A STUDY ON ENERGY CONSUMPTION AND CARBON FOOTPRINT OF ASPHALT AND CONCRETE MIXTURES

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ABSTRACT:

Moving into the future, the world is becoming increasingly focused on sustainable industrial policies and sustainable consumption and production. All sectors of industry will need to take action to reduce their environmental impacts and to achieve a more sustainable use of natural resources and energy. The highways community will need to develop a better understanding of the factors affecting the sustainability of roads and use this to develop design, production and construction and maintenance strategies appropriate for this new reality. Therefore asphalt and concrete industry as the parts of road sector have started to find their contribution to sustainability regarding energy consumption and carbon footprint in terms of the amount of greenhouse gases produced. This study will examine the key factors affecting pavement sustainability, including energy consumption, resource use and greenhouse gas and other emissions. It will analyze real data for energy consumption and whole life carbon footprint of asphalt and concrete mixtures including the production of their components such as aggregate, bitumen and cement. It will, in particular explore the effects on energy consumption when switching between alternative fuels such as fuel oil and natural gas. Recognized protocols such as the asPECT calculator prepared by TRL in UK will be used as the basis for determining carbon footprint.

Keywords: Energy consumption, carbon footprint, bituminous mixtures, concrete mixtures, energy resources, greenhouse gases emissions,

1. INTRODUCTION

In the framework of the policy of sustainable development in the world, All sectors need to take action to reduce their environmental impacts and to achieve a more sustainable use of natural resources and energy. In parallel of the world policy , road industry as a main part of transport sector have started to explore their environmental impacts to find their contribution to sustainability regarding energy consumption and carbon footprint in terms of the amount of greenhouse gases produced. Therefore asphalt and concrete industry as the parts of road sector have started to find their contribution to sustainability regarding energy consumption and carbon footprint in terms of the amount of greenhouse gases produced.

This study examines the key factors affecting pavement sustainability, including energy consumption, resource use and greenhouse gas. It was analyzed real data for energy consumption and whole life carbon footprint of asphalt and concrete mixtures including the production of their components such as aggregate, bitumen and cement. It was, in particular explore the effects on energy consumption when switching between alternative fuels such as fuel oil and natural gas. For the determination of carbon footprint of asphalt and concrete mixtures, asPECT (**as**phalt **P**avement **E**mbodied **C**arbon **T**ool)calculator prepared by TRL in UK was used .

2. ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSION ASSESSMENT FOR ASPHALT AND CONCRETE MIXTURES

The increased environmental awareness and demands of regulations are setting the way of road industry to develop sustainable technologies. The first way to reach the goal is carrying out life cycle analysis to determine environmental impacts. Road sector has already taken a considerable number of environmental measures

This study analyses the contribution to sustainability regarding energy consumption and carbon footprint of asphalt and concrete production as main road materials.

Firstly the principle of asphalt and concrete mixture techniques are analyzed. The entire production process is taken into consideration from the extraction of raw materials to the production plants including the phases of materials manufacturing .

The systematic illustration of the production asphalt and concrete mixture is given in Figure 1.
For greenhouse gas emission assessment for asphalt and concrete mixtures, it is considered GHG emissions from sources including energy use, combustion process, service provision and delivery . The scope of the emission assessment in this study is based on “cradle to gate”. Life cycle of asphalt and concrete mixtures includes the steps indicated in Figure 1.

System boundries of production of asphalt and concrete mixtures

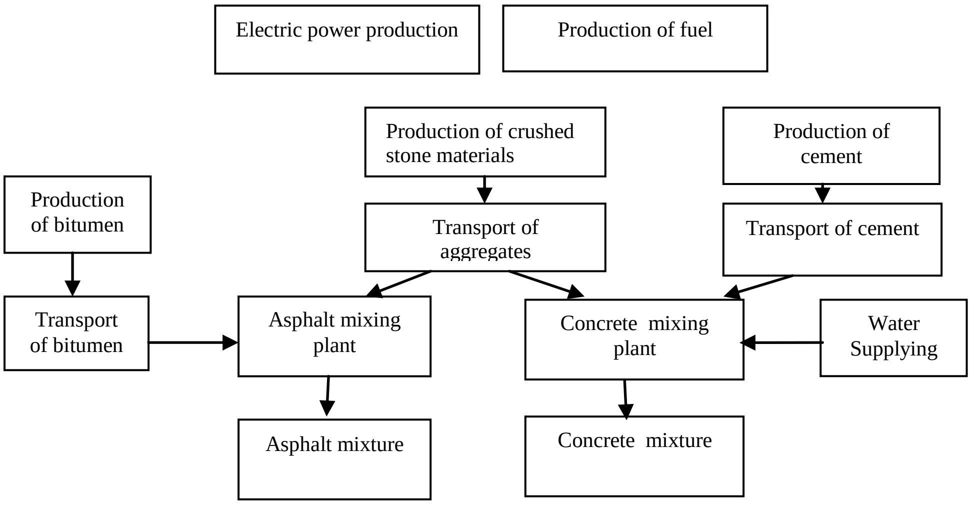


Figure 1: The schematic illustration of production of asphalt and concrete mixtures

The extraction and production of raw materials (oil, natural gas,.) and the manufacturing of constituent materials (cement, bitumen, aggregate ,water..etc) are considered in the analysis.

The asPECT software provides a framework which contains the necessary formulae, emission factors and default data to calculate GHG emissions from the mixtures per ton.

GHG emission assessment is made in terms of carbon dioxide equivalents (CO_{2e}) per ton of the mixtures. CO_{2e} is the measurement unit used to indicate the global warming potential (GWP) of greenhouse gases such as CO_2, N_2O, CH_4. Carbon dioxide is the reference gas against which other greenhouse gases are measured.

The CO_{2e} content of the mixtures is calculated the summation of the following elements:

- "Cradle to gate" CO_{2e} from each constituent materials and all consumables which are used in the production of the final product,
- The transport CO_{2e} from factory gate to plant
- CO_{2e} arising from all forms of energy involved in producing the mixture at the mixing plant, other than that involved in heating and drying .
- CO_{2e} arising from the process of heating and drying the mixture and its constituent materials

CO_{2e} mixture = Constituents CO_{2e} + Transport CO_{2e} +Mix CO_{2e} + heat CO_{2e} (for asphalt mixtures)

- Energy consumption from office and laboratory overheads is not taken into account.
- Grease, lubricating and hydraulic oils are outside of the assessment.

The cradle to gate constituent CO_{2e} of mixture is the summation of the delivered cradle to gate CO_{2e} of the constituent s used to make %100 of the mixture portioned on the basis of mix formulae.

2.1 Constituent materials

From the energy demand for the production of each constituent material, the total energy consumption of producing each material is calculated. The final energy consumption is expressed the combination of different sources and then expressed as a total value of energy necessary for the production of the required amount for the particular material. The cradle to gate CO_{2e} per ton at the source is determined. The CO_{2e} per ton involved in transportation of each constituent material to the mixture plant is calculated separately. The sum of these two is taken as a delivered CO_{2e} for the constituents. In this study , aggregate, bitumen and cement as constituent materials of the mixtures are analyzed below.

2.1.1 Aggregate

Crushed rock is used for asphalt and concrete mixtures. It is included annual usage of energy per type of fuel/energy and electricity used within a quarry for overburden removal, primary extraction, further processing, crushing, screening though to restoration and loading for delivery.

For this case study a single figure for CO_{2e} is derived for each source based on the figures from the previous year.

2.1.2 Bituminous binder and cement

A default cradle to gate CO_{2e} figure for bitumen is provided in the default data taken from Eurobitume published source in 2011 representing of European practices.

A default cradle to gate CO_{2e} figure for cement is taken from the BCA published source in 2009 used in the asPECT. The default data for bitumen and cement are found very close to Turkish practices .

2.2 Future recyclability of the mixture

2.2.1 Asphalt recycling

Asphalt can be fully recycled as asphalt. The future recyclables of the mixtures is reflected in a recoverability rate and also how much the recovered Reclaimed Asphalt Pavement - RAP will need to be supplemented with virgin material in its next life. This indicates its benefit to the next mixture to be reflected in terms of CO_{2e} . The CO_{2e} content of a virgin mixture is calculated to enable the benefits of recycling to be realized. This is done by calculating mixture CO_{2e} after substituting any recycled content for virgin binder and aggregate used in asPECT .

Although, recoverability rate of asphalt reflecting total loss of mass over the life time is fixed at 95% for calculations using asPECT. Future CO_{2e} content of processed RAP assumed equal to that of recycled aggregate specified in Defra Document set at 4 kg CO_{2e} /ton. It is anticipative that recycled aggregates and RAP will undergo a similar level of reprocessing.

Future CO_{2e} ,embodied carbon of mix constituents, is calculated taking into account their potential to be recycled into future asphalt mixtures ,and calculated by using the following equation;

Future CO_{2e}= virgin mix CO_{2e}- (95% x ((bitumen% x190) + ((100%-bitumen5) x 5,9 x 1.05)- 4)) kg CO_{2e}/ton
The factor of 1,05 is reflected the loss of virgin aggregate due to moisture and wastage.

2.2.2 Concrete recycling

Once concrete has been mixed, cement cannot be extracted from it for recycling. Concrete is broken down into aggregate for use in a new life. This new life is usually road works as aggregate, but in some areas it is also used as aggregates in new concrete. Recovering concrete has no appreciable impact on reducing greenhouse gas emissions. In the product life cycle of concrete, the main source of carbon emissions is the cement production process .The cement in concrete cannot be viably separated and reused or recycled into new cement, and thus carbon reductions cannot be achieved by recycling concrete.

2.3 Processing energy at the plants and water use in the concrete mixture

All electricity and fuel used at the plants for mechanical processing in previous year are taken into account to calculate CO_{2e} . The total GHG emissions are calculated by summation of the GHG emissions associated with each fuel by converting fuel consumption to CO_{2e} . Additionally all main water used in the plant operations and in the concrete mixtures are considered to calculate CO_{2e} by multiplying the amount of water used with the CO_{2e} factor for supplying water . CO_{2e} content of supplied water used in asPECT is 0,55 kg CO_{2e} /kg.

2.3.1 Heating and drying energy at asphalt plant

The energy involved in heating and drying is different for different mix types (High and low temperature mixtures) and moisture content of aggregate .This protocol enables the CO_{2e} for drum-mix plant and batch plant separately.Production rate for the drum mix plant and heating time for the batch plant are taken into consideration.

2.3.2 Transportation

Transport of constituent materials from source to the asphalt plant is considered to calculate transport CO_{2e} emissions by using the most appropriate "grand total GHG emissions factor in Defra document . The distance traveled is include the return journey to the first point of loading. The default assumption is for diesel use and the return journey empty.

3. PRIMARY DATA USED FOR CALCULATING CARBON FOOTPRINT BY MEANS OF asPECT

3.1 The data for energy sources

The data for energy sources such as electricity and fuels are taken from national greenhouse gases inventory .
In this framework, Constant conversion factors for main energy sources, electricity, fuel-oil, diesel natural gas are given Table-1.

Table 1: Conversion factors for main energy sources

	Grid electricity Grand total CO_{2e} kg/kWh	**Fuel-Oil, CO_{2e} kg/ton**	**Diesel CO_{2e} kg/lt**	**Natural gas CO_{2e} kg/m^3**
Converting factor	0,518	3207,7	2,646	1,981

3.2 Binders data

A default cradle to gate CO_{2e} figure for bitumen and cement is given below provided in the default data used in asPECT software . Eurobitume default data for bitumen and BCA,CSMA,UKQAA default data for cement are taken into consideration:
For bitumen; 190 kg CO_{2e}/ton,
For cement; 930 kg CO_{2e}/ton .The data for cement is on the basis of only CO_2 emission.

3.3 Data for aggregate

The figure for cradle to gate CO_{2e} is derived from the aggregate producer in Istanbul. The collected data for the previous year is given in Table-2 for electricity, fuel , explosive used by types such as ANFO,TNT and emulsion, mains water, fuel for drills, breakers, excavators, bulldozers, loaders truck ..etc. used with, a quarry for overburden removal , primary extraction and further processing and screening through to restoration and loading for sale. Since it was not carried out site restoration works , it is not taken into account for calculation.

Table 2: Data for aggregate derived from the aggregate producer in Istanbul

Aggregate Source: Quarry A	
Annual saleable tonnage	824000
Electricity, kWh	2065000
Other fuel ,diesel, lt	855800
Water usage, lt	2400
Site works-Explosive, kg: - Nitro - Emulsion - ANFO	 12440 160000 207000
Overburden removal, diesel, lt	8000

All annual consumables and total kg CO_{2e} by fuel , electricity, explosive and water calculated are illustrated in Figure 2.

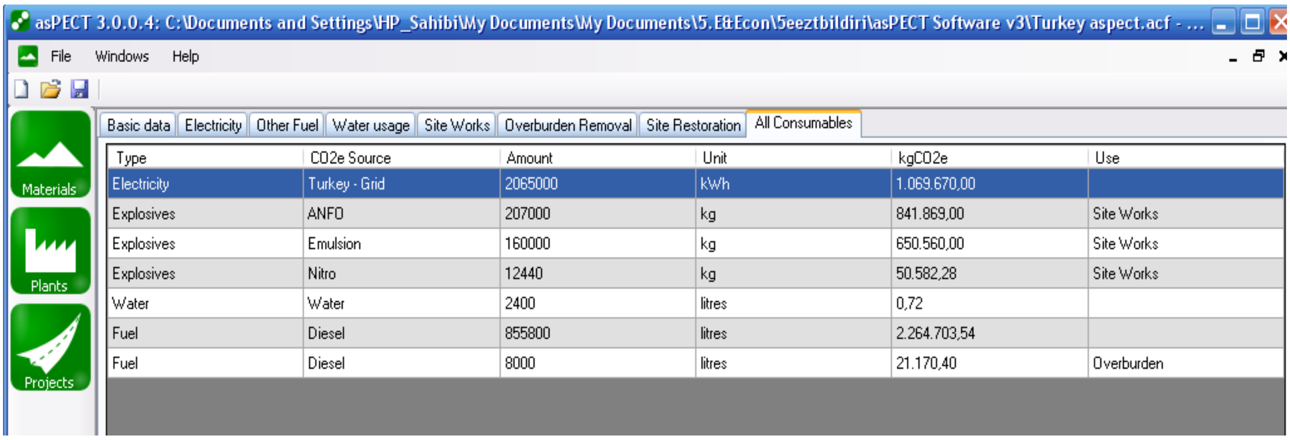
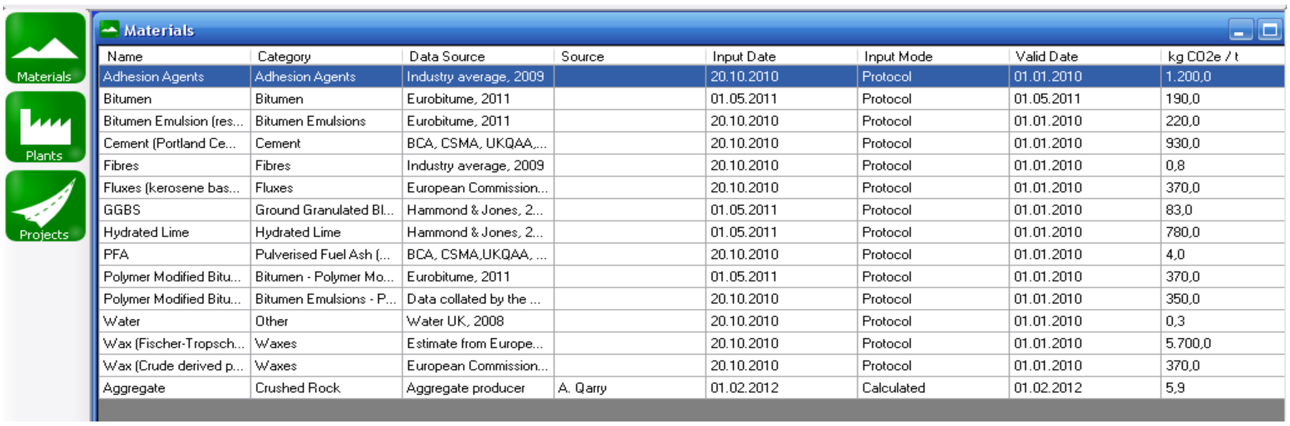


Figure 2: All consumable and total kg CO_{2e} for aggregate production in 2010

Cradle to gate CO_{2e} kg/ton aggregate calculated from the input energy is 5,9 given in the Figure 3.Figure 3 shows kg CO_{2e} per all of the materials possibly used in the mixtures.


Materials

Plants

Projects

Materials

Name	Category	Data Source	Source	Input Date	Input Mode	Valid Date	kg CO2e / t
Adhesion Agents	Adhesion Agents	Industry average, 2009		20.10.2010	Protocol	01.01.2010	1.200,0
Bitumen	Bitumen	Eurobitume, 2011		01.05.2011	Protocol	01.05.2011	190,0
Bitumen Emulsion (res...	Bitumen Emulsions	Eurobitume, 2011		20.10.2010	Protocol	01.01.2010	220,0
Cement (Portland Ce...	Cement	BCA, CSMA, UKQAA,...		20.10.2010	Protocol	01.01.2010	930,0
Fibres	Fibres	Industry average, 2009		20.10.2010	Protocol	01.01.2010	0,8
Fluxes (kerosene bas...	Fluxes	European Commission...		20.10.2010	Protocol	01.01.2010	370,0
GGBS	Ground Granulated Bl...	Hammond & Jones, 2...		01.05.2011	Protocol	01.01.2010	83,0
Hydrated Lime	Hydrated Lime	Hammond & Jones, 2...		01.05.2011	Protocol	01.01.2010	780,0
PFA	Pulverised Fuel Ash (...	BCA, CSMA,UKQAA, ...		20.10.2010	Protocol	01.01.2010	4,0
Polymer Modified Bitu...	Bitumen - Polymer Mo...	Eurobitume, 2011		01.05.2011	Protocol	01.01.2010	370,0
Polymer Modified Bitu...	Bitumen Emulsions - P...	Data collated by the ...		20.10.2010	Protocol	01.01.2010	350,0
Water	Other	Water UK, 2008		20.10.2010	Protocol	01.01.2010	0,3
Wax (Fischer-Tropsch...	Waxes	Estimate from Europe...		20.10.2010	Protocol	01.01.2010	5.700,0
Wax (Crude derived p...	Waxes	European Commission...		20.10.2010	Protocol	01.01.2010	370,0
Aggregate	Crushed Rock	Aggregate producer	A. Qarry	01.02.2012	Calculated	01.02.2012	5,9

Figure 3: Default data for cradle to gate CO_{2e} footprint of the constitutional materials

The default data calculated for aggregate (5,9 CO_{2e} kg/ton) are taken into consideration for both of asphalt and concrete mixtures**.**

3.4 Data for processing energy and water used at the mixture plants.

3.4.1 Asphalt plant

Data for the year of 2010 was collected 2 different types of plants. One of them is batch type and the other is drum-mix plant operated in Istanbul . Both of them consumed natural gas for heating and drying. In the batch type plant, 3 different types of mixtures used surface, binder and base courses were produced. In the drum -mix plant , the asphalt concrete mixture for base courses was produced in 2010. The data for these mixtures taken into consideration for calculation of GHG emissions of asphalt are given in Table 3.

Additionally the data is collected from asphalt producers for batch type asphalt plants consuming fuel oil for heating and drying process .The average figure given in Table 4 are taken into account for calculation.

Table 3: Data for asphalt plants consumed natural gas for drying and heating

Plant name	**Asphalt Plant, used natural gas for drying and heating**			
Plant type Heating time, s Production rate, t/h	Batch 300 260			Drum-mix - 150
Mixture type	AC for surface	AC for binder	AC for base	AC for base
Mixture composition: ▪ Aggregate content % ▪ Bitumen content %	 95,5 4,5	 95,9 4,1	 96,6 3,4	 96,5 3,5
Production in 2010 ,ton	106015	44037	13048	93099
Total annual production , ton	163100			93099
Electricity, kWh	40790			18620
Other fuel, diesel, lt	163161			89375
Water usage, ton	1825			1095
Heating and drying , natural gas m^3	1060547			558594
Material transport to plant - Aggregate, Rigid >17t, km itumen, Articulated vehicle>3,5-33t, km	 10 100			 10 100

Table 4: Data for asphalt plant used fuel oil

Batch type asphalt plant consumed fuel-oil for heating and drying	
Heating time, s Production rate, t/h	300 160
Mixture type	AC surface course
Mixture composition: ▪ Aggregate content % ▪ Bitumen content %	 95,5 4,5
Annual production , ton	100000
Electricity, kWh (3,24kWh/ton)	324000
Other fuel, Diesel, lt (0,9l/ton)	90000
Heating & Drying, fuel-Oil, ton (Aggregate moisture content: 4%; 7 kg fuel oil /ton)	 700
Material transport to plant - -Aggregate, Rigid >17t, km -Bitumen, Articulated vehicle>3,5-33t, km	 10 100

3.4.2 Concrete plant:

Data on the basis of 2010 production was collected from the concrete plant operated in Istanbul and additionally the general data for production of concrete as national average figure was taken from Turkish Ready Mix Concrete Association. All data used in the calculation are illustrated in Table 5.

Table 5: Data for concrete plant

Plant name	**Concrete plant in Istanbul**	**Concrete Plant (based on general data)**
Production rate , t/h	280t/h (~120m^3/h)	240 t/h (~100m^3/h)
Mixture type	C25/C30	C20/30
Mixture composition by weight: ▪ Aggregate content % ▪ Cement content % ▪ Water content %	 79 14 7	 81 12 7
Total annual production , ton	454600	100000
Electricity, kWh	1300.000	250000
Other fuel, Diesel, lt	450000	100000
Water usage for mixture, ton	34.550	7000
Material transport to plant - Aggregate, Rigid >17t, km Bitumen, Articulated vehicle>3,5-33t, km	 10 100	 10 100

4. THE RESULTS FOR ALL CONSUMABLES AND GHG EMISSION OF THE CASE STUDY

All consumables and total kg CO_{2e} for heating and non heating process for batch and drum mix asphalt plant operated with natural gas are given in Table 6

Table 6: All consumables and total kg CO_{2e} for heating and non heating process for batch and drum mix plant operated with natural gas

	Batch Plant			**Drum-mix plant**		
	Fuel Type	**Amount**	**kg CO_{2e}**	**Fuel Type**	**Amount**	**kg CO_{2e}**
Heating consumption	Natural gas	1,060547 m^3	2100944	Natural gas	556594 m^3	1106574
Non heating consumption	Electricity-Grid	40790 kWh	21130	Electricity-Grid	18620 kWh	9645
	Diesel	163161lt	431773	Diesel	89375 lt	236513
	Water	1825 lt	0,55	Water	1095 lt	0,33

All consumables and total kg CO_{2e} for heating and non heating process for batch type plant used fuel-oil are given in Table 7.

Table 7: All consumables and total kg CO_{2e} for heating and non heating process for batch type plant used fuel-oil

	Batch Plant (Moisture content of aggregate; %4)		
	Fuel Type	**Amount**	**kg CO_{2e}**
Heating consumption	Fuel oil	700 ton	2213610
Non heating consumption	Electricity-Grid	340000 kWh	176120
	Diesel	90000 lt	238167

The summary of the amount of annual asphalt production , total and average energy consumption and GHG emissions as kg CO_{2e} for the asphalt plants are calculated and illustrated in Table 8.

Table 8: The summary of the amount of annual asphalt production , energy consumption and total and average kg CO_{2e} for the asphalt plants

Asphalt plant type/fuel	Batch /Natural gas	Drum- Mix / Natural gas	Batch /fuel –oil at 4 % aggregate moisture content
Annual asphalt production, ton	163100	93099	100000
Annual energy consumption, kWh	12174263	6443568	9557100
Total annual kg CO_{2e}	2553846	1352733	2627897
Average energy consumption, kWh/ton asphalt	74,6	69,2	95,57
Average kg CO_{2e}/ton asphalt	15,66	14,53	26,28
Material defined	2	2	2
Mixture available	3	1	1

All consumables and kg CO_{2e} for concrete plants are given in Table 9.

Table 9: All consumables and kg CO_{2e} for concrete plant

	A Concrete plant in Istanbul		**Concrete Plant (based on general data)**	
Consumption	Amount	kg CO_{2e}	Amount	kg CO_{2e}
Electricity-Turkey grid	1300000 kWh	673400	250000 kWh	129500
Fuel- Diesel	450000 lt	1190835	100000 lt	264630
Water	34550 lt	10,37	7000 lt	2,10

Energy consumption and the amount of CO_{2e} per ton concrete are calculated and shown in Table 10

Table 10: Energy consumption and the amount of CO_{2e} per ton concrete

	A concrete plant in Istanbul	**Concrete Plant (based on general data)**
Annual concrete production, ton	454600	100000
Annual energy consumption, kWh	5811111	1252455
Total annual kg CO_{2e}	1864235	394130
Average energy consumption, kWh/ton concrete	12,78	12,52
Average kg CO_{2e}/ton concrete	4,1	3,94
Material defined	2	2
Mixture available	1	1

Total amount of CO_{2e} as kg per ton asphalt and concrete including GHG emissions for virgin materials and transport besides plant operations are given in Table 11 and Table 12.

Table 11: kg.CO_{2e} per ton asphalt

	CO_{2e} kg/ton asphalt				
Fuel type for Dry & Heat	**Natural gas**				**Fuel - oil**
Plant type	**Batch Type Plant**			**Drum-mix Plant**	**Batch Type Plant**
Course	AC surface	AC binder	AC base	AC base	AC surf. at 4 % moisture
Virgin mix	14,51	13,78	12,49	12,67	14,51
Material transport to plant	3,39	3,31	3,17	3,19	3,39
Energy dry and heat	12,88	12,88	12,88	11,89	22,14
Energy mix/ other	2,78	2,78	2,78	2,64	4,14
Sub total	**33,56**	**32,75**	**31,32**	**30,39**	**44,18**
RAP saving	3,37	3,09	2,59	2,66	3,37
Total	**~30**	**~30**	**~29**	**~28**	**~41**

Table 12: kg CO_{2e} per ton concrete

	CO_{2e} kg/ton concrete	
	A Concrete Plant –C25/30	Concrete Plant –based on general data
Aggregate	4,66	4,78
Cement	130,2	111,6
Water	0,002	0,002
Material transport to plant	5,59	5,11
Energy mix/ other	4,10	3,94
Total	**145**	**125**

As a conclusion; All of the GHG emissions results calculated by asPECT are shown in Figure 4.

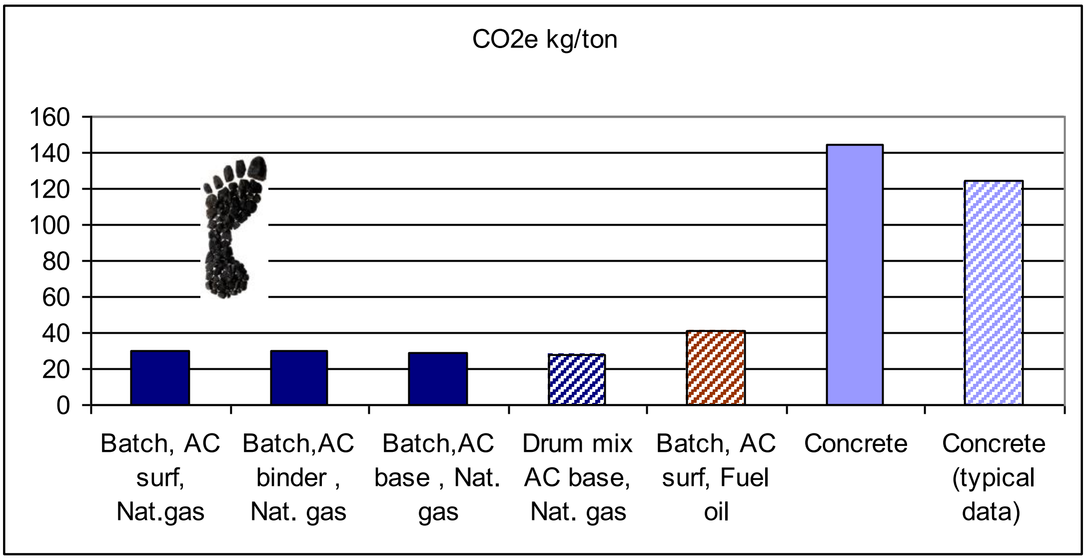


Figure 4: GHG emissions of asphalt and concrete mixtures

5. CONCLUSION

In this study, it was analyzed real data for energy consumption and whole life carbon footprint of asphalt and concrete mixtures including the production of their components such as aggregate, bitumen and cement. It was particularly explored the effects on energy consumption when switching between alternative fuels such as fuel oil and natural gas. For the determination of carbon footprint of asphalt and concrete mixtures, asPECT (**as**phalt **P**avement **E**mbodied **C**arbon **T**ool)calculator prepared by TRL in UK was used

The result obtained from this study lead to following conclusion;

- For asphalt mixtures ;
  - If fuel oil used for drying and heating operation for asphalt production, GHG emissions is 41 kg CO_{2e} /ton asphalt , in the case of natural gas, kg CO_{2e} per ton asphalt is about 30 . It is clear that natural gas has a direct effect in reduction of carbon footprints generated by asphalt plants . In this case study, 27 % reduction in GHG emissions was obtained by using natural gas for asphalt production.
  - Two main processes responsible to GHG emissions are binder manufacture and mix production, Approximately 25% of total GHG emission is derived from bitumen production. If it is used natural gas in the plant for drying and heating operation, the amount of GHG emissions generated by asphalt plant is about 16 kg CO_{2e} /ton asphalt . For the usage of fuel - oil , the GHG emissions is about 26 kg CO_{2e} /ton asphalt at 4 % moisture content of aggregate .
  - When it is compared batch type plant with drum –mix (continuous) type regarding energy consumptions and GHG emissions , it is found out that it is not significant difference between the plants.
- In the case of concrete mixtures :
  - Average GHG emissions is about 135 kg CO_{2e} /ton concrete.
  - The main process responsible to GHG emissions is cement manufacturing. Approximately 90% of total GHG emission is due to cement. The amount of GHG emissions generated from plant operation is about 4 kg CO_{2e} /ton concrete
- The average GHG emissions of concrete is about 4,5 times higher than that of asphalt, if natural gas is used for the production of asphalt .For the usage of fuel-oil in the asphalt plant, GHG emissions of concrete are about 3.2 times higher than that of asphalt. In every case, the results show that asphalt mixtures have far lower carbon footprint. This means that asphalt mixtures as road pavement material are the more sustainable choice.
- These results give a general overview on the asphalt and concrete production on a national scale in Turkey. They are about 20 % lower than that of European declared values.
- asPECT software was designed to be used easily by asphalt producers and contractors who have found detailed information required to operate this tool. Data can be easily gathered through typical company accounting systems.
- As road materials, in particular at least 95 % of asphalt pavement is either reused in new asphalt pavements or recycled as unbound materials used base courses, the binder containing in the RAP used in new mixtures is not considered as being lost. So if recycling is considered, the carbon footprint of asphalt mixture would be further reduced. On the contrary, reclaimed concrete can not be used as concrete, so there is no effects on reduction of GHG emissions. In essence, when road is paved with asphalt, it could be assumed that the aggregate and bitumen are laid up to be used like virgin materials by future generation.
- A great deal of attention should be given to limit the consumption of energy resources such as oil and shifted to low carbon energy resources such as natural gas.
- These results give a general overview on the asphalt and concrete production on a national scale in Turkey . it is important to notice that every road construction project should be assessed individually. So the owner of the project and road materials' producers and contractors should choice the best sustainable material for their construction.

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