Cradle to grave environmental-economic analysis of tea life cycle in Iran

Abstract

Tea as the second most consumed none-alcoholic beverage in the world next to the water is involved with considerable environmental impacts during its life cycle. Because of the high importance of the tea sector in northern Iran, the present study aimed to assess the environmental burdens of tea in life cycle, including green tea leaf production in the farm and its transportation to the factory, tea processing, tea packaging, processed tea transportation to the local shop and its preparation in private household in Guilan province, Iran. The hotspots of each stage were identified and then all of stages were combined and different alternatives were compared. For this purpose, Life cycle assessment (LCA) approach was used based on the ISO 14040 standard. CML-IA baseline method was applied for impact assessment. Also the economic performance was assessed for green tea leaf and packaged black tea by calculating eco-efficiency (EE) scores. Required input data were collected from 30 farms and 30 tea processing factories in Lahijan and Langroud regions. LCA results showed that machinery and diesel fuel were the most pollutant inputs in farm and factory, respectively. Tea green leaf production was identified as the major contributor (57%) to environmental burdens in comparison with other steps throughout tea life cycle. Two-layer packaging was found as the most pollutant scenario in comparison to other scenarios (one-layer, three-layer and polyethylene packages). Cooktop was found to be more environment-friendly than electric kettle. Low EE score for most impact categories indicated the necessity of reconsidering the patterns for tea leaf production. For packaging scenarios, three-layer packaging had the highest net income with lowest environmental impacts. Based on the modelled results, it is suggested that negative environmental consequences of tea life cycle can

be reduced by optimization of agro-chemicals uses such as pesticides and chemical fertilizers in the farm, using natural gas instead of diesel fuel in tea processing factory, applying three-layer packages for packaging black tea and using cooktop for boiling water.

Keywords: life cycle assessment, eco-efficiency, impact category, tea green leaf, processing factory, packaging, tea infusing

Nomenclature

GHG	greenhouse gas	FE	Fresh water aquatic Ecotoxicity
LCA	Life Cycle Assessment	AD	Abiotic Depletion
EE	Eco-Efficiency	AC	Acidification
DEA	Data Envelope Analysis	EP	Eutrophication
AHP	Analytic Hierarchy Process	GW	Global Warming
FU	Functional Unit	HT	Human Toxicity
LCI	Life Cycle Inventory	ME	Marine aquatic Ecotoxicity
LCIA	Life Cycle Impact Assessment	PO	Photochemical Oxidation
FBD	Fluidized Bed Dryers		
LDPE	Low Density Polyethylene		
TE	Terrestrial Ecotoxicity		
OLD	Ozone Layer Depletion		

1. Introduction

Almost 14% of GHG emissions is emitted by the agricultural sector in all over the world (Cichorowski et al., 2015; Soheili-Fard et al., 2014). GHGs are also identified as a critical issue in agricultural production systems (Soheili-Fard et al., 2014). There are significant potentials for the reduction of product-related GHG emissions in the field of agriculture and food (Chen et al., 2010; Cichorowski et al., 2015). Tea is the most consumed none-alcoholic beverage in the world next to the water (Chapagain and Hoekstra, 2007). The entire tea life cycle, including cultivation, production and its preparation in the private household are involved with considerable environmental impacts. Thus, it is necessary to conduct a comprehensive study on the related environmental impacts.

Iran is one of the important tea producing countries and tea is mostly cultivated in the north of Iran. Iran's share of tea global production is almost 3%, producing almost 120,000 tonnes of tea green leaf per annum (FAO, 2014). The life cycle of tea includes green tea leaf production in the farm and its transportation to the factory, tea processing, tea packaging, processed tea transportation to the local shop and its preparation in private household involved with considerable environmental impacts.

The LCA as a technique was developed to assess environmental impacts over a life cycle (Chen et al., 2010; Kouchaki-Penchah et al., 2016; Shahvarooghi Farahani and Asoodar, 2017). It has a significant potential to improve the efficiency of finite natural resources and energy utilization as well as improving the economic performance in product systems (Eady, 2017; Kouchaki-Penchah et al., 2017; Nikkhah et al., 2014; Zhang et al., 2015). For analyzing the economic issues in connection with environmental consequences, economic-ecological efficiency, known as EE can also be used (Ullah et al., 2015; Thanawong et al., 2014). EE is an effective operational concept that makes a link between economic efficiency and environmental efficiency (Yang et al., 2015). Based on the OECD definition, EE is the ratio of economic value per environmental impacts. Based on the ISO 14045 standard, three following approaches can also be considered for adoption to achieve improved EE: increasing the value of the product, optimizing the resource utilization; and reducing environmental burdens (ISO, 2012). Based on the above mentioned definition, many researchers investigated the environmental impacts and EE of crop production systems.

In a study that was conducted by Cichorowsky, et al (2015), carbon footprint was investigated in the whole Darjeeling tea cycle and potentials for GHGs emissions were identified. Results showed that boiling the water for final preparation, mode of intercontinental transportation and cultivation method had significant potential to reduce GHGs emissions. Kouchaki-Penchah et al (2017) assessed the environmental impacts of green tea leaf production using LCA and DEA. Findings showed that the highest potential for energy saving can be attributed to nitrogen fertilizer. Nikkah et al (2015) conducted a cradle to gate investigation on GHG emissions footprint for agricultural production such as tea, peanut and kiwifruit production in Guilan province of Iran. Ullah et al (2015) investigated the EE in cotton cropping systems by integrating LCA and DEA. They found that optimization of pesticides and fertilizer uses can reduce the related environmental burden without an adverse effect on yield.

Thanawong et al (2014) made the same attempt on paddy rice production and compared rain-fed and irrigated cropping systems. Eady (2017) report found the greatest emissions in the cultivation of canola oilseed in Australia came from the manufacture of fertilizer, the breakdown of crop residues and emissions from soil. Khanali et al., (2016) conducted an LCA investigation on saffron production in Iran. Zhao et al (2015) focused on increasing the EE in wheat-maize rotation by combining field data and scenario modelling. Soheili-Fard et al (2014) focused on the relation between CO_2 emission and tea green leaf yield in three field sizes (small, medium and large). It was shown that medium size field had the lowest CO_2 emission and highest tea yield and nitrogen fertilizer had the highest share in CO_2 emission with 49.26%. Nabavi-Pelesaraei et al (2015) focused on the orange orchards in the north of Iran in the aspect of resource management. Vázquez-Rowe et al (2012) investigated the energy efficiency and GHG emissions in grape production in 40 orchards using combined AHP-DEA approach. This combined approach also was used for identification of potentials for GHG emission reductions in soybean production cycle by Mohammadi et al (2013). Rajaeifar et al (2014) analyzed GHG emissions in olive oil production using the LCA technique in Iran considering four main stages, including olive production and transportation, olive oil extraction and its transportation to the shop. Olive production in the orchard was identified as the most pollutant stage in the aspect of GHG emissions. Sabzevari et al (2015) used LCA approach for hazelnut production based on the orchard size for identifying the environmental impacts and potentials for reducing related burdens. Attempts were also made to assess carbon footprint in maize (Zhang et al., 2018) and Australian vegetables industry (Maraseni et al., 2010).

Because of the importance of the tea sector in north of Iran and growing concerns about environmental and economic performance of tea green leaf and packaged tea production, this research aimed to appraise the EE of this crucial crop in this region. In particular, tea life cycle including tea green leaf production in the farm and its post-production operations including transportation to the tea processing factory, tea processing and packaging, transportation to the local shop and tea infusing was investigated. In order to evaluate both the environmental and economic performance, eco-efficiencies through tea life cycle are also calculated which illustrates how much net value can be added to the grower/producer/consumer per unit of impact categories. Last but not least, this research also compared four packaging scenarios for first time by introducing the EE indicator.

2. Materials and Methods

This study was conducted in Lahijan and Langeroud regions, both located in Guilan province, north of Iran. Guilan province is the major tea producer, which produces more than 90% of total produced tea in Iran (Anonymous, 2015). Almost 40% of the area under tea cultivation and almost 45% of tea processing factories is situated in Lahijan and Langeroud regions (Anonymous, 2015). The sample size was determined based on the simple random sampling method (Kizilaslan, 2009). Based on this method, sample size was determined as 30 for both tea farm and tea processing factory. The average farms size and average crop yield was 0.7 ha and 8 tonne.ha^{-1}, respectively. The questionnaires were designed and developed based on ISO 14044 for collecting the required data such as economic, technical and environmental information and inputs used in tea life cycle. In this study, the environmental burdens of tea leaf production, tea processing, tea packaging in four scenarios and final consumption were investigated using LCA approach based on ISO 14040 (ISO, 2006). The economic performance was assessed using EE indicator. Furthermore, tea leaf transportation to the factory and packaged tea transportation to the local shop were considered in the present study. Based on the collected data, average distance between farm and factory and between factory and local shop was assumed as 5 and 7 km, respectively.

2.1. Life Cycle Assessment (LCA)

According to the ISO 14040 standard (ISO, 2006), LCA approach considers the following steps:

2.1.1. Goal and scope

System boundary was determined based on the related goal and is shown in Fig. 1. The FU was selected based on the amount of production and convenience in representing the results. In this study, FU was assigned as one cup of tea. This includes 2.7 g black tea and 120 cm^3 water. Since 4.44 kg green tea leaves is required for obtaining 1 kg packaged black tea, so the amount of green leaf for obtaining 2.7 g of black tea is calculated as 12 g.

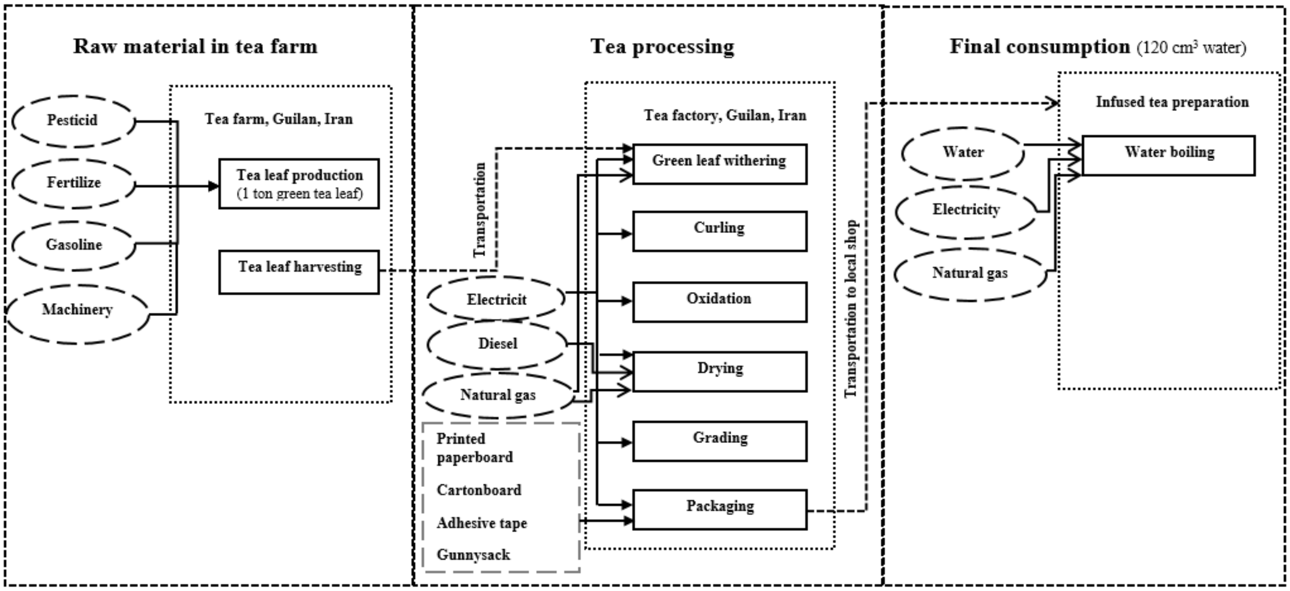

Fig. 1. System boundary of tea production cycle (one cup of tea)

2.1.2. Life cycle inventory (LCI) analysis

The second step in LCA is LCI analysis in which a product system is defined (Martínez-Blanco, et al., 2015). In this study, the inventory data were obtained from face-to-face questionnaire for foreground system. The data related to the background system were obtained from Ecoinvent 3.0 (Wernet et al., 2016), Agri-footprint (Durlinger et al., 2014), ELCD (Jensen, 1998), USLCI, LCA Food Dk and Industry data 2.0 databases and literature. Data related to the emission coefficients for consumption of diesel, gasoline and natural gas are shown in Table 1.

Table 1. Direct emission coefficients resulting from use of inputs

Inputs	Emissions								Reference
	CO_2	SO_2	CH_4	N_2O	NO_x	CO	SPM	SO_3	
Diesel ($g\ lit^{-1}$)	2860.743	14.251	0.133	0.192	21.646	4.13	7.829	0.203	Ministry of energy, Iran, 2013
Gasoline ($g\ lit^{-1}$)	2379.1	1.5	1.126	0.109	13.5	350	1.3	-	Ministry of energy, Iran, 2013
Natural gas ($g\ m^{3\ -1}$)	133	-	2.6	0.007	-	-	-	-	Ecoinvent 2.0 database, 2010

LCI for each step of the entire tea cycle, including tea farm, tea processing factory, tea packaging, considering four scenarios and final tea consumption, was obtained with two scenarios. Data related to the packaging were obtained through interviews and questionnaires. In addition, electricity used for packaging was measured.

2.1.3. Life Cycle Impact Assessment (LCIA)

ISO 14040 standard guidelines were adopted in this study. In LCIA, environmental impacts are evaluated and their potential and importance is identified (Brentrup et al., 2004). The impact categories based on the CML-IA baseline are shown in Table 2.

Table 2. Impact category base on CML-IA Baseline method

Impact categories	**Symbol**	**Unit**
Abiotic depletion	AD	kg Sb eq
Global warming	GW	kg CO_2 eq [a]
Ozone layer depletion	OLD	kg CFC-11 eq
Human toxicity	HT	kg 1,4-DCB eq [b]
Fresh water aquatic ecotoxicity	FE	kg 1,4-DCB eq [b]
Marine aquatic ecotoxicity	ME	kg 1,4-DCB eq [b]
Terrestrial ecotoxicity	TE	kg 1,4-DCB eq [b]
Photochemical oxidation	PO	kg C_2H_4 eq
Acidification	AC	kg SO_2 eq
Eutrophication	EP	kg PO_4^{3-} eq

[a] Considering 100 years
[b] DCB= dichlorobenzene

Each of the impact categories can affect human health, ecosystem quality, climate change and resources as damage categories. Table 3 shows the links between impact categories and damage categories (Chayer and Kicak, 2015).

Table 3. Links between impact categories and damage categories

Impact Categories	**Damage Categories**
AD	Human Health, Ecosystem Quality, Resources
GW	Climate Change
OLD	Human Health, Ecosystem Quality
HT	Human Health
FE	Ecosystem Quality
ME	Ecosystem Quality
TE	Ecosystem Quality
PO	Human Health, Ecosystem Quality

AC	Ecosystem Quality
EP	Ecosystem Quality

2.2. Eco-efficiency (EE) analysis

EE evaluates the relationship between economic and ecological efficiency. It assesses the production system's potential to reduce consumption of natural resources and the impact on the environment. This method is also widely used to identify the most cost-effective way to reduce environmental consequences and helping policy-makers to set policies aimed at achieving improvements in performance (Godoy-Durán et al., 2017). Both the economic and the environmental performance are required in an EE analysis (Thanawong et al., 2014). EE is defined as the ratio of economic performance to environmental impact and determined by the following equation:

$$EE = \frac{\text{Economic performance}}{\text{Environmental impact}} \tag{1}$$

Improved EE means earning more net profit with less environmental burdens (Martínez-Blanco et al., 2015). Data related to economic performance were collected from the same data set of 30 tea farms and 30 tea processing factories. To compare different environmental issues with different units in an EE analysis, the relevant data were also normalized (Kicherer et al., 2007). The normalization of scores is calculated through the following equation as suggested by Huijbregts et al (2003):

$$N_e = \frac{S_e}{NF_e} \tag{2}$$

Where N_e is the normalized score for impact category e for related product system (yr), S_e score for impact category e for related product system (kg eq.) and NF_e is normalization factor for impact category e (kg eq. yr^{-1}). Also standardizing the net income data is a necessity for EE analyzing in economic point of view. These data are standardized using GDP per capita (Yang et al., 2015). Per capita GDP was 5757.80 US dollars in Iran for 2015. Standardized net income for considered parts is tabulated in Table 4.

Table 4. Standardized net income for producing tea green leaf (12 g) and packaged black tea (2.7 g) required for one cup of tea in four packaging scenarios

	Standardized scores
Tea green leaf (12 g)	3.92E-07
One-layer packaged tea (2.7 g)	4.74E-07
Two-layer packaged tea (2.7g)	3.56E-07
Three-layer packaged tea (2.7 g)	1.52E-06
LDPE packaged tea (2.7 g)	1.53E-06

3. Results and Discussions

3.1. LCA results

In the following, the LCA results are first discussed for the individual stages of tea green leaf production in the farm and its post-production operations including transportation to the tea processing factory, tea processing and packaging, transportation to the local shop and tea infusing. After that, the analysis of entire tea life cycle is also presented.

3.1.1. The stage of tea leaves production in the farm

The LCI and environmental impacts were measured and calculated for 12 g required leaves for a cup of tea. Tables 5 and 6 show the LCI data and hotspots related to each individual impact category, respectively.

Table 5. LCI data of 12 g tea leaves production in the farm

Inputs	**Unit**	**Amount**
Machinery	h	3.60E-05
Gasoline	L	1.39E-04
Chemicals		
a. Nitrogen	kg	4.04E-04
b. Phosphate (P_2O_5)	kg	7.56E-05
Farmyard manure	kg	4.00E-04
Biocides	kg	3.72E-06

Table 6. Hotspot related to the producing 12 g tea leaves in the farm

Impact category	Hotspot
AD	Machinery, Pesticide
GW	Machinery, Nitrate
OLD	Machinery, Pesticide
HT	Machinery
FE	Machinery
ME	Machinery, Phosphate fertilizer
TE	Phosphate fertilizer, Machinery
PO	Gasoline
AC	Nitrate
EP	Phosphate fertilizer

The share of each hotspot is compared and is shown in Fig. 2. As it can be seen, machinery was found to be a major contributor to environmental impacts. The inputs of pesticides and fertilizers (nitrate and phosphate) can also significantly influence environmental impacts. Farm results related to the GW showed an amount of around 2.13 g CO_2 eq. per 12 g leaves or 1422 kg CO_2 eq. ha^{-1}, which was comparable with those obtained by Nikkhah et al (2015) as 1281.82 kg CO_2eq ha^{-1}. The most important compound that affect OLD was Chlorofluorocarbons (CFCs) (Taki et al, 2012). In the present study, OLD was obtained as about 1.82E-10 kg CFC-11 eq for producing 12 g tea leaves in farm. AC was calculated as 6.27E-05 kg SO_2 eq and nitrogen fertilizer was identified as hotspot. Climate change can be explained by AC index. SO_2, NO_X, HCl and NH_3 are known as the major components of AC (Nabavi-Plesaraei et al, 2017). Terrestrial EP is highly affected by NOx and NH_3 depositions. So EP can be reduced through increasing phosphorous and nitrogen use efficiency and minimizing their losses. Results related to each impact category showed that the amount of environmental burdens can be reduced significantly by using phosphate and nitrogen fertilizer in an efficient way. Furthermore, it is worth noting that the production of nitrogen fertilizer involves with more energy requirement compared to phosphate and potash fertilizers that causes more environmental consequences (Maraseni et al., 2010).

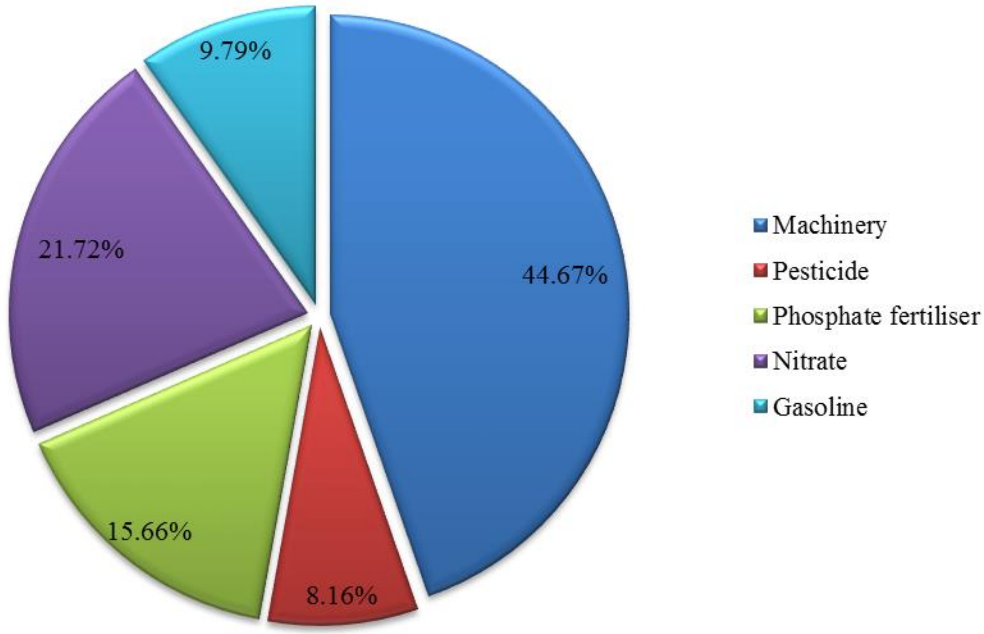

Fig. 2. Share of each hotspot in environmental pollution relating to a tea farm

Fig.2 shows that the total contribution of machinery, phosphate fertilizer, nitrate, gasoline and pesticide in environmental pollution was found to be 45, 24, 15, 10 and 8%, respectively. These results were similar with those of Kouchaki-Penchah et al. (2017).

3.1.2. The stage of tea processing

The total amount of inputs used for per FU of tea processing is given in Table 7. Based on the environmental analysis, diesel fuel was found to be a hotspot in most of the impact categories such as AD, GW, OLD, TE, PO, AC and EP. Electricity was particularly found as the most pollutant input for HT, FE and ME. The relative contributions of each input to each impact category are shown in Fig. 3.

Table 7. LCI data of 2.7 g black tea production in tea processing factory

Inputs	**Unit**	**Amount**
Electricity	kWh	1.35E-03
Natural gas	m^3	1.40E-03
Diesel Fuel	L	4.32E-04

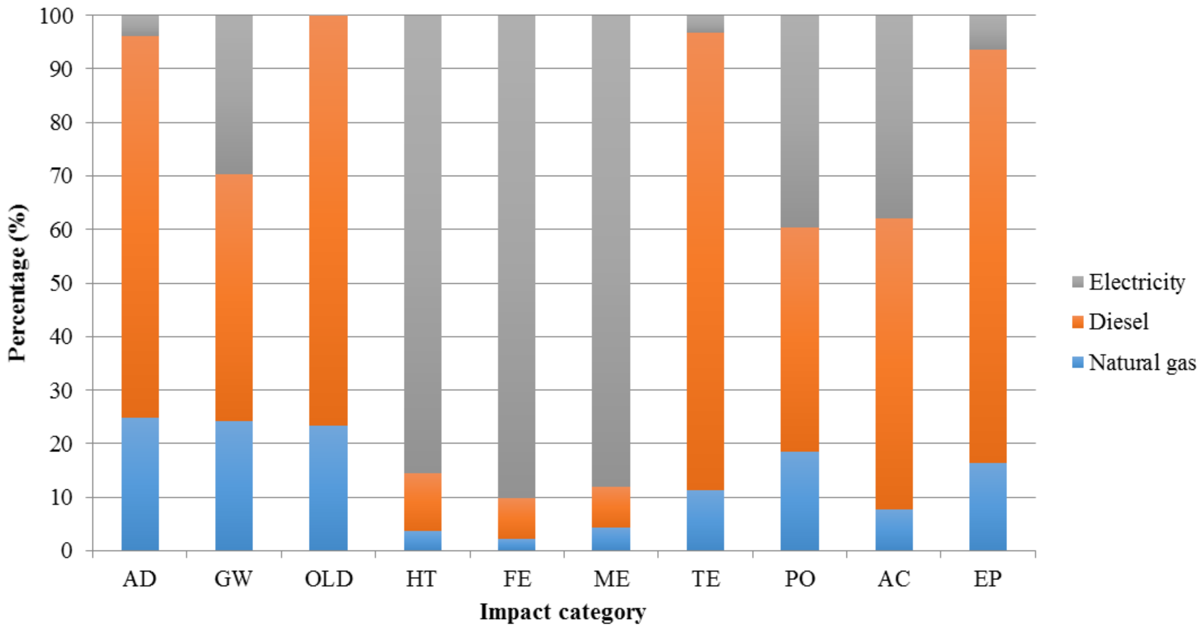

Fig. 3. Relative contributions of inputs to each impact in tea processing factory

Almost 20% of tea factories in Guilan province use diesel fuel for different stages of tea processing such as withering and drying. Withering step is involved with using considerable electrical (57% of total used electricity) and thermal energy. Almost 93% of electricity is generated in Iran in thermal power plants that causes noticeable environmental burdens, hence choosing an optimized combination of air flow rate, temperature and time duration for withering can improve energy use efficiency and reduce environmental consequences (Soheili-Fard, 2014). For the drying step, using natural gas-based dryers can eliminate environmental impacts related to diesel fuel. Also, using FBD instead of conventional dryers can increase drying capacity and reduce fuel consumption per kg of processed tea by up to 50%.

Renovation and correct settings of machinery and machine tools is another practical option to reduce pollutants. Carbon foot print related to tea processing was obtained as around 1.13 kg CO_2 per kg tea and in the other words, around 3 gr CO_2 per cup. This result agreed well with Doublet and Jungbluth (2010), who reported 3.3 gr CO_2 per cup for typical processed Darjeeling tea. In another study on Darjeeling tea, Cichorowski et al. (2015) reported GHG emissions as 1.8 kg CO_2 per kg conventional tea for tea processing that is comparable to the results obtained in the present study.

3.1.3. The stage of tea packaging

Packaging unit is commonly classified in four common packaging scenarios in Guilan province. These scenarios were designed based on the target market and customer interests. Materials used in each scenario are presented in Table 8. Environmental impacts of each packaging scenario have been shown in ten impact categories in Table 9. Based on the results, it was found that using two-layer packaging could result in more environmental burden compared with other packaging scenarios. This can be attributed to the printed paperboard that is used in this scenario, so that its contribution to environmental impacts was calculated as around 74% in comparison to other inputs. Required data for all inputs used in packaging were extracted from Ecoinvent 3 and Industry data 2.0 databases. Fig. 4 shows a comparative view of packaging scenarios in the aspect of environmental impacts in each impact category.

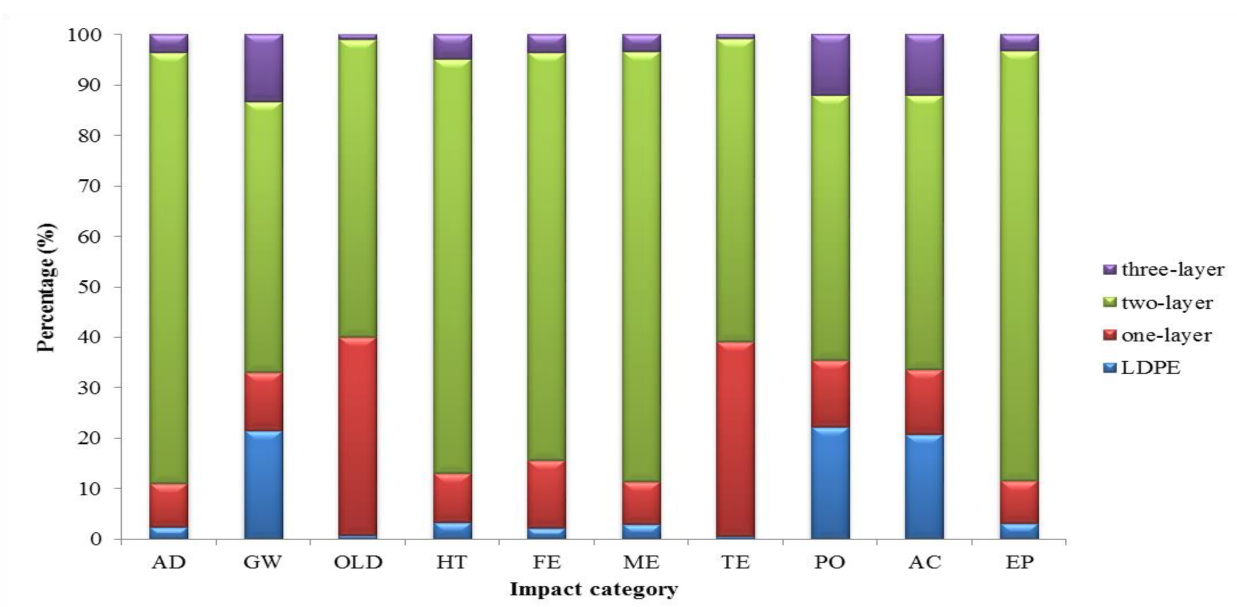

Fig. 4. Comparison of contribution of each packaging scenario to each impact category

Table 8. LCI data for packaging, specified for 2.7 g black tea

Packaging Scenarios	**Inputs**						
	Electricity (kWh)	Polyethylene (gr)	Polypropylene (gr)	Printed paperboard (gr)	Cartonboard (gr)	Adhesive tape (gr)	Gunnysack
1-kg one-layer	0.00001026	0	0.021168	0	0.1242	0.000756	0
1-kg two-layer	0.00001188	0.011826	0.011988	0.27	0.1242	0.000756	0
1-kg three-layer	0.00001134	0.051354	0.011988	0	0	0	0
20-kg polyethylene	0.0000108	0.027648	0	0	0	0	0.068958

Table 9. Emissions related to four packaging scenarios specified for 2.7 g black tea

		Packaging scenarios			
Impact categories	Unit	One-layer	Two-layer	Three-layer	LDPE
AD	kg Sb eq	2.01E-10	1.98E-09	8.27E-11	5.66E-11
GW	kg CO_2 eq	1.64E-04	7.67E-04	1.91E-04	3.08E-04
OLD	kg CFC-11 eq	5.85E-11	8.80E-11	1.48E-12	9.79E-13
HT	kg 1,4-DCB eq	4.59E-05	3.87E-04	2.32E-05	1.60E-05
FE	kg 1,4-DCB eq	4.86E-05	2.93E-04	1.29E-05	7.70E-06
ME	kg 1,4-DCB eq	1.30E-01	1.31E+00	5.25E-02	4.54E-02
TE	kg 1,4-DCB eq	1.73E-06	2.70E-06	4.01E-08	2.28E-08
PO	kg C_2H_4 eq	4.73E-08	1.86E-07	4.28E-08	7.87E-08
AC	kg SO_2 eq	9.26E-07	3.92E-06	8.75E-07	1.50E-06
EP	kg PO_4^{3-} eq	5.05E-07	5.13E-06	1.93E-07	1.88E-07

3.1.4. The stage of infused tea preparation

Two scenarios were defined for boiling the water. As it can be seen in Table 10, electricity and natural gas used in electric kettle and cooktop scenarios, respectively, were measured and provided for boiling 120 cm^3 water. The environmental impacts of using electric kettle and cooktop in each impact category are compared together (Fig. 5).

Table 10. LCI for boiling 120 cm^3 water

Scenario	Electricity (kWh)	Natural gas (Lit)
Electric kettle	0.00798	-
Cooktop	-	2.01

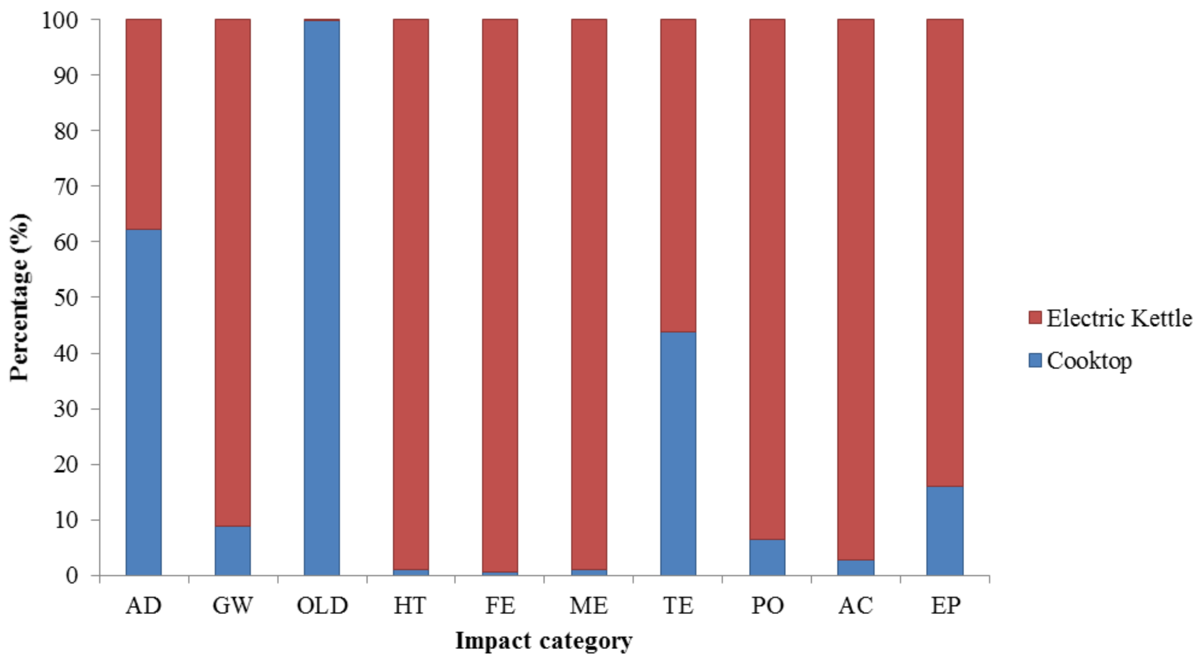

Fig. 5. Comparison of contribution of each scenario to each impact category for boiling the water

It can be seen that using electric kettle resulted in more environmental impacts compared to cooktop, but in terms of AD and OLD impact categories, cooktop had more contribution. This was because the natural gas is a kind of a clean fuel, so using cooktop has more environmental benefits. Also details of the environmental impacts in each impact category are presented in Table 11, based on boiled 120 cm^3 tap water.

Table 11. Emissions related to the two scenarios for boiling 120 cm^3 water

Impact categories	Unit	Scenarios	
		Electric kettle	cooktop
AD	kg Sb eq	3.63E-11	4.99E-11
GW	kg CO_2 eq	1.11E-02	1.06E-03
OLD	kg CFC-11 eq	2.62E-14	3.45E-11
HT	kg 1,4-DCB eq	1.66E-03	1.57E-05
FE	kg 1,4-DCB eq	5.91E-04	3.16E-06
ME	kg 1,4-DCB eq	2.25E+00	2.43E-02
TE	kg 1,4-DCB eq	1.26E-08	9.79E-09
PO	kg C_2H_4 eq	3.77E-06	2.64E-07
AC	kg SO_2 eq	9.42E-05	2.64E-06
EP	kg PO_4^{3-} eq	2.17E-06	4.11E-07

3.1.5. The comparison of entire tea life cycle

After analyzing each step of tea cycle, all steps are now combined together to identify the hotspots for a cup of tea. Based on the results, tea leaf production in the tea farm and final tea preparation were found as the main contributors to environmental pollutions and so were identified as hotspots in entire tea life cycle. Hotspots related to each impact category are presented in Table 12.

Table 12. Hotspot related to the entire cycle of tea, specified for one cup of tea

Impact category	Hotspot	Amount
AD (kg Sb eq)	Farm	2.10E-08
GW (kg CO_2 eq)	Infusing, Processing factory	6.08E-03, 3.05E-03
OLD (kg CFC-11 eq)	Farm, Processing factory	1.82E-10, 1.03E-10
HT (kg 1,4-DCB eq)	Farm, Infusing	1.16E-03, 8.38E-04
FE (kg 1,4-DCB eq)	Farm, Infusing	5.34E-04, 2.97E-04
ME (kg 1,4-DCB eq)	Farm, Infusing	1.73E+00, 1.14E+00
TE (kg 1,4-DCB eq)	Farm, Packaging	3.10E-06, 1.12E-06
PO (kg C_2H_4 eq)	Farm, Infusing	2.43E-06, 2.02E-06
AC (kg SO_2 eq)	Farm, Infusing	6.27E-05, 4.84E-05
EP (kg PO_4^{3-} eq)	Farm	7.19E-05

In comparison to the farm as the main contributor in environmental categories, the stage of final preparation and infusing tea was identified as hotspot in some impact categories such as HT, FE, ME, PO and AC. Also, packaging step had a considerable share in TE impact category. This can be attributed to materials used for packaging. However, reduction or substitution of packaging material is out of the scope of this study because it can affect the profile of the final product, so due to their noticeable share on impact categories, it can be suggested to be investigated in future studies.

Fig. 6 shows an overview of each steps' share in environmental pollution. Doublet and Jungbluth (2010) and Cichorowski et al. (2015) identified tea infusing phase as the hotspot with regard to GW potential that was followed by tea leaves production in the farm and tea processing factory. These results were comparable with those obtained in the present study. In spite of that, in the present study, the share of tea processing factory was more than tea farm in terms of CO_2 emission. It can be attributed to using obsolete machines in the factory and also inappropriate setting of them.

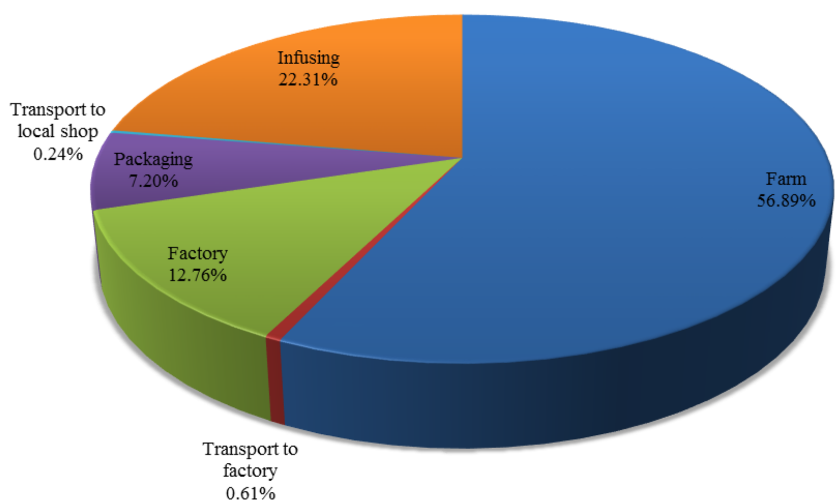

Fig. 6. Share of each step in environmental pollution

3.2. EE results

Regarding to the EE analysis, the net income from 12 g tea green leaves and 2.7 g packaged tea for each packaging scenario was calculated and then EE was calculated for each part. EE scores for 12 g tea green leaves are presented in Table 13.

Table 13. EE scores for producing 12 g tea green leaves

Impact categories	unit	EE score
AD	Net income. kg Sb eq^{-1}	1.87E+01
GW	Net income. kg CO_2 eq^{-1}	1.84E-04
OLD	Net income. kg CFC-11 eq^{-1}	2.16E+03
HT	Net income. kg 1,4-DCB eq^{-1}	3.39E-04
FE	Net income. kg 1,4-DCB eq^{-1}	7.34E-04
ME	Net income. kg 1,4-DCB eq^{-1}	2.26E-07
TE	Net income. kg 1,4-DCB eq^{-1}	1.26E-01
PO	Net income. kg C_2H_4 eq^{-1}	1.62E-01
AC	Net income. kg SO_2 eq^{-1}	6.25E-03
EP	Net income. kg PO_4^{3-} eq^{-1}	5.45E-03

Based on the results, EE scores for some impact categories such as GW, HT, FE and ME were all relatively low. This means that in terms of these impact categories, there is low income per 1 kg emissions. For example, the net income will be almost $1 per emitting one kilograms CO_2 eq or it will be almost $2 per emitting one kg toxic substance dichlorobenzene eq for HT. But comparison between different impact categories is impossible because of different units. So for comparing them together, normalized and standardized scores were used. As it can be seen in Fig. 7, the highest EE score was clearly related to the OLD. It means there is no problem with OLD, because high net income is accompanied by low CFC-11 emissions. However, its difference with other impact categories was significant and followed by TE and HT. Considering these results, the necessity of reconsidering the patterns for tea leaf production is recommended and environmental issues should not be sacrificed by gaining more income. It's common to use more chemical fertilizers such as nitrate and phosphate fertilizers to guarantee the higher yield in tea farms for gaining more income. But based on EE results, it's accompanied by more environmental burdens. For increasing EE score, chemical fertilizers should be replaced by manure and compost, also using natural gas instead of diesel fuel in processing factory can be considered as an effective way to improve EE score.

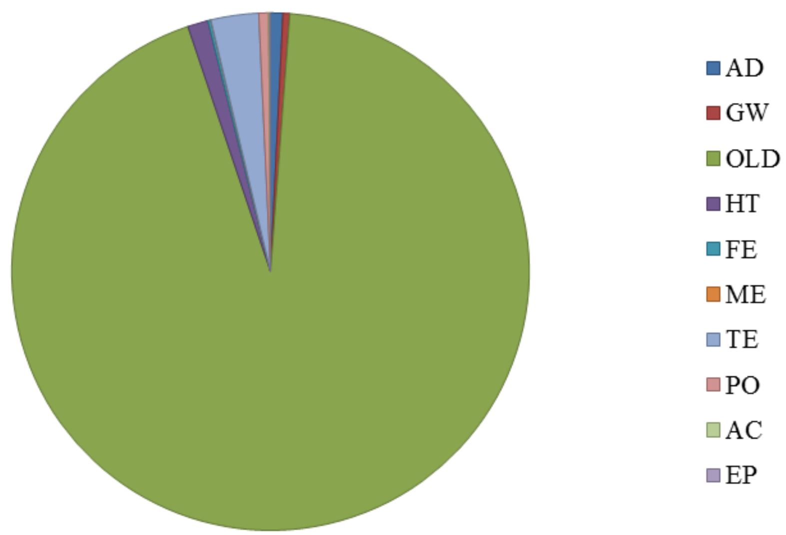

Fig. 7. Comparison the EE score of impact categories

It was also found that LDPE and three-layer packages had higher EE score in all impact categories in comparison to alternative scenarios (one-layer and two-layer) (Fig. 8).

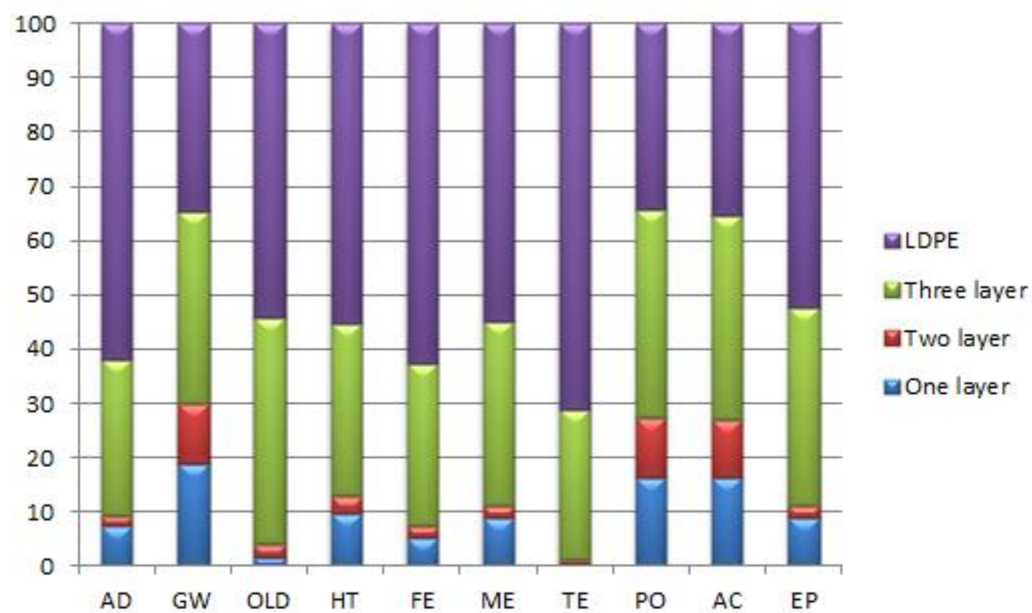

Fig. 8. Comparison of each scenario EE scores in impact categories

The relation between environmental impacts and EE score is shown in Fig. 9.

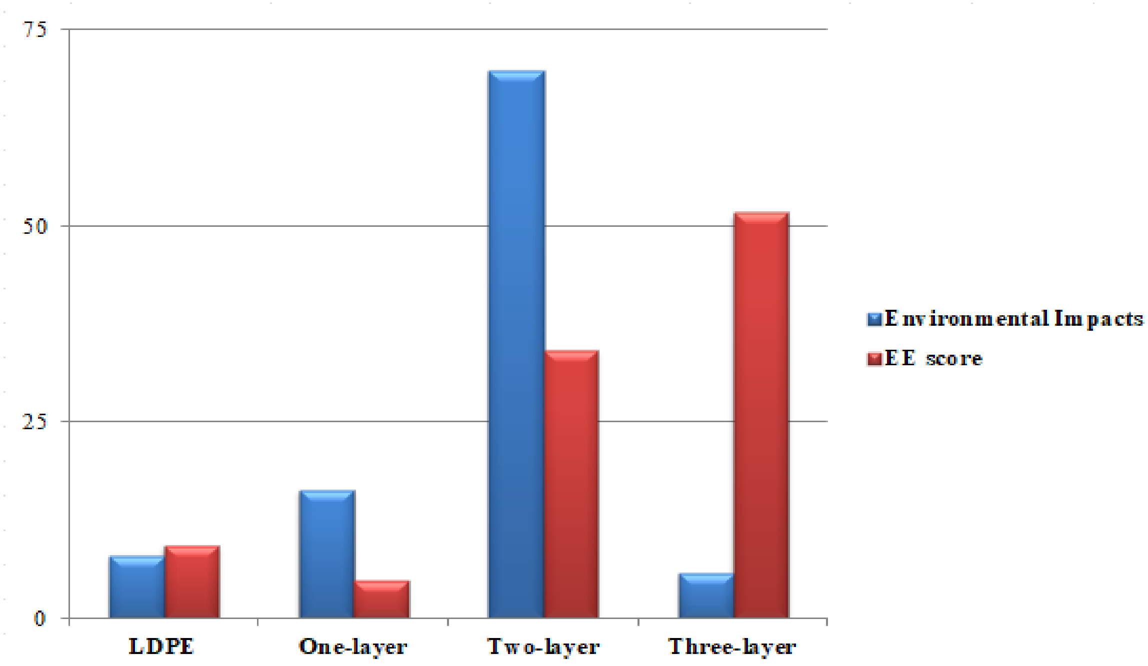

Fig. 9. Relation between environmental impacts and EE score for each packaging scenario

4. Conclusion

This study has investigated the life cycle performance of tea production and consumption in Iran, including tea green leaf production in the farm and its transportation to the tea processing factory, tea processing and packaging (four scenarios), transportation to the local shop and tea infusing. Results obtained from LCA have indicated machinery and nitrate fertilizer as the main hotspots in farm. Diesel fuel was also found as the main contributor to environmental pollutant in tea processing factory.

The comparison between four packaging scenarios has revealed that two-layer packaging has the most contribution to environmental pollution and three-layer packaging causes the lowest environmental burdens. Results related to the EE analysis of packaging scenarios have also shown that three-layer packaging had highest net income with lowest environmental impacts. Tea infusing has also been assessed considering two scenarios of electric kettle and cooktop. Cooktop was found as more environment-friendly. It has been further shown that there is high potential for reducing environmental burdens related to final consumption in private household. Using cooktop for tea infusing can reduce environmental impacts by 51% as compared to electric kettle.

After considering individual main stages, all stages have been combined together and compared. Based on the results, tea green leaf production was identified as the major contributor to environmental burdens (57%) that was followed by tea infusing (22%), tea processing factory (13%), packaging (7%) and tea green leaf and packaged tea transportation (1%). EE analysis for tea green leaf has also been conducted. It is suggested that optimization of agro-chemicals used in the farm and using natural gas instead of diesel fuel in tea processing factory can be considered to reduce negative environmental consequences of tea life cycle.

Also each tea-producing country (China, India, Kenya, Iran, Sri Lanka etc.) has their specific condition in terms of inputs. For example, 90% of electricity in Iran is produced in thermal plants that caused high amounts of pollution, while it can be different in other countries. Furthermore, for tea exporting countries, some scenarios can be considered about the state of transportation to target countries. So, the same approach can be followed for LCA and eco-efficiency investigation of tea life cycle given to their specific conditions.

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