THE ENVIRONMENTAL PERFORMANCE OF EINKORN BREAD USING CRADLE-TO-GRAVE LIFE CYCLE ASSESSMENT METHODOLOGY INCLUDING WHEAT STRAW UTILIZATION IN BIOETHANOL PRODUCTION

by

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ABSTRACT

THE ENVIRONMENTAL PERFORMANCE OF EINKORN BREAD USING CRADLE-TO-GRAVE LIFE CYCLE ASSESSMENT METHODOLOGY INCLUDING WHEAT STRAW UTILIZATION IN BIOETHANOL PRODUCTION

Changes in production and consumption patterns have led the pressure on ecological balance to increase along with the growing human population. One of these changes is industrial agriculture aiming to produce sufficient food for world population. However, it is seen that industrial agriculture requires intensive use of chemical inputs, causes serious problems on environment and human health, and reduces resistance to environmental problems such as climate change; for this reason, alternative production methods have started to be applied. Concepts of organic agriculture and permaculture appear here as methods determining amounts of inputs based on ecological characteristics of the region, avoiding chemical input use, and advocating diversity in production. In other respects, new approaches such as circular economy and industrial symbiosis, in concordance with sustainable development, encourage production of alternative fuels such as bioethanol from wheat straw. In this study, environmental performance of bread as an important source of nutrition since ancient times was evaluated by life cycle assessment (LCA) methodology with special emphasis on organic agriculture and permaculture practices. Additionally, wheat straw produced as a by-product in agricultural process was also assumed to be utilized in alternative fuel (bioethanol) production. Results showed that environmental impacts resulted from diesel and electricity used in machinery and vehicles throughout the life cycle. In addition, utilization of wheat straw as a by-product reduced environmental impact caused by bread production. Finally, by evaluating 3 different fuel types, it was concluded that bioethanol blends were better in terms of environmental performance.

ÖZET

BEŞİKTEN MEZARA YAŞAM DÖNGÜSÜ DEĞERLENDİRMESİ METODOLOJİSİ KULLANILARAK VE BUĞDAY SAPINDAN BİYOETANOL ÜRETİMİNDE FAYDALANILARAK GELİŞTİRİLEN SİYEZ EKMEĞİ ÇEVRESEL PERFORMANSI

Artan insan popülasyonu ile üretim ve tüketim alışkanlıklarında meydana gelen değişiklikler, ekolojik denge üzerindeki baskıyı artırmaktadır. Bu değişikliklerden biri de dünya nüfusuna yetecek kadar besin üretmeyi amaçlayan endüstriyel tarım üretimidir. Ancak görülmektedir ki kimyasal gübre ve tarım ilacı gibi yoğun girdi kullanımı gerektiren bu yöntem, çevre ve insan sağlığı üzerinde ciddi problemlere yol açmakta ve iklim değişikliği gibi adaptasyon gerektiren çevresel problemlere karşı olan direnci de düşürmektedir. Bu sebeple, alternatif üretim yöntemlerine başvurulmaya başlanmıştır. Girdi miktarını bölgenin ekolojik özelliklerine göre belirleyen, kimyasal girdi kullanımından kaçınan, üretimde çeşitliliği savunan ve doğal dengeye saygı duyarak ihtiyaçlarını gözeten yöntemler olarak organik tarım ve permakültür kavramları burada karşımıza çıkmaktadır. Öte yandan, günümüzde sıkça kullanılmaya başlanan endüstriyel simbiyoz ve döngüsel ekonomi yaklaşımları da sürdürülebilir kalkınma yaklaşımıyla paralellik göstermektedir. Bu bağlamda, aslında atık olarak değerlendirilmeyen, ancak yan ürün olarak başka bir endüstride girdi olarak değerlendirilen buğday sapından da biyoetanol gibi alternatif bir yakıt üretilmesi, bu yaklaşımların desteklediği faaliyetlerden biri olarak görülmektedir. Bu çalışmada, yaşam döngüsü değerlendirmesi (YDD) metodolojisi kullanılarak, organik tarım ve permakültür yöntemlerine başvurularak üretilen ve eski zamanlardan beri önemli bir besin kaynağı olma özelliğini kaybetmeyen ekmeğin çevresel performansı değerlendirilmiş ve tarımsal süreçte yan ürün olarak üretilen buğday sapı da alternatif yakıt üretiminde (biyoetanol) kullanılmıştır. Sonuçlar göstermektedir ki çevresel etkiler, yaşam döngüsü boyunca makine ve araçlarda kullanılan dizel yakıtından ve elektrikten kaynaklanmaktadır. Bunun yanı sıra, buğday sapının yan ürün olarak değerlendirilmesi ekmek üretiminden kaynaklanan çevresel etkinin azalmasını sağlamıştır. Son olarak, 3 farklı yakıt türü değerlendirilerek biyoetanol karışımlarının çevresel performans bakımından daha iyi olduğu sonucuna varılmıştır.

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LIST OF SYMBOLS/ABBREVIATIONS

Symbol	Explanation
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
H_2O	Water
H_2O_2	Hydrogen peroxide
H_2SO_4	Sulphuric acid
NaOH	Sodium hydroxide
NH_3	Ammonia
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxides
N_2O	Nitrous oxide
P	Phosphorus
PO_4^{3-}	Phosphate
SF_6	Sulphur hexafluoride
SO_2	Sulphur dioxide

Abbreviation	Explanation
AFEX	Ammonia Fiber Explosion
AP	Acidification Potential
CG	Conventional Gasoline
CSL	Corn Steep Liquor
DAP	Diammonium phosphate
EP	Eutrophication Potential
E10	10 % Bioethanol and 90 % Gasoline by volume
E85	85 % Bioethanol and 15 % Gasoline by volume
FAO	Food and Agriculture Organization
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Reference Life Cycle Data System
ISO	International Organization for Standardization
ktoe	kilo ton of oil equivalent

LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHW	Liquid Hot Water
OECD	Organization for Economic Co-operation and Development
POCP	Photochemical Ozone Creation Potential
SDG	Sustainable Development Goal
SE	Steam Explosion
SSCF	Saccharification and Co-fermentation
S1	Subsystem 1
S2	Subsystem 2
S3	Subsystem 3
S4	Subsystem 4
S5	Subsystem 5
TMO	Toprak Mahsulleri Ofisi
TUIK	Türkiye İstatistik Kurumu
YDD	Yaşam Döngüsü Değerlendirmesi
WO	Wet Oxidation
WWTP	Wastewater Treatment Plant

1. INTRODUCTION

Current global human population is already having difficulties with sustaining an environmentally friendly lifestyle, and it is expected to increase even further, putting greater pressure on the environment. To overcome the existing negative consequences of various environmental problems and to avoid any future negative impacts, along with many other targets, in 2015, the 2030 Agenda for Sustainable Development including the sustainable development goals was published (United Nations, 2015). Among the goals, Goal 2, which aims to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture, and Goal 12, which aims to ensure sustainable consumption and production patterns, are mainly covered within the scope of this study.

As a result of the expected population growth, there has been a need to increase the rate of current agricultural production with the purpose of eradicating world hunger. Although increasing the rate of current agricultural production has decreased hunger level to some extent, problems brought with such an increase have caused more environmental degradation. On a global scale, agricultural production systems are already exposed to the climate change and associated environmental problems; for instance, it is predicted that a decline will take place in crop yields because of the depletion of freshwater resources (Sarkar et al., 2020). To mitigate the adverse effects of global climate change on agricultural production systems, and to eliminate the pressure that current agricultural production systems put on the environment, concept of cleaner production which requires efficient and sustainable management of resources and energy should be adopted in parallel with achieving the SDGs as well (Giannetti et al., 2020). In this context, life cycle assessment (LCA) methodology seems to be one of the most appropriate scientific tools since it ensures the determination of environmental hot spots throughout a product's or a service's life cycle, and it leads the way for identifying more sustainable and environmental options along the life cycle (Roy et al., 2009).

Since the ancient times, cereals such as wheat, and cereal-based products such as bread have been a major part of human nutrition due to their high energy content; in this regard, cereal production has the highest share (33 % (FAO, 2020)) in world crop production. Among the cereals, wheat plays a significant role in terms of nutritional value due to the fact that it is an important source of protein, carbohydrates, B group vitamins, and fibers, and about 20 % of the required energy and protein in daily food intake are provided by wheat (Rosell, 2011). Specifically, einkorn (*Triticum monococcum subsp. monococcum* (domesticated)) wheat, which was domesticated approximately 10,000 years ago

in the southern Turkey, is one of the founder crops of agriculture. Since the beginning of the Bronze Age, its cultivation had reduced due to availability of higher yielding wheat varieties; nonetheless, several ancient cereals including einkorn have been rediscovered in association with growing interest in sustainable agricultural practices and in nutritional aspects of food since einkorn is richer in protein and antioxidant content than other wheat varieties (Brandolini and Hidalgo, 2011). Similarly, based upon these considerations, einkorn wheat cultivation and einkorn wheat bread production were chosen to be worked on in this LCA study.

On the path to achieving the SDGs, concept of circular economy, which requires reducing the consumption of raw materials, designing reusable and recyclable products, extending the life cycle of products through maintenance and repair, and recovering raw materials from the waste, has been considered as a novel pathway in recent years (Kirchherr and Piscicelli, 2019). From this point of view, it can be concluded that utilization options of materials are of utmost importance in terms of sustainable development, which brings about obtaining fuel from biomass. Biomass is an alternative resource, utilized to produce fuel and energy, which covers agricultural crops, plant residues, forest resources, and special energy plants (Toklu, 2017). Among them, plant/agricultural residues such as wheat straw have a great value to produce bioethanol which is considered as alternative to fossil fuels used in cars (Talebnia et al., 2010). In Turkey alone, the annual amount of wheat straw produced is approximately $3.4x10^7$ tons (Toklu, 2017); however, because of that agricultural residues like wheat straw are utilized in ploughing, in animal feeding, in using under the animal for bed, and/or in grazing animals, utilization of them in producing bioethanol remains low in Turkey (Avcıoğlu et al., 2019).

In this study, by using a cradle-to-grave approach, LCA methodology was applied to identify the environmental hot spots along the production line of bread produced from einkorn wheat which was cultivated in a permaculture farm (1), to conduct an allocation based on mass between wheat grain and wheat straw produced in the farm by considering that wheat straw was sent to a facility to be utilized in bioethanol production (2), and to evaluate the environmental performances of bioethanol fuel blends and conventional gasoline (3).

2. LITERATURE REVIEW

2.1. Conventional & Organic Agriculture

Life on planet depends on a variety of ecosystem services, which can be analyzed in four categories as seen in Figure 2.1 (adapted from Hoffmann and colleagues (2018)), to maintain their daily lives.

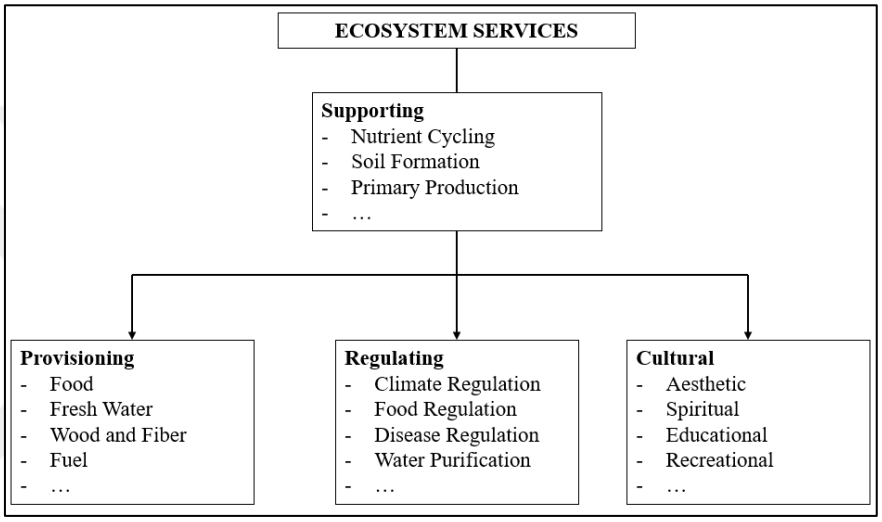

Figure 2.1. Ecosystem services categorization.

Supporting services are the type of ecosystem services on which all the other ecosystem services rely; provisioning services are the products that human beings directly obtain from ecosystems such as, in the case of agriculture, food, fibre, or fuel; regulating services are the benefits which people obtain from the regulation of ecosystem processes such as pollination; and lastly, cultural services are the non-material benefits that human beings obtain from ecosystems through, for instance, cognitive development. Agricultural practices, which range from intensive methods such as annual crop monocultures to extensive methods such as agroforestry, may have a significant negative or positive impact on the functioning of ecosystem services (Hoffmann et al., 2018). One of these agricultural practices, which affects ecosystem services in a negative way, is conventional agriculture.

To begin with, the concept of Green Revolution should be explained. Green Revolution is an agricultural phenomenon led by the Nobel Prize winner agronomist Norman Borlaug and initiated by the Consultative Group for International Agricultural Research (CGIAR) Consortium of International Agricultural Research Centers (Llewellyn, 2018). Nations had a need to follow Green Revolution to

feed the ever growing human population and to be less dependent on global food prices. In parallel to that, Green Revolution was a concept driven by government organizations and considered as a crop technology (Djurfeldt, 2018). The aim was to develop high-yielding cereals, mainly wheat, rice, and maize, which were resistant to disease (Llewellyn, 2018). In the short term, Green Revolution had been a success to address the need of the nations and to raise the economical profits; but in the long term, it led the crops to be more sensitive to pests, which resulted in the increased use of pesticides. Furthermore, these high yielding varieties required more fertilizers. In all its aspects, Green Revolution had been a burden on environment when these inputs began to cause pollution in water bodies and to increase health problems in human beings, and it did not necessarily lead to higher food security, either (Djurfeldt, 2018).

There is still a need to find the most appropriate agricultural practice to feed the human population which is expected to increase even at a slower rate. Conventional (industrialized) agriculture is one of the widely-applied practice. It basically means the intensification of agriculture in terms of the inputs such as synthetic fertilizers (Singh et al., 2020). One of the aspects of conventional agriculture is that cultivated areas are used to grow certain types of crops. In Figure 2.2, global production of crops by commodity group can be seen (FAO, 2020).

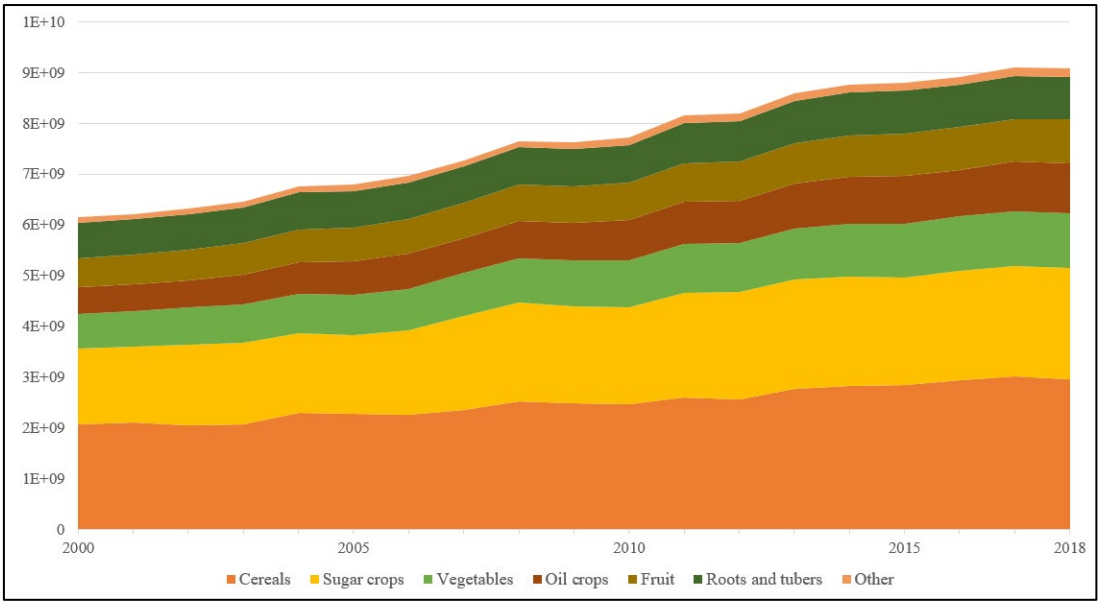

Figure 2.2. Global crop productions (in billion tons) by commodity group.

In 2018, global production of cereals including wheat, rice, and maize, was 2,962.9 million tons; and in Turkey, this number was 34.4 million tons (FAO, 2020). These crops, having high energy content, constitute the large part of human diet (Dwivedi and Ortiz, 2018); however, conventional

agriculture practice leads to high sensitivity of crops to diseases, which results in an increase in pesticide use (Figure 2.3) which is one of the inputs applied in conventional agriculture (FAO, 2020).

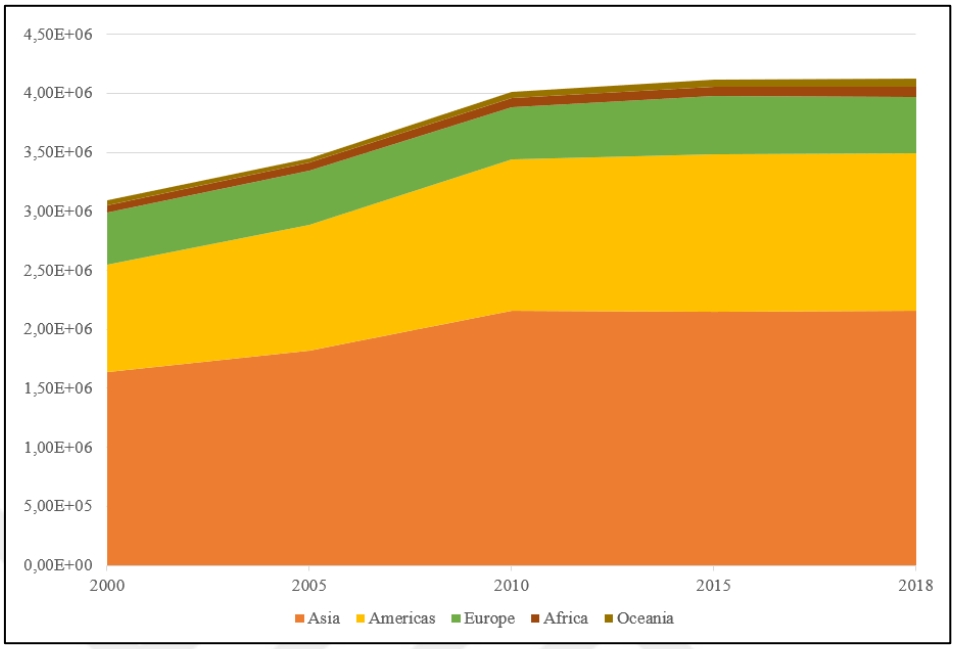

Figure 2.3. Pesticide use (in million tons) by region.

The global use of pesticides, in 2018, were 4,122.3 thousand tons, and in Turkey, this amount was 60.0 thousand tons (FAO, 2020). Similarly, in conventional agriculture, high amounts of yields are obtained because there is another factor of great environmental importance: fertilizers (Momo-Cabrera et al., 2018).

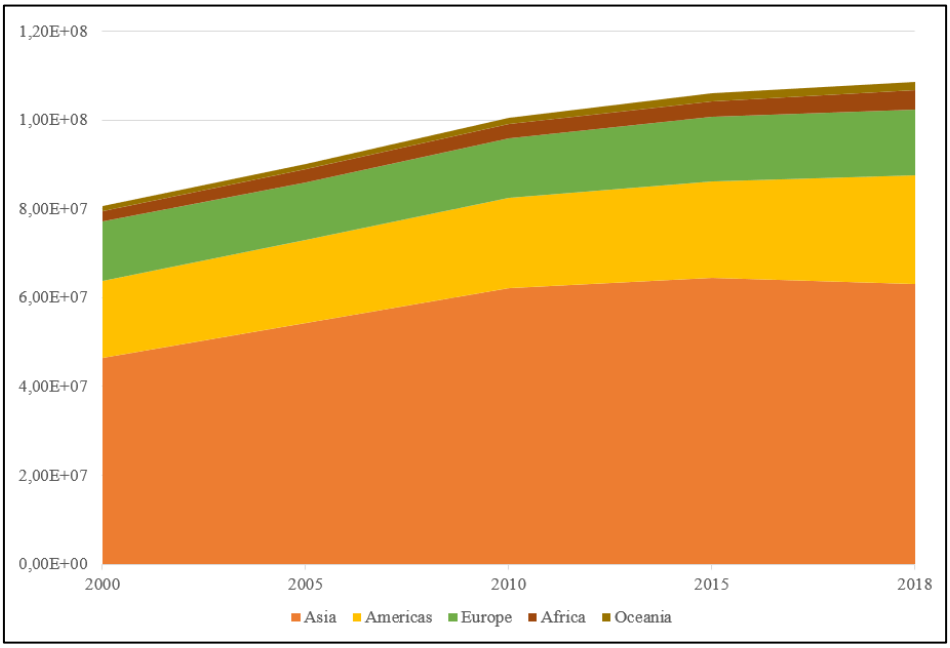

Figure 2.4. Chemical fertilizer use (in million tons) by region.

In 2018, global use of fertilizers was 188,160.0 thousand tons, and it was 2,164.2 thousand tons in Turkey. As can be seen in Figure 2.4 (FAO, 2020), fertilizer use is increasing over the years.

Pesticides and fertilizers, which are fossil fuel-based inputs, used in conventional agriculture contaminate soil and water ecosystems (Momo-Cabrera et al., 2018). Soil is an ecosystem in which there are million types of organisms living and interacting with each other. The functions of soil range from preventing organic compounds, which include fertilizer, pesticide, and plant residues, from being released to freshwater ecosystems as contaminates; to removing nitrogen and other nutrients from being released to groundwater; to fixing nitrogen from the atmosphere so that plants are able to utilize it; and to holding water and reducing run-off (Pimm et al., 1991). Water, on the other hand, is essential to all life forms existing on Earth. Unfortunately, contaminates resulting from the use of synthetic fertilizers and pesticides lead to eutrophication, acidification, greenhouse gas production, and air pollution.

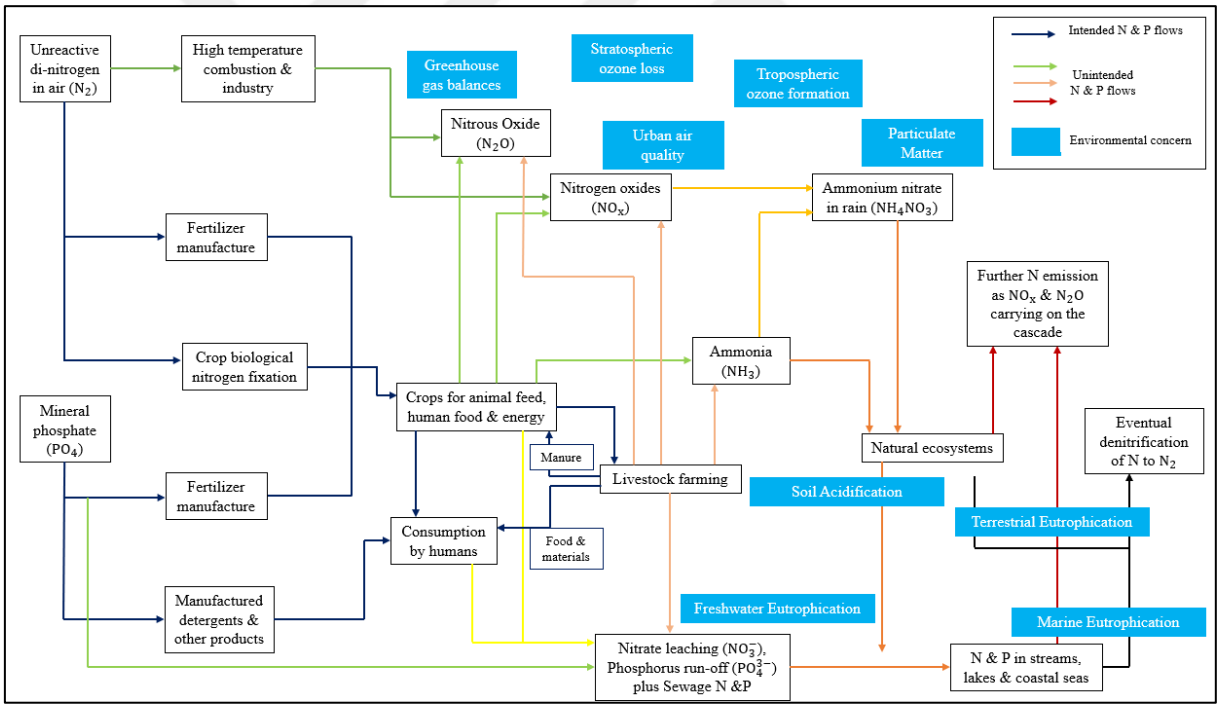

Figure 2.5. Nutrients cascading through the environment.

As can be seen in their cycle through atmosphere, soil and water (Figure 2.5) (Bleeker, 2018) (Chowdhury et al., 2018), excessive use of these chemicals disturbs the biogeochemical cycles: eutrophication leads to biodiversity loss, toxic algal blooms, and fish kills; contamination of drinking water by overuse of nitrogen causes human health problems such as cancer; air pollution by nitrogen compounds leads to particulate matter formation, increase in nitrogen dioxide, and tropospheric ozone, which results in respiratory health problems and/or cancer for human beings, and damages to

crops. In Figure 2.6, world greenhouse gas emissions related to agriculture and related land use can be seen (FAO, 2020).

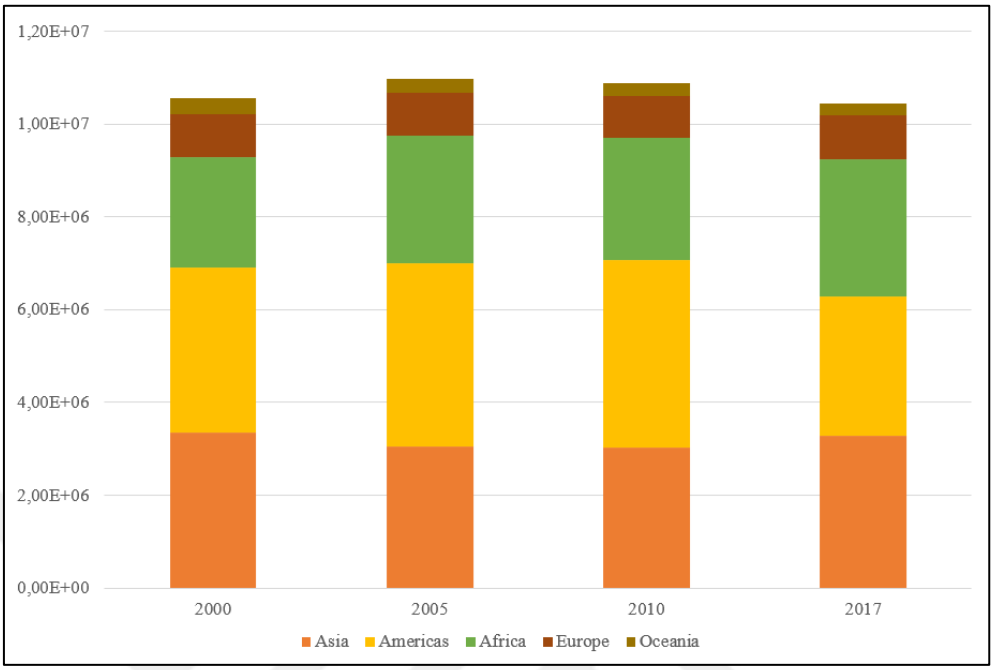

Figure 2.6. World greenhouse gas emissions (in billion tons CO_2-eq.).

In 2017, 19.8 % of global greenhouse gas emissions belonged to agriculture and related land use with the amount of 10,439.4 million tons CO_2-eq.; and in Turkey, 13.4 % of total greenhouse gas emissions belonged to agriculture and related land use with the amount of 68 million tons CO_2-eq. (TUIK, 2021). It can be concluded that conventional agricultural practices put enormous pressure on the environment; that is, with conventional agriculture, soil quality degrades, water resources are contaminated, air pollution is on the rise, and ecosystem services are disturbed due to the production and intensive use of chemical fertilizers and pesticides. Conventional agricultural practices may have been successful in meeting the food demand of the global population; however, in terms of environmental sustainability, a change of practice for the sake of the environment and future generations is needed. In this regard, organic agricultural practices seem to be a better option.

Organic agriculture is another type of farming practice in which natural resources and processes are respected and treated responsibly. Organic agricultural practices emphasize the conservation of biodiversity, the improvement of soil quality, water quality and air quality, and the sustainable use of energy and natural resources (Blaće et al., 2020). One of the drawbacks of conventional farming is that it leads to a loss of biodiversity (Hole et al., 2005), which is due to the fact that in 2018, global share of agricultural land area in total land area was 36.9 %, and in Turkey, this share was 49.1 % (FAO, 2020). Overall, a considerable share of land use is represented by agricultural land. Also

considering the fact that forests are being transformed to agricultural lands, it is expected that a big share of world's biodiversity exists on agricultural lands in which the main purpose is to produce as much crops as possible and to use what is needed in this process. According to Hole and colleagues (2005), biodiversity in terms of abundance and richness is higher on the agricultural lands where organic production practices are applied compared to the ones where conventional production practices are applied. The main reasons of that are said to be the prohibition or reduced use of chemical pesticides and synthetic fertilizers, a management system which includes non-crop habitats and field margins, and the application of mixed farming where both crops are grown and livestock is raised. When the impacts of organic agricultural practices on soil quality are analyzed, it can be said that soils, which are under organic agricultural management, have better qualities in terms of storage of carbon and nitrogen, holding more water -which results in, under drought conditions, higher crop yields-, increasing soil aggregation through the use of manure, and decreasing soil loss by erosion. In terms of water quality, because in organic agriculture, the use of harmful chemicals such as pesticides and fertilizers is prohibited or reduced, the quality of surface waters and groundwaters is higher than in conventional agriculture (Lorenz and Lal, 2016). Another advantage provided by organic agricultural practices is the mitigation of greenhouse gas emissions; that is, the prohibition or reduction of synthetic pesticide and fertilizer use, the application of cover crops, crop rotations and compost, and the conversion of organic waste into compost to be used as fertilizer are some of the ways in which greenhouse gas emissions are reduced (Squalli and Adamkiewicz, 2018). To conclude, the main characteristics of organic agricultural practices can be listed as prohibition/reduced use of chemical pesticides; prohibition of mineral-based fertilizers; mechanical weeding; farmyard and green manuring; minimum tillage; intercropping and under-sowing; sensitive field margin/hedgerow management/creation of non-crop habitats; small field size; crop rotation; and mixed farming (Hole et al., 2005). Regarding organic agricultural practices, the concept of agroforestry should be indicated explicitly. Agroforestry is a type of land use management system in which the implementation of organic farming is supported through the activities such as soil restoration, biodiversity conservation, and climate change mitigation (Ollinaho and Kröger, 2021). It achieves the maintenance of the quality of soil and water ecosystems and carbon sequestration by integrating trees or other woody perennials (such as shrubs) and agriculture, which results in the improvement of the ecosystem services (Schwarz et al., 2021).

To conclude, in Table 2.1 (adapted from (Aydın et al., 2013)), the main characteristics of conventional (industrialized) agriculture, organic agriculture and permaculture can be observed.

Table 2.1. Main characteristics of the agricultural production alternatives.

	Conventional (industrialized) agriculture	**Organic agriculture**	**Permaculture**
Degree of intensification	High intensification in terms of synthetic inputs (such as mineral fertilizer) and machinery	Moderate intensification in terms of machinery	Low intensification in terms of inputs and machinery
Seed stock	Conventionally bred seed from external and internal sources	Organic seed from external and internal sources	Organic seed from internal sources (own stock)
Fertilizer use	Mineral fertilizers	Organic/organically certified fertilizers, organic manure	Organic manure
Pest control	Pesticide use	Non-crop habitats, field margins, intercropping	Natural enemies, non-crop habitats, field margins, intercropping
Land use (for the same amount of yield)	Low	High	High
Emphasis on biodiversity	Low	High	High

2.2. Life Cycle Assessment Methodology & Its Applications

2.2.1. Life Cycle Assessment Methodology

With today's production and consumption patterns, human beings continue to put the ability of future generations to meet their needs and sustain their daily lives at more risk, which is in parallel to that more than one Earth is needed to support the demands of human beings on natural resources and ecological services. Since such a thing is not rational, environmental sustainability should be maintained and monitored. The latter requires an assessment process in which the life cycle assessment methodology is highly applied.

LCA is defined as ''the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle'' (ISO 14040, 2006). LCA methodology is considered to be a holistic and effective environmental assessment tool which evaluates and quantifies the environmental impacts of a product's or a service's life cycle by mostly using ''cradle-to-grave'' approach (Dommett, 2008) (Curran, 2013). To take up comprehensively, LCA is a scientific methodology used in identifying opportunities to improve the environmental performance of products at various points in their life cycle, in informing decision-makers from all

fields for purposes such as product or service design or redesign, in selecting relevant indicators of environmental performance, and in developing marketing strategies such as implementing an ecolabelling scheme (ISO 14040, 2006). LCA methodology quantifies and evaluates the environmental impacts of a product or a service by taking issues like emissions to ecosystems into account according to ISO standards 14040:2006 and 14044:2006 (Schramm et al., 2020). Fundamentally, LCA is conducted in four phases: the goal and scope definition, the inventory analysis, the impact assessment, and the interpretation (Figure 2.7) (ISO 14040, 2006).

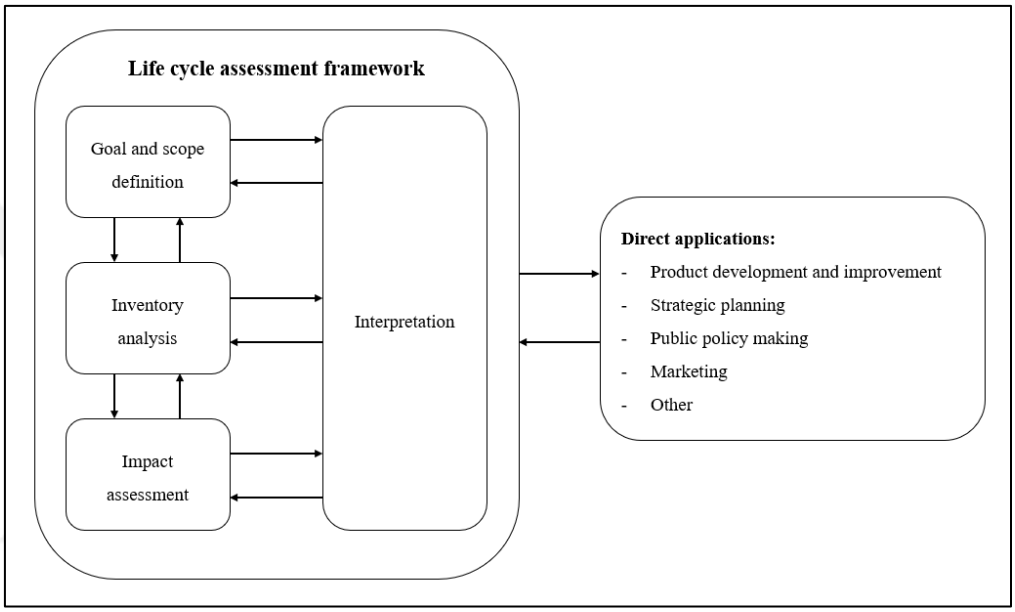

Figure 2.7. Phases of the LCA methodology.

In the goal and scope definition phase, the goal of the study, the studied system's boundaries, and the functional unit of the study are identified; in the inventory analysis phase, the compilation and quantification of inputs and outputs for a product or a service throughout its life cycle are conducted; in the impact assessment phase, the magnitude and significance of the potential environmental impacts for a product or a service system throughout its life cycle are understood and evaluated in several midpoint impact categories such as climate change, acidification, eutrophication, and ozone depletion; in the interpretation phase, significant issues are identified, limitations of the study are determined, and recommendations for further research are given (ISO 14044, 2006).

Gabi 8.0 is one of the software programs that are used to conduct an LCA study, and it was developed by the Institute for Polymer Testing Science (IKP) at the University of Stuttgart in cooperation with PE Europe GmbH in Germany. Compared to other software programs with similar functions, GaBi 8.0 is more advantageous in terms of functionality, a wide range of databases, and user friendliness (Özata, 2009).

2.2.2. LCA Applications in Agriculture

As the current and widely-applied agricultural practice, which is the conventional one, has some drawbacks that need to be addressed and the notion that the growing human population requires even more agricultural production, which is expected to put a greater burden on the environment, the effectiveness of alternative agricultural practices is being examined in terms of sustainability. In this regard, life cycle assessment methodology is applied as a means of supporting the decision-making process via the identification of environmental hot spots throughout a product's or a service's life cycle (Notarnicola et al., 2015). Within the scope of this study, the LCA studies conducted for the supply chain of bread are examined.

As mentioned before, the production of cereals has an important place in terms of both value and volume (FAO, 2020) since some cereals, such as wheat, rice, and maize, are the primary sources of nourishment for human beings. The supply chain for cereals and cereal-based products to be studied by applying LCA can be simplified as in Figure 2.8 (Notarnicola et al., 2015).

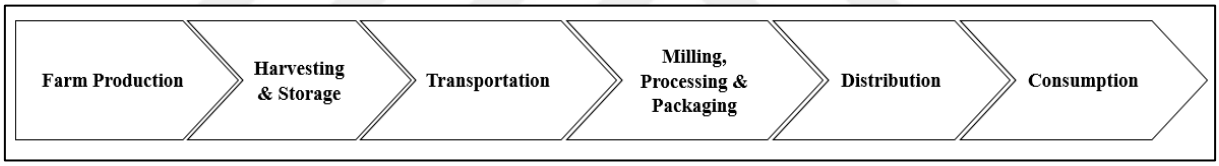

Figure 2.8. The supply chain scheme for cereals and cereal-based products.

Although these life cycle steps vary depending on the location and the capacity for production, basically, after the first three steps in the supply chain, which are the cultivation practices (farm production), harvesting, storage, and transportation, milling step in which flour is produced from cereal grains is the next step. A cereal grain consists of three parts: the embryo, the endosperm, and the protective layer of the seed coat (Notarnicola et al., 2015).The embryo, which has the highest concentration of lipid and lipid-soluble vitamins, is vital for the survival of the species; the endosperm is the largest component in all types of cereals, and it has the greatest values because of its starch content which provides human beings with nutrition, the primary reason of why they are cultivated (Evers and Millart, 2002); and the protective layer of the seed is the bran fraction (Notarnicola et al., 2015). The flour produced from cereal grains is the main raw material for the production of bread. Together with other raw materials such as water, yeast, and salt, it is used in the production of bread which is a staple product and differs from culture to culture in terms of shape, color, texture, and organoleptic characteristics (Ingrao et al., 2018). In Turkey, bread has a large share in the expenses made for food; that is, while in 2018, 17.5 % (the second largest share after meat and sea products)

of all the food expenses belonged to bread and cereals, in 2019, this percentage was 17.8 % (the second largest share after meat and sea products) (TUIK, 2020).

LCA studies conducted for bread produced from wheat mainly focus on the comparison between conventional and organic agricultural practices in the cultivation process (Notarnicola et al., 2015), and the wheat cultivation process itself. In a study conducted by Andersson and Ohlsson (1999), it was indicated that large scale industrial systems such as conventional agriculture have more environmental impact compared to small scale production systems and home-production systems, which depends on the different parameters taken into consideration; additionally, in all of the production systems compared, the process of wheat cultivation has the most environmental impact with respect to other processes along the production and consumption line. In a study conducted to measure the global warming potential of wheat production (Biswas et al., 2008), it was found that in a farm in which conventional agricultural practices are applied, the pre-farm stage which includes the production of chemical fertilizers has the largest share in the results. In another study (Espinoza-Orias et al., 2011), it was aimed to measure the carbon footprint of bread production, and it was identified that the main hot spots, which are the areas having the most environmental impact, along the production line are the cultivation of wheat and the consumption of bread. Kulak and colleagues (2015) conducted a study the scope of which was from cradle to the consumer, and they investigated the environmental performance of different supply chains in these impact categories: non-renewable energy demand, global warming potential, ozone formation (summer smog) and ozone depletion potentials, eutrophication potential to aquatic and terrestrial ecosystems, acidification potential, aquatic eco-toxicity and human toxicity potentials, land competition, and phosphorus use. The results showed that it is most likely that agricultural practices, in which a low-input system involving saving own seeds, applying less fertilizers and avoiding pesticides is implemented, have lower environmental impacts per unit of area; however, such benefits can be offset by lower amount of yields and the necessity to use more land in order to obtain higher amounts of yields. Additionally, distribution and consumer transport systems have an important role in the overall environmental performance of the supply chain, and while local supply chains seem to be more environmentally friendly, their benefits can also be offset by the need for frequent journeys since each time low volume of goods is purchased. In another study carried out by Houshyar and Grundmann (2017), five different tillage systems (two conventional tillage systems, and three conservation tillage systems (moldboard plough and combined seeder (i), reduced tillage (ii), and no tillage (iii))) were compared in terms of energy use and environmental impacts, and it was found that reduced tillage system is the most environmentally advantageous one. Todorovic and colleagues (2018) conducted a study that indicated that in the high-input intensity farming systems, there is higher amounts of agricultural production,

which results in higher amounts of water consumption, global warming potential, and energy-related issues. In another study which investigated one bread supply chain (Ingrao et al., 2018), the main environmental hot spot was found out to be the wheat cultivation process due to the production, transportation and use of the mineral fertilizers. In a similar study (Câmara-Salim et al., 2020), two cultivation processes (a monoculture system and a crop rotation system) were compared, and it was found that the monoculture system has more environmental impacts due to the use of agrochemicals and field emissions. The crop rotation system is more environmentally friendly since with crop rotation, nutrient sequestration in the soil provides avoidance of pollution resulting from chemical fertilization.

Apart from the LCA studies conducted to compare the conventional and organic agricultural practices and to evaluate the life cycle of bread, there are also studies to assess the environmental impacts of mineral fertilizers which cause adverse outcomes in terms of sustainable agricultural production. One of these studies was conducted by Brentrup and colleagues (2004), and the environmental impact of different amounts of nitrogen fertilizer in winter wheat production was evaluated. In the global warming potential impact category, it was determined that the environmental impact increased as the amount of applied nitrogen fertilizer increased, the reason of which was thought to be the nitrous oxide emissions related to the nitrogen fertilizer input. In the acidification potential impact category, a similar result was obtained, which meant that the environmental impact in that category increased with the increasing amounts of the nitrogen fertilizer use, and the reason was thought to be the ammonia emissions stemming from the application of the nitrogen fertilizer. Normalization results showed that up to 96 kg of nitrogen fertilizer use per hectare, the degradation of the natural environment due to land use was the most relevant environmental impact category; whereas, at 192 kg and higher nitrogen fertilizer use per hectare, the aquatic eutrophication was the most relevant environmental impact category. Another study conducted by Li and colleagues (2020) focused on the eco-efficiency of maize-wheat rotation production system in which 3 different fertilization practices were applied: mineral fertilizer, the substitution 50 % of mineral-N with fresh cattle solid manure, and the substitution 50 % of mineral-N with fresh cattle liquid manure. The results which were obtained by using SimaPro software and ReCiPe 2016 impact assessment methodology indicated that the total environmental impact of the rotation system decreased by 24.6 % under the substitution 50 % of mineral-N with fresh cattle solid manure and by 37.9 % under the substitution 50 % of mineral-N with fresh cattle liquid manure. The reason was thought to be the use of less amounts of mineral fertilizer in the substitutions compared to the use of mineral fertilizer only. In terms of eco-efficiency, the substitutions led to a 30 % increase in comparison with the mineral fertilizer; additionally, 17.2 % increase in the economic profits with the substitution with the solid

manure and 19.1 % increase in the economic profits with the substitution with the liquid manure were observed, which further led to the conclusion that the substitution of mineral fertilizer with manure should be encouraged through the activities such as policy support, incentives, and technique update.

2.3. Bioethanol as an Alternative Fuel

Global CO_2 emissions have their sources mostly in the use of non-renewable, fossil fuel-based energy (Figure 2.9), which results from the fact that the main energy supply of the world is coal. While in 1990, the total energy supply from coal was 2,220,587 ktoe (kilo ton of oil equivalent), this number was 3,838,326 ktoe in 2018 (Figure 2.10) (International Energy Agency, 2020).

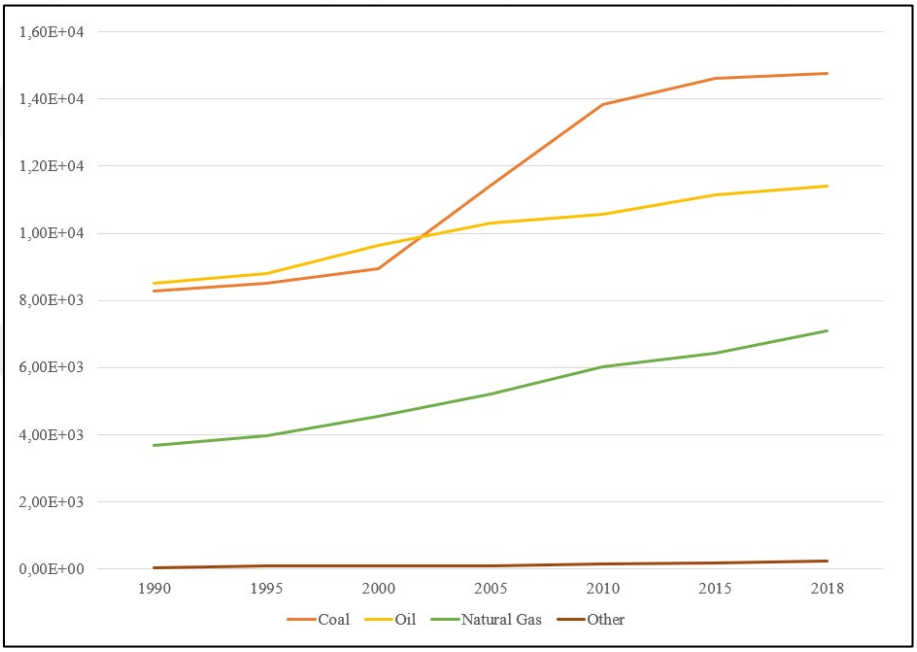

Figure 2.9. Global CO_2 emissions by energy source (in Mt CO_2).

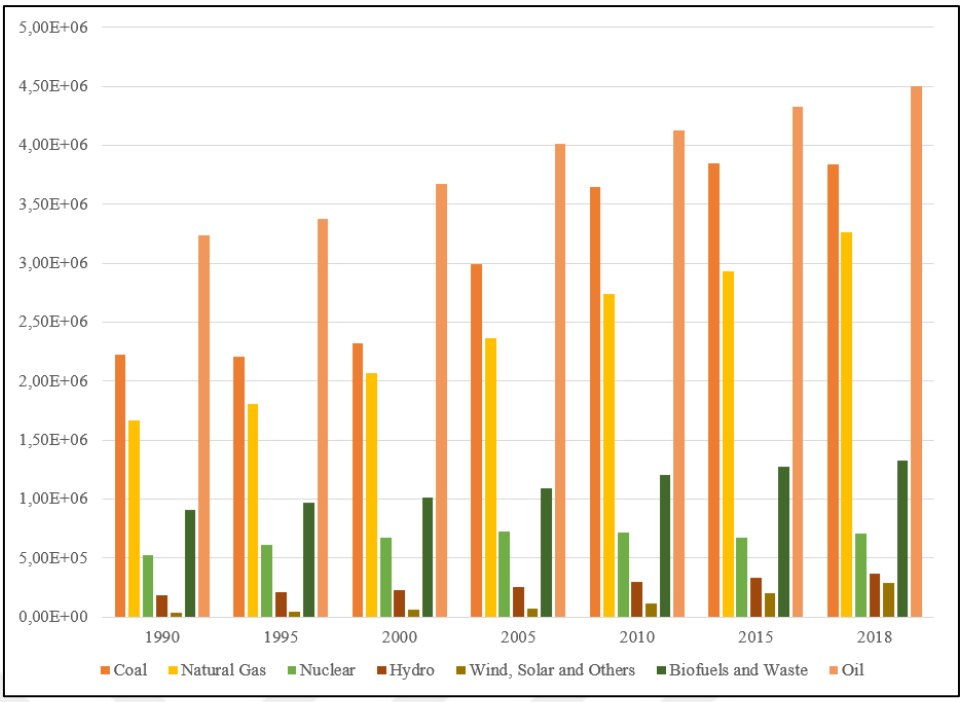

Figure 2.10. The global total energy supply by source (in ktoe).

In Turkey, the situation is similar; that is, in 1990, the total energy supplied by non-renewable sources was 41,841 ktoe, while this number was 121,960 ktoe in 2018 (Figure 2.11) (International Energy Agency, 2020). In 2020, the share of coal, oil and gas use in total energy consumption was 90.5 % in Turkey (Ozturk et al., 2017).

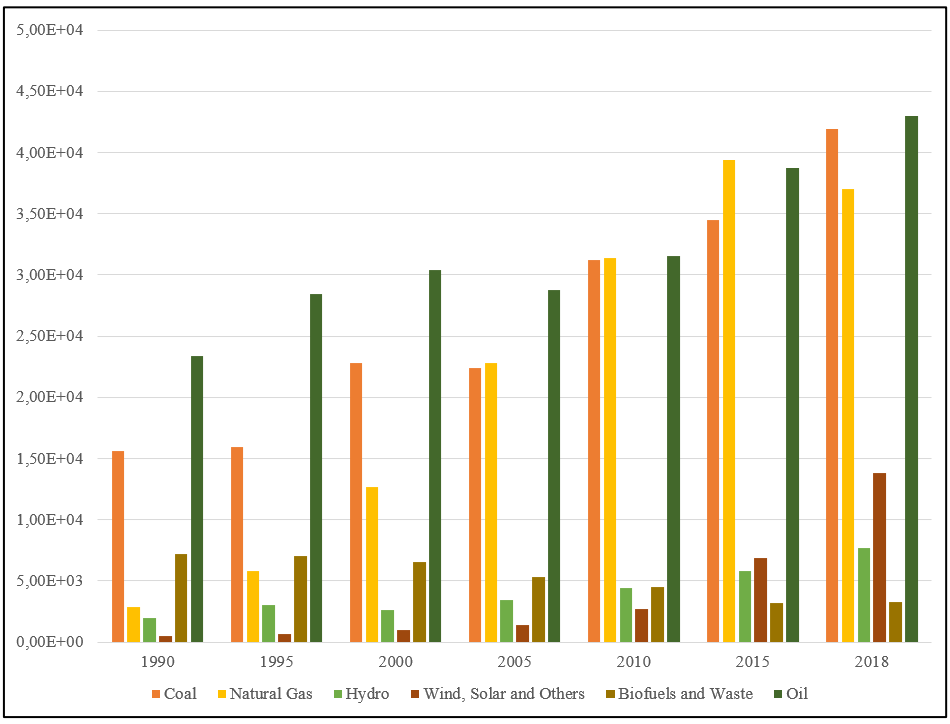

Figure 2.11. The total energy supply by source (in ktoe) in Turkey.

As can be seen, over the course of many years, energy is mostly supplied from non-renewable, fossil fuel-based sources which have some drawbacks such as their finite supply, increasing price and fluctuations on the market, and greenhouse gas emissions and global warming as the consequences (Mood et al., 2013). In addition, on a global scale, 19 % of the CO_2 emissions stems from the transportation sector (Daylan and Ciliz, 2016), and this sector operates depending mostly on the non-renewable energy sources such as gasoline, diesel and liquefied petroleum gas (LPG) (Bayrakci-Ozdingis and Kocar, 2018). In Turkey alone, the rate of increase in the number of cars is 64.33 % between 2010 and 2018 (Turkish Ministry of Transportation and Infrastructure). When the national targets are considered, Turkey has indicated in the 2015 United Nations Climate Change Conference that it aims to reduce the total amount of greenhouse gas emissions by 21 % until 2030 (Bayrakci-Ozdingis and Kocar, 2018). Consequently, 2 solutions have been proposed. The first one is to reduce the gasoline consumption, which is not considered feasible in the short term, and the second one is to gradually reduce the gasoline consumption through the integration of alternative fuels (Melikoglu and Turkmen, 2019). Therefore, there has been a search of alternative fuels for internal combustion engines. Two of these are biodiesel and bioethanol (biofuels), and the latter is produced from bioenergy crops and biomass. In the first generation bioethanol production, sugar containing raw materials like sugar cane and starch grains like corn or wheat are used as the feedstock, but these have food and feed value; because of that, in the second generation bioethanol production, lignocellulosic biomasses like wheat straw are used as the feedstock since they are abundant, cheap and renewable (Thangavelu et al., 2016), and they do not have adverse effects on the human food supply chain by reducing the amount of food to be used in nutrition (Mood et al., 2013).

Lignocellulosic biomasses are composed of cellulose (35-50 %), hemicellulose (20-35 %), lignin (15-20 %), and ash and other materials (15-20 %), and they do not tend to decompose easily due to their intricate structures. Hence, the conversion process of lignocellulosic biomass-to-bioethanol requires a pretreatment step in which it is aimed to break down the lignin seal so as to make cellulose more accessible to the conversion (Mood et al., 2013). In Figure 2.12, common pretreatment methods used to convert lignocellulosic biomass to bioethanol can be viewed (Talebnia et al., 2010).

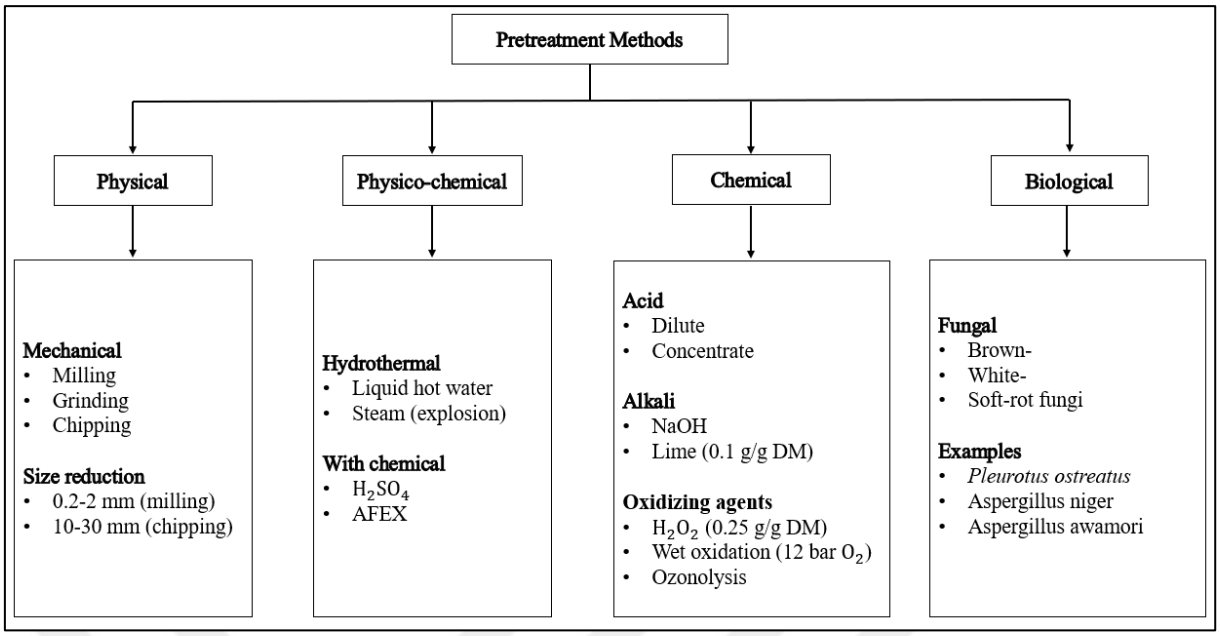

Figure 2.12. The most common pretreatment methods used on wheat straw.

The pretreatment methods for the conversion of lignocellulosic biomass to bioethanol are simply grouped into four categories: physical, physico-chemical, chemical, and biological. To achieve high sugar release efficiency, low toxicant production and low energy consumption, a combination of these pretreatment methods are usually applied. The aim of the first step of the pretreatment, which is the physical pretreatment, is to reduce the size through milling, grinding, and chipping so as to improve the efficiency of the following steps. At the end of the physical pretreatment, surface area increases, and degree of polymerization decreases (Talebnia et al., 2010).

In the physico-chemical pretreatment, liquid hot water (LHW), steam explosion (SE) and ammonia fiber explosion (AFEX) are some of the methods used to obtain hemicellulosic and cellulosic sugars. LHW belongs to the group of hydrothermal pretreatment methods in which at temperatures ranging from 170°C to 230°C, high pressure is applied to release hemicellulosic sugars, and in LHW, time and temperature are the two parameters of great importance to affect the overall efficiency. SE (autohydrolysis) also belongs to the group of hydrothermal pretreatment methods in which biomass, from the physical pretreatment step, is rapidly (from several seconds to few minutes) heated at temperatures ranging from 160°C to 230°C by applying high pressure steam, and then the materials are exposed to an explosive decompression by suddenly reducing the pressure. In SE, temperature, residence time, particle size and moisture content of the biomass are the parameters that affect the overall efficiency. Furthermore, the addition of chemicals such as H_2SO_4 improves the overall efficiency of SE method. AFEX is another method belonging to the group of alkaline thermal pretreatment methods in which size-reduced biomass is exposed to liquid ammonia under high-

temperature and high-pressure conditions for a period of time, and then a rapid pressure release is applied. In AFEX, ammonia loading, temperature, pressure, moisture content of the biomass and residence time are the parameters that affect the overall efficiency. At the end of the physico-chemical pretreatment, surface area increases, hemicellulose is partially degraded, and lignin is transformed (Talebnia et al., 2010).

In chemical pretreatment, different chemicals such as acids, alkalis and oxidizing agents are used. Among them, dilute acid (H_2SO_4) pretreatment is widely used. Additionally, the methods with alkalis and peroxide (H_2O_2), wet oxidation (WO) and ozonolysis pretreatments are more efficient in removing lignin, while acid pretreatment is more efficient in solubilize hemicellulose. In acid pretreatment (acid hydrolysis), concentrated acid or dilute acid can be used. In concentrated acid pretreatment, concentrated acids are used in the treatment of biomass at ambient temperatures. With this method, high yield of sugars is obtained, and after the pretreatment step, no enzymes are needed; but still, this method has some disadvantages such as high acid and energy consumption, equipment corrosion, and longer reaction time. In dilute acid pretreatment, low concentrated acids like 0.5-1 % H_2SO_4 are used to treat biomass at high temperatures. With this method, hemicellulose sugar decomposition is accelerated; however, during the process, many inhibiting by-products are formed, and pH neutralization is required for the subsequent steps. In alkaline pretreatment, biomass is treated with dilute bases such as sodium, potassium, calcium and ammonium hydroxides at lower temperatures and pressures. The lignin content of biomass is one of the parameters affecting the overall efficiency, and because of the high cost of alkalis, calcium hydroxide (lime), which is recoverable, or ammonia, which is recyclable, are preferred. In alkaline/oxidative pretreatment, biomass is treated with an oxidizing agent such as H_2O_2 together with an alkaline such as NaOH at mild temperatures, which is more efficient compared to NaOH treatment alone. In WO, biomass is treated with water and high pressure oxygen or air at temperatures higher than 120°C, which is an effective pretreatment method to obtain solubilized hemicellulose fraction. When alkali and WO pretreatment methods are combined, the decomposition of lignin to CO_2, H_2O and carboxylic acids is accelerated. In ozonolysis, biomass is treated with ozone at room temperature to solubilize lignin without causing any toxicity. The main disadvantage of this pretreatment method is that the use of large amount of ozone is high-priced. At the end of the chemical pretreatment, surface area increases, degree of polymerization decreases, hemicellulose id degraded, and lignin is removed (Talebnia et al., 2010).

In biological pretreatment, biomass is treated with microorganisms such as brown-, white- and soft-rot fungi among which white-rot fungi is said to be the most effective in the degradation of lignin

and hemicellulose. Biological pretreatment is the most environmentally friendly one and requires less energy with respect to other pretreatment methods; nonetheless, the rate of the degradation is very low. At the end of the biological pretreatment, surface area increases, and hemicellulose and lignin are degraded (Talebnia et al., 2010).

After the pretreatment, enzymatic hydrolysis (saccharification) in which complex carbohydrates are converted to simple monomers by the enzymes belonging to the class of cellulases produced by fungi and/or bacteria (Talebnia et al., 2010) is carried out. During hydrolysis, hemicellulose is degraded to several pentoses and hexoses, and cellulose is degraded to glucose. The parameters influencing the efficiency of the process are temperature, pH, mixing rate, substrate concentration, cellulase enzyme loading, and surfactant addition. To achieve the most efficient hydrolysis process, pretreatment method(s) should be carefully chosen to decrease cellulose crystallinity and to remove lignin as much as possible. Surfactant added to the process ensures the modification of cellulose surface by adsorbing lignin, and it minimizes enzyme loading (Sarkar et al., 2012).

In the fermentation process, saccharified biomass is fermented into ethanol by microorganisms. There is a lack of ideal microorganisms which are able to ferment both pentose and hexose sugars, which prevents industrial utilization of lignocellulosic materials for bioethanol production. Ideal microorganisms for this process should have broad substrate utilization, high ethanol yield and productivity, tolerance to high temperatures and high concentrations of ethanol. In parallel to that, genetically modified microorganisms are used to increase the efficiency of the fermentation process (Sarkar et al., 2012).

It has been stated that bioethanol consumption does not require any modifications in cars' engines (Daylan and Ciliz, 2016), and the CO_2 emissions resulting from the bioethanol consumption are not considered as extra because of the fact that bioethanol is produced from biomass; that is, such emissions are captured by plant to be used in photosynthesis reactions (Bayrakci-Ozdingis and Kocar, 2018). Considering that, even though it has been indicated that second generation bioethanol production is not feasible with the existing production technologies, it is required to further investigate and develop the pretreatment methodologies in order to obtain higher efficiency (Melikoglu and Turkmen, 2019). In terms of the economic feasibility of bioethanol production, Daylan and Cılız (2016) conducted an environmental life cycle costing analysis to evaluate the production and driving costs of conventional gasoline and bioethanol blends (E10 and E85). The results showed that the production costs of bioethanol was 0.32 €/kg (excluding taxes) for the year 2010, which was considered economically feasible in comparison with the production cost of

conventional gasoline (0.69 €/kg for the year 2009). When the driving costs of conventional gasoline and bioethanol blends were compared, it was found that the driving cost of E10 was equal to the driving cost of conventional gasoline (each 0.047 €/km). This is because the amount of bioethanol required for 1-km distance is higher than the amount of conventional gasoline required for 1-km distance due to the fact that bioethanol has a lower energy value (33 % less (Bayrakci-Ozdingis and Kocar, 2018)). Nonetheless, when E85 was used, the driving cost was calculated as 0.036 €/km, which meant a decrease by 23 % compared to the driving cost of conventional gasoline. It was concluded that in the long term, the consumption of bioethanol fuel blends were more advantageous economically.

Energy consumption is increasing the most in Turkey compared to other OECD countries; in addition to that, among the OECD countries, Turkey has the most expensive gasoline because a large share of the raw material (crude oil) is imported and a high level of tax is applied on imported products. Taking into account all of these, bioethanol production becomes even more important to reduce the dependence of the country on imported products. The amount of the potential bioethanol production in Turkey is 800,000 L/day based on the capacities of the existing bioethanol production facilities (Konya Sugar Factory-Çumra Sugar Factory (Konya), Tarkim (Istanbul), and Tezkim (Adana)) (Bayrakci-Ozdingis and Kocar, 2018). It has been estimated that in Turkey, up to 6.10 GL/year of bioethanol can be produced from lignocellulosic biomass, and when E85 is used, this bioethanol production would be equal to 4.39 GL/year of gasoline (Isci, 2012); but still, more research and development studies are required in that field.

3. MATERIALS AND METHODS

The life cycle assessment (LCA) methodology based on the standards ISO 14040-44 (ISO 14040, 2006; ISO 14044, 2006) was applied to identify the environmental hot spots throughout the life cycle of bread produced from einkorn wheat, which is an ancient type of wheat variety and was cultivated in a permaculture farm (Malva Permaculture) located in Silivri, Istanbul, Turkey. A scenario in which the produced wheat straw was assumed to be utilized in bioethanol production was developed so that a standard allocation procedure based on mass was conducted between the produced wheat grain and wheat straw. Additionally, to further support the utilization of agricultural residues such as wheat straw in the production of alternative fuels, the comparison between the bioethanol blends and conventional gasoline was included as well within the scope of this study.

The overall study was divided into 5 subsystems (cultivation stage, flour production stage, bread production stage, distribution/transportation stage, and bioethanol production stage). The functional unit was determined as the production of one loaf of bread (1 kg/loaf) in sufficient number for an individual's consumption for approximately 100 years. The required data was obtained from Malva Permaculture, GaBi 8.0 software and EcoInvent database processes, and related literature. The environmental impacts were evaluated by using GaBi 8.0 software, and CML2001 impact assessment methodology was applied in four different categories (global warming potential, acidification potential, eutrophication potential, and photochemical ozone creation potential).

3.1. The Permaculture Farm

Malva Permaculture Farm, which is located in Silivri – Istanbul/Turkey, is 130 acres of land which has a past of more than a decade of organic farming, and in the last years, it has paid attention to permaculture and climate change practices such as mitigating the climate in the area, counteracting soil erosion and finally preserving native plant trees (Müezzinoğlu, 2017). Malva Permaculture Farm is a Botanic Gardens Conservation International (BGCI) member, and a bio-farm located in Thrace region, northwest Turkey. The strategic location at the intersection of Euro-Siberian and Mediterranean zones provides repair for a vast flora and fauna. Natural conservation is one of the milestones at Malva Permaculture. Through agroforestry, good organic practices, and soil conservation, it is possible to maintain and preserve wild and native species (Müezzinoğlu, 2017). Carbon fixation is maintained in the whole farm with trees and abundance of weeds, through the concept of carbon farming (Toensmeier, 2016). Turkey has an extraordinary ecosystem due to its

location between Asia and Europe. Biological diversity is high compared to other countries with same climatic condition (Müezzinoğlu, 2017).

Soil is prepared before the sowing period which takes place in the end of October-at the beginning of November depending on the climatic conditions. At certain times, soil analysis is conducted to analyze the mineral composition, and these analyses are financially supported by the government to some extent. Nevertheless, no kind of fertilizer is used at the farm, if not needed, and the agroecology land has been cultivated by using organic practices for the last 4 years. If there is a need to use fertilizer to support the crop growth, this fertilizer will be animal manure. In that case, it can be concluded that there is no additional emission to soil and/or water ecosystems due to the production and application of this kind of fertilizer, and the reason is that animal manure, produced with nutrients taken from the soil, is reintroduced back to the soil. There are two important aspects to be considered before the sowing period: plowing and the moisture content of the soil. During plowing, a tractor is used in the field, and care is taken not to plow the soil too deeply or when too wet, which may lead the soil to be compacted. For the soil to be moist enough, seasonal rain period is waited. When the conditions are suitable, sowing period takes place. A sowing machine, which sows the seeds 5-6 cm into the soil, is used in this practice. As mentioned before, no kind of fertilizer is used at the farm, if not needed. The soil is constantly observed to determine whether it needs water, but in general, irrigation takes place through rain. At this farm, no kind of pesticide is used as well; alternatively, in order to prevent diseases, the farm introduces and enhances biodiversity and uses its own seed stock and does not buy from external sources. Furthermore, agroforestry techniques are used, and monoculture technique is not applied, which concludes that the farm management considers the needs of the regional ecosystem. Also, between neighbor fields, there are buffer zones where green fence is preferred. The time for wheat harvest is usually around July; but still, the weather conditions should be appropriate, and the crops should not tilt down too much. It is of great importance that the produce should be mature enough to be harvested; that is, the hardness of the grains is controlled. If there is dew on the crops in the morning, it is necessary that the dew must be gone before harvest; otherwise, mold might form in the warehouse. Harvest is done with a combine harvester with which also wheat is loaded simultaneously onto the trailer of the tractor. After removing substances like pebbles from the harvested wheat grain with a winnower, wheat grain is stored in a stone building which is free of any kind of chemicals and is located inside the farm where there is a pest control management for rodents and biocontrol for moths. Additionally, workers pay special attention to their hygiene by using protective clothes and footwear when in and around the warehouse.

During harvest period, about 18 cm of the wheat straws is left on the field so that they are regained to the soil. A part of the harvested wheat straw is used in the farm for several purposes such as mulching and for animals. If there are wheat straws more than needed, they are sold to the farmers who have livestock. Within the scope of this study, in the current situation, it was accepted that the harvested wheat straw was utilized in mulching.

Approximately 7 % of the wheat grain is separated as seed. The remaining wheat grain passes through a stone mill to produce flour, and in that way, wheat germ is preserved. The farm prefers to freshly produce flour; therefore, it does not use all the harvested wheat grain at once. Instead, flour is produced as long as there is demand from the customers. During milling process, the hulled wheat is removed from its kernels, passes through a stone mill. Here, Integral Wheat Flour is obtained. Then, it passes through a flour sieving machine to obtain multi-purpose flour. Produced flour is stored in packages made from certified kraft paper, and these packages are stored in a tiled area away from the sunlight. As is the case in wheat storage, pest management practices are applied when storing flour.

3.2. Goal and Scope Definition

Based on the ISO 14044 standard (2006), the goal and scope definition of this LCA study includes the purpose of the study stated clearly, the explanation of the systems to be studied, the functional unit, the systems boundaries, and the allocation procedure.

The purpose of this study is to evaluate the life cycle stages of the bread produced from einkorn wheat in a permaculture farm and to examine the impacts of the addition of bioethanol production to the system. The einkorn (scientific name: *Triticum monococcum subsp. monococcum* (domesticated)) is an ancient wheat whose earliest domesticated form was found in two Early Pre-Pottery Neolithic B sites circa 10,600-9,900 BP (before present): Çayönü and Cafer Höyük in southern Turkey (Weiss and Zohary, 2011). Einkorn wheat differs from other wheat types due to the fact that it can be cultivated in poor soils, it is more disease-resistant, and it can withstand drought. Apart from these, einkorn wheat is rich in nutrition in terms of protein and antioxidant content (Fogarasi et al., 2015), which is the reason of why consumers and the industry has begun to be more interested in it. In the processing of white flour, the germ and the external layers of the caryopses, which contain lipids, fibre, minerals, and antioxidants, are removed; therefore, products produced from white flour have a lower nutritional value compared to the products produced from einkorn wheat (Hidalgo et al., 2020). One drawback of einkorn wheat cultivation is that in comparison with other wheat types, a lower amount of yield is obtained (Fogarasi et al., 2015). When it comes to permaculture, the word itself is

a combination of *permanent*, *agriculture*, and *culture*, and it enhances the concept of farming systems towards the concept of sustainable human habitats. Permaculture recognizes that each component of a system has specific functions, and each component of a system is interrelated to one another; correspondingly, as the number of interactions within a system increases, the productivity of that system increases as well (Akhtar et al., 2016).

In this study, environmental impacts of the current situation and the alternative scenario (Table 3.1) were investigated by the life cycle impact assessment (LCIA) in four impact categories: global warming potential, acidification potential, eutrophication potential, and photochemical ozone creation potential. Allocation is defined as the ‘‘partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems’’ (ISO 14044, 2006). In this study, a standard allocation procedure was followed, and the output flows were partitioned between the wheat grain and the wheat straw.

Table 3.1. Selected scenario for the utilization of wheat straws.

The Current Situation	The wheat straw is utilized within the farm.
Alternative Scenario	The wheat straw is utilized in the bioethanol production.

3.2.1. Functional Unit

Functional unit is defined as the ‘‘quantified performance of a product system for use as a reference unit’’, and a functional unit should be relevant to the goal and scope of the study and should be clearly defined and measurable (ISO 14044, 2006). In that case, the functional unit of this study is ‘‘the production of one loaf of bread (1 kg/loaf) in sufficient number for an individual’s consumption for approximately 100 years’’.

3.2.2. System Boundaries

The system boundary, which should be consistent with the goal and scope of the study, specifies the unit processes to be included in the study (ISO 14044, 2006). This LCA study consists of a total of 5 subsystems. The first of these subsystems is the wheat cultivation (Figure 3.1). At the beginning of the cultivation process, the soil was prepared with a tractor which used diesel as the fuel (plowing). After plowing, the organic einkorn wheat seeds were sowed 5-6 cm into the soil with a sowing machine which also used diesel as the fuel (sowing). In this season of the wheat cultivation, organic fertilizer was applied with a solid fertilizer spreader bound to a tractor which used diesel as the fuel, and when the wheat was mature enough, it was harvested with a combine harvester which also used

diesel as the fuel. At the end of the cultivation process, wheat grains and wheat straws were obtained, and wheat grains passed through a winnower in order to remove the substances such as pebbles. Normally, wheat grains are stored in a stone building inside the farm, but this step was excluded from the study because there is not any energy use. After the harvest process, it was assumed that the farm workers spread the harvested wheat straw across the agricultural field without using any kind of machinery, and in the plowing and sowing processes of the next agricultural production season, the straw mulch was assumed to be mixed into the soil to a great extent.

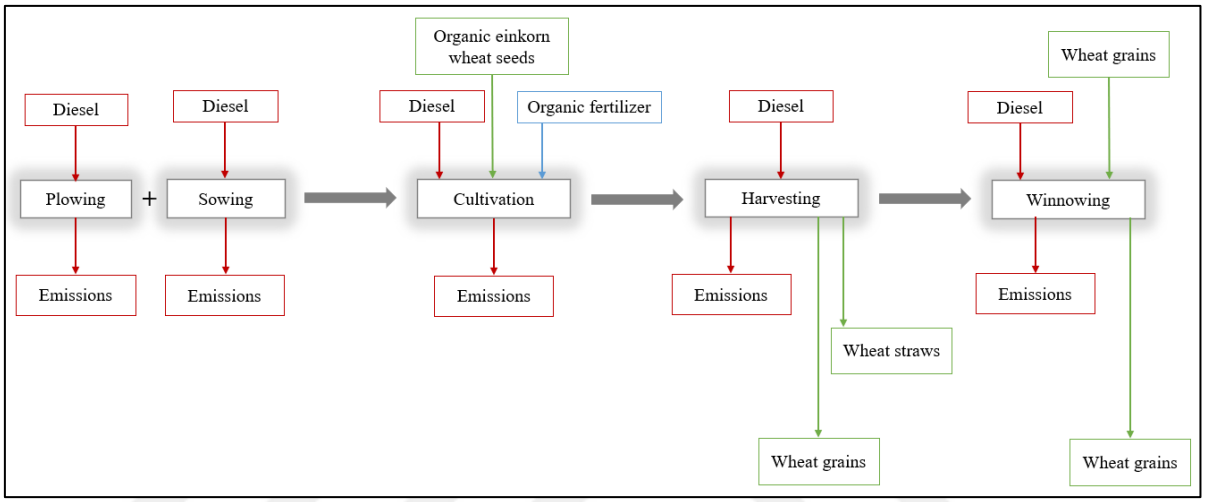

Figure 3.1. Subsystem 1 (cultivation stage).

The second subsystem is the flour production (Figure 3.2), in which the harvested wheat grains were ground in a stone mill which was powered by electricity. The wheat flour then passed through a sieving machine, which was powered by electricity as well, to obtain the multipurpose wheat flour. After that, the obtained multipurpose einkorn wheat flour was packaged in certified kraft paper, and because flour was produced as per order and shipped immediately, there was no need to include a storage (of the flour) process to this subsystem. Similarly, since packaging process is realized by the farm workers without using a machine, which would otherwise require electricity, packaging process was not included in the study. Additionally, the production and transportation of the packaging material were excluded from the scope of the study as well.

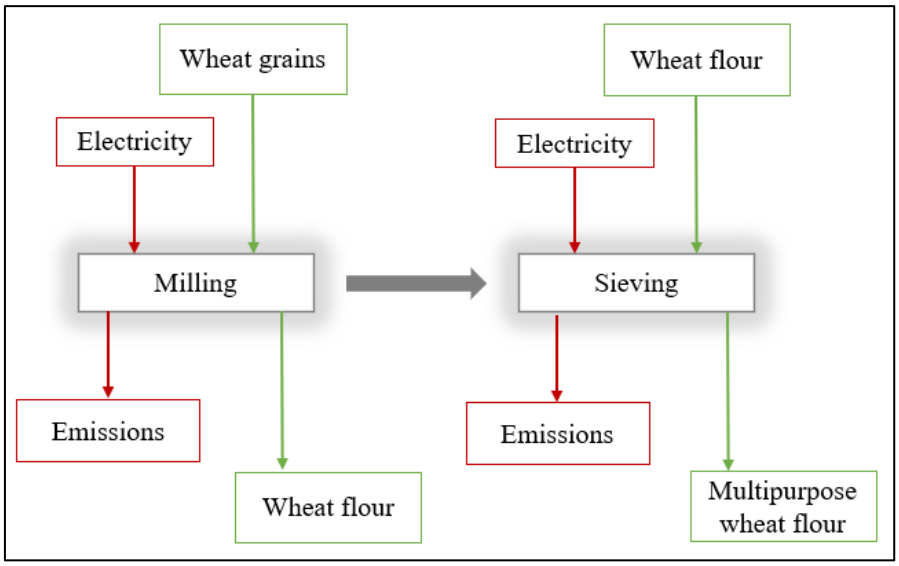

Figure 3.2. Subsystem 2 (flour production stage).

The third subsystem is the bread production (Figure 3.3). In the first place, to produce a loaf of bread, sourdough, flour, and tap water were mixed and kneaded for about 2 minutes with the kneading machine to obtain a dough, which was then left to ferment for 30 minutes. After that, rock salt, tap water, and virgin olive oil were added to the dough which was kneaded with the kneading machine for another 4 minutes and was put into the mold because it is impossible to shape the dough produced from einkorn wheat flour due to its low content of gluten. The dough in the mold was left for cold fermentation for 24 hours. The aim of the first fermentation step is to let the dough increase in volume, and the aim of the second fermentation step (cold fermentation) is to let the dough develop flavor. During fermentation processes (leavening and cold fermentation), as a result of the sourdough activity, the starch content is converted to monomers such as glucose which is then metabolized to CO_2 and ethanol (Ingrao et al., 2018). Finally, the fermented dough was baked at 175℃ for about 1 hour.

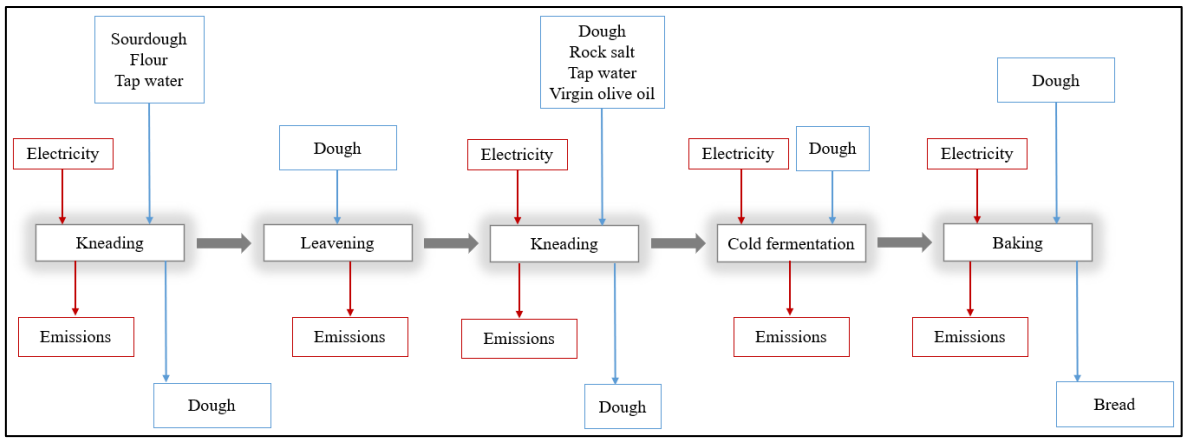

Figure 3.3. Subsystem 3 (bread production stage).

The fourth subsystem includes flour distribution and transportation of consumer waste to landfill (Figure 3.4). From the farm to the customers in the European Side of Istanbul, the average distance was assumed to be 70 km; while from the farm to the customers in the Asian Side of Istanbul, the average distance was assumed to be 100 km. For the flour distribution process, the average distance to the customers was calculated as 85 km, and in this process, diesel was assumed to be used as the fuel. According to the survey conducted by the Turkish Grain Board (TMO), 26.4 % of the households provides the bread from bakeries, and 19.1 % of them provides the bread from grocery stores. Since a total of 45.5 % of the households provides the bread from bakeries or grocery stores, it was assumed that the consumer walked to the nearest store, resulting in no emissions. As in the case of the packaging of flour, the production and transportation of the packaging material (of bread) were excluded from the scope of this study as well. Compared to other OECD countries, in Turkey, 10 % of the waste generated is sent to recovery and compost facilities, while 90 % of it is sent to landfills (OECD, 2019); for this reason, the waste generated in the consumption process, which is packaging waste, was assumed to be sent to landfills. In Istanbul, the average distance to the existing landfills, either the one in the European Side or the one in the Asian Side, was calculated as 36.2 km. Hence, this LCA study included only the emissions resulting from the transportation of the consumer waste to the landfills.

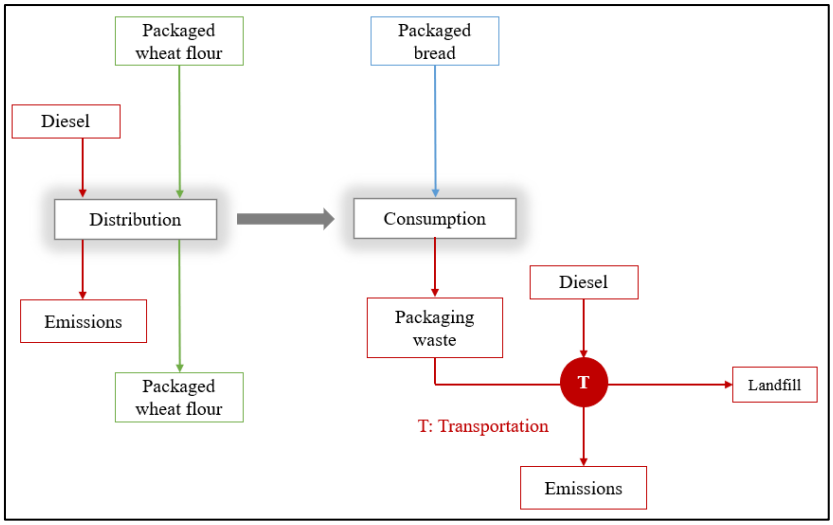

Figure 3.4. Subsystem 4 (distribution/transportation stage).

In the alternative scenario, it was assumed that the harvested wheat straw was sent to a bioethanol production facility instead of being utilized inside the farm. As can be seen in Figure 3.5, wheat straws were baled in the farm and transported to a temporary storage area (interim storage), and the bales were then transported to the bioethanol production facility. The amounts of chemicals, nutrients, enzymes used in the bioethanol production and the theoretical ethanol yield are based on the

bioethanol conversion process data provided from the PhD thesis study by Başak Daylan (2016). The bioethanol production process consists of 7 steps: feedstock storage, dilute acid/steam explosion pretreatment, saccharification and co-fermentation (SSCF), distillation to obtain a 99.5 % refined ethanol, ethanol storage, wastewater treatment (WWTP) plant in which the wastewater from the distillation step and the evaporator are treated, and energy production step in which electricity and process heat are produced from the lignin residue and the sludge from the WWTP; furthermore, since this energy is used inside the facility, it was assumed that there were no GHG emissions related to the energy requirements. In the steam explosion pretreatment step which is a kind of physico-chemical pretreatment method, the wheat straw was rapidly heated at temperatures ranging from 160°C to 230°C by applying high pressure steam, and it was exposed to an explosive decompression by suddenly reducing the pressure. The dilute acid pretreatment step, in which H_2SO_4 was used to treat the straw at high temperatures, was applied to improve the efficiency of the steam explosion step. In the SSCF step, hemicellulose was degraded to several pentoses and hexoses, and cellulose was degraded to glucose, and the saccharified biomass was fermented into ethanol. Finally, the distribution of the bioethanol to a gas station, and the evaluations between conventional gasoline (CG), E10 (10 % bioethanol and 90 % gasoline by volume), and E85 (85 % bioethanol and 15 % gasoline by volume) were included within the scope of this study as well.

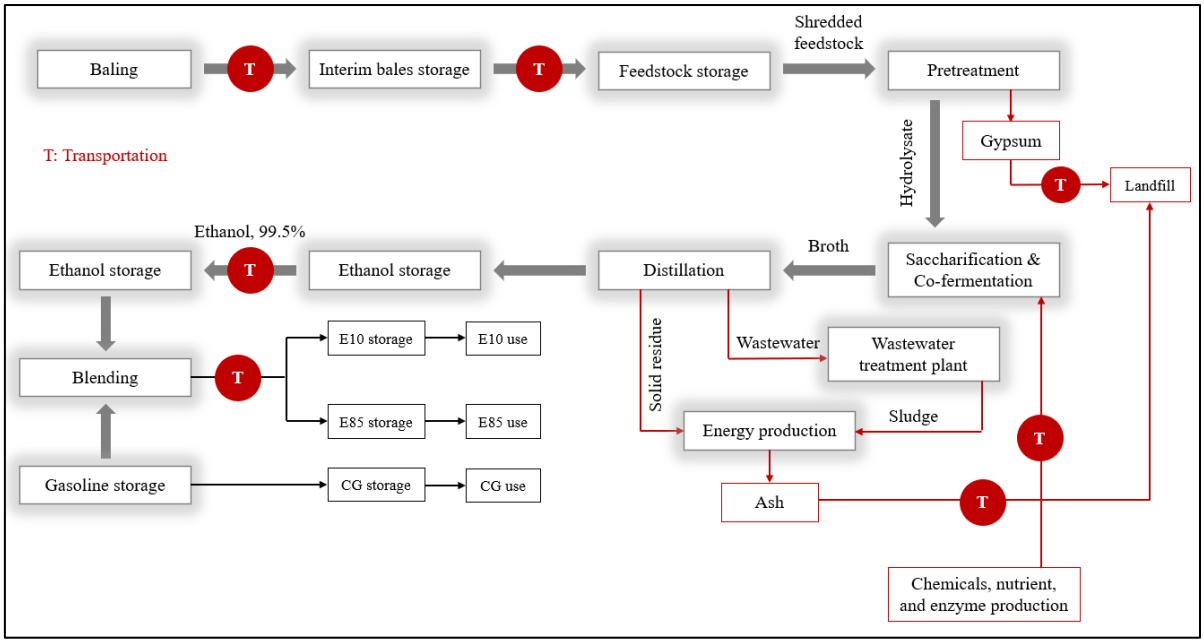

Figure 3.5. Subsystem 5 (bioethanol production stage).

3.3. Life Cycle Inventory Analysis and the Key Assumptions

Life cycle inventory (LCI) analysis is the stage in which the input and output data of a product system throughout its life cycle are collected and calculated (ISO 14044, 2006). This LCA study consists of a total of 5 subsystems, and the collected and calculated data for each of them and the assumptions made in each subsystems are explained in this stage (Table 3.2).

Table 3.2. The inventory data sources for the subsystems.

Subsystem	Required data	Data sources
S1; Cultivation stage	Fuel consumption, organic wheat seed use, the amount of produced wheat grain	GaBi 8.0 software, EcoInvent database, Malva Permaculture, Scientific paper (Ingrao et al., 2018)
S2; Flour production stage	Electricity consumption	GaBi 8.0 software, EcoInvent database, Malva Permaculture
S3; Bread production stage	Raw material consumption, electricity consumption	GaBi 8.0 software, EcoInvent database, Scientific papers ((Ingrao et al., 2018) & (Câmara-Salim et al., 2020))
S4; Distribution/transportation stage	Einkorn flour distribution, waste transportation	GaBi 8.0 software, EcoInvent database, Malva Permaculture
S5; Bioethanol production stage	Fuel consumption; electricity consumption; raw material, chemical, enzyme, and nutrient consumption and transportation; waste transportation; bioethanol transportation; E10, E85, and conventional gasoline (CG) consumption	GaBi 8.0 software, EcoInvent database, PhD thesis (Daylan, 2016), Scientific papers ((González-García et al., 2009), (González-García et al., 2010), (González-García et al., 2009), (Luo, van der Voet and Huppes, 2009))

In subsystem 1, for the plowing process, a tractor was used for 9 hours to prepare the soil, and diesel was used as the fuel, resulting in GHG emissions. When the seeds were sowed, the tractor was used for a total of 2 hours, and diesel was used as the fuel. According to the *soil cultivation; ploughing* process in GaBi 8.0 software, it was assumed that in the plowing process, 20.2 kg of diesel was used per 10 decare of soil, and according to the *sowing; seeder* process in the software, it was assumed that in the sowing process, 5.76 kg of diesel was used per 10 decare of soil. Since the cultivated area of the wheat is 60 da, the total amount of diesel used was calculated as shown in Table 3.3. 25 kg of organic einkorn wheat seed was sowed in this season, and 40 kg of organic fertilizer per decare was applied via a solid fertilizer spreader bound to a tractor using 4.9 kg/ha diesel as the fuel (Ingrao et al., 2018). In the harvesting process, 16 ton of wheat grain and 10,750 kg of wheat straw were obtained while 19.9 kg/ha of diesel (according to the *harvest; combine harvesting grain* process in

GaBi 8.0 software) was used. After harvesting, to remove small substances like pebbles from the wheat grain, a winnowing machine running on diesel was used, and 16 ton of wheat grain was passed through the machine in 12 hours; and it was assumed that the winnowing machine used 17.28 kg/h of diesel. In the current situation, the permaculture farm uses the harvested wheat straw in mulching; that is, with the purpose of conserving water and soil, the harvested straw is spread across the agricultural field, and in the plowing and sowing processes, with the use of vehicles (tractors), it mixes into the soil to a great extent; therefore, it was assumed that the mulching application did not cause any additional emissions stemming from machinery use.

Table 3.3. The input data for the subsystem 1 (cultivation stage).

Unit Operation	**Input Data**	**Value**	**Selected Flow from GaBi 8.0**	**Created Flow in GaBi 8.0**
Plowing	Diesel	121.2 kg/60 da	Diesel [Refinery products]	-
Sowing	Diesel	34.56 kg/60 da	Diesel [Refinery products]	-
Cultivation	Organic einkorn wheat seed	25 kg	-	TR: Organic einkorn wheat seed [Valuable substances]
	Organic fertilizer	2,400 kg	-	TR: Organic fertilizer [Valuable substances]
	Diesel	29.4 kg/60 da	Diesel [Refinery products]	-
Harvesting	Diesel	119.4 kg/60 da	Diesel [Refinery products]	-
Winnowing	Diesel	207.36 kg/16 ton einkorn wheat grain	Diesel [Refinery products]	-

1.5 ton of the wheat grain was separated as the seed, and the rest of it was used to produce flour by using a stone mill (30 HP (electrical horsepower) = 22.38 kWh – 550 kg/h). From 1 kg of hulled wheat, 0.45 kg of flour was ground. The produced einkorn wheat flour (6,525 kg) was passed through a sieving machine (22 kWh) to obtain multipurpose wheat flour. Since the grains were freshly ground when there was a demand from the customers, the milled flour was packaged in certified kraft papers by the workers at the farm, which means that there was not any machinery use (Table 3.4).

Table 3.4. The input data for the subsystem 2 (flour production stage).

Unit Operation	Input Data	Value	Selected Flow from GaBi 8.0	Created Flow in GaBi 8.0
Milling	Wheat grain	14 500 kg	-	TR: Einkorn wheat flour [Valuable substances]
	Electricity	22.38 kW/h	Electricity [Electric power]	-
Sieving	Electricity	22 kW/h	Electricity [Electric power]	-

In the subsystem 3 (Table 3.5), to produce a loaf of bread (1 kg bread), einkorn wheat flour was mixed with sourdough and water in a kneading machine for 2 minutes. The dough that had been prepared was leaved at ambient temperature for half an hour so that it could increase in volume, resulting in carbon dioxide and ethanol emissions. After leavening, the dough was mixed with rock salt, water, and virgin olive oil in the kneading machine for another 4 minutes. When the second kneading phase was completed, the dough was leaved in the fridge for 24 hours to ferment (cold fermentation) so that it could develop flavor. The leavened dough was baked at 175°C for 70 minutes at the end to produce 1 kg of bread.

Table 3.5. The input data for the subsystem 3 (bread production stage).

Unit Operation	Input Data	Value	Selected Flow from GaBi 8.0	Created Flow in GaBi 8.0
Kneading (1)	Multipurpose einkorn wheat flour	0.5 kg/1 kg bread	-	TR: Multipurpose einkorn wheat flour [Valuable substances]
	Einkorn sourdough	0.1 kg/1 kg bread	-	TR: Einkorn sourdough [Valuable substances]
	Tap water	0.35 L/1 kg bread	RER: tap water, at user [Appropriation]	-
	Electricity	0.027 kWh/1 kg bread	Electricity [Electric power]	-
Kneading (2)	Rock salt	0.009 kg/1 kg bread	Sodium chloride (rock salt) [Inorganic intermediate products]	-
	Tap water	0.015 L/1 kg bread	RER: tap water, at user [Appropriation]	-
	Virgin olive oil	0.015 L/1 kg bread	-	TR: Virgin olive oil [Valuable substances]

Table 3.5. The input data for the subsystem 3 (bread production stage).

Unit Operation	Input Data	Value	Selected Flow from GaBi 8.0	Created Flow in GaBi 8.0
Kneading (2)	Electricity	0.027 kWh/1 kg bread	Electricity [Electric power]	-
Cold fermentation	Electricity	0.21 kWh/1 kg bread	Electricity [Electric power]	-
Baking	Electricity	0.05 kWh/1 kg bread	Electricity [Electric power]	-

In the subsystem 4 (Table 3.6), the packaged wheat flour was distributed to the customers across the city (Istanbul). The average distance was calculated as 85 km (Table 3.6). Additionally, the produced bread was assumed to be packaged by employees. In the distribution process, there was no need for any input data since it was assumed that customers would go to bakeries and/or markets by walking. In the consumption process, packaging waste was generated, and the transportation process of the waste to landfill was included in this LCA study.

Table 3.6. The input data for the subsystem 4 (distribution/transportation stage).

Unit Operation	Input Data	Value	Selected Flow from GaBi 8.0	Created Flow in GaBi 8.0
Distribution	Transport	6,525 kg flour x 85 km	Transport [Others]	-
Disposal	Transport	16 g (per 1 kg bread) x 36.2 km	Transport [Others]	-

In the alternative scenario, the subsystem 5 was included in the LCA study. As can be seen in Table 3.7, the produced wheat straw (10,750 kg) was baled by consuming diesel as the fuel. The bales were transported from the farm to an interim storage facility, and the distance was assumed to be 50 km. At the interim storage facility, they were covered by a low-density polyethylene sheet; in addition to that, diesel was consumed when unloading the bales. The production of the polyethylene sheet and its transportation to the facility were excluded in this LCA study. The bales were then transported from the interim storage area to the bioethanol production facility, and the distance was assumed to be 100 km. Shredded wheat straws were undergone pretreatment and saccharification processes, and the amounts of the chemicals, nutrient, and enzyme and their transportation data can be seen in Table 3.7. At the end of the pretreatment process, gypsum was produced (295 kg/bale) and sent to landfill. At the distillation process, the produced ethanol (1,000 kg/bale) was refined, resulting in lignin, which was utilized to produce energy, and wastewater, which was sent to wastewater treatment plant inside the facility. 87 % of the process water was recovered from the wastewater treatment plant and sent back to the process. Overall, the energy consumption in the pretreatment, saccharification and co-

fermentation, and distillation processes was as given in Table 3.7; furthermore, since the lignin from the distillation process and the sludge from the wastewater treatment plant were utilized to produce energy, which was then used in these processes, in the milling and washing, and at the wastewater treatment plant, the bioethanol production facility was assumed to be energy self-sufficient. The ash generated at the energy production stage was sent to landfill. The distilled bioethanol was sent to the blending refinery where gasoline and bioethanol were mixed in different quantities, at the end of which E10 and E85 were obtained. The bioethanol blends were then sent to a regional storage to be used as the fuel.

Table 3.7. The input data for the subsystem 5 (bioethanol production stage).

Unit Operation	**Input Data**	**Value**	**Selected Flow from GaBi 8.0**	**Created Flow in GaBi 8.0**
Baling	Wheat straw	10,750 kg	-	TR: Einkorn wheat straw [Valuable substances]
	Diesel	0.534 kg/bale	Diesel [Refinery products]	-
	Bale	21.5 units (500 kg/unit)	-	-
Transportation from farm to temporary storage	Transport	21.5 units (500 kg/bale) x 50 km	Transport [Others]	-
Interim bales storage	Polyethylene	0.9936 kg/bale	Polyethylene (Packaging) [Packaging]	-
	Diesel	0.713 kg/bale	Diesel [Refinery products]	-
	Bale	21.5 units (500 kg/unit)	-	-
Transportation from temporary storage to facility	Transport	21.5 units (500 kg/bale) x 100 km	Transport [Others]	-
Milling and washing (shredding the wheat straw)	Electricity	69.44 kWh/bale	Electricity [Electric power]	-
Pretreatment and Saccharification & Co-fermentation	Electricity (steam pretreatment)	75 kWh/bale	Electricity [Electric power]	-
	Steam (steam pretreatment)	1,480.55 kWh/bale	Steam (MJ) [steam]	-
	Electricity (SSCF)	757.5 kWh/bale	Electricity [Electric power]	-
	Electricity (distillation)	68.055 kWh/bale	Electricity [Electric power]	-

Table 3.7. The input data for the subsystem 5 (bioethanol production stage) (continued).

Unit Operation	Input Data	Value	Selected Flow from GaBi 8.0	Created Flow in GaBi 8.0
Pretreatment and Saccharification & Co-fermentation	Steam (distillation)	510.28 kWh/bale	Steam (MJ) [steam]	-
	Well water	7,700 kg/bale	Water, well, in ground [Water]	-
	Vinyl acetate	1.1 kg/bale	RER: vinyl acetate, at plant [monomers]	-
	Sulfuric acid	133 kg/bale	Sulphuric acid (100 %) [Inorganic intermediate products]	-
	Lime	97 kg/bale	Calcium hydroxide [Inorganic intermediate products]	-
	Diammonium phosphate (DAP)	5.7 kg/bale	RER: diammonium phosphate, as P2O5, at regional storehouse [mineral fertilizer]	-
	Corn steep liquor (CSL)	44 kg/bale	Corn Steep Liquor [Materials from renewable raw materials]	-
	Enzyme	38 kg/bale	Enzymes, saccharification [Operating materials]	-
	Urea	16 kg/bale	Carbamide (urea) [Organic intermediate products]	-
	Ammonia	12 kg/bale	Ammonia [Inorganic intermediate products]	-
Transportation (of chemicals, nutrient, and enzyme) from wholesalers to facility	Vinyl acetate	354.75 kg (per 21.5 units of bale) x 15 km	Transport [Others]	-
	Sulfuric acid	42,892.5 kg (per 21.5 units of bale) x 15 km	Transport [Others]	-
	Lime	31,282 kg (per 21.5 units of bale) x 15 km	Transport [Others]	-
	Diammonium phosphate (DAP)	1,838.25 kg (per 21.5 units of bale) x 15 km	Transport [Others]	-
	Corn steep liquor (CSL)	14,190 kg (per 21.5 units of bale) x 15 km	Transport [Others]	-

Table 3.7. The input data for the subsystem 5 (bioethanol production stage) (continued).

Unit Operation	Input Data	Value	Selected Flow from GaBi 8.0	Created Flow in GaBi 8.0
Transportation (of chemicals, nutrient, and enzyme) from wholesalers to facility	Enzyme	24,510 kg (per 21.5 units of bale) x 30 km	Transport [Others]	-
	Urea	10,320 kg (per 21.5 units of bale) x 30 km	Transport [Others]	-
	Ammonia	7,740 kg (per 21.5 units of bale) x 30 km	Transport [Others]	-
Transportation (of gypsum) from facility to landfill	Gypsum	6,342.5 kg (per 21.5 units of bale) x 25 km	Transport [Others]	-
Transportation (of ash) from facility to landfill	Ash	2,064 kg (per 21.5 units of bale) x 25 km	Transport [Others]	-
Transportation (of bioethanol) from facility to blending refinery	Bioethanol	21,500 kg (per 21.5 units of bale) x 20 km	Transport [Others]	-
Transportation (of bioethanol blends) from blending refinery to regional storage	Bioethanol blends	(the total amount of E10 and E85 blends) x 30 km	Transport [Others]	-

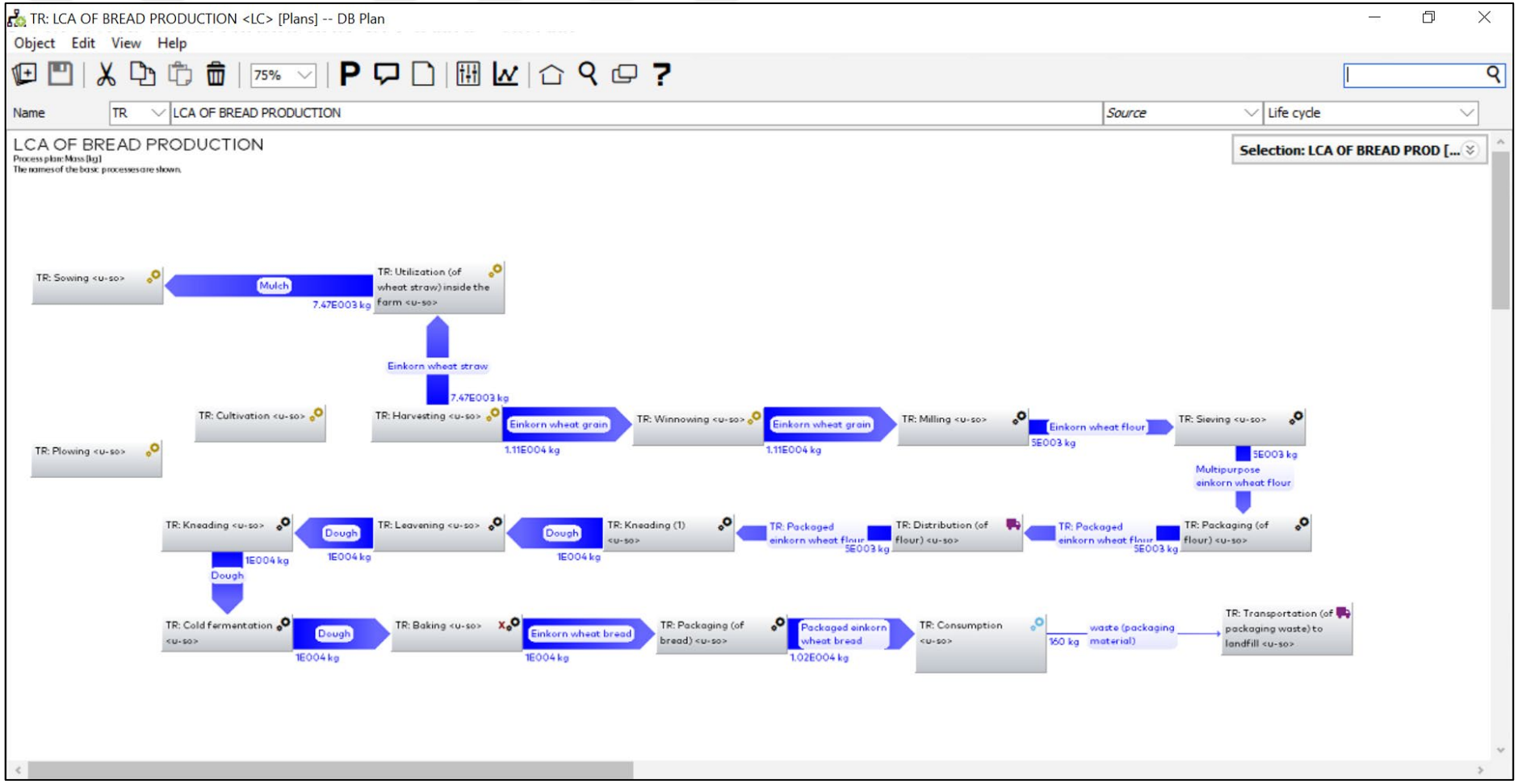

Figure 3.6. Life cycle flow for the Current Situation.

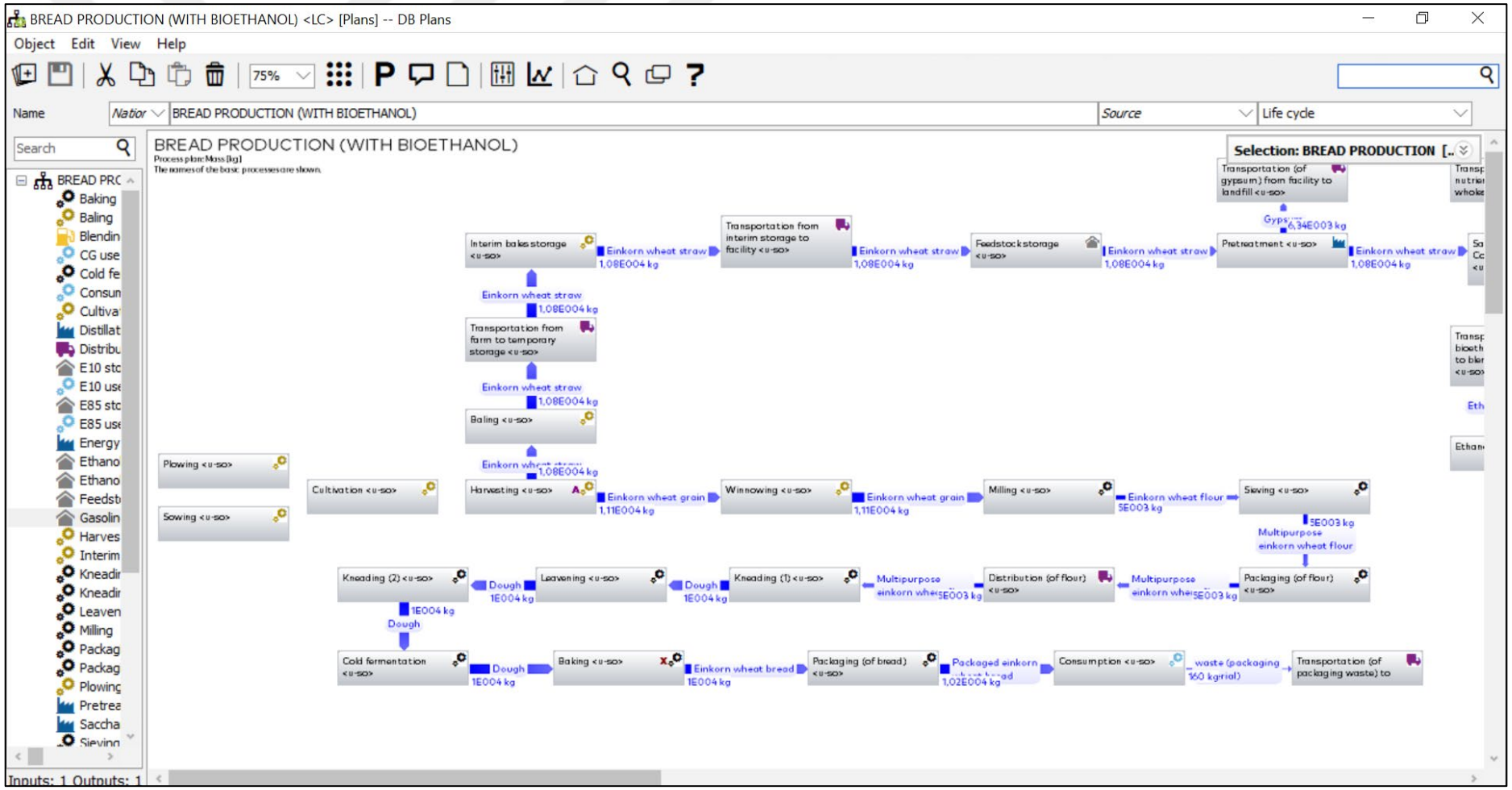

Figure 3.7. The life cycle flow for the alternative scenario.

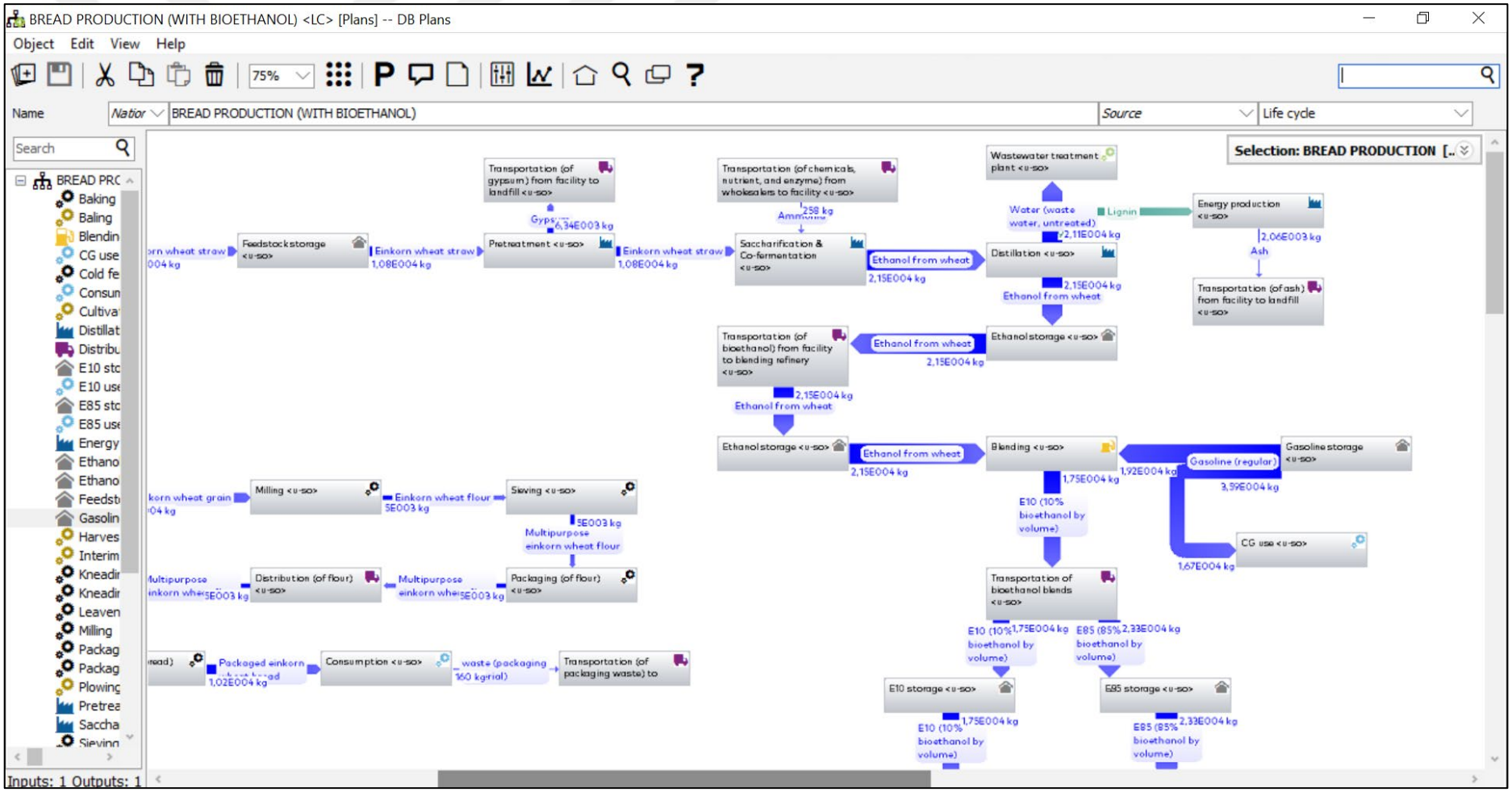

Figure 3.8. The life cycle flow for the alternative scenario (continued).

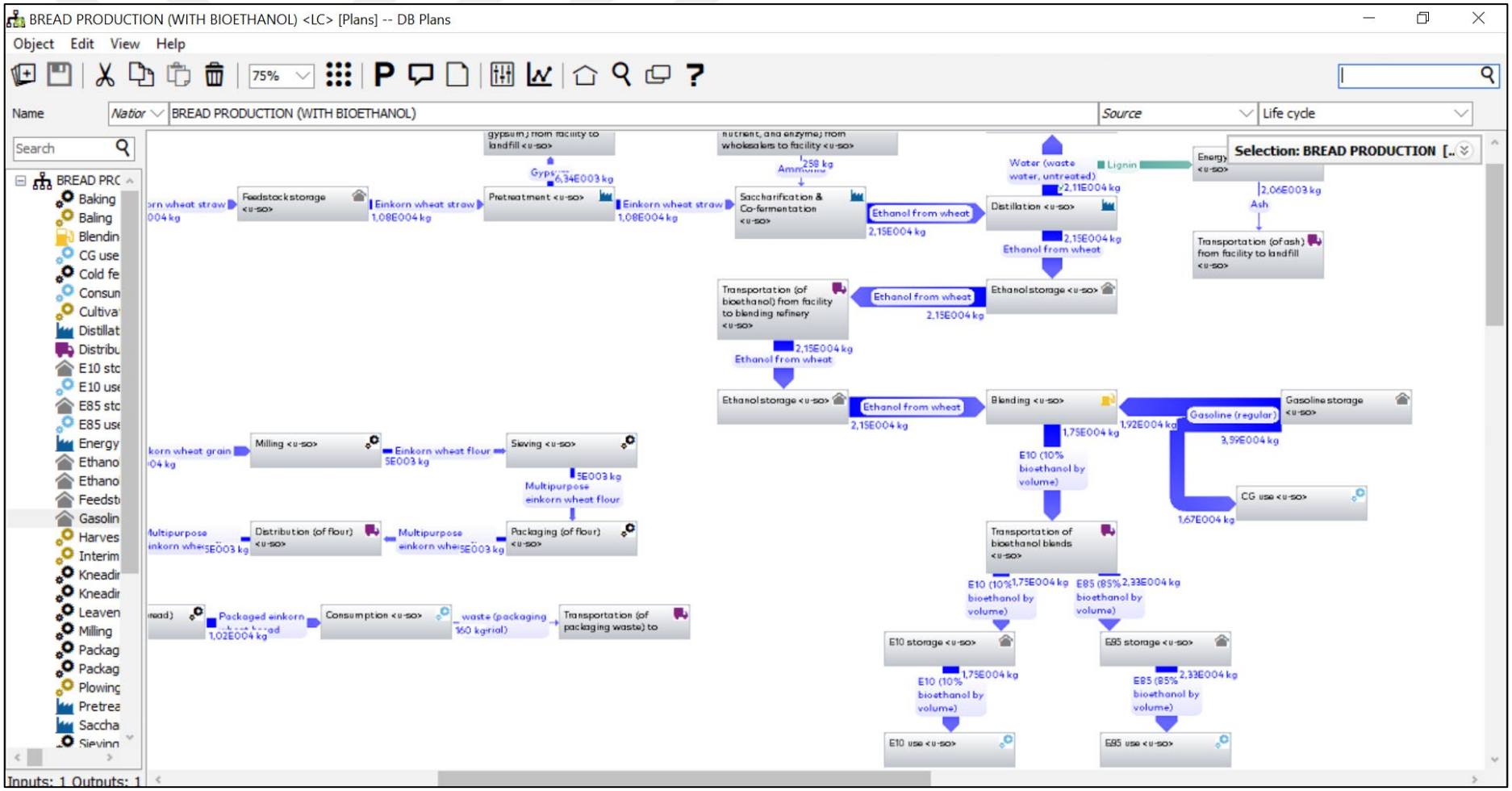

Figure 3.9. The life cycle flow for the alternative scenario (continued).

4. RESULTS AND DISCUSSION

4.1. Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is the stage in which the magnitude and significance of the potential environmental impacts for a product system throughout its life cycle are understood and evaluated. In the LCIA, classification, which includes the assignment of LCI results to the selected impact categories, and characterization, which includes the calculation of category indicator results, are mandatory; however, normalization, which includes the calculation of the magnitude of category indicator results relative to reference information, and weighting, which includes the conversion and aggregation of indicator results across impact categories by using numerical factors based on value choices, are optional (ISO 14044, 2006). Within the scope of this LCA study, classification, characterization and normalization steps of the LCIA were conducted.

CML methodology, which is the LCIA methodology used in this study, was developed by the Institute of Environmental Sciences at the University of Leiden in the Netherlands in 2001. This methodology groups the results into midpoint categories according to common mechanisms such as climate change or acidification, or commonly accepted groupings such as ecotoxicity or reduced resource availability (ILCD Handbook, 2010).

4.1.1. Classification

In the classification step, life cycle inventory results are assigned to different impact categories; in this study, the impact categories are global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and photochemical ozone creation potential (POCP), In Table 4.1, the selected LCI data for each impact category can be seen.

Table 4.1. Impact categories and the selected LCI data for this study.

Impact Categories	**Selected LCI Data**	**Unit**
Global Warming Potential (GWP)	CH_4, CO_2, N_2O, SF_6	kg CO_2-eq.
Acidification Potential (AP)	H_2SO_4, NH_3, NO_x, SO_2	kg SO_2-eq.
Eutrophication Potential (EP)	N_2O, NH_3, NO_x, P, PO_4^{3-}	kg Phosphate-eq.
Photochemical Ozone Creation Potential (POCP)	CH_4, CO, NMVOC (unspecified), NO_x, SO_2, Hydrocarbons	kg Ethene-eq.

4.1.2. Characterization

In the characterization step, the contribution of each emission type to the related impact categories is observed. To begin with, for the alternative scenario, a standard allocation procedure was conducted on the GaBi 8.0 software, and the quantified LCA characterization results were divided between the wheat grain and the wheat straw based on their amount produced (Table 4.2).

Table 4.2. A standard mass allocation conducted between the wheat grain and the wheat straw.

Impact Category	**Unit**	**Wheat Grain (14,500 kg)**	**Wheat Straw (10,750 kg)**
Global Warming Potential (GWP)	kg CO_2-eq.	105,669	71,331
Acidification Potential (AP)	kg SO_2-eq.	257.307	173.693
Eutrophication Potential (EP)	kg Phosphate-eq.	15.4623	10.4377
Photochemical Ozone Creation Potential (POCP)	kg Ethene-eq.	51.939	35.061

As can be seen in Table 4.2, the wheat grain has 59.7 % of the quantified LCA characterization results; however, the wheat straw has 40.3 % of the quantified LCA characterization results. In the real case, Malva Permaculture utilizes the harvested wheat straw inside the farm, which means that wheat straw is used in mulching; that is, the contribution to the total amount of the quantified LCA characterization results belonged to the harvested wheat grain. On the other hand, in the alternative scenario in which it was assumed that the harvested wheat straw was utilized to produce bioethanol, the contribution to the total amount of the quantified LCA characterization results was divided between two products; that is, the harvested wheat straw was considered as a resource which had an economic value in parallel with the concept of circular economy. It would be wrong to express that in the real case, the harvested wheat straw was considered as waste; nonetheless, it can be concluded that the consideration of it as the resource for another industrial process in which an alternative to the fossil fuel used in cars is produced is a more sustainable and environmental option.

Turkey is one of the countries which consumes bread the most; that is, the average annual amount of bread consumed by an individual is 121 kg (TMO). In Table 4.3, the quantified LCA characterization results for a single bread and for an annual scale can be observed.

Table 4.3. The quantified LCA characterization results for a single bread and for an annual scale.

Impact Category	**Unit**	**One bread**	**Annual**
Global Warming Potential (GWP)	kg CO_2-eq.	10.5669	1,278.5949
Acidification Potential (AP)	kg SO_2-eq.	0.0257307	3.1134147
Eutrophication Potential (EP)	kg Phosphate-eq.	0.00154623	0.18709383

Table 4.3. The quantified LCA characterization results for a single bread and for an annual scale (continued).

Impact Category	Unit	One bread	Annual
Photochemical Ozone Creation Potential (POCP)	kg Ethene-eq.	0.0051939	0.6284619

The allocated results are shown in Table 4.3; that is, the shown results belong to the alternative scenario in which the wheat straw was assumed to be utilized in the bioethanol production. When compared to the unallocated results where, the quantified LCA result is 17.7 kg CO_2-eq. in the GWP impact category, a decrease by 40.3 % per a functional unit is observed, which equals to an annual decrease by 863.1051 kg CO_2 equivalent. When the AP impact category is analyzed, a decrease by 40.3 % per a functional unit is observed compared to the current situation, which stands for an annual decrease by 2.1016853 kg SO_2 equivalent. In the EP impact category, a decrease by 40.3 % per a functional unit is observed in comparison with the current situation, which means an annual decrease by 0.12629617 kg Phosphate equivalent. Finally, in the POCP impact category, when compared to the current situation, a decrease by 40.3 % per a functional unit is observed, and that equals to an annual decrease of 0.4242381 kg Ethene equivalent. As can be observed in all the impact categories that were considered in this LCA study, the utilization of the wheat straw as a by-product which has an economic value and energy producing potential decreases the magnitude of the environmental impact attributed to the wheat grain.

When the overall quantified LCA characterization results for the current situation and alternative scenario are compared, it is concluded that, as is seen in Table 4.4, the magnitude of the environmental impact for the alternative scenario is greater in all of the four impact categories, which stems from the fact that in the alternative scenario, there are additional bioethanol production-related transportation and production processes causing emissions as well. Therefore, it is inaccurate to directly compare the two situations.

Table 4.4. The quantified LCA characterization results for the current situation and Scenario.

Impact Category	Unit	The Current Situation (total)	The Alternative Scenario (total)
Global Warming Potential (GWP)	kg CO_2-eq.	2,570	177,000
Acidification Potential (AP)	kg SO_2-eq.	18.7	431
Eutrophication Potential (EP)	kg Phosphate-eq.	2.39	25.4
Photochemical Ozone Creation Potential (POCP)	kg Ethene-eq.	49.4	87

Food waste, which is defined as ‘‘the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers’’ (FAO, 2019), is one of the global challenges that need to be overcome in order to achieve the SDGs. Every year, approximately a total of 88 million tons of food is wasted in the European Union, which stands for €143 billion in the costs; in the case of Turkey, approximately 26 million tons of food is wasted in a year, which stands for €36 billion in the costs (Aydın and Yıldırım, 2021). When the situation is examined for bread in Turkey, 4.99 % of the produced bread is wasted (TMO), which means that 43.0689 kg CO_2-eq. of the annual emissions in the GWP impact category, 0.1049 kg SO_2-eq. of the annual emissions in the AP impact category, 0.0063 kg Phosphate-eq. of the annual emissions in the EP category, and 0.0212 kg Ethene-eq. of the annual emissions in the POCP impact category belong to the wasted bread.

When the wheat straw was utilized as the feedstock to produce bioethanol, it was observed that the overall environmental impact attributed to the functional unit of the study decreased. In addition, it can be concluded that the comparison of the quantified environmental performances of the fuel blends E10 and E85, and the conventional gasoline further promotes the bioethanol production (Table 4.5).

Table 4.5. The characterization results for the fuels under study for a 1-km travel distance.

Impact Category	**Unit**	**E10**	**E85**	**Conventional gasoline**
GWP	kg CO_2-eq.	0.26	0.15	0.27
AP	kg SO_2-eq.	$0.6x10^{-3}$	$0.41x10^{-3}$	$0.6x10^{-3}$
EP	kg Phosphate-eq.	$0.3x10^{-4}$	$0.36x10^{-4}$	$0.26x10^{-4}$
POCP	kg Ethene-eq.	$0.51x10^{-4}$	$0.40x10^{-4}$	$0.56x10^{-4}$

According to the results given in Table 4.5, in the GWP, AP and POCP impact categories, E10 and E85 bioethanol fuel blends performed better from an environmental point of view in comparison with conventional gasoline; however, due to the fact that the use of nitrogen-based chemical consumption in the SSCF process led to more NH_3 emissions and the fact that the combustion of the fuel blends caused more NO_x emissions, conventional gasoline performed better in the EP impact category.

4.1.2.1. Global warming potential (GWP). Global warming potential impact category indicates the potential contribution to global warming because of the greenhouse gas (GHG) emissions to air. GWP is measured in kg of carbon dioxide equivalent (kg CO_2-eq.) (Hillege, 2019).

In Figure 4.1, the contribution to the GWP impact category by the first 4 subsystems can be seen. At the cultivation stage, diesel was used as the fuel for all of the processes; nonetheless, winnowing process is the main source of the environmental impact in this category, and the reason is that the winnower was operated for 12 hours/harvest to eliminate any undesirable substances from the wheat grain. In milling and sieving processes, the machines ran on electricity which was withdrawn from the electricity grid, which is the reason of the GHG emissions contributing to the global warming potential. In the kneading processes, the emissions stemmed from the use of electricity withdrawn from the electricity grid as well. Normally, in the leavening process, some amounts of carbon dioxide and ethanol are emitted to air, but the total amount of these emissions were added to the cold fermentation process in GaBi 8.0 software. Additionally, in the cold fermentation process, the dough was left in the fridge to ferment for 24 hours; therefore, there were also the emissions resulting from the electricity use. Finally, the baking process is the main contributor to this impact category, at the bread production stage, due to the use of electricity withdrawn from the electricity grid for a longer time. The S4 covered the flour distribution to the customers in both sides of Istanbul, and the emissions in this process stemmed from the use of diesel as the fuel. Since Malva Permaculture prefers a courier company to cargo their products to the customers, the output data was calculated by excluding the return distance. In addition to that, the study included the transportation of the packaging waste to landfill site, and it was assumed that diesel was used as the fuel, resulting in the GHG emissions in this process. Similar to the distribution process of flour, the output data was calculated by excluding the return distance.

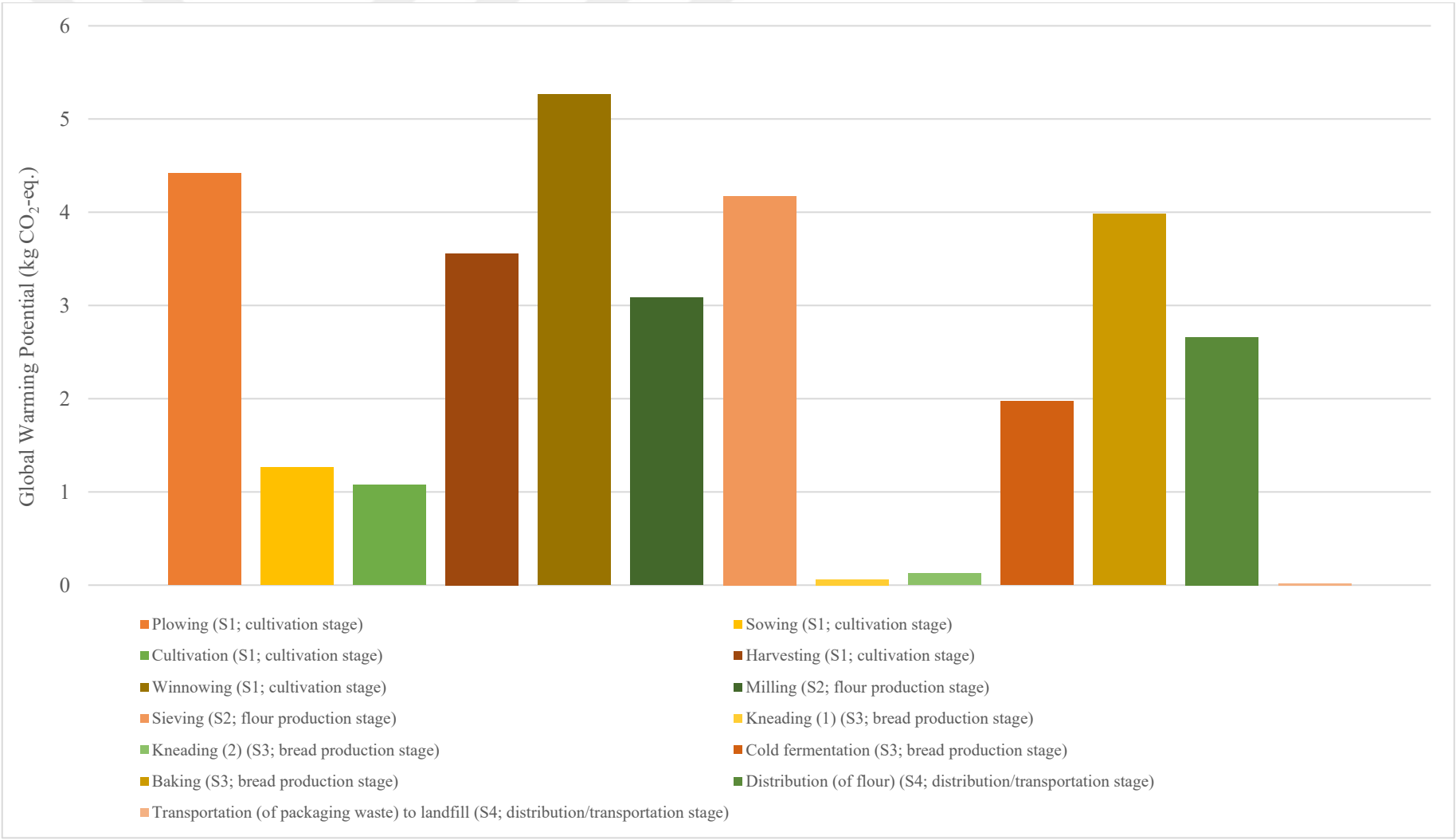

Figure 4.1. Quantified annual global warming potential for S1 (cultivation stage), S2 (flour production stage), S3 (bread production stage), and S4 (distribution/transportation stage) (kg CO_2-eq.).

In Figure 4.2, the contribution to the GWP impact category by the subsystem 5 (S5) can be seen. In the baling and interim bales storage processes, it was assumed that there was diesel use when baling the feedstock, loading and unloading the feedstock into and from the truck, resulting in the GHG emissions. In the pretreatment, saccharification & co-fermentation, distillation, and wastewater treatment plant processes, there were the uses of electricity and/or steam, which, in general, causes GHG emissions; but, because of the fact that the facility had an energy production process in which the lignin from the distillation process and the wastewater treatment sludge from the wastewater treatment plant process were utilized to produce electricity and steam that were sent back to the related processes for their energy requirement, it was assumed that there were no emissions resulting from the use of electricity and steam, and it was assumed that the facility set an example as a closed loop system in terms of energy production and consumption. The final processes that caused the GHG emissions were the transportation processes, and the total amount of the emissions were calculated to create the Figure 4.2.

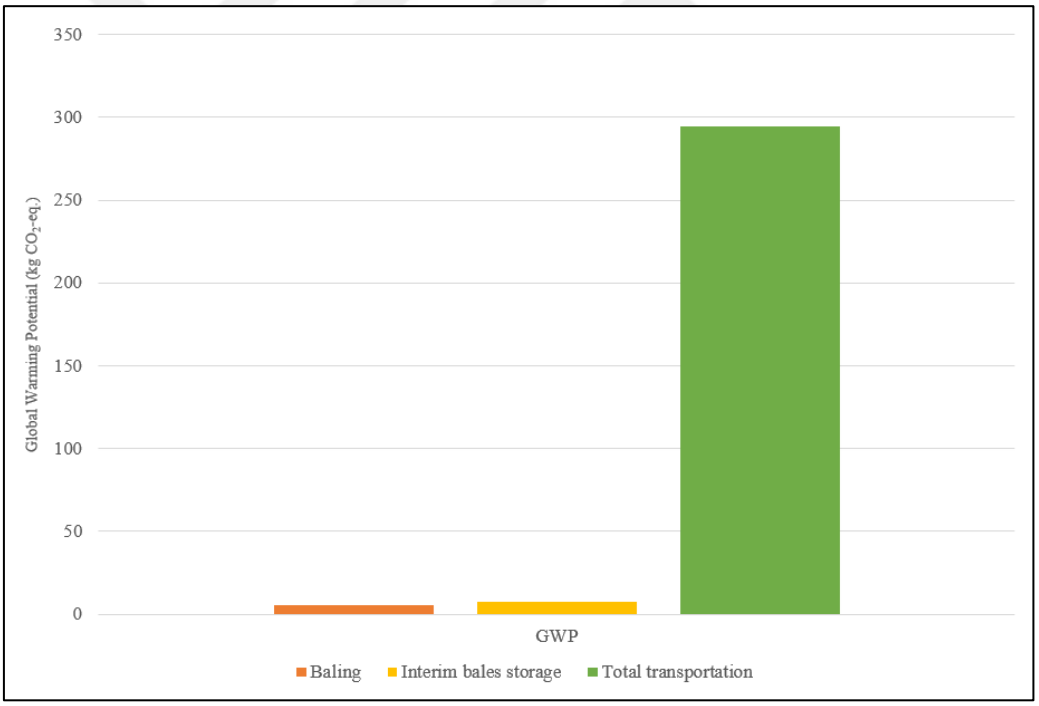

Figure 4.2. Quantified global warming potential for S5 (bioethanol production stage) (kg CO_2-eq.).

4.1.2.2. Acidification potential (AP). Acidification potential impact category indicates the potential contribution to acidification due to the emissions of gases such as nitrogen oxides and sulphur oxides to the air, water and/or soil ecosystems. AP is measured in kg of sulphur dioxide equivalent (kg SO_2-eq.) (Hillege, 2019).

In Figure 4.3, the contribution to the AP impact category by the first 4 subsystems can be seen. At the cultivation stage, the winnowing process is the main source of the environmental impact in this category due to the fact that the winnower was operated for 12 hours/harvest. After the winnowing process, plowing and harvesting processes contribute to the AP impact category the most, respectively. The dominant gas contributing to this category is NO_x (24.92 %). The sieving and milling processes are the main sources of the environmental impact at the flour production stage because of the electricity use, and the dominant gases contributing to this category are SO_2 (22.36 %) and NO_x (10.43 %). At the bread production stage, the baking process is the main contributor to this impact category due to the use of electricity withdrawn from the electricity grid for a longer time. The cold fermentation, kneading (2) and kneading (1) processes contribute to the AP after the baking process, respectively. The dominant gas contributing to this category is SO_2 (22.35 %). The S4 covered the distribution process of flour to the customers in both sides of Istanbul, and the emissions in this process stemmed from the diesel use as the fuel. Since Malva Permaculture prefers a courier company to cargo their products, the output data was calculated by excluding the return distance. The other contributor to this category is the transportation of the packaging waste to landfill site because of the diesel use as the fuel. Similar to the distribution process of flour, the output data was calculated by excluding the return distance.

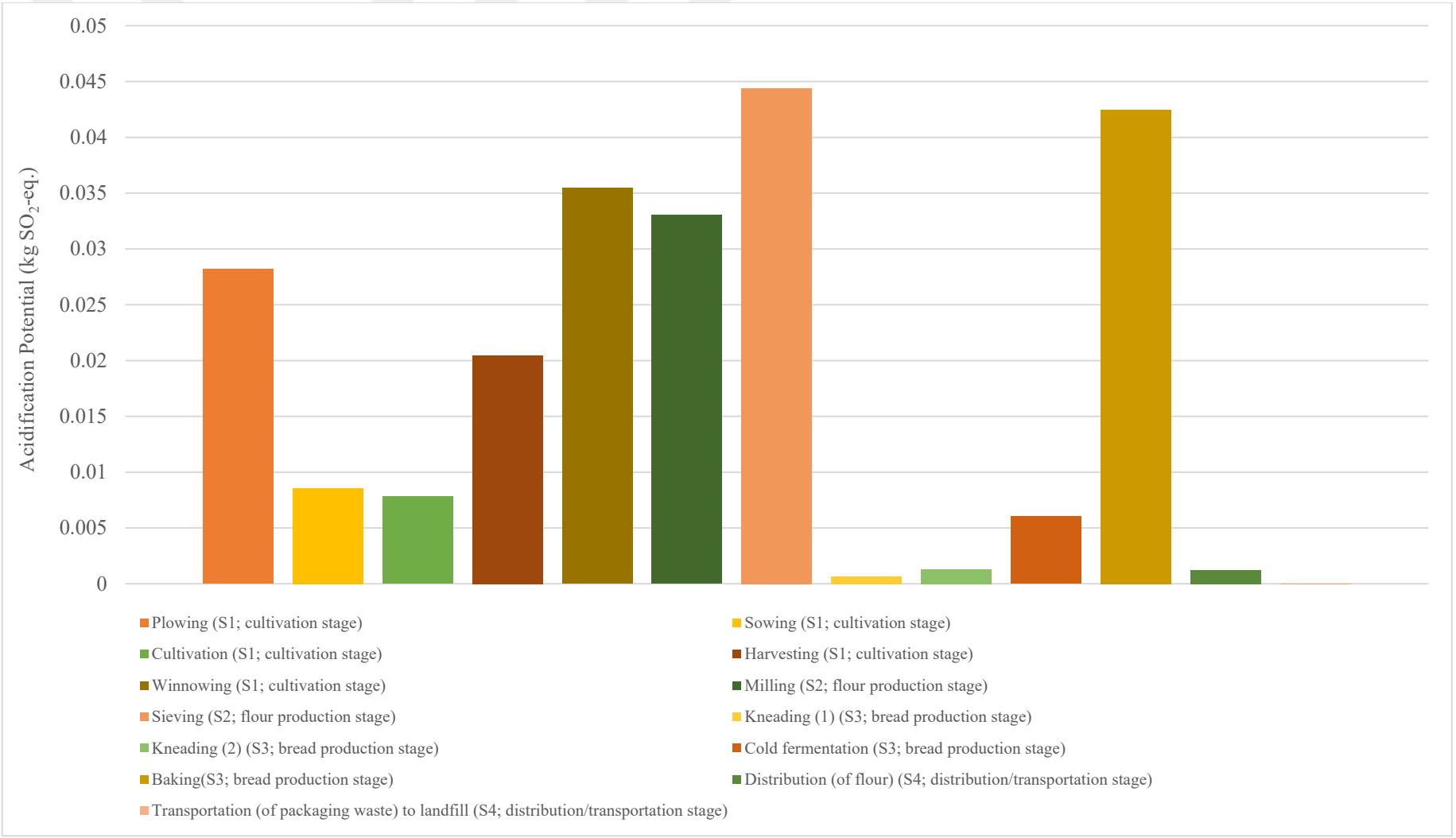

Figure 4.3. Quantified annual acidification potential for S1 (cultivation stage), S2 (flour production stage), S3 (bread production stage), and S4 (distribution/transportation stage) (kg SO_2-eq.).

In Figure 4.4, the contribution to the AP impact category by the S5 can be seen. The main contributor to this category is the total transportation process followed by the baling and interim bales storage processes, respectively. The dominant gas contributing to the AP is SO_2 (16.37 %) stemming from the diesel use as the fuel.

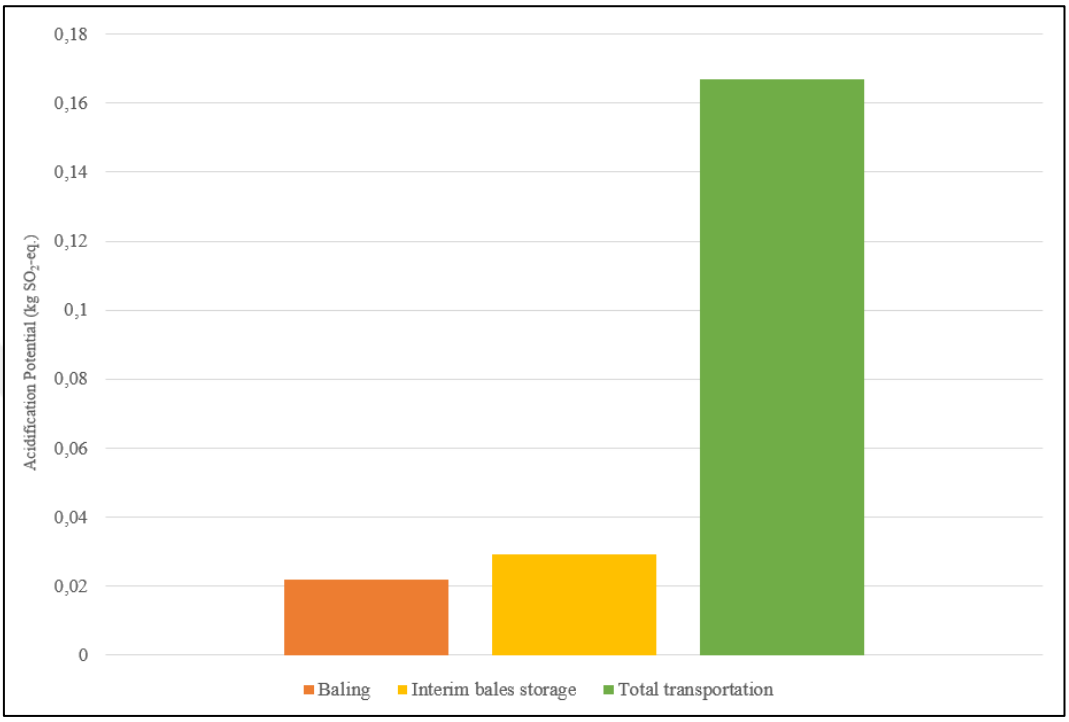

Figure 4.4. Quantified acidification potential for S5 (bioethanol production stage) (kg SO_2-eq.).

4.1.2.3. Eutrophication potential (EP). Eutrophication potential impact category includes the potential contribution to eutrophication and indicates the potential enrichment of the aquatic ecosystems due to the emissions of nitrogen and/or phosphorus containing compounds. EP is measured in kg of phosphate equivalent (kg Phosphate-eq.) (Hillege, 2019).

In Figure 4.5, the contribution to the EP impact category by the first 4 subsystems can be seen. At the cultivation stage, the winnowing process is the main source of the environmental impact in this category followed by the plowing and harvesting processes, respectively. The dominant gas contributing to the EP is NO_x (25 %). At the flour production stage, the sieving and milling processes are the main sources of the environmental impact in this category because of the electricity use, and the dominant gas contributing to the EP is NO_x (23.97 %). The baking process is the main contributor to this impact category, at the bread production stage, due to the electricity use, and it is followed by the cold fermentation, kneading (2) and kneading (1) processes, respectively. The dominant gas contributing to this category is NO_x (23.97 %). The S4 covered the distribution process of flour to the customers in both sides of Istanbul, and the emissions in this process resulted from the diesel use as

the fuel. Since Malva Permaculture prefers a courier company to cargo their products, the output data was calculated by excluding the return distance. The other contributor to this category is the transportation of the packaging waste to landfill site because of the diesel use as the fuel. Similar to the distribution process of flour, the output data was calculated by excluding the return distance.

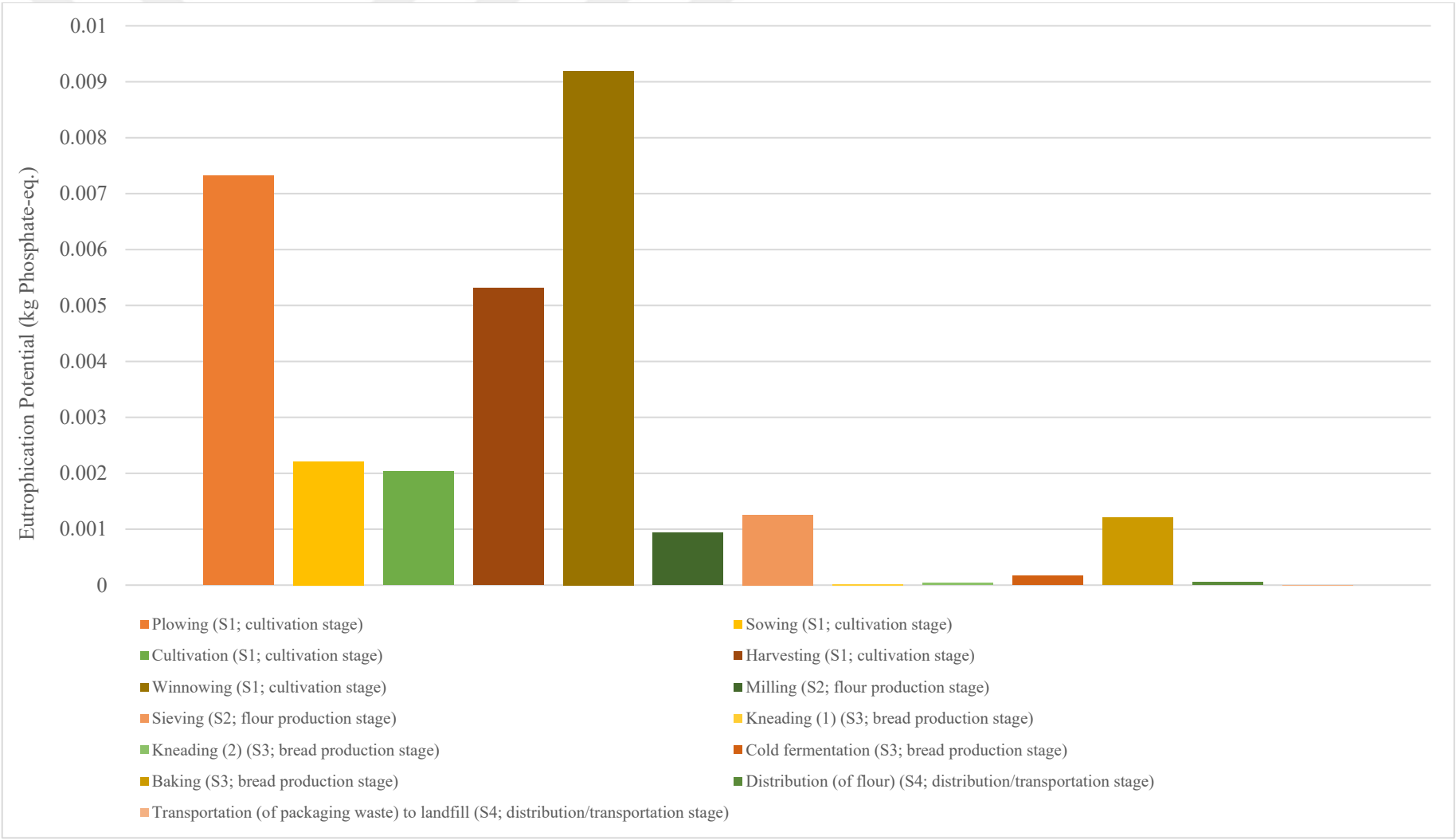

Figure 4.5. Quantified annual eutrophication potential for S1 (cultivation stage), S2 (flour production stage), S3 (bread production stage), and S4 (distribution/transportation stage) (kg Phosphate-eq.)

In Figure 4.6, the contribution to the EP impact category by the S5 can be seen. The main contributor to this impact category is the total transportation process followed by the baling and interim bales storage processes, respectively. The dominant gas contributing to the EP is NO_x (16.91 %) stemming from the diesel use as the fuel.

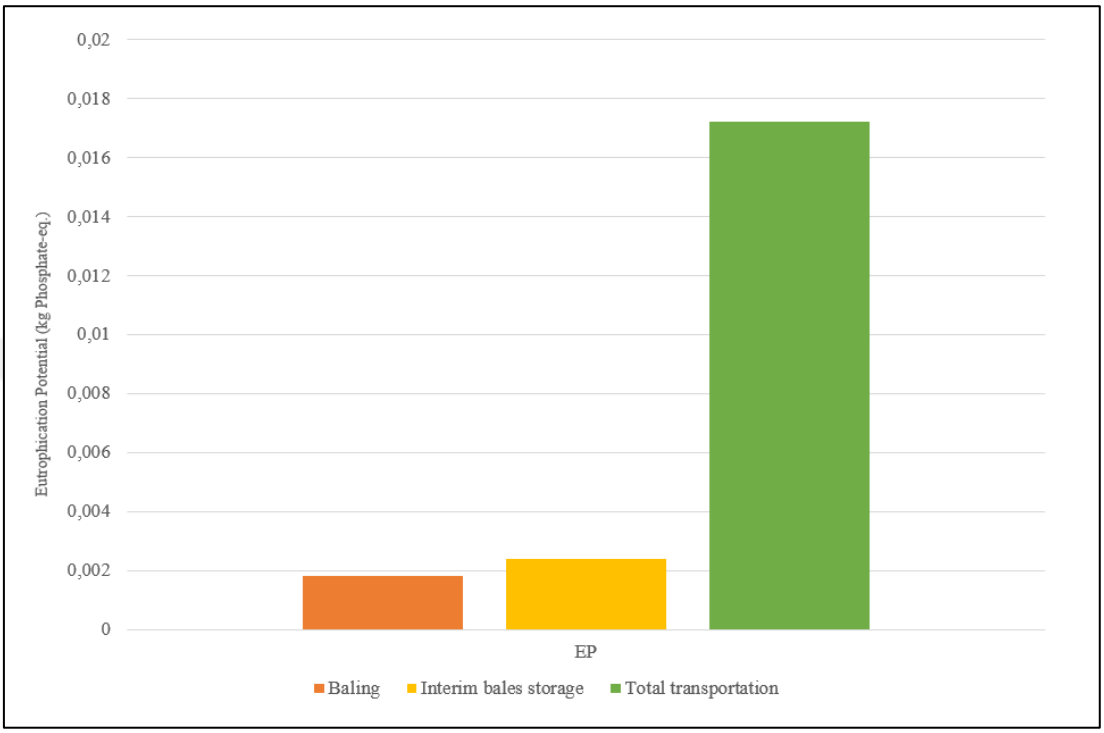

Figure 4.6. Quantified eutrophication potential for S5 (bioethanol production stage) (kg Phosphate-eq.).

4.1.2.4. Photochemical ozone creation potential (POCP). Photochemical ozone creation potential impact category includes the potential contribution to photochemical ozone creation in the lower atmosphere (smog) catalyzed by sunlight due to the emissions of gases such as CO and SO_2. POCP is measured in kg of ethene equivalent (kg Ethene-eq.) (Hillege, 2019).

In Figure 4.7, the contribution to the POCP impact category by the first 4 subsystems can be seen. At the cultivation stage, the winnowing process is the main source of the environmental impact in this category followed by the plowing and harvesting processes, respectively. The dominant gases contributing to the POCP are NO_x (16.52 %), group NMVOC (5.50 %) and CO (2.94 %), respectively. At the flour production stage, the sieving and milling processes are the main sources of the environmental impact in this category, respectively. The dominant gas contributing to the POCP is SO_2 (20.30 %) followed by NO_x (3.32 %). The cold fermentation process is the main contributor to this category, at the bread production stage, due to the emission of non-methane volatile organic

compounds, which included the ethanol emission in this case. Normally, in the leavening process, some amounts of carbon dioxide and ethanol are emitted to air, but the total amount of these emissions were added to the cold fermentation process in GaBi 8.0 software. The S4 covered the distribution process of the flour to the customers in both sides of Istanbul, and the emissions in this category resulted from the diesel use. Since Malva Permaculture prefers a courier company to cargo their products, the output data was calculated by excluding the return distance. The other contributor to this impact category is the transportation of the packaging waste to landfill site, and the dominant gases contributing to the POCP are group NMVOC (11.84 %), CO (8.53 %) and SO_2 (3.96 %), respectively. Similar to the distribution process of flour, the output data was calculated by excluding the return distance.

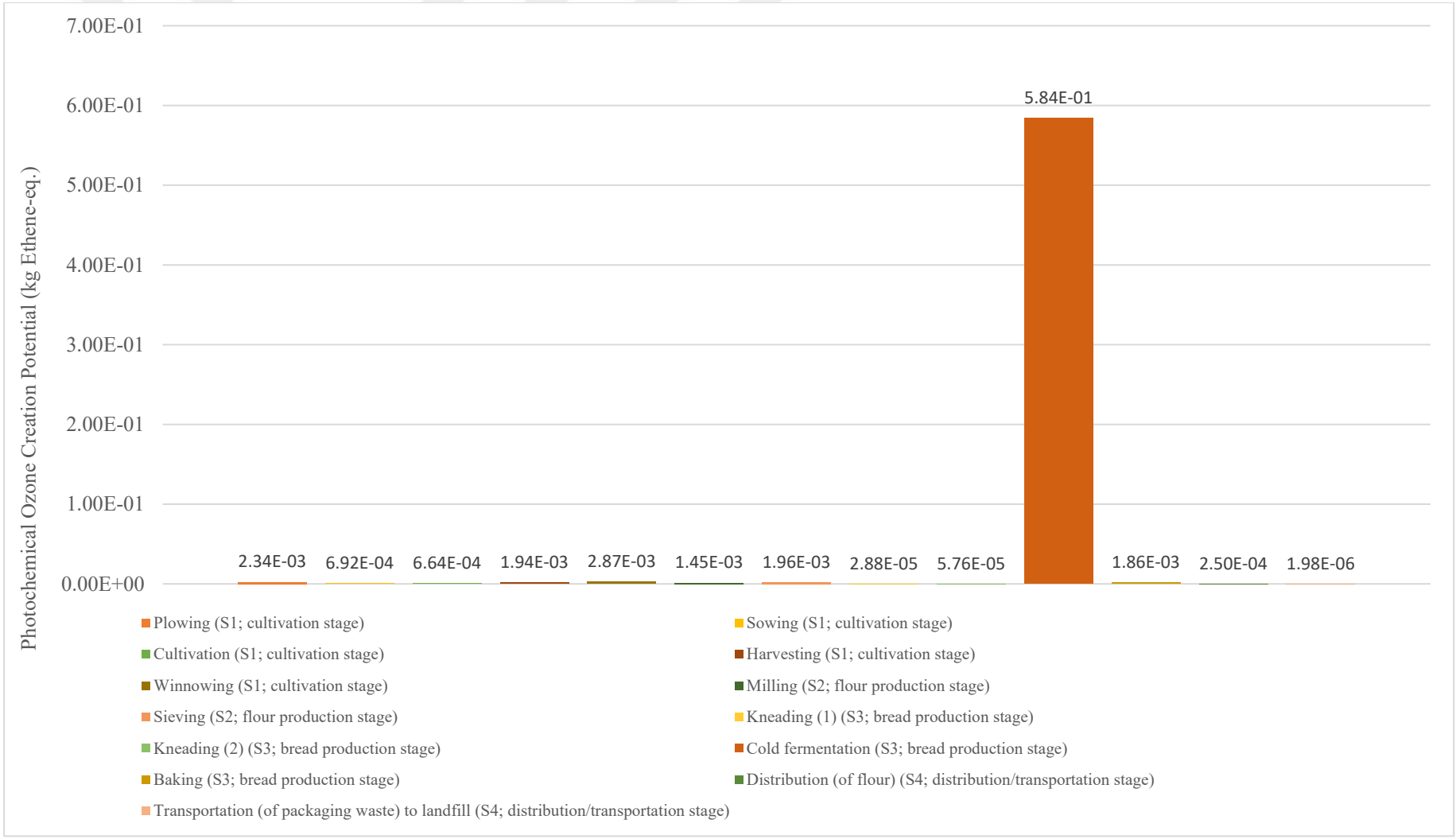

Figure 4.7. Quantified annual photochemical ozone creation potential for S1 (cultivation stage), S2 (flour production stage), S3 (bread production stage), and S4 (distribution/transportation stage) (kg Ethene-eq.).

In Figure 4.8, the contribution to POCP impact category by the S5 can be seen. The main contributor to this category is the total transportation process followed by baling and interim bales storage processes, respectively. In addition, the dominant gases contributing to the POCP are CO (8.97 %), group NMVOC (8.30 %) and SO_2 (3.93 %) resulting from the diesel use, respectively.

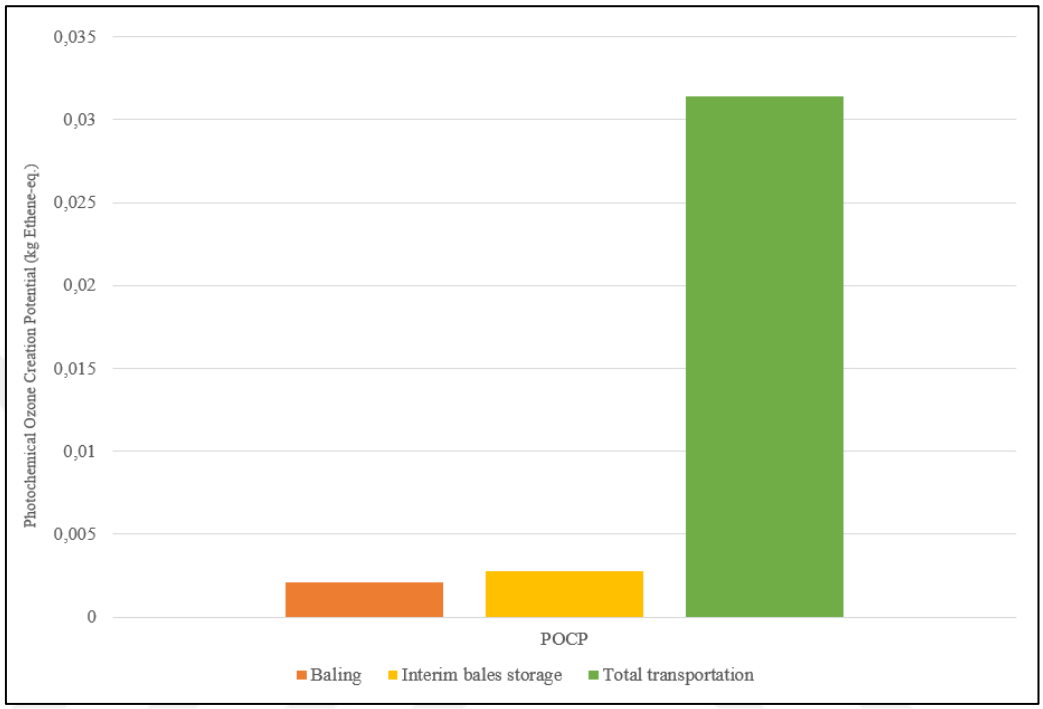

Figure 4.8. Qualified photochemical ozone creation potential for S5 (bioethanol production stage) (kg Ethene-eq.).

4.1.3. Normalization

Normalization includes the calculation of the magnitude of category indicator results relative to reference information (ISO 14044, 2006) by dividing category indicator results by the respective reference value which is generally chosen as the impact or damage results of ‘‘the total annual territorial elementary flows in a country, region, or continent, or globally, or per capita (ILCD Handbook, 2010). Normalization is not a mandatory step of the LCA methodology, and it aims to better understand the relative magnitude of each indicator result (ISO 14044, 2006). Additionally, normalization results have no unit, which allows the comparison between impact categories. In this LCA study, CML2001 – January 2016, World, year 2000 option was used. In Figure 4.9, the normalization results for the current situation and alternative scenario can be seen.

When the normalization results were evaluated, it was seen that for the current situation, the normalization result of POCP impact category was the greatest due to that in the current situation,

there were no emissions resulting from the processes in bioethanol production; that is, the current situation consisted of the first 4 subsystems. Therefore, because of the non-methane volatile organic compound emissions, especially in cold fermentation process of the subsystem 3, POCP impact category had the greatest normalization result. As the alternative scenario was included in the evaluation, the normalization result of GWP was the greatest since there were additional processes in which diesel was used as fuel. To conclude, for the current situation, photochemical ozone creation potential is the most important impact category to be considered; whereas, for the alternative scenario, global warming potential is the most important impact category to be considered. Overall, the values belonging to the alternative scenario are bigger than the values belonging to the current situation since in the alternative scenario, the number of unit processes included is higher; therefore, it would not be proper to directly compare the normalization results of the two situations.

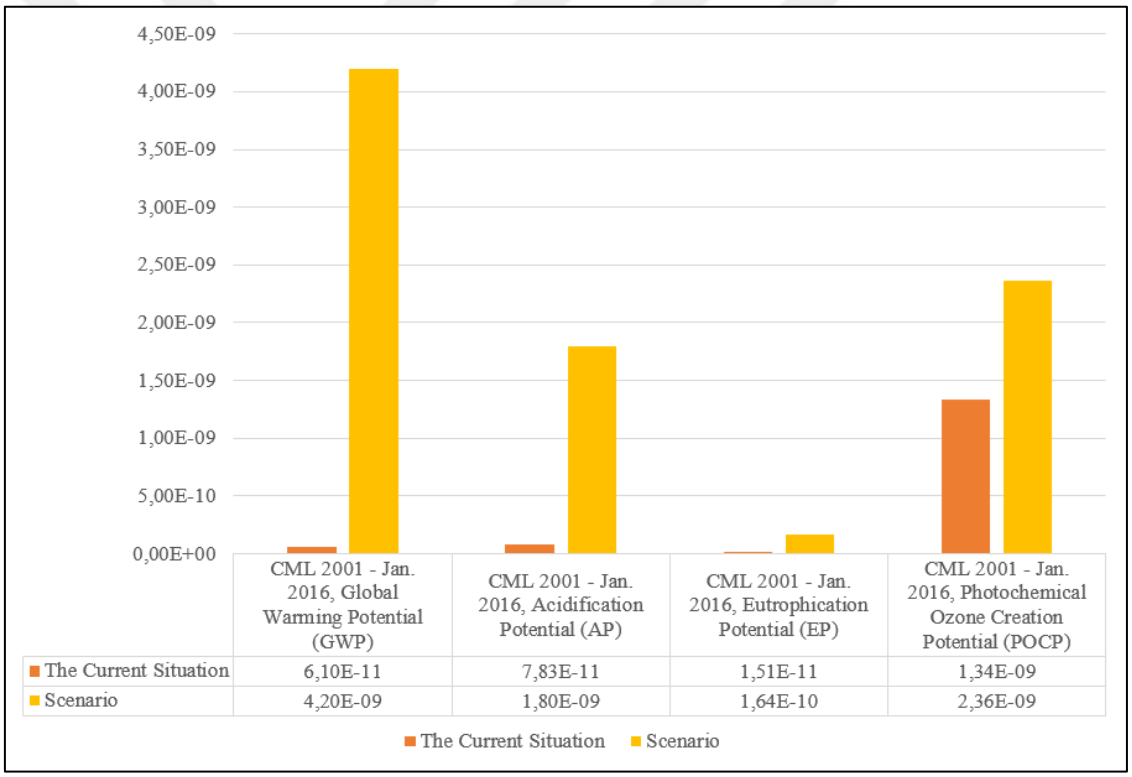

Figure 4.9. Normalization results for the Current Situation and Scenario.

5. CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to identify the environmental hot spots along the production line of bread produced from einkorn wheat which was cultivated in a permaculture farm, to conduct an allocation based on mass between wheat grain and wheat straw produced in the farm by considering that wheat straw was sent to a facility to be utilized in bioethanol production, and to evaluate the environmental performances of bioethanol fuel blends and conventional gasoline. LCA methodology was applied, and CML2001 – Jan. 2016 LCIA methodology was conducted for four different impact categories: global warming potential, acidification potential, eutrophication potential, and photochemical ozone creation potential. One of the optional steps of the LCA methodology (normalization) was also conducted within the scope of this study. The system to be studied were divided into 5 subsystems which were basically cultivation stage, flour production stage, bread production stage, distribution/transportation stage, and bioethanol production stage.

When a standard allocation based on mass was conducted, it was indicated that 59.7 % of the total quantified LCA characterization results belonged to the produced wheat grain, and 40.3 % of the total quantified LCA characterization results belonged to the produced wheat straw. In the current situation, wheat straw was utilized inside the farm , which meant that all the quantified LCA characterization results belonged to wheat grain. Whereas, in the Scenario, wheat straw was assumed to be utilized in bioethanol production, which meant that the contribution to the total quantified environmental impact was divided between two products obtained at the end of harvesting process. Besides, when bioethanol fuel blends (E10 and E85) and conventional gasoline were compared, in GWP, AP and POCP impact categories, bioethanol fuel blends performed better from an environmental point of view; however, due to the fact that the use of nitrogen-based chemicals in the SSCF process led to more ammonia emissions and that the combustion of the blends caused more nitrogen oxides emissions, in EP impact category, bioethanol fuel blends performed worse than conventional gasoline. Nonetheless, when overall results are considered, it can be concluded that, in the long term, bioethanol-included fuel blends are more advantageous and environmentally friendly, and for bioethanol production, the utilization of wheat straw should be further supported especially in countries such as Turkey where the amount of agricultural/plant residue offers a great opportunity for such applications.

When the allocated results (Scenario) attributed to functional unit (one loaf of bread (1 kg)) were compared with the current situation, it was observed that the environmental impact of 1 functional

unit decreased by 40.3 % in all the impact categories, which accounted for an annual decrease by 863.1051 kg CO_2 equivalent, 2.1016853 kg SO_2 equivalent, 0.12629617 kg Phosphate equivalent, and 0.4242381 kg Ethene equivalent in the Scenario. Additionally, it is indicated that an individual consumes 121 kg of bread annually in Turkey, and unfortunately, a total of 4.99 % of the produced bread is wasted annually also in Turkey (TMO); therefore, it can be concluded that 43.0689 kg CO_2-eq. of the annual emissions in GWP impact category, 0.1049 kg SO_2-eq. of the annual emissions in AP impact category, 0.0063 kg Phosphate-eq. of the annual emissions in EP impact category, and finally 0.0212 kg Ethene-eq. of the annual emissions in POCP impact category belonged to the wasted bread. In a world where access to food is limited in some regions, where hunger exists even today, and where the environmental problems arising from food production systems require sustainable solutions, food waste is one of the issues that need to be addressed at the earliest.

According to the characterization results of the subsystem 1, in all the impact categories under study, the main emissions stemmed from diesel use in the vehicles and machineries. Since Malva Permaculture, as its name signifies, implements the organic agriculture and permaculture production practices, there was no use of chemical inputs such as synthetic fertilizer and pesticide, which is one of the benefits provided by such agricultural production techniques. According to the results of the subsystem 2, in all the impact categories, the main emissions resulted from electricity use during milling and sieving processes because of the fact that electricity was withdrawn from the electricity grid, which required the considerations of the electricity production. According to the characterization results of the subsystem 3, in three of the impact categories, baking and cold fermentation processes caused the main emissions, respectively, due to electricity use similar to the subsystem 2; whereas, in photochemical ozone creation impact potential, cold fermentation process, during which it was assumed that carbon dioxide and ethanol were emitted to air, had the greatest contribution because of the NMVOC emissions in this process. According to the characterization results of the subsystem 4, in all the impact categories, diesel use in the transportation of flour to customers caused the main emissions. Similarly, in all the impact categories, diesel use in the transportation of packaging waste to landfill site caused the main emissions according to the characterization results of the subsystem 4. Finally, according to the characterization results of the subsystem 5, the main emissions stemmed from diesel use in baling, interim bales storage and total transportation processes. There were also electricity and steam use in several processes; however, the facility was a closed-loop in terms of energy production.

When the normalization results were evaluated, it was seen that for the current situation, the normalization result of POCP impact category was the greatest due to that in the current situation,

there were no emissions resulting from the processes in bioethanol production; that is, the current situation consisted of the first 4 subsystems. Therefore, because of the non-methane volatile organic compound emissions, especially in cold fermentation process of the subsystem 3, POCP impact category had the greatest normalization result. As Scenario was included in the evaluation, the normalization result of GWP was the greatest since there were additional processes in which diesel was used as fuel.

In this study, the environmental assessment of organic agriculture and permaculture production system was made. A comparison with a conventional agricultural system can be made to observe the difference between the environmental performances more clearly. In addition, for this study to be more comprehensive, a real case scenario can be included regarding bioethanol production. Finally, more than one scenario can be developed in terms of the utilization alternatives of wheat straw.

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