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Life cycle assessment of construction phase of monorail project in Qom, Iran

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ABSTRACT: Transportation is an important part of modern community life as well as one of the largest sources of greenhouse gas emissions in urban communities, the population growth of which can increase transportation capacity. Monorail systems are relatively new rail transportation systems which are currently being designed and constructed in different countries. We applied the Intergovernmental Panel on Climate Change (IPCC) to deal with global warming and Center of Environmental Science of Leiden University (Centrum voor Milieukunde Leiden), CML 2001, to evaluate the potential of acid raining. In order to analyze both mentioned methods, Sima Pro7.1 was used. Initially the research-related data have been prepared from Qom Monorail workplace. Moreover the sensitivity analysis was performed on the results, which indicated that the potential of causing global warming in the construction phase for a period of 100 years was equal to 26875.07 kg CO_2eq. /km. person. The reinforcement bar with 32%, concrete with 30%, and diesel fuel with 15% enjoyed the lion's share in terms of global warming creation. The likelihood of acid raining formation was equal to 101.876 kg SO_2eq ./km. person. Diesel fuel contributed the most portion to the formation of acid raining (31%) with reinforcement bar and concrete in the second (30%) and third (13%) places. For result validation, Building for Environmental and Economic Sustainability (BEES) software applied with the sensitivity analysis, indicating that the first and second effective parameters on the results were the amount of reinforcement bar and diesel fuel. Therefore, reduction of reinforcement bars, concrete, and diesel (respectively) have the most influence on mitigation of global warming and acid raining effects of Qom monorail project.

Keywords: acid raining, global warming, life cycle assessment, Qom monorail.

INTRODUCTION

Transportation is an important aspect of modern community life; however, it is the biggest source of producing greenhouse gases such as carbon dioxide, nitrogen dioxide, and particulate matter in urban environment. As urban population increase every day, we need to increase transportation capacity, which means using more fossil fuel, thus causing more air pollution and threatening public health. Growing concern related to impairment of human health and raising earth temperature is necessary as increased urban transportation not only optimizes existing transportation methods, but creates the concept and new technology (Eriksson, 2012). Monorail System, being a safe and high-capacity that requires a short time to design and construct as a relatively new rail transportation system, is currently

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under design and construction in different countries of the world. Constructed for the purpose of passenger transportation, it uses a rail to move and is often constructed above the ground, though it can be built on the ground or underground as well (Solymani and Barikani, 2015).

A Life Cycle Assessment (LCA) is a holistic method that involves the identification of all life cycle processes' loads and environmental impacts, with focus on manufacture wherein environmental harmful effects are reduced to allow the improvement and optimization of the production processes (Huntzinger and Eatmon 2009; Abeliotis et al., 2012; Valderrama et al., 2012). Osada et al. (2006) studied life cycle assessment of six types of transportation system, namely the subway, monorail, Bus Rapid Transit, High Speed Surface Transports, Light Rail Transit, Automated Guide Way Transit, and Guide Way Bus. They found out that Light Rail Transit causes lesser environmental impact than other mentioned transportations; however, this study showed a reduction of CO_2 due to increased use of public transport instead of private cars. The Swedish Environmental Research Institute conducted a study on the life cycle of Bothnia railway lines in Sweden (segment structure and vehicles). The results indicated that 93% of Global Warming Potential (GWP) emissions derived from the infrastructure section (mainly because of deforestation) and 7% were due to trains' traffic jam. Except for primary energy sources, the main part of all environmental impacts (global warming, ozone layer depletion, eutrophication, acidification, and photochemical oxidation) were generated from the extraction of raw materials and building materials such as concrete and steel, required for the infrastructure. Steel and cement, comprising 85% of the materials for the construction of rail infrastructure in Bothina, were the main sources of CO_2 emissions (Stripple and Uppenberg, 2010).

Keolian et al. (2005) compared the environmental impact of 60-year-old engineered cementitious composite link slabs with conventional steel expansion joints. Their result showed that compared with conventional steel expansion joints, the engineered cementitious composite link slabs consumed 40% less energy in LCA, reducing solid waste and its consumed material for 50% and 38% respectively. Bilec et al. (2006) investigated LCA in the construction phase of a building project; their results, showing that transportation, equipment activity, and support functions have a significant effect on the environment.

Kiani et al. (2008) compared the LCA of concrete slab track bed with ballasted track bed, stating that concrete slab track bed consumed and emitted no more energy and emission than the ballast track beds. Chester and Horvath (2009) compared the LCA of four systems, namely buses, airplanes, trains, and automobiles in USA. They found that total life-cycle energy inputs and greenhouse gas emissions contribute an extra 63% for road, 15.5% for rail, and 31% for air systems over vehicle tailpipe operation. Milford and Allwood (2009) estimated carbon dioxide emission from production, processing, and material transportation for construction, maintenance, and end life activities for the designs at high and low traffic loads. Their results indicated that road construction with sleeper concrete had a lower carbon dioxide emissions in comparison to steel, hardwood, and softwood steel. Steel, hardwood, and softwood are placed in the second, third, and fourth ranks.

Akerman (2010) studied LCA of Europaban as a high speed railway in Sweden and found 60% of LCA emission as the transportation mode changed from truck to rail freight; what is more, the emission was reduced for 40% by altering air and road travel to high-speed rail travel. Chester and Horvath (2010) investigated the LCA automobiles, heavy rail, high-speed railway, and aircraft to compare the direct effect of vehicle transportation and indirect effects of using fuel, infrastructure, and vehicles. The study indicated that even though high-speed railway had less energy consumption and greenhouse gases dedicated planning and continued investment was necessary. Ito et al. (2010) studied the LCA of supplying infrastructure and production vehicles. This investigation indicated a reduction of carbon dioxide as the number of passengers increased and technology developed.

Bilec et al. (2010) applied hybrid LCA model to determine particulate matter, global warming potential, SOx , NO*x*NOx , CO, Pb, nonmethane volatile organic compounds, energy usage, and solid and liquid wastes. Their outcome concerning the entire life cycle of the building showed that the construction phase, while not as important as the use phase, was as vital as any other life-cycle stage.

Chang and Kendall (2011) investigated LCA of establishing the infrastructure of high–speed railway system from San Francisco to Anaheim. They found out that about 2.4 million tons of carbon monoxide was generated, 80% of which came from the use of constructing material and 16% from the transportation of the construction materials. They also stated the space frame and underground structure, covering 15% of the route, was responsible for 60% of the emissions. Li et al. (2011) selected a highway in western China as a case study to concentrate on the endogenous CO_2 emission throughout tunnel construction. They stated that the oriented-diesel CO_2 emissions were at a high level, over 90%, in comparison with other types of fuel during tunnel construction.

Eriksson (2012) applied an LCA on the operation of a Personal Rapid Transit (PRT), concluding that rail construction (because of the heavy mass in the process) had the most environmental impacts, followed by wagons (because of their greater energy consumption) in the second place. He also stated that steel rails had a less environmental impact (due to their lower weight), compared to concrete rails. Using the electricity from moving wagons, in comparison to battery, had less environmental impacts owing to the lesser battery age along with greater time for recharging it and increased number of wagons to maintain the transport capacity.

Asadollahfardi et al. (2015) studied LCA of 16000 apartments in Prand Town, West of Tehran. Their results illustrated that concrete was the most effective factor to lead into global warming. Seo et al. (2016) studied the environmental impact of material production, transportation, and construction phase, dealing with carbon dioxide emission for each process via Korean life cycle inventory database. Their results showed that CO2 emissions from the material production phase contained 93.4% of the total CO_2 emissions.

In the present study, we studied LCA of Qom's monorail during its construction phase. Being the first monorail system under construction in Iran, the length of the monorail in part one is 6.2 km with a capacity of 800 passengers, including five trains, each having 4 wagons. Figure 1 shows Qom monorail in its first part. This monorail consists of a two-way rail line, the direction of which is from northeast to southwest of Qom City, parallel with Qom Rud River. The altitude of Qom City is 877.4 m from the sea level and its geographical coordinates are eastern longitude of 50.51° and latitude of 34.42°. The city is located in semi-arid climate with relatively very high differences of annual temperature.

The objective of the study was to determine a Life Cycle Assessment (LCA), including global warming and acidification of Qom monorail, during its construction, using the framework of ISO14040 and Sima Pro 7.1 Software.

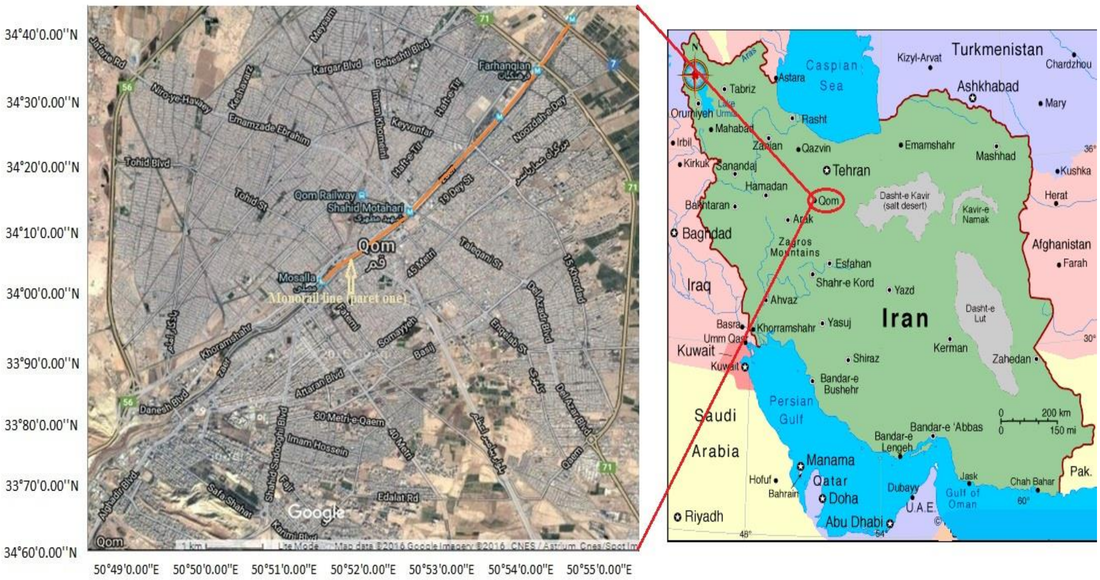

Fig. 1. The study area, Qom monorail stations (in two phases)

MATERIAL AND METHODS

A Life Cycle Assessment (LCA) is a valuable tool for assessing direct and indirect effects of the production process on the environment during the length of the product's life cycle (Huntzinger and Eatmon, 2009; Valderrama et al., 2012). Based on what is suggested by ISO 14040, the study of LCA consists of four steps which include the definition of goal and scope, inventory analysis, impact assessment, and interpretation results (Abeliotis et al., 2012), all to be explained in what follows:

Goal definition

In a transport systems LCA, along with our study, a unit function is defined as transportation of one passenger over one kilometer (km. Person). Functional units are a quantitative description of assessment goal, in which the comparison between the results of similar assessments can be possible (Eriksson, 2012).

Scope of study

Only the two phases of material preparation and construction of the Qom Monorail was analyzed (Fig. 2).

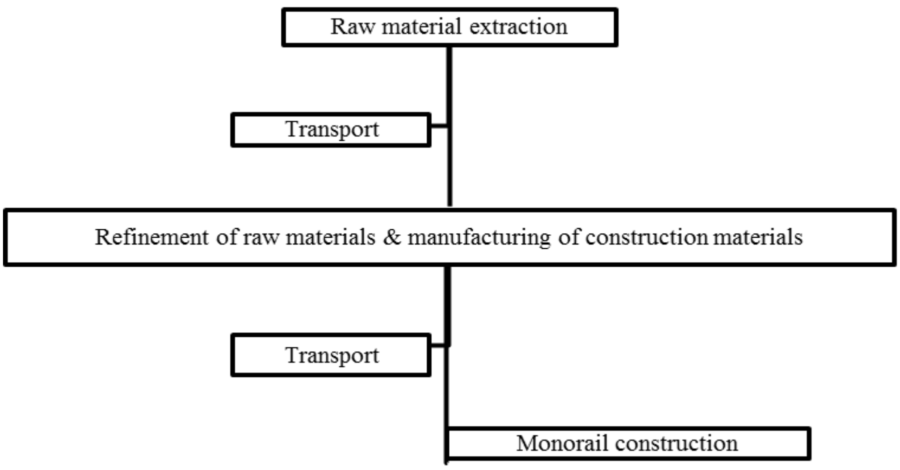

Fig. 2. System boundary of LCA study of Qom monorail

Inventory analysis for LCA in Qom monorail

SimaPro 7.1 is one of the tools for LCA (Product ecology consultant, 2007). The software is popular in the world for analyzing environmental aspects of goods and services (Calderón et al., 2010). According to the Osses de Eicker et al. (2010)'s study, the results of inventory analysis of LCA, the use of databases of European countries and developing countries are about the same (Ossés de Eicker et al., 2010). Therefore, based on the mentioned study and due to lack of access to relevant Iranian database, we used the European database Ecoinvent and IDAMAT 2001 (for slabs of reinforced concrete) for inventory analysis of Qom Monorail Project. We prepared the input data from the Qom Monorail workplace for inventory analysis and then for estimation, generation, processing, and transportation of materials in the workplace we used the databases of Sima Pro 7.1. Also, we considered the capacity of trucks and trailers, which transported the materials in the workplace, according to Blengini and Di Carlo (2010)'s study, which were 16 to 32 tons with Euro 3 standard fuel. It is assumed that same types of trucks and trailers were used in both our study and that of Blengini and Di Carlo (2010).

We only considered the transportation of bulky materials such as cement, aggregate, and reinforcement. The volume of material and working on the basis of the project's progress by the end of March 2015 and the value of operations, carried out to date for the entire project (100% of operations) were inserted to Sima Pro as the software's input.

Table 1. Life Cycle Inventory of Qom monorail

Operations	Unit	Amount and percent of operations by the end of March 2015		Calculated amount to complete the project	Description[1]	Sima Pro inputs
		Percent	Amount			
Excavation (depot)	Ton	80%	201630			
Excavation (way)	Ton	88%	19650			
Embankment (depot)	Ton	95%	86620			
Embankment (way)	Ton	88%	10000			
Total	Ton	100%		376909.6		
Reinforcing steel (way)	Ton	88%	8100			
Reinforcing steel (depot)	Ton	23%	2700			
Reinforcing steel (Station)	Ton	78%	6600			
Total	Ton	100%		29405.2		Reinforcing steel, at plant/RER[1] U[2]
Formatting	Ton	100%		950		Metal product manufacturing, average metal working/RER U
Steel scaffolding	Ton	100%		250		Steel product manufacturing, average metal working/RER U
Concrete (way)	m^3	89%	47500		Grade concrete is 400 kg/m^3. The Density of the concrete (Reinforced and Pre-stressed concrete, 15cm thick) is 2500kg/m^3	
Concrete (depot)	m^3	42%	10500			
Concrete (Station)	m^3	80%	55500			

1. Europe (According to the Europe database)
2. Unit Process

Table 1. Life Cycle Inventory of Qom monorail

Operations	Unit	Amount and percent of operations by the end of March 2015		Calculated amount to complete the project	Description[1]	Sima Pro inputs
		Percent	Amount			
Concrete	m^3	100%		147745.8		Concrete, normal, at plant/CH U
Insulation (way)	m^2	88%	8500		The density of the insulation and Bitumen sealing is 15kg/m^2	
Insulation (depot)	m^2	40%	1200			
Bitumen sealing	m^2	95%	7000			
Insulation the air channels	m^2	20%	700			
Insulation and Bitumen sealing	Ton	100%		335.43		Bitumen sealing VA4, at plant/RER U
T	m^2	30%	20000		5m^2/kg Acrylic paint	Acrylic varnish, 87.5% in H_2O, in the plant/RER U
	Ton	100%		13.34		
Water piping	m	25%	3000		The water polyethylene pipe is 2.5kg/m heavy and the sewage polyethylene pipe weighs 4kg/m.	
Sewage piping	m	20%	700			
Water and sewage piping	Ton	100%		44		Polyethylene, HDPE, granulate, at plant/RER U
Network connections	Number	25%	50000		The weight of each of the 'Network connections' (made of polyethylene), 10cm long, is 4kg.	Polyethylene, HDPE, granulate, at plant/RER U
	Ton	100%		80		
Wood door	m^2	100%	400	400	The weight of wood, 5cm thick, is 600kg/m^2	Door, outer, wood-aluminium, at plant/RER U
3D Panel	m^2	30%	20000		The 3D Panel (Plasto foam) is 30kg/m^3 heavy.	Polystyrene, expandable, at plant/RER U
Air channel (package)	m^2	20%	700		The Galvanized sheets are 5kg/m and 2.4 kg/m^2 heavy.	
Fire control facility	m	25%	2100			
Support and cable tray	m	25%	6500			
Galvanized steel[1]	m^2	100%		10824		Zinc coating, pieces/RER U
	Ton	100%		180.4		Sheet rolling, steel/RER U
Wire drawing	m	20%	62000		The Copper wire weighs 99g/m	Wire drawing, Copper/RER U
	Ton	100%		30.69		
Cabling	m	20%	90000		The Copper cable weighs 2kg/m	Cable, data cable in infrastructure, at plant/GLO[1] U
	m	100%		450000		

1. Global

Table 1. Life Cycle Inventory of Qom monorail

Operations	Unit	Amount and percent of operations by the end of March 2015		Calculated amount to complete the project	Description[1]	Sima Pro inputs
		Percent	Amount			
Steel piping	m	25%	11000		The steel pipe weighs 5kg/m	Drawing of pipes, steel/RER U
	Ton	100%		220		
PVC piping	m	25%	53000		The PVC pipe weighs 1.5kg/m	Polyvinyl chloride, at regional storage/RER U
	Ton	100%		318		
Natural stone plate	m^2	27%	21000		The density of Granite (with thickness of 3cm) is $2800kg/m^3$	Natural stone plate, cut, at regional storage/CH U
	Ton	100%		6533.34		
Tiles	m^2	30%	5000		The total weight of wall ceramic and tile is $1700kg/m^2$ and floor ceramic and tile is $2100kg/m^2$	
Ceramic	m^2	27%	35000			
Ceramic tiles	Ton	100%		8778		Ceramic tiles, at regional storage/CH[1] U
Mosaic	m^2	29%	3000		The weight of mosaic (cement mosaic), which is 4cm thick, is $2250kg/m^3$	Concrete I
	Ton	100%		931.0345		
Cement	m^2	30%	7500		The weight of Cement, which is 3cm thick, equals to 2100kg/m3	Cement, unspecified, at plant/CH U
	Ton	100%		1575		
Plastering	m^2	29%	6500		The weight of Stucco, with a thickness of 3cm, is $1300kg/m^3$	Stucco, at plant/CH U
	Ton	100%		874.14		
Roof	m^2	25%	21000		A reinforced concrete slab	Concrete (reinforced) I
	Ton	100%		31500		
Ceiling	m^2	100%	3000		The weight of Ceiling (Gypsum plaster) is 50 ton/m^2	Gypsum fiber board, at plant/CH U
	Ton	100%		150		
Window frame	m^2	20%	135	675	The weight of UPVC window, 5mm thick, is $1400kg/m^2$	Window frame, plastic (PVC), $U=1.6\ W/m^2K$, at plant/RER U
Glazing	m^2	100%	13500	13500	The weight of double glass, with a thickness of 5mm, is $2500kg/m^2$	Glazing, double (2-IV), $U<1.1\ W/m^2K$, at plant/RER U

1. Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology)

Table 1. Life Cycle Inventory of Qom monorail

Operations	Unit	Amount and percent of operations by the end of March 2015		Calculated amount to complete the project	Description[1]	Sima Pro inputs
		Percent	Amount			
Brick	m^2	30%	500		The brick, which is 20cm thick, weighs 1850kg/m^3	Brick, at plant/RER U
Cement mortar	m^2	30%	100		The weight of cement mortar with a thickness of 3cm is 2100kg/m^3	Cement mortar, at plant/CH U
		Ton	100%		21	

1. Galvanized steel was divided into two parts: Sheet rolling and Zinc coating, 2. Reference: Deputy of housing and construction, 2009

The distance for the transportation of aggregate, which included sand, gravel, and stone from Malek Ashtar manufacturing plant, located near the city of Qom, to Qom Monorail, itself, was about 30km. Also, the distance for transportation of cement to the site (from the Saveh cement plant to Qom city) was 150 km. The total amount of concrete, used in the project with a grade of 400 kg/m^3 cement was 147745.8 m^3. About 59098.315 ton cement was to be transported to the workshop. Also, assuming that the consumption rate of water for the production of concrete was 200 kg per cubic meter, the water, used for producing the concrete, amounted to 29549.1573 tons, for which 280716.9944 ton aggregate was needed. The average distance of machineries or earth-moving transportation for earthworks and embankment within the workplace was 3.5 km. The average distance required to carry reinforcement (bars) to the workplace was 600 km (the distance from Ahvaz factory to the city of Qom city was 850km and from Isfahan Factory, 350km). Trucks' road was considered to be one way towards the workplace; therefore, the total rate of material transportation was 36248561 ton.km. A total amount of 3703220 tons fuel and diesel (or gasoline) was transported to the workplace for the construction equipment as well as the machinery, which was 65% of the total amount of fuel, needed for completing Qom monorail. Hence, diesel consumption by the end of Qom monorail project (only for equipment) was 5697261.538 liter. Considering the calorific value (9232 kcal/liter or 38/63 MJ/liter) of diesel, the amount of energy consumed in construction equipment is 220085213.213 MJ (Table 2). This amount of diesel was only for the construction equipment. The diesel and diesel consumption in winter in the workplace cannot be predicted due to its change.

To have a better understanding of the potential of the environmental effects, Figures 3 and 4 illustrate the mass distribution of each of the materials used in the construction process of the Qom Monorail.

Table 2. Transportation material and used energy for construction building

Parameter	Unit	Amount	SimaPro input
Transporting material	Ton.km	36248561	Transport, lorry 16-32t, EURO3
Used energy for construction machinery	MJ	220085213.213	Diesel, burned in building machine/GLO U

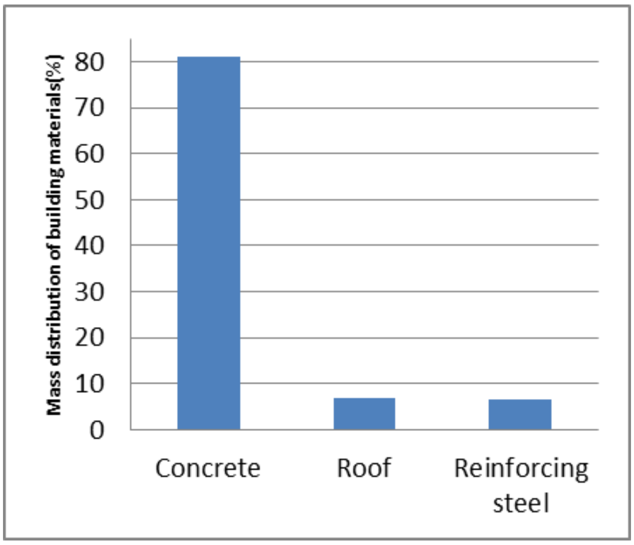

Fig. 3. Mass distribution of building materials (Major elements)

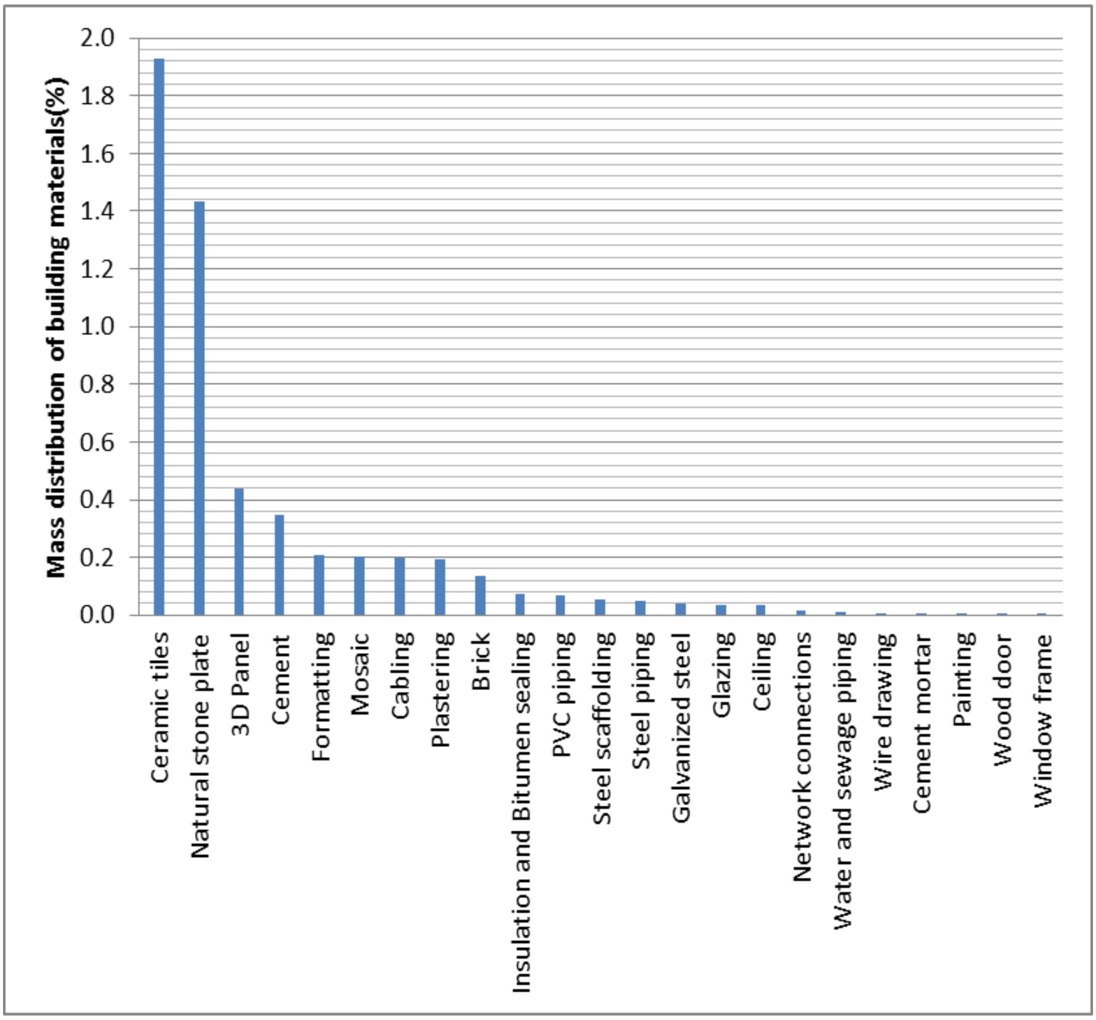

Fig. 4. Mass distribution of building materials (Miscellaneous)

As indicated in Figure 3 and 4, about 81% of the total weight of the input materials to the workplace was concrete. The reinforced concrete slab roof and bars contain 7% and 6.5%, respectively. The lowest used material was Acrylic paint materials (13.33 tons), the wood doors (12 tons) and windows (4.73 tons), respectively.

The life cycle assessment

We applied two methods, including impact assessment of the IPCC approach to estimate the potential global warming and CML baseline method (World 1995) to evaluate the potential of acid raining.

The climate change could have negative effects on ecosystem health, human health, and well-being. The emission of greenhouse to air eventually changes the climate of Earth, causing global warming. Intergovernmental Panel on Climate Change (IPCC), which uses the model describing the relation between greenhouse gases and climate change, has expanded the factors under the title "potential heating of the earth" or GWP (carbon dioxide equivalent kg), of greenhouse gas emissions (kg) for a period of 100 years. These factors have been applied in SimaPro. In 2001, a group of scientist under the supervision of the Center of Environmental Science of Leiden University recommended a classification plan for environmental effects and descriptive methods for the life cycle assessment. This method has the Midpoint attitude by allocating every pollutant to an effect (Such as allocating NO_x to the group of acid raining).

Effects like Abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, photochemical oxidation, and toxicity for human, freshwater and marine, aquatic and terrestrial ecosystem have been assessed in CML method (Product Ecology Consultant, 2013).

Sensitivity analysis

A sensitivity analysis determines the effect of specific parameters on assessment result, finding the parameters with greater effect on the results. The parameters should be reviewed if necessary and modified as changing specific parameters can successfully reduce the environmental impacts (Eriksson, 2012). Since the most commonly used materials in Qom monorail project were (on the basis of the conducted analysis) reinforcing bars, concrete, diesel fuel, and tiles and ceramics, the amount of each parameter abovementioned changed by 20% and the life cycle was reassessed, using SimaPro. Table 3 indicates the changes in these parameters.

RESULTS AND DISCUSSION

In what follows, we summarized the LCA results of Qom Monorail project in the construction phase.

Table 3. ±20% Change of the effective parameters

Parameter	Unit	Primary amount	20% reduction	20% increase
Diesel fuel	MJ	220085213.2	176068171	264102256
Concrete	m^3	147745.8	118196.64	177294.96
Roof	Ton	31500	25200	37800
Reinforcing Steel	Ton	29405.21	23524.168	35286.252
Ceramic tiles	Ton	8778	7022.4	10533.6

Table 4. Global Warming and Acidification Potential of the building materials and their transportation

Material	Global warming (GWP 100) (kg CO_2 eq.)	Global warming (GWP 100) (kg CO_2 eq./km.person[1])	Acidification (kg SO_2 eq.)	Acidification (kg SO_2 eq./km.person)
Reinforcing steel	42747567.29	8618.46	151465.96	30.54
Formatting	1868119	376.64	10119.06	2.04
Steel scaffolding	473461	95.46	1660.197	0.335
Concrete (Portland Cement)	39402361.98	7944.02	64566.53	13.02
Cement mortar	4098.41	0.83	6.614	0.0013
Insulation and Bitumen sealing	397545.9	80.15	2190.408	0.44
Painting	25221.12	5.08	113.42	0.02
Polyethylene	239405.5	48.27	808.095	0.16
Cabling	88239.9	17.79	1356.486	0.27
Wire drawing	66711.71	13.45	457.352	0.09
Steel piping	80182.42	16.17	242.953	0.05
PVC piping	627395.91	126.49	1700.804	0.34
Natural stone plate	1712576	345.28	10206.74	2.06
Ceramic tiles	7177732	1447.12	25454.76	5.13
Mosaic	62418.97	12.58	281	0.06
Cement	1218599	245.69	1681.504	0.34
Plastering	64184.04	12.94	169.1127	0.03
Roof	3360868.36	677.59	21529.52	4.34
Ceiling	43734.45	8.82	135.4205	0.03
Window frame	171877.35	34.65	926.986	0.19
Glazing	311504.84	62.8	3028.022	0.61
Brick	135390.4	27.3	337.7142	0.07
3D Panel	6749130	1360.7	21690.98	4.37
Wood doors	20024.45	4.04	217.5	0.04
Galvanized steel	131613	26.53	856.63	0.17
Diesel fuel	20037875.03	4039.89	154870.91	31.22
Transportatio n system	6082498.56	1226.31	29229.86	5.89
Total	**133300329.3**	**26875.07**	**505304.5**	**101.876**

1. Kg CO_2 eq/ 4960 km.person (transfer 800 passengers per train in the 6.2km railway)

1. Global Warming Potential (GWP) Assessment

A Global Warming Potential (GWP) is a tool to measure the amount of heat, which is trapped by a certain amount of greenhouse gases at ground level, based on time periods of 20, 100, and 500 years in kg CO_2 eq. We considered the potential of the 100-year period. Figure 5 indicates the share of each of the parameters of Qom monorail in global warming.

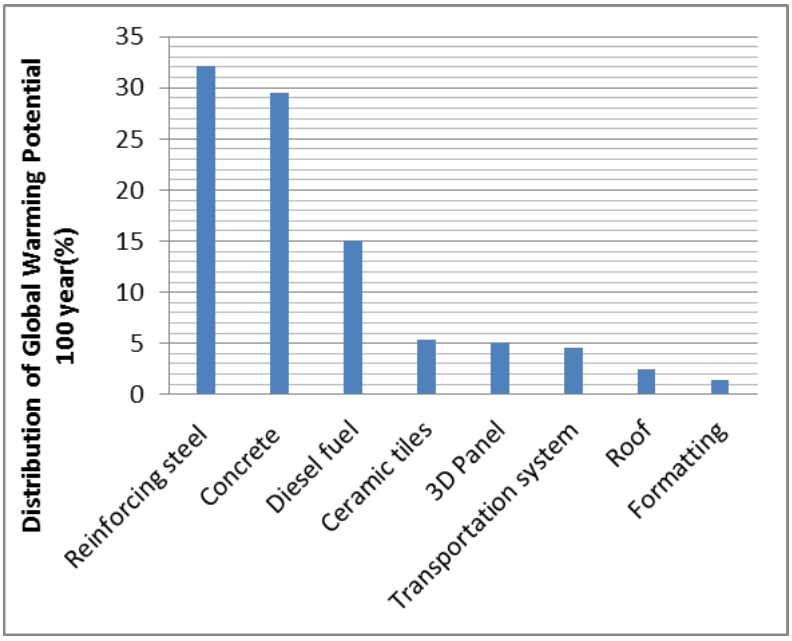

Fig. 5. Distribution of GWP 100a among various building materials and transport system (Major elements)

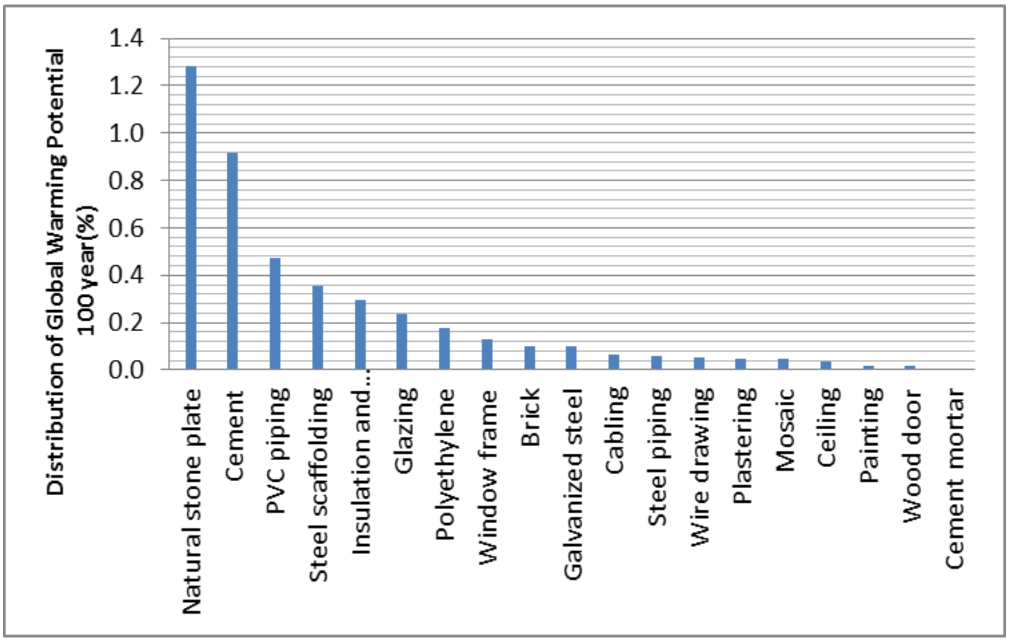

Fig. 6. Distribution of GWP 100a among various building materials and transport system (Miscellaneous)

As indicated in Figures 5 and 6, the maximum global warming potential belongs first to reinforcement bar operations with the 8618.46 kg CO_2 eq. / km.person, followed in the second place by concrete, producing 7944.02 kgCO_2eq./km.person, as well as diesel fuel (15%), ceramics and tiling (5.4%), the panel 3D (5%), transportation of equipment (4.6%), roof implementation (2.5%), and preparation of concrete mold (1.4%) in the third to eighth places, in terms of global warming potential index. The lowest GWP also belongs to the cement mortar with a rate of 0.83 kg CO_2 eq./km.person.

Potential of creation of acid rain

The most important acidic pollutants include SO_2, NO_X, HCl, and NH_3 (Banar et al., 2009). These emissions create acidic rain and utrification. The acid materials widely influence the soil, surface water, groundwater, organisms, ecosystems, and buildings (Valderrama et al., 2012). Figures 7 and 8 illustrate the contribution of spent materials and fuel in the creation of acid rain in Qom monorail project throughout its construction.

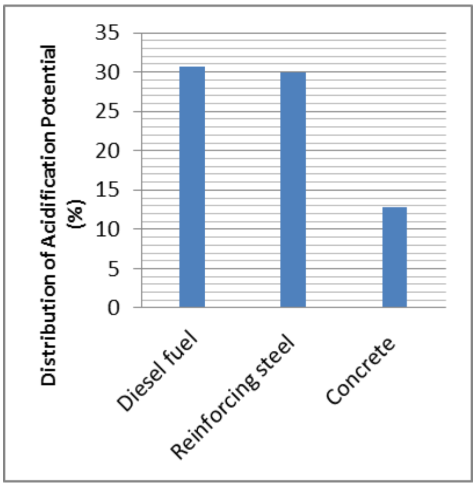

Fig. 7. Distribution of AP among various building materials and transport system (Major elements)

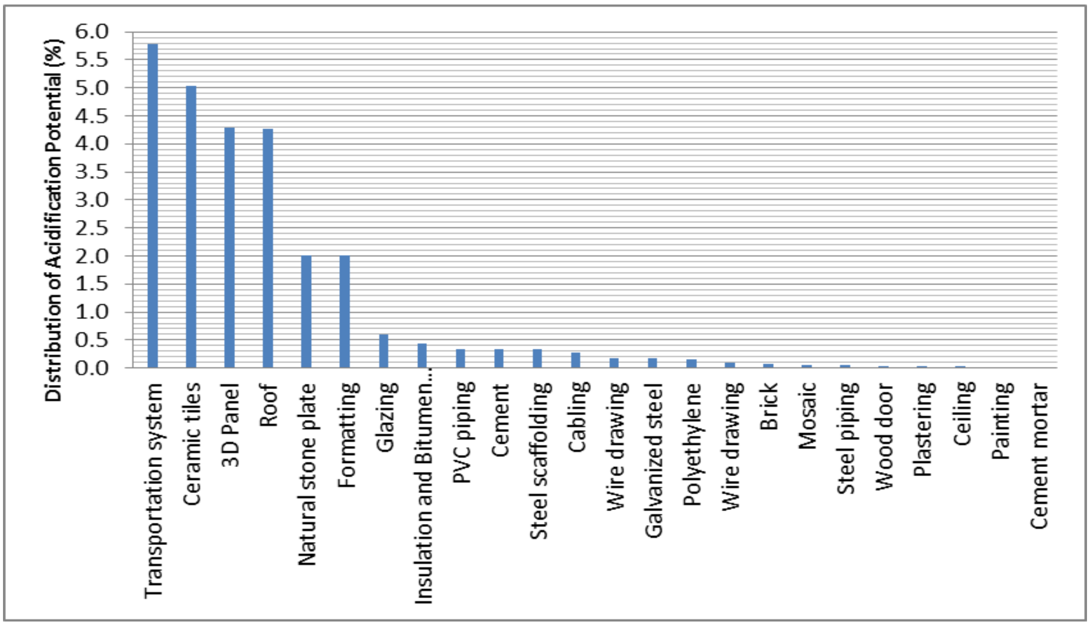

Fig. 8. Distribution of AP among various building materials and transport system (Miscellaneous)

As presented in Figures 7 and 8, the consumption of diesel fuel with an emission of 31.22 kg SO_2 eq./km.person, steel reinforcement with an emission of 30.54 kg SO_2 eq. /km.person, and concrete with the an emissions of 13.02 kg SO_2 eq./km.person had the greatest influence on the creation of acid rain. Cement mortar had the minimum effect with an emission of 0.0013 kg SO_2 eq./km.person.

The validity of study

Rankin (2011) estimated the amount of CO_2 emissions from coal power to produce 1kg of steel, which was 2.3 kg CO_2 eq./kg. Berge (2009) stated that 1 kg of concrete (cement Portland), cement mortar, and polystyrene produced 0.18 kg CO_2 eq., 0.19 kg CO_2 eq., and 3.5 kg CO_2 eq., respectively.

Concrete Centre in Great Britain as well as the potential for CO_2 emissions from reinforced concrete, concrete, and steel produced 0.115 kg CO_2 eq., 0.095 kg CO_2 eq., and 1.932 kg CO_2eq. (BCA CSMA UKQAA[1], 2008) respectively. To find the accuracy of global warming results via Sima Pro 7.1, the proportion of global warming Potential of some of the materials, used in this project, was compared to the study of Concrete Centre in Great Britain (for steel and concrete) along with Berge's study (for cement mortar and polystyrene applied in 3D panels) and is presented in Table 5.

The greatest difference of GWP between this study and the others is probably due to the kind of fuel, consumed in steel production of different countries. The amount of emitted pollution for various fuels in industries varies (Table 6).

To find the accuracy of acid rain potential results via Sima Pro 7.1, we can use Building for Environmental and Economic Sustainability method (BEES), which describes the potential of acid raining, in accordance to mole H^+. This potential in CML2000 method is described in accordance to kg SO_2 eq. Table 7 and Figures 9 and 10 indicate the assessment results along with the distribution percentage of potential of acid raining via BEES method.

Table 5. Comparison of the SimaPro 7.1 results with other studies

Material	Calculated GWP 100a by SimaPro (kg CO_2/kg)	GWP of British Cement Association and Berge study (kg CO_2/kg)	Difference (%)
Concrete	0.11	0.115	7
Steel	1.45	1.93	24
Cement mortar	0.195	0.19	2.6
Polystyrene	3.4	3.5	2.86

Table 6. The amount of emitted pollution of various fuel uses (Berge, 2009)

Fuel type	CO_2 (g/MJ)	SO_2 (g/MJ)	NO_X (g/MJ)
Oil	75	0.18	0.1
Natural gas	55	0	0.04
Coal	91	0.2	0.15
Petroleum coke	103	0.36	0.15

The table does not include emissions from extraction and transportation of the fuels, where about 15% should be added (Berge, 2009)

1. British Cement Association, Cementitious Slag Makers Association, UK Quality Ash Association

Table 7. AP of the building materials and their transportation using BEES

Material	Acidification potential (H^+ mole/kg.Person)	Material	Acidification potential (H^+ mole/kg.Person)
Reinforcing steel	1666505.27	Cement	21286.25
Formatting	101842.9	Plastering	1878.70
Concrete	826570.71	Roof	254453.30
Cement mortar	82.38	Ceiling	1655.96
Insulation and Bitumen sealing	22102.14	Window frame	11166.66
Painting	1191.44	Glazing	32096.02
Polyethylene	8497.70	Brick	4183.09
Cabling	12958.99	3D Panel	223292.10
Wire drawing	4468.59	Wood door	2606.92
Steel piping	2547.87	Galvanized Steel	8909.43
PVC piping	19568.37	Diesel fuel	2228200.85
Natural stone	142859.55	Transportation system	414617.49
Ceramic tiles	271685.25	Steel scaffolding	17556.15
Mosaic	3607.21	Total	6306391.28

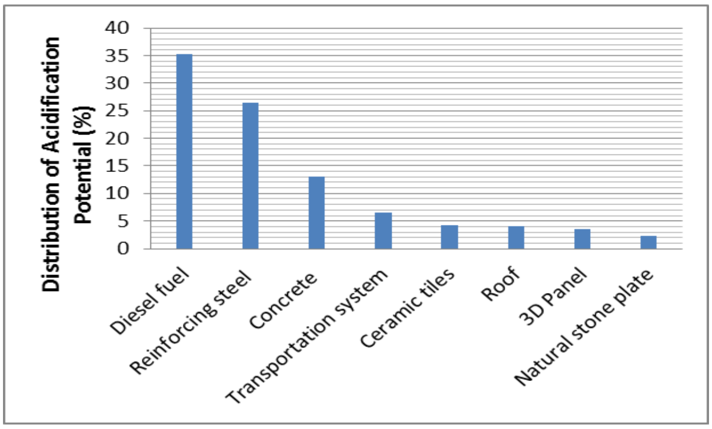

Fig. 9. Distribution of AP among various building materials and transport system by BEES method (Major elements)

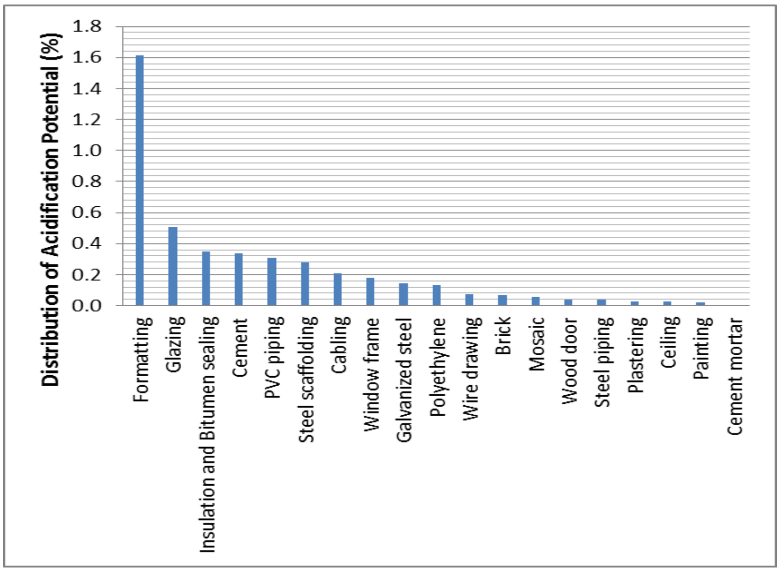

Fig. 10. Distribution of AP among various building materials and transport system by BEES method (Miscellaneous)

Table 8 compares Figures 9 and 10. By applying both methods, i.e. BEES and CML2000, the proportion of various segments of the project with potential of acid raining are approximately the same. In both methods, diesel fuel consumption, steel reinforcement, and concrete have the most potential of acid raining.

Sensitivity analysis

Figures 11 and 12 illustrate the 20% increase and 20% decrease in effective parameters.

Table 8. Comparison of AP distribution results between CML and BESS method

Material	AP distribution percentage (%) by CML method	AP distribution percentage (%) by BESS method
Diesel fuel	30.65	35.33
Reinforcing steel	29.98	26.43
Concrete	12.78	13.11
Transportation system	5.78	6.57
Ceramic tiles	5.04	4.31
3D Panel	4.29	3.54
Roof	4.26	4.03
Natural stone	2.02	2.3
Formatting	2	1.61
Glazing	0.6	0.51
Insulation and Bitumen sealing	0.43	0.35
PVC piping	0.34	0.31
Cement	0.33	0.34
Steel scaffolding	0.33	0.28
Cabling	0.27	0.21
Window frame	0.18	0.18
Galvanized steel	0.17	0.14
Polyethylene	0.16	0.13
Wire drawing	0.09	0.07
Brick	0.07	0.07
Mosaic	0.06	0.06
Steel piping	0.05	0.04
Wood door	0.04	0.04
Plastering	0.03	0.03
Ceiling	0.03	0.03
Painting	0.02	0.02
Cement mortar	0	0

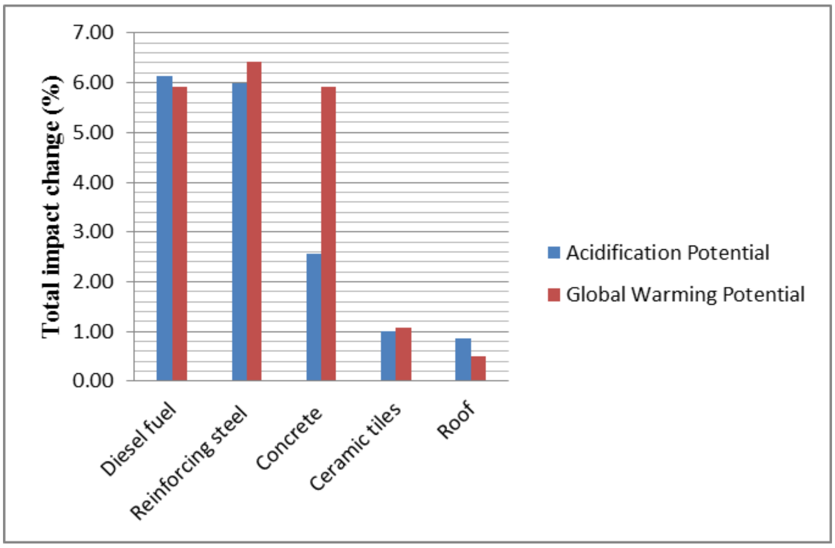

Fig. 11. The 20% increase in affective parameters (Major elements)

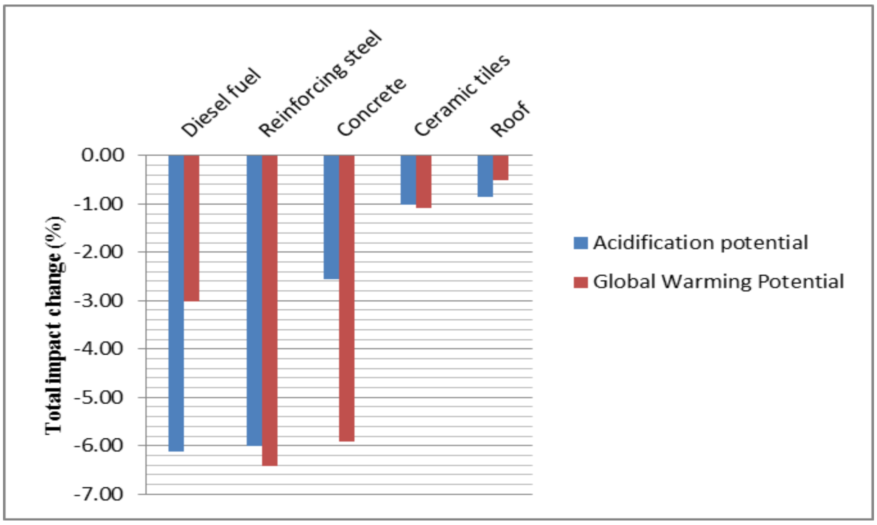

Fig. 12. The 20% decrease in affective parameters (Major elements)

Sensitivity analysis shows that the first effective parameter in LCA results is the amount of reinforcement bar. By reducing 20% of the reinforcement bar consumption, we can reduce the potential of acid raining and global warming by 6%. It is also obvious that 20% reduction in the amount of diesel fuel, due to Qom monorail construction, can reduce the potential of acid raining and global warming by 6% and 3% respectively. The 20% reduction in concrete can also reduce the potential of global warming by 6%.

CONCLUSION

The following results were obtained from Qom monorail LCA in terms of potential of both acid raining and global warming, via Sima Pro 7.1:

1. The potential of global warming in the construction phase for a period of 100 years was equal to 26875.07 kg CO_2eq./km.person. Reinforcement bar with 32%, concrete with 30%, and diesel fuel with 15% had the major part in causing global warming.
2. The potential of acid raining was equal to 101.876 kg SO_2eq./km.person based on CML2000. The greatest potential of acid raining belonged to diesel fuel with 31%, reinforcement bar with 30%, and concrete with 13%.
3. We compared the results of Sima Pro 7.1 with Berge's study and Concrete Centre in Great Britain study, finding out that in most cases the result of the software was reliable (e.g. the amount of GWP, obtained for concrete, cement mortar, and polystyrene differed only 2 to 7% from their study), but in some cases (e.g. steel production) a significant difference existed between the software's results and those of other studies, due to various kinds of the fuel and workplace conditions; therefore, creating a reliable database for various industries can increase the authenticity of life cycle assessment results.
4. The results indicated that the proportions of various segments of the project with potential of acid raining are the approximately same in CML2000 and BEES. Both of them showed that diesel fuel, steel reinforcement, and concrete had the most potential of acid raining.
5. The results of sensitivity analysis illustrated that the first and second effective parameters on the results were the amount of reinforcement bar and diesel fuel. It also showed that by reducing 20% of reinforcement bar consumption, concrete, and consumable fuel in this

project can reduce both of potential of acid raining and global warming for 3 to 6%. Therefore, reduction of reinforcement bars, concrete, and diesel (in order) have the most effect in the mitigation of global warming and acid raining effects of Qom Monorail Project.

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