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Measuring the carbon footprint of road construction using CHANGER

Yue Huang[a]*, Bachar Hakim[b1] and Susanna Zammataro[c2]

[a]*Nottingham Transportation Engineering Centre, University of Nottingham, University Park, Nottingham NG7 2RD, UK;* [b]*URS Scott Wilson, 12 Regan Way, Chetwynd Business Park, Nottingham NG9 6RZ, UK;* [c]*International Road Federation, 2 Chemin de Blandonnet, 1214 Vernier, Geneva, Switzerland*

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The road sector is coming under pressure to review current practice and the potential to reduce carbon emissions. The life cycle approach has been accepted as a robust method of measuring carbon footprint. Tools and data-sets have been developed to facilitate the measurement. Among them is the Calculator for Harmonised Assessment and Normalisation of Greenhouse-gas Emissions for Roads (CHANGER) developed by International Road Federation (IRF) and aimed to measure and benchmark the carbon footprint of road construction worldwide. This paper outlines the common methodology of road carbon footprinting, application of results in sustainable construction assessment schemes and resources available to undertake such analysis. Case studies of using CHANGER are provided for a UK trunk road widening, a public–private partnership highway construction in the United Arab Emirates and strategic highway upgrades in India. The CO_2 output of these projects is compared, and an investigation is made to seek the causes of any differences. Finally, advice is provided on carbon measurement of roads and improvements of the IRF's tool.

Keywords: carbon footprint; road construction; CHANGER; life cycle assessment; sustainable construction

1. Introduction

Climate change resulting from human activities is recognised as one of the most urgent environmental issues facing the global community. Today, no sector can afford to ignore the ecological repercussions of its activities and the growing potential for enhancing positive, while reducing negative, impacts. Representing around 15% of global greenhouse gas (GHG) and 23% of energy-related carbon dioxide (CO_2) emissions (OECD 2010), the transport sector clearly has the scope and means to make a significant contribution in terms of championing more eco-friendly techniques and technologies. Alongside other industries, the road sector has developed an array of emission assessment tools, as part of this endeavour and as an effective way to help translate into reality the low-carbon transportation strategies set up by governments.

Carbon footprinting (CFP) is a measure of the carbon dioxide (CO_2) and other GHGs of an activity or product that allows the sources of the impacts to be understood, investigated and managed. Decisions and assumptions have to be made about the nature of the systems being modelled, during which the GHG emissions from each individual process will be quantified and compiled. This can be undertaken for a business-as-usual scenario that establishes an equivalent carbon dioxide (CO_2 equiv.) baseline or for several scenarios for comparison. A business advantage of taking foresighted steps to measure and reduce the GHG emissions of road construction is that more and more international finance institutions are progressively including compulsory GHG emissions assessment in their tendering procedures (IRF 2010).

This paper outlines the common methodology (life cycle approach) of road CFP, application of results in sustainable construction assessment schemes and a computer model (Calculator for Harmonised Assessment and Normalisation of Greenhouse-gas Emissions for Roads, CHANGER) available to undertake such analysis. Case studies of using CHANGER are provided for a UK trunk road widening, a public–private partnership (PPP) highway construction in the United Arab Emirates (UAE) and strategic highway upgrades in India. Results can be valuable to (1) researchers who compare the CO_2 output of these projects and seek the causes of any differences, (2) designers and contractors who want to benchmark their design and construction options and (3) owners of CHANGER, or a similar carbon calculator, who testify the tool's functionality, validate the model and data-sets and, where possible, identify areas for improvement.

2. A life cycle approach – methodology and resources

The life cycle of a road construction can be categorised into four phases as follows. Notably, transport is integrated in all phases, and the maintenance/rehabilitation activities repeat some, or all, of previous phases.

- Raw materials sourcing and products manufacture (e.g. asphalt, concrete);

*Corresponding author. Email: y.huang@nottingham.ac.uk

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- Transport of raw materials to mixing plant, and products to site;
- Construction on site, including machinery use and office hire;
- Maintenance and rehabilitation, including recycling or disposal of unserviceable materials.

The life cycle approach of impact assessment has been accepted by the road industry. This is due to (1) the geographic layout of the road that has wide ecological implications; (2) the nature of road construction that involves cyclic maintenance work during the long service life and (3) the strong influence of road performance on users' cost. Broadly, the techniques required in CFP are similar to those of energy analysis and life cycle assessment (LCA). The international standards for LCA (BS EN ISO14044 2006) provide a framework for LCA practitioners rather than setting rigid rules and prescribing the data-sets to be used. A number of tools and data-sets have been developed over the past decade, for example:

- In 1993–1995, Swedish Environmental Research Institute (IVL) developed a life cycle inventory (LCI) model for road construction and maintenance. The second version was released in 2001 (Stripple 2001).
- In 1996, Technical Research Centre of Finland (VTT) published a comparative LCA study on the environmental impacts of asphalt and concrete pavements (Hakkinen and Makela 1996). Later, in 2001, an LCA model was developed addressing the use of industrial by-products (coal fly ash, blast furnace slag, etc.) in roads (Mroueh *et al.* 2001).
- In 1997–1999, Eurobitume conducted a partial (cradle-to-gate) LCI study on paving grade bitumen (Eurobitume 1999). A new version in 2011 included polymer-modified binder (PMB) and bitumen emulsion (Eurobitume 2011).
- In 2005, an LCA model of road construction using bottom ash from municipal solid waste incinerator was developed by Technical University of Denmark (DTU; Birgisdóttir 2005).
- In 2005–2007, Newcastle University developed an LCA model for the UK asphalt pavements that considered the traffic emissions incurred by road maintenance works (Huang 2007).
- In 2007, Portland Cement Association published the LCI of cement and three concrete products: ready mixed, precast and concrete masonry (Marceau *et al.* 2007).
- Commercial LCA softwares, such as GaBi and SimaPro, are also available with built-in sublicensed databases.

These resources are from different origins and industry sectors, and have different data support and license requirement: some are focused on materials selection; others support the measurement at a project level. To a certain degree, they serve to identify the energy/carbon intensive processes in a road construction, thus enabling the reporting and setting targets for reduction in an effective way. To use these resources, the system boundary, data source and interpretation, and assumptions made, need to be understood.

Compared to full LCA studies, the CFP focuses on the GHG emissions from the process/product, and is thus streamlined to get the results that attract most industry attention by far. Compared to some other emissions such as carbon monoxide (CO) or nitrogen oxides (NO_x) which are process (e.g. combustion) specific, CO_2 emission is product specific in which it is mainly determined by the carbon content of the product (PRé-Consultants 2010). Generally, the energy inputs to a process are in good correlation with CO_2 outputs. The Inventory of Carbon and Energy database (Hammond and Jones 2008) is widely used by the UK industry to measure the embodied (cradle-to-gate) CO_2 of construction products. Nevertheless, the CFP has unique features such as carbon storage in the product (e.g. timber) that needs an assessment method. PAS2050 has provided a standard CFP methodology for the UK goods and services (BSI 2008), although its applicability to the road sector is questionable, in particular due to its exclusion of capital goods, allocation based on economic value and land use conversion factors.

3. Application – sustainable construction assessment schemes

Well-defined targets and indicators, against which companies can measure their activities towards sustainable construction, will facilitate the pursuit for 'green' industries. Schemes that provide such sustainability indicators are available for the transport sector. The Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL) and Greenroads are among these schemes.

3.1 *CEEQUAL*

CEEQUAL developed by the UK Institution of Civil Engineers (ICE), measures the sustainability performance of a civil infrastructure project in 12 areas, a total of 2000 points are allocated to these areas, weighted as follows (ICE 2008):

- Project management – 10.9%
- Land use – 7.9%
- Landscape – 7.4%
- Ecology and biodiversity – 8.8%
- Historic environment – 6.7%
- Water resources and water environment – 8.5%
- Energy and carbon – 9.5%
- Material use – 9.4%

- Waste management – 8.4%
- Transport – 8.1%
- Effects on neighbours – 7.0%
- Relations with local community and other stakeholders – 7.4%

CEEQUAL is usually completed at the end of the design and construction when solid evidence to support the scoring is available. Interestingly, road projects measured by CEEQUAL scored systematically low in the 'energy and carbon' section (Nicholson 2010). An investigation indicated that the low uptake of LCA may be the reason. In addition, LCA also helps to 'tick' some other areas above (e.g. material use, waste management, transport).

3.2 *Greenroads*

This sustainability rating system for road design and construction project was developed by University of Washington and CH2M HILL to quantify the best practice of a road project in the following areas (Muench *et al.* 2011):

- Project requirements – mandatory
- Environment and water – 21 points
- Access and equity – 30 points
- Construction activities – 14 points
- Materials and resources – 23 points
- Pavement technologies – 20 points
- Custom credit – 10 points

The 11 mandatory 'project requirements' are intended to capture the most critical ideals of sustainability. There are 37 'voluntary credits' in five groups, each is assigned a point value (1–5 points) depending on its weighted impacts, for a total of 108 points. In addition, Greenroads allows a project to create and use 'custom credit', subject to approval by Greenroads, for a total of up to 10 points. It is noted that LCA is required by both the 'project requirements' (mandatory) and 'materials and resources' section. Road authorities, design consultants and contractors may wish to use CEEQUAL or Greenroads point values or certification levels for new build projects, or as metrics by which they can measure and manage their sustainability efforts, that are either voluntary or prescriptive. As seen from above, the LCA (full or carbon) results are identified as one of the areas to gain credits.

4. Overview of CHANGER

CHANGER was developed by the International Road Federation (IRF) and the first version was released in November 2009. The model is being developed with a view to elaborate an IRF standard and certification. The goal of this tool is multifaceted (Zammataro *et al.* 2011):

- To facilitate an environmental analysis of road projects;
- To provide a basis for the comparative analysis of various road laying techniques and materials;
- To optimise site supply schemes with respect to the choice of suppliers, delivery locations and transport modes;
- To enable an estimation of the carbon footprint of road construction activities.

The tool development, in partnership with Ammann, Colas and Scott Wilson (now URS), undertakes an iterative approach that includes data sourcing, initial analysis, feedback to data provider and revisit the calculation, in accordance with ISO 14044. The tool takes into account a range of emission sources during project life, and analyses at a project level to benchmark the carbon footprint per kilometre of road construction. The data-sets and the calculation have been validated by the Traffic Facilities Laboratory (LAVOC) of the Swiss Federal Institute of Technology (EPFL; Bueche and Dumont 2009).

CHANGER adopts a typical process-based modelling approach (Figure 1). The calculation model is based on a set of equations that enable accurate estimation of overall GHG emissions (outputs) generated by each identified and quantified source (inputs; IRF 2007). Data will be sourced for the following activities:

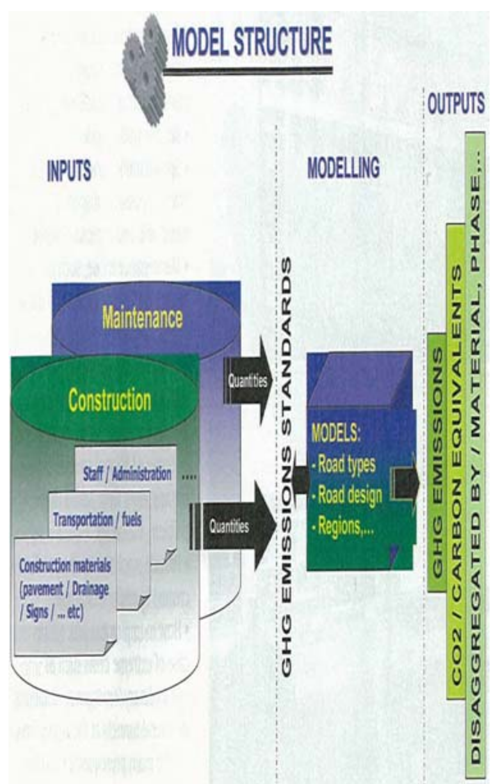


Figure 1. Model structure of CHANGER.

- Preconstruction: site clearance, cut and fill, deforestation;
- Onsite energy (electricity, fossil fuels) consumption;
- Materials quantity;
- Transport mode and distance;
- Construction vehicles and equipments.

The carbon footprint of road projects comes mainly from three sources: (1) materials' embodied carbon dictated by the type and quantity, i.e. the manufacture and upstream processes, commonly referred to as 'cradle-to-gate' where the ICE data (Hammond and Jones 2008) is used by CHANGER, which is multiplied by the quantity of each type of material; (2) carbon from transport vehicles that bring raw materials/products to plant/site (Figure 2) or unserviceable materials to a place of disposal (e.g. recycling, stockpile, landfill). UK Department for Environment, Food and Rural Affairs (Defra) has standard emission factors for an array of payloads and fuel types (Defra/DECC 2008), which is multiplied by tonnage and distance and (3) carbon from construction activities (e.g. excavation, paving, rolling) that are calculated either for each individual process (Stripple 2001) or for a paving assembly as a whole (ECRPD 2010), which is multiplied by dimension/quantity of the field work.

The effects of three GHGs have been considered in the calculation: carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), all converted to the CO_2 equiv., using conversion factors provided by the Intergovernmental Panel on Climate Change (IPCC 2007). A detailed description of CHANGER can be found on the IRF website: http://www.irfghg.org/index.php. The current version of the model does not include maintenance activities, provision and powering of street lighting, road signs and barriers, and impact associated with traffic using the road. The model does not account for the loss of CO_2 absorption by removal of trees or other land use change. CHANGER generates reports, either aggregated (total) or disaggregated (inherent to one or more steps of the process), that can be exported to Excel, Word, PDF and HTML.

5. Case studies

Materials' embodied carbon varies among countries due to the difference in materials sourcing and energy mix. Similarly, transport requirements and site activities are dependent on where the road is built. The CHANGER has

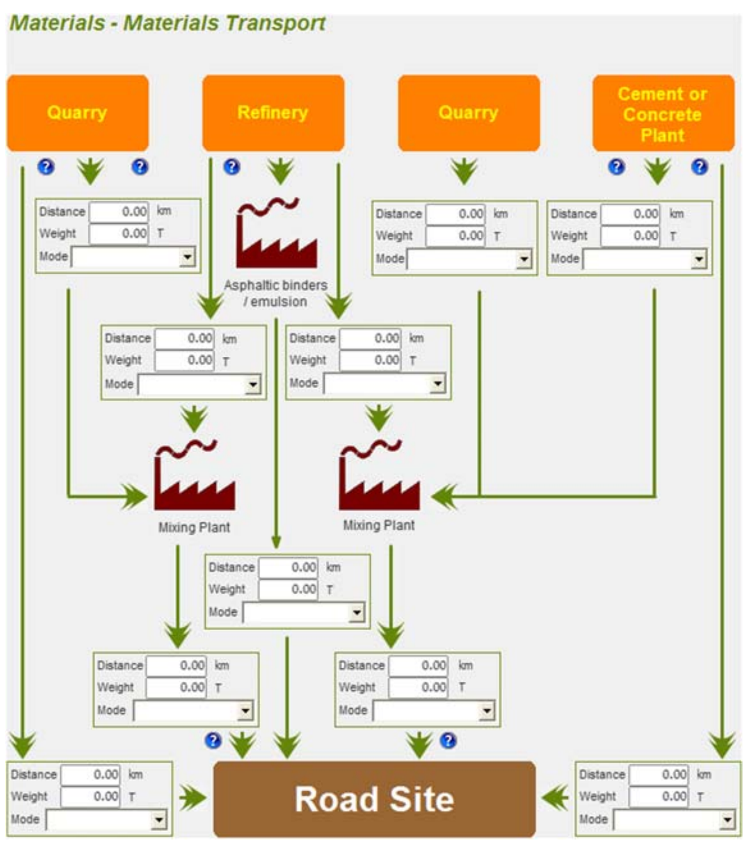


Figure 2. Materials transport input sheet.

been applied to major road projects in different technical and economic environments for testing, calibration and functionality improvement. The case studies include a UK trunk road widening, a PPP highway construction in UAE and five strategic highway upgrades in India.

5.1 *UK trunk road widening*

The single-lane trunk road located in the UK carries up to 25,300 vehicles per day, of which approximately 15% are heavy goods vehicles. The existing road is generally straight and undulating, making vehicle overtaking difficult, which is made considerably worse by many junctions and access roads, giving rise to daily congestion and a poor safety record. The UK Highways Agency (HA) proposed to widen it into a 28 km long two-lane dual carriageway, with 8 grade-separated junctions and 13 over/under bridges. The contract was awarded under a HA's 'Early Contractor Involvement' agreement.

A composite pavement construction with 180 mm asphalt surfacing over 200 mm hydraulically bound base over 250 mm stabilised class 3 foundation was considered for the majority of the road length (Figure 3). This pavement option improved project resource efficiency compared with the conventional full-depth asphalt construction over granular sub-base. Stabilising the foundation using local materials negated the need to import good quality aggregates and improved its bearing capacity, which led to reduction in pavement thickness and the associated resources use and lorry movement.

The project data (as-built) including pavement, geotechnical and drainage were collected from design consultants, over a period of 9 months between April and December 2009 (i.e. a quarter of the construction period). These data were run through the CHANGER. In summary, the results indicated the following:

- The construction activities released a total CO_2 equiv. of 20,788 t.
- Provided the 9-month data (April–December/2009) available representing one-third of the project's overall activities, this trunk road widening (28 km long) would release about 2,047 t CO_2 equiv./km construction.[3]

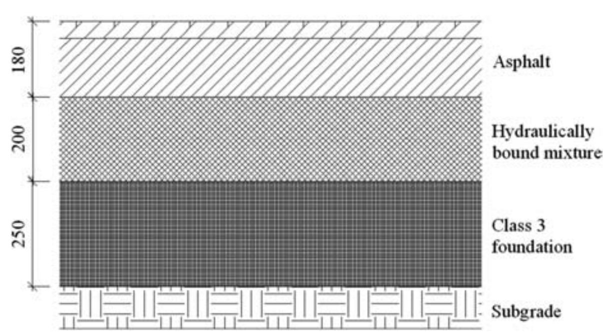


Figure 3. As-built pavement design, UK.

The project contractor was required by the Client to report the carbon footprint using the HA's carbon calculator, which indicated a CO_2 of 17,252 t between April and December 2009. Data that was already populated in the HA's carbon calculator were extracted and translated into CHANGER. In other words, there is a 20% difference between results from the two calculators. This variation is believed to be caused by a difference in the system boundary set up by the two calculators, rather than emission factors, because the two calculators share the same main references (Defra/DECC 2008, Hammond and Jones 2008). For instance, the HA's tool takes the 'top-down' input/output-based approach that measures the total fuel consumption on site, whereas CHANGER follows the 'bottom-up' process-based approach calculating the energy for each individual transport/construction activity.

5.2 *UAE's PPP highway construction*

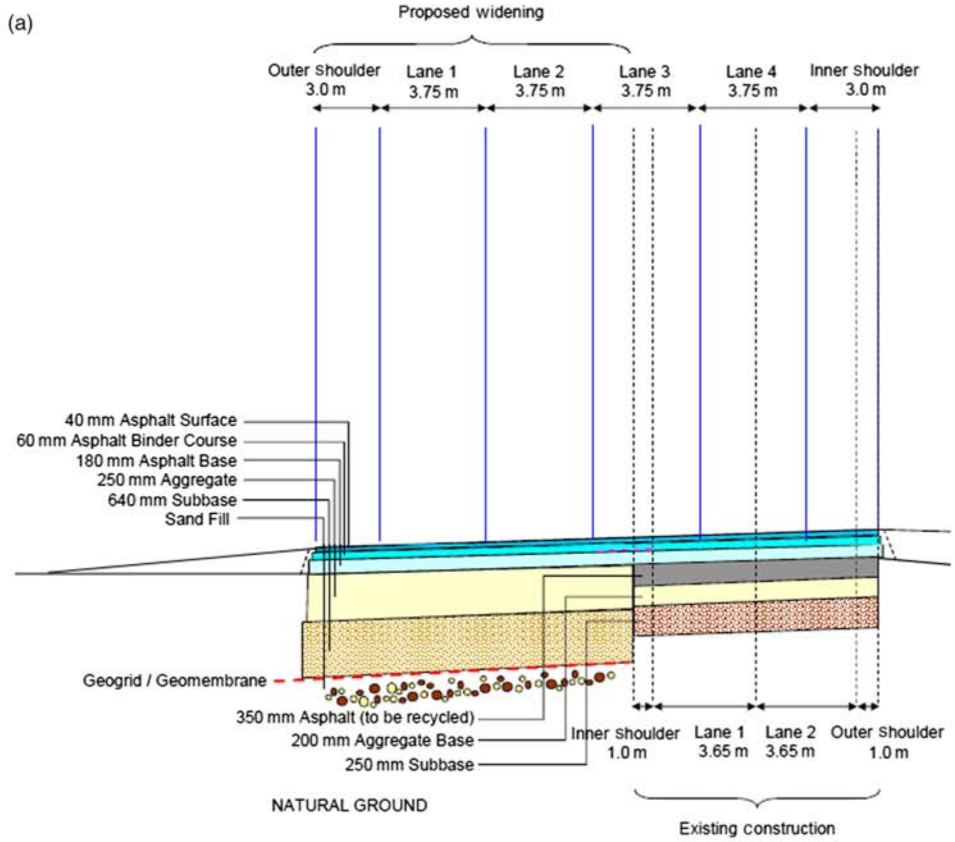
The Department of Transport of the Government of the Emirate of Abu Dhabi issued a tender to upgrade/reconstruct an existing 250 km road to a four-lane dual carriageway under PPP. URS Scott Wilson prepared design options and a detailed design for one of the bidding consortia to optimise the solution considering project contract performance requirements, whole life cost, constructability and sustainability.

Pavement Option A incorporates standard asphalt construction in accordance with the local standards as shown in Figure 4(a). An alternative pavement Option B, shown in Figure 4(b), was proposed to enhance the use of local materials in a cement-bound base, using an analytical design approach and an end-product performance testing, to ensure that the design parameters are met during construction in order to better control the pavement quality.

The CO_2 results from CHANGER for design options A and B are presented in Table 1. In summary, Option B saves about 266,710 t of CO_2 compared with Option A (11% less). The saving comes from transport (164,332 t less) and materials manufacture (123,286 t less), which is slightly offset by site activities (20,896 t more). In both options, materials' embodied CO_2 accounts for some 52% of the project total representing the 'hot spot' in this project. It is noted, however, that this carbon exercise was undertaken at the 'pre-qualification' stage so that some project data were not available, such as transport distance and construction equipments. The literature data were used, and assumptions were made in order to proceed with the analysis.

5.3 *Indian strategic highway upgrades*

The Karnataka State (South West India) Highways Improvement Project (KSHIP) is an initiative by the Public



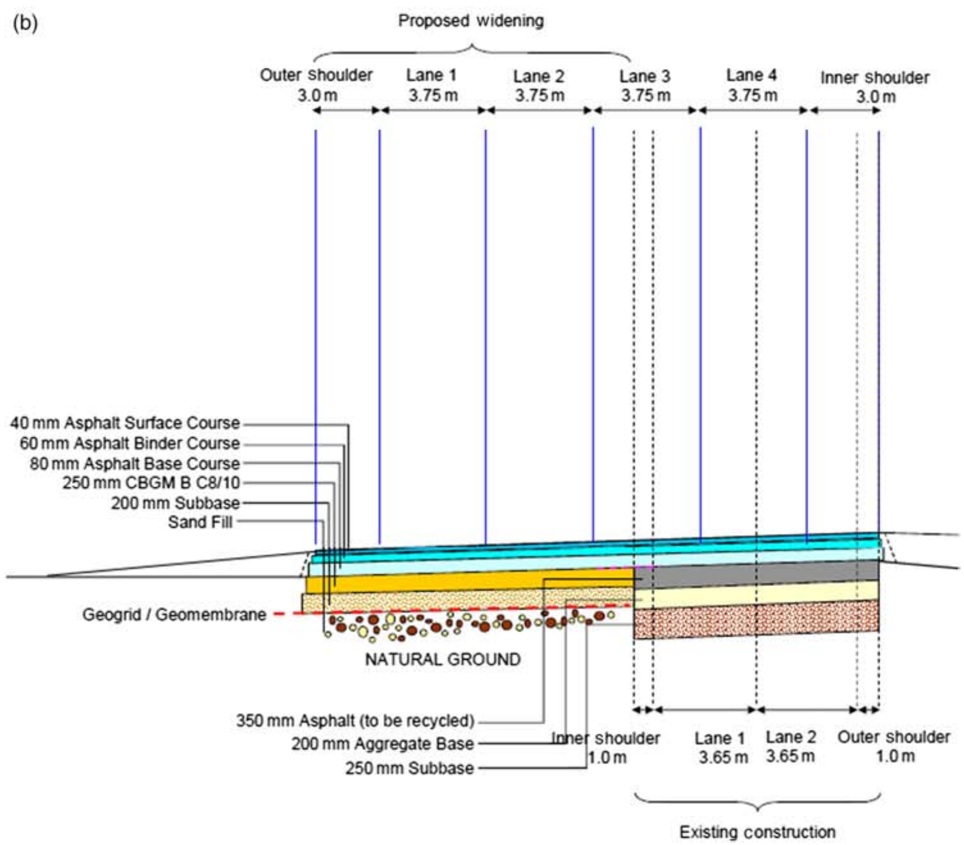


Figure 4. (a) Conventional pavement design, UAE. (b). As-built pavement design, UAE.

Table 1. Carbon footprint of UAE pavement designs.

	Unit	Material embodied	Transport	Construction	Total
Option A	t CO_2	1,254,509	792,185	359,705	2,406,400
Option B	t CO_2	1,131,223	627,853	380,601	2,139,690
Savings (A minus B)	t CO_2	123,286	164,332	−20,896	266,710

Works Department (PWD) of the Government of Karnataka (GoK) to undertake improvement of roads consisting of state highways and major district roads. A total of 4887 km of the roads was selected on the basis of a strategic option study. Furthermore, after a feasibility study, the GoK has selected 268.59 km of roads for upgrade in a phased manner under KSHIP-II. The proposed project is grouped into five contract packages (WEP) consisting of eight road links spread across the state of Karnataka (Figure 5). The project was designed by URS Scott Wilson and involves improving existing single-lane and intermediate lane roads to a 12 m roadway with a standard two-lane 7 m carriageway and alignment improvements to relevant Indian standards for roads and bridges.

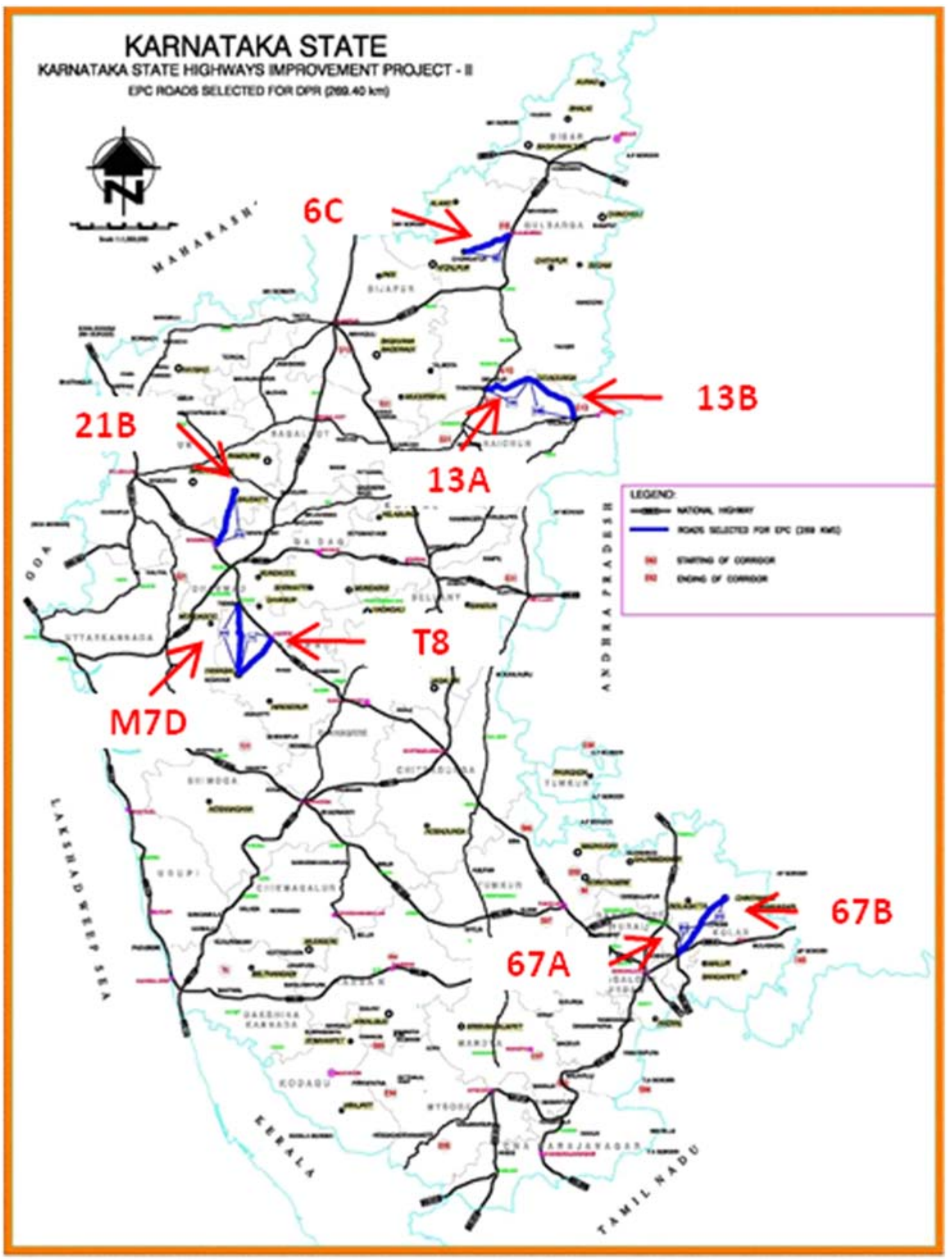


Figure 5. KSHIP-II project locations in India.

Table 2. Carbon footprint of KSHIP-II road upgrades.

Project	Link	Length (km)	Package length (km)	25 year traffic[a]	Weighted traffic[b]	Construction cost[c]	CO_2 equiv. emissions (t)	CO_2 equiv. per kilometre (t)
WEP1	67A	23.50	52.40	81,727	53,889	1163	169,132	3228
	67B	28.90		31,253				
WEP2	T8	31.80	75.26	8495	34,091	1386	67,500	897
	M7D	43.46		52,819				
WEP3	21B	38.50	38.50	41,488	41,488	919	60,631	1575
WEP4	13A	32.45	73.80	24,675	26,732	1853	92,041	1247
	13B	41.35		28,346				
WEP5	6C	28.63	28.63	30,096	30,096	734	46,870	1637
Total	na	268.59	268.59	Na	na	6054	436,174	1624

[a] Unit: passenger car unit (pcu) per day.
[b] For example WEP1: (23.5 km*81,727 pcu + 28.9 km*31,253 pcu)/(23.5 km + 28.9 km) = 53,889 pcu.
[c] Indian rupees in millions (1 sterling pound = 72 rupees, as in October 2011).

The project is promoting sustainability in highway construction by focusing on innovative standards and development activities. As a proactive measure, a decision was made to quantify the CO_2 emissions by using CHANGER to assess these five contract packages. The WEP length, design traffic (25 years), construction cost and carbon footprint estimated using CHANGER are presented in Table 2.

As indicated in Table 2, the CO_2 emission per kilometre construction varies greatly between these five projects from 897 to 3228 t/km. The project details indicated that the following elements and their impacts have contributed to the above difference.

- Design traffic: construction type and pavement layer thickness;
- Location (built up or non-built up) and topography: transport distance, right of way width, paved/un-paved hard shoulder width, drainage type;
- Existing road layout (for alignment design) and pavement condition;
- Geology: subgrade strength and swelling nature of the foundation soil;
- Drainage, number of structures (bridges and ducts): quantities of concrete, steel and PVC pipes;
- Construction techniques: e.g. soil replacement versus cement/lime stabilisation;
- Land acquisition.

6. Interpretation of results

In Table 3, the carbon footprint of materials manufacture, transport and site activities per kilometre of all case studies described above is presented. Analysing the numbers in Tables 1–3 leads to the following observations:

- The carbon footprint per kilometre construction of the UAE highway is substantially higher than the UK trunk road widening and strategic highway upgrades in India, indicating that new construction, in general, has bigger impacts than improvement works.
- Materials sourcing and manufacture, in general, account for the biggest portion of CO_2 from road construction, this is the case in both the UAE design options and four out of the five Indian projects; reducing materials' embodied carbon thus deserves more research and development resources in a company's carbon reduction campaign.
- Carbon emissions from site activities, i.e. electricity and fuel use, were allocated to 'construction', while in practice fuels on site may be used for local transport; thus, the carbon numbers for 'transport' in these case studies may be underestimated.
- WEP1–WEP5 of the Indian projects indicated that there is some correlation between the construction cost (accounting for about 75% of the project total

Table 3. Carbon footprint of road construction projects.

Country	Project	Length (km)	Materials (t CO_2/km)	Transport (t CO_2/km)	Construction (t CO_2/km)	Total (t CO_2/km)
UK	Trunk road	28	743	236	1069	2047
UAE	Option A	250	5018	3169	1439	9626
	Option B	250	4525	2511	1522	8559
India	WEP1	52.4	2982	82	163	3227
	WEP2	75.3	461	255	181	897
	WEP3	38.5	496	140	938	1574
	WEP4	73.8	565	363	319	1247
	WEP5	28.6	589	549	499	1637

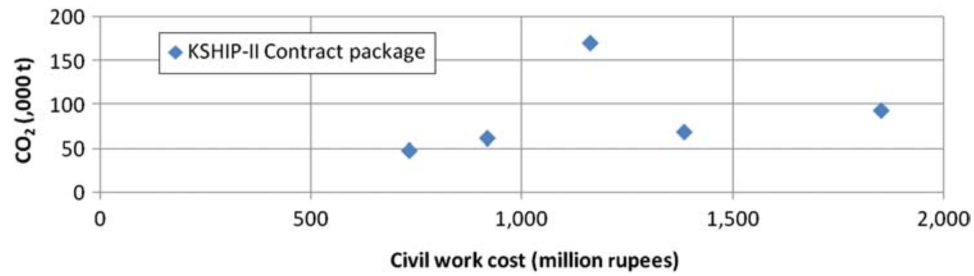


Figure 6. Correlation between civil work cost and CO_2 emission.

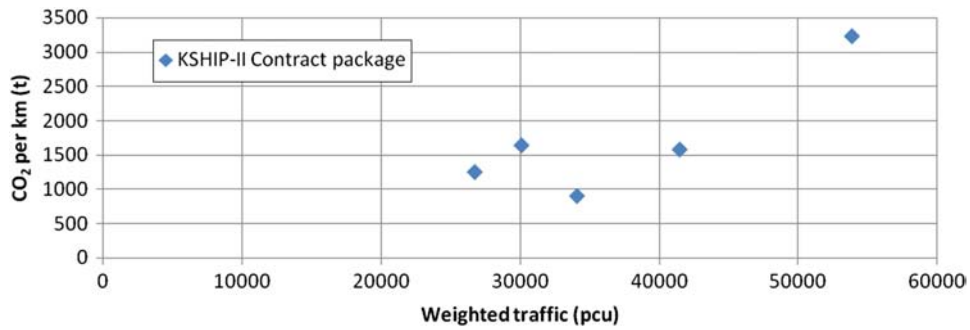


Figure 7. Correlation between weighted traffic and CO_2 emission.

cost in these projects) and carbon emission, as shown in Figure 6.

- The traffic volume of WEP schemes varies. For analysis, the weighted traffic for each WEP is calculated (see Table 2). Figure 7 shows that carbon emission per kilometre is in some correlation with traffic, depending on the traffic level (e.g. $<$30,000 pcu, $>$30,000 pcu). It is noted though that traffic is only one of the aspects that contributed to the CO_2 difference, as elaborated in Section 5.3.

7. Conclusion

Governments will be increasingly required to submit regular GHG emission accounts as part of their international commitment, in particular under the UN Climate Change Convention. The road sector is coming under pressure to review current practice and the potential to reduce carbon emissions. The life cycle approach has been accepted as a robust method of measuring carbon footprint. A carbon study, in general, shares common features with a full LCA study, albeit it has some unique aspects to look at. Point-based scoring systems for road sustainability require the life cycle/carbon analysis results. Some tools and data-sets have been developed to facilitate the measurement. Aimed to provide a unique 'clear path' to both the public and private sectors to simplify the analysis of complex technical information, CHANGER is developed to measure and benchmark the carbon footprint of road construction worldwide.

It is noted, however, that road construction in different countries is subject to compliance with technical standards, materials availability and practice as usual. The quality and completeness of data can be varied. Case studies in this paper obtained data for a UK trunk road widening, a PPP highway construction in the UAE and strategic highway upgrades in India. The CHANGER results of these projects are compared, and investigation is made to seek the causes of any differences. Several elements and their impacts are found to contribute to the variation in CO_2 per kilometre construction, namely but not in particular order, the technical standards (e.g. traffic, lane width), current condition (e.g. foundation, pavement), materials option, construction technique, drainage and structures (type, number, etc.). Data quality in these case studies is summarised below.

- The temporal scope of data on the UK trunk road is 9 months; CO_2 output from CHANGER was thus extrapolated in order to estimate the whole duration, i.e. 36 months, of the project.
- Data on materials quantity for UAE highway are complete and relatively accurate, compared with transport and site activities, a considerable portion of which is estimated. However, this case study presents a representative project prototype in which the number of lanes and materials availability are very different to the other two case studies, which results in the high CO_2 per kilometre of construction.
- Indian case studies benefit from an abundance of project data that allow the CO_2 to be compared

between contract packages, and correlated with technical (e.g. traffic) or economic (e.g. civil works cost) parameters.

Carbon measurement of an ongoing road construction is often undertaken with an absence of project data. Data from literature or comparable projects are normally used, and assumptions are made in order to proceed with the analysis. Data validation and sensitivity check can be carried out thereafter, once the 'hot spot' areas are identified. The details of proxy data and assumptions need to be documented for transparency; the aim is to allow the carbon impact of roads provision to be understood and managed on an informative basis.

CHANGER can be used to check the carbon variation due to design option (e.g. the UAE case study), or it can measure a project that has a multitude of technical and economic drivers (e.g. the Indian case study). It provides a boundary so that road projects of different background can be measured against a consistent functional unit (i.e. per kilometer construction), although the boundary may be different in another carbon tool that leads to truncation/double-counting errors and disparity in results when transferring data from one tool to the other (e.g. the UK case study). Generally speaking, CHANGER is suitable for large projects where it may be impractical to model every process in detail. This comes at the expense of using general emission data rather than project/material-specific data, which may reduce accuracy. There is a trade-off in ensuring consistency but losing flexibility.

8. Recommendation

The demonstration of road CFP methodology and how to use CHANGER to determine the carbon footprint are the primary purpose of this paper. This is achieved alongside some benchmark figures, established through case studies in an international context. It is not appropriate at this stage, however, to provide conclusive advice on how to optimise design and supply chain in order to reduce the carbon footprint of a road construction, purely based on CHANGER results. A number of engineering aspects (e.g. traffic, foundation) will influence on the project attributes (e.g. pavement, drainage) which ultimately determine the carbon footprint. This may become plausible when more projects of comparable attributes are run through the tool. Looking forward, the model needs to be further developed, and the data-sets updated to reflect the latest materials engineering and construction practice. The following areas for improvement have been identified.

- Model improvement so that the 'fuel consumption on-site' can be allocated distinctively to materials transport and construction activities.
- A fairly long analysis period (e.g. 60 years) with maintenance schemes defined to include all activities inherent to the provision of road infrastructure.
- End-of-life scenarios for pavement materials relevant to all possible means of disposal as such remain in place, recycle and landfill.
- The carbon estimates of road transport, in particular the impacts associated with lighting provision and using the road (vehicle emissions), which the authors believe represent the majority of emissions from a road.

CHANGER provides the carbon measurement of road construction. Other carbon tools, developed by the UK public sector, may provide supplementary information to the overall carbon footprint of a road project. For example, the Environment Agency's tool may help to track the carbon from site activities based on the project size, duration or number of staff (Environment Agency 2007). The HA's tool included the carbon of staff commuting (Highways Agency 2008). Transport Research Laboratory (TRL) developed the asPECT tool that allowed the mixture recipe and energy data to be customised by the user (TRL 2011). When time and budget allows, it is always advisable to cross-check the results from different tools, in order to test and calibrate the tool, and verify any benchmark figures for a typical construction in a specific country.

Carbon footprint has managed to get the life cycle thinking into public attention and organisations' decision-making process (e.g. procurement, tender selection). However, global warming is not the only environmental problem. Other impacts associated with a road (e.g. leaching, fuming, noise), especially when recycled materials are increasingly used, should not be traded off for GHGs. Companies aiming for environmental labelling need to ensure that their pursuit of 'green' construction is not simply based on a single aspect such as CO_2 saving.

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Notes

1. Email: bachar.hakim@scottwilson.com
2. Email: szammataro@irfnet.org
3. All numbers of CO_2 below denote CO_2 equiv.

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