salt (27.5 kg)	283.3	12.5
	Water (145 kg)	10.2	1.4
	Unpackaged ketchup total (1000 kg)	5,408	1,190
Packaging materials (Energy utilization and CO_2 emission data are adapted from Özilgen [92])			
	LDPE (7 kg)	336	15
	PP (0.1 kg)	0.2	0.03
	PVC (4.1 kg)	234	7.4
Energy utilization for processing	Electric power	94.5	13.2
	Coal (375 kg)	9,375	1,099
Transportation	Diesel (3.3 kg)	190	3.1
	Packaged ketchup total	15,638	2,328
Salt production			
Unprocessed salt is dried with solar energy and then transported in trucks for 500 km		274.4	4.5

Table 3.6 Energy consumption and CO_2 emission along mayonnaise, ketchup and salt production (continued)

Conveying of the unprocessed salt with JUNYU (China), model TDT J vertical transportation unit, capacity 26 t/h, power 5.5 kW	2.8	0.4
Washing in JUNYU (China), model LX62 spiral salt washer, capacity 10 t/h, power 5.5 kW	0.8	0.1
Separation with centrifugation, capacity 15 t/h, double, power 15 kW	7.2	8.2
Screening with JUNYU (China), model GLS 15 screen, capacity 15 t/h, 8 kW	1.9	0.3
Drying in JUNYU (China), model ZDG 12x7.5 vibrating fluid bed dryer, capacity 350 kg/h, power 1 kW	10.3	1.4
Packaging the salt with Turpack PLC (Turkey) packaging machine, capacity 500 packages/min, power 3 kW	360	50.4
Packaging material 0.1 g of paper is used for packaging 1 g of salt	1,650	188
30 g of LDPE is used for packaging 1 kg salt of packs	2,610	63
500 g of corrugated cardboard box is used for 10 kg LDPE packages	2,165	58.5
Stretching material 184 g of LDPE is used for packaging one pallet	2,859	69
Transportation to fast food warehouse in trucks for 324 km	361	6
Salt total	10,302	455

Treatment of water was achieved by filtering spring water through activated carbon and sand to remove the course particles, and then subjecting to ultra-filtration to remove particles which are in the size range of 0.01 μm, including the bacteria, and treating with reverse osmosis to remove the minerals. Mayonnaise is pasteurized after primary packaging. The ketchup production line consists of a mixer (capacity 4 t/h, power 6 W), a heater (Onur Makine, Turkey, capacity 4 t/h, power 6 W), a deodorization unit (Onur

Makine, Turkey, capacity 4 t/h, power 3W), pasteurizer (Osmanlı Makine, Turkey) capacity 4 t/h, power 20 W, a homogenizer (Hommak, Turkey), capacity 5 t/h, power 45 W. Both mayonnaise and ketchup are packaged in 10 kg containers. During ketchup production, electric power is utilized for homogenizing, packaging and other activities, coal is utilized for pasteurization; 281 g of polyethylene is used for packaging 10 kg of ketchup, 40 LDPE packages are placed on a pallet and wrapped with 184 g of polypropylene; 2 kg of PVC is used for packaging 220 kg of tomatoes paste. 281 g of LDPE is used to manufacture each mayonnaise package; 40 packages were placed on a pallet and wrapped in 184 g of polypropylene. Vinegar, lemon juice and the other ingredient packages are made by using 200 g of HDPE. Salt is produced after drying the sea water in ponds. The raw salt is carried to the factory for processing, where it is washed, dried, sieved and packaged. Basic steps of the salt production process are described in Table 3.6.

3.1.5. Potato Chips

Basic steps of the potato chips production process are presented in Table 3.7, and the flow chart of the production is described in Figure 2.4.

Table 3.7. Energy consumption and CO_2 emission along potato agriculture and processing

Stages of Processing	**Energy Utilization (MJ/t)**	**CO_2 Emission (kg/t)**
Agriculture (data is adapted from Mohammadi et al. [124], yield of 28.5 t/ha year)		
Seeds 3091.8 kg/ha	391	6.3
Chemical fertilizers (NH_4NO_3, 33%, P_2O_5 4%, K_2O 3%) 1191.6 kg/ha,	1,677	307.3
Agrochemicals (herbicides 72%, fungicides 28 %) 3.02 kg/ha	13	0.6

Table 3.7. Energy consumption and CO_2 emission along potato agriculture and processing (continued)

Diesel oil used for agriculture 290.04 kg/ha	586	9.6
Water utilization 11145.5 m^3 /ha	0.40	-
Delivery of the patato to the processing factory for 30 km	41	0.7
Total	2,709	324.4
Processing in the factory		
Removing dust and stones	13	1.8
Peeling	18	2.6
Sorting and trimming	11	1.5
Cutting to a standard size	14	1.9
Blanching	13	1.8
Drying	1,231	12.2
Frying	68	86.4
Oil removal	8	1.1
Cooling	4	0.6
Freezing and cooling	104	14.6
Packaging	28	3.9
Oil for frying (17 kg of oil is used while producing one t of chips)	1,319	77
LDPE for packaging	870	21
Cardboard for cartooning	1,256	50
Storage and transportation to a distance of 500 km in refrigerated trucks	1,022	24
Frozen storage in the restaurant	52	7.3
Refrying in the restaurants	2550	357
Total	11,288	988

After receiving the at the factory dust and stones are removed, potatoes are washed and sorted with EIMA (Germany) model VWS 5 potato cleaner (capacity 5 t/h, power 4.5 kW). Potatoes are peeled with EIMA (Germany) model WS 10-30 L, steam peeler (capacity 3-5 t/h, power 6.8 kW), trimmed and cut into a standard size with EIMA (Germany), model G-AGK-A industrial chips cutting machine (capacity 2 t/h, engine power 1.7 kW). Potatoes are blanched in two steps. At the first step, they are blanched in SBL-05-50 blanching equipment (Germany, capacity = 1.1 t/h, power= 0.6 kW) at 85 ^{o}C for 4 min and than the second stage of blanching occursin SBL-08-60 blancher (Germany, capacity = 3.5 t/h, engine power = 0.8 kW) with 10 m^3/h water utilization. The blanched potatoes are dryed in EIMA (Germany), model BT-EBT-150-9 belt dryer (capacity = 1.430 kg/h), fried in EIMA (Germany) model DBO 07-60 continuous fryer (capacity = 1000 kg/h, power utilization = 20 kW. During processing in the factory 50 percent of the initial weights of the potatoes are lost due to peeling, trimming, cutting to a standard size, shaping and drying. Excess oil will be removed by centrifugation in EIMA FAS 08-20 centrifuge (capacity = 2000 kg/h, power = 2.2 kW). The chips are cooled with ventilation and frozen in EIMA (Germany) freezing tunnel, (model SF-P-3-2, capacity = 2.000 kg/h, power = 30 kW, freezing time = 20 minutes, freezing temperature = 18 ^{o}C). The frozen chips were packaged with EIMA (Germany) model WUV 1000 P weighing and packaging machine (capacity= 40 packages/ min, power =7.7 kW). Energy consumption and CO_2 emission for the production of one t of sunflower production oil are adapted from Özilgen and Sorgüven [30] as 7,795 MJ/t and 492 CO_2/kg, respectively. After processing the final product will have 68 percent water, 5.5 percent oil and 26.5 percent of oil-free dry matter.

Frozen chips were packed in LDPE bags (100 g of LDPE is used for packaging one kg of partially fried potato chips) and then ten packages of frozen chips are placed in a carton (290 g of corrugated cardboard was used for 40 packages) and 30 cartons are placed on a pallet. The frozen chips will be stored in the same place as the patties in the restaurant, and then refried in Frymaster (model H17-2) fryer (US, power 17 kW), 140 kg of vegetable oil is consumed while frying one t of frozen French-fried potato (frying time = 2.30 minutes, frying temperature = 177 ± 3 ^{o}C).

3.1.6. Carbonated Drink

Basic steps of the carbonated drink production process are presented in Table 3.8, and the flow chart of the production is described in Figure 2.5.

Table 3.8. Energy consumption and CO_2 emission along production of the carbonated drink

Stages of Processing	**Energy Utilization (MJ/t)**	**CO_2 Emission (kg/t)**
Production of sugar [83]	1,824	177
Transportation of the sugar to the carbonated drink factory	51	0.75
Packaging materials of sugar	25	0.85
Water treatment	0.4	0.1
Mixing of the ingredients	4.3	0.6
Primary packaging of the syrup and the pressurized CO_2	6.6	0.9
Paper for manual labelling	132	15
Palleting and wrapping	11.4	0.5
Storage and transportation	140	2.3
Serving the beverage in the restaurants	0.2	0.03
Production of ice	27	8.3
Soft drink total	2,222	206

Carbonated drink syrup is made of 87.6 percent water, 10.8 percent sugar, 0.2 percent caffeine, 0.6 percent phosphoric acid, 0.01 percent cola flavor, 0.01 percent caramel and 0.8 percent carbon dioxide. Water which is used for carbonated drink production undergoes the same treatment as as explained for ketchup. The ingredients are mixed in a tank (MITECO, Switzeland, engine power = 17.85 kW) at 1ºC under 2-3 bar of pressure. Energy utilization and the associated CO_2 utilization for caffeine, phosphoric acid, cola flavor and caramel are neglected because of their extremely small percentage in the formulation. The syrup is transported to the restaurants in 50 L cylinders. CO_2 is filled into steel cylinders with Kelin Aier Qiyuan (China, model GV-20/1-25) food grade compressor (power = 5.5 kW, capacity = 20 Nm^3/h). The beverage is served in the restaurants with Shaoin (China) beverage dispenser (power 660 W). Ice production with Chuangli (China) industrial cubed ice making machine, power 2300 W, capacity 450 kg/day (180 kg ice is needed per 1 ton carbonated drink).

3.1.7. Napkins, Pallets and Cleansers

Napkins and pallets are the major non-edible constituents used during production, transportation and consumption of the edible menu items. Napkins are made of recycled paper. In Turkey 45 percent of the paper is recycled (industrial data), for the given of recycling rate energy utilization and CO_2 emission rates for paper production is 18 GJ/t and 700 kg CO_2/t paper [125] 50 percent of the energy was obtained from natural gas and the rest from electric power, the major steps of the napkin production process are clarified in Table 3.9.

Table 3.9. Energy requirement and CO_2 emission during napkin and pallet production

Stages of Processing	**Energy Utilization (MJ/t)**	**CO_2 Emission (kg/t)**
Napkin production from industrial paper		
Paper napkin making process (1000 kg)	18,000	700

Table 3.9. Energy requirement and CO$_2$ emission during napkin and pallet production (continued)

Package raw materials (energy utilization and CO$_2$ emission data are adapted from Özilgen, submitted)		
LDPE (10 kg)	48	2.1
Corrugated cardboard (25 kg)	43.3	1.17
PP (2 kg)	1.8	0.25
Electric power utilization during primary packaging	219	30
Box production and labeling with Shanghai Liu Xiang (China) carton maker, 250 cartons/min, 135 kW including dryer	6	0.84
Palletizing with Dalian Jialin (model JT 1200, China) palletizer, 1200 cartons/h, 9 kW	5.2	0.73
Diesel utilization for transportation for 50 km	250	3.75
Napkins total	18,573	739
Pallet making		
Agriculture of unprocessed or recycled wood (natural product, 10,676 kg)	0	0
Electricity power for drying (343 MJ)	342.6	41
Electric power for sawing (78 MJ)	78	9
Electric power utilization by the pallet making machinery (Form Makine, Turkey), power 45 kW, capacity 80 pallet/h	77	11
Steel for nail making (32 kg))	454	54.4
Nail making with Bidragon (China, model B294 -6.5c) nail making machine, 160 nails/min, 11 kW, 660 nail/kg	87	12.2
Diesel utilization for transportation of the wood for 50 km	250	3.75
Pallets total (1000 kg)	1,289	131

Napkin packages for the dispensers are made by using Omet (Italy, model TV841) packaging machine (capacity 1 package/s, power 82 kW), 250 pieces of napkins are packaged with 3 g of polyethylene, 18 packages are placed in a 43-cm x 29.5-cm x 30-cm carton (made of 380 g of corrugated cardboard) and then 24 cartons are placed on a pallet; 8 pallets are needed for one t of napkins and every pallet is wrapped in 250 g of polypropylene.

Wooden pallets (size = 80 cm x 120 cm, weight 17 kg) made of pine tree are used for transportation of the hamburger menu items. 8,715 kg of recycled wood and 1,961 kg virgin timber are used for the production of the 1,000 kg of pallets. The difference between these two numbers was caused by the loss of scraps while shaping the timber and the loss of water during drying the shaped timber. Nails, electricity and fuel oil were the other inputs of the pallet manufacturing process (Table 3.9). The pallets were used for 15 trips without repair. The average round trip travel distance was 320 km [126].

Consumption of sanitizer is 23.6 kg per 1000 menu in fast food shop which is located in İstanbul. CEnC and CCO_2E of the sanitizers are estimated with the group contribution. Energy consumption and carbon dioxide emission in sanitizer are measured as 1,662 MJ/t and 231 kg/t in. Chemical structure and the estimation of the thermodynamic properties of the sanitizers with the group contribution method are supplied in Table 3.10-3.14

Table 3.10. Estimation of the thermodynamic properties of Triclosan

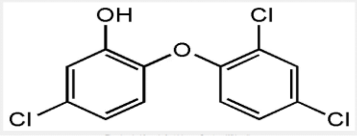
Atomic group	**Occurrence**	**ΔG_f (kJ/mol)**	**$n_j X_{chne}$ (kj/mol)**
Triclosan			
			
-CI	3	-128,0	
-OH	1	-173,6	
>C=	6	-97,1	
=CH-	6	212,4	

Table 3.10. Estimation of the thermodynamic properties of Triclosan (continued)

-O-	1	174,5	
Cl	3		261,3
H	1		331,3
C	12		4918,4
O	2		467,4
		$\sum \Delta Gf$ = -11.88 kJ/mol	$\sum n_j X_{chne}$ =5978.44 kJ/mol
		-0,041 MJ/kg	774,4 Mj/kg
Total		774,3 Mj/kg	

Table 3.11. Estimation of the thermodynamic properties of Betaine

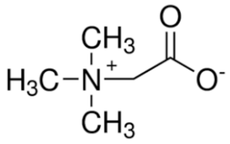
Atomic group	**Occurrence**	**ΔG_f (kJ/mol)**	**$n_j X_{chne}$ (kj/mol)**
Betaine			
			
$-COO^{1-}$	1	-347,7	
--CH_3	3	-45,8	
*> CH_2	1	6,8	
>N+< *	1	-90,8	
N	1		0,7
H	11		3644,3
C	5		2049,4

Table 3.11. Estimation of the thermodynamic properties of Betaine (continued)

O	2		467,4
		$\sum \Delta Gf$ = -477.5 kJ/mol	$\sum n_j X_{chne}$ =6161.8 kJ/mol
		-4,1 Mj/kg	3.842,9 MJ/kg
Total		3838,8 Mj/kg	

Table 3.12. Estimation of the thermodynamic properties of Cocomide Dea

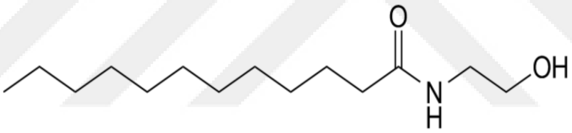
Atomic group	**Occurrence**	**ΔG_f (kJ/mol)**	**$n_j X_{chne}$ (kj/mol)**
Cocomide Dea			
			
*-CH_3	1	-15,3	
> CH_2	14	94,9	
>C=O	1	-118,8	
>N-	1	102,1	
-OH	2	-347,3	
N	1		0,7
H	1		331,3
C	15		6148,1
O	3		701,1

Table 3.12. Estimation of the thermodynamic properties of Cocomide Dea (continued)

		$\sum \Delta Gf$ = -284,4 kJ/mol	$\sum n_j X_{chne}$ =7181.2 kJ/mol
		-1 Mj/kg	883,3 MJ/kg
Total		882,3 Mj/kg	

Table 3.13. Estimation of the thermodynamic properties of Sodium Lauryl Sulfate

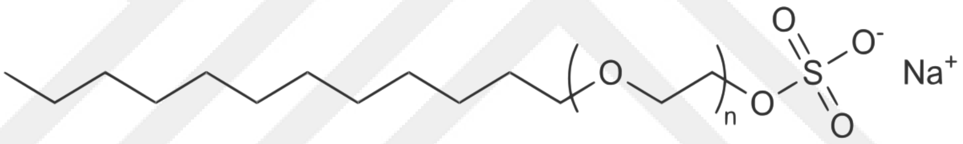
Atomic group	**Occurrence**	**ΔG_f (kJ/mol)**	$n_j X_{chne}$ **(kj/mol)**
Sodium Lauryl Sulfate			
			
*-CH_3	1	-15,3	
*> CH_2	11	74,6	
*-$OSO^{1}{}_{3}^{-}$ *	1	-652,7	
S	1		609,6
Na	1		336,6
H	25		8282,5
C	12		4918,4
O	4		934,8
		$\sum \Delta Gf$ = -593,4 kJ/mol	$\sum n_j X_{chne}$ =15081,9kJ/mol
		-2,1 Mj/kg	8781,4 MJ/kg
Total		8779 Mj/kg	

Table 3.14. The values of the CEnC and CExC as calculated for hand sanitizer

Organic Compound	**Recipe (%)**	**Exergy in each compound (MJ/kg)**	**Exergy (MJ/kg)**
Triclosan	0.3	774,3	2,3
Bethaine	3	3.838,8	115,2
Cocomide Dea	1.5	882,3	13,2
Sodium Lauryl Sulfate	15	8.779,0	1.316,9
Water	80	0,0	0,0
		Total Exergy	1447,6 MJ/kg
		Exergy per menu	1.3 MJ/kg
		Energy per 1 ton of hamburger menu	1662 MJ/kg

Energy utilization and CO_2 emission during the production of hamburger menu in Turkey were 40,844 MJ/t and 15,399 kg/t, respectively (Table 3.1). Mass, specific cumulative energy consumption and CO_2 emission along production of the hamburger menu production processes are presented in Table 3.1**.**

The index which is suggested in this study may be referred as a measure of energy efficiency and environmental impact. There is a general belief that the use of disposable service items in the restaurants causes pollution. The results of this study show that the share of the paper wares and napkins were 1.5 percent in energy consumption and 1 percent in CO_2 emissions, respectively.

Index values presented in Table.3.1 are sensitive to the materials use. If the LDPE utilization can be reduced by 5 percent in the hamburger menu production, the index presented in Table.3.1 would be 40,717 MJ/t menu and 15,334 kg CO_2/t menu. For 5 percent reduction in paper utilization, the index presented in Table.3.1 would be 40,439 MJ/t menu and 15,350 kg CO_2/t menu.

Energy cost of beef production is considerably variable depending on the technology employed. Table 3.3 means that the energy consumption for the beef production of the slaughter house was 1.328 MJ/kg. Those findings are consistent good enough with the study of Doublet et al.[127], who revealed the energy consumption in Romania as 1.5 MJ/kg beef. Energy consumption along production of meat was greater in the nations that are more industrialized. Ramirez et al. [128] declined the energy cost of the beef production as 2.15 MJ/kg carcass, on the average 20 percent of the carcass is bone [129], producing the energy cost of the bone free beef approximately 2.68 MJ/kg. Williams et al. [130] determined a higher energy consumption, i.e. 28 MJ/kg, for the beef production in United Kingdom. On the other hand, their results contain the energy consumed to produce the grass, which made up 41 percent of the total energy consumption.

Carlsson- Kanyama and Faist [1] revealed the energy use for hamburger patty production as 6,200-116,000 MJ/t. The result obtained in the present study was 8,684 MJ/t, close to the lower level. In the current study, CO_2 emission was measured as 37 kg CO_2 /t of meat produced at the exit of the slaughter house (Table 3.3). This finding is consistent and convenient to the result of a study reported in Japan, e.g., 40 kg CO_2 eq/t meat [131], but much greater than what Desjardins [132] declared, e.g., 19.6 kg CO_2 /t meat, in a study reported in Canada. Cooking the patties in the restaurants causes emission of 325 kg CO_2/t of frozen patty (Table 3.3).

The most energy intensive operation in the manufacture of frozen French-fried potatoes along freezing was declined by Massanet et al. [133], with specific energy utilization of 1,363 kJ/t. In Table 3.13, water was evaporated first by utilizing 1,231 MJ/t and then the potatoes were frozen by utilizing 104 MJ/t of energy giving were quite similar results with those of Massanet et al. [133]. The potatoes have between 63.2 to 86.9 percent of water content [134], most of the energy utilized in a potato chips frying process is allocated to evaporate the cellular water of the potatoes and the frying oil [133] and to ventilate them out [135]. Removing water by drying after blanching, prior to freezing, may be a better idea, since it reduces the energy load of the phase change of water during freezing. Improving the energy efficiency of food production, without deteriorating the quality is among the major goals of the current research. Van Loon et al. [136] tried reducing the cellular water content of the potatoes by using alternative technologies, such as superheated steam, pre-drying with air and vacuum freezing, but the novel processes did not produce the crispy crust such as the ones produced with the conventional process.

After freezing, largest consumption of energy in frozen French-fried potato manufacture is typically the frying process, which needs an important amount of direct fuel utilization to heat the frying oil. In this study, energy consumption of fryer is 68 MJ/t (Table 3.7). Genç and Hepbasli [137] submitted that the exergetic efficiency of a potato chips frying process was only 4 percent. The used oil for frying has a significant effect on the environmental along its production and the removal of the waste after being used in the frying process. It was quite energy consuming to refry the potato in the restaurants such as 2.550 MJ/kg of energy, presumably the inefficient use of the fryers, for instance carrying out them for very small amounts of potatoes and for very long times, while no potatoes are being fried.

Emission of 147 kg CO_2/t of potato production in Dutch agriculture system was submitted by Kramer et al. [138]. Findings of the current study were given 324 kg CO_2/t of potatoes (Table 3.7). Energy consumption along pickles production was 19.2 MJ/kg (Table 3.5). The value of 6.2-7.6 MJ/kg reported by Carlsson- Kanyama and Faist [1] was half of the this result. The same research group determined 13-44 MJ/kg of energy consumption along hamburger bun production, which was reported as 13.6 MJ/kg by Değerli et al. [25] for production in Turkey. Coca Cola Company [139] reported 0.24 MJ/L of energy utilization in production. A similar energy consumption rate was calculated for the bottled carbonated drink production in the present study as 0.22 MJ/L. Moreover, in the current study, energy consumption was 0.18 MJ/L for the carbonated drink production in keg. Energy utilization for the entire menu in Turkey was 41,285 MJ/t accompanied with 3,269 kg/t of CO_2 emission (Table 3.1). The relatively low energy utilization in Turkey is presumably the result of the lower mechanization level in the Turkish fast food industry, and may imply higher rate of labor employment, when compared to the more industrialized nations pointing the need for the improvement of the mechanization and CO_2 emission. On the contrary, CO_2 emission was at the higher end of the range, probably emphasizing the use of relatively older or inefficient technology.

In the current study, CO_2 emission regarding to energy utilization is discussed. There are additional CO_2 emissions sources, which are not in the scope of this study. Van der Werf and Petit [140] suggested an approach to observe environmental effect at the farm level by considering a number of other reasons, covering soil erosion and quality of water, Girardin et al. [141] argued the interactions of the region-specific parameters, like the sowing dates and leaching times, on the environmental effect of agriculture. A model was developed by Lopez et al., [142]l to determine the impact of a carbon border tax on the carbon food print of international trade.

Clarity involved in our analyses basically based on the measurements and the inevitable variations among the individual production applications assessed the same procedure followed by Ozgener and Hepbasli as well [143]. The industrial production stages are simple to control; therefore about ± 5 percent of uncertainty was calculated to include these stages. After all, agricultural production was subject to seasonal variations and ± 15 percent of uncertainty was estimated involving in these stages. When the agricultural product is a direct input of the industrial production stage, a value between ± 5 percent and ± 15 percent is calculated, based on the share of energy utilization in agriculture relatively with that of the total stage. The uncertainty was estimated to be ± 10 percent non-edible items due to the variability among different energy utilization practices by the manufacturers of the non-edible items accompanying the menu. Ozgener and Hepbaslı [143] revealed that the uncertainty with the values of CEnC was estimated to be ± 7.5 percent and that of CCO_2E was estimated to be ± 7.7 percent. The index which is suggested in this study is a measure of the energy efficiency. Variation of the values of the index cannot be tested in time and geographical location yet because of the lack of the comparative index values pertinent to the other countries. If data should be collected over time, the benefits of the proposed index may be assessed, further.

Energy efficiency and CO_2 emission are among the major factors affecting the sustainability of the food systems, but interaction of the economic, social and environmental factors may encourage production under the conditions non-sustainable different conditions. Environmental approaches of pasteurized milk production in Iran was studied by Rafiee et al. [144] and they focused on feed production, dairy farm and dairy factory to observe how and where Iranian pasteurized milk production might be made more environmentally friendly and energy efficient. Although dairy production ingredients are the significant part of the human diet. It is also in charge of important emissions of enormous greenhouse gases and other pollutants. Results reported by Rafiee et al. [144] demonstrated clearly that the production stage of feed was accounting for the largest parts of the environmental burdens. While comparing their results with those obtained in other countries Rafiee et al. [144] clarified that non-renewable energy demand in Iran for the production of alfalfa was three times of that in Spain. In order to be able to improve sustainability the policy makers and the practitioners who apply them should be aware of the effect of the energy utilization on the environment.

"*Greenhouse effect*" is among the major causes of the temperature increase in the atmosphere and the subsequent global climate change. It is caused by trapping of heat by the greenhouse gases including carbon dioxide in the atmosphere. These gases absorb radiated heat from the surface of the Earth and then the less atmosphere radiate majority of the reflected energy to the surface [145]. In the present study CO_2 accumulation, the atmosphere was shown to be increasing with the use of older technology.

3.2. THERMODYNAMIC ASSESSMENT OF WORK PRODUCTION VIA RANKINE CYCLE WITH INCINERATION OF THE FAST FOOD RESTAURANT WASTE WITH ATMOSPHERIC DRYING OF WASTES BEFORE COMBUSTION

3.2.1. Drying Method: Atmospheric Drying

During the atmospheric drying, a certain part of the packaging wastes was burned which provides necessary heat to remove present water within the food waste. The remaining packaging wastes and the dried food wastes were incinerated subsequently in the combustion chamber to provide heat to the Rankine cycle. Calculations were repeated for atmospheric drying before combustion by considering the air leaves the dryer has the temperature and relative humidity varying from 30°C to 50°C and from 70 percent to 90 percent, respectively.

As shown in Figure 3.1, in the atmospheric drying, amount of packaging wastes should be burned is calculated as 70.61 kg to supply required heat energy to remove water contained in the food waste.

Almost all these inedible constituents of the menu go to the waste along with the leftover edibles. The study revealed that 1 t fast food restaurant waste, after pressing its water out and pre-drying, can produce approximately 3.5 GW electricity, when used as a fuel in the Rankine cycle. Electric power produced via this process corresponds to 17,472 MJ/t hamburger menus. This is the recoverable amount from the utilized 40,844 MJ/t, therefore the non-recoverable fraction of the energy employed for hamburger menu production would actually be 23,412 MJ/t.

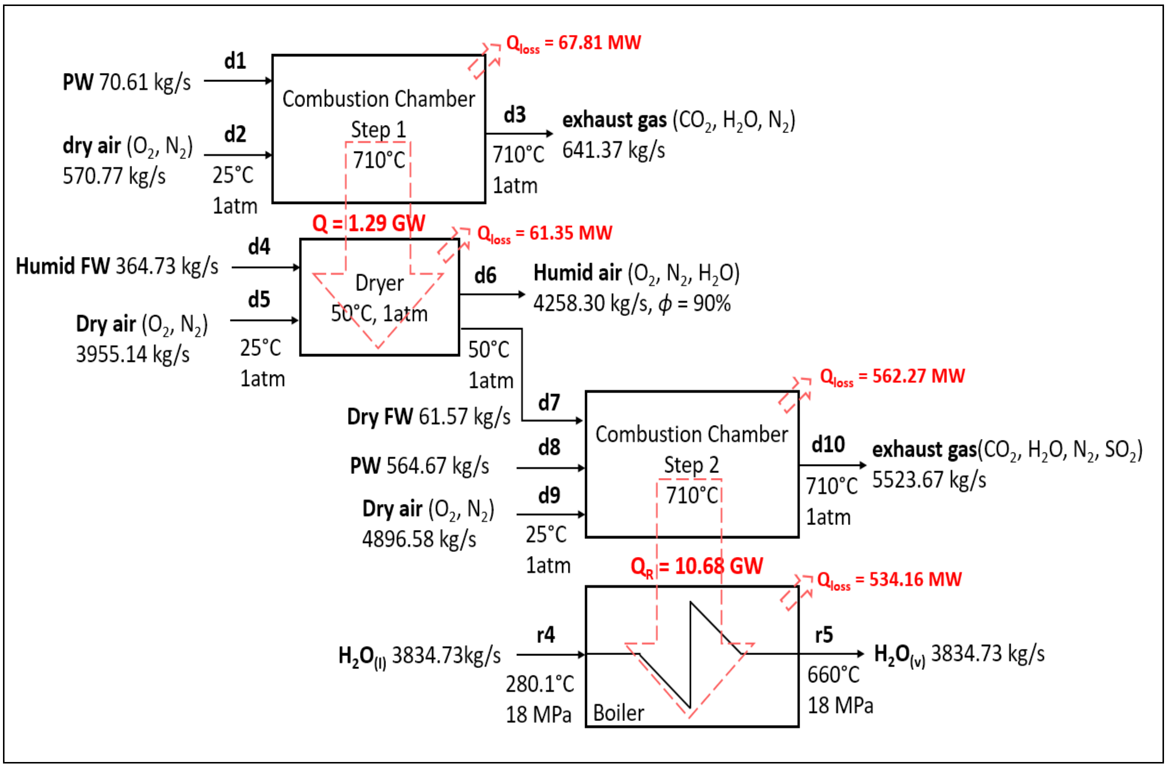


Figure 3.1. Flowchart of the atmospheric drying and combustion of the waste

As a result of combustion of abovementioned amount of packaging waste at 710 °C, 1.29 GW heat is supplied to the dryer. Note that, dryer is considered as operate at 50 °C and the humid air which carries the moisture removed from food waste has a relative humidity of 90 percent. Figure 3.2 shows the amount of packaging wastes required to supply heat load to the dryer at different drying temperatures and relative humidity of the exiting air.

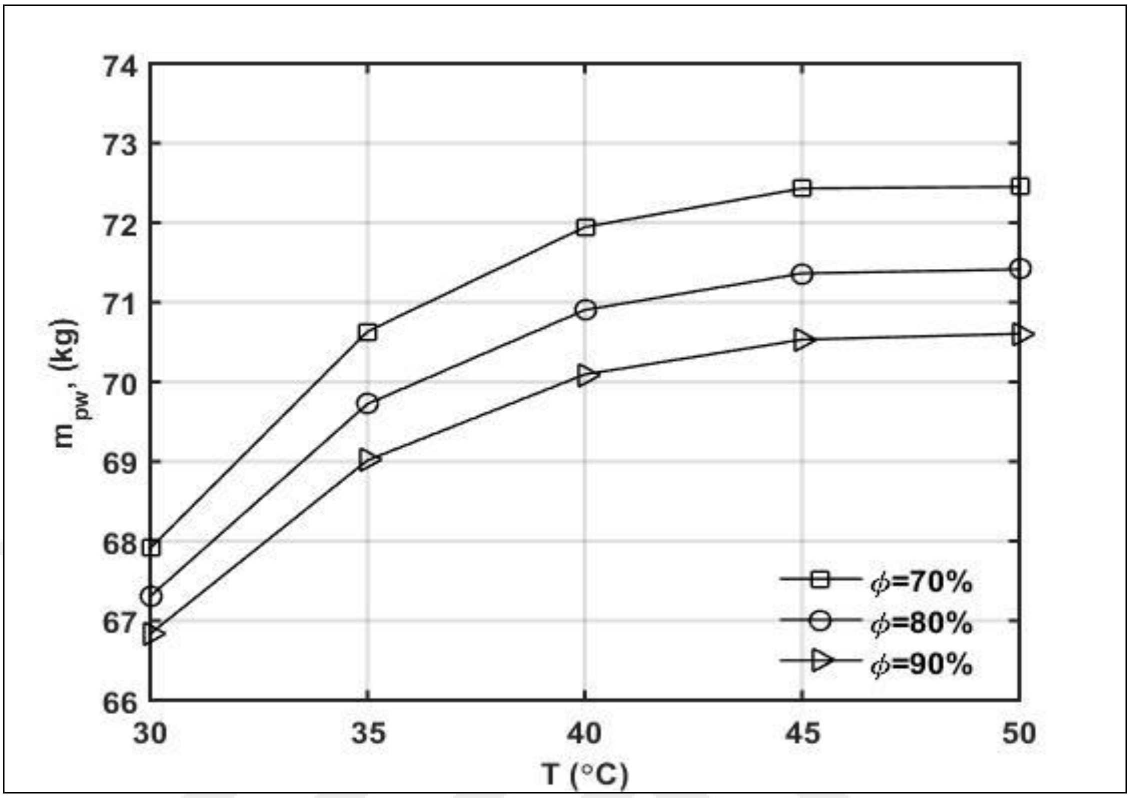


Figure 3.2. Rate of packaging waste burned in 1st step of the combustion for atmospheric drying

Since the amount of dry air needs to be supplied to carry the moisture transferred from food waste increases when relative humidity of the air at the exit decreases, more packaging wastes need to be burned if the air at the exit has lower relative humidity. In addition, although minor energy is required to vaporize water at higher temperatures, more packaging waste needs to be burned to overcome the drying process since temperature difference between drying and initial temperature increases. Table 3.15 shows the results of thermodynamic analysis of the atmospheric drying. At the end of the atmospheric drying process, the remaining packaging wastes and water-free food wastes enter the combustion chamber with the rates of 564.67 kg/s and 61.57 kg/s, respectively. Because of the second step of the combustion at 710 °C, 10.68 GW heat is supplied to the boiler of the Rankine cycle. If the all heat losses during drying and 1st and 2nd steps of combustion are somehow eliminated, 6.73 kg/s packaging waste is saved in the first step of combustion which can be used, after, in the second step of combustion process and has the potential to increase the rate of transferred heat into the boiler up to 6.5 percent. Nevertheless, approximately 80 percent of total heat loss and exergy destruction occur in the second step of combustion implying that the main attention should be paid to improve the second step of combustion, rather than that of first step and drying, to have higher amount of heat energy with lower rate of dissipated availability. Flow parameters and results of waste atmospheric drying, combustion and Rankine cycle with regeneration is submitted in Table 3.15.

Table 3.15. Flow parameters and results of waste atmospheric drying, combustion and Rankine cycle with regeneration

		Temperature	**Pressure**	**Mass Flow Rate**	**Energy Flow**	**Exergy Flow**
		T, (°C)	P, (MPa)	$\dot{m}$, (kg/s)	$\dot{m}h$, (MJ/s)	$\dot{m}ex$, (MJ/s)
d1	PW	25	0.1	70.61	-234.83	1991.54
d2	Dry air	25	0.1	570.77	0.00	0.00
	O_2	*25*	*0.1*	*132.99*	*0.00*	*0.00*
	N_2	*25*	*0.1*	*437.78*	*0.00*	*0.00*
d3	Exhaust	710	0.1	641.37	-1590.94	252.22
	CO_2	*710*	*0.1*	*150.82*	*-1261.25*	*97.68*
	H_2O	*710*	*0.1*	*52.78*	*-640.91*	*49.77*
	N_2	*710*	*0.1*	*437.78*	*311.22*	*104.77*
d4	Humid FW	25	0.1	364.73	-5144.45	1209.37
d5	Dry air	25	0.1	3955.14	0	0
	O_2	*25*	*0.1*	*921.58*	*0*	*0*

Table 3.15. Flow parameters and results of waste atmospheric drying, combustion and Rankine cycle with regeneration (continued)

	N_2	*25*	*0.1*	*3033.56*	*0*	*0*
d6	Humid air	50	0.1	4258.30	-3955.07	356.61
	O_2	*50*	*0.1*	*921.58*	*21.18*	*115.18*
	N_2	*50*	*0.1*	*3033.56*	*78.71*	*81.09*
	H_2O	*50*	*0.1*	*303.15*	*-4054.95*	*160.34*
d7	Dry FW	50	0.1	61.57	-719.86	496.46
d8	PW	25	0.1	564.67	-1878.06	15927.43
d9	Dry air	25	0.1	4896.58	0	0
	O_2	*25*	*0.1*	*1140.71*	*0*	*0*
	N_2	*25*	*0.1*	*3757.57*	*0*	*0*
d10	Exhaust	710	0.1	5523.67	-13845.32	2467.85
	CO_2	*710*	*0.1*	*1303.65*	*-10902.14*	*844.58*
	H_2O	*710*	*0.1*	*462.33*	*-5614.01*	*370.26*
	N_2	*710*	*0.1*	*3757.57*	*2671.31*	*1252.49*
	SO_2	*710*	*0.1*	*0.11*	*-0.48*	*0.53*
r1	$H_2O_{liq.}$	25	0.1	2821.79	296.09	0
r2	$H_2O_{liq.}$	25.15	2	2821.79	302.41	5.14

Table 3.15. Flow parameters and results of waste atmospheric drying, combustion and Rankine cycle with regeneration (continued)

r3	$H_2O_{liq.}$	212.38	2	3834.73	3484.32	704.06
r4	$H_2O_{liq.}$	216.06	18	3834.73	3569.26	780.92
r5	$H_2O_{vap.}$	660	18	3834.73	14252.45	6553.57
r6	$H_2O_{vap.}$	351.62	2	1012.94	3181.91	1083.33
r7	$H_2O_{vap.}$	113.38	0.1	2821.79	7627.49	1392.02
r8	H_2O_{liq}	5	0.1	83003.70	1744.68	236.23
r9	H_2O_{liq}	25	0.1	83003.70	402.38	0

Additionally, Table 3.16 describes the results of subsystems.

Table 3.16. Results of the subsystems

Subsystem	$\dot{Q}(MJ/s)$	$\dot{Q}_{loss}(MJ/s)$	$\dot{W}(MJ/s)$	$\dot{Ex}_{dest}(MJ/s)$
Combustion Chamber (Step 1)	-1288.31	-67.81	0	758.22
Dryer	1288.31	-61.35	0	956.65
Combustion Chamber (Step 2)	-10683.19	-562.27	0	7943.94
Pump 1	0	0	6.32	1.18
Open Feed Water Heater	0	0	0	3402.27
Pump 2	0	0	84.96	8.08
Boiler	10149.03	534.16	0	1497.16

Table 3.16. Results of the subsystems (continued)

Turbine	0	0	3443.72	635.17
Condenser	-6964.84 (to cw)	366.57	0	1544.44

4. CONCLUSIONS

Energy utilization and CO_2 emission assessed during farm-to fork hamburger menu production process with the data collected from the Turkish manufacturers. Energy utilization for the entire menu in Turkey was 40,844 MJ/t accompanied with 15,399 kg/t of CO_2 emission. Energy intensity associated with the production of the ingredients was found consistently in the lower end of the international range, implying that machinery was at least partially substituted with labor in some production lines. Meanwhile, CO_2 emission was at the higher end of the international range, emphasizing the use of relatively inefficient technology and pointing the need for improvement of mechanization and the level of the technology employed.

Combustion is among the major processes employed for elimination of the municipal waste. Waste from the fast food restaurants is generally too moist to be combusted without preliminary drying; therefore, performance of the Rankine cycle with regeneration was assessed in association with atmospheric drying. The waste from the fast food industry was assessed for possible electric generation via combustion in Rankine cycle with regeneration and found to have a potential for generation of 3.5 GW/t of waste.

Hamburger is an international food, produced with similar ingredients and formulation around the world. Its edible constituents, beef, potatoes, buns frying oil, etc., and non-edible constituents, e.g., items made of plastics, paper, wood, nails, etc., extend over a very large range. These similarities establish the basis for the Big Mac ® index, a practical global index used by the economists to assess numerous issues. Present study may offer a new dimension to this concept, without referring to a specific brand name. Our results suggest that energy utilization and CO_2 emission during manufacturing of ingredients of the hamburger menu are greatly influenced by how efficiently energy is utilized in a specific country. The results presented in this study show that energy intensity associated with the production of the ingredients of the hamburger menu in Turkey are consistently in the lower end of the range given in the literature, implying that in some production lines machinery were at least partially substituted with labor, in contrast with the practice in the more industrialized nations. On the contrary, CO_2 emission was at the higher end of the range, probably emphasizing the use of relatively older technology and pointed the need for improvement of mechanization and the level of the technology employed.

The results of this study appear to be convincing that choosing the hamburger menu as a representative “*basket*” may make it possible to start a new index to assess the energy utilization efficiency in the food industry of a country. This index may prove to be more useful, if data from other countries should become available.

REFERENCES

1. Carlsson-Kanyama A, Faist M. Energy use in the food sector: a data survey. *Swedish Technical Report of Environmental Protection Agency Stockholm,* Sweden; 2000: AFR-R-291.

2. Tokmak ATC. Tüketicilerin Türk üsülü fastfood işletmelerini tercih etme sebepleri üzerine bir araştırma. *Elektronik Sosyal Bilimler Dergisi.* 2007;22(22):169-181.

3. Ritzer G. *Explorations in the sociology of consumption: Fast food, credit cards and casinos*. London: Sage; 2001.

4. Royle T. *Working for McDonald's in Europe: the unequal struggle*. London: Routledge; 2004.

5. Schlosser E. *Fast food nation: The dark side of the all-American meal*. New-York: Houghton Mifflin Harcourt; 2012.

6. Food Outlook, FAO's food price index revisited: FAO; 2013 [cited 2015 21 September]Availablefrom:http://www.fao.org/fileadmin/templates/worldfood/Reports_and_docs/Special_feature_FFPI_en.pdf.

7. Ferrari G, Laureti T, Mostacci F. Time–Space harmonization of consumer price indexes in Euro-Zone countries. *International Advances in Economic Research*. 2005;11(4):359-78.

8. Reinsdorf M, Triplett JE. A review of reviews: Ninety years of professional thinking about the consumer price index. *Price index concepts and measurement*. University of Chicago Press; 2009: 17-83.

9. Csipak JJ, Zuccaro C. The CPI market basket: A review of economic and marketing validity issues. *Journal of Economics and Economic Education Research*. 2014;15(3):69-70.

10. Glazer F. Burgers boom even as consumers rein in restaurant spending. Nation's Restaurant News; [cited 2017 5 October]. Avaliable from: https://www.nrn.com/quick-service/how-mcdonald-s-became-symbol-fast-food.

11. Lynn J. Restaurant and Five Other Businesses. 2001.

12. Sökmen A. *Yiyecek içecek hizmetleri yönetimi ve işletmeciliği*. İstanbul: Detay Yayıncılık; 2005.

13. Parsley DC, Wei SJ. A Prism into the PPP Puzzles: The micro- foundations of big mac real exchange rates. *The Economic Journal*. 2007;117(523):1336-56.

14. Burgers or beans? A new theory is percolating through the foreign-exchange markets; [cited 2017 27 December]. Available from: http://www.econ.boun.edu.tr/elgin/starbucks.pdf

15. Lansingh VC, Carter MJ, Eckert KA, Winthrop KL, Furtado JM, Resnikoff S. Affordability of cataract surgery using the Big Mac prices. *Revista Mexicana de Oftalmologia*. 2015;89(1):21-30.

16. Fukumoto Y. International price dispersions of the Big Mac and economic integration. *Applied Economics Letters*. 2011;18(17):1633-8.

17. Ong LL, Mitchell JD. Professors and hamburgers: an international comparison of real academic salaries. *Applied Economics*. 2000;32(7):869-76.

18. Wilson JM, Wilson TK. Turning the Big Mac index into the medical Mac index. *Southern African Journal of Anaesthesia and Analgesia*. 2013;19(6):306-13.

19. Martinelli LA, Nardoto GB, Chesson LA, Rinaldi FD, Ometto JPH, Cerling TE, et al. Worldwide stable carbon and nitrogen isotopes of Big Mac® patties: an example of a truly “glocal” food. *Food Chemistry*. 2011;127(4):1712-8.

20. Singh RP, Carroad P, Chhinnan M, Rose W, Jacob N. Energy accounting in canning tomato products. *Journal of Food Science*. 1980;45(3):735-9.

21. Anundskas A. Technical improvements in mineral nitrogen fertilizer production. *Harvesting energy with fertilizers*. 2000:6.

22. Kongshaug G. Energy consumption and greenhouse gas emissions in fertilizer production. *IFA Tech Conf, Marrakech, Morocco*, 1998: Int. Fertilizer Industry Assoc.

23. Ramirez C, Blok K, Neelis M, Patel M. Adding apples and oranges: The monitoring of energy efficiency in the Dutch food industry. *Energy Policy*. 2006;34(14):1720-35.

24. Ma CM, Chen MH, Hong GB. Energy conservation status in Taiwanese food industry. *Energy Policy*. 2012;50:458-63.

25. Degerli B, Nazir S, Sorgüven E, Hitzmann B, Özilgen M. Assessment of the energy and exergy efficiencies of farm to fork grain cultivation and bread making processes in Turkey and Germany. *Energy*. 2015;93:421-34.

26. Klemes J, Smith R, Kim JK. *Handbook of water and energy management in food processing*. Cambridge: Elsevier; 2008.

27. Therkelsen P, Masanet E, Worrell E. Energy efficiency opportunities in the US commercial baking industry. *Journal of Food Engineering*. 2014;130:14-22.

28. Galitsky C, Worrell E. *Energy efficiency improvement and cost saving opportunities for the vehicle assembly industry: an energy star guide for energy and plant managers*. Berkeley: Lawrence Berkeley National Lab.(LBNL); 2008.

29. Khan S, Khan M, Hanjra M, Mu J. Pathways to reduce the environmental footprints of water and energy inputs in food production. *Food Policy*. 2009;34(2):141-9.

30. Özilgen M, Sorgüven E. Energy and exergy utilization, and carbon dioxide emission in vegetable oil production. *Energy*. 2011;36(10):5954-67.

31. Andersson K, Ohlsson T, Olsson P. Screening life cycle assessment (LCA) of tomato ketchup: a case study. *Journal of Cleaner Production*. 1998;6(3-4):277-88.

32. Carlsson-Kanyama A. Climate change and dietary choices—how can emissions of greenhouse gases from food consumption be reduced? *Food Policy*. 1998;23(3-4):277-93.

33. Montelongo- Luna JM, Svrcek WY, Young BR. An exergy calculator tool for process simulation. *Asia- Pacific Journal of Chemical Engineering*. 2007;2(5):431-7.

34. Balaji N. Modelling of transient temperature distribution during bread baking by finite difference analysis. *B Tech Thesis, IIT, Kharagpur, India*. 1991.

35. Decock P, Cappelle S. Bread technology and sourdough technology. *Trends in Food Science and Technology*. 2005;16(1-3):113-20.

36. Giannou V, Kessoglou V, Tzia C. Quality and safety characteristics of bread made from frozen dough. *Trends in Food Science and Technology*. 2003;14(3):99-108.

37. Stampfli L, Nersten B. Emulsifiers in bread making. *Food Chemistry*. 1995;52(4):353-60.

38. Delcour J, Hoseney RC. Principles of cereal science and technology authors provide insight into the current state of cereal processing. *Cereal Foods World*. 2010;55(1):21-2.

39. Foster C, Green K, Bleda M. Environmental impacts of food production and consumption: final report to the Department for Environment Food and Rural Affairs. 2007.

40. Martin J. Managing the envirmonmental stability in the European food and drink industries. Brussels: CIAA, 2007.

41. Spath LP, Mann, K.M. Life cycle assessment of a natural gas combined-cycle power generation system. U.S. Department of Energy: National Renewable Energy Laboratory 2000; [cited 2013 15 October]. Available from: http://library.umac.mo/ebooks/b28020261.pdf.

42. Viesi D, Pozzar F, Federici A, Crema L, Mahbub MS. Energy efficiency and sustainability assessment of about 500 small and medium-sized enterprises in Central Europe region. *Energy Policy*. 2017;105:363-74.

43. Glazer F. Burgers boom even as consumers rein in restaurant spending. Nation’s Restaurant News. 2008.

44. Idowu SO, Capaldi N, Zu L, Gupta AD. *Encyclopedia of corporate social responsibility*. New York: Springer; 2013.

45. Hoornweg D, Bhada-Tata P. Waste Generation. *World Bank Urban Development Series-Knowledge Papers.* 2011:03-15.

46. Istanbul Büyükşehir Belediyesi; [cited 2017 28 February]. Available from: http://www.ebelediye.info/dosya/belediyelerde-kati-atik-yonetimi.

47. Tatàno F, Caramiello C, Paolini T, Tripolone L. Generation and collection of restaurant waste: Characterization and evaluation at a case study in Italy. *Waste Management*. 2017;61:423-42.

48. Aarnio T, Hämäläinen A. Challenges in packaging waste management in the fast food industry. *Resources, Conservation and Recycling*. 2008;52(4):612-21.

49. Bucciol A, Montinari N, Piovesan M. Do not trash the incentive! Monetary incentives and waste sorting. *The Scandinavian Journal of Economics*. 2015;117(4):1204-29.

50. Lam CH, Ip AW, Barford JP, McKay G. Use of incineration MSW ash: a review. *Sustainability*. 2010;2(7):1943-68.

51. Yang GC, Chuang TN, Huang CW. Achieving zero waste of municipal incinerator fly ash by melting in electric arc furnaces while steelmaking. *Waste Management*. 2017;62:160-8.

52. Johnson DR. Nanometer-sized emissions from municipal waste incinerators: A qualitative risk assessment. *Journal of Hazardous Materials*. 2016;320:67-79.

53. Deng C, Xie H, Ye X, Zhang H, Liu M, Tong Y, et al. Mercury risk assessment combining internal and external exposure methods for a population living near a municipal solid waste incinerator. *Environmental Pollution*. 2016;219:1060-8.

54. Candela S, Bonvicini L, Ranzi A, Baldacchini F, Broccoli S, Cordioli M, et al. Exposure to emissions from municipal solid waste incinerators and miscarriages: A multisite study of the MONITER Project. *Environment International*. 2015;78:51-60.

55. Wongsa A, Boonserm K, Waisurasingha C, Sata V, Chindaprasirt P. Use of municipal solid waste incinerator (MSWI) bottom ash in high calcium fly ash geopolymer matrix. *Journal of Cleaner Production*. 2017;148:49-59.

56. Singh D, Kumar A. Geo-environmental application of municipal solid waste incinerator ash stabilized with cement. *Journal of Rock Mechanics and Geotechnical Engineering*. 2017;9(2):370-5.

57. Sun W, Yue X, Wang Y. Exergy efficiency analysis of ORC (Organic Rankine Cycle) and ORC-based combined cycles driven by low-temperature waste heat. *Energy Conversion and Management*. 2017;135:63-73.

58. Kim YM, Sohn JL, Yoon ES. Supercritical CO_2 Rankine cycles for waste heat recovery from gas turbine. *Energy*. 2017;118:893-905.

59. Toro C, Lior N. Analysis and comparison of solar-heat driven Stirling, Brayton and Rankine cycles for space power generation. *Energy*. 2017;120:549-64.

60. Kazemi N, Samadi F. Thermodynamic, economic and thermo-economic optimization of a new proposed organic Rankine cycle for energy production from geothermal resources. *Energy Conversion and Management*. 2016;121:391-401.

61. Guercio A, Bini R. Biomass-fired Organic Rankine Cycle combined heat and power systems. *Organic Rankine Cycle (ORC) Power Systems*: Elsevier; 2017: 527-67.

62. Roy P, Nei D, Okadome H, Nakamura N, Orikasa T, Shiina T. Life cycle inventory analysis of fresh tomato distribution systems in Japan considering the quality aspect. *Journal of Food Engineering*. 2008;86(2):225-33.

63. Tassou S, De-Lille G, Ge Y. Food transport refrigeration–Approaches to reduce energy consumption and environmental impacts of road transport. *Applied Thermal Engineering*. 2009;29(8-9):1467-77.

64. Lal R. Carbon emission from farm operations. *Environment International*. 2004;30(7):981-90.

65. Sainju UM. Comparison of Net Global warming potential and greenhouse gas intensity affected by management practices in two dryland cropping sites. *Journal of Environmental Protection*. 2015;6(09):1042.

66. Vink ET, Rabago KR, Glassner DA, Gruber PR. Applications of life cycle assessment to NatureWorks™ polylactide (PLA) production. *Polymer Degradation and Stability*. 2003;80(3):403-19.

67. Tipi T, Çetin B, Vardar A. An analysis of energy use and input costs for wheat production in Turkey. *Journal of Food, Agriculture and Environment*. 2009;7(2):352-6.

68. Oren MN, Ozturk HH. An analysis of energy utilization for sustainable wheat and cotton production in Southeastern Anatolia region of Turkey. *Journal of Sustainable Agriculture*. 2006;29(1):119-30.

69. Everman W. *Chemical weed control in wheat, barley, oats, rye, and triticale- North Carolina Agricultural Chemicals Manual.* North Carolina: NC State Extension Publications; 2015.

70. Suggested insecticides, rates, and restrictions for small-grain insect control: Penn State College of Agricultural Sciences Extension 2014; [cited 2014 24 July]. Available from: http://extension.psu.edu/agronomy-guide/pm/tables/table-2-5-8.

71. Small grains production Clemson Cooperative Extension 2014; [cited 2014 24 July]. Available from: https://www.clemson.edu/extension/rowcrops/small_grains/pdfs/disease_control.pdf.

72. Hellevang KJ. Grain moisture content effects and management NDSU Agriculture and Extension 2015; [cited 2015 24 April]. Available from: https://www.ag.ndsu.edu/extension-aben/documents/ae905.pdf.

73. Moghimi MR, Alasti BM, Drafshi MAH. Energy input-output and study on energy use efficiency for wheat production using DEA technique. *International Journal of Agriculture and Crop Sciences*. 2013;5(18):2064.

74. Houshyar E, Sheikh Davoodi M, Nassiri S. Energy efficiency for wheat production using data envelopment analysis (DEA) technique. *Journal of Agricultural Technology*. 2010;6(4):663-72.

75. Zhang L, Ning D, Kang L, Fang K, Xia T, Cao L. Preparation of reducing sugar from corn bran by steam explosion combined with acid hydrolysis: process optimization using

response surface methodology and analysis of hydrolysis degree. *Food Science*. 2016;37(16):75–82.

76. Helsel ZR. Energy and alternatives for fertilizer and pesticide use. *Energy in Farm Production*. 1992;6:177-201.

77. Banaeian N, Omid M, Ahmadi H. Energy and economic analysis of greenhouse strawberry production in Tehran province of Iran. *Energy Conversion and Management*. 2011;52(2):1020-5.

78. Brehmer B. Chemical biorefinery perspectives: the valorisation of functionalised chemicals from biomass resources compared to the conventional fossil fuel production route.2008.

79. Erdal G, Esengün K, Erdal H, Gündüz O. Energy use and economical analysis of sugar beet production in Tokat province of Turkey. *Energy*. 2007;32(1):35-41.

80. Koknaroglu H. Cultural energy analyses of dairy cattle receiving different concentrate levels. *Energy Conversion and Management*. 2010;51(5):955-8.

81. Saygın D, Patel MK, Tam C, Gielen DJ, editors. Chemical and Petrochemical sector. Potential of best practice technology and other measures for improving energy efficiency. *IEA Information Paper*; 2009: Citeseer.

82. Barber A. *EcoCover™, Woody Mulch and LDPE primary energy and greenhouse gas emissions*. New Zealand: EcoCover International Limited; February 2011.

83. Sorgüven E, Özilgen M. Energy utilization, carbon dioxide emission, and exergy loss in flavored yogurt production process. *Energy*. 2012;40(1):214-25.

84. Gielen D, Tam C, editors. Proposal for energy and CO_2 emission indicators in the petrochemical sector. *IEA Workshop: Feedstock Fubstitutes, Energy Efficient Technology and CO_2 Reduction for Petrochemical Products in Collaboration with CEFIC IEA, Paris*; 2006.

85. Carbon dioxide and GHG emissions values; ecological footprint values; life cycle assessment data sources Switzerland: MDPI; [cited 2018 3 August]. Available from: www.mdpi.com/2071-1050/5/5/1960/s1.

86. Chow S, Ganji AR, Hackett B, editors. Opportunities for energy efficiency and demand response in corrugated cardboard manufacturing facilities. *Industrial Energy Technology Conference Louisiana*; 2005: IETC.

87. Szargut J, Morris DR, Steward FR. *Exergy analysis of thermal, chemical, and metallurgical processes*. Orlando: Hemisphere; 1987.

88. Muthu SS. *The carbon footprint handbook*. New-York: CRC Press; 2015.

89. Özilgen M. Assessment of the energy utilization and carbon dioxide emission reduction potential of the microbial fertilizers. A case study on “farm-to-fork” production chain of Turkish desserts and confections. *Journal of Cleaner Production*. 2017;a 165: 564-78.

90. Karakaya A, Özilgen M. Energy utilization and carbon dioxide emission in the fresh, paste, whole-peeled, diced, and juiced tomato production processes. *Energy*. 2011;36(8):5101-10.

91. M. EAaO. Effect of manure utilisation preferences on the sustainability of model network of chicken meat and egg producing and consuming businesses. *Int. J. Sustainable Agricultural Management and Informatics*. 2018;4:2-151.

92. Özilgen M. Energy utilization and carbon dioxide emission during production of snacks. *Journal of Cleaner Production*. 2016;112:2601-12.

93. Özilgen M. Assesment of the use of zero-emission vehicles and microbial fertilizers in beverage production. *Journal of Cleaner Production*. 2017;165:298-311.

94. Bartocci P, Fantozzi P, Fantozzi F. Environmental impact of Sagrantino and Grechetto grapes cultivation for wine and vinegar production in central Italy. *Journal of Cleaner Production*. 2017;140:569-80.

95. Szargut J, MORRIS D, Steward F. *Exergy analysis of thermal, chemical and metallurgical processes.* New York (NY): Hemisphere Publishing Co;1988.

96. Reddy PJ. *Clean coal technologies for power generation.* Boston: CRC Press; 2013.

97. BSI British Standarts. *PAS 2050 DefRA. Guide to PAS 2050-How to assess the carbon footprint of goods and services*. London: British Library Cataloguing in Publication Data Press; 2008.

98. Energy B. Energy baseline study for municipal wastewater treatment plants. *Report prepared by BASE Energy, Inc, San Francisco, USA for the Pacific Gas and Electric Company New Construction Energy Efficiency Program*. 2006.

99. Jankowski MD, Henry CS, Broadbelt LJ, Hatzimanikatis V. Group contribution method for thermodynamic analysis of complex metabolic networks. *Biophysical Journal*. 2008;95(3):1487-99.

100. Self-Nutrition Data; [cited 2014 6 October]. Available from: http://nutritiondata.self.com/.

101. Szargut J. International progress in second law analysis. *Energy*. 1980;5(8-9):709-18.

102. Sorguven E, Özilgen M. Thermodynamic assessment of algal biodiesel utilization. *Renewable Energy*. 2010;35(9):1956-66.

103. Rakopoulos CD, Giakoumis EG. Second-law analyses applied to internal combustion engines operation. *Progress in Energy and Combustion Science*. 2006;32(1):2-47.

104. A. B. *Advanced engineering thermodynamics*. New York: Wiley; 1988.

105. Ozilgen M, Oner ES. *Biothermodynamics: principles and applications*. Istanbul: CRC Press; 2016.

106. Perry RH, Green, DW, and Maloney JO. *Perry’s chemical engineers handbook*- 7th ed. New York: McGraw-Hill; 1999.

107. Singh J. *On farm energy use pattern in different cropping systems in Haryana, India.* Flensburg: International Institute of Management, University of Flensburg; 2002.

108. Klingler RW. *Grundlagen der Getreidetechnologie*. Hamburg: Behr's Verlag DE; 2010.

109. Food and Agriculture Organization of the United Nations; [cited 2018 8 August]. Available from: http://www.fao.org/docrep/x5738e/x5738e0j.htmFCDRFmpAa.

110. Energy saving in flour milling-Grain and feed milling technology magazine; [cited 2018 25 June]. Available from: https://www.slideshare.net/GFMT/energy-saving-in-flour-milling.

111. Klingler RW. *In: Getreidetechnologie Gd*. Hamburg: B. Behr's Verlag; 2010.

112. Cauvain SP, Young LS. *Technology of breadmaking.* BakeTran: Springer Science Business Media; 2007.

113. Codina GG, Mironeasa S, Voica DV, Mironeasa C. Multivariate analysis of wheat flour dough sugars, gas production, and dough development at different fermentation times. *Czech Journal of Food Science*. 2013;31(3).

114. Stear CA. *Handbook of breadmaking technology*. Hampshire: Elsevier Science Publishers Ltd.; 2012.

115. Percentages Bs.; [cited 2014 24 July]. Available from: http:// www.artisanbakers.com/ percentage.html.

116. Şenel H. *Hayvan besleme.* İstanbul: İstanbul Üniversitesi Veteriner Fakültesi Yayınları; 1986.

117. Coşkun B, İnal F, Şeker E. *Hayvan Besleme*. Konya: Selçuk Üniversitesi, Veteriner Fakültesi Yayınları; 1997.

118. Lattouf R, Oliveira, S. Exergy analysis of environmental impact mitigation processes. *17th International Congress of Mechanical Engineering*; November 10 – 14,2003; Sao Paulo 2003.

119. Woodgate S, Van Der Veen J. The role of fat processing and rendering in the European Union animal production industry. *Biotechnologie, Agronomie, Société et Environnement*. 2004;8(4):283-94.

120. Prokop WH. Food and Agriculture Industry. *Section on rendering plants*. Van Nostrand Reinhold, New York: Air Pollution Engineering Manual; 1992.

121. Moore SR. Energy efficiency in small-scale biointensive organic onion production in Pennsylvania, USA. *Renewable Agriculture and Food Systems*. 2010;25(3):181-8.

122. Djevic M, Dimitrijevic A. Greenhouse energy consumption and energy efficiency. *Balkan Agricultural Engineering Review*. 2004;5:1-9.

123. Abdir TM, Akbarpour M. An Analysis of energy input-output and emissions of greenhouse gases from agricultural productions. *International Journal of Natural and Engineering Sciences*. 2012;6(3):73-79.

124. Mohammadi A, Tabatabaeefar A, Shahin S, Rafiee S, Keyhani A. Energy use and economical analysis of potato production in Iran a case study: Ardabil province. *Energy Conversion and Management*. 2008;49(12):3566-70.

125. Laurijssen J, Marsidi M, Westenbroek A, Worrell E, Faaij A. Paper and biomass for energy?: The impact of paper recycling on energy and CO_2 emissions. *Resources, Conservation and Recycling*. 2010;54(12):1208-18.

126. Philip A, Sebastian K. *Environmental analysis of pallets using life cycle analysis and multi-objective dynamic programming*. Pennsylvania: The Pennsylvania State University; 2010.

127. Sense:Harmonised Environmental Sustainability in the European Food and Drinks; [cited 2018 17 June]. Available from: http://esu-services.ch/projects/lcafood/sense/.

128. Ramirez C, Patel M, Blok K. How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries. *Energy*. 2006;31(12):2047-63.

129. Rentfrow G. *How much meat to expect from a carcass. A consumer's guide to purchasing freezer meats Cooperative Extension Service.* Lexington: University of Kentucky College of Agriculture; 2010.

130. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities, Defra project report IS0205; [cited 2018 3 May]. Available from: *http://randd defra gov uk/Default aspx*.

131. Roy P, Orikasa T, Thammawong M, Nakamura N, Xu Q, Shiina T. Life cycle of meats: an opportunity to abate the greenhouse gas emission from meat industry in Japan. *Journal of Environmental Management*. 2012;93(1):218-24.

132. Desjardins RL, Worth DE, Vergé XP, Maxime D, Dyer J, Cerkowniak D. Carbon footprint of beef cattle. *Sustainability*. 2012;4(12):3279-301.

133. Ernest Orlando Lawrence Berkeley National Laboratory; [cited 2017 1 October]. Available from: https://www.energystar.gov/ia/business/industry/Fruit_and_Vegetables_Energy_Guide.pdf.

134. Talburt WF, Schwimmer S, Burr HK, Talburt WF. *Structure and chemical composition of the potato tuber*. New-York: Van Nostrand Company; 1987.

135. Wu H, Jouhara H, Tassou S, Karayiannis T. Modelling of energy flows in potato crisp frying processes. *Applied Energy*. 2012;89(1):81-8.

136. van Loon WA, Linssen JP, Legger A, Heijmans RM, van Deventer HC, Burgering MJ, et al. Study of a new energy efficient process for French fries production. *European Food Research and Technology*. 2005;221(6):779-86.

137. Genc S, Hepbasli A. Performance assessment of a potato crisp frying process. *Drying Technology*. 2015;33(7):865-75.

138. Kramer KJ, Moll HC, Nonhebel S. Total greenhouse gas emissions related to the Dutch crop production system. *Agriculture, Ecosystems and Environment*. 1999;72(1):9-16.

139. Coca Cola Company Turkish; [cited 2018 12 September]. Available from: https://www.cci.com.tr/surdurulebilirlik/oncelikli-alanlarimiz.

140. Van der Werf HM, Petit J. Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. *Agriculture, Ecosystems and Environment*. 2002;93(1-3):131-45.

141. Girardin P, Bockstaller C, Van der Werf H. Assessment of potential impacts of agricultural practices on the environment: the AGRO* ECO method. *Environmental Impact Assessment Review*. 2000;20(2):227-39.

142. López L-A, Cadarso M-A, Gómez N, Tobarra M-Á. Food miles, carbon footprint and global value chains for Spanish agriculture: assessing the impact of a carbon border tax. *Journal of Cleaner Production*. 2015;103:423-36.

143. Ozgener O, Hepbasli A. Performance analysis of a solar-assisted ground-source heat pump system for greenhouse heating: an experimental study. *Building and Environment*. 2005;40(8):1040-50.

144. Rafiee S, Khoshnevisan B, Mohammadi I, Aghbashlo M, Clark S. Sustainability evaluation of pasteurized milk production with a life cycle assessment approach: An Iranian case study. *Science of the Total Environment*. 2016;562:614-27.

145. Karl TR, Melillo JM, Peterson TC, Hassol SJ. *Global climate change impacts in the United States.*New York: Cambridge University Press; 2009.

146. De Vries M, de Boer IJM. Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock. Science*. 2010;128(1-3):1-11.

APPENDIX A: RAW DATA OBTAINED FROM THE MANUFACTURERS

Table A.1. Raw data obtained from slaughtering plant

Addition	**Flux**	**Composition %**	**Raw Data Mass Flow Rate**	**Unit For Mass Flow Rate**	**Balanced Mass Flow Rate**	**Unit**	**Energy Used To Produce That Material (MJ/Kg)**	**Unit**	**Total Cumulative Energy (MJ)**	**CO_2 Consumption Kg Per Kg**
	Slaughter Plant								0	
INPUT	Concentrate		789600	Kg /(Cow Year)	23.85	Kg	2.80	MJ/Kg	66.8	5.4
400 Cows Per Day	Roughage		260400	Kg /(Cow Year)	7.86	Kg	2.80	MJ/Kg	22.0	1.8
6-6.5 Tonnes Per Laroy. About 12-13 Cows	Diesel Oil		680727.3	Kg /(Cow Year)	20.56	Kg	57.45	MJ/Kg	1,181.7	19.0
	Electricity		2559168	MJ/(Cow Year	77.32		1.00	MJ/Kg	77.3	10.7
	Water		120000	M3 /(Cow Year)	3.62		0.00	MJ/Kg	0.0	
	Cow	10909	60000000	Kg /(Cow Year)	1812.9	Kg				
	Fat	10.3	6180000	Kg /(Cow Year)	186.7	Kg	39.00	MJ/Kg	7,282.5	
	Protein	19.7	11820000	Kg /(Cow Year)	357.1	Kg	23.80	MJ/Kg	8,500.0	
	Water	70	42000000	Kg /(Cow Year)	1269.03	Kg	0.00	MJ/Kg	0.0	

Table A.1. Raw data obtained from slaughtering plant (continued)

The Delivery For Truck 17500 Kg/250 Kg Carcas, 2 Container Per Day	Transport To Meat Processing Factory		249200.6	Kg /(Cow Year)	7.52		57.45	MJ/Kg	432.6	7.0
OUTPUT	Organic Manure		2520000	Kg /(Cow Year)	76.14				0.0	
	Hemicellulose	21	529200	Kg /(Cow Year)	15.98	Kg				
	Cellulose	25	630000	Kg /(Cow Year)	19.035	Kg				
	Lignin	13	327600	Kg /(Cow Year)	9.89	Kg				
	Protein	12	302400	Kg /(Cow Year)	9.13	Kg	0.00	MJ/Kg	0.0	
	Ash	9	226800	Kg /(Cow Year)	6.85	Kg				
1920	**Raw Meat**		33600000	Kg /(Cow Year)	1,015.2					
	Protein	19.7	6619200	Kg /(Cow Year)	200	Kg	23.80	MJ/Kg	4,760.0	
	Fat	10.3	3460800	Kg /(Cow Year)	104.568	Kg	39.00	MJ/Kg	4,078.2	
	Water	70	23520000	Kg /(Cow Year)	710.65	Kg	0.00	MJ/Kg	0.0	
	Cutting Meat								0.0	
İnlet	Fresh Meat(4C)		1000	Kg/Ton Patty	1,015.2	Kg			0.0	
	Fat	10.3	103	Kg/Ton Patty	104.6	Kg	39.00	MJ/Kg	4,078.2	

Table A.1. Raw data obtained from slaughtering plant (continued)

	Protein	19.7	197	Kg/Ton Patty	200.0	Kg	23.80	MJ/Kg	4,760.0	
	Water	70	700	Kg/Ton Patty	710.7	Kg	0.00	MJ/Kg	0.0	
Cutting Process)	Electricity		23.976	MJ/Ton Patty	24.3	MJ	1.00	MJ/Kg	24.3	3.4
Cooling +4 C	Electricity		2.543655	MJ/Ton Patty	2.6	MJ	1.00	MJ/Kg	2.6	0.4
Freezing -18 C	Electricity		28.69898	MJ/Ton Patty	29.1	MJ	1.00	MJ/Kg	29.1	4.0
Boxing	PVC		400	Kg/Ton Patty	406.1	Kg	57.00	MJ/Kg	23,147.2	720.0
OUTPUT	For Delivery				0.0	Kg			0.0	
	Frozen Meat(-18 C)		500	Kg/Ton Patty	507.6	Kg			0.0	
	Fat	10.3	51.5	Kg/Ton Patty	52.3	Kg	39.00	MJ/Kg	2,039.1	
	Protein	19.7	98.5	Kg/Ton Patty	100.0	Kg	23.80	MJ/Kg	2,380.0	
	Water	70	350	Kg/Ton Patty	355.3	Kg	1.02	MJ/Kg	362.4	
	Fresh Meat(+4C)		500	Kg/Ton Patty	507.6	Kg			0.0	
	Fat	10.3	51.5	Kg/Ton Patty	52.3	Kg	39.00	MJ/Kg	2,039.1	
	Protein	19.7	98.5	Kg/Ton Patty	100.0	Kg	23.80	MJ/Kg	2,380.0	
	Water	70	350		355.3	Kg	1.02	MJ/Kg	362.4	
	Grinding Meat								0.0	
INPUT	Fresh Meat(4C)		500	Kg/Ton Patty	507.6	Kg			0.0	
	Fat	10.3	51.5	Kg/Ton Patty	52.3	Kg	39.00	MJ/Kg	2,039.1	
	Protein	19.7	98.5	Kg/Ton Patty	100.0	Kg	23.80	MJ/Kg	2,380.0	
	Water	70	350	Kg/Ton Patty	355.3	Kg	0.00	MJ/Kg	0.0	
	Frozen Meat(-18 C)		500	Kg/Ton Patty	507.6				0.0	
	Fat	10.3	51.5	Kg/Ton Patty	52.3	Kg	39.00	MJ/Kg	2,039.1	
	Protein	19.7	98.5	Kg/Ton Patty	100.0	Kg	23.80	MJ/Kg	2,380.0	
	Water	70	350	Kg/Ton Patty	355.3	MJ	0.00	MJ/Kg	0.0	

Table A.1. Raw data obtained from slaughtering plant (continued)

	Electricity		88.776	MJ/Ton Patty	90.1	MJ	1.00	MJ/Kg	90.1	12.45
OUTPUT					0.0	Kg			0.0	
	Grinding Meat		998	Kg/Ton Patty	1,013.2	Kg			0.0	
	Fat	10.3	102.794	Kg/Ton Patty	104.4	Kg	39.00	MJ/Kg	4,070.0	
	Protein	19.7	196.606	Kg/Ton Patty	199.6	Kg	23.80	MJ/Kg	4,750.5	
	Water	70	698.6	Kg/Ton Patty	709.2	Kg	1.02	MJ/Kg	723.4	
					0.0				0.0	
	Mixing With Seasonings And Grinding									
INPUT	Fat Added Grinding Meat(-5 / -2°C)		998	Kg/Ton Patty	1,013.2	Kg			0.0	
	Fat	25	249.5	Kg/Ton Patty	253.3	Kg	39.00	MJ/Kg	9,878.7	
	Protein	12	119.76	Kg/Ton Patty	121.6	Kg	23.80	MJ/Kg	2,893.7	
	Water	63	628.74	Kg/Ton Patty	638.3	Kg	0.00	MJ/Kg	0.0	
					0.0				0.0	
	Mix Seasoning		102	Kg/Ton Patty	103.6	Kg				
	Fat	24.42	24.9084	Kg/Ton Patty	25.3		39.00	MJ/Kg	986.2	
	Protein	18.25	18.615	Kg/Ton Patty	18.9		23.80	MJ/Kg	449.8	
	Water	56.83	57.9666	Kg/Ton Patty	58.8		0.00	MJ/Kg	0.0	
	Salt	0.4	0.408	Kg/Ton Patty	0.4		0.00	MJ/Kg	0.0	
	Paper Cartonboard		2.0808	Kg/Ton Patty	2.1		43.30	MJ/Kg	91.5	2.21
	LDPE		0.66096	Kg/Ton Patty	0.7	Kg	87.00	MJ/Kg	58.4	1.26
	Electricity		119.88	MJ/Ton Patty	121.7	Kg	1.00	MJ/Kg	121.7	15.26

Table A.1. Raw data obtained from slaughtering plant (continued)

OUTPUT	Seasoned & Grinded Meat		1100	Kg/Ton Patty	1,116.8				0.0	
	Protein	15	165	Kg/Ton Patty	167.5	Kg	23.80	MJ/Kg	3,986.8	
	Fat	20	220	Kg/Ton Patty	223.4	Kg	39.00	MJ/Kg	8,710.7	
	Carbohydrate	7	77	Kg/Ton Patty	78.2	Kg	17.90	MJ/Kg	1,399.3	
	Water	55	605	Kg/Ton Patty	614.2	Kg	0.00	MJ/Kg	0.0	
	Forming Meat								0.0	
									0.0	
INPUT	Seasoned & Grinded Meat		1100	Kg/Ton Patty	1,116.8	Kg			0.0	
	Protein	15	165	Kg/Ton Patty	167.5	Kg	23.80	MJ/Kg	3,986.8	
	Fat	20	220	Kg/Ton Patty	223.4	Kg	39.00	MJ/Kg	8,710.7	
	Carbohydrate	7	77	Kg/Ton Patty	78.2	Kg	17.90	MJ/Kg	1,399.3	
	Water	55	605	Kg/Ton Patty	614.2	Kg	0.00	MJ/Kg	0.0	
	Electricity		86.4	MJ/ Ton Patty	87.7	Kg	1.00	MJ/Kg	87.7	11.6
OUTPUT	Hamburger Patty		1045	Kg/Ton Patty	1,060.9	Kg			0.0	
	Protein	15	156.75	Kg/Ton Patty	159.1	Kg	23.80	MJ/Kg	3,787.5	
	Fat	20	209	Kg/Ton Patty	212.2	Kg	39.00	MJ/Kg	8,275.1	
	Carbohydrate	7	73.15	Kg/Ton Patty	74.3	Kg	17.90	MJ/Kg	1,329.3	
	Water	55	574.75	Kg/Ton Patty	583.5	Kg	0.00	MJ/Kg	0.0	
									0.0	
	Freezing								0.0	
INPUT	Hamburger Patty		1045	Kg/Ton Patty	1,060.9	Kg			0.0	
	Protein	15	156.75	Kg/Ton Patty	159.1	Kg	23.80	MJ/Kg	3,787.5	
	Fat	20	209	Kg/Ton Patty	212.2	Kg	39.00	MJ/Kg	8,275.1	

Table A.1. Raw data obtained from slaughtering plant (continued)

	Carbohydrate	7	73.15	Kg/Ton Patty	74.3	Kg	17.90	MJ/Kg	1,329.3	
	Water	55	574.75	Kg/Ton Patty	583.5	Kg	0.00	MJ/Kg	0.0	
	Electricity		56.3976	MJ/Ton Patty	57.3	MJ	1.00	MJ/MJ	57.3	7.63
					0.0				0.0	
OUTPUT	Frozen Hamburger Patty (-15-18 C)		1035	Kg/Ton Patty	1,050.8				0.0	
	Protein	15	155.25	Kg/Ton Patty	157.6	Kg	23.80	MJ/Kg	3,751.2	
	Fat	20	207	Kg/Ton Patty	210.2	Kg	39.00	MJ/Kg	8,195.9	
	Carbohydrate	7	72.45	Kg/Ton Patty	73.6	Kg	17.90	MJ/Kg	1,316.6	
	Water	55	569.25	Kg/Ton Patty	577.9	Kg	0.00	MJ/Kg	0.0	
	Foreign Material Controlling(X Ray). Boxing And Stacking				0.0				0.0	
(-15-18 C)	Frozen Hamburger Patty		1035	Kg/Ton Patty	1,050.8				0.0	
	Protein	15	155.25	Kg/Ton Patty	157.6	Kg	23.80	MJ/Kg	3,751.2	
	Fat	20	207	Kg/Ton Patty	210.2	Kg	39.00	MJ/Kg	8,195.9	
	Carbohydrate	7	72.45	Kg/Ton Patty	73.6	Kg	17.90	MJ/Kg	1,316.6	
	Water	55	569.25	Kg/Ton Patty	577.9	Kg	0.00	MJ/Kg	0.0	
					0.0				0.0	
X Ray	Electricity		9.576	MJ/Ton Patty	9.7	MJ	1.00	MJ/Kg	9.7	1.4
Stacker	Electricity		11.88	MJ/Ton Patty	12.1	MJ	1.00	MJ/MJ	12.1	1.69
					0.0	MJ		MJ/MJ	0.0	0

Table A.1. Raw data obtained from slaughtering plant (continued)

Boxing (500 G Per A Box. Labelling Paper)	Paper (Cartonboard)		76	Kg/Ton Patty	77.2	Kg	43.30	MJ/Kg	3,341.0	90.3
150 G	LDPE		23	Kg/Ton Patty	23.1	Kg	87.00	MJ/Kg	2,013.9	48.6
OUTPUT	Packed And Staked Frozen Hamburger Patty		985	Kg/Ton Patty	1,000.0	Kg			0.0	
	Protein	15	147.75	Kg/Ton Patty	150.0	Kg	23.80	MJ/Kg	3,570.0	
	Fat	20	197	Kg/Ton Patty	200.0	Kg	39.00	MJ/Kg	7,800.0	
	Carbohydrate	7	68.95	Kg/Ton Patty	70.0	Kg	17.90	MJ/Kg	1,253.0	
	Water	55	541.75	Kg/Ton Patty	550.0	Kg	0.00	MJ/Kg	0.0	
	Storage & Tranportation								0.0	
INPUT									0.0	
	Packed And Staked Frozen Hamburger Patty		985	Kg/Ton Patty	1,000.0	Kg			0.0	
	Protein	15	147.75	Kg/Ton Patty	150.0	Kg	23.80	MJ/Kg	3,570.0	
	Fat	20	197	Kg/Ton Patty	200.0	Kg	39.00	MJ/Kg	7,800.0	
	Carbohydrate	7	68.95	Kg/Ton Patty	70.0	Kg	17.90	MJ/Kg	1,253.0	
	Water	55	541.75	Kg/Ton Patty	550.0	Kg	0.00	MJ/Kg	0.0	
Cooling	Electricity		565.35	MJ/Ton Patty	574.0	Kg	1.00	MJ/Kg	574.0	80.35431472
Collecting	Electricity		11.988	MJ/Ton Patty	0.1	Kg	1.00	MJ/Kg	0.1	

Table A.1. Raw data obtained from slaughtering plant (continued)

30 Box Per A Pallet	Diesel Oil		0.022483	Kg/Ton Patty	0.02	MJ	57.45	MJ/Kg	1.3	0.021455535
									0.0	
OUTPUT	Refrigrated Packed And Staked Frozen Hamburger Patty		985	Kg/Ton Patty	1,000.0	Kg			0.0	
	Protein	15	147.75	Kg/Ton Patty	150.0		23.80	MJ/Kg	3,570.0	
	Fat	20	197	Kg/Ton Patty	200.0		39.00	MJ/Kg	7,800.0	
	Carbohydrate	7	68.95	Kg/Ton Patty	70.0	Kg	17.90	MJ/Kg	1,253.0	
	Water	55	541.75	Kg/Ton Patty	550.0	Kg	0.00	MJ/Kg	0.0	

Table A.2. Raw data obtained from pickled cucumber plant

Addition	**Flux**	**Composition %**	**Raw Data Mass Flow Rate**	**Unit For Mass Flow Rate**	**Balanced Mass Flow Rate**	**Unit**	**Energy Used To Produce That Material (MJ/Kg)**	**Unit**	**Total Cumulative Energy (MJ)**	**CO_2 Consumption Kg Per Kg**
	Cucumber (Agriculture)								0	
INPUT M=88123 Kg /Ha	Literature								0.0	
	Cucumber Seed		0.15	Kg/(Ha)	0.025	Kg	1	MJ/Ha	0.025	
	Water		1,769.00	M3/(Ha)	293.4	Kg	0.001	MJ/Kg	0.3	0
	Electricity		2,056.00	Kg/(Ha)	341.0	MJ/Kg	1.00	MJ/MJ	341.0	3.27
	Nitrogen		2.10	Kg/(Ha Year)	0.3	Kg/Ha Year	66.14	MJ/MJ	23.0	0.17
	Phosphate(P2 O5)		325.00	Kg/(Ha Year)	53.9	Kg/Ha Year	12.44	MJ/Kg	670.5	9.96
	Potasium(K2O)		251.00	Kg/(Ha Year)	41.6	Kg/Ha Year	11.15	MJ/Kg	464.1	71.21
	Organic Manure		14,200.00	Kg/(Ha Year)	2,354.9	Kg/Ha Year	0.30	MJ/Kg	714.2	
	Hemicellulose	0.28	3,976.00	Kg/(Ha Year)	659.4	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Cellulose	0.28	3,976.00	Kg/(Ha Year)	659.4	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Lignin	0.2	2,840.00	Kg/(Ha Year)	471.0	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Protein	0.15	2,130.00	Kg/(Ha Year)	353.2	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Ash	0.09	1,278.00	Kg/(Ha Year)	211.9	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Insecticide		4.20	Kg/(Ha Year)	0.7	Kg/Ha Year	101.20	MJ/Kg	70.5	0.24
	Herbiced		2.50	Kg/(Ha Year)	0.4	Kg/Ha Year	238.00	MJ/Kg	98.7	0.18
	Fungicides		3.40	Kg/(Ha)	0.6	Kg	216.00	MJ/Kg	121.8	0.15
	Diesel Oil		1,165.00	L/(Ha)	193.2	Kg	56.30	MJ/Kg	10,877.2	12.4
	Diesel Oil		0.0021	Kg/ Kg Of	30.4	Kg	56.30	MJ/Kg	1,709.0	1.95
OUTPUT					0.0					

Table A.2. Raw data obtained from pickled cucumber plant (continued)

	Cucumber		88,123.00	Kg/(Ha)	14,614.1	Kg	0.8	MJ/Ha	11,691.306	
	Water	96.0	84,598.08	Kg/(Ha)	14,029.6	Kg	0.00	MJ/Kg	0.0	
	Protein	0.8	704.98	Kg/(Ha)	116.9	Kg	23.80	MJ/Kg	2,782.5	
	Fat	0.2	132.18	Kg/(Ha)	21.9	Kg	39.00	MJ/Kg	854.9	
	Carbohydrate	3.0	2,643.69	Kg/(Ha)	438.4	Kg	17.90	MJ/Kg	7,847.8	
				Ha	0.1658					
	Receiving & Calibrating & Sorting & Washing Cucumber									
INPUT	Cucumber		6,000.00	Kg/H	14,614.1	Kg			0.0	
	Protein	0.8	48.00	Kg/H	116.9	Kg	23.80	MJ/Kg	2,782.5	
	Fat	0.2	9.00	Kg/H	21.9	Kg	39.00	MJ/Kg	854.9	
	Carbohydrate	3.0	180.00	Kg/H	438.4	Kg	17.90	MJ/Kg	7,847.8	
	Water	96.0	5,760.00	Kg/H	14,029.6	Kg	0.00	MJ/Kg	0.0	
	PVC(525x365 x200mm)		390.00	Kg	949.9	Kg	57.00	MJ/Kg	54,145.4	469
	Water		0.00	M3/H	0.0		0.001	MJ/Kg	0.0	0
	Electricity		97.20	MJ/Day	236.7	MJ	1.00	MJ/MJ	236.7	9.1
OUTPUT								64.89735		
	Sorted & Washed Cucumber		1,497.75	Kg/Day	3,648.1	Kg			0.0	
Waste (About 1.91 %)	Protein	0.8	11.98	Kg/Day	29.2	Kg	23.80	MJ/Kg	694.6	
	Fat	0.2	2.25	Kg/Day	5.5	Kg	39.00	MJ/Kg	213.4	
	Carbohydrate	3.0	44.93	Kg/Day	109.4	Kg	17.90	MJ/Kg	1,959.0	

Table A.2. Raw data obtained from pickled cucumber plant (continued)

	Water	96.0	1,437.84	Kg/Day	3,502.1	Kg	0.00	MJ/Kg	0.0	
	Preparation Of Brine									
INPUT	Water		7,948.75	Kg/Batch	3,177.5	Kg	0.00	MJ/Kg	0.0	
	Salt	12.0	1,095.12	Kg/Batch	437.8	Kg	0.00	MJ/Kg	0.0	
Per 30 Lt Acetic Acid	PE		0.80	Kg/Batch	0.3	Kg	46.50		14.9	0.01
	Electricity		8.10	MJ/Batch	3.2	MJ	1.00	MJ/MJ	3.2	0.12
OUTPUT									0.0	
	Salted Water(Brine)		9,126.00	Kg/Batch	3,648.1	Kg	0.00	MJ/Kg	0.0	
	Water	88	8,030.88	Kg/Batch	3,210.3		0.00	MJ/Kg	0.0	
	Salt	12	1,095.12	Kg/Batch	437.8	Kg	0.00	MJ/Kg	0.0	
	Fermentation								0	
INPUT	**Sorted & Washed Cucumber**		9,000.00	Kg/Batch	3,648.1	Kg			0.0	
	Protein	0.8	72.00	Kg/Batch	29.2	Kg	23.80	MJ/Kg	694.6	
	Fat	0.2	18.00	Kg/Batch	7.3	Kg	23.80	MJ/Kg	173.6	
	Carbohydrate	3.0	270.00	Kg/Batch	109.4	Kg	39.00	MJ/Kg	4,268.2	
	Water	96.0	8,640.00	Kg/Batch	3,502.1	Kg	0.00	MJ/Kg	0.0	
	K-Sorbate	0.1	18.00	Kg/Batch	7.3	Kg	0.00	MJ/Kg	0.0	
	Na-Benzoat	0.1	18.00	Kg/Batch	7.3	Kg	0.00	MJ/Kg	0.0	
	Cacl2	0.2	18.25	Kg/Batch	7.3	Kg	0.00	MJ/Kg	0.0	
	Acetic Acid	0.5	90.00	Kg/Batch	36.5	Kg	0.00	MJ/Kg	0.0	
	Salted Brine		9,000.00	Kg/Batch	3,648.1	Kg		MJ/Kg		

Table A.2. Raw data obtained from pickled cucumber plant (continued)

	Water	88	7,920.00	Kg/Batch	3,210.3	Kg	0.00	MJ/Kg	0.0	
	Salt	12	1,080.00	Kg/Batch	437.8		0.00	MJ/Kg	0.0	
Per 30 Lt Acetic Acid	HDPE		2.40	Kg/Batch	1.0	Kg	3.20	MJ/Kg	3.1	0.6
	Electricity		259.20	MJ/Batch	105.1	MJ	1.00	MJ/MJ	105.1	21.8
OUTPUT									0.0	
Waste Of Cucumber	Fermented Cucumber		1,667.59	Kg/Batch	675.9	Kg			0.0	
	Protein	0.46	7.67	Kg/Batch	3.0	Kg	23.80	MJ/Kg	71.5	
% 8 Atık.08 Kg	Carbohydrate	1	16.68	Kg/Batch	6.8	Kg	17.90	MJ/Kg	121.0	
	Water	85.54	1,426.46	Kg/Batch	578.2	Kg	0.00	MJ/Kg	0.0	
	Salt	12.0	200.11	Kg/Batch	81.1	Kg	0.00	MJ/Kg	0.0	
					0.4					
	Slicing				0				0	
INPUT					0.0				0.0	
	Fermented Cucumber		1,725.00	Kg/Batch	675.9	Kg			0.0	
	Protein	0.46	7.94	Kg/Batch	3.1	Kg	23.80	MJ/Kg	74.0	
	Carbohydrate	1	17.25	Kg/Batch	6.8	Kg	17.90	MJ/Kg	121.0	
	Water	85.54	1,475.57	Kg/Batch	578.2	Kg	0.00	MJ/Kg	0.0	
	Salt	12.0	207.00	Kg/Batch	81.1	Kg	0.00	MJ/Kg	0.0	
	Electricity		28.80	MJ/Batch	11.3	MJ	1.00	MJ/MJ	11.3	2.4

Table A.2. Raw data obtained from pickled cucumber plant (continued)

OUTPUT					0.0					
	Fermented & Sliced Cucumber		1,699.13	Kg/Batch	665.8	Kg				
	Protein	0.46	7.82	Kg/Batch	3.1	Kg	23.80	MJ/Kg	72.9	
	Carbohydrate	1	16.99	Kg/Batch	6.7	Kg	17.90	MJ/Kg	119.2	
	Water	85.54	1,453.43	Kg/Batch	569.5	Kg	0.00	MJ/Kg	0.0	
	Salt	12.0	203.90	Kg/Batch	79.9	Kg	0.00	MJ/Kg	0.0	
	Standardisation								0	
INPUT									0.0	
	Fermented & Sliced Cucumber		1,699.13	Kg/Batch	665.8	Kg			0.0	
	Protein	0.46	7.82	Kg/Batch	3.1	Kg	23.80	MJ/Kg	72.9	
	Carbohydrate	1	16.99	Kg/Batch	6.7	Kg	17.90	MJ/Kg	119.2	
	Salt	12.0	203.90	Kg/Batch	79.9	Kg	0.00	MJ/Kg	0.0	
	Water	85.54	1,453.43	Kg/Batch	569.5	Kg	0.00	MJ/Kg	0.0	
	Electricity		28.80	MJ/Batch	11.3	MJ	1.00	MJ/MJ	11.3	2.87
Washing	Water		1,000.00	Kg/Batch	391.8	Kg	0.001	MJ/Kg	0.4	99.7
OUTPUT	Packaging				0.0					
0,2 % Acidity 5 % Salty Product	Standardisated & Fermented & Sliced Cucumber		1,403.63	Kg/Batch	550.0	Kg			0.0	
	Protein	0.46	6.46	Kg/Batch	2.5	Kg	23.80	MJ/Kg	60.2	

Table A.2. Raw data obtained from pickled cucumber plant (continued)

	Carbohydrate	1	14.04	Kg/Batch	5.5	Kg	17.90	MJ/Kg	98.5	
	Water	92.53	1,298.77	Kg/Batch	508.9	Kg	0.00	MJ/Kg	0.0	
	Salt	5.0	70.18	Kg/Batch	27.5	Kg	0.00	MJ/Kg	0.0	
	Pastorisation Of Brine								0	
INPUT	Water		1,403.63	Kg/Batch	2,561.8	Kg	0.00	MJ/Kg	0.0	
	Salt	5.0	70.15	Kg/Batch	128.0	Kg	0.00	MJ/Kg	0.0	
	Water		10.00	M3/Batch	18.3	Kg	0.00	MJ/Kg	0.0	
	Diesel Oil		26.67	Kg/Batch	48.7	Kg	57.45	MJ/Kg	2,796.8	21.8
	Electricity		14.40	MJ/Batch	26.3	MJ	1.00	MJ/MJ	26.3	1.76
OUTPUT										
2 Salt % And 1.8 % Acetic Acid Pasteuried Brine	Salted Water(Brine)		1,148.42	Kg/Batch	2,096.0	Kg	0.00	MJ/Kg	0.0	
	Water	98	1,125.45	Kg/Batch	2,054.1	Kg	0.00	MJ/Kg	0.0	
	Salt	2.0	22.97	Kg/Batch	41.9	Kg	0.00	MJ/Kg	0.0	
					1.8					
	Packaging								0	
INPUT									0.0	
	Standardisated & Fermented & Sliced Cucumber		1,531.20	Kg/Batch	600.0	Kg			0.0	
	Protein	0.46	7.04	Kg/Batch	2.8	Kg	23.80	MJ/Kg	65.7	
	Salt	3.0	45.94	Kg/Batch	18.0	Kg	0.00	MJ/Kg	0.0	
	Carbohydrate	1	15.31	Kg/Batch	6.0	Kg	17.90	MJ/Kg	107.4	

Table A.2. Raw data obtained from pickled cucumber plant (continued)

	Water	94.54	1,447.60	Kg/Batch	567.2	Kg	0.00	MJ/Kg	0.0	
	Electricity		87.30	MJ/Batch	34.2	MJ	1.00	MJ/MJ	34.2	4.79
	Diesel Oil		7.00	M3/Batch	2.7	MJ	57.45	MJ/Kg	157.6	2.58
	Water		3.00	M3/Batch	1.2	MJ	0.00	MJ/Kg	0.0	0.16
	Salted Water(Brine)		1,020.80	Kg/Batch						
	Water	98	1,000.38		392.0		0.00		0.0	
	Salt	2.0	20.42	Kg/Batch	8.0	Kg	0.00	MJ/Kg	0.0	
3 Kg. Totally 6 Packs	PET		267.75	Kg/Batch	104.9	Kg	4.80	MJ/Kg	503.6	22.03
	Corrugated Board		5.95	Kg/Batch	2.3	Kg	43.30	MJ/Kg	101.0	273
Shrink (2.36 Pallet. 30 G Per A Pallet) And 141 Tray	LDPE		4.04	Kg/Batch	1.6	Kg	87.00	MJ/MJ	137.7	3.32
OUTPUT					0.0					
Waste 1 % ,25.5245 Kg	1 % Acidity Ve 3-3.5 % Salty Fermented Sliced. Standardized Cucumber		2,552.00	Kg/Batch	1,000.0	Kg			0.0	

Table A.2. Raw data obtained from pickled cucumber plant (continued)

	Protein	0.46	11.74	Kg/Batch	4.6	Kg	23.80	MJ/Kg	109.5	
	Carbohydrate	1	25.52	Kg/Batch	10.0	Kg	17.90	MJ/Kg	179.0	
	Water	94.53	2,412.41	Kg/Batch	945.3	Kg	0.00	MJ/Kg	0.0	
	Salt	3.0	76.56	Kg/Batch	30.0	Kg	0.00	MJ/Kg	0.0	
	Storage and Transportation								0	
INPUT									0.0	
	Pastrurised Fermented And Filled Pickled Cucumber		2,552.00	Kg/Batch	1,000.0	Kg			0.0	
	Salt	3.0	76.56	Kg/Batch	30.0	Kg	0.00	MJ/Kg	0.0	
	Protein	0.46	11.74	Kg/Batch	4.6	Kg	23.80	MJ/Kg	109.5	
	Carbohydrate	1	25.52	Kg/Batch	10.0	Kg	17.90	MJ/Kg	179.0	
	Water	94.53	2,412.41	Kg/Batch	945.3	Kg	0.00	MJ/Kg	0.0	
	Electricity		42.12	MJ/Batch	16.5	MJ	1.00	MJ/MJ	16.5	2.31
Delivery To Market	Diesel Oil		0.003744	Kg/Kg Pickled Cucumber	3.7	Kg/H	57.45	MJ/Kg	215.1	3.52
OUTPUT										
141.78	Packed Sliced Cucumber		2,552.00	Kg/Batch	1,000.0	Kg			0.0	
2.36	Protein	0.46	11.74	Kg/Batch	4.6	Kg	23.80	MJ/Kg	109.5	
1080	Carbohydrate	1	25.52	Kg/Batch	10.0	Kg	17.90	MJ/Kg	179.0	
	Water	94.53	2,412.41	Kg/Batch	945.3	Kg	0.00	MJ/Kg	0.0	
33 Pallet Track	Salt	3.0	50.97	Kg/Batch	20.0	Kg	0.00	MJ/Kg	0.0	

Table A.3. Raw data obtained from carbonated drink plants

	Flux	Composition %	Raw Data Mass Flow Rate	**Unit For Mass Flow Rate**	Balanced Mass Flow Rate	**Unit**	**Energy Used To Produce That Material (MJ/Kg)**	**Unit**	Total Cumulative Energy (MJ)	CO_2 Consumption Kg Per Kg
	Processing Water									
INPUT	Water		29,782,942	Kg/Year	1,025.6	Kg	0.00	MJ/Kg	0.00	
					0.0					
	Electricity		10,454	MJ/Year	0.4	MJ	1.00	MJ/MJ	0.36	0.06
OUTPUT					0.0					
	Processing Water		24,502,500	Kg/Year	843.79	Kg	0.00	MJ/Kg	0.00	
	Preparation Of Simple Syrup									
INPUT										
	Sugar		3,136,320	Kg/Year	108.01	Kg	16.00	MJ/Kg	1,728.1	
	Water		1,344,137	Kg/Year	46.29	Kg	0.00	MJ/Kg	0.0	
Melting	Natural Gas		29	MJ/H	0.00	MJ	50.00	MJ/MJ	0.0	0.00
OUTPUT					0.0					
	Liquid Sugar		4,480,457	Kg/Year	154.3	Kg	0.00	MJ/Kg	0.0	
	Sugar	70	3,136,320	Kg/Year	108.0	Kg	16.00	MJ/Kg	1,728.1	
	Water	30	1,344,137	Kg/Year	46.3	Kg	0.00	MJ/Kg	0.0	
	Mixing								0	

Table A.3. Raw data obtained from carbonated drink plants (continued)

INPUT			29,040,238		1,000.0					
	Liquid Sugar	10.8	4,076,108	Kg/Year	140.4	Kg	16.00	MJ/Kg	2,245.8	
	Carbondioxide	0.82	238,128	Kg/Year	8.2	Kg		MJ/Kg	0.0	
	Caffeine	0.145	42,108	Kg/Year	1.5	Kg	17.56	MJ/Kg	25.5	
	Phosphoric Acid	0.6	174,241	Kg/Year	6.0	Kg		MJ/Kg	0.0	
	Cola Flavour	0.01	2,904	Kg/Year	0.1	Kg	0.00	MJ/Kg	0.0	
	Caramel	0.01	2,904	Kg/Year	0.1	MJ	0.00	MJ/MJ	0.0	
	Processing Water	87.615	24,503,844	Kg/Year	843.8	Kg	0.00	MJ/Kg	0.0	
					0.0				0.0	
Mixer	Electricity		124,407	MJ/H	4.3		1.00	MJ/MJ	4.3	0.600
Filtration	Electricity		129	MJ/H	0.004		1.00	MJ/MJ	0.0	0.001
OUTPUT									0.0	
	Filtred Mixed. Carbondioxided Anf Fiiled Product İn Steel Keg		29,040,238	Kg/Year	1,000.0				0.0	
	Protein	0.1	29,040	Kg/Year	1.0	Kg	23.80	MJ/Kg	23.8	
	Fat	0.1	14,520	Kg/Year	0.5	Kg	39.00	MJ/Kg	19.5	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	
					0.00003				0.0	
	Filling. Labeling And Coding For Kegs								0.0	

Table A.3. Raw data obtained from carbonated drink plants (continued)

INPUT									0.0	
	Capped & Filled Carbonated Soft Drink		29,040,238	Kg/Year	1,000.0	Kg			0.0	
	Protein	0.1	29,040	Kg/Year	1.0	Kg	23.80	MJ/Kg	23.8	
	Fat	0.1	14,520	Kg/Year	0.5	Kg	39.00	MJ/Kg	19.5	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	
Label	Paper		232,320	Kg/Year	8.0	Kg	16.50	MJ/Kg	132.0	15.03987674
Washing.Filling Electricity		9680.07933	191,666		6.6		1.00	MJ/MJ	6.6	0.924
Stainless Kegs	Packaging		580,805	Kg/Per Year	20.0	Kg				
OUTPUT									0.0	
	Coded & Labelled &Capped & Filled Carbonated Soft Drink		29,040,238	Kg/Year	1,000.0				0.0	
	Protein	0.1	29,040	Kg/Year	1.0	Kg	23.80	MJ/Kg	23.8	
	Fat	0.1	14,520	Kg/Year	0.5	Kg	39.00	MJ/Kg	19.5	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	
	Palletesing &Streching								0.0	

Table A.3. Raw data obtained from carbonated drink plants (continued)

INPUT									0.0	
	Coded & Labelled &Capped & Filled Carbonated Soft Drink		29,040,238	Kg/Year	1,000.0	Kg			0.0	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Protein	0.1	14,520	Kg/Year	0.5	Kg	23.80	MJ/Kg	11.9	
	Fat	0.0	0	Kg/Year	0.0	Kg	39.00	MJ/Kg	0.0	
	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	
Streching For Pallet 38 G Per A Pallet	LDPE		3,120	Kg/Year	0.1	Kg/H	87.00	MJ/Kg	9.3	0.23
Streching.Palletig And Transporting for Pallet	Electricity		58,942	MJ/H	2.0		1.00	MJ/MJ	2.0	0.28
OUTPUT									0.0	
	Palletlised & Coded & Labelled &Capped & Filled Carbonated Soft Drink		29,040,238	Kg/Year	1,000.0				0.0	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Protein	0.1	14,520	Kg/Year	0.5	Kg	23.80	MJ/Kg	11.9	
	Fat	0.0	0	Kg/Year	0.0	Kg	39.00	MJ/Kg	0.0	
	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	

Table A.3. Raw data obtained from carbonated drink plants (continued)

	Storage & Tranportaion								0.0	
INPUT									0.0	
	Palletlised & Coded & Labelled &Capped & Filled Carbonated Soft Drink		29,040,238	Kg/Year	1,000.0	Kg			0.0	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Protein	0.1	14,520	Kg/Year	0.5	Kg	23.80	MJ/Kg	11.9	
	Fat	0.0	0	Kg/Year	0.0	Kg	39.00	MJ/Kg	0.0	
	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	
Delivery To The Market 18 Kegs Per A Pallet	Diesel Oil		70,886	Kg	2.44	MJ	57.45	MJ/Kg	140.2	2.294492525
			15,840						0.0	
OUTPUT					1000.0	12	83.33		83,333.3	
	İn The Market Palletlised & Coded & Labelled &Capped & Filled Carbonated Soft Drink		29,040,238	Kg/Year	1000.0				0.0	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Protein	0.1	14,520	Kg/Year	0.5	Kg	23.80	MJ/Kg	11.9	
	Fat	0.0	0	Kg/Year	0.0	Kg	39.00	MJ/Kg	0.0	

Table A.3. Raw data obtained from carbonated drink plants (continued)

	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	
INPUT	**Serving**									
	Soft Drink İn Keg		0	Kg/Year	0.0	Kg			0.0	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Protein	0.1	14,520	Kg/Year	0.5	Kg	23.80	MJ/Kg	11.9	
	Fat	0.0	0	Kg/Year	0.0	Kg	39.00	MJ/Kg	0.0	
	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	
Dispenser Electricty 125 Glass/ 50 Litres Keg	Electricity		6,307	Kg	0.2	MJ	1.00	MJ/MJ	0.2	0.0
			15,840						0.0	
OUTPUT					1000.0	12	83.33		83,333.3	
	Soft Drink İn Glass		0	Kg/Year	1000.0				0.0	
	Carbohydrate	10.3	2,991,145	Kg/Year	103.0	Kg	17.90	MJ/Kg	1,843.7	
	Protein	0.1	14,520	Kg/Year	0.5	Kg	23.80	MJ/Kg	11.9	
	Fat	0.0	0	Kg/Year	0.0	Kg	39.00	MJ/Kg	0.0	
	Water	89.6	26,020,053	Kg/Year	896.0	Kg	0.00	MJ/Kg	0.0	
	Processing Water And İce									
INPUT	Water		547	Kg/Year	547.4	Kg	0.00	MJ/Kg	0.00	
					0.0					
	Electricity		17	MJ/Year	17.3	MJ	1.00	MJ/MJ	0.19	0.05
Ice	Electricity		26		26.5		1.00	MJ/MJ	26.50	8.24
OUTPUT					0.0					
	Processing Water		450	Kg/Year	450.0	Kg	0.00	MJ/Kg	0.00	

Table A.4. Raw data obtained from frozen potatoes plant

	Flux	Raw Data Mass Flow Rate	Unit For Mass Flow Rate	Balanced Mass Flow Rate	Unit	Energy Used To Produce That Material (MJ/Kg)	Unit	Total Cumulative Energy (MJ)	CO$_2$ Consumption Kg Per Kg
	Potatoes Production (Agriculture & Processing)								
INPUT M=28453.61 Kg /Ha Year	Literatur Data							0.0	
	Potatoes Seed	3092	Kg/(Ha Year)	217.3	Kg/Ha Year	3.6	MJ/Kg	782.4	
	Water	11146	Kg/(Ha Year)	783.4	M3/Ha Year	0.00	MJ/Kg	0.8	
	Nitrogenous (NH4NO3)	402	Kg/(Ha Year)	28.3	Kg/Ha Year	78.20	MJ/Kg	2,212.3	100.6
	Phosphate(P2O5)	284	Kg/(Ha Year)	20.0	Kg/Ha Year	17.50	MJ/Kg	349.6	27.0
	Potasium(K2O)	205	Kg/(Ha Year)	14.4	Kg/Ha Year	13.80	MJ/Kg	198.4	179.7
	Sulfur	297	Kg/(Ha Year)	20.9	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Zinc	2	Kg/(Ha Year)	0.2	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Organic Manure	27845	Kg/(Ha Year)	1,957.3	Kg/Ha Year	0.3033	MJ/Kg	593.6	
	Hemicellulose	866	Kg/(Ha Year)	548.0	Kg/Ha Year				

Table A.4. Raw data obtained from frozen potatoes plant (continued)

	Cellulose	3121	Kg/(Ha Year)	548.0	Kg/Ha Year				
	Lignin	80	Kg/(Ha Year)	391.5	Kg/Ha Year				
	Protein	43	Kg/(Ha Year)	293.6	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Ash	18	Kg/(Ha Year)	176.2	Kg/Ha Year				
	Insecticide	2	Kg/(Ha Year)	0.2	Kg/Ha Year	120.00	MJ/Kg	18.6	0.5
	Herbiced	1	Kg/(Ha Year)	0.1	Kg/Ha Year	120.00	MJ/Kg	7.2	0.2
					Kg/Ha Year				
	Diesel Oil	290	L/(Ha Year)	20.4	Kg/Ha Year	57.50	MJ/Kg	1,172.3	9.6
	Transportation Diesel	0		1.4	Kg/Ha Year	57.45	MJ/Kg	82.3	0.7
INPUT Potatoes M=15840 Ton /Year For Factory									
OUTPUT		28453		2,000.0	Kg/Ha Year			0.0	
	Water	22762		1,600.0	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Starch	3870		340.0	Kg/Ha Year	14.38	MJ/Kg	4,889.2	
	Protein	77		40.0	Kg/Ha Year	23.80	MJ/Kg	952.0	

Table A.4. Raw data obtained from frozen potatoes plant (continued)

	Ash	1	Ha	20.0	Kg/Ha Year	0.00	MJ/Kg	0.0	
	Destoning. Pre Sorting And Washing								
INPUT	Raw Potatoes	2000	Kg/H	2,000.0	Kg/H				
	Water	1600	Kg/H	1,600.0	Kg/H	0.00	MJ/Kg	0.0	
	Starch	340	Kg/H	340.0	Kg/H	14.38	MJ/Kg	4,889.2	
	Protein	40	Kg/H	40.0	Kg/H	23.80	MJ/Kg	952.0	
	Ash	10	Kg/H	10.0	Kg/H	0.00	MJ/Kg	0.0	
	Electricity	24	MJ/Kg	24.1	MJ	1.00	MJ/MJ	24.1	1.8
	Water	1	M3/H	0.5	M3/H	0.00	MJ/Kg	0.0	
OUTPUT									
	Patotoes (Losses 3.6)	1928	Kg/H	1,928.0	Kg/H				
Cleaning Loss(%3.6)	Water	1581	Kg/H	1,581.0	Kg/H	0.00	MJ/Kg	0.0	
	Starch	289	Kg/H	289.2	Kg/H	14.38	MJ/Kg	4,158.7	
	Protein	39	Kg/H	38.6	Kg/H	23.80	MJ/Kg	917.7	
	Ash	19	Kg/H	19.3	Kg/H	0.00	MJ/Kg	0.0	
	Peeling								
INPUT	Cleaned Potatoes	1900	Kg/H	1,900.0	Kg/H				
	Water	1558	Kg/H	1,558.0	Kg/H	0.00	MJ/Kg	0.0	
	Starch	285	Kg/H	285.0	Kg/H	14.38	MJ/Kg	4,098.3	
	Protein	38	Kg/H	38.0	Kg/H	23.80	MJ/Kg	904.4	
	Ash	10	Kg/H	9.5	Kg/H	0.00	MJ/Kg	0.0	
	Electricity	24	MJ/Kg	24.3	MJ	1.00	MJ/MJ	24.3	2.6
OUTPUT									

Table A.4. Raw data obtained from frozen potatoes plant (continued)

	Patotoes (Loss %30)	1330	Kg/H	1,330.0	Kg/H				
Peeler Loss(%30)	Water	1091	Kg/H	1,090.6	Kg/H	0.00	MJ/Kg	0.0	
	Starch	200	Kg/H	199.5	Kg/H	14.38	MJ/Kg	2,868.8	
	Protein	27	Kg/H	26.6	Kg/H	23.80	MJ/Kg	633.1	
	Ash	13	Kg/Day	13.3	Kg/H	0.00	MJ/Kg	0.0	
	Sorting(Trimming Etc)							0	
INPUT	Potatoes	1330	Kg/H	1,330.0	Kg/H				
	Water	1091	Kg/H	1,090.6	Kg/H	0.00	MJ/Kg	0.0	
	Starch	200	Kg/H	199.5	Kg/H	14.38	MJ/Kg	2,868.8	
	Protein	27	Kg/H	26.6	Kg/H	39.00	MJ/Kg	1,037.4	
	Ash	13	Kg/H	13.3	Kg/H	0.00	MJ/Kg	0.0	
	Electricity	14	MJ/Kg	13.5	MJ	1.00	MJ/MJ	13.5	1.5
OUTPUT									
Trimming Loss (%4)	Patotoes (Loss %4)	1277	Kg/H	1,276.8	Kg/H				
	Water	1047	Kg/H	1,047.0	Kg/H	0.00	MJ/Kg	0.0	
	Starch	192	Kg/H	191.5	Kg/H	14.38	MJ/Kg	2,754.1	
	Protein	26	Kg/H	25.5	Kg/H	23.80	MJ/Kg	607.8	
	Ash	13	Kg/H	12.8	Kg/H	0.00	MJ/Kg	0.0	
	Cutting								
INPUT									
	Potatoes	1277	Kg/H	1,276.8	Kg/H				
	Water	1047	Kg/H	1,047.0	Kg/H	0.00	MJ/Kg	0.0	
	Starch	192	Kg/H	191.5	Kg/H	14.38	MJ/Kg	2,754.1	

Table A.4. Raw data obtained from frozen potatoes plant (continued)

	Protein	26	Kg/H	25.5	Kg/H	23.80	MJ/Kg	607.8	
	Ash	13	Kg/H	12.8	Kg/H	0.00	MJ/Kg	0.0	
	Electricity	17	MJ/Kg	16.9	MJ	1.00	MJ/MJ	16.9	1.9
OUTPUT									
Cutting Loss (%3)	Patotoes (9*9 Mm)(Loss %3)	1239	Kg/H	1,238.8	Kg/H				
	Water	1016	Kg/H	1,015.8	Kg/H	0.00	MJ/Kg	0.0	
	Starch	186	Kg/H	185.8	Kg/H	14.38	MJ/Kg	2,672.1	
	Protein	25	Kg/H	24.8	Kg/H	23.80	MJ/Kg	589.7	
	Ash	12	Kg/H	12.4	Kg/H	0.00	MJ/Kg	0.0	
	Blanching							0	
INPUT								0.0	
	Potatoes	1239	Kg/H	1,238.8	Kg/H				
	Water	1016	Kg/H	1,015.8	Kg/H	0.00	MJ/Kg	0.0	
	Starch	186	Kg/H	185.8	Kg/H	14.38	MJ/Kg	2,672.1	
	Protein	25	Kg/H	24.8	Kg/H	23.80	MJ/Kg	589.7	
	Ash	12	Kg/H	12.4	Kg/H	0.00	MJ/Kg	0.0	
	Water	10	M3/H	10.0	M3/H	0.00	MJ/Kg	0.0	
	Electricity	15	MJ/Kg	15.5	MJ	1.00	MJ/MJ	15.5	1.8
OUTPUT									
Blanched Loss (%2.1)	Patotoes (Losses %2)	1213	Kg/H	1,212.8	Kg/H				
	Water	994	Kg/H	994.5	Kg/H	0.00	MJ/Kg	0.0	
	Starch	182	Kg/H	181.9	Kg/H	14.38	MJ/Kg	2,616.0	
	Protein	24	Kg/H	24.3	Kg/H	23.80	MJ/Kg	577.3	
	Ash	12	Kg/H	76.7	Kg/H	0.00	MJ/Kg	0.0	
	Drying							0	
INPUT								0.0	

Table A.4. Raw data obtained from frozen potatoes plant (continued)

	Potatoes	1213	Kg/H	1,212.8	Kg/H				
	Water	994	Kg/H	994.5	Kg/H	0.00	MJ/Kg	0.0	
	Starch	182	Kg/H	181.9	Kg/H	14.38	MJ/Kg	2,616.0	
	Protein	24	Kg/H	24.3	Kg/H	23.80	MJ/Kg	577.3	
	Ash	12	Kg/H	12.1	Kg/H	0.00	MJ/Kg	0.0	
	Electricity	90	MJ/Kg	90.0	MJ	1.00	MJ/MJ	90.0	10.8
	Natural Gas	27	Kg/H	26.8	Kg/H	50.00	MJ/Kg	1,341.9	1.4
OUTPUT								0.0	
Water Loss (%4)	Potatoes	1164	Kg/H	1,163.5	Kg/H				
	Water	908	Kg/H	907.5	Kg/H	0.00	MJ/Kg	0.0	
	Starch	221	Kg/H	221.1	Kg/H	14.38	MJ/Kg	3,178.9	
	Protein	23	Kg/H	23.3	Kg/H	23.80	MJ/Kg	553.8	
	Ash	12	Kg/H	11.6	Kg/H	0.00	MJ/Kg	0.0	
8	**Frying**							0	
INPUT								0.0	
	Potatoes	1164	Kg/H	1,163.5	Kg/H				
	Water	908	Kg/H	907.5	Kg/H	0.00	MJ/Kg	0.0	
	Starch	221	Kg/H	221.1	Kg/H	14.38	MJ/Kg	3,178.9	
	Protein	23	Kg/H	23.3	Kg/H	23.80	MJ/Kg	553.8	
	Ash	12	Kg/H	11.6	Kg/H	0.00	MJ/Kg	0.0	
	Frying oil (Sunflower)	166	Kg/H	166.0	Kg/H	7,945.40		1,318.9	76.9
	Electricity	72	MJ/Kg	72.0	MJ	1.00	MJ/MJ	72.0	9.5
OUTPUT								0.0	
	Patotoes (%7)	1063	Kg/H	1,063.0	Kg/H				
	Water	755	Kg/H	754.7	Kg/H	0.00	MJ/Kg	0.0	

Table A.4. Raw data obtained from frozen potatoes plant (continued)

	Fat	74	Kg/H	74.4	Kg/H	39.00	MJ/Kg	2,902.0	
	Carbonhydrate	201	Kg/H	200.6	Kg/H	17.90	MJ/Kg	3,590.5	
	Removed Oil							0	
INPUT								0.0	
	Potatoes	1063	Kg/H	1,063.0	Kg/H				
	Water	755	Kg/H	754.7	Kg/H	0.00	MJ/Kg	0.0	
	Fat	74	Kg/H	74.4	Kg/H	39.00	MJ/Kg	2,902.0	
	Carbonhydrate	201	Kg/H	200.6	Kg/H	17.90	MJ/Kg	3,590.5	
	Electricity	8	MJ/Kg	7.9	Mj	1.00	MJ/MJ	7.9	1.1
OUTPUT								0.0	
	Potatoes	1047	Kg/H	1,047.0	Kg/H				
	Water	743	Kg/H	743.4	Kg/H	0.00	MJ/Kg	0.0	
	Fat	58	Kg/H	57.6	Kg/H	39.00	MJ/Kg	2,245.8	
	Carbonhydrate	198	Kg/H	197.6	Kg/H	17.90	MJ/Kg	3,536.5	
	Cooling							0	
INPUT								0.0	
	Potatoes	1047	Kg/H	1,047.0	Kg/H			0.0	
	Water	743	Kg/H	743.4	Kg/H	0.00	MJ/Kg	0.0	
	Fat	58	Kg/H	57.6	Kg/H	39.00	MJ/Kg	2,245.8	
	Carbohydrate	198	Kg/H	197.6	Kg/H	17.90	MJ/Kg	3,536.5	
	Electricity	5	MJ/Kg	4.6	MJ	1.00	MJ/MJ	4.6	0.6
OUTPUT								0.0	
	Potatoes	1047	Kg/H	1,047.0	Kg/H			0.0	
	Water	712	Kg/H	712.0	Kg/H	0.00	MJ/Kg	0.0	
	Fat	58	Kg/H	57.6	Kg/H	39.00	MJ/Kg	2,245.8	
	Carbohydrate	198	Kg/H	197.6	Kg/H	17.90	MJ/Kg	3,536.5	
	Freezing							0	

Table A.4. Raw data obtained from frozen potatoes plant (continued)

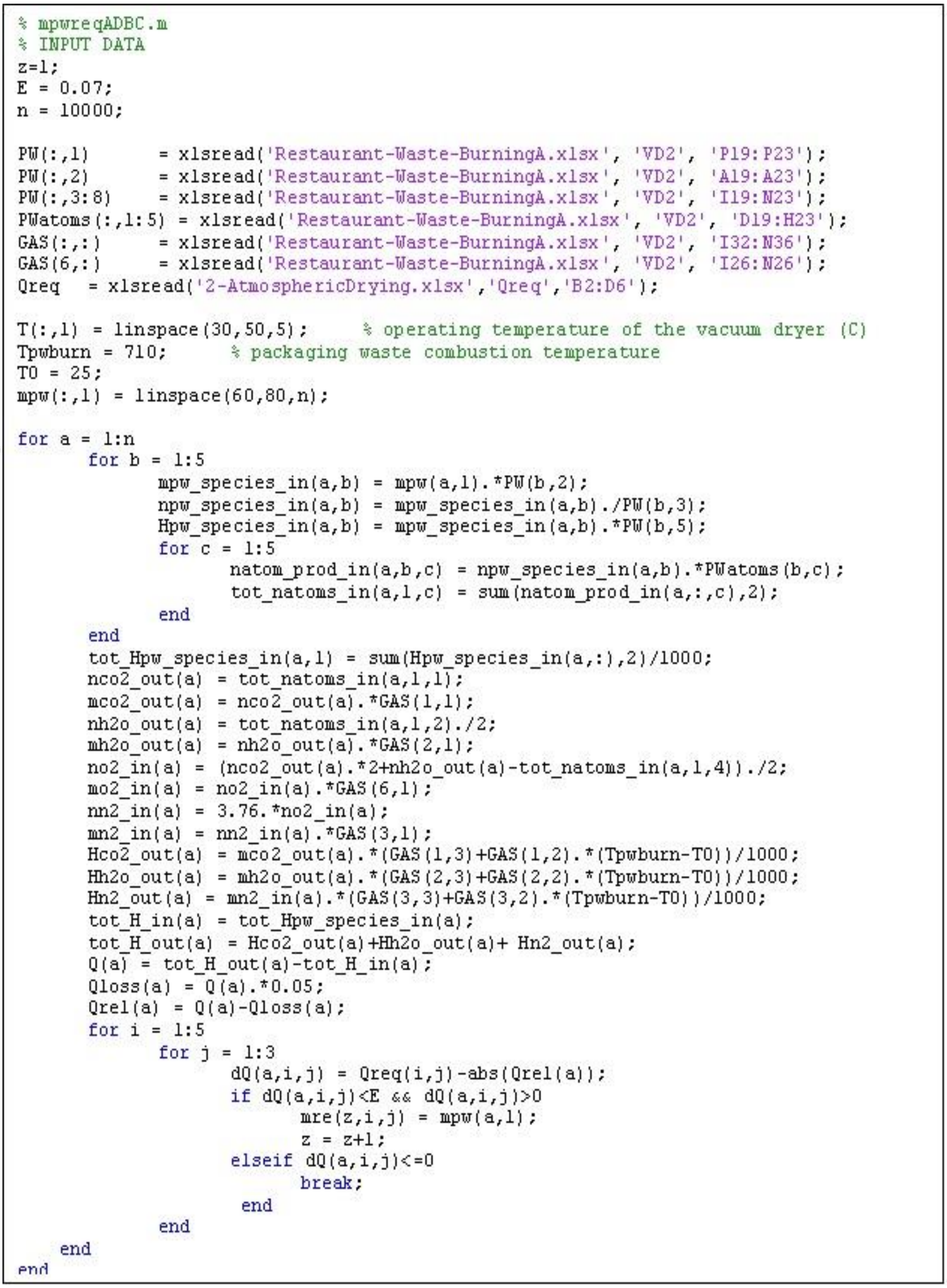
	Potatoes	1047	Kg/H	1,047.0	Kg/H				
	Water	712	Kg/H	712.0	Kg/H	0.00	MJ/Kg	0.0	
	Fat	58	Kg/H	57.6	Kg/H	39.00	MJ/Kg	2,245.8	
	Carbohydrate	198	Kg/H	197.6	Kg/H	17.90	MJ/Kg	3,536.5	
	Electricity	108	MJ/Kg	108.0	MJ	1.00	MJ/MJ	108.0	14.6
	Potatoes	1037	Kg/H	1,036.5	Kg/H				
	Water	705	Kg/H	704.8	Kg/H	0.00	MJ/Kg	0.0	
	Fat	57	Kg/H	57.0	Kg/H	39.00	MJ/Kg	2,223.4	
	Carbohydrate	196	Kg/H	195.6	Kg/H	17.90	MJ/Kg	3,501.1	
	Packaging							0	
INPUT								0.0	
	Potatoes	1037	Kg/H	1,036.5	Kg/H				
	Water	705	Kg/H	704.8	Kg/H	0.00	MJ/Kg	0.0	
	Fat	57	Kg/H	57.0	Kg/H	39.00	MJ/Kg	2,223.4	
	Carbohydrate	196	Kg/H	195.6	Kg/H	17.90	MJ/Kg	3,501.1	
								0.0	
Paletting. Streching And Packaging	Electricity	28	MJ/Kg	27.7	MJ	1.00	MJ/MJ	27.7	3.9
Box	Paper (Cardboard)	29	Kg/H	29.0	Kg/H	43.30	MJ/Kg	1,255.7	49.9
Paletting Strech	LDPE	0	Kg/ H	0.1	Kg/H	87.00	MJ/MJ	8.7	3.8
Box	LDPE	10	Kg/H	10.0	Kg/H	87.00	MJ/Kg	870.0	21.0
OUTPUT									
40 Packs/Minute	Frozen Potatoes	1000	Kg/H	1,000.0	Kg/H				

Table A.4. Raw data obtained from frozen potatoes plant (continued)

500 G	Water	680	Kg/H	680.0	Kg/H	0.00	MJ/Kg	0.0	
%3.6 Fire	Fat	55	Kg/H	55.0	Kg/H	39.00	MJ/Kg	2,145.0	
	Carbohydrate	189	Kg/H	188.7	Kg/H	17.90	MJ/Kg	3,377.7	
10	**Storage And Tranportation**							0	
INPUT								0.0	
	Packed And Staked Frozen Potatoes	1000	Kg	1000	Kg/H			0.0	
	Fat	55	Kg	55	Kg/H	39.00	MJ/Kg	2,145.0	
	Carbohydrate	189	Kg	188.7	Kg/H	17.90	MJ/Kg	3,377.7	
	Water	680	Kg	680	Kg/H	0.00	MJ/Kg	0.0	
Refrigerator	Electricity		MJ/Kg Frozen Potatoes	56.5	MJ	1.00	MJ/Kg	56.5	7.9
Refrigerated Transportation From The Plant To The Market	Diesel Oil	0	Kg/Kg Frozen Potatoes	16.8	Kg/H	57.45	MJ/Kg	965.7	15.8
30 Box Per A Pallet	300							0.0	
OUTPUT	Refrigrated Packed And Staked Frozen Frozen Potatoes	985	Kg	1,000.0	Kg/H			0.0	

Table A.4. Raw data obtained from frozen potatoes plant (continued)

	Fat	54	Kg	55.0	Kg/H	39.00	MJ/Kg	2,145.0	
	Carbohydrate	186	Kg	188.7	Kg/H	17.90	MJ/Kg	3,377.7	
	Water	670	Kg	680.0	Kg/H	0.00	MJ/Kg	0.0	

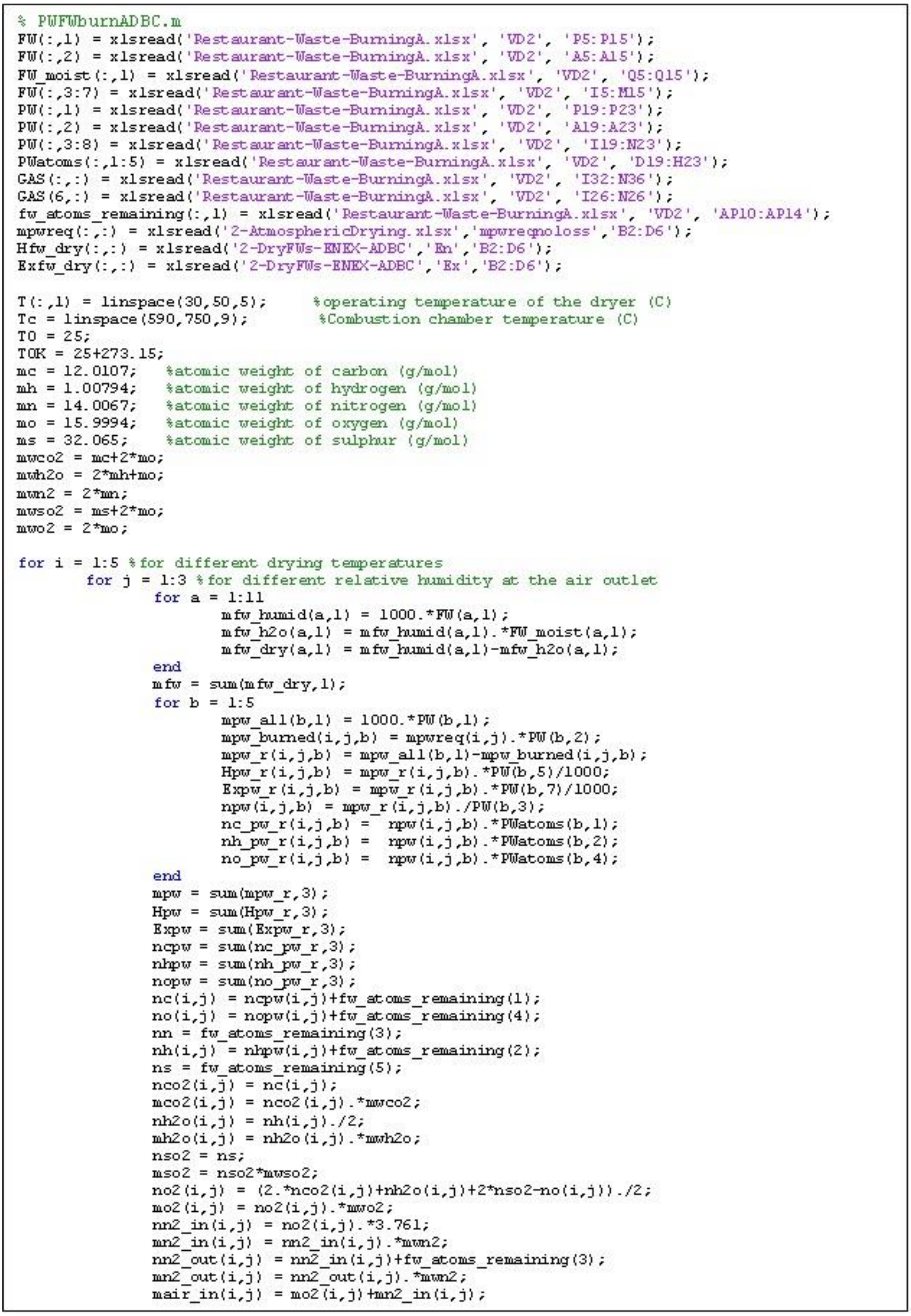


```
% mpwreqADBC.m
% INPUT DATA
z=1;
E = 0.07;
n = 10000;

PW(:,1)       = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'P19:P23');
PW(:,2)       = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'A19:A23');
PW(:,3:8)     = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I19:N23');
PWatoms(:,1:5) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'D19:H23');
GAS(:,:)      = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I32:N36');
GAS(6,:)      = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I26:N26');
Qreq   = xlsread('2-AtmosphericDrying.xlsx','Qreq','B2:D6');

T(:,1) = linspace(30,50,5);     % operating temperature of the vacuum dryer (C)
Tpwburn = 710;      % packaging waste combustion temperature
T0 = 25;
mpw(:,1) = linspace(60,80,n);

for a = 1:n
        for b = 1:5
                mpw_species_in(a,b) = mpw(a,1).*PW(b,2);
                npw_species_in(a,b) = mpw_species_in(a,b)./PW(b,3);
                Hpw_species_in(a,b) = mpw_species_in(a,b).*PW(b,5);
                for c = 1:5
                        natom_prod_in(a,b,c) = npw_species_in(a,b).*PWatoms(b,c);
                        tot_natoms_in(a,1,c) = sum(natom_prod_in(a,:,c),2);
                end
        end
        tot_Hpw_species_in(a,1) = sum(Hpw_species_in(a,:),2)/1000;
        nco2_out(a) = tot_natoms_in(a,1,1);
        mco2_out(a) = nco2_out(a).*GAS(1,1);
        nh2o_out(a) = tot_natoms_in(a,1,2)./2;
        mh2o_out(a) = nh2o_out(a).*GAS(2,1);
        no2_in(a) = (nco2_out(a).*2+nh2o_out(a)-tot_natoms_in(a,1,4))./2;
        mo2_in(a) = no2_in(a).*GAS(6,1);
        nn2_in(a) = 3.76.*no2_in(a);
        mn2_in(a) = nn2_in(a).*GAS(3,1);
        Hco2_out(a) = mco2_out(a).*(GAS(1,3)+GAS(1,2).*(Tpwburn-T0))/1000;
        Hh2o_out(a) = mh2o_out(a).*(GAS(2,3)+GAS(2,2).*(Tpwburn-T0))/1000;
        Hn2_out(a) = mn2_in(a).*(GAS(3,3)+GAS(3,2).*(Tpwburn-T0))/1000;
        tot_H_in(a) = tot_Hpw_species_in(a);
        tot_H_out(a) = Hco2_out(a)+Hh2o_out(a)+ Hn2_out(a);
        Q(a) = tot_H_out(a)-tot_H_in(a);
        Qloss(a) = Q(a).*0.05;
        Qrel(a) = Q(a)-Qloss(a);
        for i = 1:5
                for j = 1:3
                        dQ(a,i,j) = Qreq(i,j)-abs(Qrel(a));
                        if dQ(a,i,j)<E && dQ(a,i,j)>0
                                mre(z,i,j) = mpw(a,1);
                                z = z+1;
                        elseif dQ(a,i,j)<=0
                                break;
                         end
                end
     end
end
```

Figure A.1. MATLAB scripts part 1

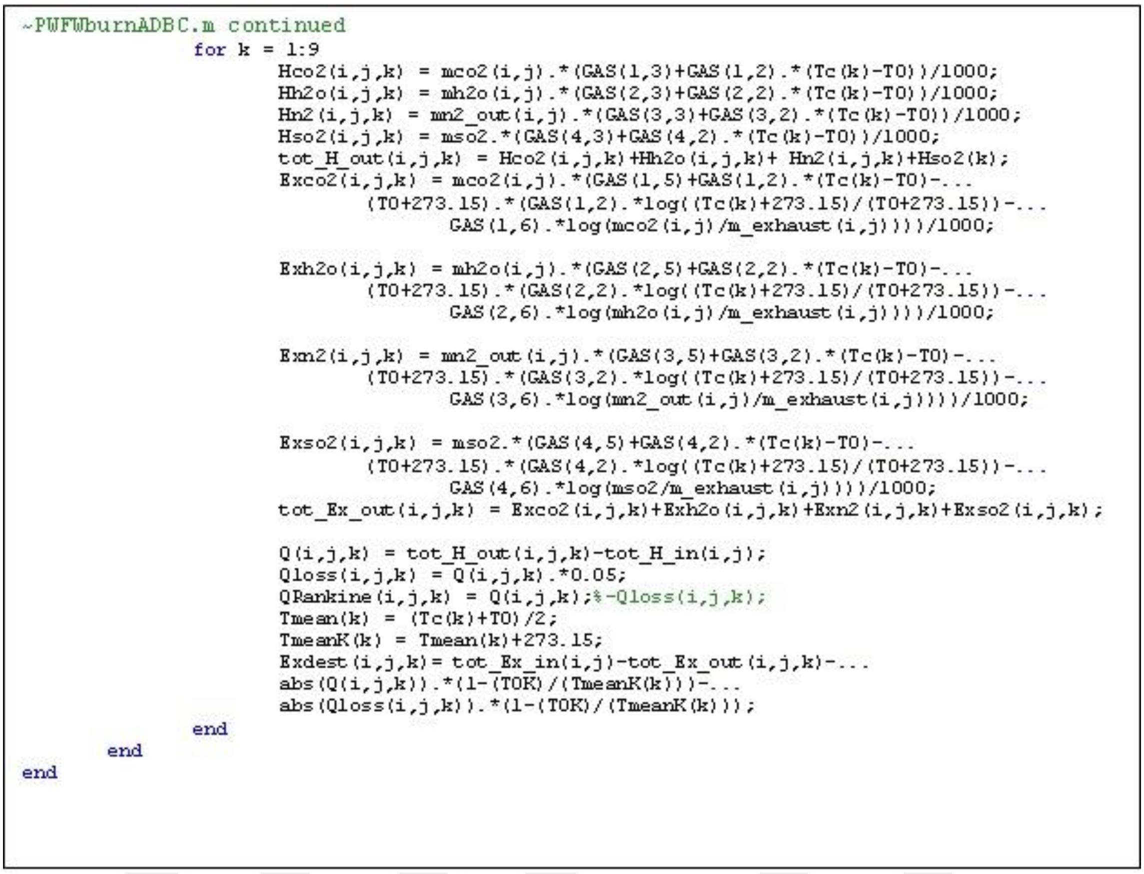
```
% pwburnenexbalanceADBC.m
% INPUT DATA
PW(:,1)        = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'P19:P23');
PW(:,2)        = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'A19:A23');
PW(:,3:8)      = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I19:N23');
PWatoms(:,1:5) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'D19:H23');
GAS(:,:)       = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I32:N36');
GAS(6,:)       = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I26:N26');
mpwreq(:,:)    = xlsread('2-AtmosphericDrying.xlsx','mpwreq','B2:D6');

T(:,1) = linspace(30,50,5);     %operating temperature of the dryer (C)
Tpwburn = 710;
T0 = 25;
Tmean = (Tpwburn+T0)/2;

for m = 1:3
        for i = 1:5
                for j = 1:5
                        m_pwreq_species_in(i,j,m) = mpwreq(i,m).*PW(j,2);
                        H_pwreq_species_in(i,j,m) = m_pwreq_species_in(i,j,m).*PW(j,5);
                        n_pwreq_species_in(i,j,m) = m_pwreq_species_in(i,j,m)./PW(j,3);
                        Ex_pwreq_species_in(i,j,m) = m_pwreq_species_in(i,j,m).*PW(j,7);

                        for k = 1:5
                                natom_in(i,j,m,k) =
n_pwreq_species_in(i,j,m).*PWatoms(j,k);
                                sum_natoms_in(i,m,k) = sum(natom_in(i,:,m,k),2);
                        end
                end
                sumt_H_pwreq_species_in(i,m) = sum(H_pwreq_species_in(i,:,m),2)/1000;
                sumt_Ex_pwreq_species_in(i,m) = sum(Ex_pwreq_species_in(i,:,m),2)/1000;
                nco2_out(i,m) = sum_natoms_in(i,m,1);
                mco2_out(i,m) = nco2_out(i,m).*GAS(1,1);
                nh2o_out(i,m) = sum_natoms_in(i,m,2)./2;
                mh2o_out(i,m) = nh2o_out(i,m).*GAS(2,1);
                no2_in(i,m) = (nco2_out(i,m).*2+nh2o_out(i,m)-sum_natoms_in(i,m,4))./2;
                mo2_in(i,m) = no2_in(i,m).*GAS(6,1);
                nn2_in(i,m) = 3.76.*no2_in(i,m);
                mn2_in(i,m) = nn2_in(i,m).*GAS(3,1);
                mair_in(i,m) = mo2_in(i,m)+mn2_in(i,m);
                sum_m_in(i,m) = mpwreq(i,m)+mo2_in(i,m)+mn2_in(i,m);
                sum_m_out(i,m) = mco2_out(i,m)+mh2o_out(i,m)+mn2_in(i,m);
                dm_pw_comb(i,m) = sum_m_in(i,m)-sum_m_out(i,m);
                Hco2_out(i,m) = mco2_out(i,m).*(GAS(1,3)+GAS(1,2).*(Tpwburn-T0))/1000;
                Hh2o_out(i,m) = mh2o_out(i,m).*(GAS(2,3)+GAS(2,2).*(Tpwburn-T0))/1000;
                Hn2_out(i,m) = mn2_in(i,m).*(GAS(3,3)+GAS(3,2).*(Tpwburn-T0))/1000;
                Exco2_out(i,m) = mco2_out(i,m).*(GAS(1,5)+GAS(1,2).*(Tpwburn-T0)-...
                        (T0+273.15).*(GAS(1,2).*log((Tpwburn+273.15)/(T0+273.15))-...
                                GAS(1,6).*log(mco2_out(i,m)./sum_m_out(i,m))))/1000;
                Exh2o_out(i,m) = mh2o_out(i,m).*(GAS(2,5)+GAS(2,2).*(Tpwburn-T0)-...
                        (T0+273.15).*(GAS(2,2).*log((Tpwburn+273.15)/(T0+273.15))-...
                                GAS(2,6).*log(mco2_out(i,m)./sum_m_out(i,m))))/1000;
                Exn2_out(i,m) = mn2_in(i,m).*(GAS(3,5)+GAS(3,2).*(Tpwburn-T0)-...
                        (T0+273.15).*(GAS(3,2).*log((Tpwburn+273.15)/(T0+273.15))-...
                                GAS(3,6).*log(mco2_out(i,m)./sum_m_out(i,m))))/1000;
                sum_H_in(i,m) = sumt_H_pwreq_species_in(i,m);
                sum_H_out(i,m) = Hco2_out(i,m)+Hh2o_out(i,m)+ Hn2_out(i,m);
                sum_Ex_in(i,m) = sumt_Ex_pwreq_species_in(i,m);
                sum_Ex_out(i,m) = Exco2_out(i,m)+Exh2o_out(i,m)+ Exn2_out(i,m);

                Q(i,m) = sum_H_out(i,m)-sum_H_in(i,m);
                Qloss(i,m) = Q(i,m).*0.05;
                Qdryer(i,m) = Q(i,m)-Qloss(i,m);
                Exdest(i,m) =sum_Ex_in(i,m)-sum_Ex_out(i,m)+...
                Q(i,m).*(1-((T0+273.15)/(Tpwburn+273.15)))+...
```

Figure A.2. MATLAB scripts part 2



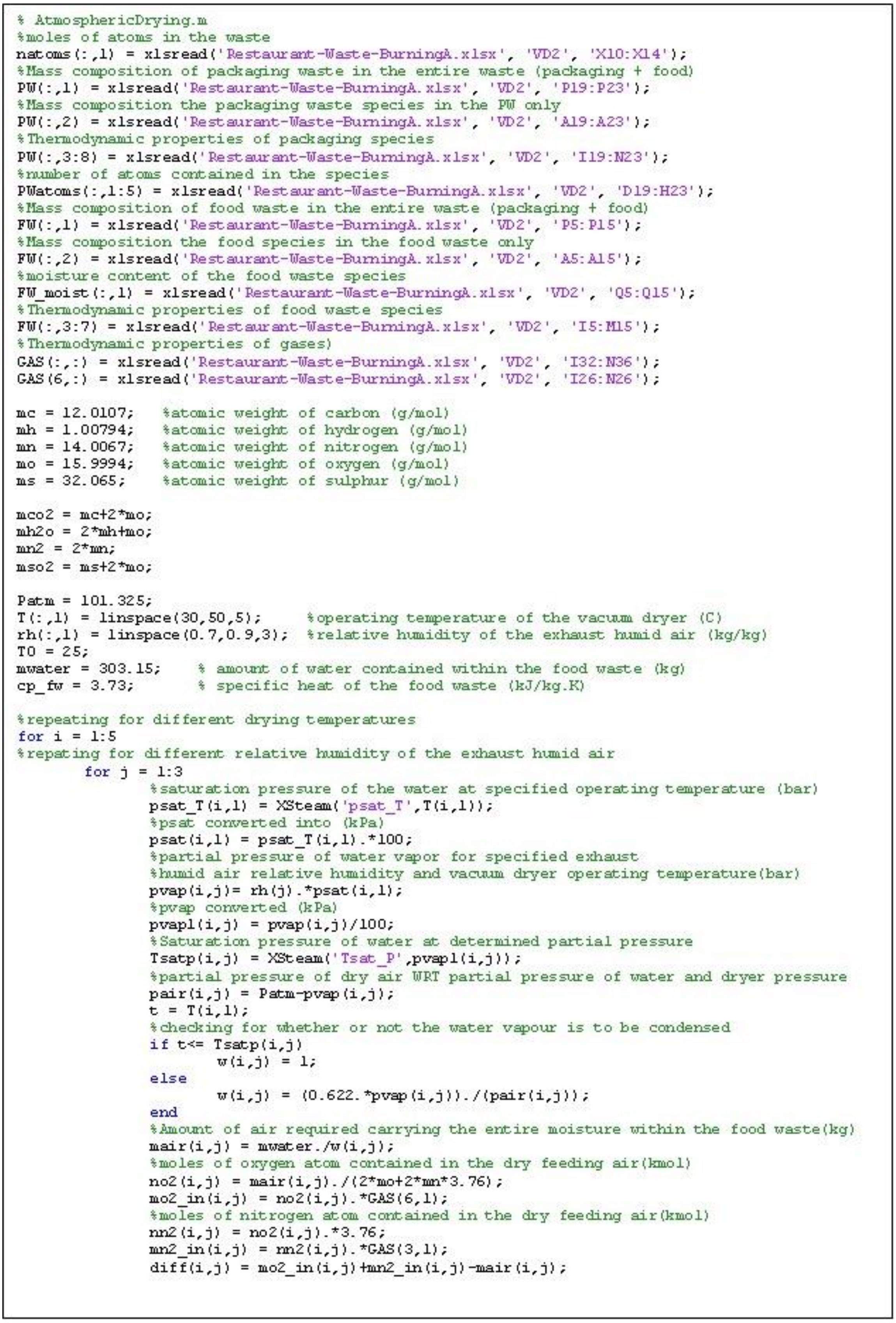
```
% PWFWburnADBC.m
FW(:,1) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'P5:P15');
FW(:,2) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'A5:A15');
FW_moist(:,1) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'Q5:Q15');
FW(:,3:7) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I5:M15');
PW(:,1) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'P19:P23');
PW(:,2) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'A19:A23');
PW(:,3:8) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I19:N23');
PWatoms(:,1:5) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'D19:H23');
GAS(:,:) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I32:N36');
GAS(6,:) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I26:N26');
fw_atoms_remaining(:,1) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'AP10:AP14');
mpwreq(:,:) = xlsread('2-AtmosphericDrying.xlsx','mpwreqnoloss','B2:D6');
Hfw_dry(:,:) = xlsread('2-DryFWs-ENEX-ADBC','En','B2:D6');
Exfw_dry(:,:) = xlsread('2-DryFWs-ENEX-ADBC','Ex','B2:D6');

T(:,1) = linspace(30,50,5);     %operating temperature of the dryer (C)
Tc = linspace(590,750,9);       %Combustion chamber temperature (C)
T0 = 25;
T0K = 25+273.15;
mc = 12.0107;    %atomic weight of carbon (g/mol)
mh = 1.00794;    %atomic weight of hydrogen (g/mol)
mn = 14.0067;    %atomic weight of nitrogen (g/mol)
mo = 15.9994;    %atomic weight of oxygen (g/mol)
ms = 32.065;     %atomic weight of sulphur (g/mol)
mwco2 = mc+2*mo;
mwh2o = 2*mh+mo;
mwn2 = 2*mn;
mwso2 = ms+2*mo;
mwo2 = 2*mo;

for i = 1:5 %for different drying temperatures
        for j = 1:3 %for different relative humidity at the air outlet
                for a = 1:11
                        mfw_humid(a,1) = 1000.*FW(a,1);
                        mfw_h2o(a,1) = mfw_humid(a,1).*FW_moist(a,1);
                        mfw_dry(a,1) = mfw_humid(a,1)-mfw_h2o(a,1);
                end
                mfw = sum(mfw_dry,1);
                for b = 1:5
                        mpw_all(b,1) = 1000.*PW(b,1);
                        mpw_burned(i,j,b) = mpwreq(i,j).*PW(b,2);
                        mpw_r(i,j,b) = mpw_all(b,1)-mpw_burned(i,j,b);
                        Hpw_r(i,j,b) = mpw_r(i,j,b).*PW(b,5)/1000;
                        Expw_r(i,j,b) = mpw_r(i,j,b).*PW(b,7)/1000;
                        npw(i,j,b) = mpw_r(i,j,b)./PW(b,3);
                        nc_pw_r(i,j,b) =  npw(i,j,b).*PWatoms(b,1);
                        nh_pw_r(i,j,b) =  npw(i,j,b).*PWatoms(b,2);
                        no_pw_r(i,j,b) =  npw(i,j,b).*PWatoms(b,4);
                end
                mpw = sum(mpw_r,3);
                Hpw = sum(Hpw_r,3);
                Expw = sum(Expw_r,3);
                ncpw = sum(nc_pw_r,3);
                nhpw = sum(nh_pw_r,3);
                nopw = sum(no_pw_r,3);
                nc(i,j) = ncpw(i,j)+fw_atoms_remaining(1);
                no(i,j) = nopw(i,j)+fw_atoms_remaining(4);
                nn = fw_atoms_remaining(3);
                nh(i,j) = nhpw(i,j)+fw_atoms_remaining(2);
                ns = fw_atoms_remaining(5);
                nco2(i,j) = nc(i,j);
                mco2(i,j) = nco2(i,j).*mwco2;
                nh2o(i,j) = nh(i,j)./2;
                mh2o(i,j) = nh2o(i,j).*mwh2o;
                nso2 = ns;
                mso2 = nso2*mwso2;
                no2(i,j) = (2.*nco2(i,j)+nh2o(i,j)+2*nso2-no(i,j))./2;
                mo2(i,j) = no2(i,j).*mwo2;
                nn2_in(i,j) = no2(i,j).*3.761;
                mn2_in(i,j) = nn2_in(i,j).*mwn2;
                nn2_out(i,j) = nn2_in(i,j)+fw_atoms_remaining(3);
                mn2_out(i,j) = nn2_out(i,j).*mwn2;
                mair_in(i,j) = mo2(i,j)+mn2_in(i,j);
```

Figure A.3. MATLAB scripts part 3



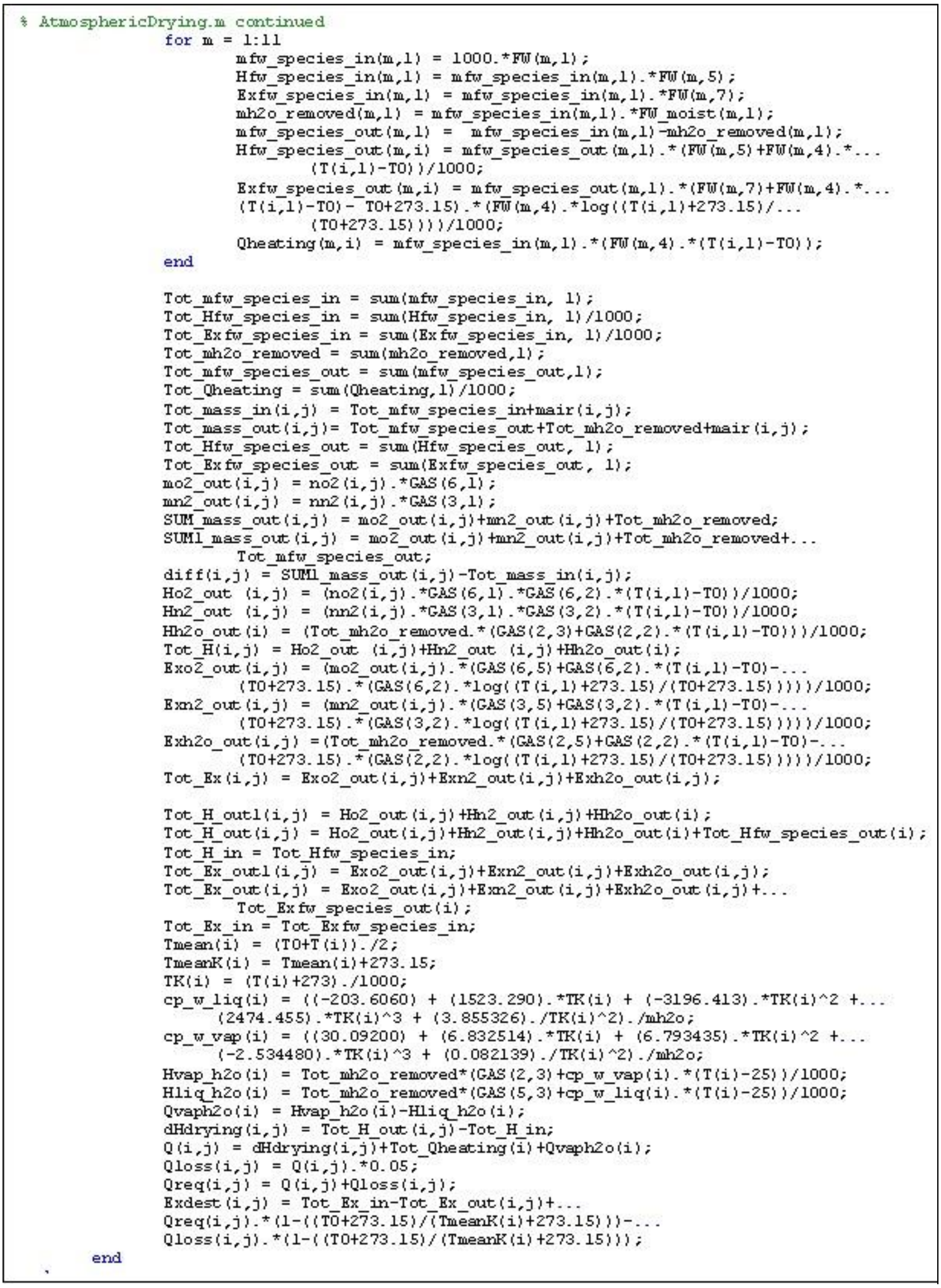
```
~PWFWburnADBC.m continued
             for k = 1:9
                    Hco2(i,j,k) = mco2(i,j).*(GAS(1,3)+GAS(1,2).*(Tc(k)-T0))/1000;
                    Hh2o(i,j,k) = mh2o(i,j).*(GAS(2,3)+GAS(2,2).*(Tc(k)-T0))/1000;
                    Hn2(i,j,k) = mn2_out(i,j).*(GAS(3,3)+GAS(3,2).*(Tc(k)-T0))/1000;
                    Hso2(i,j,k) = mso2.*(GAS(4,3)+GAS(4,2).*(Tc(k)-T0))/1000;
                    tot_H_out(i,j,k) = Hco2(i,j,k)+Hh2o(i,j,k)+ Hn2(i,j,k)+Hso2(k);
                    Exco2(i,j,k) = mco2(i,j).*(GAS(1,5)+GAS(1,2).*(Tc(k)-T0)-...
                           (T0+273.15).*(GAS(1,2).*log((Tc(k)+273.15)/(T0+273.15))-...
                                 GAS(1,6).*log(mco2(i,j)/m_exhaust(i,j))))/1000;

                    Exh2o(i,j,k) = mh2o(i,j).*(GAS(2,5)+GAS(2,2).*(Tc(k)-T0)-...
                           (T0+273.15).*(GAS(2,2).*log((Tc(k)+273.15)/(T0+273.15))-...
                                 GAS(2,6).*log(mh2o(i,j)/m_exhaust(i,j))))/1000;

                    Exn2(i,j,k) = mn2_out(i,j).*(GAS(3,5)+GAS(3,2).*(Tc(k)-T0)-...
                           (T0+273.15).*(GAS(3,2).*log((Tc(k)+273.15)/(T0+273.15))-...
                                 GAS(3,6).*log(mn2_out(i,j)/m_exhaust(i,j))))/1000;

                    Exso2(i,j,k) = mso2.*(GAS(4,5)+GAS(4,2).*(Tc(k)-T0)-...
                           (T0+273.15).*(GAS(4,2).*log((Tc(k)+273.15)/(T0+273.15))-...
                                 GAS(4,6).*log(mso2/m_exhaust(i,j))))/1000;
                    tot_Ex_out(i,j,k) = Exco2(i,j,k)+Exh2o(i,j,k)+Exn2(i,j,k)+Exso2(i,j,k);

                    Q(i,j,k) = tot_H_out(i,j,k)-tot_H_in(i,j);
                    Qloss(i,j,k) = Q(i,j,k).*0.05;
                    QRankine(i,j,k) = Q(i,j,k);%-Qloss(i,j,k);
                    Tmean(k) = (Tc(k)+T0)/2;
                    TmeanK(k) = Tmean(k)+273.15;
                    Exdest(i,j,k)= tot_Ex_in(i,j)-tot_Ex_out(i,j,k)-...
                    abs(Q(i,j,k)).*(1-(T0K)/(TmeanK(k)))-...
                    abs(Qloss(i,j,k)).*(1-(T0K)/(TmeanK(k)));
             end
      end
end
```

Figure A.4. MATLAB scripts part 4



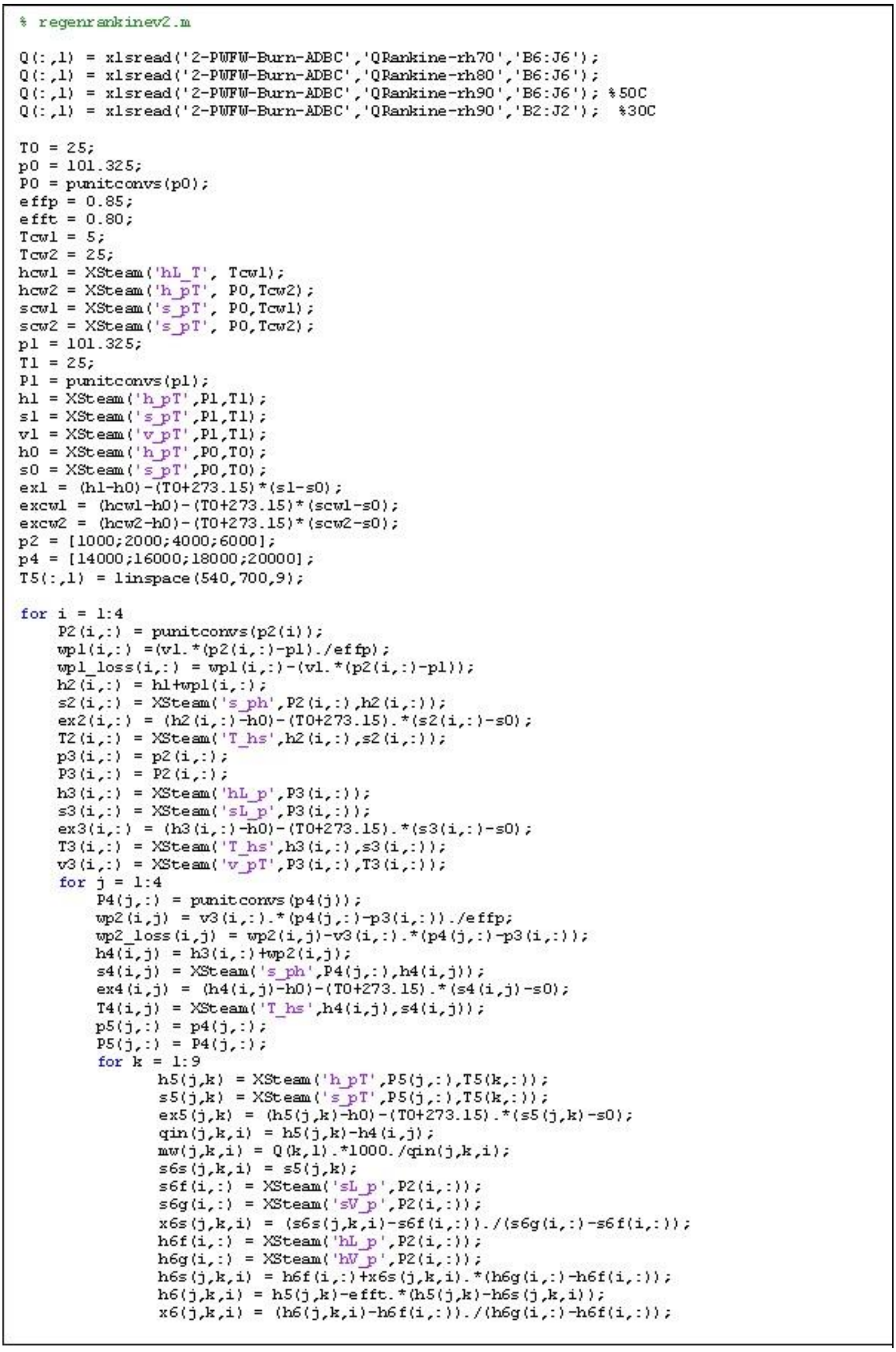
```
% AtmosphericDrying.m
%moles of atoms in the waste
natoms(:,1) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'X10:X14');
%Mass composition of packaging waste in the entire waste (packaging + food)
PW(:,1) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'P19:P23');
%Mass composition the packaging waste species in the PW only
PW(:,2) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'A19:A23');
%Thermodynamic properties of packaging species
PW(:,3:8) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I19:N23');
%number of atoms contained in the species
PWatoms(:,1:5) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'D19:H23');
%Mass composition of food waste in the entire waste (packaging + food)
FW(:,1) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'P5:P15');
%Mass composition the food species in the food waste only
FW(:,2) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'A5:A15');
%moisture content of the food waste species
FW_moist(:,1) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'Q5:Q15');
%Thermodynamic properties of food waste species
FW(:,3:7) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I5:M15');
%Thermodynamic properties of gases)
GAS(:,:) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I32:N36');
GAS(6,:) = xlsread('Restaurant-Waste-BurningA.xlsx', 'VD2', 'I26:N26');

mc = 12.0107;   %atomic weight of carbon (g/mol)
mh = 1.00794;   %atomic weight of hydrogen (g/mol)
mn = 14.0067;   %atomic weight of nitrogen (g/mol)
mo = 15.9994;   %atomic weight of oxygen (g/mol)
ms = 32.065;    %atomic weight of sulphur (g/mol)

mco2 = mc+2*mo;
mh2o = 2*mh+mo;
mn2 = 2*mn;
mso2 = ms+2*mo;

Patm = 101.325;
T(:,1) = linspace(30,50,5);     %operating temperature of the vacuum dryer (C)
rh(:,1) = linspace(0.7,0.9,3);  %relative humidity of the exhaust humid air (kg/kg)
T0 = 25;
mwater = 303.15;    % amount of water contained within the food waste (kg)
cp_fw = 3.73;       % specific heat of the food waste (kJ/kg.K)

%repeating for different drying temperatures
for i = 1:5
%repating for different relative humidity of the exhaust humid air
        for j = 1:3
                %saturation pressure of the water at specified operating temperature (bar)
                psat_T(i,1) = XSteam('psat_T',T(i,1));
                %psat converted into (kPa)
                psat(i,1) = psat_T(i,1).*100;
                %partial pressure of water vapor for specified exhaust
                %humid air relative humidity and vacuum dryer operating temperature(bar)
                pvap(i,j)= rh(j).*psat(i,1);
                %pvap converted (kPa)
                pvap1(i,j) = pvap(i,j)/100;
                %Saturation pressure of water at determined partial pressure
                Tsatp(i,j) = XSteam('Tsat_P',pvap1(i,j));
                %partial pressure of dry air WRT partial pressure of water and dryer pressure
                pair(i,j) = Patm-pvap(i,j);
                t = T(i,1);
                %checking for whether or not the water vapour is to be condensed
                if t<= Tsatp(i,j)
                        w(i,j) = 1;
                else
                        w(i,j) = (0.622.*pvap(i,j))./(pair(i,j));
                end
                %Amount of air required carrying the entire moisture within the food waste(kg)
                mair(i,j) = mwater./w(i,j);
                %moles of oxygen atom contained in the dry feeding air(kmol)
                no2(i,j) = mair(i,j)./(2*mo+2*mn*3.76);
                mo2_in(i,j) = no2(i,j).*GAS(6,1);
                %moles of nitrogen atom contained in the dry feeding air(kmol)
                nn2(i,j) = no2(i,j).*3.76;
                mn2_in(i,j) = nn2(i,j).*GAS(3,1);
                diff(i,j) = mo2_in(i,j)+mn2_in(i,j)-mair(i,j);
```

Figure A.5. MATLAB scripts part 5



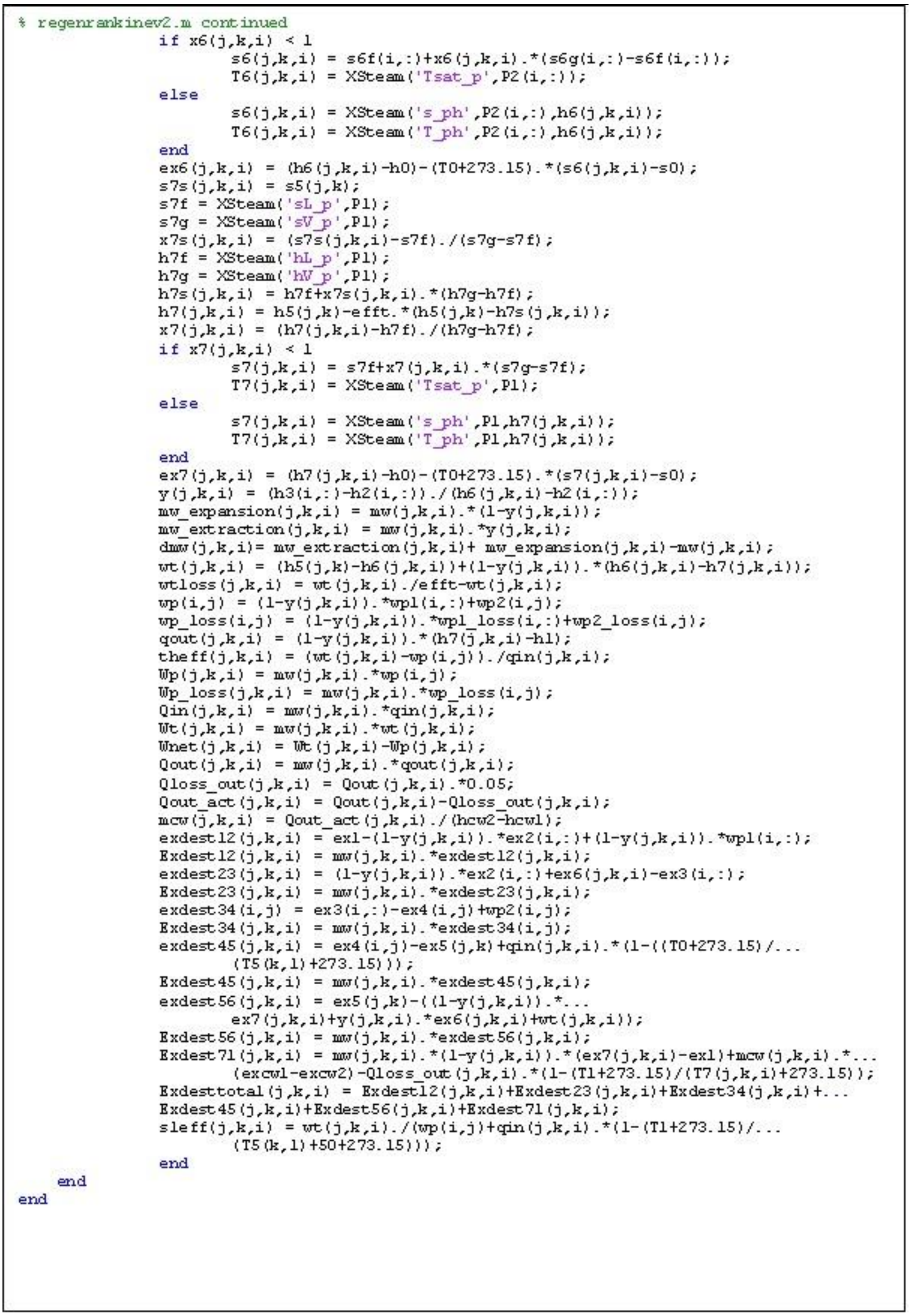
```
% AtmosphericDrying.m continued
                    for m = 1:11
                              mfw_species_in(m,1) = 1000.*FW(m,1);
                              Hfw_species_in(m,1) = mfw_species_in(m,1).*FW(m,5);
                              Exfw_species_in(m,1) = mfw_species_in(m,1).*FW(m,7);
                              mh2o_removed(m,1) = mfw_species_in(m,1).*FW_moist(m,1);
                              mfw_species_out(m,1) =  mfw_species_in(m,1)-mh2o_removed(m,1);
                              Hfw_species_out(m,i) = mfw_species_out(m,1).*(FW(m,5)+FW(m,4).*...
                                        (T(i,1)-T0))/1000;
                              Exfw_species_out(m,i) = mfw_species_out(m,1).*(FW(m,7)+FW(m,4).*...
                              (T(i,1)-T0)- T0+273.15).*(FW(m,4).*log((T(i,1)+273.15)/...
                                        (T0+273.15))))/1000;
                              Qheating(m,i) = mfw_species_in(m,1).*(FW(m,4).*(T(i,1)-T0));
                    end

                    Tot_mfw_species_in = sum(mfw_species_in, 1);
                    Tot_Hfw_species_in = sum(Hfw_species_in, 1)/1000;
                    Tot_Exfw_species_in = sum(Exfw_species_in, 1)/1000;
                    Tot_mh2o_removed = sum(mh2o_removed,1);
                    Tot_mfw_species_out = sum(mfw_species_out,1);
                    Tot_Qheating = sum(Qheating,1)/1000;
                    Tot_mass_in(i,j) = Tot_mfw_species_in+mair(i,j);
                    Tot_mass_out(i,j)= Tot_mfw_species_out+Tot_mh2o_removed+mair(i,j);
                    Tot_Hfw_species_out = sum(Hfw_species_out, 1);
                    Tot_Exfw_species_out = sum(Exfw_species_out, 1);
                    mo2_out(i,j) = no2(i,j).*GAS(6,1);
                    mn2_out(i,j) = nn2(i,j).*GAS(3,1);
                    SUM_mass_out(i,j) = mo2_out(i,j)+mn2_out(i,j)+Tot_mh2o_removed;
                    SUM1_mass_out(i,j) = mo2_out(i,j)+mn2_out(i,j)+Tot_mh2o_removed+...
                              Tot_mfw_species_out;
                    diff(i,j) = SUM1_mass_out(i,j)-Tot_mass_in(i,j);
                    Ho2_out (i,j) = (no2(i,j).*GAS(6,1).*GAS(6,2).*(T(i,1)-T0))/1000;
                    Hn2_out (i,j) = (nn2(i,j).*GAS(3,1).*GAS(3,2).*(T(i,1)-T0))/1000;
                    Hh2o_out(i) = (Tot_mh2o_removed.*(GAS(2,3)+GAS(2,2).*(T(i,1)-T0)))/1000;
                    Tot_H(i,j) = Ho2_out (i,j)+Hn2_out (i,j)+Hh2o_out(i);
                    Exo2_out(i,j) = (mo2_out(i,j).*(GAS(6,5)+GAS(6,2).*(T(i,1)-T0)-...
                              (T0+273.15).*(GAS(6,2).*log((T(i,1)+273.15)/(T0+273.15)))))/1000;
                    Exn2_out(i,j) = (mn2_out(i,j).*(GAS(3,5)+GAS(3,2).*(T(i,1)-T0)-...
                              (T0+273.15).*(GAS(3,2).*log((T(i,1)+273.15)/(T0+273.15)))))/1000;
                    Exh2o_out(i,j) =(Tot_mh2o_removed.*(GAS(2,5)+GAS(2,2).*(T(i,1)-T0)-...
                              (T0+273.15).*(GAS(2,2).*log((T(i,1)+273.15)/(T0+273.15)))))/1000;
                    Tot_Ex(i,j) = Exo2_out(i,j)+Exn2_out(i,j)+Exh2o_out(i,j);

                    Tot_H_out1(i,j) = Ho2_out(i,j)+Hn2_out(i,j)+Hh2o_out(i);
                    Tot_H_out(i,j) = Ho2_out(i,j)+Hn2_out(i,j)+Hh2o_out(i)+Tot_Hfw_species_out(i);
                    Tot_H_in = Tot_Hfw_species_in;
                    Tot_Ex_out1(i,j) = Exo2_out(i,j)+Exn2_out(i,j)+Exh2o_out(i,j);
                    Tot_Ex_out(i,j) = Exo2_out(i,j)+Exn2_out(i,j)+Exh2o_out(i,j)+...
                              Tot_Exfw_species_out(i);
                    Tot_Ex_in = Tot_Exfw_species_in;
                    Tmean(i) = (T0+T(i))./2;
                    TmeanK(i) = Tmean(i)+273.15;
                    TK(i) = (T(i)+273)./1000;
                    cp_w_liq(i) = ((-203.6060) + (1523.290).*TK(i) + (-3196.413).*TK(i)^2 +...
                           (2474.455).*TK(i)^3 + (3.855326)./TK(i)^2)./mh2o;
                    cp_w_vap(i) = ((30.09200) + (6.832514).*TK(i) + (6.793435).*TK(i)^2 +...
                           (-2.534480).*TK(i)^3 + (0.082139)./TK(i)^2)./mh2o;
                    Hvap_h2o(i) = Tot_mh2o_removed*(GAS(2,3)+cp_w_vap(i).*(T(i)-25))/1000;
                    Hliq_h2o(i) = Tot_mh2o_removed*(GAS(5,3)+cp_w_liq(i).*(T(i)-25))/1000;
                    Qvaph2o(i) = Hvap_h2o(i)-Hliq_h2o(i);
                    dHdrying(i,j) = Tot_H_out(i,j)-Tot_H_in;
                    Q(i,j) = dHdrying(i,j)+Tot_Qheating(i)+Qvaph2o(i);
                    Qloss(i,j) = Q(i,j).*0.05;
                    Qreq(i,j) = Q(i,j)+Qloss(i,j);
                    Exdest(i,j) = Tot_Ex_in-Tot_Ex_out(i,j)+...
                    Qreq(i,j).*(1-((T0+273.15)/(TmeanK(i)+273.15)))-...
                    Qloss(i,j).*(1-((T0+273.15)/(TmeanK(i)+273.15)));
          end
```

Figure A.6. MATLAB scripts part 6



```
% regenrankinev2.m

Q(:,1) = xlsread('2-PWFW-Burn-ADBC','QRankine-rh70','B6:J6');
Q(:,1) = xlsread('2-PWFW-Burn-ADBC','QRankine-rh80','B6:J6');
Q(:,1) = xlsread('2-PWFW-Burn-ADBC','QRankine-rh90','B6:J6'); %50C
Q(:,1) = xlsread('2-PWFW-Burn-ADBC','QRankine-rh90','B2:J2');  %30C

T0 = 25;
p0 = 101.325;
P0 = punitconvs(p0);
effp = 0.85;
efft = 0.80;
Tcw1 = 5;
Tcw2 = 25;
hcw1 = XSteam('hL_T', Tcw1);
hcw2 = XSteam('h_pT', P0,Tcw2);
scw1 = XSteam('s_pT', P0,Tcw1);
scw2 = XSteam('s_pT', P0,Tcw2);
p1 = 101.325;
T1 = 25;
P1 = punitconvs(p1);
h1 = XSteam('h_pT',P1,T1);
s1 = XSteam('s_pT',P1,T1);
v1 = XSteam('v_pT',P1,T1);
h0 = XSteam('h_pT',P0,T0);
s0 = XSteam('s_pT',P0,T0);
ex1 = (h1-h0)-(T0+273.15)*(s1-s0);
excw1 = (hcw1-h0)-(T0+273.15)*(scw1-s0);
excw2 = (hcw2-h0)-(T0+273.15)*(scw2-s0);
p2 = [1000;2000;4000;6000];
p4 = [14000;16000;18000;20000];
T5(:,1) = linspace(540,700,9);

for i = 1:4
    P2(i,:) = punitconvs(p2(i));
    wp1(i,:) =(v1.*(p2(i,:)-p1)./effp);
    wp1_loss(i,:) = wp1(i,:)-(v1.*(p2(i,:)-p1));
    h2(i,:) = h1+wp1(i,:);
    s2(i,:) = XSteam('s_ph',P2(i,:),h2(i,:));
    ex2(i,:) = (h2(i,:)-h0)-(T0+273.15).*(s2(i,:)-s0);
    T2(i,:) = XSteam('T_hs',h2(i,:),s2(i,:));
    p3(i,:) = p2(i,:);
    P3(i,:) = P2(i,:);
    h3(i,:) = XSteam('hL_p',P3(i,:));
    s3(i,:) = XSteam('sL_p',P3(i,:));
    ex3(i,:) = (h3(i,:)-h0)-(T0+273.15).*(s3(i,:)-s0);
    T3(i,:) = XSteam('T_hs',h3(i,:),s3(i,:));
    v3(i,:) = XSteam('v_pT',P3(i,:),T3(i,:));
    for j = 1:4
        P4(j,:) = punitconvs(p4(j));
        wp2(i,j) = v3(i,:).*(p4(j,:)-p3(i,:))./effp;
        wp2_loss(i,j) = wp2(i,j)-v3(i,:).*(p4(j,:)-p3(i,:));
        h4(i,j) = h3(i,:)+wp2(i,j);
        s4(i,j) = XSteam('s_ph',P4(j,:),h4(i,j));
        ex4(i,j) = (h4(i,j)-h0)-(T0+273.15).*(s4(i,j)-s0);
        T4(i,j) = XSteam('T_hs',h4(i,j),s4(i,j));
        p5(j,:) = p4(j,:);
        P5(j,:) = P4(j,:);
        for k = 1:9
              h5(j,k) = XSteam('h_pT',P5(j,:),T5(k,:));
              s5(j,k) = XSteam('s_pT',P5(j,:),T5(k,:));
              ex5(j,k) = (h5(j,k)-h0)-(T0+273.15).*(s5(j,k)-s0);
              qin(j,k,i) = h5(j,k)-h4(i,j);
              mw(j,k,i) = Q(k,1).*1000./qin(j,k,i);
              s6s(j,k,i) = s5(j,k);
              s6f(i,:) = XSteam('sL_p',P2(i,:));
              s6g(i,:) = XSteam('sV_p',P2(i,:));
              x6s(j,k,i) = (s6s(j,k,i)-s6f(i,:))./(s6g(i,:)-s6f(i,:));
              h6f(i,:) = XSteam('hL_p',P2(i,:));
              h6g(i,:) = XSteam('hV_p',P2(i,:));
              h6s(j,k,i) = h6f(i,:)+x6s(j,k,i).*(h6g(i,:)-h6f(i,:));
              h6(j,k,i) = h5(j,k)-efft.*(h5(j,k)-h6s(j,k,i));
              x6(j,k,i) = (h6(j,k,i)-h6f(i,:))./(h6g(i,:)-h6f(i,:));
```

Figure A.7. MATLAB scripts part 7



```
% regenrankinev2.m continued
                if x6(j,k,i) < 1
                        s6(j,k,i) = s6f(i,:)+x6(j,k,i).*(s6g(i,:)-s6f(i,:));
                        T6(j,k,i) = XSteam('Tsat_p',P2(i,:));
                else
                        s6(j,k,i) = XSteam('s_ph',P2(i,:),h6(j,k,i));
                        T6(j,k,i) = XSteam('T_ph',P2(i,:),h6(j,k,i));
                end
                ex6(j,k,i) = (h6(j,k,i)-h0)-(T0+273.15).*(s6(j,k,i)-s0);
                s7s(j,k,i) = s5(j,k);
                s7f = XSteam('sL_p',P1);
                s7g = XSteam('sV_p',P1);
                x7s(j,k,i) = (s7s(j,k,i)-s7f)./(s7g-s7f);
                h7f = XSteam('hL_p',P1);
                h7g = XSteam('hV_p',P1);
                h7s(j,k,i) = h7f+x7s(j,k,i).*(h7g-h7f);
                h7(j,k,i) = h5(j,k)-efft.*(h5(j,k)-h7s(j,k,i));
                x7(j,k,i) = (h7(j,k,i)-h7f)./(h7g-h7f);
                if x7(j,k,i) < 1
                        s7(j,k,i) = s7f+x7(j,k,i).*(s7g-s7f);
                        T7(j,k,i) = XSteam('Tsat_p',P1);
                else
                        s7(j,k,i) = XSteam('s_ph',P1,h7(j,k,i));
                        T7(j,k,i) = XSteam('T_ph',P1,h7(j,k,i));
                end
                ex7(j,k,i) = (h7(j,k,i)-h0)-(T0+273.15).*(s7(j,k,i)-s0);
                y(j,k,i) = (h3(i,:)-h2(i,:))./(h6(j,k,i)-h2(i,:));
                mw_expansion(j,k,i) = mw(j,k,i).*(1-y(j,k,i));
                mw_extraction(j,k,i) = mw(j,k,i).*y(j,k,i);
                dmw(j,k,i)= mw_extraction(j,k,i)+ mw_expansion(j,k,i)-mw(j,k,i);
                wt(j,k,i) = (h5(j,k)-h6(j,k,i))+(1-y(j,k,i)).*(h6(j,k,i)-h7(j,k,i));
                wtloss(j,k,i) = wt(j,k,i)./efft-wt(j,k,i);
                wp(i,j) = (1-y(j,k,i)).*wp1(i,:)+wp2(i,j);
                wp_loss(i,j) = (1-y(j,k,i)).*wp1_loss(i,:)+wp2_loss(i,j);
                qout(j,k,i) = (1-y(j,k,i)).*(h7(j,k,i)-h1);
                theff(j,k,i) = (wt(j,k,i)-wp(i,j))./qin(j,k,i);
                Wp(j,k,i) = mw(j,k,i).*wp(i,j);
                Wp_loss(j,k,i) = mw(j,k,i).*wp_loss(i,j);
                Qin(j,k,i) = mw(j,k,i).*qin(j,k,i);
                Wt(j,k,i) = mw(j,k,i).*wt(j,k,i);
                Wnet(j,k,i) = Wt(j,k,i)-Wp(j,k,i);
                Qout(j,k,i) = mw(j,k,i).*qout(j,k,i);
                Qloss_out(j,k,i) = Qout(j,k,i).*0.05;
                Qout_act(j,k,i) = Qout(j,k,i)-Qloss_out(j,k,i);
                mcw(j,k,i) = Qout_act(j,k,i)./(hcw2-hcw1);
                exdest12(j,k,i) = ex1-(1-y(j,k,i)).*ex2(i,:)+(1-y(j,k,i)).*wp1(i,:);
                Exdest12(j,k,i) = mw(j,k,i).*exdest12(j,k,i);
                exdest23(j,k,i) = (1-y(j,k,i)).*ex2(i,:)+ex6(j,k,i)-ex3(i,:);
                Exdest23(j,k,i) = mw(j,k,i).*exdest23(j,k,i);
                exdest34(i,j) = ex3(i,:)-ex4(i,j)+wp2(i,j);
                Exdest34(j,k,i) = mw(j,k,i).*exdest34(i,j);
                exdest45(j,k,i) = ex4(i,j)-ex5(j,k)+qin(j,k,i).*(1-((T0+273.15)/...
                        (T5(k,1)+273.15)));
                Exdest45(j,k,i) = mw(j,k,i).*exdest45(j,k,i);
                exdest56(j,k,i) = ex5(j,k)-((1-y(j,k,i)).*...
                        ex7(j,k,i)+y(j,k,i).*ex6(j,k,i)+wt(j,k,i));
                Exdest56(j,k,i) = mw(j,k,i).*exdest56(j,k,i);
                Exdest71(j,k,i) = mw(j,k,i).*(1-y(j,k,i)).*(ex7(j,k,i)-ex1)+mcw(j,k,i).*...
                        (excw1-excw2)-Qloss_out(j,k,i).*(1-(T1+273.15)/(T7(j,k,i)+273.15));
                Exdesttotal(j,k,i) = Exdest12(j,k,i)+Exdest23(j,k,i)+Exdest34(j,k,i)+...
                Exdest45(j,k,i)+Exdest56(j,k,i)+Exdest71(j,k,i);
                sleff(j,k,i) = wt(j,k,i)./(wp(i,j)+qin(j,k,i).*(1-(T1+273.15)/...
                        (T5(k,1)+50+273.15)));
                end
    end
end
```

Figure A.8. MATLAB scripts part 8

```
% Results of the selected case i=2 (2 MPa), j=3 (18 MPa), k=7 (660 C)
Temperature_C_18 = [T1; T2(2); T3(2); T4(2,3); T5(7); T6(3,7,2); T7(3,7,2); Tcw1; Tcw2];
Pressure_kPa_18 = [p1; p2(2); p3(2); p4(3); p5(3); p4(3); p1; p1; p1];
m1 = mw(3,7,2).*(1-y(3,7,2));
m2 = mw(3,7,2).*y(3,7,2);
m3 = mw(3,7,2);
m4 = mcw(3,7,2);
MassFlowRate_kgs = [m1; m1; m3; m3; m3; m2; m1; m4; m4];
H1 = m1*h1;
H2 = m1*h2(2);
H3 = m3*h3(2);
H4 = m3*h4(2,3);
H5 = m3*h5(3,7);
H6 = m2*h6(3,7,2);
H7 = m1*h7(3,7,2);
Hcw1 = m4*hcw1;
Hcw2 = m4*hcw2;
Ex1 = m1*ex1;
Ex2 = m1*ex2(2);
Ex3 = m3*ex3(2);
Ex4 = m3*ex4(2,3);
Ex5 = m3*ex5(3,7);
Ex6 = m2*ex6(3,7,2);
Ex7 = m1*ex7(3,7,2);
Excw1 = m4*excw1;
Excw2 = m3*excw2;
Energy_MW = [H1; H2; H3; H4; H5; H6; H7; Hcw1; Hcw2];
Exergy_MW = [Ex1; Ex2; Ex3; Ex4; Ex5; Ex6; Ex7; Excw1; Excw2];
Stream = {'r1'; 'r2'; 'r3'; 'r4'; 'r5'; 'r6'; 'r7';'r8'; 'r9'};
TABLE1 = table( Temperature_C_18, Pressure_kPa_18, MassFlowRate_kgs,...
    Energy_MW, Exergy_MW, 'RowNames', Stream);

Components = {'Pump1';'OFWH';'Pump2';'Boiler';'Turbine';'Condenser'};

Wpump1_rep = m1.*wp1(2);
Wpump1_loss = m1.*wp1_loss(2);
Wpump2_rep = m3.*wp2(2,3);
Wpump2_loss = m3.*wp2_loss(2,3);
Qin_rep = QR(7);
Qboiler_loss = Qloss(7);
Wturb_rep = Wt(3,7,2);
Wturb_loss = m3.*wtloss(3,7,2);
Qout_rep = Qout_act(3,7,2);
Qcond_loss = Qloss_out(3,7,2);
Exdest_p1 = Exdest12(3,7,2);
Exdest_ofwh = Exdest23(3,7,2);
Exdest_p2 = Exdest34(3,7,2);
Exdest_Boiler = Exdest45(3,7,2);
Exdest_Turb = Exdest56(3,7,2);
Exdest_Cond = Exdest71(3,7,2);
Q_MW = [0; 0; 0; Qin_rep; 0; Qout_rep];
Qloss_MW = [0; 0; 0; Qboiler_loss; 0; Qcond_loss];
W_MW = [Wpump1_rep; 0; Wpump2_rep; 0; Wturb_rep; 0];
Wloss_MW = [Wpump1_loss; 0; Wpump2_loss; 0; Wturb_loss; 0];
Exdest_MW = [Exdest_p1; Exdest_ofwh; Exdest_p2; Exdest_Boiler; Exdest_Turb; Exdest_Cond];
```

Figure A.9. MATLAB scripts part 9