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CERCOM
Circular Economy in Road Construction and Maintenance

Review of Data Needs, Data Quality and Data Management Systems

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CEDR Call 2021: Transnational Road Research Programme

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Circular Economy in Road COnstruction and Maintenance

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Executive summary

This document carries out the objectives outlined in Work Package 2, Task 2.2 of the CERCOM project. Accomplishing the task's primary aim of facilitating the data collection necessary for developing the CERCOM Risk Based Assessment Framework (RBAF) in WP3 will require the completion of five key objectives, the results of which are described throughout this document:

1) Establishing data requirements of WP3
2) Mapping available data
3) Evaluating available data quality
4) Reviewing existing data management systems (DMS)
5) Recommendations for integration of data across Asset Management systems (AMS)

The goal is to identify and map out all relevant data available, as well as information required from national road authorities, and identifying the overlap in their standards for road maintenance and reconstruction, with the aim of harmonizing the tool's applicability across CEDR NRAs.

This will provide the means for developing the CERCOM Life Cycle Assessment (LCA) Road Modelling Tool in WP3, as well as establishing the data to be used in calculating the lifecycle environmental impacts of pavement maintenance strategies. The tool will require data at a disaggregated level in order to include the capability for users to define individual specified processes, and configure them into the specific maintenance scenarios being considered by the user and selected from a library of materials and resources. It will also be possible to import additional materials from Environmental Product Declarations (EPDs).

Integrating the CERCOM LCA tool with existing databases and asset management systems for pavement maintenance will connect sources of relevant data (e.g. geospatial data systems, object type libraries or road condition surveying data) with the tool thereby improving the representativeness of the tool's results, while expanding its applicability to support more decisions across a greater geographic range. The possibilities for this integration have been explored through a review of existing data and asset road management systems which have been used by the CERCOM project's partner nations.

1 Overview of LCA tool and Data Requirements

An LCA methodology will be incorporated into WP3's Risk Based Assessment Framework (RBAF), through the development and application of the CERCOM LCA tool. Developed under WP3, this tool will be based in Excel, and utilize lifecycle impact assessment (LCIA) data generated from modelling carried out in LCA software (i.e. GaBi)[1].

The tool will be comprised of three parts: An interface for the user to provide input; a library to provide data for the LCA impact calculations; as well as a dashboard to display results comparing the impacts of scenarios selected by the user. The results calculated by the tool will give an accurate account of the environmental risks associated with carrying out road maintenance over the course of multiple lifecycles. When using the CERCOM tool, decision makers within NRAs, will provide road and maintenance specifications for a specific proposed scheme through an interface. The interface will also include more generic predefined options, for instance where more specific data is not available. This will allow for more circular and resource efficient decisions to be made. The environmental impacts accrued over multiple lifecycles of the road are captured by the tool through increasing the period of time in years for which maintenance of the road will be assessed.

A modular approach will be taken in structuring the LCA tool's sections, as outlined in Figure 1. Beginning with Road and Assessment Specifications, where site specific data supplied by NRAs will be used in defining the context of the maintenance applications to be compared. Further modules include selection of maintenance strategies; unit processes; executions of maintenance; and lastly end-of-life treatment. NRAs would be responsible for providing data for standards, as well as site and country specific data in the first section, defining the context for road maintenance. The NRAs also possess information pertinent to maintaining a catalogue of all materials, unit processes, operations, and maintenance strategies, carried out during the entire life cycle, as described in this document.

Data collected and utilized in the development of the CERCOM LCA tool can be grouped into five classifications based on their source. Each maintenance method and its associated components (i.e. processes and operations, materials and resources, equipment and execution, and end-of-life (EoL) processes) are stored in the tool's library, and will draw on data sourced from NRAs, project research partners, generic LCA modelling data, EPD data, as well as data sourced from published research. By accessing the more advanced section of the tool's interface, the user will have the additional option to create and store custom entries in the tool's library where their own specific data a can be added. The data will also be qualified based on its geographic, temporal, and technological representativeness, as defined in the EPD standard (EN 15804:2012+A2:2019). The representativeness of the data source will be selected for in the development of the tools data library.

[1] https://gabi.sphera.com/nw-eu-danish/overview/what-is-gabi-software/

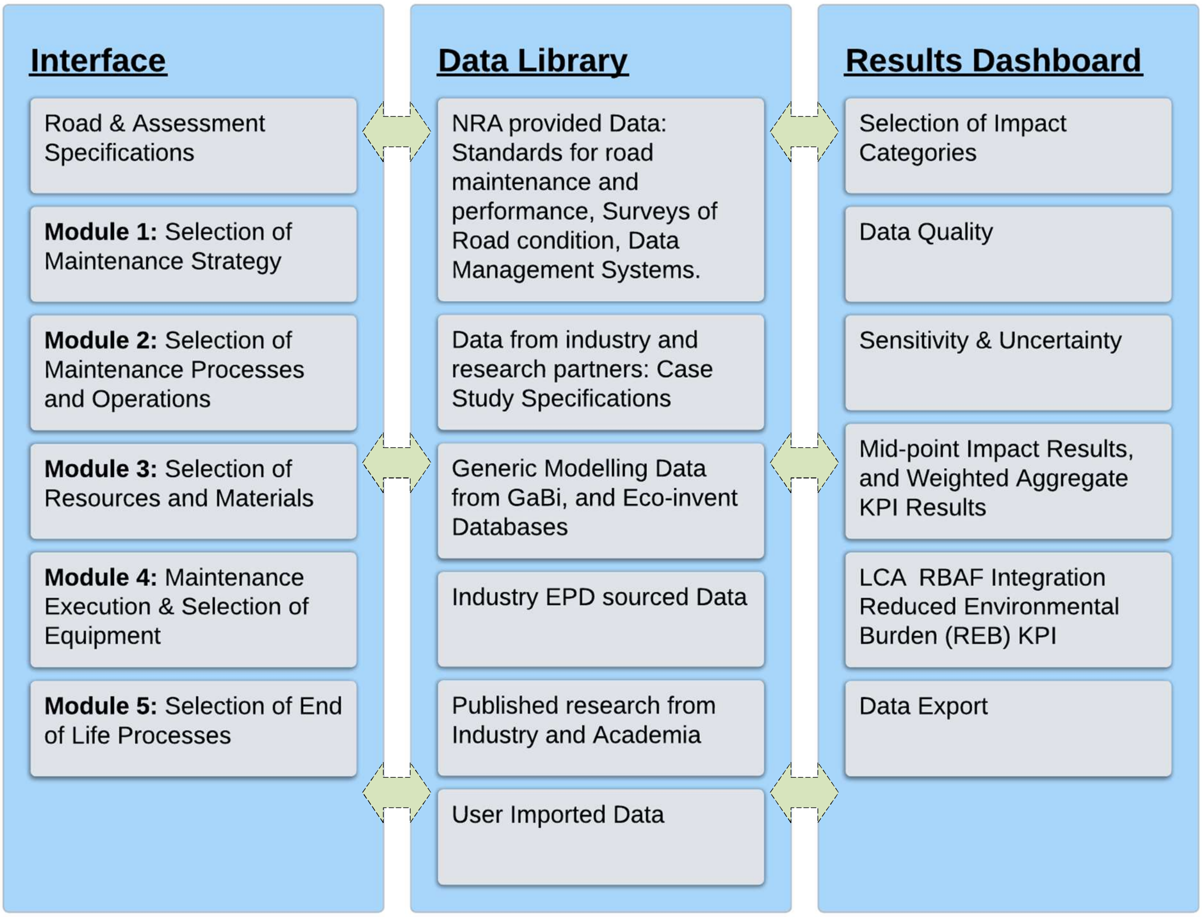

Figure 1: Overview of CERCOM LCA tool structure including interface, data library and results dashboard

The user will set the parameters of the assessment and select the scenarios for road maintenance using generic pre-defined modules. The interface will also have an advanced section where the user can specify their own modules to be stored in the data library and selected from the interface. The contents of the data library will include a catalogue of maintenance strategies, processes and operations, materials and resources, equipment and machinery, end of life processes, as well as the associated LCA impacts (i.e. characterization factors). The results section of the tool will provide a visualization, benchmarking the assessed maintenance strategies against a baseline reconstruction scenario where maintenance is omitted.

The results of the LCA will be quantified as mid-point impact categories. A weighting will then be applied to aggregate these impacts into a single end-point key performance indicator (KPI) representing a total environmental burden. This will allow for the subsequent integration of the environmental KPI into the comprehensive RBAF developed as part of WP3. Much of the data required for the LCA will also be necessary in quantifying the RBAF's additional KPIs, reflecting the specified scenarios technical, cost, resource efficiency, and social performances (Figure 2).

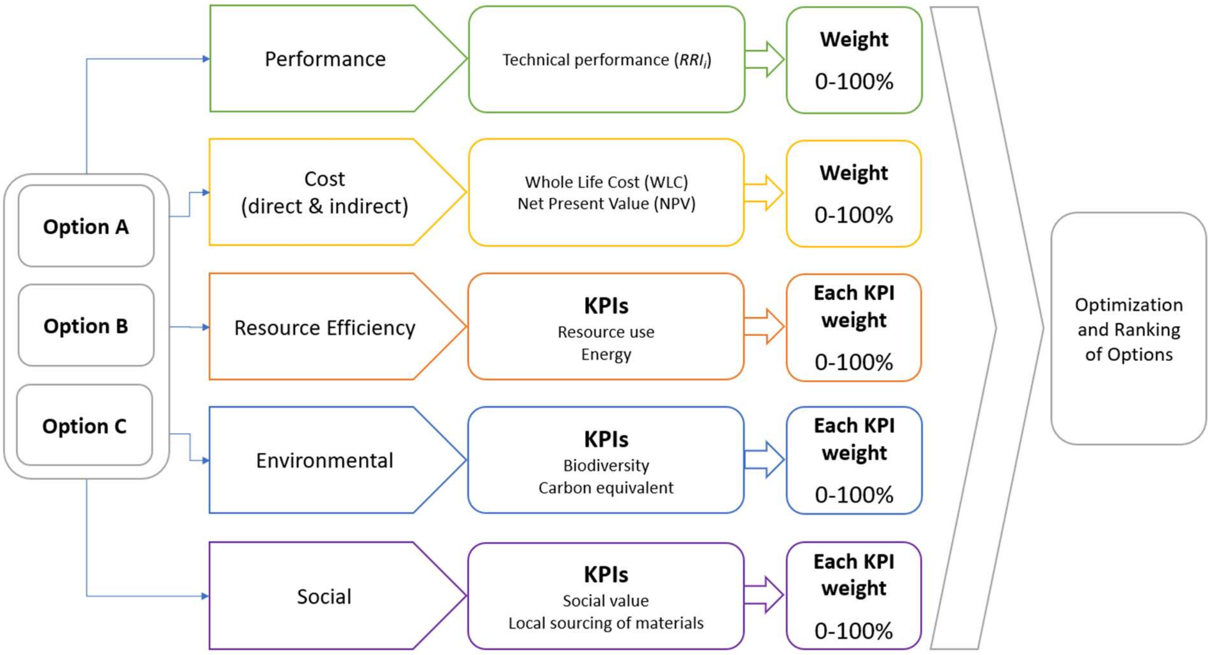

Figure 2: CERCOM Risk-Based Analysis Framework KPI division and weighting process developed in WP3

2 Interface and applied Data Library

The first section of the LCA tool's interface will specify the road for which the applications of maintenance strategies are to be assessed and will require data characterizing the standards for each sub-type of road (e.g. dual/single carriageway). Site specific data from road surveying should be used where possible. The NRA would be responsible for making this data available to decision makers and users of the tool.

Information defining each NRA's "do nothing" strategy, where roads are allowed to fully depreciate before reconstruction will also need to be collected. This will act as a baseline for which alternative maintenance strategies can be benchmarked.

Outlined below is a list of NRA provided data that will be relevant to the scope of developing the contextual options, which will be included in the tool from which the user can select:

- Specific data on traffic loading for each road type, such as equivalent single-axle load (ESAL) or million equivalent standard axles (MESA)
- Standard geometry of road dimensions (lane width and length) for each sub-type
- Site specific survey data on the depth and condition of each road layer. This would include the seal coat, the surface or wearing course, tack coat, the binder course, prime coat, base, and sub-base (in case of reconstruction scenario). Scenarios for road maintenance may include the removal of old (and potentially hazardous) materials no longer in use such as tar.
    - Other specific information could be derived from data from surveying, such as visual distress surveys (CVI, and DVI); dynamic plate tests with a deflectometer;

ground penetration radar (GPR) surveys; dynamic cone penetrometer (DCP) testing; data from coring samples, data from Sideway-force Coefficient Routine Investigation Machines (SCRIM) .

- Generic standard data on depth of road layers for each road type (Figure 3 and Figure 4). It would be beneficial to supplement data on road layers with available survey data.
- Generic data on the composition of each road layer. Input from available survey data will supplement data on road composition.
- Data on the materials and quantities used for road signing. The placement and maintenance of road signage will form part of the “do nothing” strategy.
- Functional lifespan of each road type as well as the associated extension in lifespan from each maintenance activity. It is assumed for the practicality of modelling, that the rate of degradation is linear over the road’s functional lifespan.
- A list of NRA enforced standards relevant to construction and maintenance of roads.

Along with NRA sourced data, the user will also need to select the number of scenarios to be assessed, the type of road (e.g. dual or single carriage way) being considered for maintenance, the corresponding road surface (rigid or flexible), and the number of lanes. In this section of the tool, the user will also select the period in years, for which considered maintenance strategies will be assessed, with a maximum period of 150 years. This selection of time will allow for the assessment to capture the impacts of recovering residual materials from road maintenance and recirculating them in place of virgin resources over multiple material lifecycles. The results derived from this assessment period are not intended to give an accurate account of the impacts that will occur over a period of 150 years as the uncertainty associated with these impacts increases exponentially with time.

Data on impacts accrued from use during the pavement’s functional lifespan will cover leaching of materials from the road surface into soil, ground water, emissions of Volatile Organic Compounds (VOCs) from materials processed and applied during reconstruction and maintenance of the road, as well as impacts on the fuel consumption and emissions of vehicles travelling on the pavement from suspension travel. The movement of vehicle suspension consumes energy which would otherwise have contributed to moving the vehicle and is a direct reflection of the road’s topology on a longitudinal profile. Impact of road topology on fuel consumption will be derived from the International Roughness Index (IRI). This index represents the accumulation of vertical forces applied to the suspension of a wheel travelling at a reference speed of 80 km/hr (Otto et al., 2019).

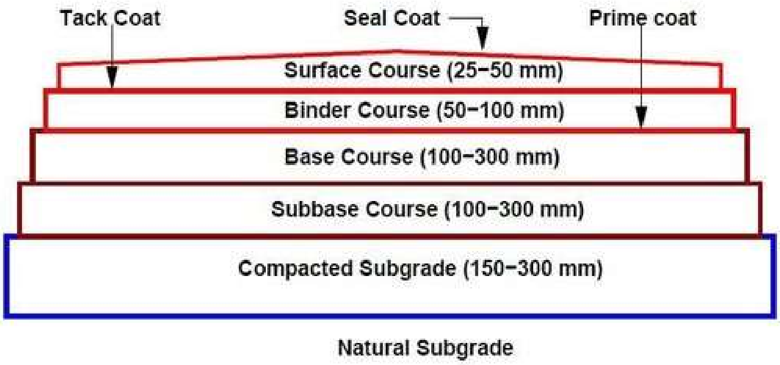

Figure 3 Road material layers from cross section of an Asphalt pavement road[2].

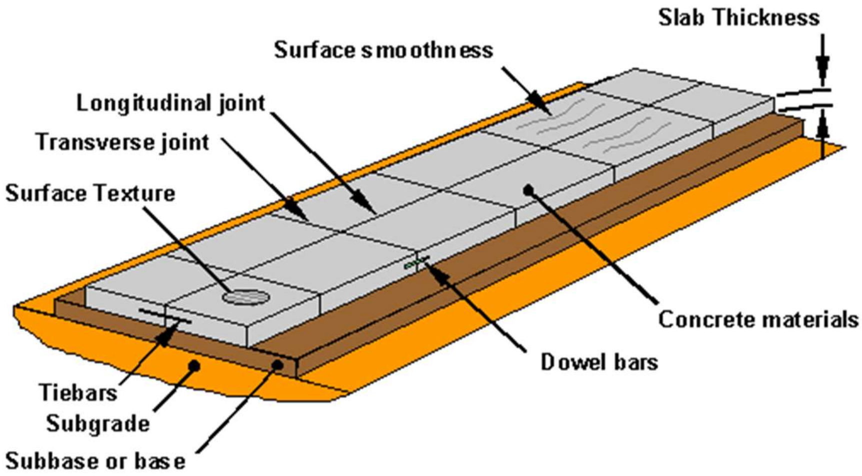

Figure 4 Concrete pavement structure[3].

2.1 *Module 1. Selection of Maintenance Strategy*

Once the specifications of the road have been defined, the user will select, for each scenario, the specific types of maintenance to be carried out. Each maintenance type will include generic input data, as well as the option for users to define specific compositions of material inputs and configure individual processes. The user will also need to provide data on the modes of transport (e.g. by rail, water, road, and air) and transport distances associated with the supply chain of materials (e.g. from point of extraction to production plant/depot, from extraction to site of operations, from production plant/depot to site of operations, and from site of operations to end of life (EoL) treatment).

A data catalogue of the below listed road maintenance methods will be included for both rigid and flexible pavement types in the tool's inventory.

[2] https://iconsmat.com.au/lesson/products/attachment/road00/
[3] http://metiebar.acpa.org/Concrete_Pavement/Technical/Fundamentals/

Flexible road surface maintenance treatments include:

- Road pavement resurfacing
- Asphalt patchwork repair
- Full depth repair
- Fog seals/rejuvenators
- Crack filling/sealing
- Chip sealing (surface dressing)
- Slurry sealing
- Micro-surfacing
- Ultra-thin and thin asphalt overlaying
- Ultra-Thin bonded Wearing Course (UTBWC)
- Bonded concrete overlaying
- Hot in-Place Recycling (HIR)
    - Surface recycling
    - Remixing
    - Repaving
- Cold In-Place Recycling (CIR)
- Open Graded Friction Course (OGFC)
- High Friction Surfacing (HFS)
- Rehabilitation / Reconstruction

Rigid Road Surface Maintenance treatments include:

- Crack Sealing
- Resealing of joints and cracks
- Transverse Grade reprofiling (TGP)
- Thin Asphalt Overlay on Concrete (ACOL)
- Partial depth repair
- Diamond grinding/grooving
- Slot/Cross Stitching (CST) and joint/crack sealing
- Slab undersealing
- Full depth repair
- Restore Load Transfer (RLT)
- Slab stabilization/slab jacking
- Dowel Bar Retrofit
- Ultra-thin bonded wearing course
- Bonded concrete overlays
- High friction surfacing
- Open Graded Friction Course (OGFC)
- Micro-milling

Data relevant in modelling the applied maintenance methods are outlined below:

- Data on the quantities and composition of input materials will be required for each selected process and operation (e.g. Binders (PFA, Cement, Bitumen)), aggregates (e.g. sand, gravel, crushed stone, manufactured aggregate, secondary aggregates, recycled aggregate), water, additives (e.g. chemicals, and fibers). Predefined maintenance methods will be characterized by data sourced from NRAs and supplemented with data from industry and published research. The user will also have the option to define their own tailored maintenance methods.

- Data on percentage recycled content of each input material will be collected from NRAs with regard to predefined input materials. The user will also have the option to provide input defining this parameter for each input.

- Quantities and composition of recovered residual materials (e.g. crumb rubber [substitutes binder, or mixture], mixed plastics [substitutes binder], steel slag [substitutes aggregate], lignin [substitutes binder], waste kitchen oil, and seed/nutshell liquid, bottom ash, fly ash, Reclaimed Asphalt Pavement (RAP), reclaimed asphalt shingles, shredded rubber tires, crushed glass, crushed concrete). The best available data would be sourced from NRAs, and supplemented with generic modelling data from Gabi, and eco-invent databases.

- Data on system outputs, which will include quantities and compositions of road material removed during maintenance operations. Predefined operations will be characterized by data from NRAs, supplemented with industry data and published research.

- Data on supply chain related transport of raw materials (i.e. distances transported, and mode of transport) will be provided by the user as input when using the tool.

- Life extension of the road associated with each maintenance type. The user will also specify the exact intervals over the selected assessment period (at which each maintenance operation and process would take place).

- Indication of reliability of maintenance activities/level of confidence in methods and materials/impact of premature failure of maintenance option.

- Impact of maintenance on the tyre rolling resistance, skid resistance, and the international roughness index (IRI). This will directly impact the fuel efficiency of vehicles travelling on the road. This data will be provided by the NRAs and supplemented with data from industry and published research.

For predefined maintenance methods data will be sourced from NRA's and supplemented with data from industry, as well as published research. The user will provide input to the interface of the tool when customizing the parameters of a predefined maintenance method.

2.1.1 Assessment of Case Studies

As part of the CERCOM project, a selection of three types of alternative maintenance strategies demonstrating principles of Circular Economy (CE) and Resource Efficiency (RE) were chosen as case studies to be assessed by the LCA tool. The assessment of these case studies will receive input from eight projects currently participating in CERCOM. These Case studies will be saved in the tool's library as predefined maintenance strategies which can be selected by the user.

Case Study I: Maintenance options for asphalt pavements (Flexible)

- In-situ rejuvenation
- Preservation of surface course with Rhinophalt Resin
- Refurbishing milled asphalt into new bound layers
- High recycled content surface course
- Waste plastic as warm mix modifier (new trial)
- BioBitumen - 100% natural binder and alternative approach to bitumen

Case study II: Recycling concrete technologies (Rigid)

- Processing technologies for aggregate recycling (ex/in situ)
- Recycled concrete from old and degraded civil structures

Case study III: Decarbonising pavement maintenance

- A systems approach to Circular Economy, which will include considerations for zero emission schemes, and integration of renewable energy generation technologies.

2.2 Module 2: Selection of Maintenance Processes and Operations

Each maintenance strategy will include processes and operations which will demand specific equipment and machinery. This will be selected by the user from a list of predefined equipment. Data will be required on all the individual processes undertaken for each type of road maintenance and reconstruction, including their associated energy and water requirements, as well as any associated efficiencies and losses. Data characterizing the included processes and operations will be sourced from NRAs and supplemented by generic LCA modelling data from the GaBi and Eco-invent databases. Modelling the impacts from unit processes and operations will require the following input and output data:

- Input: quantities and composition of all materials, and energy used in relation to each process. This data will be utilized in modelling predefined processes and operations, which can then be selected by the user for inclusion in the maintenance methods of their specific interest. The tool will also include the functionality for the user to build and store custom processes and operations within the tool's data library.

- Outputs: quantities and composition of residual waste generated by each process. This would also include direct emissions to air and leaching from the road. The outputs will be predefined by the selected process. The data on outputs will be collected from NRAs, and supplemented with data from industry, published research, and generic LCA data from GaBi, and Eco-invent.

2.2.1 Examples of process and operations configurations

A list of maintenance methods and their respective processes and operations are listed below, as examples for both concrete and asphalt pavement types, which will be part of the pre-set selection of maintenance methods within the tool. The predefined processes and operations within the tool can also be reconfigured by the user within the Advanced User Section (AUS).

Resurfacing
1. Surface removal
2. Sweeping \ cleaning of surface material
3. Applying bonding coat
4. Laying material aggregate
5. Rolling and Compaction
6. Marking and lining of road.

Patchwork repair
1. Cutting potholes
2. Cleaning of surface and application of priming coat
3. Preparing premix (coarse aggregate, bitumen, water)
4. Filling Premix and compaction and application of sand and grit.

Treatment of cracks
1. Cleaning with brush and compressed air
2. Application of kerosene oil
3. Application of Sealing compounds
4. Dust layer application

In-Situ Cold Recycling of Bitumen and Tar Bound Roads (Transport Scotland, 2021)

1. Milling: Removal of the upper layer of pavement. When the original upper layers are removed the depth of the pavement will increase, this will be corrected to the initial depth once new layers are established.
2. Pulverisation process of extracted materials for recycling creating a granulated aggregate
3. Stabilisation: Mixing with binding agents (cement or hydraulic biner), water and bitumen added. In the final phase of stabilisation, aggregate is laid and compacted.
4. Surfacing: stabilized materials are sealed with a bond coat prior to being surfaced with a layer of new asphalt, the thickness of which will be dependent on traffic loading requirements.
5. New standard surface coarse is laid over material

Concrete Maintenance, repair, and preservation methods

1. Crack Sealing
2. Resealing of joints and cracks
3. Transverse grade reprofiling (TGP)
4. Thin asphalt overlay on concrete (ACOL)
5. Partial depth repair
6. Diamond grinding
7. Cross stitching (CST) and joint/crack sealing
8. Slab Undersealing
9. Full depth repair
10. Restore load transfer (RLT)

2.3 Module 3: Selection of Resources and Materials

Listed below are the categories of materials and resources that will be included in the CERCOM tool to assess maintenance and reconstruction of roads. A complete list of all materials and resources within these categories can be found in Annex A. Mass and compositional modelling data will be required for each entry in the data library. An inventory of materials and resources to include would be sourced with input from NRAs and supplemented with input from industry and published research. The user will be able to add new resources and materials to the tools data library using EPDs in place of generic LCA modelling data. These custom entries can then be included as inputs and outputs in the processes and operations of customized maintenance methods, defined by the user.

1. Admixtures and Additives
2. Aggregates
3. Asphalt Binder (Bitumen)
4. Cementitious Materials
5. Electricity
6. Element
7. Fuel
8. Recycled, Co-Product or waste material
9. Steel
10. Concrete surfaces
11. Asphalt mixtures

12. Other

The tool will also include options for the user to create custom specified mixes of materials and processes for both asphalt and concrete. The interface for creating custom specified mixes will include an option for importing specific EPD data into the tool.

2.4 Module 4: Maintenance Execution & Selection of Equipment

Once maintenance processes have been defined, data will be required on the execution of road maintenance, this will primarily involve the logistics of transporting machinery and equipment from the depot to the site of maintenance and back, as well as the additional amount of fuel combusted from the rerouting of traffic associated with maintenance execution. The additional amount of fuel will also be dependent on the length of time the maintenance will take place. The high degree of variability of traffic rerouting will require that it be provided as input by the user (e.g. additional km driven from rerouting, along with number of vehicles rerouted) An aspect of road maintenance that must also be considered is what construction processes occur on site, and what processes and components are carried out off site. Collection of the following data will be sourced from NRAs where available and supplemented by industry published data, as well as generic modelling data.

- Resource Inputs (data on equipment mass, fuel type, and average operational fuel consumption in kWh for each piece of equipment or machinery being transported to the site will be required). For each selected piece of equipment, the user will provide an estimate for the total hours of operation required.

- Transport distances and transport type associated with moving each piece of equipment from its depot to maintenance site and back will need to be specified by the user.

- Outputs (residual losses and emissions from execution, this also includes materials lost as leachate during the roads operation). This will include data sourced from NRAs on leaching and emissions profiles from road surfaces during execution of maintenance as well as during road use. Instances where NRA data is unavailable, industry and research sourced data will be used.

- Data on the impact of traffic disturbance and flow rerouting on increased fuel usage and impact on fuel efficiency caused by the surfaces impact on vehicle suspension. This would include data on the change of total km of travel caused by the maintenance activities, as well as data on the impact of maintenance activities on skid and rolling resistance.

- Data specifying the road performance and rate of performance degradation will also be required. A significant portion of the total impacts related to road maintenance will be the impact of maintenance activities on the fuel efficiency of vehicles travelling on the road over the course of its use. This is directly related to the impact of the road surface topology on vehicle suspension, as well as skid and tyre rolling resistance, and how these characteristics change over time.

A selection of pre-set generic equipment relevant to the maintenance operations of concrete and asphalt pavements, are listed below:

- Milling/planning machines
- Asphalt Paving Machines
- Pneumatic Rollers
- Vibratory Compactors
- Sweeper/scrubber
- Surface Sealer
- Aggregate Trucks
- Excavator
- Wheel loaders
- Dumper
- Maintenance vehicles
- Tack coating machine
- Mobile cold mixing asphalt plant
- Cement and Mortar Mixers
- Cranes
- Material transfer vehicles
- Asphalt mixing operations (at plant)
- Concrete mixing operations (at plant)
- Slurry/Micro-surfacing machines
- Soil haulers
- Tacker/emulsion distributor trucks/spray trucks
- Tractors/backhoes
- Generic construction equipment
- Jaw Cone and Jaw Roll compaction crushers
- Horizontal Shaft Impactor

Additional equipment can also be added to the tool's library by the user. Equipment mass, fuel type, and fuel consumption will need to be specified by the user.

2.4.1 Impacts from road use and maintenance execution

Throughout the period where the road is in service, as well as during execution of maintenance, there will be a number of emissions which will vary depending on type and condition of the road, the processes employed, as well as environmental factors. Each of which are discussed in this section.

VOC emissions

Negligible amounts of VOCs are emitted from the lifecycle of rigid concrete pavements. The VOCs that are emitted come from the chemical additives to concrete mixtures. VOCs emitted from asphalt roads come from the use of cutback asphalt where solvents such as naphtha and kerosene are added to the asphalt (EPA, 2020). There are currently no regulations establishing limits on VOC emissions from road construction and maintenance operations. This is an area where data is lacking and more will need to be collected to ascertain extent of the impact.

VOCs emitted during production of materials such as bitumen from asphalt and concrete mixes will be covered by modelling data from GaBi and Eco-invent databases.

Leaching from road surface

Leaching from concrete road surfaces will be modelled according to the methodology from Butera et al 2015. In this study, leaching from road surfaces made with recycled construction and demolition material as aggregate was modelled as part of a larger LCA of construction and demolition waste.

Carbonation of concrete

Carbonation of concrete used in rigid type road surfaces will be included in the tool and will be calculated in accordance with the methodology published in the most recent EPD Product Category Rules (PCR) for concrete elements (EN 16757:2017).

2.5 Module 5: Selection of End-of-Life Processes

Lastly the user will select from a list of predefined end-of-life processes for each residual material removed from the road (e.g. cold mix asphalt recycling), as well as defining whether material processing occurs *in situ* or *ex situ*. The tool will include five primary treatment options: landfilling, onsite recycling, offsite recycling, reuse, and incineration. For each treatment option the user will also select the necessary equipment, as well as estimated hours of equipment operation.

A list of included treatment processes will be supplemented with input from NRAs. Data defining the properties of each included treatment process will be sourced from industry and published research. Generic modelling data will be used in instances where more specific primary data is unavailable. Outlined below is a list of data relevant for modelling end of life treatment for each type of residual material generated from road maintenance.

- A list of treatment processes for each material (e.g. cold mix asphalt recycling, hot mix asphalt recycling, rubblization).
- Inputs: Quantities and composition of all materials and energy required in processing each residual material for each treatment process.
- Outputs: Including all quantities and compositions recovered and recycled materials, as well as for residual materials which are incinerated, landfilled, or used as backfill. Data on any relevant emissions to air should also be included, as well as any wastewater generated, and leaching of materials.
- Transport type and distances for residual materials will be specified by the user; for residuals to the point of recovery when treatment occurs ex situ, and transport of equipment to the site when treatment occurs in situ.

3 Results Dashboard

Once the user has completed filling out all the specifications of their assessment through the CERCOM LCA tool interface, the user will be prompted to select a lifecycle impact assessment methodology prior to generating the results. The user will be able to select from a list of LCIA methods including: CML, ILCD, ReCiPe, TRACI, EPD, IMPACT, EF, and EPD.

3.1 Life Cycle Impact Indicators

The chosen methodology will define the midpoint impact categories (e.g. EPD impact categories listed below) of which all the elementary flows of materials and resources for each scenario will contribute to. The amount a specific flow contributes to each impact category will be based on the characterization factors implemented by each LCIA method. The characterization factors for each methodology will be stored in the data library. Once a methodology has been selected, the tool will begin generating a series of results which will be visualised in the tool's results dashboard, selected based on relevancy to the projects, potentially including:

1. Climate change – total, fossil, biogenic and land use	(kg CO2-eq)
2. Ozone depletion	(kg CFC-11-eq)
3. Acidification	(kg mol H+)
4. Eutrophication – freshwater	(kg PO4-eq)
5. Eutrophication – marine	(Kg N-eq)
6. Eutrophication – terrestrial	(mol N-eq)
7. Photochemical ozone formation	(kg NMVOC-eq)
8. Depletion of abiotic resources – minerals and metals	(kg Sb-eq)
9. Depletion of abiotic resources – fossil fuels	(MJ, net calorific value)
10. Human toxicity – cancer, non-cancer	(CTUh)
11. Eco-toxicity (freshwater)	(CTUe)
12. Water use	(m^3 world eq. deprived)
13. Land use	(Dimensionless)
14. Ionising radiation, human health	(kBq U-235)
15. Particulate matter emissions	(Disease incidence)

An overview of the average quality of data used in calculating the results will also be presented. This can give an indication of the uncertainty that should be associated with the results, as well as identifying data gaps that should guide any subsequent data collection efforts.

3.2 LCA → RBAF Integration

A weighting will be applied to the LCA impact categories in order to aggregate the LCA results into one environmental burden score(E_i), for each assessed scenario defined by the user (Eq.1). This weighting will reflect the degree of importance of each impact category to be in alignment with the priorities of the NRA.

A KPI representing the reduced environmental burden(REB_i) will be calculated, based on difference of the aggregated environmental impacts for each scenario(E_i), in relation to the aggregated environmental impacts of the reference "do nothing" scenario (E_{Ref}).

$$REB_i = \frac{E_{Ref} - E_i}{E_{Ref}} \quad \text{(Eq.1)}$$

The REB will then be incorporated into the RBAF's KPI, Net Risk Reduction Gain (NGGR), as described in D3.1.

Various other data aspects of standardised LCA information will be fed directly into the quantitative risk assessment process including technical information on required lifecycle, economic costs, uncertainty in test data, geometric data and end of life information. ThE CERCOM tool will incorporate a specific output protocol for data relating to the RBAF, facilitating the integration of the two methodologies together. Other specific data required for the RBAF is identified in CERCOM D3.1.

4 Data quality and availability

The quality of data utilized in the modelling of life cycle impacts associated with each resource is given in Annex B. The evaluation was carried out in accordance with EN15804 v.2019. The methodology prescribed by this standard evaluates data quality based on geography (Ge), time (Ti), and technological (Te) representativeness. Each of these three metrics are qualitatively assessed on a scale from very good (VG), good (G), fair (F), poor (P), to very poor (VP). The sources of data include certified EPD data directly from manufacturers and representative modelling data from GaBi and eco-invent data bases. This data will be used to model the lifecycle impacts of the activities they represent.

4.1 Resources and Materials

A high grading of quality was generally found in the available data for materials and resources when assessed according to the previously described EPD methodology. EPD data, GaBi and Eco Invent modelling data was able to source LCIA data for all materials mapped out in Annex A. Most of the data assessed was graded as having good to very good quality for all geographic, temporal, and technological categories, reflecting an extensive availability of high-quality data. This data will be utilized in modelling predefined processes and operations as well as complete maintenance strategies where the user will be able to specify road and assessment parameters. The complete assessment of data availability and quality for resources and materials can be found in Annex B. Some data which was graded as having less than good quality was selected as the only available modelling data from US EPD sources.

4.2 Equipment and Machinery

Modelling of equipment and machinery will primarily require data for the unit mass, fuel type consumed, and average operational fuel consumption in kWh. Both the mass and operational fuel consumption is highly variable to each individual unit model, its engine size, as well as its engine loading profile during use.

Each unit will include a mass classification divided into equipment weighing less than one tonne, between one and five tonnes, more than five tonnes. The fuel consumed during equipment operation is dependent on engine size, the average engine loading factor, and hours of operation (Eq.2). Data correlating fuel consumption and engine loading is very specific to each unit model and is not available. In its absence, average loading profile data will be used reflecting steady state engine conditions equivalent to the average load over 7 engine cycles (EPA, 2010). The user will be able to select from three engine sizes: less than 18 kW, between 18 and 75 kW and greater than 75 kW. The sources of modelling data available to these engine ranges can be found in Annex B. The Impacts associated with the use of each selected equipment will then be derived by the tool based on additional inputs provided by the user regarding fuel type and an estimate of operational hours required for the maintenance process (Table 1).

$$Fuel\ Consumption\ (kWh) = Engine\ Size\ (kW) * Avg.Loading\ Factor * Operational\ Hours \quad \text{(Eq. 2)}$$

Table 1: Data points required for equipment included in the data library.

Equipment Type	Mass [tonnes]	Fuel Type	Fuel Consumption [kWh]
Milling/planing machines	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	Eq. 2
Asphalt Paving Machines	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Pneumatic Rollers	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Vibratory Compactors	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Sweeper/scrubber	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Surface Sealer	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Aggregate Trucks	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Excavator	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Wheel loaders	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Dumper	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Maintenance vehicles	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Tack coating machine	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Mobile cold mixing asphalt plant	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Cement and Mortar Mixers	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Cranes	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Material Transfer Vehicles	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Asphalt Mixing Operations (at plant)	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Concrete Mixing Operations (at plant)	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Slurry/Micro-surfacing machines	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Soil Haulers	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Tacker/Emulsion Distributor Trucks/Spray trucks	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Tractors/backhoes	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Generic Construction equipment	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	
Jaw Cone and Jaw Roll compaction crushers	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	

Horizontal Shaft impactor	<1 tn, 1-5 tn, >5 tn	Diesel, Biofuel, fuel oil, Petrol	

5 Comparative Review of Existing Data Management Systems

This section details the current state of the art in managing pavement data across the United Kingdom, Ireland, Norway, Sweden, Denmark, The Netherlands, and Switzerland.

5.1.1 United Kingdom

Documents containing data covering England's classifications, road conditions, geospatial data, and road geometry are published by authorities through a web platform, The Single Data List (LGA and MHCLG, 2019). This data list contains data relevant to the condition of national and local roads, as well as their lengths, and geospatial data in GIS and GML formats.

Data relating to national road infrastructure managed by the NRA, National Highways, which includes trunk roads and motorways, is handled by the Highways England Pavement Management System (HAPMS).

The HAPMS stores data generated from TRACS and SCANNER methods for collecting road condition data used to calculate a road condition index (RCI) (Figure 5). These RCI values are then used to classify roads into red, amber and green (RAG) RCI performance scores as a way of planning maintenance and allocating resources (National Highways, 2020). Roads receiving an amber or red scoring are reviewed for consideration of maintenance.

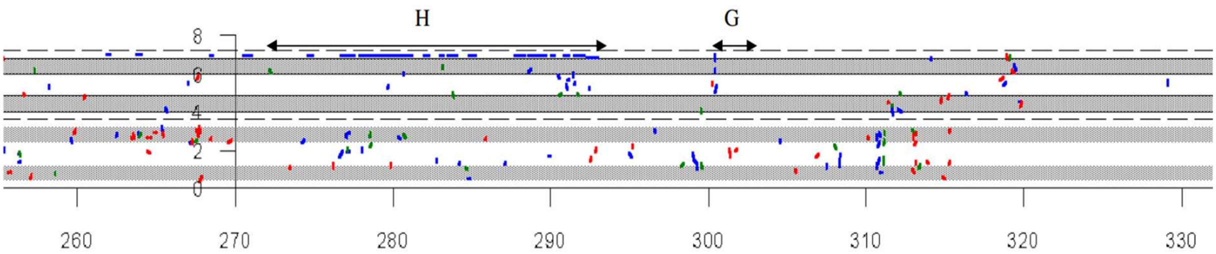

Figure 5: SCANNER Data for road tracking road defects

Data from a Carbon Accounting Tool developed in the UK for Road Maintenance could also benefit from being integrated with the CERCOM tool (National Highways 2021).

5.1.2 Ireland

The Irish Road authority, Transport Infrastructure Ireland (TII), has implemented a pavement management system which is based on the Deighton Total Infrastructure Management System (dTims) platform for managing road infrastructure. This management system is interlinked to a larger asset management system as seen in Figure 6. This system is widely used among road authorities around the world. The tool is used to predict future changes in road conditions and subsequent maintenance requirements over the course of a road's service life. This is the same platform being used in the development of the Danish Road data management system (TII, 2021).

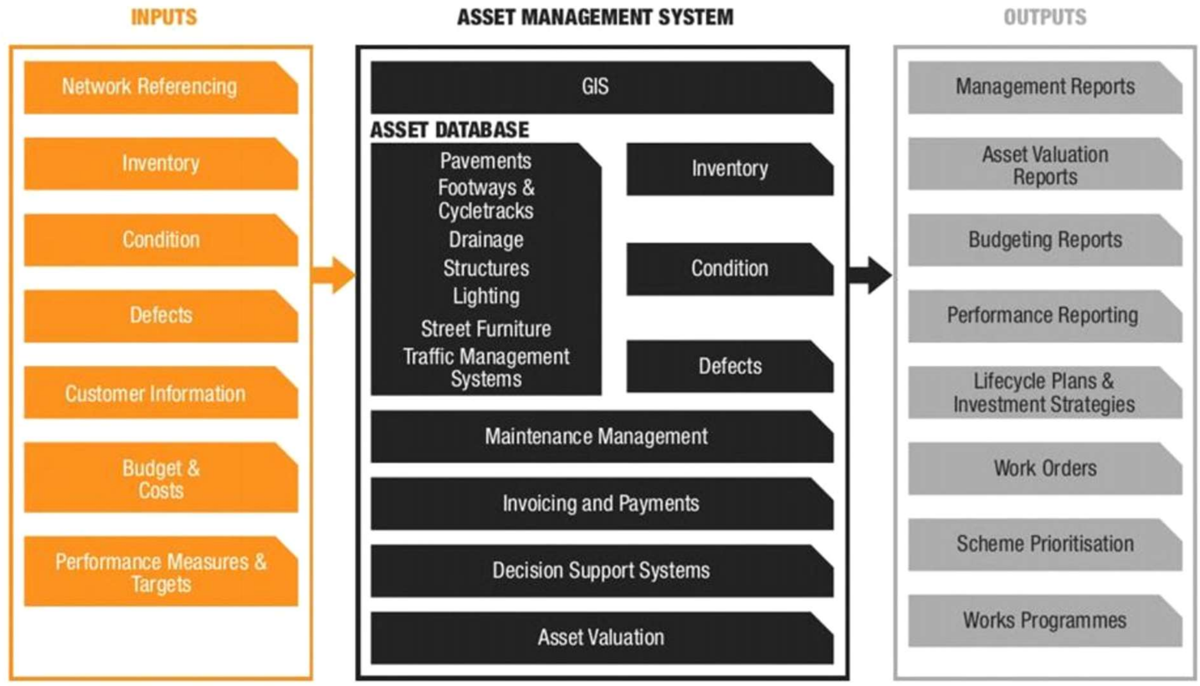

Figure 6: Transport Infrastructure Ireland's Asset Management System.

TII also has various other data systems in operation including, Eirspan SQL Bridge Management system, AFMS Asset Fault Management System, TII GeoApp, MMaRC RMMS, TII Defects management system, as well as TII ArcGIS Online (AGOL) web platform (Figure 7). The number of systems makes correlating data across assets a challenge (TII, 2021).

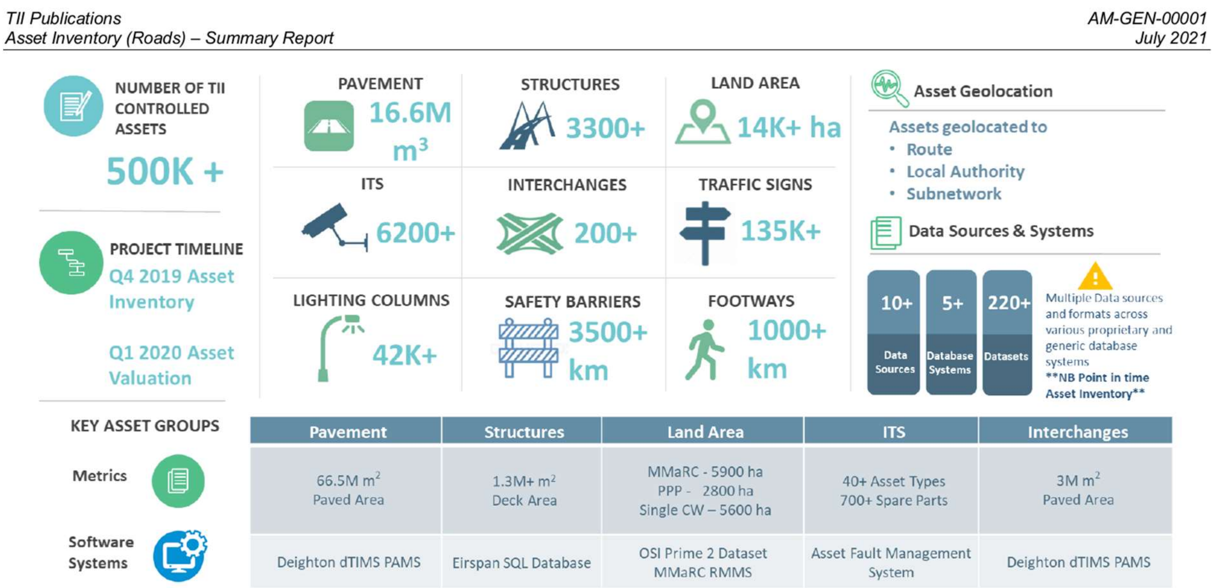

Figure 7: TII Asset Inventory Dashboard. Overview of asset data systems(TII, 2021)

5.1.3 Norway

The Norwegian NRA, Statens Vegvesen, has a national road databank (NVDB) containing data related to road infrastructure, which utilizes standardized data formats OpenTNF, CoClass, and InfraKit. The Triona company which also developed the road asset management system for Sweden, has developed the Asset Information Modelling (AIM) system for managing and integrating all road asset data in Norway (Figure 8).

Vegvesen has also prioritized as part of its transport system road map 2018-23 to establish a national access point (NAP) for road and traffic data (e.g. passenger vehicle sensor data), as well as defining the national architecture for data flow, ownership, and data criteria.

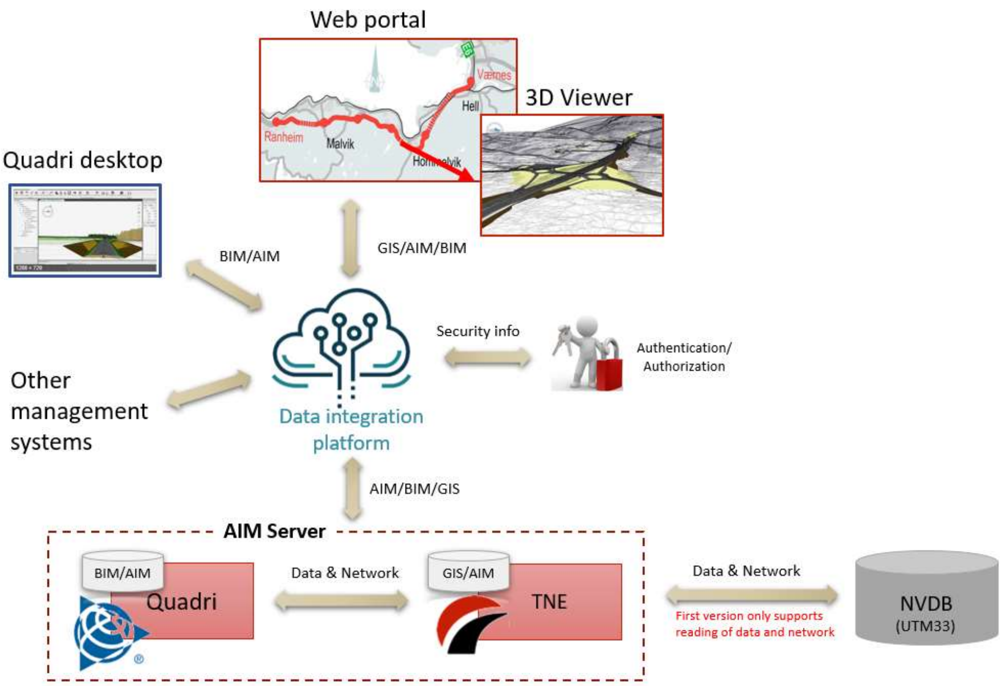

Figure 8 AIM solution for road asset management(Thomas 2020).

There has also been a collaboration between Dutch and Norwegian road administrations to create a data management system for bridges and roads

5.1.4 Sweden

Trionia have developed in collaboration with Trimble and BIMPRO, an asset management system for Sweden's NRA, Trafikverket (TRIONA, 2020). Pavement Data management systems, IDA, Chaos, BatMan, CoClass, InfraKit and NVDB are linked through this centralized asset management system, much like the system in Norway (Malmkvist, 2016). Several countries use this CoClas standard for organizing and standardizing information regarding road construction, including Norway.

5.1.5 Denmark

In Denmark a system is currently in development which is based on dTIMs, a pavement asset management system solution developed by Deighton. The Danish NRA have recently developed a new digital road information model called VIMO which will be incorporated into their processes for Data management (VD 2022). Datasets are publicly accessible at the National Access Point web platform, https://du.vd.dk/. Denmark is also implementing BIM principles into its infrastructure through its BIMINFRA initiative with a plan to reach BIM level 3 in 2022 (VD, 2018). Denmark also has a system for modelling CO2 emissions from infrastructure construction which follows the EPD methodology, called INFRALCA(Vejdirektoratet and Banedanmark, 2022).

5.1.6 The Netherlands

The Netherland's NRA Rijkswaterstaat publishes all their collected data related to road infrastructure on the Overheid.nl webportal. National Road data for pavements, road networks, and road quality is managed by the Winfrabase data management system (Figure 9) which makes up part of the NRA's Strategic Planning for Road Surfaces (MJPV). IVON2 is the underlying asset management system which functions at the level of managing the pavement and calculating proposals for technical planning of pavements (Rijkswaterstaat, 2015).

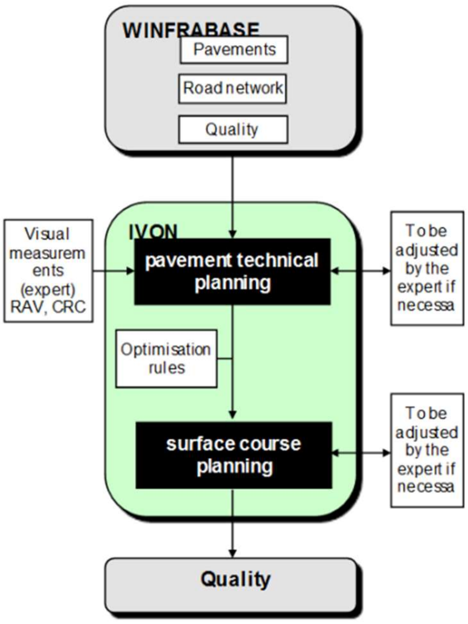

Figure 9: Pavement Asset Management System Utilized in the Netherland (Rijkswaterstaat 2015).

5.1.7 Switzerland

FEDRO or federal roads Office is the Swiss NRA responsible for road infrastructure and private road transport. In Switzerland, the Management Information System for roads and road traffic, MISTRA, contains object type data for all national roads. The system's geospatial data is not publicly accessible, however there does exist a MISTRA basis system where inventory objects of all national roads can be found (FEDRO, 2022).

Within the MISTRA system an application has been developed, TRASSEE (TRA), to manage objects in the road space including surveyed geometry, pavement structure, and characteristics (FEDRO, 2021).

6 Recommendations for integration of a Pavement LCA database through asset management systems.

Most project partners have existing data base management systems, forming part of a larger pavement asset management system for centralising data, which is accessible through various platforms (e.g. web platform and Application Program Interface (API)), while standardizing its format and documentation. In many cases these are a recent development from a more decentralized and localized state, where data would be siloed off within the systems of each local authority. Management systems for data and assets are developed in accordance with ISO 55000 and 55001 standards for asset management. The Integration of building information modelling (BIM) into asset management systems in accordance with PAS1192 has also been a growing trend among NRAs with respect to managing their infrastructure data.

A lack of compatibility between the various systems of data management adopted by each national authority creates a barrier to accessing, evaluating, and comparing data across systems. CEDR has been responsible for attempting to harmonize and interconnect systems across member states through transnational research programme calls to fund projects like ARISE, INTERLINK, and most recently CoDEC (CEDR, 2021), which standardizes data formats, provides best practice guidelines, develops methods for BIM implementation, and works towards aligning the AMS software industry with CEDR's BIM objectives (CEDR, 2022). Ideally these projects could link together the various AMS which exist within member states under one umbrella asset management network. The alignment of the CEDR's projects in Figure 10 illustrates how the CERCOM RBAF could be integrated with other data management systems through a larger asset management network. There have also been efforts to standardize the methods of collecting data on road conditions such as the IRI which could be used to compare the dynamics of pavement conditions across countries.

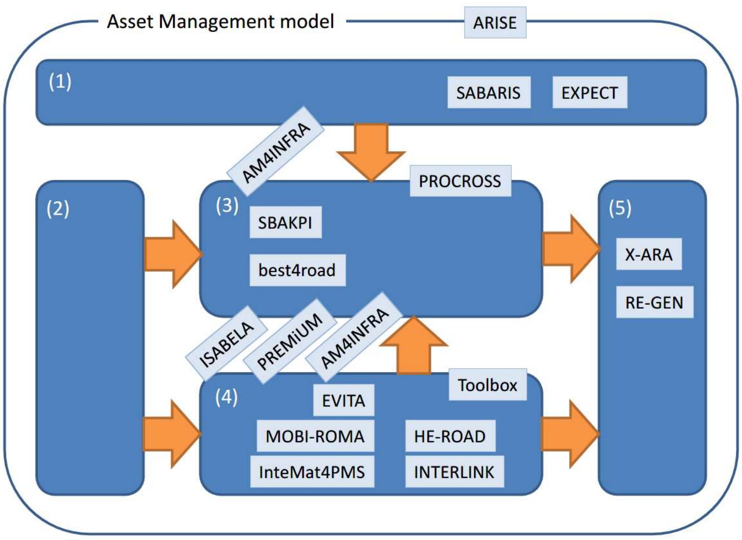

Figure 10: Research projects developing Transportation Asset Management Model (1) = Stakeholders (2) = People and Organisation, (3) = Strategy and planning (4) = Management of Data assets, knowledge and information (CEDR 2017).

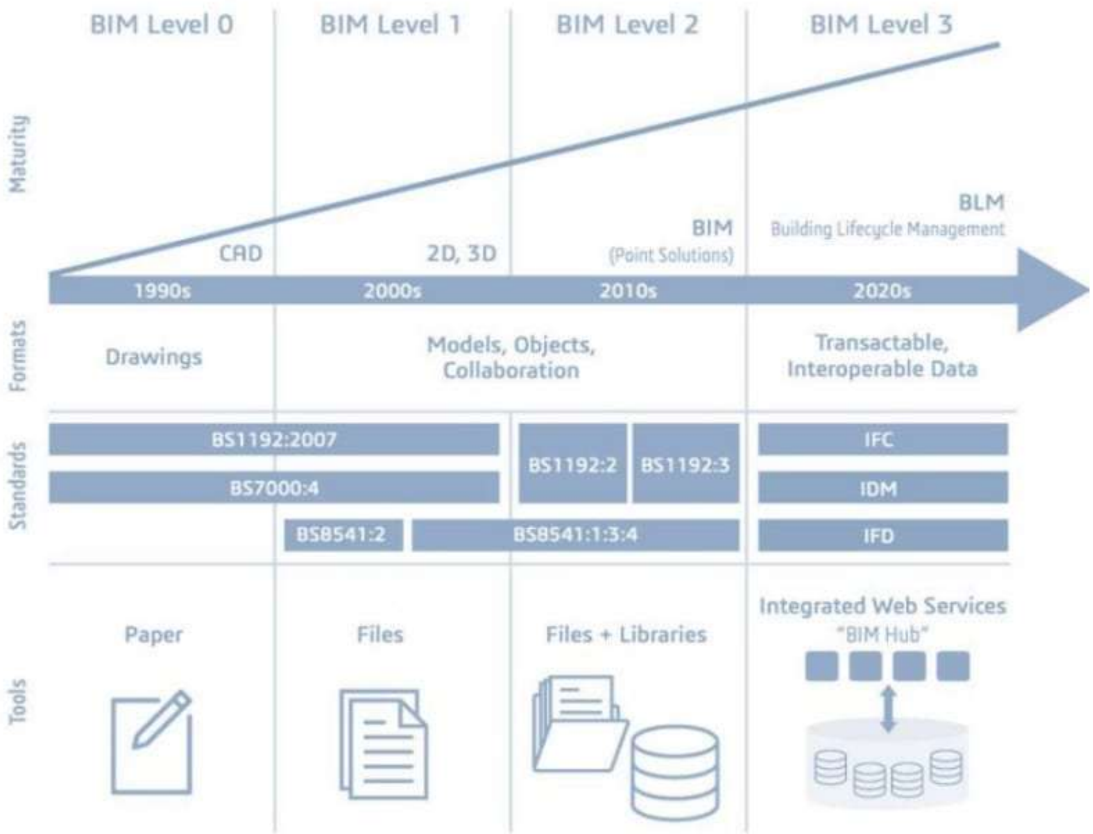

Figure 11: Progression of BIM Maturity Levels (Biblus, 2019).

Figure 11 above presents the various levels of BIM maturity, increasing from level 0 up to level 3 with the inclusions of more sophisticated formats and tools for the transference of information. More mature BIM models facilitate the collaboration and information exchange between the various stakeholders in a project. The figure illustrates the steps required to achieve each of the BIM levels.

Creating these big data systems will be necessary for facilitating the future, where decision making derived from algorithms will need to analyse large sets of data in order to produce highly accurate projections, as well as optimization of current management systems for many contexts including road maintenance. The collection of sensor data from passenger road vehicles potentially providing infinite quantities of road data would be one example of the great benefit for interlinked data management systems (Innovations Fonden, 2022).

NRAs should work towards developing a clear asset management strategy, which creates a semantic information mapping system for harmonizing asset management systems in accordance with ISO 55000, and 55001 standards.

NRAs should also work towards implementing and developing BIM principles in the way road assets are managed, in accordance the PAS1192 specification standards.

Developing and integrating a material exchange network platform such as the Recycled Material Web Map would foster the right conditions for embracing principles of circularity and resource efficiency through establishing recirculating material pathways, replacing traditional linear virgin material extraction and deposition pathways (RMRC, 2022).

Improving knowledge, establishing monitoring, and assessing potential control mechanisms for VOCs associated with road maintenance and construction processes is also recommended, as well as similar information for leaching of substances from road surfaces into soil and ground water.

Lastly, it is recommended to develop methods for projecting dynamic, as opposed to linear rates of degradation of road conditions. This will improve the accuracy of predicted impacts on CO_2 emissions from improved vehicle fuel efficiency.

Annex A

Material and Resource Inventory

Admixtures and Additives
Accelerating admixture (Hardening)
Accelerating Admixture (set)
Air Entrainer
Curing Compound
Other chemical admixtures for concrete
Plasticizers
Retarding admixtures
Water proofing agents
Liquid Calcium Chloride
Magnesium Chloride

Aggregates
Base and Subbase Material
Granite (for chip seal application)
Concrete Sand
Crushed Stone (Coarse Aggregate for Concrete)
Crushed Stone, granite (coarse Aggregate for Asphalt)
Crushed stone, granite (coarse aggregate for concrete)
Fine Aggregate (for asphalt)
Fine Aggregate (for concrete)

Asphalt Binder (Bitumen)
Asphalt binder, 0.5% polyphosphoric acid (PPA).
Asphalt binder, 3.5% Styrene-butadiene-styrene (SBS)
Asphalt Binder, 8% Gound rubber tire (GRT)
Asphalt binder, no additives
Liquid Asphalt Binder at refinery
Liquid Asphalt Binder, With Polymer
Paraffin Wax
Sealer/Rejuvenator
Asphalt Emulsion with Surfactants
Foamed Asphalt
Asphalt cutback blended with Solvents

Cementitious Materials
Cement (Blended with SCMs)
Cement (Preheater and Precalciner method)
Fly Ash
Silica Fume
Slag Cement
Portland Cement

Electricity
Grid mixes for Denmark, Ireland, Norway, Switzerland, Netherlands, and the UK

A grid mix of electrical energy generation representing the average production in the EU's 28 member countries.
Renewable marginal energy technologies if certificates are utilized representing energy from wind and solar power generation.

Element
Geotextile fabric
Precast concrete
Rubber, synthetic

Fuel
Coal combusted in industrial boiler
Diesel combusted in boiler
Diesel combusted in industrial equipment
Gasoline Combusted in equipment
Oil, combusted in industrial boiler
Natural Gas combusted in industrial boiler
Natural Gas, combusted in industrial equipment
Residual fuel oil combusted in industrial boiler

Recycled, Co-Product or waste material
Ground granulated blast furnace slag (GGBFS)
Ground Tire Rubber (GTR)
Reclaimed Asphalt Pavement (RAP)
Recycled Asphalt Shingles (RAS)
Recycled Concrete Aggregate (RCA)
Crushed Glass
Waste cooking oil
Lignin containing residuals from agricultural cultivation and processing operations.

Steel
Steel Reinforcing
Steel Reinforcing, Epoxy coated
Steel, rod, galvanized
Steel, stainless
Dowel Bar (length x, diameter y)
Tie-bar, threaded

Other
Lime, hydrated
Quicklime (calcium oxide)
Primer White paint
Water

Concrete surfaces
Continuously Reinforced Concrete Pavement (CRCP)
Jointed Reinforced Concrete Pavement (JRCP)
Jointed Plain Concrete Pavement (JPCP)
Performance Engineered Mixtures

Asphalt mixtures
Dense-graded
Open graded

Gap graded
Stone Mastic Asphalt
Mastic Asphalt
Asphalt Pavement
WMA, HMA, CMA
Asphalt Concrete Base
Crumb rubber modified asphalt
Performance Engineered Mixtures

Annex B

Assessment of data quality and availability

Table 2: Assessment of data availability and data quality through geographic (Ge), time (Ti) technological (Te)

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Admixture/Additive								
Accelerating admixture (Hardening)	EU	Hardening accelerators	2021	https://epd-online.com/PublishedEpd/Download/13227	IBU	G	VG	VG
Accelerating Admixture (set)	EU	Concrete admixture - set accelerators (A1-A3, A5, C1, C2, C4, D)	2021	https://epd-online.com/PublishedEpd/Download/13225	IBU	G	VG	VG
Air Entrainer	EU	Air Entrainers	2021	https://epd-online.com/PublishedEpd/Download/13224	IBU	G	VG	VG
Plasticizer	EU	Concrete admixtures – Plasticizers and Superplasticizers	2021	https://epd-online.com/PublishedEpd/Download/13229	IBU	G	VG	VG
Retarding admixture	EU	Retarders	2021	https://epd-online.com/PublishedEpd/Download/13226	IBU	G	VG	VG
Water proofing agent	EU	Concrete admixtures – Water Resisting Admixtures	2021	https://epd-online.com/PublishedEpd/Download/13228	IBU	G	VG	VG
Aggregate								
Base and Subbase Material	EU-28	Limestone, gravel (grain size 16/32) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/97938ad7-045d-4b2b-afff-9b701707fc1b.xml	GaBi	G	VG	G
Granite (for chip seal application)	EU-28	Crushed stone grain 2-15 mm (dried) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1b7a2b1e-7521-40de-8de4-b9dd823ebfc6.xml	GaBi	G	VG	G
Concrete Sand	EU-28	Crushed sand grain 0-2 mm (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/35e1cf03-637b-4006-a030-c003e85bfe4e.xml	GaBi	G	VG	G
Crushed Stone (Coarse Aggregate for Concrete)	EU-28	Crushed stone grain 2-15 mm (dried) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1b7a2b1e-7521-40de-8de4-b9dd823ebfc6.xml	GaBi	G	VG	G

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Crushed Stone, granite (coarse Aggregate for Asphalt)	EU-28	Crushed stone grain 2-15 mm (dried) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1b7a2b1e-7521-40de-8de4-b9dd823ebfc6.xml	GaBi	G	VG	G
Crushed stone, granite (coarse aggregate for concrete)	EU-28	Crushed stone grain 2-15 mm (dried) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1b7a2b1e-7521-40de-8de4-b9dd823ebfc6.xml	GaBi	G	VG	G
Fine Aggregate (for asphalt)	EU-28	Limestone, crushed stone fines (Grain size 0/2) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/17452dff-0f8f-4add-bd9a-a7e7bf070ec5.xml	GaBi	G	VG	G
Fine Aggregate (for concrete)	EU-28	Limestone, crushed stone fines (Grain size 0/2) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/17452dff-0f8f-4add-bd9a-a7e7bf070ec5.xml	GaBi	G	VG	G
Asphalt Binder (Bitumen)								
Asphalt binder, 0.5% polyphosphoric acid (PPA).	EU-28	Asphalt binder (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b528fdd1-cd82-4315-b28c-57ff0fe4b7a6.xml	GaBi	G	VG	F
Asphalt binder, 3.5% Styrene-butadiene-styrene (SBS)	EU-28	Asphalt binder (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b528fdd1-cd82-4315-b28c-57ff0fe4b7a6.xml	GaBi	G	VG	F
Asphalt Binder, 8% Gound rubber tire (GRT)	EU-28	Asphalt binder (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b528fdd1-cd82-4315-b28c-57ff0fe4b7a6.xml	GaBi	G	VG	F
Asphalt binder, no additives	EU-29	Asphalt binder (EN15804 A1-A3)	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b528fdd1-cd82-4315-b28c-57ff0fe4b7a6.xml	GaBi	G	G	VG
Liquid Asphalt Binder at refinery	EU-30	Asphalt binder (EN15804 A1-A3)	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b528fdd1-cd82-4315-b28c-57ff0fe4b7a6.xml	GaBi	G	G	G
Liquid Asphalt Binder, With Polymer	EU-31	Asphalt binder (EN15804 A1-A3)	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b528fdd1-cd82-4315-b28c-57ff0fe4b7a6.xml	GaBi	G	G	G

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Paraffin Wax	EU-28	Wax / Paraffins at refinery	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/fbc2a7e8-b503-4165-a0b2-22a70f651a4c.xml	GaBi	G	G	VG
Sealer/Rejuvenator	NL	Anova™ 1817 rejuvenator	2022	https://data.mrpi.nl/resource/datastocks/30eb1f4a-99e5-4ddf-9c31-c792ea16b24e/processes/e42ad05c-3aa4-489f-b033-1c9c912895e5/epd?version=10.00.002	MRPI	F	VG	G
Emulsion	EU-28	Bitumen emulsion (EN 15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/6301937a-b440-4b21-9544-ffe441fac61f.xml	GaBi	G	VG	VG
Cementitious								
Cement (CEM I 32.5) Portland cement (economically allocated binders)	EU-28	Cement (CEM I 32.5) Portland cement (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1f021fd1-26ff-44e3-ba71-f691d1661c83.xml	GaBi	G	VG	VG
Cement (CEM I 42.5) Portland cement (economically allocated binders)	EU-28	Cement (CEM I 42.5) Portland cement (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/865b8f05-e0f2-4bfa-a12c-ed26ca8984b6.xml	GaBi	G	VG	VG
Cement (CEM I 52.5) Portland cement (economically allocated binders)	EU-28	Cement (CEM I 52.5) Portland cement (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/156175a6-7b19-4055-bfd7-a251e78a06a2.xml	GaBi	G	VG	VG
Cement (CEM II 32.5) (economically allocated binders)	EU-28	Cement (CEM II 32.5) (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/9ff5bf7c-48fb-43ec-a48c-6f99bf434ca7.xml	GaBi	G	VG	VG
Cement (CEM II 42.5) (economically allocated binders)	EU-28	Cement (CEM II 42.5) (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/ae4dc250-ad2b-4d17-9909-8e934cf7c9a6.xml	GaBi	G	VG	VG
Cement (CEM II 52.5) (economically allocated binders)	EU-28	Cement (CEM II 52.5) (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/62577562-d1c0-400b-9614-8f4b4f79d02e.xml	GaBi	G	VG	VG
Cement (CEM II/A) (economically allocated binders)	EU-28	Cement (CEM II/A) (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/f741f634-c419-4c19-bd2f-465cad86f813.xml	GaBi	G	VG	VG

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Cement (CEM II/B) (economically allocated binders)	EU-28	Cement (CEM II/B) (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1050c610-75f0-4a6d-a4eb-42dcf9662c03.xml	GaBi	G	VG	VG
Cement (CEM III 32.5) blast furnace cement (economically allocated binders)	EU-28	Cement (CEM III 32.5) blast furnace cement (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/5baf368e-9bf4-41f0-8d16-6e1b2bc64c27.xml	GaBi	G	VG	VG
Cement (CEM III 42.5) (economically allocated binders)	EU-28	Cement (CEM III 42.5) (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/798b07f0-2eac-4196-a13c-091320d8866b.xml	GaBi	G	VG	VG
Cement (CEM III A) blast furnace cement (economically allocated binders)	EU-28	Cement (CEM III A) blast furnace cement (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/70a1f24a-92d1-4518-92ee-bf761cd668b8.xml	GaBi	G	VG	VG
Cement (CEM IV 42.5) (economically allocated binders)	EU-28	Cement (CEM IV 42.5) (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/067285ac-2d1e-447a-a205-7dc39fa0096d.xml	GaBi	G	VG	VG
Cement mix (average) (economically allocated binders)	EU-28	Cement mix (average) (economically allocated binders)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/cc98564e-3114-4f6b-9b15-5bf0f752b04d.xml	GaBi	G	VG	VG
Fly Ash	EU-28	Fly ash from hard coal power plant	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/19e066d3-495e-4ddb-841e-6d4be2e38cb4.xml	GaBi	G	G	VG
Silica Fume	NO	Microsilica/Silica fume, by-product ferro silicon	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/985c4202-8c6d-4675-ae64-83381d17488e.xml	GaBi	G	VG	VG
Slag Cement	IN	Portland slag cement	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/d9aa59c4-7230-43af-9458-ebc697c45678.xml	GaBi	P	VG	VG
TRASS - Puzzolan	EU-28	Trass (flour)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/d30d7ca6-6f5c-4668-a359-01265c8a2ab1.xml	GaBi	G	VG	VG
Electricity								
Grid mix for DK	DK	Electricity grid mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/c51b3a74-4a67-483b-be83-b6d6b8d21061.xml	GaBi	VG	G	VG

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Grid mix for IE	IE	Electricity grid mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/493e9446-ad0f-437c-a7f8-fa11b3f315ca.xml	GaBi	VG	G	VG
Grid mix for NO	NO	Electricity grid mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1e17b418-defe-4d75-87ec-9c0d8a398859.xml	GaBi	VG	G	VG
Grid mix for CH	CH	Electricity grid mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/de60e9f5-87a0-40cb-ae54-11ec7eac8909.xml	GaBi	VG	G	VG
Grid mix for NL	NL	Electricity grid mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/ba65b4f5-b979-4609-81ff-d0e16d8d2e59.xml	GaBi	VG	G	VG
Grid mix for GB	GB	Electricity grid mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/00043bd2-4563-4d73-8df8-b84b5d8902fc.xml	GaBi	VG	G	VG
Grid mix for EU-28	EU-28	Electricity grid mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/001b3cb7-b868-4061-8a91-3e6d7bcc90c6.xml	GaBi	VG	G	VG
Electricity from Wind	EU-28	Electricity from wind power	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/fe1c3d03-072b-4da7-8fff-3505f9b01efc.xml	GaBi	VG	G	VG
Electricity from Solar	EU-28	Electricity from solar thermal	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/01f0d98b-3231-4d70-98ac-149681257ecd.xml	GaBi	VG	G	VG
Element								
Geotextile fabric	BE	EPD - Woven Geotextile by Beaulieu Technical Textiles	2020	https://api.environdec.com/api/v1/EPDLibrary/Files/cd7fbbd6-913b-490b-e661-08da019c6d51/Data	GaBi	G	VG	VG
Precast concrete	EU-28	Pre-cast concrete	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/898618b0-3306-11dd-bd11-0800200c9a66.xml	GaBi	G	VG	VG
Rubber	EU-28	Styrene-butadiene rubber (S-SBR)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/a3be803d-77e4-4152-97b9-4833d14e10b8.xml	GaBi	G	VG	VG
Fuel								

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Anthracite Coal combusted in industrial boiler	EU-28	Hard coal mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/fd9db250-4998-11dd-ae16-0800200c9a66.xml	GaBi	G	G	G
Bituminous coal combusted in industrial boiler	EU-28	Hard coal mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/fd9db250-4998-11dd-ae16-0800200c9a66.xml	GaBi	G	G	G
Diesel combusted in boiler	EU-28	Diesel at refinery	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/6a14e8d6-acf8-458e-9aac-4db4b237ef8a.xml	GaBi	G	G	G
Diesel combusted in industrial equipment	EU-28	Diesel at refinery	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/6a14e8d6-acf8-458e-9aac-4db4b237ef8a.xml	GaBi	G	G	G
Gasoline Combusted in equipment	EU-28	Gasoline (regular) at refinery	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/80490a99-0faf-4e26-8f72-6ad2863152c3.xml	GaBi	G	G	G
Lignite Coal combusted in industrial boiler	EU-28	Hard coal mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/fd9db250-4998-11dd-ae16-0800200c9a66.xml	GaBi	G	G	G
Liquified petroleum gas, combusted in industrial boiler	EU-28	Liquefied Petroleum Gas (LPG) (70% propane, 30% butane)	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/0ab1ed73-8af0-4fc2-a288-eac53f7ae0f0.xml	GaBi	G	G	G
Natural Gas combusted in industrial boiler	EU-28	Natural Gas Mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/c6387e19-933f-4726-a7ad-7a8050aa418c.xml	GaBi	G	G	G
Natural Gas, combusted in industrial equipment	EU-28	Natural Gas Mix	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/c6387e19-933f-4726-a7ad-7a8050aa418c.xml	GaBi	G	G	G
Residual fuel oil combusted in industrial boiler	EU-28	Heavy fuel oil at refinery (1.0wt.% S)	2018	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/50462b0d-7d2b-40d4-843e-9857061e3c08.xml	GaBi	G	G	G
Recycled, Co-Product or residual material								
Ground granulated blast furnace slag (GGBFS)	DE	Slag-tap granulate (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/a9725df3-6c69-40fb-ba96-065fbef96001.xml	GaBi	F	VG	F

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Ground Tire Rubber (GTR)	EU - CH	market for waste rubber, unspecified	2011-2021	https://v36.ecoquery.ecoinvent.org/Details/UPR/b91a25ac-1a76-44a7-a595-b709b6a4be4d/8b738ea0-f89e-4627-8679-433616064e82	eco-invent	G	P	VG
Recycled Asphalt Shingles (RAS)	IN	Asphalt shingles	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/759b0414-50b1-4b2b-aa3d-9380281c0289.xml	GaBi	P	VG	G
Crushed Glass	GLO	Waste packaging (glass)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b72c9352-3353-4770-aa57-01eec819f36b.xml	GaBi	G	VG	G
Residual Styrene-butadiene-styrene (SBS)	DE	Styrene butadiene copolymer (SBS, TPS, TPE-S) star block	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/fe015902-faa9-4d48-9021-6636e103759b.xml	GaBi	F	VG	G
Waste cooking oil	GLO	Market for waste cooking oil	2011	https://v38.ecoquery.ecoinvent.org/Details/UPR/5e5be4ab-71be-4fc1-bbab-efb43fae4fde/8b738ea0-f89e-4627-8679-433616064e82	Eco-invent	G	P	F
Lignin containing residuals from agricultural cultivation and processing operations.				-				
Steel								
Steel Reinforcing	EU-28	Reinforced steel (wire) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/918b0154-4f5b-4b65-beab-9d3a7b0fb9ba.xml	GaBi	G	VG	VG
Steel Reinforcing, Epoxy coated	DE	Epoxy Resin (EP) Mix; from Bisphenol A and epichlorohydrin; consumption mix, to consumer	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/50125a08-978e-4156-bcc0-2d13ec3b49c7.xml	GaBi	F	VG	F
Steel, rod, galvanized	EU	Steel wire rod (2019)	2019	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/17270c1b-cd0f-403f-9050-5750a18033a4.xml	worldsteel	G	G	F
Steel, stainless	EU-28	Stainless steel cold rolled coil (304)	2014 (valid until 2024)	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1277624c-102e-4a4e-b80b-86721d96665a.xml	Eurofer	G	F	G
Dowel Bar (length x, diameter y)	US	Gaerdau Lond Steel Fabricated Reinforcing Bar	2016	cqd.io/e/ec3nddj7y8	SCS Global Services	F	F	G

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Tie-bar, threaded		Reinforced steel (wire) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/918b0154-4f5b-4b65-beab-9d3a7b0fb9ba.xml	GaBi	G	VG	G
Other								
Road maintenance	EU-CH	road maintenance	1990-2021	https://v36.ecoquery.ecoinvent.org/Details/UPR/6d6d827e-45b8-47ad-b2c6-bb0b9ce2432f/8b738ea0-f89e-4627-8679-433616064e82	Eco-invent	G	VG	VG
Lime, hydrated	EU-28	Lime (CaO; quicklime lumpy) (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/1598e3ea-812d-4250-82ff-c477a7e57cfd.xml	GaBi	G	VG	VG
Polyphosphoric Acid (PPA) liquid polymer binder additive	EU-29	Phosphoric acid (H3PO4, 54% P2O5)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/fefe1855-2fb9-4bc0-874d-a72c3f54de71.xml	GaBi	G	VG	G
Primer White paint	EU-28	Solvent paint white (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b71d50a8-f839-4a4d-8d01-3c5db5a3fcf2.xml	GaBi	G	VG	G
Water	EU-29	Tap water from groundwater	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/db009013-338f-11dd-bd11-0800200c9a66.xml	GaBi	G	VG	VG
Transportation								
Rail	EU-28	Transportation by rail (EN15804 A4)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/43056e50-b04b-497c-aa67-10d8c5cd1ea0.xml	GaBi	G	VG	G
Road	GLO	Truck, Euro 6, 28 - 32t gross weight / 22t payload capacity	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/659fe88d-fbd9-4139-9820-73c9b07dfaeb.xml	GaBi	G	VG	G
Sea	GLO	Container ship, 5,000 to 200,000 dwt payload capacity, ocean going	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/14b21448-160f-4f43-962d-20a65461902a.xml	GaBi	G	VG	G
Asphalt								
Cutback Asphalt - made fluid by addition of naptha, kerosene, or heavy oil	EU-28	Asphalt Emulsion no additives	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/b528fdd1-cd82-4315-b28c-57ff0fe4b7a6.xml	GaBi	G	VG	G

Material	Geo	Process / Product ref.	Ref. year	Link	Source	Ge	Ti	Te
Asphalt Emulsion - using surfactants to suspend in water	EU-28	Bitumen emulsion (EN 15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/6301937a-b440-4b21-9544-ffe441fac61f.xml	GaBi	G	VG	G
Stone Mastic Asphalt SMA	EU-28	Stone mastic asphalt SMA (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/eb8ac2e2-0baf-421c-8a90-1fde25986768.xml	GaBi	G	VG	VG
Mastic Asphalt	EU-28	Mastic asphalt (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/3bc70dc2-5239-47c4-a1be-e4838b9c9422.xml	GaBi	G	VG	VG
Asphalt Pavement	EU-28	Asphalt pavement (EN15804 A1-A3)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/cdcc6dfb-79bb-4593-a74c-0f50eca6b9a5.xml	GaBi	G	VG	VG
Asphalt Supporting Layer	EU-29	Asphalt Supporting Layer	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/90ad4d77-dca8-4a42-a90d-8530505b80dc.xml	GaBi	G	VG	VG
Equipment								
machine operation, diesel, < 18.64 kW, steady-state	US	machine operation, diesel, < 18.64 kW, steady-state	2014	https://v36.ecoquery.ecoinvent.org/Details/UPR/de3369dc-a2ec-426c-9f3e-12c74c45de4f/8b738ea0-f89e-4627-8679-433616064e82	Eco-invent	F	F	G
machine operation, diesel, >= 18.64 kW and < 74.57 kW, steady-state	US	machine operation, diesel, >= 18.64 kW and < 74.57 kW, steady-state	2014	https://v36.ecoquery.ecoinvent.org/Details/UPR/bc84487b-4c15-49e9-96d4-c048497c04a1/8b738ea0-f89e-4627-8679-433616064e82	Eco-invent	F	F	G
machine operation, diesel, >= 74.57 kW, steady-state	US	machine operation, diesel, >= 74.57 kW, steady-state	2014	https://v36.ecoquery.ecoinvent.org/Details/UPR/426f667a-5ad1-40e8-bec8-fea23fbddfdc/8b738ea0-f89e-4627-8679-433616064e82	Eco-invent	F	F	G
Excavator	GLO	Excavator, 100KW, construction	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/9e6d3b0e-cb47-4df3-969b-f23a75a0ae42.xml	GaBi	G	VG	G
Wheel loader	GLO	Wheel loader (newer standard)	2021	http://gabi-documentation-2022.gabi-software.com/xml-data/processes/e2ed419a-1266-4c1f-9dcb-df59069f2e8b.xml	GaBi	G	VG	G

7 References

Biblus, 2019, BIM maturity Levels: from stage 0 to stage 3. <https://biblus.accasoftware.com/en/bim-maturity-levels-from-stage-0-to-stage-3/>

Butera, Stefania, et al. "Life Cycle Assessment of Construction and Demolition Waste Management." *Waste Management*, vol. 44, 2015, pp. 196–205., https://doi.org/10.1016/j.wasman.2015.07.011.

Conference of European Directors of Roads (2017), CEDR, Technical Report 2017/06, TG Asset Management final report 2017.

Conference of European Direcors (CEDR) 2022, Research and Innovation: Transnational Research Programme, <https://www.cedr.eu/research-and-innovation>

Conference of European Directors of Roads (2021), CEDR, Connected Data for Effective Collaboration (CoDEC) Final Project Report D0.4 2021

European Standards (2019), Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products EN 15804:2012 +A2 2019,

European Standards EN 16757:2017, Product Category Rules (2017) Concrete and concrete elements, <https://docs.wbcsd.org/2018/03/Concrete_and_concrete_elements.pdf>

FEDRO, 2022, MISTRA Basissystem, web-platform, https://bs.mistra.ch/pages/viewpage.action?pageId=59277339

FEDRO, Documentation IT MISTRA TRASSEE – TRA Data Entry Manual Release 2.1.0, 2021 Edition V 2.1.0.

International Organization for Standardization (2006). ISO 14044:2006 Environmental management- Life cycle assessment – Requirements and guidelines

International Organization for Standardization (2014). ISO 55000:2014 Asset management – Overview, principles and terminology

International Organization for Standardization (2014). ISO 55001:2014 Asset management – Requirements

International Organization for Standardization (2014). ISO 55002:2014 Asset management – Guidelines on the application of ISO 55001

Innovations Fonden (2022), Digitalisering af vejenes tilstand fra bilers sonsere kan give besparelser på vejvedligeholdelse, Project LiRA Live Road Assessment based on Modern car Sensors, <https://innovationsfonden.dk/da/i/historier/digitalisering-af-vejenes-tilstand-fra>

LGA and MHCLG (2019), Ministry of Housing Communities & Local Government, The Single Data List (SDL): a guide an LGA / MHCLG guide to the SDL which explains the purpose of the list and how the SDL process works, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/824800/Single_Data_List_Guidance_document.pdf

Mikael Malmkvist, Trafikverket, BIM for Infrastructure trafikverkets view on Open Standards,2016, <https://arkiv.buildingsmart.no/sites/arkiv.buildingsmart.no/files/1105_mikael_malmqvist_0.pdf>

National Highways, Carbon Emissions Calculation Tool, (2021) <https://nationalhighways.co.uk/suppliers/design-standards-and-specifications/carbon-emissions-calculation-tool/>

National Highways, 2020, CS 230 – Pavement maintenance assessment procedure, <https://www.standardsforhighways.co.uk/dmrb/search/df44f6b0-4bf4-4189-90a2-912c19cc247a>

Otto A. et al 2019, Effect of road quality on fuel consumption and the generation of externalities derived from transport. Case of study: Barranquilla, Colombia.

Publicly Available Specification (PAS) 1192-2 BIM Framework Specification, <https://www.hfms.org.hu/joomla/images/stories/PAS/PAS1192-2-BIM.pdf>

Rijkswaterstaat, Strategic Planning Road Surfaces 2016-2022. 2015 <https://www.iampro-portaal.nl/getattachment/praktijkvoorbeelden/Maintenance-Strategy-Pavements-(Onderhoudsstrategi/4_maintenance_strategy_pavements_-_planning_district_text_2015.pdf.aspx>

RMRC, Recycled Materials Resource Center (2022), Wisonsin DOT, Recycled Material Web Map 2022, <http://rmwm.caps.ua.edu/>

Statens Vegvesen, 2018, ITS Strategy for the NPRA Norwegian Public Roads Administration 2018-2023, A Road Map to the Future Transport System, <https://www.vegvesen.no/globalassets/fag/trafikk/its-portalen/npra-its-strategy-2018-2023.pdf>

TII 2021, Asset Inventory (Roads) – Summary Report AM-GEN-00001, Transport Infrastructure Ireland (TII) Publications, <https://www.tiipublications.ie/library/AM-GEN-00001-01.pdf>

Thomas Jenssen, NyeVeier, Pilotprosjekt AIM i NV Trøndelag, datafly fra projekt til drift og hvorfor NVDB er viktig for oss, 2020. <https://www.vegvesen.no/globalassets/fag/fokusomrader/forskning-innovasjon-og-utvikling/teknologidager/teknologidagene-2019/nvdb/pilotprosjekt-aim-i-nye-veier-trondelag-thomas-jenssen.pdf>

Transport Scotland, McHale, M., and M. Gordon 2021. *An Approach to Cold Recycling of Bitumen and Tar Bound Roads*, WSP, 2021. <https://www.transport.gov.scot/media/49404/an-approach-to-cold-recycling-of-bitumen-and-tar-bound-roads.pdf. >

TRIONA 2020, New Framework agreement with the Swedish transport administration (Trafikverket), <https://www.triona.eu/news/2020/new-frame-agreement-with-the-swedish-transport-administration-trafikverket/>

US EPA, 2020, AP-42 Vol. I, CH4.5: Asphalt Paving Operations, <https://www.epa.gov/sites/default/files/2020-10/documents/c4s05.pdf>

US EPA 2010, Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling, NR-005d.Assessment and Standards Division Office of Transportation and Air quality. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P10081RV.TXT

Vejdirektoratet (VD) 2022, Den Digitale Vejmodel (VIMO) http://digitalvej.vejdirektoratet.dk/Sider/default.aspx

Vejdirektoratet (VD) 2018, BIM Infra.dk Et samarbvejde om den digitale transformation i anlægsbranchen, Kommissorium, information. https://biminfra.dk/wp-content/uploads/2018/08/BIM-Infra.dk-kommissorium_info.pdf

Vejdirektoratet and Banedanmark (VD) 2022, InfraLCA, https://www.vejdirektoratet.dk/infralca