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CEREAL

Final Report

Deliverable Nr 6 & 7

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Royal
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Enhancing Society Together

KOAC·NPC

Road Directorate

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CO₂ EMISSION REDUCTION IN ROAD LIFE CYCLES

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Executive summary

The threat from climate change to our society and increasing prices of energy are real and relevant to road administrations. Reduction of CO_2 emissions and energy conservation are therefore instrumental to sustainable construction, and should be included in decision making. So far, no comprehensive, widely applied and commonly accepted tools for reduction of energy use and CO_2 emission are available on how roads should be designed, constructed, maintained or rehabilitated, what materials can best be applied and what logistic processes should be chosen for reasons of sustainability and not durability.

In the last decade plenty of models and tools were developed to facilitate national road administrations (NRA's), contractors and consulting agencies in their endeavour to identify low CO_2 emission solutions in road construction. Most of these, usually nationally oriented, models focus heavily on the design phase, whereas 90% of road works is maintenance and rehabilitation and not construction. Another feature of many models is that they allow input of all type of data on materials, equipment, manpower, etc. This model structure has as benefit that the model can be tailored to the local situation. The huge drawback of those models is that they require amount and type of data with which the user is usually not familiar with. In other words, the tools are too complex in use.

The CEREAL project was initiated to enhance Europe wide carbon foot printing of road construction and pavement maintenance. In more detail the following goals were listed at the start of the project:
- Development of a tool for the assessment of the CO_2 emission in different phases of a road pavement life cycle (design, construction, maintenance and rehabilitation)
- Identification of the predominant factors in the CO_2 emission preventing that the tool should be too complex. The objective was to keep the tool as simple as possible though still gaining sufficient information to make the proper decisions. The simpler a tool is the less adaptation will be needed later on.
- Easy to use for non-experts, and with a friendly interface. This condition was considered to be very important to ensure a widespread use among European road administrations, contractors and consulting agencies.
- Applicable to most member states of Europe, but hopefully even more transnational.

The development of a new tool requires thorough preparation to ensure that existing knowledge is fully used and that the new tool fulfils the needs of the potential users or target group. Therefore the first step in the project was to gather information on the present experience with CO_2 tools for road construction and maintenance projects and to inventory the tools available. This step was made by conducting a survey and a series of more in-depth interviews. Based on this information the functional requirements of the tool were determined, describing the structure, purpose and application of the tool, the target group and the features that are needed to create a useful tool.

In order to make complete use of existing knowledge, all known existing tools and databases have been acquired and assessed for usefulness of structure and data. The match between the existing tools and the functional requirements has been studied in this assessment.

The functional requirements and knowledge of existing tools and their positive and less useful aspects formed the basis for the tool development. The result of the tool development is the Carbon Road Map. The beta version of the Carbon Road Map has been tested in several steps. First a series of internal tests and re-adjustments within the project team have been carried out. Secondly an external test and survey among the members of the expert panel has been conducted. In the last phase, the tool has been demonstrated and evaluated in two international workshops. Based on the

results the tool has been adjusted several times and a final version has been prepared.

The work presented in this report is performed by the CEREAL project team. CEREAL is a research project of the cross-border funded joint research programme ENR2011 ENERGY - Sustainability and Energy Efficient Management of Roads" that was initiated by "ERA-NET ROAD II – Coordination and Implementation of Road Research in Europe" (ENR2), a Coordination Action in the 7th Framework Programme of the European Commission. The parties in the project team are Royal HaskoningDHV (Project co-ordinator, the Netherlands), KOAC•NPC (the Netherlands) and the Danish Road Directorate.

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1 Introduction

1.1 Organisation

This transnational research programme **"Energy - Sustainability and Energy Efficient Management of Roads"** is initiated by ERA-NET ROAD II (ENR2). The main objective of this joint research programme is to recommend "ERA-NET ROAD II – Coordination and implementation of Road Research in Europe". ENR2 is a Coordination and Support Action funded by the 7th Framework Programme of the EC. ENR2 partners are Austria, Belgium (Flanders), Denmark, Finland, France, Germany, Hungary, Ireland, Lithuania, Netherlands, Norway, Poland, Slovenia, Sweden, Switzerland, United Kingdom, with CEDR (Conference of European Directors of Roads) as an Associate Partner.

The participating NRAs in this Joint Research Programme are Germany, Denmark, Ireland, Netherlands, Norway, Sweden and United Kingdom. As in previous ERA-NET ROAD programmes, they established a Programme Executive Board (PEB) and a Programme Management (PM), having the task to address the administrative issues.

The work presented in this report is performed by the CEREAL project team. CEREAL is a research project of the cross-border funded joint research programme ENR2011 ENERGY - Sustainability and Energy Efficient Management of Roads" The parties in the project team are Royal HaskoningDHV (Project co-ordinator, the Netherlands), KOAC•NPC (the Netherlands) and the Danish Road Directorate.

1.2 Background & goals

The threat of climate change to our society and increasing prices of energy are real and relevant to road administrations. Reduction of CO_2 emissions and energy conservation are therefore instrumental to sustainable construction, and should be included in decision making. So far, no comprehensive, widely applied and commonly accepted tools for reduction of energy use and CO_2 emission are available on how roads should be designed, constructed, maintained or rehabilitated, what materials can best be applied and what logistic processes should be chosen for reasons of sustainability and not durability.

In the last decade plenty of models and tools have been developed to facilitate national road administrations (NRA's), contractors and consulting agencies in their endeavour to identify low CO_2 emission solutions in road construction. Most of these, usually nationally oriented, models focus heavily on the design phase, whereas 90% of road works is maintenance and rehabilitation and not construction. Another feature of many models is that they allow input of all type of data on materials, equipment, manpower, etc. This model structure has as benefit that the model can be tailored to the local situation. The huge drawback of those models is that they require amount and type of data with which the user is usually not familiar with. In other words, the tools are too complex in use.

The CEREAL project was initiated to enhance Europe wide carbon foot printing of road construction and pavement maintenance in a more harmonized way. In more detail the following goals were listed at the start of the project:

- Development of a tool for the assessment of the CO_2 emission in different phases of a road pavement life cycle (design, construction, maintenance and rehabilitation) that contributes to an energy efficient road infrastructure.

- Identification of the predominant factors in the CO_2 emission preventing that the tool to be too complex. The objective was to keep the tool as simple as possible though still able to gain sufficient information to make the proper decisions. The simpler a tool is the less adaptation will be needed later on.
- The development of a tool which is easy to use for non-experts, and with a friendly interface. This condition was considered to be very important to ensure a widespread use among European road administrations, contractors and consulting agencies.
- Applicable to most member states of Europe, but hopefully even more transnational.

1.3 Project plan

The development of a new tool requires thorough preparation to ensure that existing knowledge is fully used and that the new tool fulfils the need of the potential users. Therefore the project was designed according to the following steps:

1. Gather information on the present experience with CO_2 tools for road construction and maintenance projects and inventory the tools available. This action was performed by conducting a survey and a series of more in-depth interviews.
2. The formulation of functional requirements of the tool based on the results of the first step.
3. Acquire and assess the existing tools for usefulness of structure and data.
4. Development of the tool.
5. Testing, training, dissemination and reporting.

This final report describes the starting points and results of each step in the project chronologically. The appendices contain additional information on the survey and interviews. They also include reporting of the tool assessment, the user's guide and the workshop presentation.

2 Results of the survey & interviews

In section 2.1 and 2.2 the goals, working method, conclusions and results of the survey is described, whereas in section 2.3 the results and conclusions of the interviews are summarised.

2.1 Survey goals and working method

Goals

Within the overall goal of the CEREAL project the goal for the survey & interviews was to identify characteristics of the future CEREAL tool in a sense that the tool would be applicable to European countries, with a special focus on North-Western Europe. Furthermore, the identification of the potential user group in Europe in public and private organisations was a main challenge.

More specifically the goals of the survey were:

- Identify the general level of experience with CO_2 related tools in road projects.
- Inventory the existing tools.
- Identify the potential user group, the desired results and the use of specific protocols.
- Verify the scope of the tool.
- Identify the requirements for effective and long term use.

Target group

The target was to get at least 40 complete filled out surveys by experts in Europe. Special focus was to get information of all NRA's of the funding countries, since these organisations will be the key-stakeholders in the development and implementation of the tool. The following selection criteria were applicable to the respondents: knowledge of the road sector, working for a road authority, contractor or consultancy firm in Europe, and experience with or special interest in CO_2 calculations for road constructions.

Invitations and pre-announcements were made by using personal networks of all team members, the PEB and the project coordinators of the other Era-Net Road projects, several associations (EAPA, IRF, CEDR) and by using several groups on sustainability and pavement or building discussion groups in social networks such as LinkedIn. Some of these LinkedIn discussion groups: Pavement Engineer, Pavement Materials, National asphalt pavement association users group (all English) and Road Builders, "Duurzame GWW", "CO_2 prestatieladder", "CO_2 reductie GWW sector" (all Dutch).

The actual survey was online at 'Survey monkey'[1] for about 6 weeks in February and March 2012. Also the survey was available through the project website www.cereal.dk. The main results of the survey are available at the website except for any personal information of the respondents.

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[1] Specific address; https://www.surveymonkey.com/s/WGKPVX3.

2.2 Survey results

2.2.1 General results and conclusions

- 47 completed surveys have been acquired, of which 18 from relevant stakeholders within NRA's (all NRA's of contributing countries included).
- The respondents represent a good distribution over different countries, with different backgrounds working in different organisations.
- The current experience with CO_2 (tools) includes many different (specific) tools but very limited use. Only few respondents use tools on a regular basis.
- The opinion on existing CO_2 tools varied, most tools were regarded as too complex, not transparent, too much of a black box, not user friendly software, too high requirements to input data.
- A few (national) tools were regarded as very useful and adequate.
- The quality and availability of input data is a key issue among the respondents as well as the use of a wide scope.
- The intended use and purpose according to the respondents is mainly optimizing the pavement design and calculation of maintenance strategies, thus use in the design phase of the decision making process.
- Based on the answers, a preliminary conclusion was drawn that the new CEREAL tool should need to be simple but complete, including relevant country specific differences.
- Most of the tools are not embedded (yet) in national policies. It seems that only the use of Dubocalc in the Netherlands is obligatory in national design and contracting processes.

The results of the survey are used as a basis to conduct a series of in-depth interviews with NRA's of the funding countries. The results of the survey and interviews are the basis for the formulation of the functional requirements of CEREAL in the next phase of the project. The results of the interviews are described in section 2.3.

2.3 Background of the respondents

Functions of respondents:

- 20 of the 48 respondents identified themselves as 'specialist / researcher'
- 4 identified themselves as 'policy maker'
- 12 identified themselves as 'consultant'
- 12 identified themselves as 'other' (for example: road engineer, technical manager, environmental expert, purchaser, HSE manager, marketing specialist, etc.)

Operational level of the organisation:
- 6 of the 48 respondents were working within an organisation on a 'local level'
- 5 were working within an organisation on a 'regional' level
- 30 were working within an organisation on a 'national' level
- 14 were working within an organisation on a 'multinational' level

Type of organisation:
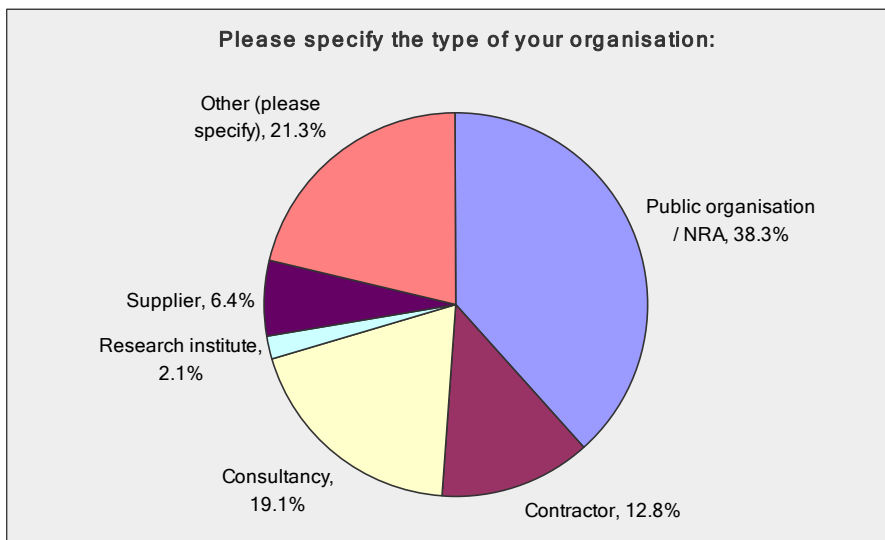
Figure 2.1: Type of organisation of the respondents

Others are specified as universities and associations related to infrastructure.

Field of expertise of the respondents:
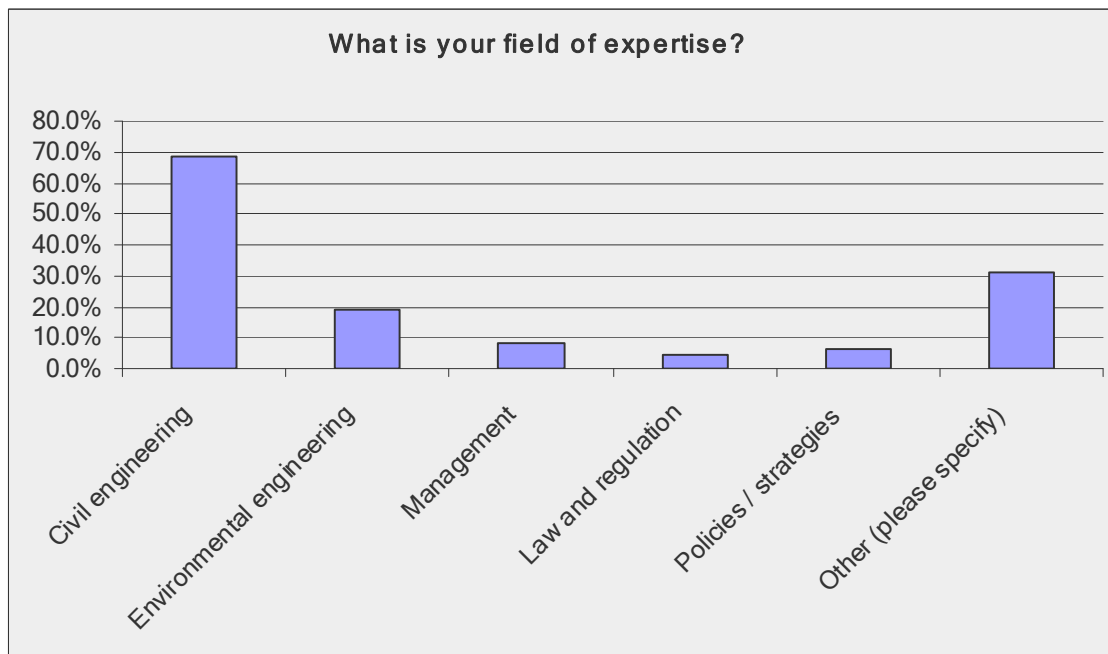
Figure 2.2: Field of expertise of the respondents

The respondents are mainly engineers, representing the potential user group quite well. Others are specified as chemical engineering, waste management, sustainability, climate change, software development, etc.

Home country of the organisation:

Figure 2.3: Home country of the organisation

A lot of responses came from the UK and the Netherlands. This is coherent with the relative high level of development and implementation of CO_2 tools in these countries. Knowledge and experience with CO_2 in road projects
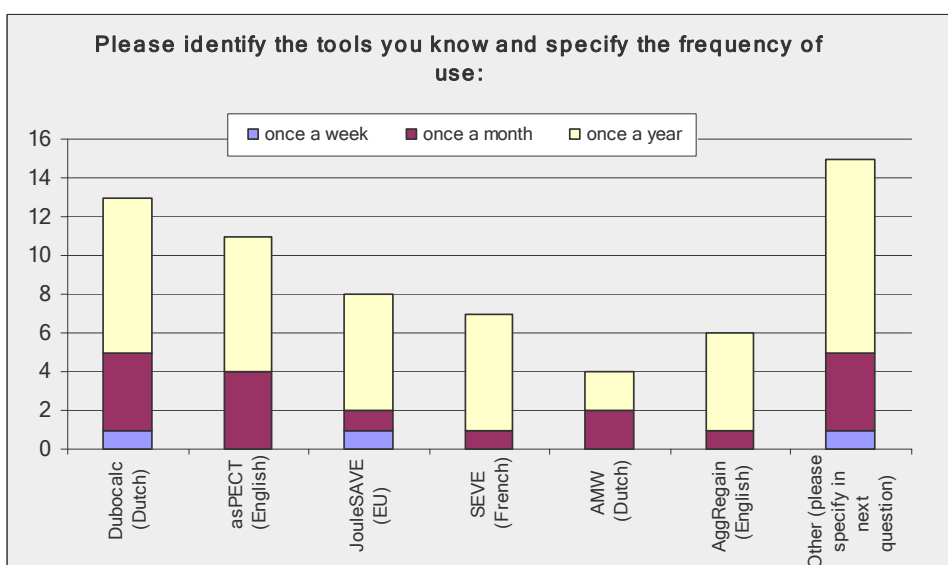
Figure 2.4: Experience with existing tools

Only a few tools, Dubocalc and Aspect, are used on a regular basis by a few respondents. The majority of the tools is country specific and used in one country only.

Other tools mentioned were among others: GHG calculator for infrastructure, Highways Agency Carbon Calculation tool (UK), CO_2 ladder (Netherlands), Transport Scotland toolkit, ECORCE (French), GreenDOT and GreenRoads. All tools mentioned are subject to evaluation in the next phase of the project.

The Opinion on existing tools

The opinions on the existing tools differ a lot:

- The NRA's in France, the UK, Netherlands and Denmark are positive on their own national tools.
- JouleSAVE is seen as not user friendly and very complex. It is developed for a very specialist user group in combination with MX software.
- Users of Aspect and AMW are positive.
- Highways Agency Carbon Calculator is used for foot printing of organisations and is not applicable for maintenance strategy analysis in road projects.
- Many of the tools are not transparent and too much a black box.
- Tools are too complex and require too much input data.
- Data quality and availability are very important.

Motivation of interest in a (new) CO_2 tool

According to the respondents there is a point for development of a (new) CO_2 tool mainly in policy-making, implementation in contracts and for research objectives. Other identified reasons to use CO_2 tools are monitoring and communication on CO_2 emissions in organisations.
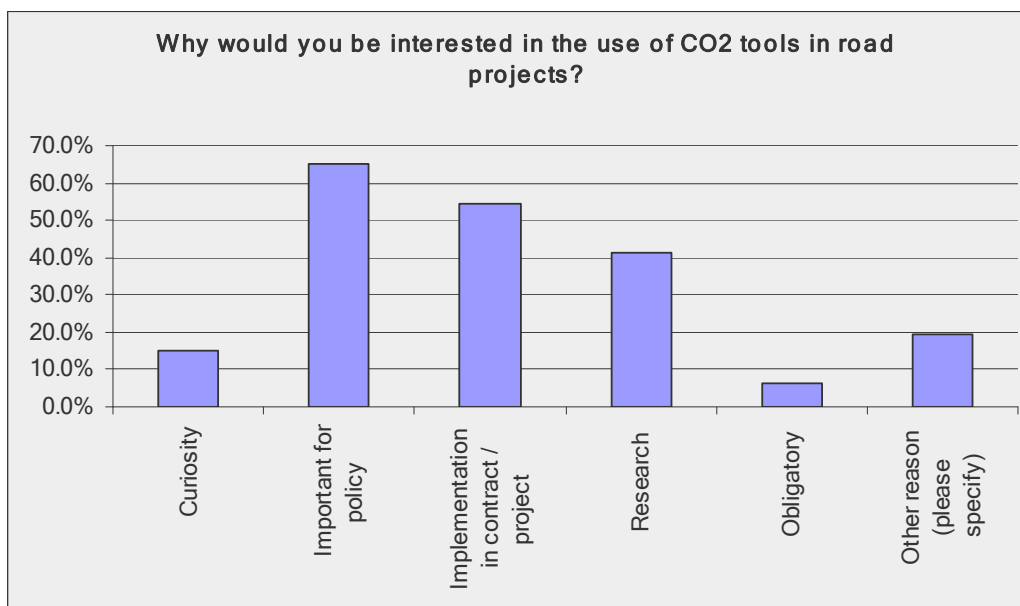
Figure 2.5: Motivation of interest in a (new) CO_2 tool

Examples of CO_2 in road projects

Some good examples in the UK, the Netherlands and Sweden were reported. If possible, these examples will be used in the testing phase of the CEREAL tool.

For JouleSAVE some specific 'pilots' were conducted: N25 Waterford to Glenmore (Ireland), M20 Cork to Limerick (Ireland), N11 Gorey Bypass (Ireland), A29 (Portugal), IC-6 (Portugal), Expressway R43 (Czech Rep), RD921 (France), Route 50 and 32 (Sweden).

2.4 Functional requirements

Scope

According to the respondents all aspects mentioned are important and must be included in the CEREAL tool. Example: nearly 60% of the respondents state that cuts and fills (embankment) in the road profile should be included.

In the scope of the CEREAL tool the dominant aspects of the road life cycle must be included. Please indicate which of the following objects or activities must be included:
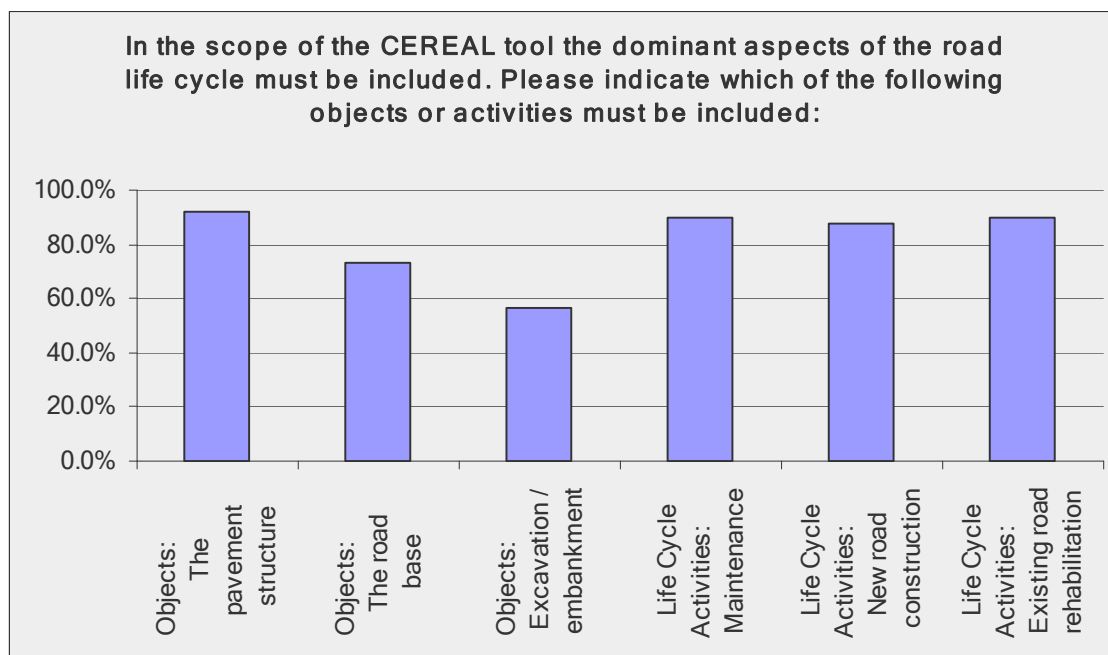
Figure 2.6: Desired scope of the CO$_2$ tool

The respondents were asked what other objects and activities should be included in the CEREAL tool. This resulted in the following statements.

Objects considered to be included in the CEREAL model, other than in the graph above are: bridges, drainage, road marking and signs and safety objects. These objects may be included in the tool in a simple way.

Other CO$_2$ generating activities to be considered are: winter maintenance, demolition at the end of structural life, production and transport of constituent materials, routine maintenance, recycling of existing pavement materials. These activities are included in the life cycle if the relevance is evident.

Beside these activities a lot of respondents mentioned the importance of the effect of road user CO$_2$ emissions. CO$_2$ emissions as a result of the use of the road are influenced by the traffic (intensity and speed) vehicles (vehicle type, construction and engine, tyres) and the pavement structure itself (slope, alignment and roughness of the pavement, air resistance & influence of wind).

Methodologies and protocols

The respondents proposed to use the following methodologies and protocols to help backbone the CEREAL tool: ISO 14040 [34], ISO 14064-1 and -2 [35, 36], ISO/TS 14067 [37], GHG Protocol including recent Scope 3 protocol, [38], PAS 2050 [39], Bath ICE [17], CESSM3 Carbon and Price Book, Proprietary Materials [pm], EU requirements for GHG reporting [16] and the Eurobitume bitumen life cycle inventory [13].

Most of the protocols are strongly related and include similar starting points, guidelines and working methods for LCA, which makes it possible to use most of the common protocols for the development of the tool.

Intended use

All possible application areas for a CO_2 tool are interesting for the respondents. A majority of the respondents wanted to use such a tool for optimizing design and drafting of remedial strategies.
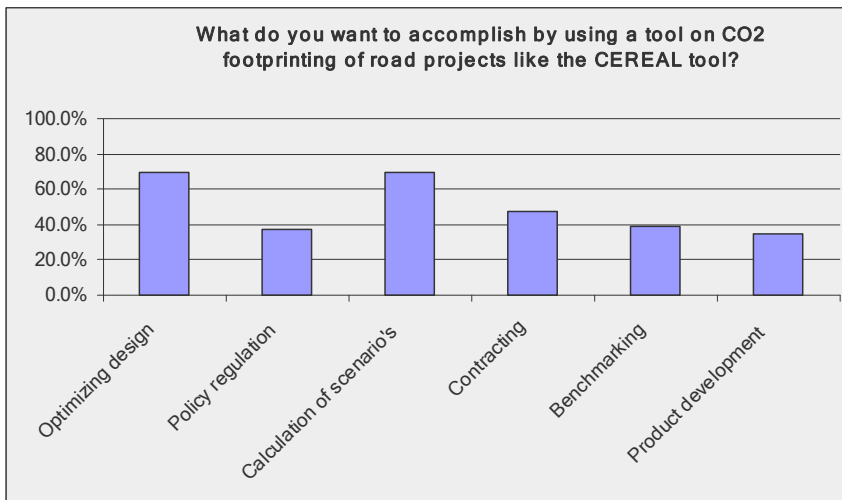
Figure 2.7: Intended use of the CO_2 tool

Contribution of the new CO_2 tool to the intended use

Many different answers were obtained on this issue. The expected added value of the new CO_2 tool can be summarised as:

*   Assessment of alternative constructions for a given alignment and support of the decision making.
*   Stimulation of contractors to provide sustainable solutions.
*   Uniform calculation and benchmarking of CO_2 emissions across countries/EU.
*   Monitoring and reporting of CO_2 emissions.

Contribution of CO_2 tools to the (policy of) the organisation

How will the use contribute to the policy of the organisation?

*   Various respondents mention that there organisation has goals on sustainability, decreasing environmental impact and also CO_2;
*   The most important identified contribution is the influence on the design, evaluation of different construction or rehabilitation options, and procurement. There may be an indirect contribution in the choice of applied materials;
*   The use of the tool may lead to more dedicated marketing of the policy, demonstration of carbon savings (as non direct cost benefits) by providing numbers and improvement of knowledge and awareness of the organisation;
*   Not all respondents believe that a CO_2 tool like CEREAL will effectively change the way decisions are made by their organisation.

In which phase of the decision making process a CO_2 tool like CEREAL will be used?

The respondents see the applicability of the tool mainly in the design and contracting phase.
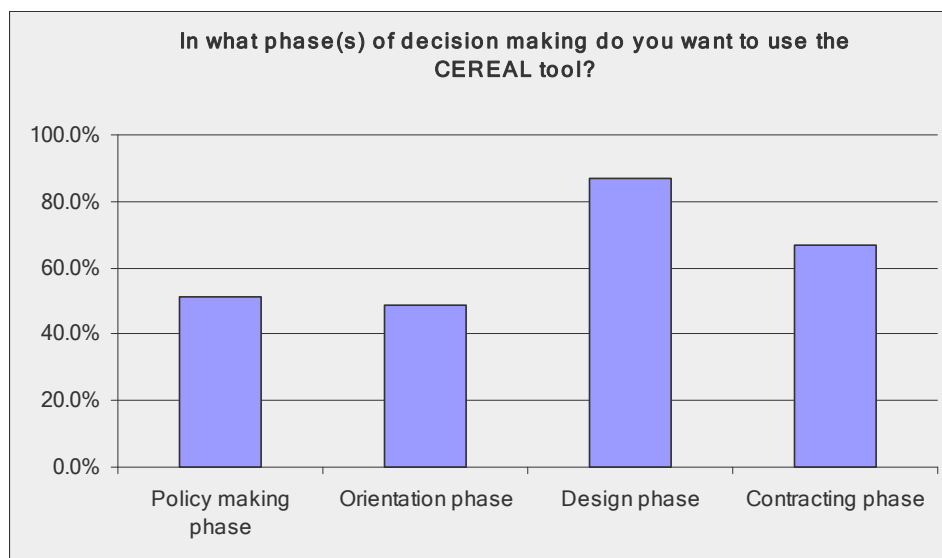
Figure 2.8: Use of the CO_2 tool in specific phase of the decision making process

Connection with existing management systems

The majority of the respondents (66%) expect that that the CEREAL tool will fit into an existing management system mostly in order to work on continuous improvement of quality. They identified most organisation specific management systems but also guidelines as ISO 9001 and ISO 14001.

2.5 Data availability & project structures (Q21 – Q26)

Data availability

In general, respondents have as a rule detailed data available on the amount of building materials used in road projects. Also data on operational maintenance activities is available on a high level of detail. General data on building logistics and energy use in road projects are usually available too. A significant group of 12 (out of 47) states that no data is available on building logistics and 15 states that no data is available on the amount of energy used.

Table 2.1: Data availability (example)

In road management projects, do you or does your organisation have information on:	no data	general data	detailed data
Amount of building materials (such as ton asphalt, ton sand, etc)	5	15	28
Building logistics (such as types of trucks, km's, frequency)	12	22	13
Operational maintenance (such as type of maintenance activities, frequency, etc)	8	19	19
Energy use (by use of generators, electricity, etc.)	15	21	11

Is data on road management country specific?

The answers to this question are very diverse. Apparently many respondents want to include specific data for materials. They mentioned they would like to have the focus on the development phase and maintenance phase of road projects, as new roads are rarely built in their countries. Also the need to have maintenance and construction activities for asphalt as well as cement concrete roads has been mentioned. Specific asphalt mixes used as wearing coarse have been mentioned such as noise reducing mixes and porous asphalt.

Except for the materials commonly used in road pavement structures (bitumen, modifiers, fillers, aggregates, etc), the respondents also referred to the need for specific road construction materials in their countries. Examples are the recycling of (sub)base materials like concrete and masonry granulates applied in some countries in the EU. Further specific needs are inclusion of data on modified bitumen and light coloured aggregate. Some respondents said they would like to have general data about transport distances in the program.

The respondents mentioned some maintenance strategies as being country specific such as reinforcing, milling (planning) and paving. Some respondents also said they would like to see in the new software specific activities related to weather and winter conditions (damage due to weather conditions).

Road classes

According to the respondents, they are mostly involved in projects on motorways, dual/multilane carriageways or single carriageways. Urban collectors, low-volume roads and residential areas are less frequently subject of their work.
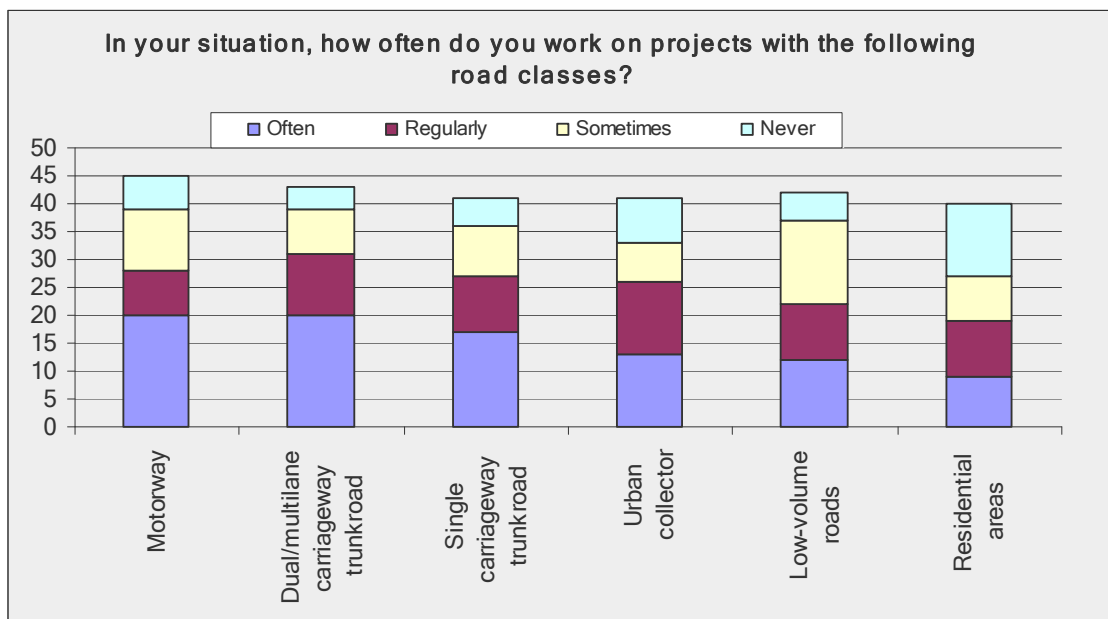
Figure 2.9: Relevant road classes

Pavement types

The most used pavement type is asphalt. According to the respondents the most used base on asphalt pavement is the unbound base, followed very closely by the bound base. Those types of base are widely used.
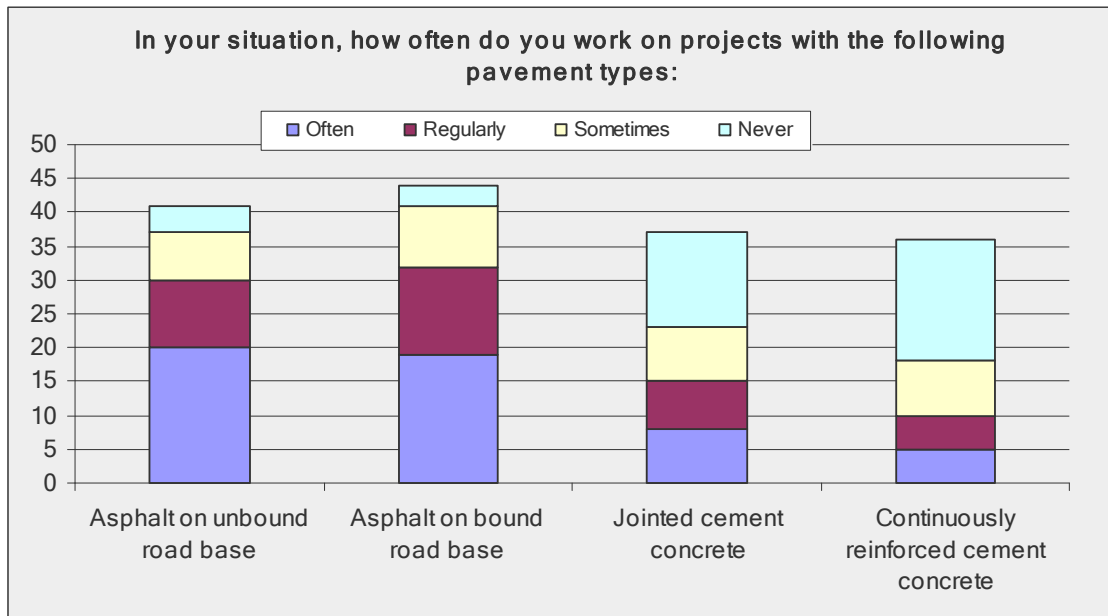
Figure 2.10: Relevant pavement types

Cement concrete pavements are less applied according to the respondents. Jointed cement concrete is more used than the continuously reinforced cement concrete. Cement concrete pavement still require a higher initial investment and is mainly intended for use at heavy duty pavements in subgrade areas with strong support.

Annual Average Daily Traffic intensity per road class

The reported intensities are quite high. The AADT differs very much per country or even per road. The intensities are a good match to the most mentioned road classes, such as motorway, dual multilane carriageway or single carriageway. The AADT together with the available subsoil are the main input needed for the structural design of the pavement structure and the maintenance strategies.

Maintenance measures

The four main maintenance measures mentioned by the respondents are patching, asphalt overlay (reinforcing), milling (planning) in combination with asphalt overlay and total reconstruction of asphalt or cement concrete road. Again, the mentioned strategies match well with the types of strategies applied to the main road classes chosen by the respondents. Application of the aforementioned road maintenance treatments extends the pavement life considerably Coating and rejuvenators are not indicated as maintenance for a long term measures. They are mainly used as a short-term pavement life extension measure.

To what extent do you use the following maintenance measures?
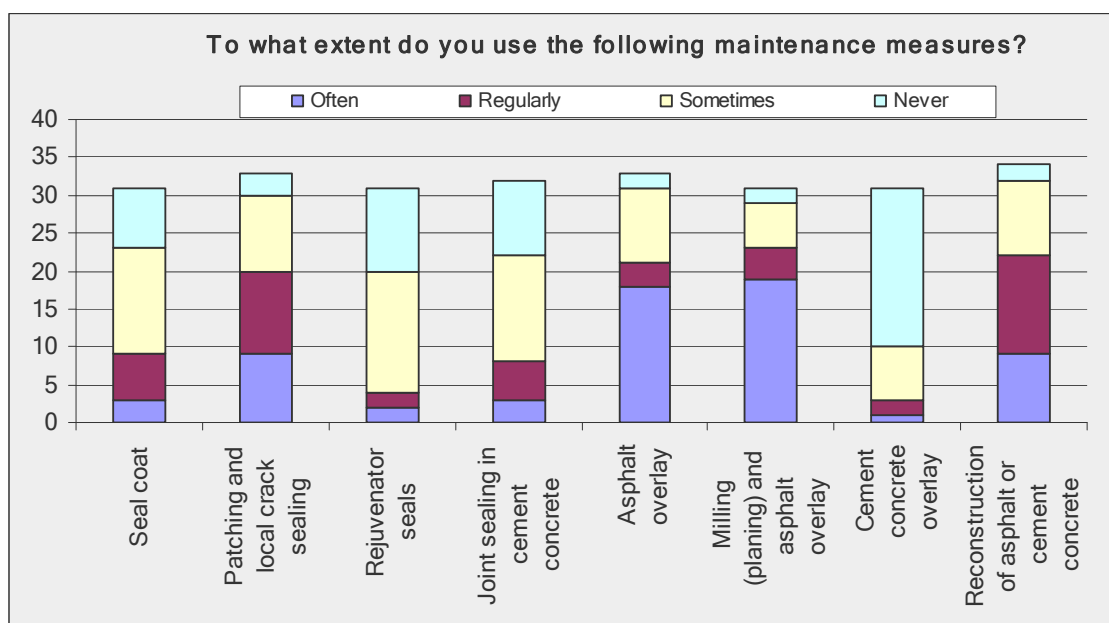
Figure 2.11: Relevant maintenance measures

2.6 Goals and results of the interviews

2.6.1 Interview goals and conclusions

From the survey and the meeting with the PEB it has become clear that the NRA's will be the main users. If the tool is adopted by the pavement experts from the NRA's, contractors will follow, since NRA's have a leading position as commissioners of road projects. Therefore the interviews were focused on the NRA's of the contributing countries of Era-net Road. Gerwin Schweitzer (Netherlands), Karl Fredriksen (Norway), Martin Strid (Sweden), Jørn Raaberg (Denmark) and Tom Casey (Ireland) have been interviewed. The NRA contacts from Germany and the UK have not been able to follow-up on our request.

In the interviews a set of general questions were asked as well as country specific questions related to the existing tools.

From the interviews some general conclusions could be drawn:

1. A new European CO_2 tool will be successful if it:
   - Is easy to use.
   - Is easy to update with new data.
   - Is giving the almost right answer as a rough estimate.
   - Can compile valid data throughout Europe.
   - Can be used by many.
2. The tool must be helpful and successful for decision makers at NRA's, contractors, consultants and clients.
3. The tool must be able to use both default general global values and country specific values.
4. The tool must be able to compare results within the country, and does not have to be suitable for international comparison or benchmarking.

2.6.2 Summary of the answers of the general questions.

In this paragraph an overall short summary of the answers to the general questions is given. The full descriptions of the individual interviews can be included later on in the appendix. General questions:

1. Which CO_2 tools do you know of and what are the positive and less suitable points?
   Summary: Different kinds of tools are used in the 4 countries, but not intensively. The repliers have no experience with the use of LCA tools and cannot give positive or less suitable points. Only the Netherlands seem to have used LCA tools more systematically.

2. What is – in your opinion – most important for the design of CEREAL?
   Summary: Designing a tool which is easy to use, easy to update with new data and which is giving the almost right answer as a rough estimate.

3. What kind of use do you see if you think about successful use of CEREAL?
   Summary: Helpful and a successful tool for decision makers in NRA's, contractors, consultants and clients.

4. What can be learned about the implementation of CO_2 tools in other infrastructural projects?
   Summary: It is difficult to compare different projects, and specific for the Netherlands the use of DUBOCALC and CO2PL is positive, but the main issue is data quality and availability.

5. What are the most essential elements in the scope of CEREAL?
   Summary: To have a tool which can be used by many and give the almost right answer. A normalized tool made compatible for input of new materials and innovations.

6. What is more important: quick (general) results or use of country and project specific data?
   Summary: Both are important. Use of default general indicative values, but also possibilities for country specific values.

7. What is the value of CO_2 data for your organisation? How will they be used?
   Summary: Important indicator for management of sustainability and important for communication on the political level. Assessment and choice of the project, either in investment or maintenance phase.

8. What – in your opinion – is the value of comparing results? (international / national projects)
   Summary: Only comparing results within the country, not for international comparison or benchmarking.

9. How will NRA's in Europe use a tool like CEREAL?
   Summary: Only answer from the Netherlands: different countries, different use!

10. What are success and failure factors for such a tool?
    Summary: Success: To have a tool which can be used by many and give the almost right answer and which can compile valid data throughout Europe. Failure: Problems with getting data and updating the database, which will lead to no use of the tool.

11. What should be the maximum time required to use CEREAL?
    Summary: Depend on the project (no specific answer!!)

12. Who would you advise to consult for the development of CEREAL?
    Summary: Harpa Birgisdóttir, Danish Building Research Institute, Aalborg University (experience with ROAD-RES) Susanna Zammataro (IFR) (experience with CHANGER). Different kinds of contractors and decision makers who need it.

3 Functional requirements

These Functional Requirements (FR) are based on the results and conclusions from the international survey and interviews (see chapter 2), the assessment of existing CO_2 tools and additional analysis and discussion within the CEREAL project team. A draft version of these functional requirements was reviewed in June 2012 by the expert panel, consisting of about 20 civil engineers of NRA's and contractors, which resulted in positive feedback and various good comments from technical to organisational, general to detailed. The document is revised according to these comments.

This chapter gives readers an overview of the content, structure and purpose of the tool. The functional requirements will be used as a guideline for the tool development. The tool developed within the CEREAL project will be called the Carbon Road Map and is henceforth referred to as such.

3.1 Goal & scope definition

Why should we develop Carbon Road Map?

From the survey and interviews it has become clear that most of the existing tools are not used or used only on a very limited basis, because they are too complex or require too much data. Furthermore, most tools are very country specific, which obstructs the comparison of projects among countries and makes it difficult to spread knowledge and learn from each other. The fact that there is no general European tool also leads to the development of more national tools in countries still lacking these tools. With the CEREAL project we aim to solve these problems.

What is the goal of the tool?

The overall goal of the tool is to calculate CO_2 footprints in road pavement construction and maintenance for different scenario's and thus help decision making on reduction measures for CO_2. The goal is to provide a user friendly interface (in Excel) that harmonizes existing national CO_2 tools, using country specific data. Since it is not possible to link existing tools, the contents of the tools will be used in the structure and database for the tool. This means harmonization is mainly focused at using the best available country specific data and definition of road structure and maintenance strategies.

The results should help NRA's with decision making in the design and maintenance phase by comparing measurement scenario's and/or different designs. (see also Outputs and Results) The tool will focus on CO_2 equivalent emissions as an indicator for sustainability, the correlated energetic footprint (in MJ) is out of the scope of the CEREAL project.

Who will be the main users?

The main users will be civil engineers working for NRA's and contractors in the EU (primarily North-Western Europe). The main users are involved in the decision making process for design and maintenance of roads. While the main focus is laid on design and maintenance, other purposes like monitoring and reporting will not be forgotten. The language of the tool will be English.

In which phase of the decision making process can the tool be used?

The tool can be used during the design phase and the maintenance phase (pave management). In both phases the tool will help NRA's and contractors to facilitate their decision making process by

providing data on CO_2 emissions of road projects. In principle the tool can also be used for contracting and realisation with default calculations or data prescribed by the commissioner.
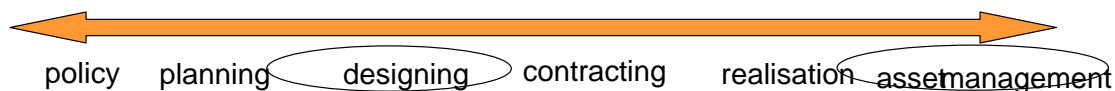
policy   planning   designing   contracting   realisation   assetmanagement

Figure 3.1: Phases for the use of the tool

What type of projects?

- The tool will focus on a predefined time horizon (e.g. 50 years) of road projects including dominant life-cycle processes such as construction and maintenance and all upstream emissions associated with these processes. It is assumed that no roads will be demolished without renovation or building a new construction and therefore final demolition (e.g. end-of-life of the road itself) is formally out of the scope and the demolition processes will be included in the renovation/reconstruction processes. Thus it is assumed that all roads will be continuously kept in operation by maintenance and reconstruction. The structural pavement life is in principal infinite, with a cyclic set of maintenance measures and strengthening activity. The end-of-life treatment of waste from the maintenance measures is included.
- The tool will make it possible to analyse new road pavement structures (green field), major renovation of roads and maintenance measures of roads.

Which activities are included or excluded?

- The tool will include all directly related activities for road construction and maintenance activities in the time horizon of the project (cradle to grave). This means production and transportation of materials, activities for realisation and re-use/recycling are included.

design   contracting   (re)construction   maintenance   demolition
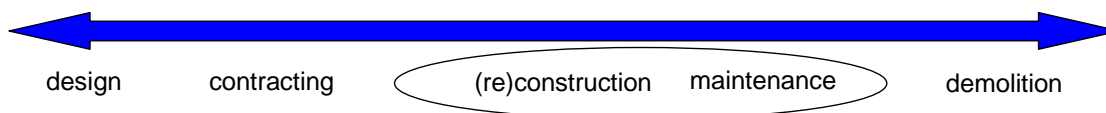
Figure 3.3: Main activities within the scope of tool

- Activities related to the design and contracting process itself (paperwork and people transport), and end-of-life demolition activities of the road are thus NOT included in the tool.
- All specific activities in construction and maintenance that contribute less than 1% of the overall footprint will NOT be included. The assessment of existing tools will help to identify all relevant activities and materials. Decisions on omitting less important processes will be made on the basis of the results of overall footprints reference calculations and pilot projects in the testing phase of the project.

Which objects are included or excluded?
- The tool will focus on the CO_2 impact of pavement construction of roads and all related activities to the maintenance of the pavement construction.
- Within the road construction we specifically define: fast and slow-lane(s), hard shoulders and exit and entry slip-roads.
- Hard shoulders and slip roads will be considered to be part of the road. Slip roads will be considered to have the same pavement structure and width as the truck traffic lane of the main carriage way. All slip roads will have a standard length and standard width in the tool. This implies that the user only has to specify the number of slip roads in the roadway section in the analysis.

- Generic, default data will be provided on other objects such as safety and noise barriers, tunnels, drainage systems and road markings if available. The reason to NOT include these objects in a detailed way, is that there is a lot of variation in the type of objects and therefore it is difficult to program in an easy way.
- The tool will NOT provide data on lampposts and traffic lights. These objects are very specific and probably will change many times during the time horizon of the project.
- The tool will NOT provide CO_2 data on emissions of road traffic (use of the road). It is well known that the emissions of the traffic are many times higher than the emissions related to the road maintenance and construction. The surface of the road, the cross fall, gradient and rolling resistance can be influenced by the pavement structure, but scientific information is scarce and is researched in the project "MIRAVEC". The CEREAL project therefore focuses on the direct influence of the NRA's on the road maintenance and construction. In the user guide or background documents, available information on the impact of the traffic will be included to inform the users.

3.2 Design Principles & Methodology

What are the guiding principles for the development of the Carbon Road Map?

- The tool will be developed in Excel, making it easy accessible and adjustable for all potential users. Users will be able to add data on specific materials used and processes applied.
- The tool will be transparent in calculations and data used (so calculations are traceable). The overview of data will highlight where default data is changed or substituted.
- The tool will make comparisons of various construction and maintenance options possible while providing clear overviews of in- and outputs.
- The tool will be easy to use by providing a simple user interface including default values (see figure 2.3). This means a standard calculation is available but individual parameters and data can be adjusted and added according to specific circumstances. The tool is open and gives more design freedom in the "detailed mode". Here the user can provide and analyse more specific and realistic data.
- The tool will be principally designed for the North-Western region of Europe. Later on, when sufficient information is available, the tool can be extended to the rest of Europe.
- The tool will include as much country specific data (general road structures, material production, transport distances, related maintenance measures) as necessary, derived mainly from existing CO_2 calculation models. Per sub region or country a specific dataset will be included and users will be able to add specific datasets.

What are the methodologies applied?

The structure and calculation rules of the tool will be based on general LCA principles (ISO 14040-45) as they are used for example in the Dutch models Dubocalc and AMW and a number of other models as well (e.g. Road-RES). CO_2 calculations will be based on the GHG-protocol, resulting in CO_2 equivalents.

Most recent and more specific protocols like the PAS 2050, ISO 14067, EPD-EN 15084 are all based on the ISO 14040-45 guidelines and focus on LCA, CO_2 and carbon foot printing of product life cycles. As the CEREAL tool will calculate projects consisting of materials and various activities these specific protocols are less suitable and do not have a lot of added value compared to the basic principles described in the ISO 14040-45 & GHG-protocol.

3.3 Structure of Carbon Road Map

What is the overall structure of the tool?

The Carbon Road Map can be structured in two levels: the "user interface" and the "calculation core". The database and the calculation rules will be hidden in the calculation core but of course the Carbon Road Map won't function without it. For example, while filling out the input data the user is offered sets of menus and multiple assisting choices of the database.
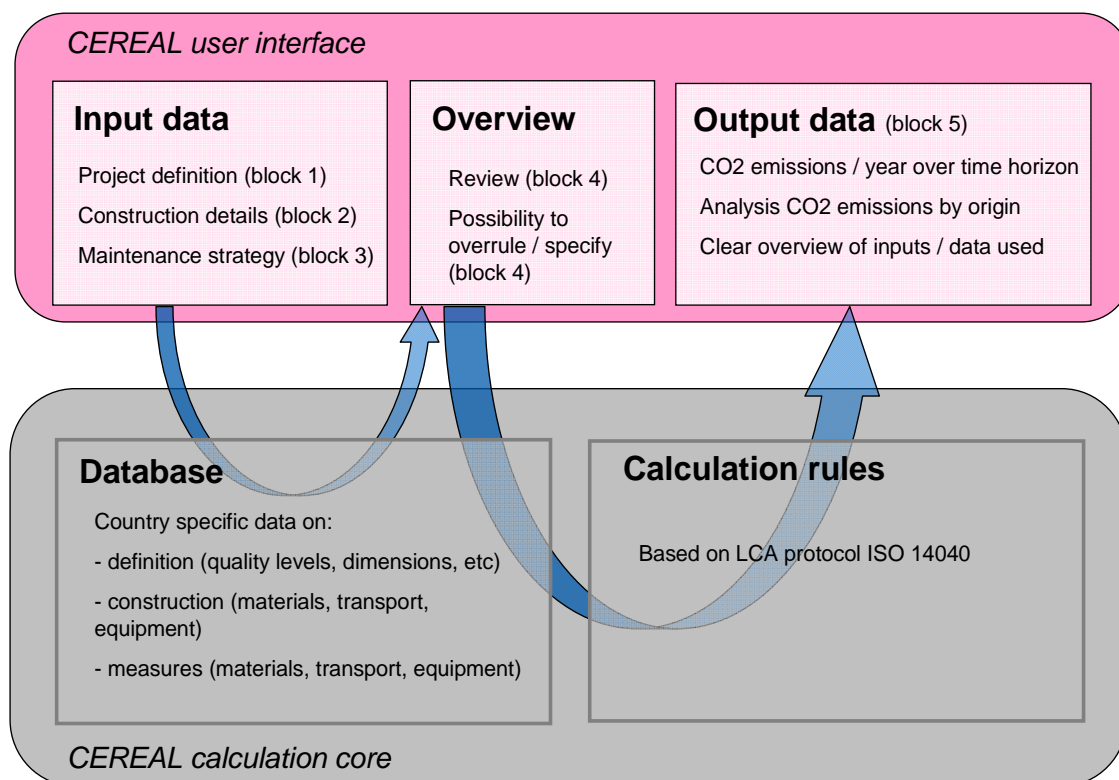
Figure 3.3: General structure of the tool

First of all, the user should provide all necessary input data (block 1-3), Table 3.1 gives a detailed overview of the various input data. Where possible, the user will be assisted by the tool by providing default values or sets of options.

Secondly, after providing all necessary input data, the user will see an overview of all data for facilitating review and further specification of all data (block 4). The user can decide to formulate extra strategies or options before (or after) generating results. By using the calculation rules the results of the strategies or options can be generated and analysed.

How can the user provide input?

The table below provides an overview of required user input and necessary actions to generate results. In the first block the user is asked to provide general information. For example in 1.2 the user will have to indicate the country where the road is located. This choice determines the type of database that will be used.

Table 3.1: Outline of input data (example)

User interface blocks		Explanation input parameter
1) Project definition (block 1)		
1.1	Type of road project	Menu: New construction, renovation, maintenance strategy [12]
1.2	Country / region	Menu: Denmark, Norway, Sweden, Germany, The Netherlands, UK and Ireland.
1.3	Road type	Menu: AC1motorway, AC2 motorway, AC3 motorway, etc. PCC1 motorway, etc. (numbers of lanes per direction) [12]
1.4	Identify elements	Menu: left/right lane, truck/slow lane, hard shoulders, slip roads, etc.
1.5	Length/Width	Open fields: length and width for all elements. (if possible, defaults will be derived from road type and country)
1.6	Traffic intensity ADT	Menu: ADT per carriage way
1.7	Time horizon project (in years)	Open field: # years
2) Construction details (block 2)		
2.1	Thickness of layers (of all elements)	Thicknesses will be derived from input on road type, quality level and maintenance strategy [9, 10, 11].
2.2	Use of (building) materials (of all elements)	Menu: asphalt type A, asphalt type B, asphalt type with 50% RAP, granular base course, soil cement, etc. (descriptions will be provided)
2.3	Transportation distances	Open field: providing default values for different materials per country (km's)
2.4	Means of transport	Menu: 10-20 ton truck, >20 ton truck, inland vessel, sea-going vessel, etc.
2.5	Other objects	Menu: tunnel, drainage, road markings, safety -, noise barriers
2.6	Number of other objects	Menu: # / km objects
3) Maintenance strategy (block 3)		
3.1	Maintenance strategies	Menu: Sets of maintenance strategies will be defined. The set will depend on the road type and whether the wearing course consists of an asphalt layer or a cement concrete layer. Each strategy will contain sets of maintenance measures. Strategies will range from sets of repetitive simple and cheap measures, e.g. patching and seal coats to structural solutions consisting of milling (planing) and in/overlays. (see table 2.2) [11, 14]
4) Review input data (block 4)		
4.1	Review input data	List of default and user defined input data. The user will be allowed to change the default settings or add new specific data.
5) Overview results (block 5)		
5.1	Result	General results visualized and detailed analysis in tables. (see figures 4-7 and table 4 and 5)

The maintenance strategies (including frequency of measures) will be based on general national/regional quality of roads. The quality indicators will be determined based on levels of acceptable distress per type per country and road type. This means that if the requested quality level is set higher, the frequency of maintenance treatments will be higher probably combined with a shorter time interval between two rounds of maintenance. Defaults for frequency will be derived from target quality levels, maintenance treatment and time horizon per country. An example for a set of maintenance treatments is demonstrated in table 3.2.

Table 3.2: Example of set of default maintenance strategies for different road types

Motorway / dual carriageway					
Year	Treatment	Area%	Out (mm)	In (mm)	
15	patching wearing course 10% area	10	40	40	
20	milling and inlay wearing course slow lane	30	40	40	
25	patching wearing course 15%	15	40	40	
25	slurry seal fast lane	30	0	5	
30	milling, strenghtening and wearing course full width	100	40	90	start new cycle
Motorway / dual carriageway porous asphalt					
Year	Treatment	Area%	Out (mm)	In (mm)	
10	milling and inlay wearing course slow lane	30	50	50	
20	milling and inlay wearing course full width	100	50	50	
30	milling and inlay wearing course slow lane	30	50	50	
40	milling, strengthening and wearing course full width	100	50	110	start new cycle
Motorway / dual carriageway or highway single carriageway, no height restrictions					
Year	Treatment	Area%	Out (mm)	In (mm)	
15	patching wearing course 10% area	10	40	40	
20	patching wearing course 15%	15	40	40	
25	milling, strengthening and wearing course full width	100	40	80	start new cycle
Motorway / dual carriageway or highway single carriageway, with height restrictions					
Year	Treatment	Area%	Out (mm)	In (mm)	
15	patching wearing course 10% area	10	40	40	
20	patching wearing course 15%	15	40	40	
25	milling and inlay wearing course full width	100	40	40	
25	extra milling and inlay binder layer	20	60	60	start new cycle

3.4 Database

What is the structure and content of the database?

The Carbon Road Map tool will make use of country specific databases in order to calculate with specific national data, as much as possible. General data will be extracted from LCA databases such as Eco-Invent 2.0. The following tools and included databases are indicated at forehand:

1) Denmark, Norway and Sweden (ROAD-RES as basis),
2) Ireland and UK (AggRegain and asPECT as basis)
3) The Netherlands, Belgium and Germany (DuboCalc and AMW as basis).

The (country specific) databases can be divided in three blocks: data on project definition aspects, data on design and construction aspects and data on specific maintenance measures (see figure 3.3). The list below gives an idea of the data that will be included:

- Definition: standard types of road types per country, dimensions of standard national road types (cross section and width) etc.
- Construction: various standard materials for pavement construction: approximately 15 strategies with min. 5 types of granular materials, cement concrete, road base, etc. per country, environmental impact reference values per transportation module, reference value for transportation distances for building materials etc.
- Measures/maintenance: various standard maintenance treatments: approximately 10 strategies for asphalt and 3 for cement concrete. Each strategy will consist of combinations of maintenance treatments ranging from simple to structural.

Which data sources will be used?

In total 15 existing road construction tools have been extensively assessed to investigate the availability of the (potential) data. A short summary can be found in Table 3.3, a detailed tool analysis is provided in chapter 4. Other tools that are assessed: JouleSAVE, GreenDot, Palate, Ceequal and HDM-4. Unfortunately Changer, Ceequal [27] and SEVE were not available for assessment.

Table 3.3: Data sources

CO2 tools	Relevant data
asPECT	CO2e emissions for asphalt with a very detailed input on energy and materials used, transport etc..
AMW	For the environmental data the DuboCalc database (version 2006) the concrete database version 3.1 and the asphalt database of Vakgroep Bitumineuze Werken (VBW)* have been used. The data has been completed with producer specific material for innovative asphalt applications and lightweight materials.
AggRegain	Process parameters of unbound, HBM, concrete, unbound (like emissions of mixing, laying, waste and conversion factors of energy carriers)
	CO2e emissions of various transport modes
	Emissions of (many) materials

	Detailed data of asphalt
ROAD-RES	CO2 impact of production of materials
	Upgrading residues
	Road construction processes
	Land filling processes
DuboCalc	CO2(e?) emissions of (many) materials
	Default values on maintenance measures.
	data on impact of building
Highway agency carbon calculator	CO2e impact of the productions of a wide variety of materials
	CO2e emissions of various transport modes

*The Vakgroep Bitumineuze Werken' is a branche organization for the asphalt sector.

3.5 Outputs and Results

What type of results will the tool generate?

Besides the total of the CO_2 footprints of the analysis, the Carbon Road Map will provide results on specific activities and origin of the data. In the overview detailed numeric results are shown. In the result window graphs will be demonstrated including the total CO_2 equivalents per object (fast lane, slow lane, slip roads, road objects) for the project and the CO_2 equivalents per project phase.

Figure 5.9 in chapter 5 shows the type of results that will be generated.

Comparison of strategies is important and is a requirement. The tool allows for this type of analyses, for example by saving one strategy, changing some input data, analysing the modified version and comparing the results of both files. Within Excel file management is easy and different types of strategies and scenarios may be compared.

Detailed overviews

In the window results, the tool will also give an overall impact table providing all CO_2 generating activities/components broken down per phase (construction and maintenance) and strategy. The table has an 'explorer' like program. The table makes it possible to analyse the origin of the CO_2 data in more detail. The table 3.4 presents an example.

Table 3.4: Overall impact table (example)

Strategy A					Strategy B			
1	**Construction - truck lane**				**Construction - truck lane**			
1.1		Materials	20	kton		Materials	x	
1.1.1		Wearing course	5			Wearing course	x	
1.1.2		Base course	10			Base course	x	
		…				…		
1.2		Transportation	10	kton		Transportation	x	
1.3		Equipment	5	kton		Equipment	x	
2	**Treatment 1 - truck lane**				**Treatment 1 - truck lane**			
2.1		Materials	1	kton		Materials	x	
2.2		Transportation	0.5	kton		Transportation	x	
2.3		Equipment	0.5	kton		Equipment	x	
3	**Treatment 2 - truck lane**				**Treatment 2 - all lanes**			
3.1		Material	1	kton		Material	x	
3.2		…	0.5	kton		…	x	
4	**Treatment 3 - truck lane**				**Treatment 3 - truck lane**			
4.1		Material	1	kton		Material	x	
4.2		…	0.5	kton		…	x	

Table 3.5: Impact table structured by road elements and years (example) [kton CO_2e/year]

Road elements	Activities	Year 1	Year 1	Year 1	Year 1	Year 1	Year etc
Element A	Construction	30	0	0	0	0	
	Maintenance	0	0	0	0	5	
	…						
Element B	Construction	20	0	0	0	0	
	Maintenance	0	0	0	0	7	
Etc.							

4 Tool Assessment

4.1 Summary

This Tool Assessment outlines the pros and cons of 9 existing CO_2 calculation tools applied in road infrastructure projects over Europe in comparison with the results from a survey and interviews and the functional requirements. In total 16 CO_2 calculation tools were briefly assessed. Based on the criteria that the tool should focus on infrastructure and calculation of CO_2, 9 tools were selected for a more thorough assessment. The outcomes of this assessment are combined with the results of the survey and interviews and together form the base of the functional requirements of the CEREAL tool.

The goal, concluded from the survey and interviews, is to build a tool that:

- does not require a lot of data, but is open for adding project specific data,
- uses calculations that can be refined depending on the available information, using successive calculations.
- uses the best available engineering knowledge and process data resulting in easy calculation of reliable results.
- has predefined maintenance treatments and strategies based on present engineering technology that can be changed or added,
- includes primarily the full life cycle of roads, but focuses in more detail on maintenance projects and differences in maintenance strategies,
- includes the main road objects if sufficient information is available on the life cycle of road objects like tunnels etc.,
- uses existing databases and calculation rules from the existing models, with available country specific databases on e.g. maintenance measures, asphalt mixes, transport distances, electricity generation etc.,
- is designed to calculate carbon footprints of projects in North-Western Europe,
- does not include calculations on road user's phase based on road characteristics.

The general conclusion is that none of the existing instruments fulfils the needs expressed by the survey, the interviews and the Program Executive Board. An important reason for this is that the purposes of the existing tools are different from the purpose of the Carbon Road Map.

The following general conclusions can be drawn, resulting from the differences between the proposed Carbon Road Map and the available tools:

- None of the existing tools has the same objective as is preferred for the Carbon Road Map.
- Existing tools are mostly canned software (difficult to add project specific data) and are not transparent.
- Existing tools mainly require a lot of data and/or are complex in structure,
- Existing tools focus mainly on construction (new constructions) and give little variation on maintenance.
- European models appear to have problems with generating results in an easy way, American (US) models are more user-friendly than their European equivalents.
- European models contain the same scope or subjects as CEREAL and thus they contain useful components and material data.
- The DuboCalc tool, contains detailed information about the Dutch situation, whereas asPECT and ROAD RES do the same for the United Kingdom and the Scandinavian countries.

From this perspective the overview below gives the key pros and cons of the most valuable tools assessed in relation to the requirements for the new tool that resulted from the survey and interviews.

Table 4.1 Overview of the key pros and cons in relation to the requirements of CEREAL

CO2 calculation tools	Pros (one of)	Cons (one of)
asPECT (UK)	+ useful (accessible) database	- amount of input data needed
Afwegingsmodel wegen (NL)	+ transparent and easy in use + includes maintenance and rehabilitation measures	- no option of editing of adding to the database
AggRegain / ESRSA (UK)	+ useful (accessible) database	- input-intensive and detailed knowledge required
ROAD-RES (DK)	+ good methodological structure	- input-intensive and detailed knowledge required
DuboCalc (NL)	+ completeness and databases (NL)	- transparency of generation of results
JouleSave (EU)	+ includes effect of interaction between road (design) and traffic	- requires advanced knowledge of detailed road design
GreenDOT (US)	+ good look and feel	- based on US data / circumstances
PaLATE (US)	+ structure / look and feel	- based on US data / circumstances
WLCO2T (UK)	+ useful database based on Price Book (UK)	- not known

4.2 Availability and usefulness of existing tools

An important part of the CEREAL project is the evaluation of the existing tools that calculate the CO_2 emissions of road construction and pavement maintenance. This part of the project is termed 'tool assessment'. The goals of the tool assessment are:

- determination of the usefulness of (parts) of the existing tools;
- evaluation of the availability of the possible input data of the CEREAL tool.

With help of the expert-judgment of the CEREAL-team and the results of the survey the following 11 tools were selected for detailed assessment. Some other tools were also identified but were not analysed in detail (see list below). The tools that were assessed in detail are:

1) asPECT [7, 15]
2) Afwegingsmodel wegen [6]
3) AggRegain CO2e emissions estimator tool (ESRSA) [20]
4) ROAD-RES [25, 18]
5) DuboCalc [23]
6) JouleSave [8]
7) GreenDOT [21]
8) PaLATE [26]

9) WLCO2T
10) SEVE* [19]
11) CHANGER* [30]

*) Unfortunately these tools were not accessed. The reasons are elaborated in sections 4.3.10 and 4.3.11.

After a brief review the following tools were not analysed in detail because these are not suitable for the primary goal of the project:

- Écologiciel (Colas, France) [22]
- CO_2NSTRUCT
- LCI Model [13]
- HDM-4 [28]
- VETO [24]

4.2.1 Analysis approach

The CEREAL team divided the evaluation into three subjects:

1) Background of the CO_2 calculation tool
2) Technical related aspects
3) User related aspects

Furthermore these subjects contain the following assessment questions:

1) **Background of the CO_2 calculation tool**
   - What is the name of the CO_2 calculation tool and what is the language used?
   - What is the purpose of the CO_2 calculation tool?
   - What is the availability of the CO_2 calculation tool? Who can use the tool?
   - Which organisation developed the program?
   - Who funded the development of the CO_2 calculation tool?
   - For which region is the tool suitable?
   - Which protocol is used to calculate the Greenhouse Gas (GHG) emissions?

2) **Technical related questions**
   - What is the program language of the tool?
   - Is the source code (program language) transparent and easy to access?
   - Is the source data (databases) transparent and easy to access?
   - Is the data useful for implementation in CEREAL?
   - Is it transparent what the origin is of the source data?
   - Are the calculation rules transparent and easy to access/alter?
   - Are the results easy to reproduce?
   - Which kind of pavement does the program treat?
   - Which phase in the road lifecycle is the program for?
   - Which are the (main) inputs needed?
   - Is the database easy to change/add?

3) **User related questions**
   - What is the intended user group?
   - Who are the main users of the tool?

- How are the results used?
- For what purpose are results generated?
- Please judge the user-friendliness of the CO2 calculation tool
- Are the results of the CO2 calculation tool useful?
- For which type of use?
- For which type of organisation?
- How much time is needed to fill the model before you have results?
- Is this time in proportion in relation with the goal of the tool?
- Is the program easy to use?
- Does it provide a tutorial?
- Is there a clear user manual available?
- Is there a installed database to start working with?
- Are the needed inputs easy to gather and apply?
- What are the end-result units? (kgCO2e, €, other)

4.3 Detailed tool assessment

This section will elaborate on the benefits (pros) and drawbacks (cons) of the analysed tools. The complete lists of answers of the questions listed aforementioned (section 4.2), is provided in the annexes.

4.3.1 asPECT (asphalt Pavement Embodied Carbon Tool)

The program aspect [7,15] considers the CO_2e impacts of building and maintaining a road pavement, from sourcing raw materials and laying asphalt mixes to maintenance through periodic interventions to ultimate deconstruction. The protocol considers all emissions that contribute to climate change from sources including energy use, combustion processes, chemical reactions, service provision en delivery.

Notable positive aspects (pros) of this program that can be used in the Carbon Road Map are:

- **Calculation of the results for different phases of the project**
  This enables the user to see where the largest sum of emission takes place helping him to focus on those features only for accomplishing improvements.
  ➢ The Carbon Road Map should generate CO_2e per phase (construction, maintenance) over the years of a project.

- **Detailed level of environmental databases**
  The detailed level of the environmental database makes it possible to differentiate a lot among the asphalt mixes, energy source and equipment used. This means that calculations can be made very project specific rather than just generating a rough estimate.
  ➢ The Carbon Road Map databases should be editable for facilitating detailed project specific calculations.

Notable less suitable aspects (cons) of this program from which can be learned from:

- **Too detailed level of the database**
  The detailed level of the databases makes it impossible to use this program quickly from the start. For example, the need for specification of your own asphalt mix and origin of energy used during asphalt production makes it hardly possible for a non-specialist to acquire reliable calculation results or even rough estimates.

> ➢ The Carbon Road Map should have a default mode that enables non-specialists to perform some estimating calculations/comparisons between different constructions.

- **The program is limited to flexible pavements only**
  Comparison between asphalt pavements and cement concrete pavements, and to compare cement concrete mutually on the same basic calculation rules, is not possible.
  > ➢ The Carbon Road Map should allow entry of both types of materials and pavement structures.

4.3.2 AfwegingsModel Wegen, AMW 1.1

The CROW-software "Afwegingsmodel Wegen (AMW)"* [6] is an objective and transparent model where the user has the choice between several types of pavements: asphalt, cement concrete or block paving. The purpose of the tool is to provide a transparent and objective choice between different pavement types or maintenance strategies based on environmental, financial and other aspects as criteria.

Notable positive aspects of this program that can be used in the CEREAL software are:

- **Applicable for as well asphalt as cement concrete pavement structures**
  It is very well possible to compare energy consumption and CO_2 emission of asphalt roads to cement concrete roads within the same project, calculation rules and report. This really adds an extra choice to the users of the program.
  > ➢ This choice/comparison should be included in Carbon Road Map

- **Construction and maintenance / rehabilitation measures**
  Construction as well as major and local maintenance and rehabilitation measures can be defined. These measures may be applied at a given moment in time or cyclic.
  > ➢ Carbon Road Map should have the whole life cycle encompassing construction and maintenance in its scope.

- **Input can be saved to (re)use later**
  What we can learn from this is that saving of input and results adds to the user friendliness of the program. An export file of the results to Excel would make it even better for copying and pasting of the results in presentations or reports.
  > ➢ Carbon Road Map should give user the possibility to save (and re-use).

Notable less suitable aspects (cons) of this program from which can be learned from:

- **There is no option of editing of adding to the database**
  What we can learn from this is that a preset database is limited in its use in time and its users. Preset databases should be updated regularly preventing them to become obsolete and lack behind on material innovations. This might lead to incorrect use or no use at all for project specific calculations due to the fixed, preset (average) parameters. The unchangeable distance from asphalt plant to the project site is an example of an unwanted feature.
  > ➢ Carbon Road Map will have an open database in which project specific data can be added. However, user defined entries should be labelled as "user data" allowing to trace the origin of the data.

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*The "Afwegingsmodel Wegen (AMW)" is a decision model for roads.

- **The tool could be a little more user-friendly**
  The layout of the program makes it difficult to compare the differences and similarities in input between two constructions. The look of the window changes while working on a construction variant.
  - ➤ What we can learn from this is that a simple and consequent setup and "look" of the program makes it most user-friendly to work with. Consistency through the program and "knowing where you are" during input or in results will improve the user-friendliness.

4.3.3 AggRegain CO2e emissions estimator tool

The English AggRegain CO2e emissions estimator tool [20] focuses on giving an estimate of the climate change contribution by selecting different construction techniques and supplying alternatives (use of primary or recycled and secondary aggregates). The tool was developed by UK's TRL (Transport Research Laboratory) and funded by WRAP (Waste & Resources Action Program).

The tool itself seems not directly useable for the purpose of Carbon Road Map, mainly because of the large amount of data that is needed to generate results. However, the CO_2 emission sources are largely the same as the Carbon Road Map, so specific numbers are very useful.

Notable positive aspects (pros) of this program that can be used in the Carbon Road Map software are:

- **Detailed accessible databases with emission factors**
  The AggRegain tool provides a large database with CO_2 emission sources which are largely the same as the Carbon Road Map.
  - ➤ Carbon Road Map Table 4.1 Overview of the key pros and cons in relation to the requirements of CEREAL will make use of the data (CO_2 emission factors) for the UK situation.

- **Four types of construction applications**
  The tool assesses the carbon dioxide output resulting from four types of construction applications: bitumen bound, concrete, hydraulically bound, unbound.
  - ➤ This structure will be applied in the Carbon Road Map tool as well.

Notable less suitable aspects (cons) of this program from which can be learned from:

- **Large amount of input variables**
  Because of the large amount of input variables needed, the results are not easy to reproduce.
  - ➤ Carbon Road Map will work with a default and expert mode. In the default mode, little input data is required (and most detailed data is hidden) and in the expert mode the user can modify detailed choices.

  Not saving input data AggRegain is input-intensive and when generating a scenario or second option all the data should be provided (once) again.
  - ➤ Carbon Road Map will have an option to copy / take over the base-case inputs when a second option / scenario will be built.

4.3.4 ROAD-RES

The Danish ROAD-RES model [25,18] has two objectives: (i) to evaluate the environmental impacts and resource consumption in different life cycle stages of road construction with virgin materials and residues from waste incineration; (ii) to evaluate and compare two disposal methods for waste incineration residues, namely land filling, and utilization in roads. ROAD-RES was developed by the Technical University of Denmark in collaboration with the Danish Road Directorate, two incinerators and a contractor.

Notable positive aspects (pros) of this program that can be used in the CEREAL software are:

- **Possibility to use other databases**
  EDIP97 is the default life cycle impact assessment method in ROAD-RES. The user can, however, supplement the model with other life cycle impact assessment methods, such as Eco-indicator 95, Eco-indicator 99 or CML 2001.
  - ➢ This requires advanced software linked to other LCA software and thus will not be included in the Carbon Road Map tool.

- **Detail/focus in demolition phase**
  In the demolition phase, removal of road materials and disposal or recycling of the materials can be modelled as well as the rehabilitation of the area.
  - ➢ In reality, demolition of roads is something that hardly ever happens and is thus not included in the scope of CEREAL.

Notable less suitable aspects (cons) of this program from which can be learned from:

- **Complicated to use and not transparent**

- **Specific software required**
  ROAD-RES is developed as a software program using C++ and PARADOX database.
  - ➢ CEREAL will be developed as a (stand alone) excel based file

4.3.5 DuboCalc

Purpose of DuboCalc [23] is to optimize design on environmental impact (original purpose). Currently, DuboCalc is mainly used for contracting. The contractor with the lowest calculated environmental impact is awarded. DuboCalc was developed and funded by the Dutch Rijkswaterstaat (RWS).

The DuboCalc tool is canned software, since the focus is on contracting, no data can be added in an easy way. DuboCalc is not very transparent, has no focus on maintenance and the life cycle is predefined and is based on the Dutch situation. Therefore the model as a whole is not suitable to link to the Carbon Road Map tool, but the basic principles, calculation rules and data are.

Notable positive aspects (pros) of this program that can be used in the CEREAL software are:

- **Basic principles, calculation rules and data**

DuboCalc is a good example of how the Carbon Road Map tool could look like. It is pretty user friendly, the LCA methodology is good and there are useful databases for the user.
Carbon Road Map will copy the structure, methodology and data where possible.

Notable less suitable aspects (cons) of this program from which can be learned from:

- **Little variation in maintenance**
  DuboCalc focuses on construction / renovation and offers little detail in maintenance measures, due to a small amount of standard estimated (not specific) options to choose from.
  - ➢ Carbon Road Map will include detailed treatments in the maintenance phase of roads.

- **Not transparent in calculations**
  DuboCalc is not transparent in the way calculations are made. Results are not easy to reproduce. The database is managed by SBK (*Stichting Bouwkwaliteit*), data layer is owned by Conesco and RWS is the main user and overall manager (status mid 2013).
  - ➢ Carbon Road Map will include a sheet with an overview of data used, what is the base for the calculations.

- **Somewhat outdated data**
  Data is not easy to extract from DuboCalc. There is plenty of (typically Dutch) data available, although some data is old.
  - ➢ Old data is not always a problem as most development is not so fast. Carbon Road Map will hence make use of data from DuboCalc.

4.3.6 JouleSave

JouleSave [8] is a specific software product of an earlier European program. JouleSave is built as a additional module to the MX software, which is used by detailed (road) designers. The main comment on this program from which we can learn is that the specific software (MX) is only accessible to a very small user's group. Besides this small user's group the main comment is that the tool is hardly used, as far as known. As reason for this limited use the developers state that CO_2 is hardly ever a criteria for the detailed design, mostly functional requirements are leading. Road designers in this (final) design phase have little incentive to apply such a tool. JouleSave is too detailed in terms of input and output data (to be applied in final design phase) and too specific in the software (MX). The tool is therefore not useful for the intended user group of the Carbon Road Map.

Notable positive aspects (pros) of this program that can be used in the CEREAL software are:

- **Very detailed (integral) analysis possible**
  JouleSave makes it possible to include the CO2 effect of traffic related to the road.
  - ➢ This application is too detailed for Carbon Road Map.

Notable less suitable aspects (cons) of this program from which can be learned from:

- **Extraordinary knowledge necessary**
  In order to use (and access) JouleSave, the user should have good road design skills.
  - ➢ Carbon Road Map will not be developed for road designers.

4.3.7 GreenDOT

The purpose of Greenhouse Gas Calculator for State Departments of Transportation (GreenDOT) [21] is to calculate carbon dioxide emissions from the operations, construction, and maintenance activities of state Departments of Transportation (DOTs). GreenDOT was developed by ICF International and Venner Consulting and was part of the National Cooperative Highway Research Program (NCHRP) Project 25-25.

Notable positive aspects (pros) of this program that can be used in the Carbon Road Map software are:

- **Good look and feel for users**
  The interface and structure are very user friendly.
  ➢ The tool provides great inspiration of the 'look and feel' for the Carbon Road Map tool.

- **Provides good assistance**
  Most of the inputs are not easy to collect. However, the tool provides other possibilities to estimate these inputs.
  ➢ Carbon Road Map will work with defaults (and suggestions) in order to simplify the input for less frequent users.

Notable less suitable aspects (cons) of this program from which can be learned from:

- **Data is specific for US circumstances**
  ➢ Carbon Road Map will include European data.

4.3.8 PaLATE

The purpose of Pavement Life-cycle Assessment Tool for Environmental and Economic Effects (PaLATE) [26], is to calculate life-cycle assessment (LCA) of environmental and economic effects of pavements and roads. The program was developed by the Consortium on Green Design and Manufacturing, University of California, Berkeley and was funded by Recycled Materials Resource Center of the University of New Hampshire and the University of California Transportation Center.

PaLATE is a very useful tool because it has a very simple and clear structure. This tool can be an inspiration of how Carbon Road Map should look like. Notable positive aspects (pros) of this program that can be used in the Carbon Road Map software are:

- **Structure and look and feel**
  PaLATE assesses emissions associated with materials production, construction, transportation, and maintenance of asphalt and Portland cement concrete pavement, sub base, embankment and shoulders materials.
  ➢ PaLATE provides a good structure and great inspiration of the 'look and feel' for the Carbon Road Map tool.

Notable less suitable aspects (cons) of this program from which can be learned from:

- **Data is specific for US circumstances**
  ➢ Carbon Road Map will include European data.

4.3.9 WLCO2T

The WLCO2T tool [29] is developed by URS in the UK. Unfortunately the CEREAL team was not able to access the tool itself but only (one of) the database(s). Therefore no complete detailed analysis was possible.

Notable positive aspects (pros) of this program that can be used in the CEREAL software are:

- **Provides good UK data**
  The unit costs are generic and are taken from previous work done by the Highways Agency.

The emission factors for each activity are based on CESSM3 Carbon and Price Book.
➢ Carbon Road Map will make use of the same emission factors based on CESSM3 Carbon and Price book.

- **Opportunity to change and add (own) local data**
  The tool offers users the possibility to ad (own) locally available data.
  ➢ Carbon Road Map will offer this option as well.

4.3.10 SEVE

It was not possible to obtain the French model SEVE [19]. Therefore it is not assessed. Despite various attempts no password was provided by the organisation behind the program and thus no access was gained.[2]

4.3.11 CHANGER

The CEREAL team was unable to assess the CHANGER tool [30] issued by the International Road Federation (IRF). The tool seems to be distributed from Lausanne. For this reason Prof. André-Gilles Dumont of LAVOC in Lausanne was contacted for acting as a go between. Valuable information was gathered via Prof. Dumont, but unfortunately no CHANGER related information could be gathered. Review of a Powerpoint presentation by an IRF delegate shows that the programme is comprehensive and has good appearance.

4.3.12 Other tools

As mentioned not all identified CO_2 calculating tools are within the same intended scope of CEREAL. The following tools were briefly analysed but not assessed in detail.

4.3.13 Écologiciel (Colas, France)

Écologiciel [22] is the first carbon footprint comparison tool for road projects. The developer Colas was a key participant in the development of the eco-comparison tool known as SEVE® (see section 4.3.10).

4.3.14 CO2NSTRUCT

A database and Web application called CO2NSTRUCT has been developed starting from an intense research, analysis and data collection. The application proposed aims to quantify direct and indirect emissions associated with each item based on the database and to assign them to each stakeholder. This tool is a first approach to GHG quantification and allocation in the road life cycle, but is currently non-existent in state of the art, although there exist other attempts of quantification in specific road projects or in structures such as bridges.

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[2] Attempts were made by contacting Lars Ladehoff and Jean Paul Michaut: http://international.seve-tp.com, and password: admin@seve-tp.fr

4.3.15 LCI MODEL (EAPA/EuroBitume)

This tool is focuses on CO_2 emissions of materials and thus not constructions and maintenance [13]. The tool is also used in AggRegain. Therefore the use of the tool is included in AggRegain.

4.3.16 HDM-4 RUC

The HDM-4 RUC Model [28] is Excel-based and focuses mainly on the user phase of a road. It could therefore be useful for estimations in the user phase.

4.3.17 VETO

The program VETO [24], which was developed by the Swedish National Road and Transport Research Institute, predicts fuel consumption on the basis of pavement parameters such as IRI and texture depth. It does not calculate the emissions of the construction phase.

4.4 Conclusions of the tool assessment

4.4.1 General findings

Generating results

In general can be concluded that the European tools appear to have problems with easy generation of results. They are usually complicated to fill with all necessary data. In most cases they are country specific and cannot be used Europe wide without adaptation in one way or another.

The use of the best available engineering knowledge and process data must result in easy calculation of reliable results. Easy generation of results, no complicated input data and European wide use are three important requirements of the Carbon Road Map tool. None of the existing tools complies fully with these specifications.

The assessed models from the United States are far more user-friendly than their European equivalents. They clearly separate 'general input data' from 'detailed input data'. They are therefore an inspiration for what a clear and user-friendly Excel-tool should look like.

Scope of the tool

Most of the European models cover the same subjects as Carbon Road Map will do. This implies that the existing tools contain components and material data that might be applicable to Carbon Road Map. The tool DuboCalc e.g. contains detailed information about the Dutch situation, whereas asPECT and ROAD RES do the same for the United Kingdom and the Scandinavian countries.

5 Tool Development

5.1 Introduction

The functional requirements and experiences with existing tools form the basis for the development of the Carbon Road Map. The Carbon Road Map is an Excel tool, including most necessary data to calculate carbon footprints of road project in an easy way, but the tool is also open for adjustment and addition of more detailed data.

The main features of the tool are:

1 The use of a so-called Navigation Ribbon (or Dash Board)

The lay-out of the tool is constructed in a series of logical, consecutive steps, visualized by a "Navigation Ribbon" to navigate easily through the calculation.

Figure 5.1 The Navigation Ribbon

2 The use of two different „modes", default and expert

The use of 2 different modes is based on the fact that in many cases not a lot of specific CO_2 data is available. A first estimate of the carbon footprint can be made by using the default calculation with a minimum of input data. In the expert mode all data is visible and specific data can be changed or added. In this way the tool can be used by different types of users in a different way.

3 Inclusion of best available datasets from different regions

The data used are derived from existing tools and represent 3 regions: UK, Netherlands and Denmark/Scandinavia. It is possible to copy a country specific database and make adjustments or create a whole new database.

5.2 Project definition

The project definition is the general description of the project. In this step the project needs to be defined by entering strategic parameters of the project. These are:

- **Country**

The countries of Denmark, the Netherlands and United Kingdom can be entered in the tool. The number of countries is limited because only the pavement design procedures and emission data of these countries are entered into the database. To some extent, these data may also be applicable for other Scandinavian countries, Germany, Belgium and Ireland.

- **Type of project**

Either building a new road or maintenance of an existing road can be entered as type of project. When building a new road is chosen, the maintenance stage can be entered and assessed as well.

The tool encompasses assessment of the CO_2-emission of the construction phase of a road pavement structure and/or the rehabilitation and maintenance phase. The two phases can be assessed in aggregate, but the tool also allows evaluation of one of the phases only.

In the detail window the specific default values that are related to these calculations are shown. In the expert mode these data can be changed when the expert has more accurate data.

- **Length**

The maximum length of the main road to be analysed is 500 km.

- **Number of lanes**

The number of lanes might be either 2x1, 2x2 or 2x3.

- **Number of slip roads**

The slip roads (maximum 20) are all roads that form part of the main project. In case of a motorway with connections to the local road network, all connections may be considered slip road. Only one length and width of a slip road can be entered. This implies that in case of multiple slip roads average values need to be entered into the tool.

- **Project life**

The project life is the time horizon over which the project is analysed. The project life varies usually around 50 to 60 years. Preferably multiples of maintenance cycles should be used for the project life. The project life may not exceed 100 years.

- **Name of the project**

A unique project name can be entered.

5.3 Construction data

5.3.1 Mode of data entry

The new pavement structure that needs to be evaluated in terms of CO_2-emission can be inputted by the user without having to perform any design computation. The input may be just based on estimations or wild guesses of layer thicknesses and characteristics. However, for an accurate quantification of the CO_2-emission, the pavement structure should be the result of application of design software of a design catalogue.

The user has several options for the input of the pavement structure, i.e.:

- Entry of the layer thicknesses and material descriptions of an in-service road. This mode of entry applies especially to cases in which the CO_2-emission has to be assessed for the rehabilitation and maintenance phase only.

- Entry of the layer thicknesses and material descriptions resulting from design calculations made by a pavement design tool or from a standard pavement design catalogue.

- Entry of traffic intensities, pavement design life, type of road base and sub grade, etc. forming the basis on which the Carbon Road Map tool derives the most appropriate thickness of the total of the asphalt concrete layers or cement concrete layers. This mode of entry is useful when the user has no detailed data on the pavement structure yet, and still wants to have a clear picture of the CO_2-emission of various construction variants. This mode of data entry uses linear interpolation techniques on design results that have been found with well known design procedures and catalogues in various countries.

5.3.2 Quick structural design of pavement structure

In all modes of data entry, materials need to be extracted from the materials data base. This implies that when the user wants to use materials not forming part of the database, he has to add these data, together with their principal characteristics in the database first. The first two modes of entry of data do not need any further clarification. The third mode of entry of pavement structure will be explained stepwise below.

1. Choose country. Selection one of the countries implies that the country specific pavement structures will be proposed to the user. The pavement structures are either based on design procedures of that country or pavement structure catalogues. The following sources were used: KMW for the Netherlands [1], MMOPP for Denmark [2] , DMRB for United Kingdom [3].and Catalogue des structures de chaussées for France [4]. The last one was not implemented in the tool. In all cases the type of pavement structure (asphalt concrete or cement concrete, type of sub grade, road class and traffic intensity will be the important parameters.

2. Enter the following pavement structure and sub grade details

   - Entry of the layer thicknesses and material descriptions of an in-service road. This mode of entry applies especially to cases for the assessment of the rehabilitation and maintenance phase on existing roads.

   - Type of sub grade

   - Type and layer thickness of road foundation

   - Type of pavement: asphalt concrete, jointed concrete or continuously reinforced concrete

   The layer thicknesses of the capping layer (sub-base) between sub grade and road foundation is preset to a fixed value. This value depends on the type of sub grade. The following three parameters will be retrieved from the pavement structure database for computing the layer thicknesses.

3. Enter the following design criteria:

   - Design life in years (= TD)

- Percentage of truck traffic (=TP)

- Annual growth of truck traffic intensity (%) (=TG)

- Speed limit for truck traffic (km/h) (=TV)

- Average daily traffic intensity per direction of travel (= ADT)

The truck traffic growth factor is computed as follows. The truck traffic growth factor equals the design life (FG = TD), when the annual growth of truck traffic intensity is zero.

$$FG = \left((1 + TG/100)^{TD} - 1\right)/(1 + TG/100)$$

The adjustment factor for truck traffic speed, FTV equals 1,00 for design speeds of 80 km/h and more. For speeds in the interval between 20 and 80 km/h, the factor is computed as follows:

$$FTV = 6 \cdot TV^{-0,4091}$$

The design traffic load N_D over the design period is computed as follows, where W is the number of working days per year (set to 250).

$$N_D = ADT \cdot W \cdot FG \cdot TP \cdot FTV$$

This design load serves as input for the computation of the layer thickness of layer 1 (asphalt concrete or cement concrete). Figure 5.2 shows the computation schematically. The orange line is the design line. This line is represented by three sections: the minimum layer thickness, the maximum layer thickness and the traffic intensity dependent section. The sloping line is characterised by the pivotal point and the slope. The pivotal point is characterised by the reference traffic design load and the corresponding thickness of layer 1.
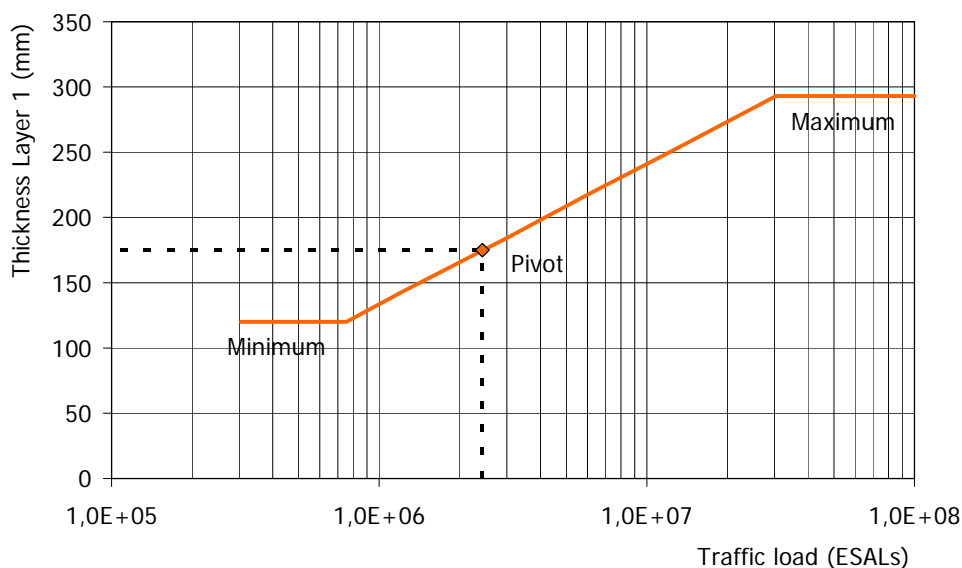
Figure 5.2: Schematic presentation of approach used for thickness design

The database contains many combinations of slope of design line, pivotal point, minimum thickness and maximum thickness. The numeric values of these parameters depend on the type of pavement, type of road foundation, thickness of road foundation, type of sub grade. The parameter values are country dependent and have been calculated by making pavement designs by accepted design procedures used in various countries [1, 2, 3, 4] and country. The procedure for calculation of the

slope of the design line makes use of the assumption that the logarithm of the traffic load has a linear relationship with the thickness of layer 1.

5.4 Maintenance

In the maintenance section, several common maintenance strategies are included for each road type. A maintenance strategy includes several treatments in a specific cycle.

- Source of the information
- Included strategies and treatments

In maintenance and rehabilitation distinction is made between maintenance strategies and maintenance treatments. A maintenance treatment is a single or combined remedial activity. A maintenance strategy is a combination of, usually cyclic, applications of treatments within the specified time horizon of the analysis period.

Table 5.1: Example of maintenance strategy

presents an example of a strategy for AC/PA repair at a dual carriageway consisting of three treatments. Actually two treatments are used, but the periodicity of treatment 111 on the slow lane is different from that of treatment 111 on the fast lane. Cycle means "and then every xx years". The example demonstrates that more maintenance is applied on the truck traffic lane than on the fast lane. Details of the treatments, such as proportion of the area locally planed, are provided in Table 5.4.

Table 5.1: Example of maintenance strategy

Id	Treatment	First year	Cycle	Lane
111	Planing wearing course + PA inlay	1	12	Slow
111	Planing wearing course + PA inlay	1	24	Fast
102	Local planing + PA patch	13	24	Fast

5.4.1 Strategies

Table 5.2 lists the default strategies in Carbon Road Map. The user may add or change strategies. Table 5.3 shows the composition of the strategies applicable to asphalt roads. The table presents the treatment ID and name, the first year of application, the periodicity and the lanes to be treated.

Table 5.2: Maintenance strategies predefined in Carbon Road Map

Type of pavement	Maintenance strategy
Asphalt	AC/PA repair - PA overlay and patching
Asphalt	AC/PA repair - AC inlay and PA overlay and patching
Asphalt	AC/PA repair - AC overlay and patching
Asphalt	AC/PA repair - AC inlay and AC overlay and patching
PCC	PCC repair - AC overlay and patching

PCC	PCC repair - PA overlay and patching

Table 5.3: Composition of predefined asphalt strategies in the Carbon Road Map

AC/PA repair - PA overlay and patching

Id	Treatment	First year	Cycle	Lane
111	Planing wearing course + PA inlay	1	12	Slow
111	Planing wearing course + PA inlay	1	24	Fast
102	Local planing + PA patch	13	24	Fast

AC/PA repair - AC inlay and PA overlay and patching

Id	Treatment	First year	Cycle	Lane
119	Planing wearing course + AC binder + PA overlay	1	48	All
111	Planing wearing course + PA inlay	13	24	Slow
119	Planing wearing course + AC binder + PA overlay	25	48	Slow
102	Local planing + PA patch	13	24	Fast
111	Planing wearing course + PA inlay	25	48	Fast

AC/PA repair - AC overlay and patching

Id	Treatment	First year	Cycle	Lane
110	Planing wearing course + AC inlay	1	15	Slow
101	Local planing + AC patch	11	15	Slow
110	Planing wearing course + AC inlay	1	20	Fast
101	Local planing + AC patch	16	20	Fast

AC/PA repair - AC inlay and AC overlay and patching

Id	Treatment	First year	Cycle	Lane
118	Planing wearing course + AC binder + AC overlay	1	30	All
101	Local planing + AC patch	11	15	Slow
110	Planing wearing course + AC inlay	16	30	Slow
101	Local planing + AC patch	16	30	Fast
101	Local planing + AC patch	26	30	Fast

5.4.2 Treatments

A maintenance treatment is a single or combined remedial activity specified by:

- Treatment ID and name
- Type of pavement to be applied
- Type of activity (e.g. planing, cleaning) and material (e.g. tack coat, asphalt)
- Area to be treated (in percentage of lanes specified)
- Depth of layer to be (partially) removed
- Thickness of inlay and/or overlay

Table 5.4 lists the default treatments in the Carbon Road Map tool. The user may add or change treatments.

Table 5.4: Treatments in the database of the Carbon Road Map

ID	Pavement	Stage	Treatment	Area (%)	Out (mm)	In (mm)
101	Asphalt	Repair	Local planing + AC patch	20	40	40
102	Asphalt	Repair	Local planing + PA patch	20	50	50
110	Asphalt	Repair	Planing wearing course + AC inlay	100	40	40
111	Asphalt	Repair	Planing wearing course + PA inlay	100	50	50
118	Asphalt	Repair	Planing wearing course + AC binder + AC overlay	100	50	60 + 40
119	Asphalt	Repair	Planing wearing course + AC binder + PA overlay	100	50	60 + 50
127	Asphalt	Reconstruction	Full depth reconstruction asphalt + AC wearing course	100	250	250
130	Asphalt	Reconstruction	Full depth reconstruction asphalt + PA wearing course	100	250	250
211	PCC	Repair	Crack & Seat + AC overlay	100	0	60 + 40
216	PCC	Reconstruction	Full depth reconstruction PCC	100	250	250

Each material per treatment is characterised by the material ID, material name, layer thickness (mm) and transport distance to the site (km).

Each equipment or activity per treatment is characterised by the equipment ID, equipment name and production rate (hours/m²). All emission related information of each type of equipment is identified by fuel consumption in litres per hour. All emission data in the database are referenced to their source.

5.4.3 Materials and equipment

The material data used in the Carbon Road Map are derived from a number of sources. Choices for specific sources are based on the results of the match between the functional requirements and results of the tool assessment. The data available in the specific tools that are from complete and trusted sources have been incorporated. Mostly country specific databases have been used.

The level of detail of the data was insufficient for some materials. For example, in order to distinguish different types of asphalt, a specific emission factor is needed for each type of asphalt. For part of the materials these were not available, resulting in the use of one general number for different types of asphalt.

The user may change data or add data to the materials data base. The most important material data are the density and the CO_2 impact per ton of material. In table 5.5 the specific materials and emission factors are listed.

Table 5.5 specifically shows that the CO_2 impact and sometimes even the density of certain materials may vary per country. The country specific databases used are based on various studies and may have used different methods of calculation and different assumptions. The studies, which

form the basis for these databases, show large data ranges and may have set different boundaries for energy usage. This explains the differences in CO_2 impact of the various materials per country. In this project the data in the country specific databases have been considered as fact. No further research in the background of all the numbers has been conducted. This should be taken into account when using the Carbon Road Map Tool.

Table 5.5: Density and CO2 impact of different materials

ID	Material	NL Density (kg/m³)	NL CO₂ impact (kg/ton)	DK Density (kg/m³)	DK CO₂ impact (kg/ton)	UK Density (kg/m³)	UK CO₂ impact (kg/ton)
1000	Peat	-	-	-	-	-	-
2000	Clay	-	-	-	-	-	-
3000	Sand	1700	2.7	1700	2.7	1700	5.1
4000	Asphalt concrete	2300	80.9	2300	30.4	2300	68
5000	Unreinforced cement concrete	2384	58.0	2384	98.3	2384	107
6000	Continuously reinforced cement concrete	2450	128	2450	120.5	2450	202
7000	Cement treated base	2384	58	2384	98.3	2348	107
8000	Blast furnace slag	2650	2.4	2650	3.8	2650	2.4
9000	Slag bound granular base	1950	2.8	1950	3.8	1950	2.8
10000	Unbound granular base	1800	2.8	1800	3.8	1800	2.8
10	Cationic asphalt tack coat	2100	277	2100	277	2100	550
20	AC11 Surf	2350	37.9	2350	30.4	2300	68
30	Porous asphalt PA16	2000	88.9	2000	30.4	2300	68
40	AC22 Base	2350	37.9	2350	30.4	2300	68
50	AC22 Bind	2350	37.9	2350	30.4	2300	68
80	Cold-applied slurry-micro surfacing	2100	277	2100	277	2100	550
130	Concrete PCC C35/45 CEM III	2384	58	2384	98.3	2384	107
160	Curing compound	1200	2910	1200	2910	1200	2910
170	Steel: FeB 220 Ø 20 mm - length 800 mm - spacing 250 mm	7800	908	7800	837	7800	450
180	Steel: FeB 500 Ø 20 mm - length 1000 mm - spacing 250 mm	7800	908	7800	837	7800	450
210	Steel: AC Reinforcement Mesh Track Bitufor MT1	7800	908	7800	837	7900	450

The sources used for the data for the Dutch situation are:
- www.gwwmaterialen.nl (a website for material parameters such as density)
- www.bodemrichtlijn.nl
- CROW
- Dubocalc library 2.2 (for CO2 data) [23]
- SBK (national environmental database) for CO_2 data (www.sbk.nl)

The sources used for the data for the Danish situation are:
- NORDEL data from the LICCER model (for CO_2 data)
- Data on density were not available and thus copied from the Dutch database.

The sources used for the data for the UK situation are:
- The Bath Inventory – Version 2.0 (2010) [17]

- For some of the materials UK specific data were unavailable and thus copied from the Dutch database.

For transports of materials off-site a general emission factor from NORDEL/LICCER is used and the transport distance is estimated. For a specific project these distances may be adjusted.

The use of specific on-site equipment for each activity or treatment has been calculated by using Easycalc [5], a tool for quantity and production calculations in the civil engineering and infrastructure sector. For each treatment of construction activity the use of specific types of equipment in hours was calculated.

The fuel consumption of each type of equipment is derived from the NUID energy spreadsheet, developed for ECRPD (from the Joulesave software) [33]. This database provided the most detailed data on equipment fuel use.

Table 5.5: Fuel consumption by equipment

ID	Equipment name	Country	Fuel consumption (l/hour)
102	Cold planer	All	51
122	Street sweeper/cleaner	All	10
165	Truck ca. 18 m3	All	13.5
182	Asphalt paver, incl. operator and screed man	All	28.75
206	Roller 9 ton	All	14
220	High-pressure air jet cleaner	All	36.3
260	Slurry micro-surfacing machine	All	10
292	Hydraulic excavator, tracks, bucket size 1200 litres	All	13
300	Slip form Paver, width 3,50 - 6,00 m, incl. operator	All	28.75
380	Tractor 145 pk, 4WD	All	15
400	Joint sawcut machine	All	12.5

Suppliers of equipment may have detailed information on the standard fuel consumption of a wide variety of equipment. These consumption rates may be added to the database, making it more tailored to the actual type of equipment used on a specific work.

The user should be aware that the effect of the type of equipment and/or the accuray of the fule consumption rates on the total CO_2 emission is limited. The proportional distribution of the material itself is of greater importance on the total carbon footprint.

Table 5.7 shows the use of type and quantity of material per treatment and the production rates of the equipment. Each material per treatment is characterised by the material ID, material name, layer thickness (mm) and transport distance to the site (km). Each equipment or activity per treatment is characterised by the equipment ID, equipment name and production rate (hours/m²).

Table 5.7 is explained by the following example. The roadway authorities of the dual carriage way A123 want to apply treatment 101 in the following year. They want to apply the treatment to the nearside lanes. The choice of lanes to which a treatment is applied can be defined in the set-up of the strategies in Carbon Road Map. The remaining characteristics of treatment 101 are presented in the top of Table 5.7.

The treatment consists of 40 mm deep planing of the existing wearing course over 20% of the surface area. The absolute surface area to be planed is calculated by multiplying the 20% by the product of number of lanes to be treated, average widths and lengths of the lane. The planed

sections of the road are inlaid by a 40 mm AC wearing course. In this case the exact type of AC is not specified in the name of the treatment. The differences among AC11, AC16, AC22, etc. are small in terms of equipment and CO_2 emission. The material column identifies the exact type of AC applied. The 250 mm thick reconstruction of treatment 127 consists of 140 mm AC22 base (ID 40), 70 mm AC22 bind (ID 50) and 40 mm AC11 surf (ID 20).

The planing requires no material but only equipment. The equipment descriptions are presented in table 5.7. Planing in treatment 101 makes use of a cold planer (102) and a street sweeper/cleaner (122). The last column of Table 5.7 shows that planing requires 0.0167 h/m² and 0.02 h/m² street sweeping and cleaning.

The AC inlay requires a tack coat and the actual 40 mm inlay. The material column of Table 5.7 shows use of a 0.29 mm thick tack coat (Material ID 10; see table 5.5) and the 40 mm thick AC surf layer (Material ID 20). The following equipment is needed for the inlay: a truck with a payload of 18 m³ (165), an asphalt paver with operators (182) and rollers (206). Their production rate is respectively 0.07, 0.02 and 0.04 h/m².

Only one type of truck, roller, etc. is defined in the standard database of Carbon Road Map. More detailed use of equipment can be user defined.

Table 5.6: Material and equipment used per treatment

ID	Treatment	Area (%)	Out (mm)	In (mm)	Material type (mm)	Equipment type (h/m²)
101	Local 40mm planing + 40 mm AC patch	20	40	40	10 (0.29) 20 (40)	102 (0.0167) 122 (0.02) 165 (0.07) 182 (0.02) 206 (0.04)
102	Local 50mm planing + 50mm PA patch	20	50	50	10 (0.29) 30 (50)	102 (0.0016) 122 (0.0014) 165 (0.0159) 206 (0.0039) 182 (0.0013)
110	Planing 40mm wearing course + 40mm AC inlay	100	40	40	10 (0.29) 20 (40)	102 (0.0032) 122 (0.0024) 165 (0.0188) 206 (0.0042) 182 (0.0014)
111	Planing 50mm wearing course + 50mm PA inlay	100	50	50	10 (0.29) 30 (50)	102 (0.0032) 122 (0.0024) 165 (0.0294) 206 (0.0084) 182 (0.0028)
118	Planing 50mm wearing course + 60mm AC binder + 40mm AC overlay	100	50	60 + 40	10 (0.58) 50 (60) 20 (40)	102 (0.0032) 122 (0.0024) 165 (0.0299) 206 (0.0086) 182 (0.0029)
119	Planing 100mm wearing course + 60mm AC binder + 50mm PA overlay	100	50	60 + 50	10 (0.58) 50 (60) 30 (40)	102 (0.0032) 122 (0.0034) 165 (0.061) 206 (0.0212) 182 (0.0066)
127	Full depth 250mm reconstr. asphalt + 250 AC layers	100	250	250	10 (0.878) 40 (140) 50 (70) 20 (40)	102 (0.0032) 122 (0.0034) 165 (0.061) 206 (0.0212) 182 (0.0066)

ID	Treatment	Area (%)	Out (mm)	In (mm)	Material type (mm)	Equipment type (h/m²)
130	Full depth 250mm reconstr. asphalt + 200mm AC base and binder + 50mm PA	100	250	200 + 50	10 (0.878) 40 (140) 50 (60) 30 (50)	380 (0.0004) 260 (0.0016) 122 (0.0016) 165 (0.0214) 206 (0.0084) 182 (0.0028)
211	Crack & Seat cement concrete + 100mm AC overlay	100	0	60 + 40	210 (0.2306) 80 (20) 10 (0.582) 50 (60) 20 (40)	292 (0.0206) 165 (0.0518) 300 (0.0046) 400 (0.0053) 220 (0.0053)
216	Full depth 250mm reconstr. PCC + 250mm PCC	100	250	250	130(250) 160(0.125) 170(1.00528) 180(1.57075)	102 (0.0016) 122 (0.0014) 165 (0.0159) 206 (0.0039) 182 (0.0013)

5.5 Overview of in- and outputs

In the overview of in- and outputs the complete calculation can be viewed. The CO_2 emissions can be traced back to the detailed input of materials by clicking the blue cells.

Table 5.7: Overview of in- and outputs
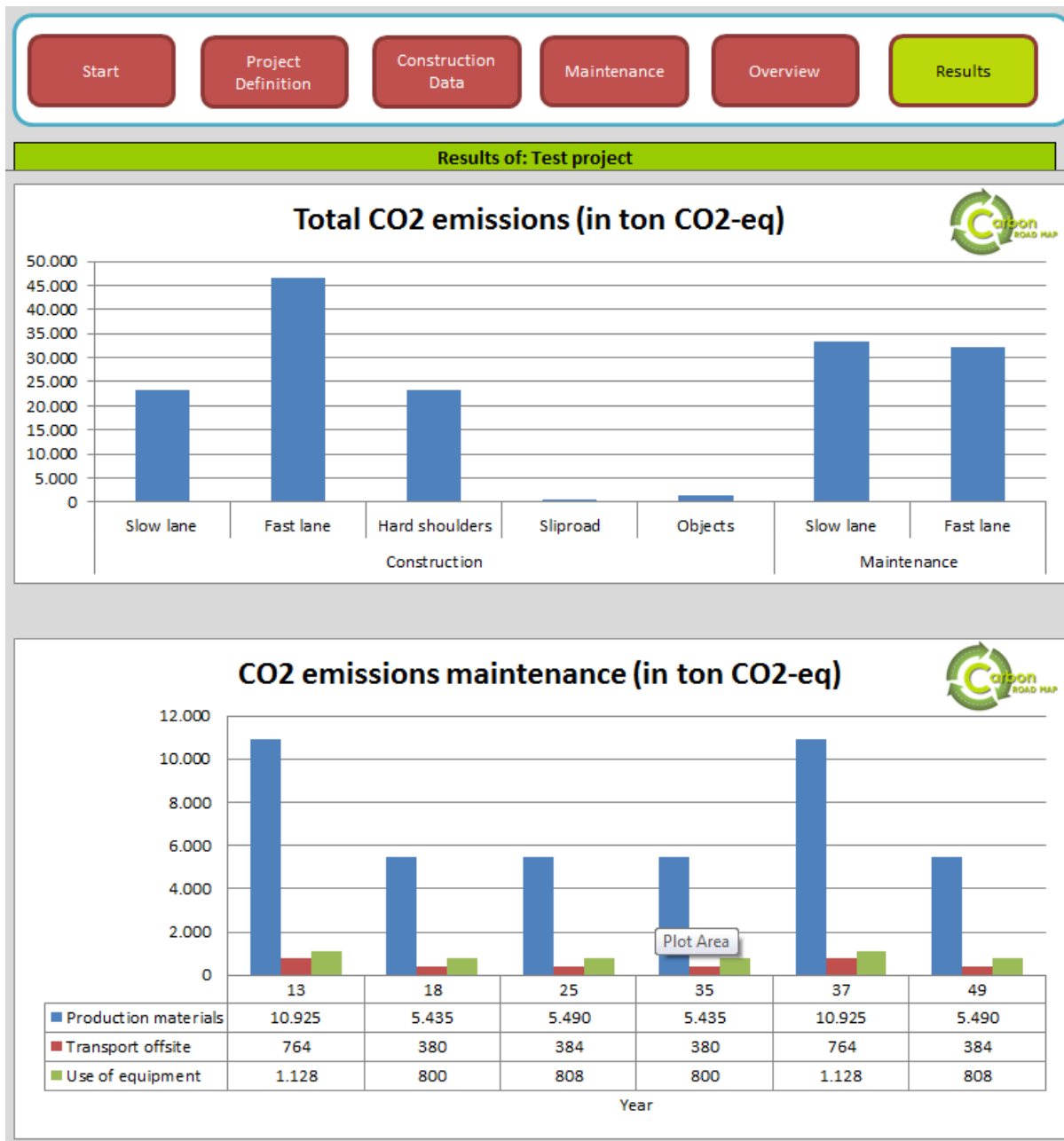
5.6 Results

Table 5.8: Results of the calculations

5.7 Testing of the tool

The beta version of the Carbon Road Map has been tested in several steps:

1. A series of internal tests and re-adjustments within the project team

2. An external test and survey among the members of the expert panel

3. Testing within the two international workshops

5.7.1 Internal test

The internal tests were carried out by calculating test projects and re-adjusting the model, removing the bugs.

5.7.2 External test

An external test was carried out within the expert panel. The model was distributed to the members together with a short survey. The expert panel includes 20 persons from different countries mainly in North-Western Europe. The response was 65% (13 respondents). The results of this external evaluation are summarised below:

- 80% of the responding experts are civil engineers from governmental organisations and contractors.

- The experts were positive about the navigation, the user friendliness and considered the tool as easy to use and easy to update.

- It seemed however that the experts were not so sure on the validity of the results and data and the use of the results for decision making.

A more elaborate description of the results can be found in appendix 2.

Based on the results of this evaluation the tool was made even more transparent; by creating extra windows in expert mode that show all data & sources in the databases and a detailed overview of inputs and outputs. The data quality of existing available data may still be an issue, but in the Carbon Road Map the best available data have been used. Improvements can be made by creating specific data within a project, but this will take quite some effort.

5.7.3 Testing in the workshops

In the workshops in Amsterdam, 15 November 2013 and Copenhagen, 9 December 2013, the adjusted version of the Carbon Road Map has been used and evaluated. The following questions were raised during and after the presentations. The responses are given directly after each question.

1 Can the Carbon Road Map be easily extended with pavement design rules for other countries?

The structural pavement design tool in the Carbon Road Map calculates the layer thickness of the asphalt or PCC layer for the inputted combination of type and thickness of road

foundation, type and thickness of capping layer, and type or stiffness modulus of subgrade. Five design coefficients need to be determined for each of those combinations for feeding the design tool in the Carbon Road Map. This exercise requires the design catalogues and/or design software of the country or region to be added. Computation of the coefficients is not really complicated but cannot be performed by the user. Once the set of coefficients for the requested number of pavement types for the new country or region are available, they can be entered into the Carbon Road Map. Some minor adjustments have to be applied to the current version of the tool for allowing entry of sets of structural pavement design coefficients.

2 How can I use the tool when the pavement structure of the road varies along the selected road section due to differences in support? One part of the road may have been constructed on an embankment, whereas the rest of the runs over a bridge.

When the width, number of lanes, layer thicknesses, etc. of a road pavement vary along the length of the selected section, the road section should be delineated into homogeneous subsections with the same width, number of lanes and layer thicknesses. Carbon Road Map must be run for each subsection separately. The results should be summed to obtain the aggregated result.

3 How can I use the tool when a dual carriageway consists of 2x4 lanes with a cement concrete pavement structure on the lane trafficked by the heavy goods vehicles and an asphalt pavement on all other lanes.

The Carbon Road Map is limited to defining 2x3 lanes. If the road under study contains four lanes per direction of travel, the analysis can be performed in two runs; one for the nearside lane and the other for the remaining three lanes. This approach can also be applied when the nearside lane consists of a different pavement structure or different materials than the other lanes.

4 Can the Carbon Road Map be used for analysis of bus lanes or lanes only open to heavy goods vehicles?

Yes, in the beta version of the tool demonstrated at the workshop the maximum percentage of truck traffic to be entered was limited to a value of 20%. This value should be lifted to 100% in the final version.

5 What should I enter in the Carbon Road Map when my road does not have any hard shoulders?

Just enter width = 0 m if a specific lane does not exist in your case study.

6 How can I enter a maintenance treatment that needs to be applied only once during the analysis period?

Enter in the maintenance treatment window under "First year" de year that the treatment should be applied. Enter a very high number under "Ten every xxx years". The value of xxx should be greater than the length of the analysis time horizon.

7   Can I assess the carbon footprint when I use four different types of asphalt layers in the total of asphalt layers?

Only the following four layers can be defined in Carbon Road Map: sub grade, sub-base, road foundation and at the top either asphalt or cement concrete. This implies in the case of an asphalt road that only one type of asphalt mix can be entered. However, Carbon Road Map tool can be tricked to enter the data of the other mixes. Enter the type and layer thickness of the asphalt base course in the program. Carbon Road Map has defined year 1 as the year of construction. In the definition of maintenance strategies and treatments the user may add his own set of strategies and treatments. In the case of this question, the user should define a treatment consisting of three different types of asphalt mix overlying the AC base course. The year of application of the treatment should be set to 1 (is equal to year of construction) and the cycle should be set to a value greater than the analysis time horizon.

8   In the definition of the thickness of the road foundation the tool will offer only two values (250 and 300 mm), what if another value should be entered here?

The restriction to the layer thickness of the road foundation only applies if the user wants to make use of the structural design tool embedded in Carbon Road Map. If you want to make use of pavement structure data collected in another different way, the following steps can be made. Fill all cells of the window "Construction Data". These data do not have to be indicative for your case study. Proceed to the window "Details" and change all data that need adjustment. In this way you can enter any type of material (as long as the material has been defined in the database) and any layer thickness.

Appendix 3 presents the PowerPoint presentation used at the workshop.

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