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ASSESSING CARBON DIOXIDE (CO_2) OF EARTHWORKS' OPERATIONS DURING ROAD CONSTRUCTION

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ABSTRACT:

Climate change became one of the most important issues facing the global community. Transportation is considered one of the major factors affecting on climate change specially road sector. This can be caused by emissions of roads' construction, use and maintenance. These emissions can be assessed by using environmental Life-Cycle Assessment (LCA) approaches. The fundamental objective of this paper is to assess the emissions of earthworks during roads construction. A case study from Egypt was selected to perform this study. The paper presents the methodology that will be followed for developing tools for assessing carbon dioxide emissions (Co_2) during earthwork construction of roads. The preliminary analysis confirmed the necessity of the classification of the construction activities in order to develop energy and emissions models. Further analysis looked at the differences between machines used in each activity and significant differences were found between the activities of work according to earthwork masses, leveling, compaction and transportation activities. This tool is very useful and can be used in the design stage to evaluate the Co_2 emissions and compare between the different alternatives to select the most proper alternative from the environmental prospective.

الملخص:

اصبح التغير المناخى من اهم القضايا التى تواجه المجمتع العالمى. ويعتبر النقل أحد العوامل الرئيسية التي تؤثر على تغير المناخ خاصة قطاع الطرق. ويمكن أن ينجم ذلك عن انبعاثات انشاء الطرق واستخدامها وصيانتها. ويمكن تقييم هذه الانبعاثات باستخدام نهج تقييم دورة الحياة البيئية (LCA). تم اختيار دراسة حالة من مصر لأداء هذه الدراسة. وبناءا عليه فإن الهدف الأساسي من هذا البحث هو تقييم انبعاثات ثانى اكسيد الكربون من الاعمال الترابية لانشاء الطرق. ويعرض البحث المنهجية التي سيتم اتباعها لتطوير أداة تقييم انبعاثات الأعمال الترابية أثناء تشييد الطرق. وأكد التحليل الأولي ضرورة تصنيف أنشطة البناء من أجل تطوير نماذج الطاقة والانبعاثات. كما وجد ايضا ان هناك فروق بين الآلات المستخدمة في كل نشاط من الانشطة المختلفة ، و اختلافات كبيرة بين أنشطة العمل مع كميات الاتربة ، التسوية والدمك والنقل. ويعد الاسلوب المقترح مفيد جدا ويمكن استخدامه في مرحلة التصميم لتقييم انبعاثات ثاني أكسيد الكربون والمفاضلة بين البدائل المختلفة للتصميم من المنظور البيئى.

Keywords: Climate Change - Road Construction - Life-Cycle Assessment (LCA) – Earthworks- Emission - Co_2

1. INTRODUCTION

Currently, Egypt has many running engineering projects. Almost of these projects are classified under the transportation sector. Upgrade road network is the most important issue to the stakeholders in Egypt. The Central Agency for Public Mobilization and Statistics (CAPMAS) announced that the road networks length in Egypt reached to 175,000 km in 2015/2016.

So the transportation sector should have the responsibility to make significant strategies achieving eco-friendly techniques and technologies to face one of the most urgent environmental issues facing the global community, such as climate change resulting from human activities.

Today, no sector can afford to ignore the ecological repercussions of its activities and the growing potential for enhancing positive, while reducing negative, impacts. As shown in Figure 1, the transportation is the fourth source of energy related emissions or about 14% of total Green-House Gas (GHG) emissions.

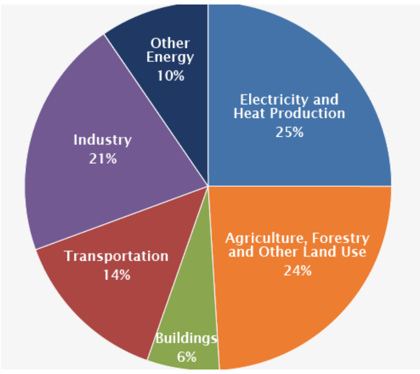

Figure (1) GHG emissions by sectors [1].

Alongside other industries, the road sector should develop an array of emission assessment tools, as part of this endeavor and as an effective way to help translate into reality the low-carbon transportation strategies to be decided by governments [2].

The main aim of this research is to assess the embodied Co_2 emissions resulting from road earthworks. These emissions were studied in relation to the fuel consumption of the construction's machines.

In order to accomplish the main goal of this work, the following objectives were set:

- To review the relation between energy consumption and Co_2 emission during road construction.
- To select and collect the necessary geometric data, construction techniques, equipment used in construction and construction activity data.
- To present the methodology that will be followed for developing tool that assesses earthworks emissions for the case study.
- To estimate the fuel consumption and carbon emissions.
- To compere between the different alternatives to select the most proper alternative from the environmental prospective.

2. LITERATURE REVIEW

Assessing emissions (related to the roads across its life cycle) can be achieved by dividing this cycle to stages such as planning, design and construction…etc.

There are several steps involved in road construction, which contribute to the production and release of (GHG) emissions, beginning with site clearing, preparation of the sub-grade, production of construction materials (i.e. granular sub-base, base course, surfacing), site delivery, construction works, ongoing supervision, maintenance activities…etc. The aggregate GHG emissions for each project (phase, section, alignment) can be calculated depending on equipment, local condition, and standard construction and maintenance practice in a country [3].

For most construction activities, emissions embodied in building materials during manufacture represent the largest proportion. When the quantities of these materials are known, it is simple to apply embodied carbon dioxide coefficients to arrive at a total emissions value for the activity. Most currently adopted methods use standard, academically derived data from the Inventory of Carbon and Energy (ICE) [4].

The embodied Co_2 of construction activities emitted from three components as following:

1- Manufacture of construction materials.

2- Transporting construction materials, labors and plants to/from site.

3-Construction's equipment during construction.

Several previous studies were summarized as in the following substance

- Hughes et al. [4], studied the carbon dioxide from road earthworks. According to their study, they found that most construction materials have reasonably standardized production processes and can use carbon dioxide coefficients to calculate Co_2 but the use of published coefficients is usually not appropriate when calculating for earthworks operations. Co_2 should be calculated by estimating the machinery requirements for the necessary movements, the fuel used by the machinery and the subsequent Co_2 emitted from combustion of fuel.
- Hughes. [5], raised some issues with regards to the use of the ICE data and Highways Agency Carbon Accounting Tool for soil, for clay and sand when calculating the Co_2 of earthworks operations. It reports high Co_2 figures associated with earthworks. The study gives a comparison (for the A421 Highway Improvement), between the Highways Agency Carbon Accounting Tool which reported a carbon footprint of 82,660 ton attributed to 197,751 m^3 of excavated clay and its earthworks tool which reported a carbon footprint of 99 ton attributed to 197,751 m^3 of clay.
- Ghazy et al. [6], listed some basic data about energy consumption rates of road construction machines as shown in Table 1. These rates were based on the Egyptian operating conditions.

Table (1): Machinery energy Consumption [6].

Machine	Energy Consumption
Grader	80 liter /1000 m^2 (Solar)
Heavy vibratory roller	20 liter /1000 m^2 (Solar)
Rubber tire roller	20 liter /1000 m^2 (Solar)
Asphalt paver	40 liter /1000 m^2 (Solar)

- Krantz. [7], studied the relationship between energy consumption and greenhouse gas emissions in road construction project and developed a model for Co_2 emissions. The model had some important knowledge that worth this research such as the methodology of calculating the Co_2 emissions and the schematic model for earthworks in road construction projects as shown in Figure 2.

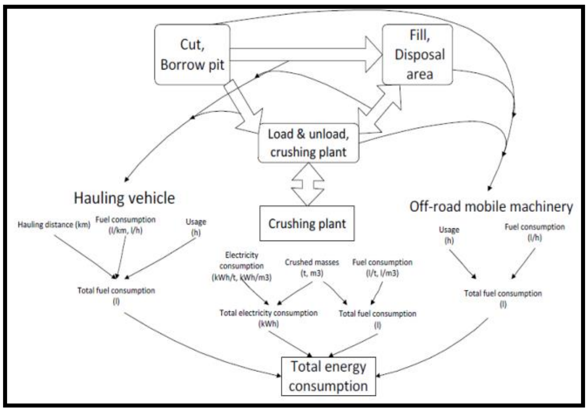

Figure (2) Model of the basic activities, flows and the machines [7].

- Younes et al. [8], work on developing road's LCA tool (EGY-LCA). Figure 3 shows the suggested framework of EGY-LCA tool; but the suggested framework did not include the earthworks; which are considered the first phase of road construction and this framework should be for the pavement operations (flexible pavement).

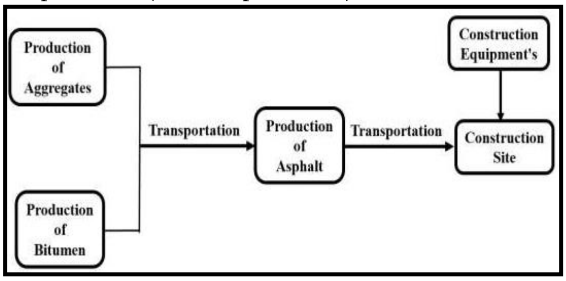

Figure (3) Suggested framework of EGY-LCA tool: Construction phase [8].

Finally, because of the climate change issues, understanding the Co_2 resulting from infrastructure projects became progressively critical. It is key that the Co_2 related to the infrastructure project is accurately evaluated to guarantee the components in charge of the Co_2 are distinguished and followed up on. Accurate modeling of the embodied Co_2 of earthworks operations will ensure the correct amount of Co_2 attributed to the earthworks part of projects.

3. CASE STUDY

This case study is a part of one of the running projects in Egypt. The case study is the development of the Al Wahat- El Frafra existing road in the Western Desert of Egypt, which connects Bahariya Oasis and El- Frafra Oasis, this road is two-way, two-lanes with 11 m width. The development of this road (as shown in Figure 4, 5) will consist of the following:

- Construction of three lanes with 3.5m width for each one, in addition to shoulder with 1.5m width.
- Rehabilitation of the existing road, adding one more lane.

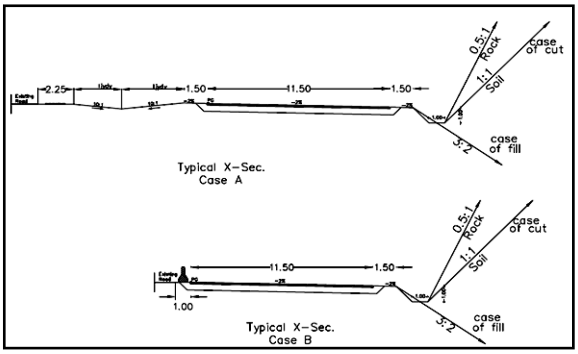

Figure (4) typical cross section

Figure (5) Earthwork operations from site**.**

Finally, the road will be divided road with 3 lanes in each direction.

The case study focuses on the final part of this road as the embankments and earthworks operations are being in construction. This part starts from station 136+000.00 to station 143+521.83 with a length of 7.521 km. The quantities and distances are being obtained from the Civil 3D program and are the basis for the calculations of fuel consumption. Total earthworks' quantities can be summarized in table 2.

Table (2): Cut and fill quantities

Length (Km)	Cut Volume (m^3)	Fill Volume (m^3)	Base & Sub Base (m^3)
7.521	8,228.51	167,954.52	45,130

4. METHODOLOGY

The methodology depends on calculating fuel consumption of the construction equipment's during activities involved in the earthwork operations. The earthworks' activities divided to the following 3 majors' activities:

- Cutting and filling activities.

- Levelling and compacting activities.
- Transportation activities.

These activities, various sub-activities and equipment used in each project may change from project to another because of differences between construction materials, ground conditions, quantities of the earthworks and availability of construction equipment.

The calculations will be divided according to the 3 major activates. This method can be used when it seems difficult to obtain the fuel consumption of the construction equipment used during construction.

4.1. Cutting and Filling Activities

Moving masses and loading haul vehicles are considered primary usage for wheel loaders and excavators. Figure 6 and Equations 1 show the proposed methodology used in calculating the fuel consumption for cutting and filling machines.

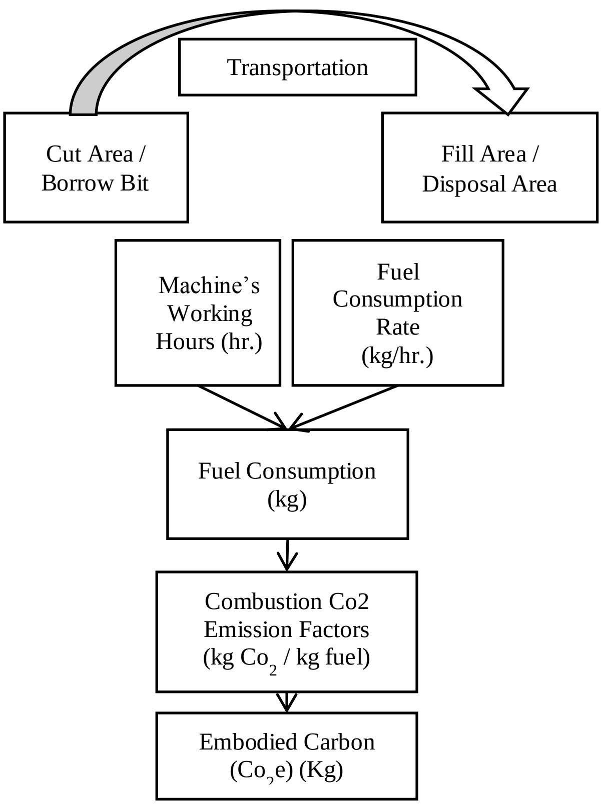

Figure (6) Energy model frame work of cutting and filling activities

The total working hours of cutting and filling machines can be calculated from the Equation 1[9]

$$W\,(hr.) = \frac{Q\,(m^3)}{M\,(m^3/hr)} \qquad \textbf{Equation 1}$$

where:

W = Machine Working Hours;
Q = Earthworks Quantity; and
M = Machine Productivity;

4.2. Levelling and Compacting Activities

This part associates with machines that work with the surface of the road and could move masses such as graders and rollers.

Figure 7 shows the proposed frame work used in calculating the fuel consumption of the machines that work with surfaces.

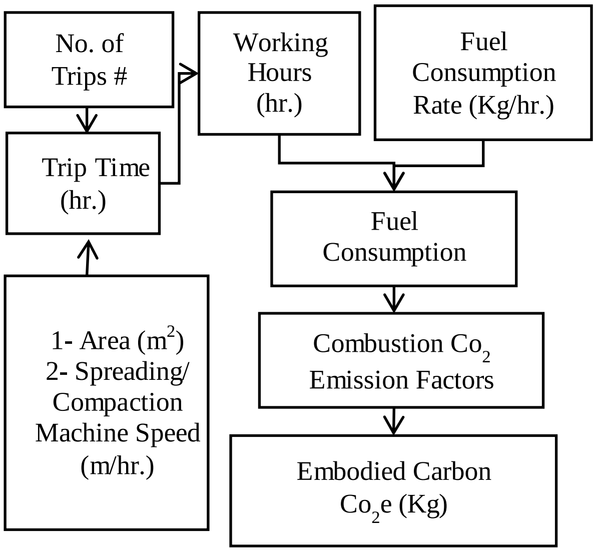

Figure (7) Energy model frame work of Levelling & Compacting activities

No. of trips is the number of compaction trips that achieve field density > 95% from the laboratory density.

The working hours of leveling and compaction machines can be calculated from the Equation 1

4.3. Transportation Activities

This part associates with construction materials' transportation. Figure 8 shows the proposed frame used in calculating the fuel consumption for the martial transportation.

The working hours of the dump truck can be calculated from the Equation 1.

The cycle time of the transportation truck is the summation of loading, unloading, traveling and return time.

The cycle time's fractions depend on the following:

- The capacity (ton).
- Loading machine rate (ton/hr.).
- Distance (m).
- Transportation truck Speed (m/hr.).

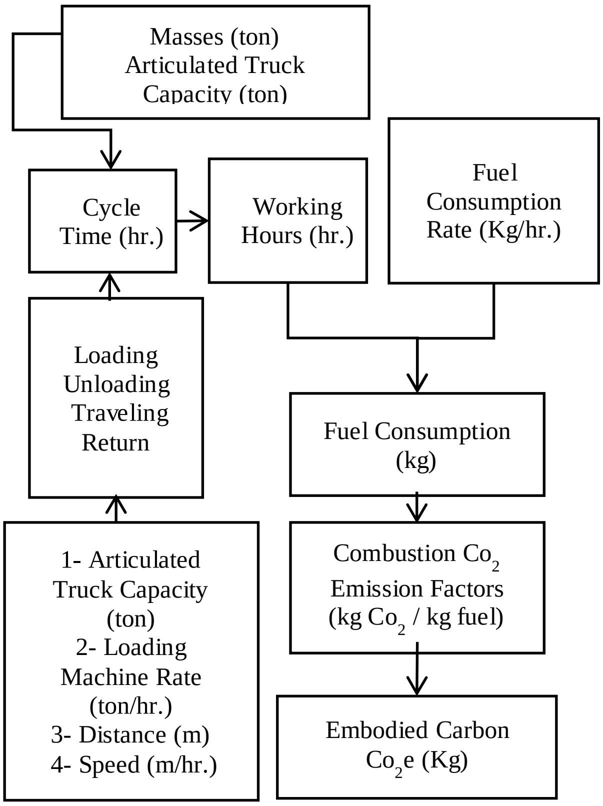

Figure (8) Energy model frame work of transportation activities

After getting machine's working hours, the total fuel consumption can be calculated from Equation 2 [7]:

$$\textbf{F.C(kg)} = \textbf{W(hr.)} \times \textbf{PI (kw)} \times \textbf{LF} \times \textbf{BF (kg/kw.hr)}$$

Equation2

Where:
F.C = Fuel Consumption;
W = Machine Working Hours;
PI = Machine's Power Interval;
BF = Break Fuel Consumption Rate; and
LF = Load Factor

The power interval is depending on the machine's engine type. The break fuel consumption rate of the engine is depending on the power interval as follows:

- BF (130-560 kW) = **254** g/kw.hr.
- BF (75-130 kW) = **260** g/kw.hr.

These values were derived from the emission inventory guidebook [10].

J. Krantz [7] listed load factors (LF) as a function of machine type and power interval as shown in Table 3.

Table (3): Load factors as a function of machine type and power interval [7].

Machine type	75-130 kW	130-560 kW
Bulldozer	0.58	0.58
Drill rig (diesel)	0.43	0.43
Excavator	0.40	0.40
Backhoe loader	0.21	0.21
Wheel loader	0.48	0.48
Road roller	0.59	0.59

4.4. Fuel Conversion to Embodied Emission

When the total fuel consumption quantity of the construction machines and transportation vehicles are known, it can be translated to embodied emissions by applying fuel conversion coefficients. Emission factors for GHG Inventories contain a wide range of fuel conversion coefficients used for GHG emissions estimation as shown in Table 4 [11].

Table (4): Mobile combustion Co_2 factors [11].

Fuel Type	**kg Co_2 / unit**	**Unit**
Aviation Gasoline	8.31	gallon
Biodiesel (100%)	9.45	gallon
Compressed Natural Gas	0.0545	scf (standard cubic foot)
Diesel Fuel	10.21	gallon
Ethane	4.05	gallon
Ethanol (100%)	5.75	gallon
Jet Fuel (kerosene type)	9.75	gallon

5. RESULTS AND DISCUSSION

This section presents the output date of the developed tool and the conversion of fuel consumption to carbon emissions during road construction (specifically earthwork phase).

Table 5 shows the construction machines used in the various construction activities and computed fuel consumption from the calculation tool. The detailed calculations' tables can be found in Annex 1.

Table (5): Activities of the earthworks operation

Location	Activity	Construction Plant	Fuel Consumption (kg)
Earth cut			
Earth cut	Loosening / loading	Loader CAT 980	2,351
Earth fill	Transport	Articulated Hauler A40	2,295
Earth fill			
Borrow Bit	Loading	Loader CAT 980	45,641
To filling Areas	Transport	Articulated Hauler A40	74,374
Earth fill	Receiving	Bulldozer CAT D7	37,328
Earth fill	Levelling	Motor Grader	10,296
	Compacting	Road Roller 16 tons	145,831
Base & Sub-Base			
Crushing Plant	Loading	Loader CAT 980	13,140
Road Line	Transport	Articulated Hauler A40	49,114
fill	Receiving	Bulldozer CAT D7	10,030
Final	Leveling	Motor Grader	4,118
	Compacting	Road Roller 16 tons	58,332

Table 6 shows the summary of the machines fuel consumption used in various construction activities. Where:

- ➢ The conversion factor for emission (Co_2) is 10.21 kg Co_2/ gallon. From table (4)
- ➢ The density of fuel = 0.83 kg/litter [12].
- ➢ 1 gallon= 3.78 litters.
- ➢ The fuel cost is 3.65 LE/ litter according to the fuel prices in Egypt at the end of year 2017 which is mean 4.40 LE/ kg.

Table (6): summary of the machines fuel consumption

	Case Study			
	Fuel Consumption (kg)	Fuel Consumption (Gal)	Emitted Co_2 (Ton)	Fuel Cost (LE)
Earthwork	241,448	75,042	766	1,063,720
Base & Sub-Base	85,891	26,695	273	378,399
Transport	125,783	39,093	399	554,148
Total	**440,598**	**136,938**	**1,398**	**1,996,267**

Figure 8 and 9 show the Co_2 breakdown by the contribution from the machinery used and the transportation of materials.

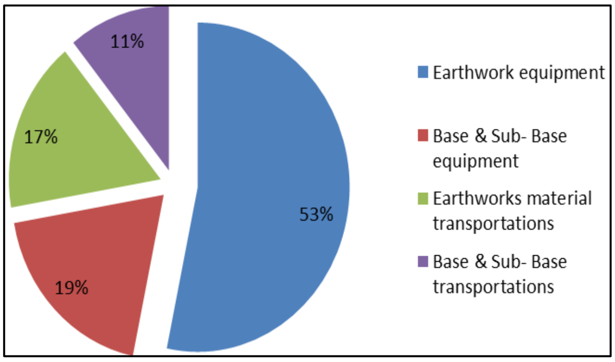

Figure (8) Co_2 associated with case study

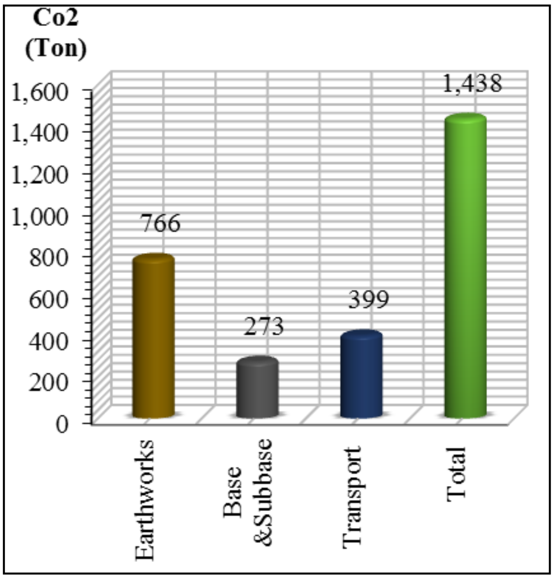

Figure (9) Co_2 results of case study

From Figure 8, 9; it is noticed that Co_2 from earthworks is the highest quantity because of the total earthworks were fill. The filling operations such as receiving, spreading and compaction of filling material take more time than cutting operations, however Co_2 from transportation is considered a mix of Co_2 emitted from transporting earthwork and base & sub base materials.

Also, transportation Co_2 is lower due to the fill material imported from borrowing bits close to the site,

The average distance between the borrow bit and road line was 5 km for earthworks.

The average distance between the crashing plant and road line was 25 km for base & sub base.

<u>Alternatives Study</u>

In this section there is a new alternative was set. The proposed option is the same horizontal alignment and has different vertical alignment. In this alternative, the design level is lower than the case study design level by 1 m. Table 7 summaries the earthwork quantities.

Table (7): Summary of scenarios under consideration

Options	Cut m^3	Fill m^3	Imported material m^3	Exported material m^3
Case study	8,228	167,954	159,725	0
Option 1	57,280	51,670	0	5,610

Figure 10 shows the Co_2 breakdown of the case study and propped option

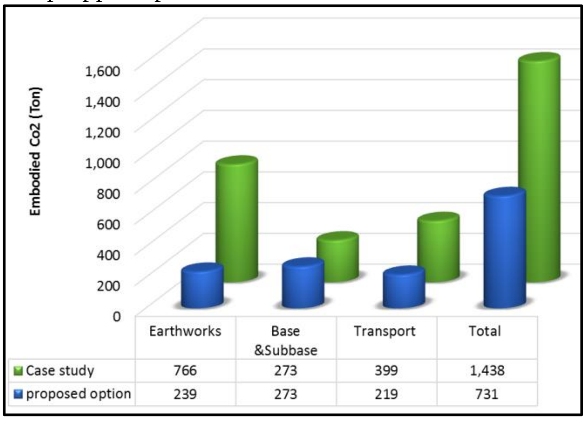

Figure (10) Co_2 results of case study.

From Figure 10, the case study and the proposed option, Co_2 is the same for both during Construction sub base and base layer; also Co_2 from transportation is the same for both.

In the proposed option, Co_2 is lower due to the decreasing in earthwork quantities which were almost balanced, earthworks construction will be done in the road line and Co_2 from transportation is lower than the case study.

6. SUMMURY AND CONCLUSIONS

This work aimed to estimate the carbon emission associated with road construction. A case study from Egypt was selected. It was the development of the Al Wahat- El Frafra existing road in the Western Desert of Egypt. From the detailed analysis of the collected data, the research conclusions can be drawn as follows:

1- Road construction has significant environmental impacts because of the GHG emissions.
2- Carbon dioxide (Co_2) emissions are evaluated and calculated for a case study in Egypt, including raw materials acquisition, transportation, and construction processes. The total Co_2 emission of the 7.521 km long earthwork construction in Bahariya - El Frafra road project is 1,438 Ton.
3- It was found that road earthwork construction causes the most of the emissions, with a contribution to the overall impact. Reduce the earthwork quantities will help decrease the carbon emissions.
4- This tool can be used in the design stage after calculating the total earthworks; finishing mass haul diagram, and setting the construction management plan (CMP).
5- The developed tool's structure is depending on the type of the construction activity and the used plant in the construction process, this will allow users to choose the degree of detail assessment.
6- The developed tool will be useful to the decision makers in Egypt to improve performance of road construction. It is necessary to concern the benefit provided by this kind of models that assessing the various designed alternatives of roads according to environment, time and Cost effective.
7- The developed tool could be a part of LCA tool which will be used for estimating the environmental impacts. It can be useful for various related studies in order to show the importance of using these tools to be applied widely.

7. RECOMMENDATION

However, this study achieved its main objectives and goals, there is always a chance to improve and expand knowledge. There are many recommendations and future research as follows:

1- It is recommended that further research should be conducted on pavement operations during road construction. And in other projects in different places in Egypt to adequate the study findings and be capable of estimating the GHG emissions associated with road constructions.
2- The developed methodology was conducted to estimate the Co_2 emissions for roads earthwork through construction phases only. So, future research should be carried out to estimate the Co_2 emissions through all stages of roads life cycle (design, construction, operating, maintenance and end of life).
3- It is recommended that optimizing the earthwork quantities and transportation distances which can be useful for reducing the Co_2 emission.
4- It is recommended that studying the replacement of natural martial with recycled and secondary in road embankments construction to reduce landfill pressures and quarrying demands.

5- It is recommended that studying processes of natural martial production such as aggregate crushing.
6- It is recommended that studying the difference between using static crusher and mobile crusher plant to optimize the transportation distance.
7- It is recommended that searching for another source alternatives of energy instead of fuel such as electricity or natural gas for the crusher and the construction equipment.

8. References

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Annex 1

Location	Quantity (m^3)	Machine capacity (m^3/hr.)	Activity	Construction Plant	Machine working hours (hr.)	PI (machine power) (kW)	LF	BF (kg/kWh)	Fuel Cons (kg)
Earth cut									
Earth cut	8228	100	Loosening / loading	Loader CAT 980	82.28	250	0.45	0.254	2,351
Earth fill	8228	60	Transport	Articulated Hauler A40	138	Fuel Consumption rate 16.60 kg/hr.			2,295
Earth fill									
Borrow Bit	159725	100	Loading	Loader CAT 980	1597	250	0.45	0.254	45,641
To filling Areas	159725	35	Transport	Articulated Hauler A40	4,480	Fuel Consumption rate 16.60 kg/hr.			74,374
Earth fill	167954	120	Receiving	Bulldozer CAT D7	1399	175	.60	0.254	37,328
Earth fill	167954	388	Leveling/	Motor Grader	432	159	0.59	0.254	10,296
	167954	19	Compacting	Road Roller 16 tons	8846.5	110	0.59	0.254	145,831
Base & Sub-Base									
Crushing Plant	45126	100	loading	Loader CAT 980	452	250	0.45	0.254	13,140
Road Line	45126	15.25	Transport	Articulated Hauler A40	3008	Fuel Consumption rate 16.60 kg/hr.			49,114
Base & Sub-Base fill	45126	120	Receiving	Bulldozer CAT D7	376	175	.60	.254	10,030
Base & Sub-Base Final	45126	260	Leveling	Motor Grader	174	159	.59	.254	4,118
	45126	12.74	Compacting	Road Roller 16 tons	3542	110	.59	.254	58,332

Note:

1- Machine capacities were obtained from filed
2- PI (machine power) (*sources: Krantz, J. (2013). "An Earthworks Energy Model for Practical use in Road Construction". M.Sc. Thesis, Department of Civil, Environmental and Natural resources engineering, Luleå University of Technology. Sweden)*