University of Twente

Harmonization of environmental databases for road pavement in EU

Master Thesis

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Abstract
Purpose Considering that the outcome of environmental impact analysis such as life cycle assessment (LCA) is very much dependent on the quality of the data used, it is crucial to choose an appropriate LCA database. However, the decision can be difficult due to the high number of databases available. A harmonized database could be a way to increase data reliability by having all the data in one place instead of scattered databases all over Europe.
The paper investigates the main data harmonization challenges in databases and proposes a systematic approach to deal with these challenges.
Methods First, a literature study was done. To identify the main harmonization challenges, a database inventory and other harmonization attempts were investigated. Afterwards, based on the literature research and input from two experts with background in LCA harmonization, an Impact Effort matrix was drawn. As a final step, a procedure to data harmonization was developed and verified.
Results and Discussion There are 5 main problem areas that have to be solved to achieve data harmonization – data modelling, quality of the data, scope and access to the database, and environmental impact categories. According to the matrix, the hardest part, where the most attention should be payed, is data modelling (e.g. structure of the database and elementary flow lists). Since there are almost no similarities on these elements between the databases, and all the stakeholders (e.g. NRAs, LCA practitioners, commercial database managers) involved in the process, has distinct needs and wishes, reaching a consensus can be difficult and time consuming.
Conclusions Even though harmonization is difficult, it is not impossible. There are many occasions where harmonization has been done successfully, like ISO standards, national databases, initiatives taken by groups of stakeholders and many more.
The matrix and roadmap created in the paper, can ease the whole process by steering it in the right direction. The matrix shows which issues are the most time and energy consuming and the roadmap provides clear steps towards data harmonization. The main steps are – establishing strong management team, arraging workshops where the main outline of the databse can be discussed and drawn, and creating a technical manual where the outlook of the database is established and described to ensure consistency between the datasets.

Keywords Life cycle assessment; Databases; Harmonization; Road pavement.

1. Introduction

Any construction activity, including road construction, has a significant impact on the environment (Araújo, Oliveira and Silva, 2014). Pavement life cycle (e.g. material extraction, construction, maintenance and demolition) creates significant amount of waste, releases gaseous emissions into the atmosphere and requires huge quantities of non-renewable resources and energy (Cruz, Gaspar & de Brito, 2019)
With the well-established threat of climate change upon us, practitioners, engineers, researchers, and governments have been seeking solutions to mitigate environmental impacts from road construction (Hu, Shu & Huang, 2019).
The environmental impacts are usually characterized using LCA (Santero, Masanet and Horvath, 2011). It is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO, 2006a,b). It can cover all the phases of the life cycle from raw material extraction, through manufacturing, distribution, use, maintenance, and end of useful life, or may encompass a subset of the steps in the production and life of a product (Balaguera et al., 2018). The life cycle stages are shown in Figure 1.
Even though LCA is a useful tool to analyse environmental impacts, the outcome of the LCA is very much dependent on the availability and quality of the data (Björklund, 2002). Reliable, comprehensive and high quality databases are crucial for data input and the result of LCA.
Information and communication technologies allow for smart and effective database solutions. To push LCA and environmental goals, public and private sectors have compiled a wide variety of data with the sole purpose of use in LCA (Frischknecht, 2005). Countries like the Netherlands, Germany and France, have used this to their advantage and established centralised databases complementing or integrating databases developed by public or private

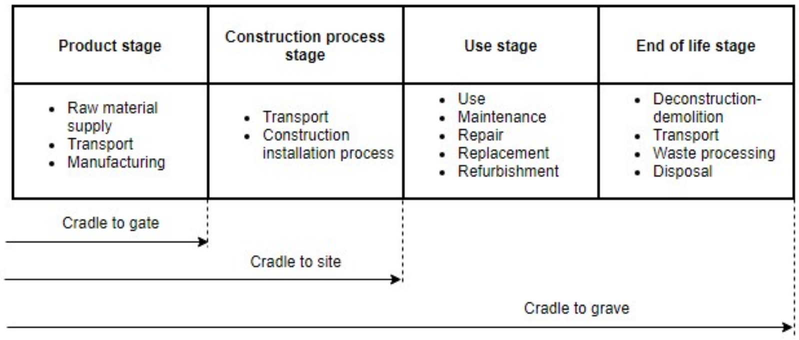

Figure 1. Life cycle stages (adapted from EN 15804)

sectors (Maki consulting, 2014). Building them has brought a real benefit and has helped to perform a comprehensive LCA analysis. However, this multitude of "local" initiatives can create confusion, frustration and problems, now, when sustainability has become a European/global issue.

Policy makers, national road authorities (NRAs) and practitioners have to deal with many scattered databases all over Europe, each with different data-structures, logic and datasets. Since modelling of datasets is not consistent between databases, it can lead to double counting, unidentified data gaps, differences in allocation methodologies, and result in divergent outcomes for the same dataset. This furthermore leads to incomparability between the results since differences in databases will result in variations in the outcomes of LCA. It means that involved governments, LCA practitioners, and other stakeholders have a hard time transferring knowledge and learning from other countries because every country uses a different database and it makes it much more difficult to interpret the data.

The large amount of available databases also makes it difficult for the beginners in LCA to choose the right pathway and tool to conduct LCA analysis (Conference of European Directors of Roads, 2017).

Available high-quality data across industry sectors exists only in few countries, even though the availability has increased in recent years. There are a lot of databases available and their coverage of different materials, transport, waste management, etc. is very diverse. The same goes for the quality of the available data. Availability of data that embodies country-specific production and materials is very diverse amongst the available databases (Frischknecht, 2005).

Data harmonisation might be a way to facilitate transnational comparison of results and could increase the total amount of available data, instead of having scattered databases amongst countries. Harmonisation could also be positive for European road associations and other governmental institutions that want to apply LCA, since coherence of data could also improve the quality of overall LCA.

The aim of the study is to:

a) Explore the needs, possibilities, and challenges of data harmonization in environmental databases in European Union (EU) member states;

b) Create a matrix of the main harmonization issues/parts, depending on their implementation difficulty and importance.

c) Create a detailed approach (roadmap), describing the necessary steps towards data harmonization.

2. Harmonization: a literature review

To understand the data harmonization process and its intricacy, it is important to start with a definition of harmonization.

2.1 Harmonization process

Harmony can be defined as "the combination or adaptation of parts, elements, or related things, so as to form a consistent orderly whole" thus harmonization implies a state of consensus or accord (Boodman, 1991).

Harmonization has two important features. The first feature is that it preserves the diversity of objects that are being harmonized and the second one is that while its components retain their individuality, they form a new and more complex unit. In brief, harmonization is a process where different elements are combined, modified, or adapted to each other to be able to form a coherent whole while also maintaining their individuality (Boodman, 1991).

At its most basic, harmonisation looks for commonalities. This may mean something as simple as finding a common language to communicate. The spread of English as a global language is a good example for harmonisation as communication (Backer, 2007).

Most commonly, harmonisation is applied in law and legal processes (Kerameus, 1995). In EU, adoption of framework legislation, called 'directives', is especially important. Directives are laws meant for EU member states and they obligate each of them to amend its own domestic laws, in order to achieve the objectives, described in the directive (Backer, 2007).

It is also very common to apply harmonization in different business and manufacturing processes. Then harmonization is used together with standardization.

Main goal of standardization is to create uniform business processes across various divisions or locations. Harmonization, on the other hand, defines the extent of standards and how they fit together (Richen and Steinhorst, 2015).

Even though globalisation and advancement of technology has made harmonization and standardization common for most businesses, there still has not been a single time in history when an attempt to integrate behaviour within one set of norms, has not met resistance. There always has been individuals or communities who try to reject the harmonised set of behaviour (Backer, 2007).

The advantages of standardization:

1. The process becomes more reliable and there is less variations in quality;
2. Less expenses in development of new practises;
3. Comparing performances between different organizations/studies becomes easier (Richen and Steinhorst, 2015).

However, there is also downside to standardization:

1. It may be difficult to agree to what extent standardization should be applied;
2. Standardized methodology may not be the best one;
3. It may put companies/organizations who already apply the standardized method into advantage over the organizations who use different methods since they have to change their approach.

It means that standardization and harmonization efforts should be carefully considered, and their benefits and flaws clearly established.

2.2 LCA harmonization

LCA has been around since the 1960 when degradation of environment and limited access to resources, slowly started to become a concern. It was first used in packaging studies, focusing mainly on energy use and few emissions. The LCA method development in Northern Europe and USA was completely uncoordinated. Studies were mostly done internally and there was almost no stakeholder involvement and practically no collaboration took place (Hauschild, Rosenbaum and Olsen, 2018).

In 1980ties and 1990ties LCA experienced an increase in methodological development. An international coordination and cooperation took place in scientific community. However, only the establishment of ISO (International Organisation for Standardization) 14040 series in 1997 led to a worldwide acceptance of LCA (Klopffer and Curran, 2014). Even though they give main principles and frameworks of LCA, there are still no specific details on methodological choices included in the standards. The ambiguity, and the demand for environmental information, has led to additional standards both under ISO and within other standardization bodies.

However, many practitioners are not in favour of harmonization and standardization. They argue that using different perspectives and approaches may lead to new knowledge, which consequently can be more useful in development of more comprehensive LCA analysis (Abraham, 2017).

For example, studies using different allocation methods aid a deeper understanding of how the impacts on the environment may change depending on the changes in the market. For example, the most suitable allocation method to investigate a product system may not be the best for researching the disposal options at the end of the life cycle (Abraham, 2017).

Nevertheless, harmonization is still continuing. The main drivers for harmonization are:

- Health and safety – safe and healthy working conditions are a must. Unfortunately, construction industry has an unenviable safety record. Risk of a major injury is more than two times higher than in other industries, like manufacturing (Sawacha, Naoum and Fong, 1999).
  Road construction can also have negative affect on the health. Asphalt workers are exposed to bitumen fume and vapor that can lead to chest tightness, shortness of breath and eye irritation (Randem, 2004).
  To decrease the risk of an accident and minimize potential health problems, norms and standards on product design, operation and disposal has to be in place (Stevens, 1993). Since it is a problem worldwide, harmonization on the main safety rules may take place.
- Trade – for companies to be able to expand their market and trade internationally common rules are necessary. By having common rules, products can be compared, improved and recognized. For example, companies can promote their products using eco labels in order to advertise how 'environmentaly friendly' the product is. LCA can also be part of it. If LCA in each country is done differently then, in order to enter another countries market, its LCA approach has to be adapted. The barrier can be eliminated, if there is a harmonized approach.
- Awareness of environmental issues – society is becoming more and more conscious of environmental issues which consequently leads to choosing a product who does the least damage to the environment (Roy et al., 2009). In order to determine the impact on environment, common rules/methods has to be in place.
  In EU, there are several instruments on how to asses it. One example is green public procurement (GPP) – public procurement that aims at purchasing products and goods with

reduced environmental impact (European Commission, 2016). It is used by public authorities to ensure environmentally friendly goods and services and EU has already created common rules for GPP.

3. Methodology

In order to achieve the research goals, 3 steps were implemented in the paper (Figure 2).

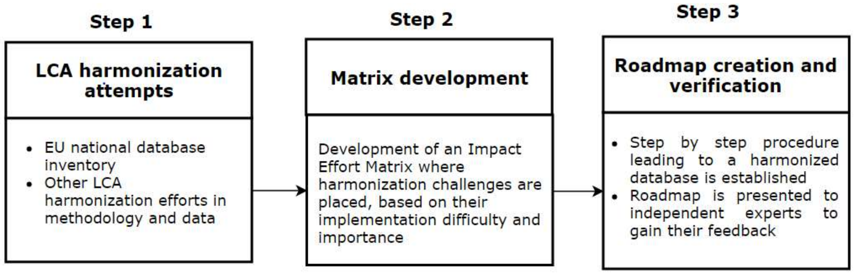

Figure 2 Research methodology

own national databases may not be in favour of harmonization because they already have an established way of conducting LCAs and available data for it. Considering that a harmonized database would lead to a lot of compromises, and many NRAs would have to change their incorporated approach, they may oppose harmonization.

3.1. LCA harmonization attempts

In step 1, database inventory and other harmonization attempts were investigated.

3.1.1. Database inventory

Current state of LCA databases and the main differences between them showed the magnitude of the problem, and highlighted the main parts of the database that has to be harmonized.
There is an enormous amount of information and data involved in LCA studies (Martínez-Rocamora, Solís-Guzmán & Marrero, 2016), both for inputs – “product, material or energy flow that enters a unit process” (ISO 14040:2006) and outputs – “product, material or energy flow that leaves a unit process” (ISO 14040:2006), which consequently means there are a lot of LCA databases available. The precise number of different databases is unknown, but there are more than 30 LCA software tools available and most of them include one or several databases from external sources (Koskela and Hiltunen, 2004).
Considering that the timeframe of the research is 6 months and the amount of databases available, only EU national databases were investigated.
The National LCA database is a database with authoritative information and is governmentally (co) led, or partly funded by the government (Maki consulting, 2014).
During a CEDR (Conference of European Directors of Roads) Pavement LCM workshop, where representatives from several countries were present (Denmark, Netherlands, Sweden, Belgium and UK), it became clear that countries who already have their NRAs who do not use LCA, on the other hand, are willing to support harmonization since it would make it easier for them to choose a database to work with.
Industry and commercial companies are also open to a harmonized database. It would make it easier for them to expand their market to different countries because the same data and framework could be used. Considering that it will be more challenging to achieve compliance from NRAs, then it is especially important to understand the main differences between EU national databases to see to what extent they differ.
Six national databases were compared – CPM LCA in Sweden, NMD in the Netherlands, Probas and Ökobaudat in Germany, and Ecorce and Inies in France.
Detailed description of the databases is available in appendix 1.
To compare the databases, seven features (derived from Martínez-Rocamora, Solís-Guzmán & Marrero (2016) paper) were investigated (Table 1 and Table 2), plus the data modelling (not included in the tables) were analysed as well.
Since the main goal of the research is data harmonization for road pavements, then road pavement products available in each database were compared on following characteristics:

1) *Scope* – LCA stages available, number of road pavement products included, and territory the database covers.
2) *License* – is it required or is the database available free of charge?
3) *Access* – is the database accessible via a tool or on its own?

4) *Year* – when was the data collected.
5) *Source* – what are the main sources for data?
6) *Verification method* – how was the available data verified?
7) *Environmental indicators* – what parameters are used to describe environmental impacts?
8) *Data modelling* – structure of the database and its datasets.

3.1.2. Other harmonization attempts

After the database inventory, both methodological and data harmonization attempts were investigated to see what can be learnt from previous experiences. LCA databases and methodology are interrelated and by investigating attempts in methodology, the knowledge and approach can be transferred to data as well. Reviewing several harmonization attempts in Europe and other places in the world, also gave a well needed insight into the LCA harmonization process and helped in establishing the database and the matrix by providing information about the process.

There are many networks and organizations attempting harmonization or guidance on LCA. In 2012, 58 networks on LCA were identified (Bjørn et al., 2012), currently the number could be even higher. It would be impossible to describe them all so only global or regional (above country level) networks were analysed. Furthermore, to gain better insight into the diverse harmonization attempts, each chosen network/harmonization effort is distinct and represents specific parts of LCA or is meant for different parties.

First, harmonization attempts in methodology were analysed:

- ISO standards, as the only global international standards on LCA.
- Environmental Product Declarations (EPDs).
- European Platform on Life Cycle Assessment (EPLCA), including, International Reference Life Cycle Data System (ILCD) handbook, Life Cycle Data Network, Resource Directory and Environmental Footprint.
- InData.
- Life cycle initiative.

Afterwards, data harmonization attempts were examined in:

- Food sector.
- LCA database in US.

3.2. Matrix development

In step 2, based on the LCA harmonization attempts, an Impact Effort Matrix was developed mapping out the harmonization challenges, depending on their implementation difficulty and importance. It is a simple technique that helps to choose which activities to prioritize in order to make the process more time efficient (Mulder, 2012).

To assess the model as precisely as possible, two experts were interviewed. They were chosen according to their current and previous job responsibilities. Both experts have worked with harmonization policies in NRAs so they can give an insight into the whole process and they have a first-hand experience with the main harmonization issues. The interview protocol can be found in appendix 5.

The first expert was a product coordinator from a National road authority. He is working on sustainable asphalt and he has a unique insight into the harmonization process since European Commission (EC) is currently trying to achieve harmonization regarding asphalt mixtures and production.

The second expert was a project manager in a pavement research center. Currently, he is working on a harmonized pavement database for California but soon a project will start where it will be attempted to create a harmonized database for the whole USA.

Both experts mentioned above, could provide useful insight and input on the database harmonization and how the main harmonization parts fit into the matrix.

3.3. Roadmap creation and verification

After the matrix, the last part of the research took place – a step by step procedure (roadmap) leading to a harmonized database was created and verified.

3.3.1. Roadmap to a harmonized database

The roadmap was consolidated using the input from literature study, matrix and experts mentioned in part 3.2.

The previous harmonization efforts were especially important since they showed what has been harmonized and how so the processes could be adopted for the roadmap. For example, a description of USA database creation put the foundation for the first steps of the roadmap.

3.3.2. Roadmap verification

The roadmap was presented to five independent experts to gain their feedback on the output. To all the experts the proposal was presented during an informal meeting. Three meetings were organized in total. Each step of the roadmap was described during the meeting and afterwards, the experts provided comments, questions and suggestions.

Since the paper, including the roadmap is part of a bigger CEDR project "Complete package for Life Cycle Management of green asphalt mixtures and road pavement" (PavementLCM), first, the roadmap was presented during a meeting where the whole project and its progress was discussed. The first

version of the roadmap was presented to the involved participants – project manager and two other experts who are both working on other parts of the project.
Afterwards, the roadmap was presented to a consultant for building and infrastructure sustainability at TNO who previously was involved in a Product Environmental footprint (PEF) database creation providing him with deep understanding of the data harmonization process. Considering his first hand knowledge of data harmonization process, he expressed some comments and suggestions on how to make the whole process smoother and more reliable.
As a final step, the roadmap was proposed to another expert. He is a senior pavement advisor in Highways England and he could give an important input from a NRA's point of view. It is especially important considering that the NRAs are the main target audience of the research.

4. Results

This section portrays the results of previously described research steps.
First LCA harmonization attempts are described. Afterwards based on the inventory, main harmonization challenges are summarized and placed into a matrix. Finally, a roadmap to database harmonization is illustrated and described.

4.1. LCA harmonization attempts

Database inventory and previous harmonization attempts are outlined, first.

4.1.1. Database inventory

The comparison of the databases can be viewed in table 1 and 2. The first table outlines main differences in scope, licence, access, year, source and verification methods and second shows indicators used in the databases.

It is visible that there are many differences in the databases. First, coverage of road pavement products differs to a great extent. For example, in the database in Sweden, there is only one type of asphalt – the average one, but in the Netherlands there are many road products available. The structure of each database varies greatly as well. Even naming of data is different.
A detailed description of all the differences can be found in appendix 2.
The main differences that were used to create the matrix (section 4.2.) are:

- *System boundaries* – stages of product life cycle that should be available in the database. Should it only include product stage or construction, use and end of life stages should be available as well. Life cycle stages can be viewed in Figure 1.
- *Categories* –what type of road pavement materials are included in the database?
- *Territory* – what territory the database should cover, should it include country specific materials or should it be more generic?
- *Accesibility of the database* – it has to be agreed whether the database will be free of charge or it will require a licence, whether it will only be available via a tool or it will be accessible on its own.
- *Source of the data* – right now there are various sources – industry, academic papers, existing comercial databases etc. Even though there can be different sources for data, it is important to agree what sources to use for eah specific data so there is no overlap.
- *Verification of data* – how and by whom the data verification will be done. It is also important to have common data quality requirements so only high quality data can be found in the database.
- *Data modelling* – structure of the database, treatment of data gaps, and other modelling aspects has to be defined and consensus reached.

Table 1. Main differences between the databases

Aspect		CPM LCA	NMD	Ecorce	INIES	Ökobaudat	ProBas
Scope	LCA stages covered	cradle to gate	cradle to grave	cradle to grave	cradle to grave	cradle to gate	cradle to grave
	Road pavement materials	1	17	4	2	5	2
	territory	Mostly Sweden	Mostly Netherlands	Mostly France	Mostly France	Mostly Germany	Mostly Germany
Licence	Required?	No	Yes	No	No	No	No
Access		Free	with license via tools	Free via tool	Free	Free	Free
Year	When data was collected	2001	not known	not known	2015	2017	2000
Source	background data sources	scientific papers, thesis	Industry	Scientific publications	Industry	Gabi, Ecoinvent	research institutes
Verification method	How data is verified	Based on data documentation requirements	Verification protocol	2 anonymous reviewers	Independent third party, recognized by a program operator	According to principles for the acceptance	Not known

Table 2. Indicators available in the databases

Indicators	NEN-EN 15804	CPM LCA	NMD	Ecorce	INIES	Ökobaudat	ProBas
Climate change	x	x	x	x	x	x	x
Ozone depletion	x		x				
Acidification of land and water	x		x	x	x	x	
Eutrophication	x		x	x	x	x	
Photochemical ozone creation	x		x	x	x	x	
depletion of abiotic resources (elements)	x	x	x	x	x	x	
depletion of abiotic resources (fossil)	x		x	x	x		

4.1.2. Harmonization attempts

After the database inventory that sums up harmonization processes regarding national databases in EU, other attempts were investigated as well.
There have been a lot of attempts to harmonize LCA, in many industries. The attempts differ in scope, technique, and application. There are attempts to harmonize methodology, databases, standards, etc. Data harmonization is just one part of LCA, and there are many ways to attempt and perform harmonization. Thorough description of each harmonization effort can be viewed in appendix 3.
The main lessons (a comprehensive description is available in appendix 4) are:

- Make sure there is a need for a harmonized database. Without a strong push from the industry, the database financing cannot be justified.
- Many different stakeholders should be involved in data harmonization process – industry, governments and LCA practitioners can provide useful knowledge on the challenge
- Since harmonized database affects so many stakeholders, then to achieve the desired outcome teamwork between the stakeholders is crucial.
- Ensure strong leadership to make sure that everything is going according to plan and that different database parts are compatible between themselves.
- Plan ahead of the initial launch so there is enough budget to maintain and expand the database later on.
- Keep consistency between the datasets and between the database and existing standards.

4.2. The matrix

The main problem areas can be divided into five categories (derived from data inventory). Each of these parts are put into the matrix in Figure 3:

1) Data modelling:
   a) Structure of the database – naming, categorizing, storing.
   b) Treatment of data gaps
   c) *Common Elementary flow list* – naming, categorizing, using, storing.
   d) *Documentation requirements* – common documentation requirements like geographical validity of data, time representativeness.
2) Quality of the data:
   e) *Source of the data* – main sources are industry, academic papers, and existing commercial databases. The database can include all the sources or only one of them. For example, in the French Ecorce database, only academic papers are used.
   f) *Verification method* – how and by whom data verification can be achieved. For example, Netherlands has a verification protocol, but data in Ecorce is peer-reviewed.
3) Scope of the database:
   g) *Territory* – what territory should the database cover? Should it include country specific materials, or should it be more generic?
   h) *Categories* – what categories are included in the database. Is it only for road pavement, or should it be more extensive and include more construction materials?
   i) System boundaries – product life cycle stages the database includes. Should it only include product stage or construction, use and end of life stages should be available as well (stages available in Figure 1).
4) Access to the database:
   j) Is `license necessary?
   k) Is it available on its own or via a tool?
5) Environmental impact categories:
   l) *Indicators* that are used for environmental assessment, such as depletion of raw materials, climate change, ozone layer depletion, etc.

As already mentioned, the matrix was designed based on input from two experts. In general, both experts had very similar views, as they both think that a harmonized database is necessary, but they also admit that it will be very hard to achieve consensus on it. The first expert emphasized that a harmonized database would help to create similar market conditions in all the EU countries, making it easier to trade and compare products.
The second expert had the same opinion. A harmonized database could help businesses expand and use LCA more freely because data would be comparable. It could also help other organizations to start using LCA since there would be no confusion on which database to use.
Both experts acknowledged that it would be enough to create a 'rough' database with minimal background data in the beginning. Over time the database could be expanded to include more information. It would ease the implementation of the database and it would be easier to reach an agreement on harmonized parts. However, it should also be extensive enough that it is still useful to the interested stakeholders thus it is important to find a balance.
The second expert also stressed that the database should not include the whole life cycle (Figure 1) and should only focus on cradle to gate model, not including use and end of life stages. Data for products and their manufacturing processes are more refined and reliable. Information on maintenance and recycling, on the other hand, is less developed. If the information on these aspects would turn out not to be precise enough, the database users may lose

trust in the database and the whole project could be at risk.

The size of the database, information available in it, and importance of this information also depends on the target audience. Each involved stakeholder may have different demands and wishes, and it is important to understand them all.

Both experts also discussed the harmonization challenges and how they fit into the matrix.

The matrix plays an important part of the harmonization process. It shows the main problem areas and on which parts the most attention should be spent, and can be seen in Figure 3.

In quadrant A, there is access to the database, indicators, and system boundaries. Each of these requirements are important, but there are a lot of similarities in these requirements between the databases and it should be possible to reach consensus.

In quadrant B, there are the parts that are the most difficult to harmonize. Harmonization of this quadrant will take the most time. Almost the whole data modelling is placed here. Each database has a completely different structure, including names, categories, and storing, and there are many different possibilities on how to tackle the issue so it will be hard to reach an agreement on these parts.

Quadrant C contains parts that can be expanded and developed in more detail later, such as territory or categories. With a precise maintenance plan, database can be extended and more territories and road products added.

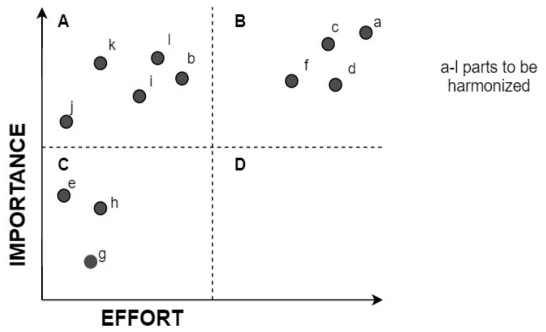

Figure 3 The Impact Effort Matrix

Below is the description of each quadrant and part of the matrix.

Quadrant A – high importance, low effort.

First, in this quadrant there are the *treatment of data gaps (b)*. If there are missing values in LCA analysis, it may lead to data gaps. Mainly this issue is avoided by using unspecific data – data from similar processes, but of unrepresentative geographical origin, age, or technical performance. Lower quality data can be used as well, for example, in the Netherlands unverified data is used for data gaps. Considering that there are only few options on how to treat data gaps, then an agreement is possible. However, it is important to decide on the issue because it represents how reliable the data is for calculations.

When it comes to *system boundaries (i)*, it must be decided whether the whole life cycle (Figure 1) is included or only a part of it. Most EU national databases use a cradle to grave model, however, there are some (CPM LCA and Ökobaudat) who do not take use and end of life stages into account and use the cradle to gate model. The importance of this part is very much dependent on the interested party. Manufacturers are only concerned with the product phase, but other interested parties, like NRAs may prefer cradle to grave model where all the phases are included. Nevertheless, since the database can always be expanded, other phases added and the decision depends on the availability of the data then consensus is achievable. The decision itself is of high importance since it will affect by whom and how the database will be used.

License (j) is an important part to decide as well. It will affect not only the users, but also the owner of the database. If the database is free of charge, then it is very important to plan the budget and finances accordingly. It is not enough to have budget only for the launch of the database. Afterwards it needs to be maintained, new data added, old data renewed etc. Financing mechanism has to be in place for all of these activities. All of the EU databases are free of charge except for the Dutch database. Considering that most databases do not require a licence then the decision on the licence should not take a lot of time.

Accessibility of the database can greatly affect the time necessary to develop it. If the database is accessible via a *tool (k)* then calculation method must be established and that would greatly complicate the situation. 3 out of 5 national databases are available on their own, the rest can only be viewed via a tool so the situation is mixed in Europe. Nevertheless, since it would be a harmonized database and it should be easily accessible to any interested party, then it should not take too much effort to come upon a unitary decision.

Indicators (l) play a large role as well. It is important to know what environmental impact categories are available in the database. By knowing impact categories, users of the database can see what environmental aspects are considered during the analysis. Depending on the available impact categories, the result of the LCA can differ.

Indicator coverage in the databases were similar for most of the databases. They mainly follow EN 15804 “Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products” (EN 15804) where main impact categories are mentioned. The standard simplifies the task and can be used as a guideline to agree on the issue.

Quadrant B –high importance, high effort

Parts in this quadrant are the most difficult to achieve. Almost all the data modelling category is placed here.
Structure of the database (a) is of very high importance since it forms the basis and core of the database. However, it may not be that easy to come to an agreement on it. Each national and commercial database has its own structure, including naming, categories, and data placement. For the database to be usable, the datasets must have full consistency and interoperability so they can be combined in life cycle models. If datasets are not fully interoperable, they cannot be used in the same life cycle model and the data has little value. Even though industry is more supportive of data harmonization, because it would mean they can expand their market more easily, they may still try to push their own agenda and their database structure. The same goes for national databases as well. NRAs and governments may try to persuade to use their model because then they would have an obvious advantage comparing to the rest of the involved parties.
Common *elementary flow list (c)*, just as the structure of the database, are essential components in LCA analysis. Elementary flow lists are used to describe material/energy entering the system from the environment and material/energy leaving the systems and being released into the environment. There are various conventions for naming, using, storing, and categorizing elementary flows. The high variety means that it will be hard to come to an agreement, since there will be many different opinions.
There are some *documentation requirements (d)* that are usually included into the database, such as time when the data was collected, and which geographical region it represents. In the ILCD handbook, there are documentation requirements provided and most databases already are in line with these requirements. However, some companies who provide data for databases do not want complete data transparency and want to keep their data at least partly confidential. This means that balance between transparency (increased detail) and opacity (protecting sensitive business interests) must be achieved. It may not be easy to achieve consensus on the documentation since industry, governments and LCA practitioners may have very different needs and demands considering documentation requirements. It is important to reach an accord since transparency is one of the most important parts in a database because it provides trust and confidence in the displayed data.
Verification method (f) is important as well. If the requirements in the verification method is lower or less specific than in other databases, then acceptance of the database may be reduced. However, each country has their own verification methods and requirements, some use independent, external qualified reviews, some use a whole review panel. It will be hard to define how verification should take place and what should be the main requirements.
Quadrant C – low effort, low importance
One of the elements here are *data sources (e)*. Agreeing on source of the data should not pose a challenge. Most databases use company generated data (data from the industry) or already existing databases. Only the French Ecorce did not use any commercial database and relied solely on academic papers.
Even though data source is important because, if it is unreliable then data cannot be used, in general there are mainly three sources for data – industry, other commercial databases and scientific papers. It is not of high significance to agree exactly which source to use since all of them are credible and have been used with good results.
It should also be relatively easy to reach an agreement on *territory (g)*. If countries want to put their data into the database and if data is of good quality, there is no reason for them not to be able to do so. Also later, if necessary, the database can be expanded to include more territories. Since the database can be slowly expanded over time, it is not too important to decide on the territory right away.
Categories (h) for the database are also relatively easy to decide upon. In general, the database will be used for pavement materials, so it is already decided upon and then later, if required, it can be expanded to include more road and construction materials.

4.3. The roadmap creation and verification

4.3.1. Roadmap to a harmonized database

After the matrix, the roadmap was consolidated. It is available in Figure 4. Each step in the roadmap is showed as a box. To show the order of the steps, boxes are numbered and connected by arrows. Decisions that must be made are showed as diamonds. The necessary steps vary depending on the decision. At some of the steps, there are blue ovals. They represent, the main input in the specific step.
The whole harmonization process is divided into 4 phases based on project management life cycle. The phases make up a path of the project from the very beginning till the end:

- *Initiation phase* – The beginning of the project. The idea of data harmonization is explored and elaborated via market research. The goal of this phase is to examine the need and feasibility of the project. Moreover, a decision ought to be made regarding who will carry out the project and project management team established.
- *Planning phase* –The requirements for the project are established (action plan and technical guidelines). The main goal is to create rules for the technical guidelines and maintenance plan as detailed and clear as possible. It is important to

involve all the stakeholders during this phase and collaborate with them via several workshops. The end result of this phase is the technical guidelines that are as specific as possible, since they will be the main manual for implementation phase.

- *Implementation phase* – It involves performing the planned work, in this case, creating the database. At the end of the phase, the database is reviewed and validated and afterwards put into action.
- *Use phase* – The database is in full use and maintenance plan that was developed in planning phase can be implemented to ensure that everything is running smoothly and is kept up to date.

The minimum implementation time is also given for each phase. It can vary greatly depending on the main outlook of the database (e.g. alone standing or available via tool, centralised development of datasets or each country develops its own) and how fast the consensus can be reached so the timeframe is only approximate and is meant to help in understanding the minimal duration of the activities. Below a detailed description of the roadmap is given. The number in the description matches the number of the step.

1. Before creating the database, it is necessary to examine whether a harmonized database is necessary. Although there could be a lot of benefits of such a database, the industry and other involved stakeholders may have a different opinion and without strong support and clear gain, its development cannot be justified. To understand the viewpoint of the different stakeholders, a market research must be done. During the market research, it is important to not only understand whether the database is necessary, but also why it would be beneficial and which parts of the database are the most important and the most difficult to achieve. It is not enough for the stakeholders to agree on harmonization, it is crucial to understand their perspective on the whole issue and their reasons for wanting the harmonization. Only by understanding their point of view, a firm outlook on the problem can be grasped.
   The matrix shown in Figure 3 can serve as a basis for the research. The main parts that should be harmonized are already given and mapped out. Even though, there should not be too much variation on the parts that has to be harmonized (detailed list available in chapter 4.2.), their placement in the model can change. Only two experts were involved in the creation of the matrix and input from a wider range of stakeholders is necessary to make a complete overview.
   However, the model would be useful in understanding the attitude of each stakeholder and which parts of the database they deem to be the most important and difficult. Understanding stakeholder perspective would help greatly during the process.
2. If, after the market research, it can be concluded that majority of involved stakeholders are not willing to support a harmonized database, other possible solutions and scenarios must be discussed.
3. If there is an agreement on database harmonization, project management team can be established. It should be chosen with great care since the foundation of a successful project is strong project management. They are the ones who steer the whole process and make sure that everything goes according to plan.
4. In the next step, an action plan is created. It, amongst other things, should include main goal, vision, timeframe and a budget plan.
5. A workshop is organized to discuss the main objectives of the project and to understand if they are in line with the involved stakeholder standpoint. A lot of different stakeholders should be present during the workshop – LCA practitioners, members of NRAs, commercial databases, academic and research institutions. If it is necessary, then after the workshop, the action plan can be amended.
6. After the workshop, an advisory board is established. It should consist of the members of the workshop. It would assure that the members in advisory board are up to date and are involved in the process. Choosing an advisory board before the workshop could lead to insufficient board by overlooking some important stakeholders. During the workshop, the involved parties can be examined and from several members, an appropriate advisory board created. The main responsibility of the board is to provide technical guidance of the project.
7. A plan for the next workshop have to be created. This workshop is aimed at creating and discussing the main outlook of the database. To have a baseline for the discussion, existing standards and guidelines on LCA can be debated. The main goal is not to create something completely new, but to harmonize already existing databases. Also an improved matrix (Figure 3) is an important part of the workshop. The matrix would provide clear guidance on the main discussion topics.
8. The matrix could change after the market research but based on the quadrants, the attendees can be divided into groups and each group should discuss the harmonization possibilities represented in the specific quadrant. Considering the amount of work that must be done during the workshop, it would take at least

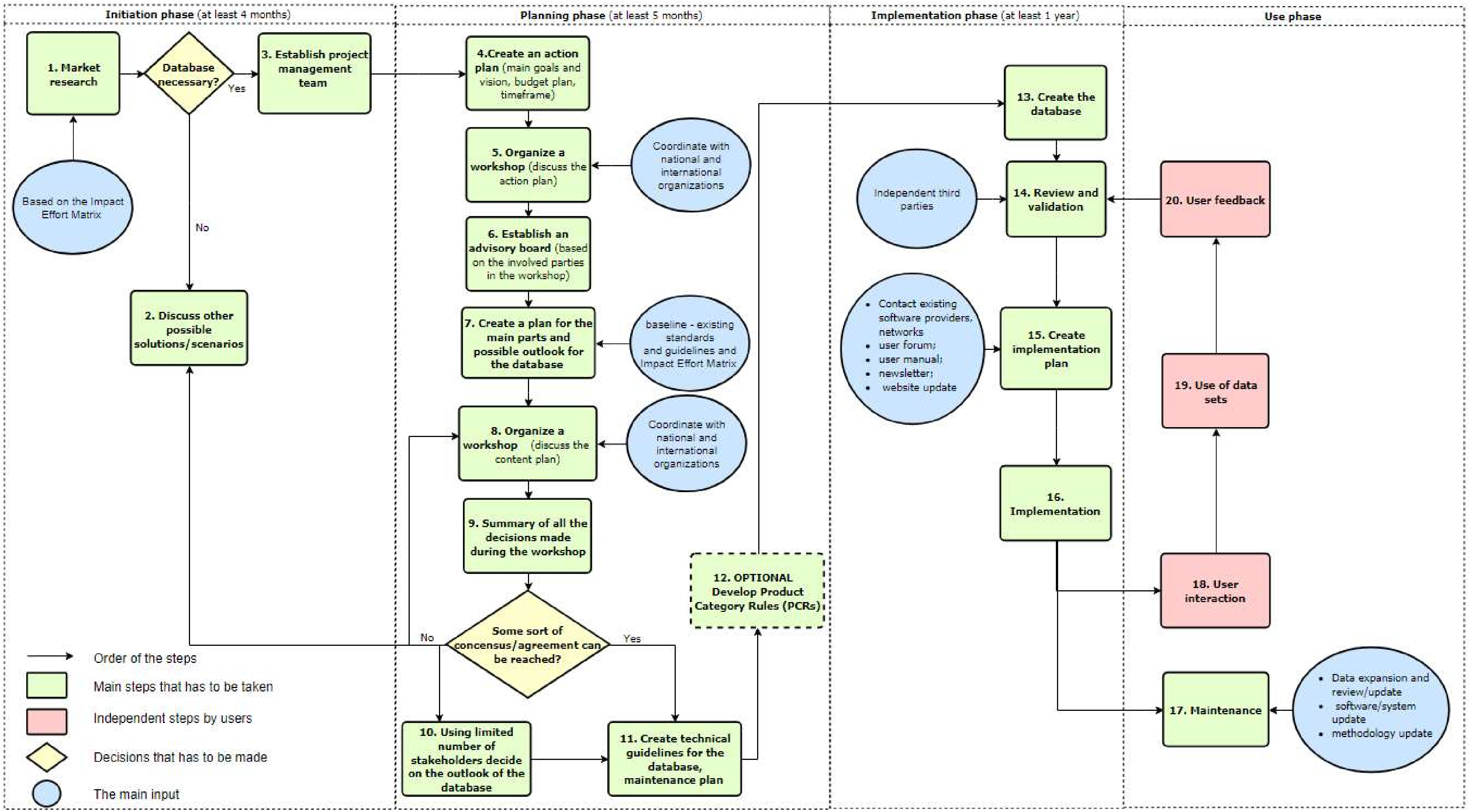

Figure 4 The proposed roadmap for data harmonization

3 days, maybe even more. Just as in the previous workshop very divergent stakeholders have to be involved to get a clear overview and to be able to understand the needs and wishes of each party.

9. Afterwards a summary of the main decisions made during the workshop can be drafted. It would make it clearer where consensus could be reached and which parts still require extra work. Depending on the result, more workshops may be necessary to arrive at an agreement.
10. If no consensus can be reached, then either a different solution must be found or the outlook of the database have to be created involving only a small number of stakeholders and excluding the rest.
11. If some sort of agreement/consensus can be reached, then the next step is to provide technical guidelines for the database and maintenance plan.
    In the guidelines, the main rules and outlook of the database must be specified. The guidelines should at least include information on:
    - Data collection;
    - Scope of the database (categories, system boundaries);
    - Indicators;
    - Structure of the database;
    - Data verification protocols;
    - Documentation requirements;
    - Treatment of data gaps;
    - License creation;
    - Data publication and updating procedures.

    It is important to develop a maintenance plan as well to make sure that after the launch, the database is kept up to date. It must include information on staffing, budgeting, data review process, software updates etc. Creating these documents would ensure that the process runs smoothly, and the main parts have been established and agreed upon. Considering that different companies are usually involved in the creation of the database, it is important that each company has guidelines on the process, so all the parts are in line with each other.
12. Product Category Rule (PCR) development is optional and the necessity of it should be discussed during the second workshop. If it is decided to create PCRs, then it has to be taken into account that some countries already have their own PCRs and an agreement on the content may be difficult.
13. The database development can begin. The most important part is to have consistent guidelines, so the database development goes as smoothly as possible.
14. Review and validation of the database is undertaken at this point. The review and validation process must be included in the technical guidelines. To avoid conflict of interest, it should be performed by an independent, qualified third party.
15. Implementation plan is created. List of LCA software companies and networks is concluded so they can be contacted to make sure that the database is included into their system. In addition, to make it as user-friendly as possible, user manual, guidelines, website, and newsletter are made.
16. Implementation procedure can begin.
17. Maintenance of the database. Amongst other things, data expansion, review, and update should be done.
18. Independent of the whole process, a user interaction and feedback on the database is happening. Based on the feedback, a review process must be done to implement the necessary changes.

4.3.2. The roadmap verification

After presenting the draft roadmap (appendix 6) to the CEDR PavementLCM project leader and two experts who are involved in the project, no comments or recommendations were received.
During the second meeting several suggestions were made by the expert:

- To establish project advisory board after the first workshop since it could provide the management team of a more comprehensive look on all the involved stakeholders.
- To create technical guidelines for the outlook of the database to ensure consistency and provide a maintenance plan to ensure that the database will be kept up to date.

These comments were taken into account and the roadmap modified (Figure 4). To ensure that the modified roadmap is as accurate as possible, it was presented to the last expert who also did not have any additional comments so the roadmap was left unmodified and its final version can be found in Figure 4.

5. Discussion and limitations

The analysis of data harmonization in environmental databases has revealed some expected and some unexpected results.
As anticipated, there are many challenges to data harmonization, also expressed in several previous research papers (Martínez-Rocamora, Solís-Guzmán & Marrero, 2016, AzariJafari, Yahia and Ben Amor, 2016).
Based on the database inventory, the main problem areas are: data modelling, quality of the data, scope and access to the database, and environmental impact categories.
The findings were consistent with previously done reserach (Martínez-Rocamora, Solís-Guzmán &

Marrero, 2016) where differences between construction databases were investigated.

However, despite the challenges, data harmonization is still continuing. There are several data harmonization attempts such as a publication on "Global guidance principles for LCA databases", composed by UNEP and SETAC and development of PEF database by EC.

There are also harmonization efforts that affect databases indirectly. The most important one is standard development, for example EN 15084 provides information on necessary indicators and ISO 14067 provides information and requirements on Greenhouse Gas emission reduction.

Harmonization can also happen on a national scale like database and tool development for one specific country.

Different stakeholders can be involved in the process as well. Previously mentioned processes were mainly done by governmental institutions, but, for example, InData network for EPD/LCA harmonization, was created by an informal, non-profit working group, consisting of different types of members.

These are only a few examples of LCA harmonization activities, there are many more happening all over the world.

The Impact Effort matrix and roadmap, established in the paper, can assist with the harmonization process. The matrix shows which parts will be the hardest to harmonize and will take the most time and effort, and which parts will require fewer compromises. The hardest part is data modelling – structure of the database, treatment of data gaps and elementary flow lists. The main reason is that there are almost no similarities on these elements between the databases. Everything differs, even the naming, and consensus must be reached.

It has previously been discussed by different authors as well, like Edelen et al. (2017), Frischknecht, R. (2005) and Björklund (2002).

The roadmap, on the other hand, provides clear steps on how to achieve data harmonization. It was created using knowledge from experts and previous research (European Commission Joint Research Centre, 2013).

Considering the timeframe of the study, there are also several limitations. First, a stakeholder analysis to identify all the involved parties and their significance was not done. A lot of stakeholders should be involved in the process but considering that the main goal was to create a roadmap to data harmonization, not to create the database itself, then stakeholder involvement was not necessary. During further research, all the involved stakeholders should be identified.

Another important limitation was the number of experts involved in the creation of the matrix. Currently, the matrix was made, using opinions of the policy makers since the matrix and the roadmap is mainly meant for governments and NRAs. This means that only an outline of the matrix was created and to arrive at a more comprehensive result, all the stakeholders must be involved and interviewed to see their point of view. When the actual harmonization process starts, the matrix must be supplemented.

6. Conclusion and recommendations

The analysis of data harmonization shows the difficulty and the scale of the process. There are a lot of differences between the existing databases. Each has a completely different structure, elementary flow lists, and data verification method. Even names of the categories included in the databases differ and has to be agreed upon.

It is especially challenging since a lot of stakeholders (e.g. NRAs, LCA practitioners, commercial database managers) must be involved. To ensure that the database is implemented and used, their wishes and needs must be acknowledged.

Even though it is difficult, the task is not impossible. There are a lot of examples where harmonization has been done succesfully, like ISO standards, GPP and national databases to name a few. There are also many ongoing harmonization processes like PEF database.

To make sure that the harmonization happens as smoothly as possible, the Impact Effort Matrix and the roadmap was created.

The matrix clearly points out the biggest challenges that should be prioritized – structure of the database, treatment of data gaps and elementary flow lists. It can help greatly during the discussions and workshops mentioned in the roadmap since it provides a clear outline of the main talking points.

The roadmap gives specific steps that must be taken in order to achieve harmonization. It can, not only help CEDR, EU, or any other party to establish an international LCA database but also guide NRAs towards a national database development. Currently, there are only six EU countries who have their own databases – Netherlands, UK, Sweden, Belgium, France and Germany. Considering that LCA is very much dependent on the data used, it is important to have country specific data, to be able to perform a comprehensive LCA analysis, hence using data from local databases.

The most important steps in the roadmap are:

- To establish a strong management team that can lead and steer the whole process. Previous experiences (e.g. PEF database) showed that without strong guidance the effort may fail due to the huge number of stakeholders involved in the process.

- To arrange workshops where the outline of the database is decided. Many stakeholders with different backgrounds (e.g. NRAs, LCA practitioners, commercial database managers) has to participate in the workshops to gain comprehensive knowledge of the needs and wishes of all involved parties. The baseline of the workshops are existing standards and the matrix.
- To create a technical manual of the main rules and outlook of the database to ensure consistency between the datasets.

Even though a lot has already been achieved regarding LCA harmonization, there are still many aspects that has to be taken into account to reach the goal.

The main purpose of the research was to draw a roadmap with precise steps towards data harmonization. To create the structure of the database or to harmonize the data more research is necessary.

The next immediate steps to continue the research should be:

- Presenting the main findings to NRAs and discuss the posibility of a harmonized database.
- Stakeholder analysis to identify all the involved parties and their significance in order to be able to understand their attitude towards harmonization.
- Creating the Impact Effort matrix, using input from all the involved stakeholders. During this project only two experts were interviewed to draw the matrix. To have a more inclusive view of the matrix more stakeholders has to be involved in the process.

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Appendix 1 Inventory of the databases

Database in Belgium

The database Totem (Tool to Optimise the Total Environmental impact of Materials) is maintained by Flemish public waste agency (OVAM), Walloon public service (SPW) and Brussels environment agency (Brussels Environment).
Since 2010, OVAM was working on developing a framework for unequivocal calculation of Environmental performance for construction materials. In 2014 SPW and Brussels Environment joined the team to develop a Belgian tool to use for calcualtion of Environmental performance.
The framework was developed together with various experts from the government authorities and from the construction industry. The experts could express their opinion on the matter during several meetings and workshops.
The database is accessible via the Totem tool and is meant only for buildings, there is no information on road pavement. The tool itself is available online and is free of charge. The database is in line with existing European initiatives for example, the environmental indicators used in the framework are based on CEN/TC 350 standard "Sustainability of construction works" as well as on PEF guide (Totem, 2019).
For the data, ecoinvent database was used as much as possible. However, some manufacturers and other companies offered their own environmental data of building products as well. The whole database is divided into three databases – Materials Database, Work Section Database and Elements Database (Allacker et al., 2018). The structure of the database is visible in Figure 5.

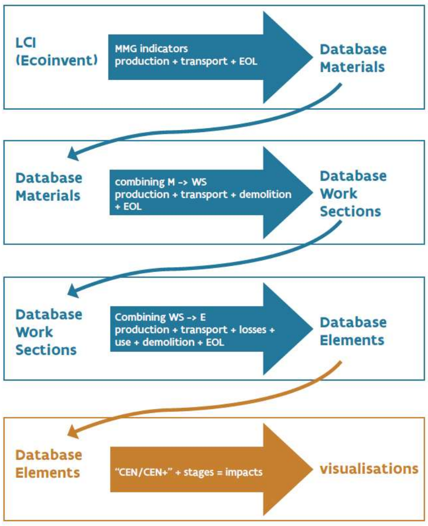

Figure 5 Totem database overview (Allacker et al., 2018)

Databases in France

In France there are four national databases. First two are created by ADEME, the French Environment and Energy Management Agency.

Base Impacts
Base Impacts is a database for environmental labelling (green labels) of consumer goods so this database is more meant for different consumer goods such as furniture, doors, kitchen items and so on. It is not meant for construction process (Base Impacts, 2019).

Base Carbone
Base Carbone is designed to determine greenhouse gas balance and it has data on CO2 emissions in France and its colonies. The online database follows a cradle-to-grave model, separated into life cycle stages (including manufacture of new or recycled material, and end of life), with an output expressed in equivalent CO2 kilograms per ton, as well as an uncertainty percentage for this value. It has data on different building materials, like metals, plastic, glass, concrete, bitumen and others. However, this database only shows CO2 emissions so other LCA inventories are excluded (Ademe, 2019).

Ecorce
Ecorce database was developed by IFSTTAR together with French Ministry of Ecology and is dedicated specifically to roads (Ecorce, 2019). It provides various life cycle inventory data and results of environmental indicators with respect to various technical choices available during the tender phase, project execution phase or upon final completion of the works.
It provides information on all life cycle stages – raw materials, material mixing, road construction and end of life (Dauvergne, el al, 2014).
The database is updated once a year to integrate new LCA data. It only contains data about France, although, data for other countries (Spain, UK, Germany) are slowly being introduced as well (Jullien, Dauvergne & Proust, 2015). The data sets are provided according to ISO 14040 series and French standard NFP 01010 (Ecorce, 2019). The database is only accessible via Ecorce tool. This means that the data can only be accessed when LCA is conducted. The data for database were collected by IFSTTAR and were submitted via publication proposals to international journals – IFFSTTAR published that they are gathering datasets and then companies and researchers sent in their collected data. The data were afterwards validated through a review process, consisting of at least 2 anonymous reviewers, no commercial database was used to retrieve data so flows used are derived from data found in literature and then standardized to suit the generic system of the software (IFFSTAR, 2014). The tool is available via Java software and is free of charge.

INIES
It provides Environmental and Health Declaration sheets (FDES) for building products, Product environmental Profiles (PEP) for equipment and also data about different services (water, energy etc.). Information is provided by manufacturers and trade associations based on LCA. They collect environmental and health data on the product and then, using an appropriate LCA tool, calculate the product's environmental information. The data is afterwards audited by an independent, certified third party.
FDES is a standardised document that shows the result of product's LCA and health's information. It takes the whole product life cycle into account and is designed to help involved stakeholders make an informed decision, making their building more sustainable and environmentally friendly. Each FDES provides information on:
- product specifications (raw materials, possible dangerous substances etc.).
- product's functional unit and lifespan.
- environmental profile (set of environmental indicators, calculated over product's life cycle).
- information on the products effect on health and identity of the party that issued the FDES.

PEP is an environmental identity card and is made for electrical and electronic equipment. It includes the same information as FDES, except for information on health and just as FDES it is based on LCA calculations and it takes into account the whole product's life cycle.
The database is available online, free of charge (Inies, 2019).

Databases in Germany

In Germany, there are two national databases – ProBas and Ökobaudat.

ProBas
The provider of the ProBas database is Federal Environment Agency. Main topics covered in the database are energy, materials&products, transportation services and waste. The database was made compliant with ISO 14040 and ISO 14048 standards. Two thirds of the processes are representing Germany, however other countries are included as well (Martínez-Rocamora, Solís-Guzmán, Marrero, 2016).
Around 700 construction materials, are included in the database, but only two types of road materials are accessible in the database – asphalt and cement. For both materials, the data is from the year 2000. The main environmental aspects are air pollution, emissions and water pollution.
For each dataset there are general information with description, references, comments, technical characteristics and environmental aspects (raw materials, emissions) available (ProBas, 2019). The database is only accessible in German.

Ökobaudat
Ökobaudat database is maintained by the Federal Ministry of the Interior, Building and Community and is designed for environmental assessment of buildings and different construction materials. The database contains information about building materials, construction, transport, energy and disposal processes (BBSR, 2019).
All datasets in Ökobaudat represent EPDs and are compliant with the product category rules defined in the DIN EN 15804 (the German equivalent to the European EN 15804 standard: "Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products"). This means

that the datasets are already in EPD format and do not require a separate impact assessment since they already contain finalized category indicator results (BBSR, 2019).
The datasets included in the database are a subject to strict quality requirements and can be used in different building assessment systems. More than 1200 datasets are available in the database (BBSR, 2019). Datasets are based on the background database GaBi, datasets based on Ecoinvent are also available in 'additional datasets'. There are three data categories in the database (Table 3). Database itself is publicly available and free of charge.

Table 3. Data categories (BBSR, 2019)

Data Category	Description
Category A	Verified EPD created in accordance with DIN EN 15804 and in accordance with the rules in DIN EN ISO 14025 and as a programme operation in accordance with DIN EN ISO 14025
Category B	Verified EPD (B1)/life cycle assessment data with external review (B2), that has been created in accordance with DIN EN 15804, but not as part of a programme operation in accordance with DIN EN ISO 14025
Category C	Life cycle assessment data in accordance with DIN EN 15804 without external verification/critical review, for example "generic datasets"

To include new data in the database, the manufacturer selects an EPD programme operator that issues the EPD and then delivers it to Ökobaudat (Figure 6).

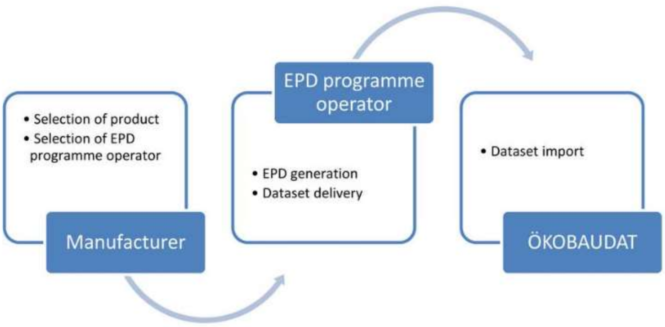

Figure 6. Data inclusion in the database (BBSR, 2019)

It is mandatory to use this database for Assessment System for Sustainable Building (BNB). BNB is a quantitative assessment method for office, administrative, teaching and laboratory buildings completing the guide to sustainable construction. Materials and processes for all of these buildings are included in the database, however, road construction is quite poorly represented (BBSR, 2019).

Database in the Netherlands
The Netherlands uses NMD database – Dutch National Environmental database. The database contains information on products and activities in the form of product cards that refer to environmental profiles and are in accordance with Assessment Method Environmental Performance Constructions and Civil Engineering Works (Assessment Method) (Stichting Bouwkwaliteit, 2019). These profiles are then used via different calculation tools to calculate the environmental performance of buildings and civil engineering works. The database is mostly used together with DuboCalc – a calculation instrument developed by Rijkswaterstaat. However, it can be used together with other tools as well like GreenCalc, GPR and others, including generalist softwares, like SimaPro. Basically, the database can be used together with any calculation tool as long as the tool has integrated the Assessment Method into their software. This is very important because the Netherlands only uses this Assessment Method for calculation of the environmental performance (Stichting Bouwkwaliteit, 2015). The necessity to use the Assessment Method to determine environmental performance is also stated in Dutch Law – "Bouwbesluit 2012" (Building Code 2012), article 5.9. This ensures that there is always uniformity in results of LCA analysis.
The NMD database consists of following databases:

- Database with products and Item cards.
- Process database – it is a collection of basic processes stored in SimaPro which is a popular software in the Netherlands. The calculation of the basic processes results in base profiles of, for example, the production of basic materials, disposal of the material and transportation.

- Database with basic profiles – it contains environmental information per building material and is generated based on the Process database. The product cards include general product information (no environmental information) relating to construction products and components, for example composition, service life maintenance scenarios and disposal scenarios.
- Database with disposal scenarios – waste scenario is entered together with the basic profiles (Milieudatabase, 2019).

The database has data on environmental impacts of all basic materials in different impact categories such as: depletion of raw materials, depletion of fossil energy carriers, climate change, ozone layer depletion, photochemical oxidation (smog), acidification, eutrophication, human-toxicological effects, ecotoxicological effects, aquatic (freshwater), ecotoxicological effects, aquatic (seawater), ecotoxicological effects, terrestrial.
The database has 3 product information categories:

- Category 1 – brand data that is verified by a qualified, independent third party. Data is not available to public but can be accessed as Life Cycle Inventory (LCI) through calculating instruments like DuboCalc, GPR etc.
- Category 2 – branch representative data that is verified by a qualified, independent third party. This data is an average representative of the Dutch market. Data is not available to public but can be accessed as LCI through calculating instruments like DuboCalc, GPR etc.
- Category 3 –generic data, which is not verified. It consists of data from Ecoinvent database but with 30% penalty since they're not verified (the results will be increased by 30%). The underlying data like composition of product/item cards and base profiles are available to public (Stichting Bouwkwaliteit, 2019).

As visible above, only data that is not verified is available to public. The rest of the data can only be accessed via different instruments (e.g. DuboCalc). The category 3 data are used as a safety net, if there is not enough data available from the first two categories (Stichting Bouwkwaliteit, 2015). The calculation instruments are not free of charge which means that to access verified data, it is necessary to have a licence from one of the suitable softwares.
The verified data from the first two categories is reviewed according to a verification protocol, maintained by the "Stichting Bouwkwaliteit (SBK)" (Institution for Construction Quality). There are three main steps on how to include data in the NMD:

- Step 1: LCA analysis for the construction product based on the Assessment Method.
- Step 2: LCA project file is verified by an independent LCA expert, recognized by SBK. The testing is done according to the verification protocol.
- Step 3: The verified LCA report is supplied to SBK and entered into the database (Stichting Bouwkwaliteit, 2015).

Database in Sweden

Sweden performs extensive LCA's including all three pillars of sustainability. They also have their own database – CPM LCA. It was developed within the Swedish Life Cycle Center and is a result of the continuous work to establish transparent and quality reviewed LCA data. Nowadays the database is maintained by Environmental Systems Analysis at the Department of Energy and Environment at Chalmers University of Technology (CPM LCA Database, 2019).
Quality of data in CPM depends on data documentation, meaning criteria has been established on how the data should be documented. Documentation of data consists of six closely integrated sections (Figure 7):

1. *Description of model of technical system* (process) – It is described through name (most commonly known name of the process), one or more classes (category of the process, for example according to sector), quantitative reference (functional unit or reference flow), short description of technical scope, time span (description of time span during which the documented process and data may be valid, e.g. time of data collection and geography (description of the geographical area or location where the data is valid).
2. *Data for input and output flows* – inputs and outputs of a system that are environmentally relevant. They are specified by identification number (specific number identifying the input or output), direction (input to or output from the process), group (group to which input or output belongs, e.g. natural resource, emission), name of the substance entering or leaving the process and functional unit.
3. *Description of methods used to acquire the numerical data* – data for input and output flows has been acquired using different methods, like, different measurement techniques, theoretical models etc. The description of the collected data consists of type of data collection (e.g. modelled from data describing a similar system, derived from continuous measurements etc.), collection date (time period during which the data was collected), description of data treatment (methods, sources and assumptions used to generate the data) and reference to data source.
4. *Description of choices made during the modelling* – describes different choices made, for example, system boundaries.

5. *Recommendations for the use of the method and the data* – if there are certain aspects that the data user should be aware about, like data limitation, special circumstances etc.
6. *Administrative and general information* – information on organisation responsible for the data, identification number etc.

To fulfil the data documentation criteria, all sections should be assessed (FlemStrom & Pallson, 2003).

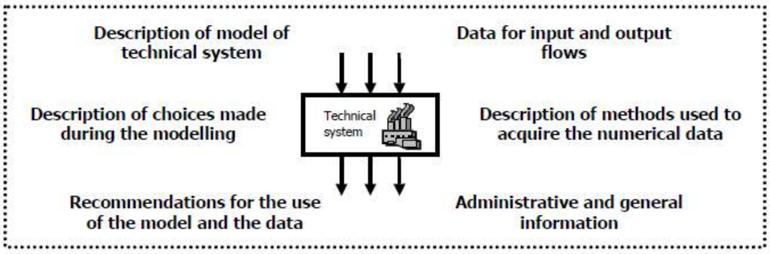

Figure 7 Data documentation criteria (FlemStrom & Pallson, 2003)

Databases in UK

There are two databases in UK. One is for construction materials manufactured or sold in the UK market. It is the only database in UK with multiple environmental indicators at each life cycle stage of the product. However, government has not been involved in the development, maintenance and financing of the database so it does not count as a 'national database' (UKCoMDat, 2019).

The other database – ICE (Bath Inventory of Carbon and Energy) is meant for energy and carbon emissions of building materials. Provider of the database is Bath university. The data comes from different sources such as government publications, academic research, industry statistics and other LCA databases (BRE, FEFCO, Athena Institute International) (Ghgprotocol, 2019). In the beginning, the database was relatively small but overtime it has expanded and now it consists of over four hundred values of embodied energy and carbon (Hammond and Jones, 2008).

The database is accessible free of charge. It is basically an excel spreadsheet with a lot of materials. There is information on asphalt provided as well. However, the information is quite poor and only GHG emissions are included (Table 4 4).

Table 4 Asphalt in ICE database (Hammond and Jones, 2008)

Material Profile: Asphalt

Embodied Energy (EE) ICE-Database Statistics - MJ/Kg

Main Material	No. Records	Average EE	Standard Deviation	Minimum EE	Maximum EE	Comments on the Database Statistics:
Asphalt	**17**	**6.63**	**11.89**	**0.20**	**50.20**	There was a large data range, some of the collected data included feedstock energy but others excluded it. This was problematic and was complicated by the fact that it was not always possible to determine if the feedstock energy was included or excluded! An additional indication of the difficulty in selecting the 'best' value was that the standard deviation was much higher than the mean Value.
Asphalt, General	17	6.63	11.89	0.20	50.20	
Predominantly Recycled	2	7.32	0.28	7.12	7.52	
Unspecified	13	7.46	13.47	0.23	50.20	
Virgin	2	0.49	0.40	0.20	0.77	

Selected Embodied Energy & Carbon Coefficients and Associated Data

Material	Embodied Energy - MJ/Kg	Feedstock Energy (Included) - MJ/Kg	Embodied Carbon - Kg CO2e/Kg	Boundaries	Best EE Range - MJ/Kg		Specific Comments
					Low EE	High EE	
Asphalt, 4% (bitumen) binder content (by mass)	2.86	1.68	0.066	Cradle to Gate	(+/- 30%)		Modelled from the bitumen binder content. The fuel consumption of asphalt mixing operations was taken from the quarry products association, it represents typical UK industrial data. Feedstock energy is from the bitumen content.
Asphalt, 5% binder content	3.39	2.1	0.071				
Asphalt, 6% binder content	3.93	2.52	0.076				
Asphalt, 7% binder content	4.46	2.94	0.081				
Asphalt, 8% binder content	5.00	3.36	0.086				

European life cycle database (ELCD)
The Joint Research Centre of European Commission developed ELCD to increase availability of quality assured life cycle data. The database was released in 2006. It consisted of LCI data from EU-level business associations and other sources. The data was in line with ISO standards and the quality was according to ILCD Data Network entry-level data quality requirements (Nexus, 2019). The database was free of charge and available to anyone. However, in 2018, it was discontinued. Currently, it is not available online but can still be downloaded as a zip package (Eplca, 2019).

Product environmental footprint (PEF) database
European Commission has launched PEF database with secondary data. Database is part of a PEF project, which was intended to develop a common methodology on the impact of products on the environment throughout their life cycle in order to support the assessment and labelling of products. The project still isn't finished since when finalizing the pilots, it was found that they were not consistent in terms of modelling approach, background and reference data used and more. It is mainly because the pilots were created independently by different LCA consultants. Currently PEF remodelling project has been launched.
All of this means that the PEF database has very restricted information and only companies and stakeholders involved in the PEF projects have access to the database. However, there is still some information available on the database.
For now, datasets are available on only fully aggregated processes with very few exceptions. There are different providers for each data type and full consistency among datasets are not guaranteed. There is data provided on following processes: Agriculture products, end of life treatment, energy carriers, material production, systems (e.g. construction, packaging) and transport services (Recanati and Ciroth, 2019).

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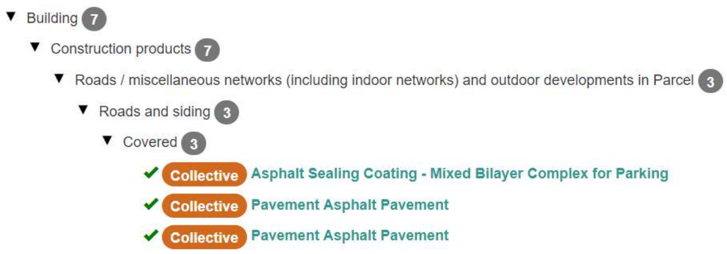
Appendix 2 Comparison of the databases

Both French databases, maintained by ADEME (Base impacts and Base Carbon) will not be included in the comparison. Also ELCD, PEF, ICE and Totem databases will be excluded. Base impacts are meant for consumer goods and there is no information on construction included. Totem has information on construction materials but nothing on road pavements. Since road pavement products are used for comparison of databases, then Base impacts and Totem has to be excluded. Base Carbon and ICE only calculates greenhouse gasses so any other LCI is excluded, this means that the coverage of the databases is too poor for them to be included in the comparison. When it comes to ELCD and PEF, then ELCD is not functional anymore but PEF database is still under construction and is not available to public so there is no extra value in comparing a half functional database to databases that have been functional for years.
This means that Ecorce, INES, Probas, Ökobaudat, CPM LCA and NMD are compared in this section.
As already visible from the descriptions of each database, there are several major differences between them. The basic differences are visible in Table 1 and Table 2. The differences are described in more detail below.

Scope
Most of the databases cover craddle to grave scenarios. However, CPM LCA and Ökobaudat only covers craddle to gate when it comes to asphalt.
The coverage of pavement categories is diverse as well. Ecorce is specifically designed for road construction. It is the only database dedicated specifically for roads when it comes to EU national databases. This means, that the road construction is completely covered, starting from earthworks, then including all the necessary layers and ending with the destruction of the pavement. When it comes to asphalt pavement, then hot-mix, warm-mix and cold-mix asphalts are included. Recycled asphalt is available as well.
The other French database INIES is not that comprehensive and only two asphalt pavements are available (Picture 1)



Picture 1 Road pavement in INIES (HQE-GBC, 2019)

In Sweden, the data on pavement also is very limited. When searching in the database in class ''construction'' very few processes appear (Table 5) and there is only one type of asphalt available which is the average asphalt used in Sweden.

Table 5. Construction processes included in the CPM LCA (Cpmdatabase, 2019)

#	Name of process	Technical scope	Product or service	Date Completed	Report: SPINE HTML	Report: ILCD XML More info	Report: ISO/TS 14048 HTML	CPM Quality
1	Dismounting of bearing	Unit operation	1.2 ton bearing	2002-12-18				A
2	Linoleum flooring. ESA-DBP	Cradle to grave	Linoleum flooring	1994				S
3	Manufacturing of plywood boxes at Nefab in Alfta	Gate to gate	plywood box	02-12-31				S
4	Mounting of bearing	Unit operation	1.2 ton of bearing	2002-12-				A
5	Production of hot mix for asphalt pavement.	Cradle to gate	Hot mix	2001-02-09				S
6	Solid wood flooring. ESA-DBP	Cradle to grave	Solid wood flooring	1994				S
7	Vinyl flooring. ESA-DBP	Cradle to grave	Vinyl flooring	1994				S

German database ProBas is almost just as poor as CPM LCA when it comes to road pavement (Picture), only asphalt and cement are provided as road pavement products.

process name attributes		Environmental data for ...	sites
asphalt			
Year:	2000	air emissions	References: 2
Data Source:	ifeu - Institute for Energy and Environmental Research Heidelberg	Air emissions (aggregated)	
outputs:	asphalt	resources	
Nace Code:	Construction roads railways runways sports facilities	Resources (aggregated)	
		water discharges	
cement			
Year:	2000	air emissions	References: 2
Data Source:	ifeu - Institute for Energy and Environmental Research Heidelberg	Air emissions (aggregated)	
outputs:	cement	resources	
Nace Code:	Producing cement	Resources (aggregated)	
		water discharges	

Picture 2 Road pavement products accessible in ProBas (Probas, 2019)

The relatively new German database Ökobaudat has more asphalt pavement products included (Picture), so it is way more extensive than ProBas and CPM LCA. However NMD and Ecorce are still the most comprehensive ones.

Name	Langu-ages	Classification	Location	Valid Until	Type	Owner	
Search...	Choos	Search...	Choos	select	Choose	Search...	
Asphalt binder; 170 - 250 kg/m2	en de	1.5.03 Mineralische Baustoffe / Asphalt / Asphaltbinder	DE	2021	generic dataset	thinkstep	
Asphalt supporting layer; 2350 kg/m3	en de	1.5.04 Mineralische Baustoffe / Asphalt / Tragschichten	DE	2021	generic dataset	thinkstep	
Mastic asphalt; 2400 kg/m3	en de	1.5.02 Mineralische Baustoffe / Asphalt / Gussasphalt	DE	2021	generic dataset	thinkstep	
Mastic asphalt screed	en de	1.5.02 Mineralische Baustoffe / Asphalt / Gussasphalt	DE	2021	generic dataset	thinkstep	
Stone mastic asphalt SMA; SMA	en de	1.5.01 Mineralische Baustoffe / Asphalt / Splittmastixasphalt	DE	2021	generic dataset	thinkstep	
Asphalt surface layer; 2400 kg/m3	en de	1.5.04 Mineralische Baustoffe / Asphalt / Tragschichten	DE	2021	generic dataset	thinkstep	

Picture 3. Road pavement in Ökobaudat (BBSR, 2019)

If looking at the territory, all national databases mostly cover their respective countries, with very small amount of data available on other countries.

Access and licence

All the national databases are free of charge except for NMD which require a licence for the tool that incorporates the database (e.g. DuboCalc, SimaPro, etc.). Access to category 3 data is free of charge, however category 3 data is not verified so to perform a rigid LCA, it is necessary to acquire a licence.

The access to databases differs as well. Both German databases are freely accessible online, the same goes for the database in Sweden and INIES database, but the other French database is only accessible via Ecorce tool and as already mentioned, NMD database is accessible via different tools. Ecorce is the only database that is not available online. To use the database, it is required to download the tool which is available via Java software.

Data sources and verification

Data sources and verification methods differs greatly. NMD uses other databases like SimaPro or Ecoinvent specifically for the third category data. Also any company or involved stakeholder can provide data for the database as long as the data is verified according to the Verification protocol.

When it comes to Ecorce, then data was not taken from any commercial database, but it was collected via scientific journals. The data was afterwards validated through a review process, consisting of at least 2 anonymous reviewers. The database is reviewed once a year but no external party can put their data into the database.

Data in Ökobaudat are already available as EPDs, the same as data in INIES. To create Ökobaudat, GaBi database and Ecoinvent databases were used for background data. To include new data, it has to be converted into EPDs. INIES data comes from the industry and it has to be converted into EPDs as well. All the data also has to be verified by an independent third party. ProBas has different data sources, for example the data for asphalt comes from a research institute.

Data acquired in the CPM LCA database also comes from different sources, like scientific papers, master thesis etc. For example, data for hot mix asphalt was collected by A. Ries thesis. Data is verified based on data documentation which consists of six parts described in more detail in apendix 1.

Environmental impact categories

Considering that in EN 15804 main impact categories are given then the databases were compared based on the information there. Comparing to the EN 15804 most databases have almost the same coverage. Only CPM LCA and ProBas has a rather thin range of indicators. It can be due to the fact that both databases does not offer a lot of road products so the information on them is limited.

Some databases like NMD and Inies have more indicators available than in EN 15804 but considering that at least EN 15804 indicators should be included then they were not listed.

Structure of the database

The structure of the databases is completely different as well. Even though there is extensive information on each dataset in all of the databases, information itself differs. For example, there is no seperate information on process boundaries in Ökobaudat available but in CPM LCA, there are extensive information on boundaries provided. There are differences even in categories of datasets. For example, asphalt in CPM LCA database is under “Construction”, but in Ökobaudat database it is under “Mineral building products”.

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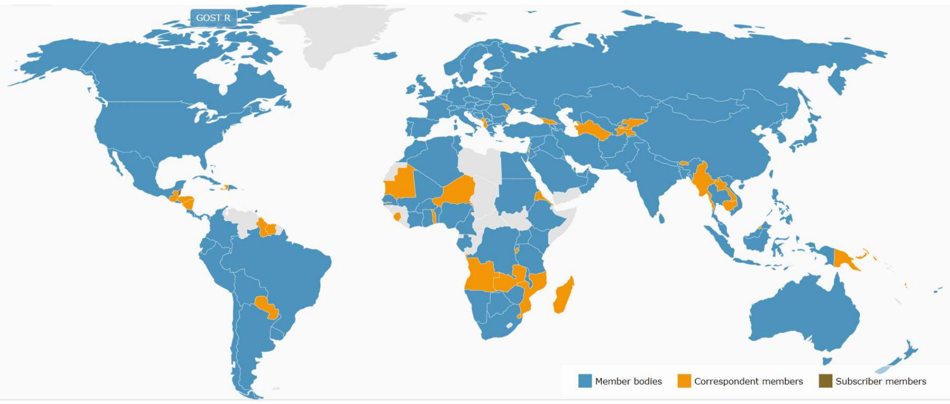
Appendix 3 Harmonization attempts in LCA

ISO standards

ISO standards are one of the most important LCA harmonization documents. They are the only globally relevant international standard documents on LCA and they are being used by almost every country in the world.
ISO is the International Organization for Standardization. It has more than 160 memberships of national standards institutes all over the world (Picture). Each member represents its country and there cannot be more than one member per country (ISO, 2019).
ISO has released more than 22000 standards, including standards on LCA. In the beginning, it was a real challenge to achieve consensus on LCA methodology, only establishment of ISO 14040 series led to a worldwide acceptance of LCA (Klopffer and Curran, 2014).



Picture 4 Members of ISO (ISO, 2019)

The first developed standard was ISO 14040, addressing the principles and frameworks of LCA. The standard had to meet the concerns from the industry who wanted to use LCA for product development and marketing of greener products, but saw that the lack of standardized methodology could give opposite results on the same product, depending on the methodological choices. After ISO 14040, three more standards followed – ISO 14041 on goal and scope definition, ISO 14042 on life cycle impact assessment and ISO 14043 on life cycle interpretation. In 2006 the latter three standards were compiled in ISO 14044 – principles and framework. Nowadays these two standards – ISO 14040 and 14044 are the core but many LCA spin-off standards such as ISO 14067 on carbon footprint of products, ISO 14025 on EPDs and so on have been released as well (Hauschild, Rosenbaum and Olsen, 2018).
Even though the core ISO standards give direction and basic rules on LCA, they still do not give specific details on methodological choices. This has led to other, more explicit harmonization attempts.

Environmental product declaration (EPD)

An EPD is an independently verified and registered document that communicates transparent and comparable information about environmental impact of products and services. It is generated based on data obtained through LCA (Environdec, 2019). EPDs are used both externally for marketing purposes and internally for the improvement of product manufacture, or process efficiency (Designingbuildings, 2019).
There are also specific standards for developing the declarations and labels. The two main ones in Europe are ISO 14025: Environmental labels and declarations – Type III environmental declarations and EN 15804 (Ecomatters - Sustainability, 2019).
The purpose of an EPD in the construction sector is to provide the basis for assessing buildings and other construction works, and identifying those, which cause less stress to the environment. EPD can cover all stages of a product's life cycle or can include only some of the stages (NEN-EN 15804:2008).

European Platform on Life Cycle Assessment (EPLCA)

EU has a long history of supporting LCA integration in policies and businesses. There has been several attempts to establish agreed methods for LCA assessment, ensuring data availability, coherence and quality. EC has also repeatedly advocated or adopted LCA in a wide range of policies and documents. One of the most important parts in LCA harmonisation in Europe was launching EPLCA in 2005. It is meant to support governments, businesses and practitioners in providing data, studies and guidelines on LCA so EPLCA with all its features are meant to ease the use of LCA and to give guidelines for specific methodologies. The platform consists of several important developments, described below.

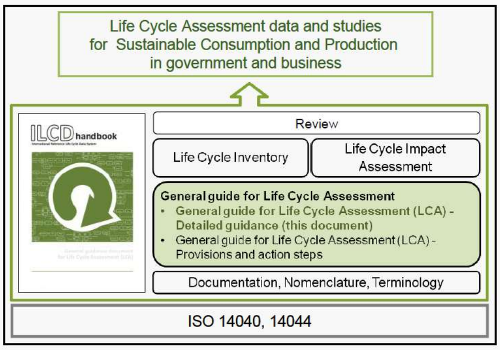
International Reference Life Cycle Data System (ILCD) handbook

Since ISO standards provide a lot of room for interpretation and variation, ILCD handbook was created to provide more precise guidelines for greater consistency and quality of LCA.

It is a series of technical guidance documents that consists primarily of the ILCD Handbook, additional Entry Level Requirements, the Life Cycle Data Network, plus a range of supporting documents and tools (JRC-IES, 2010).

It was created during a comprehensive process by evaluating existing LCA methods and involving experts, practitioners, advisory groups and other stakeholders. The aim was to reach the best-attainable consensus, reflecting on the best practices in industry and government. It was not meant to build new methods but to compile the main aspects of already existing practices. ILCD handbook is a general guide on LCA analysis, LCI data sets, framework and requirements for Life Cycle Impact Assessment (LCIA) (JRC-IES, 2010).

The structure of the ILCD Handbook is visible in Picture . Guidance is available on documentation, nomenclature, terminology for LCA studies, review requirements, LCI, and LCIA (Sala et al., 2012).



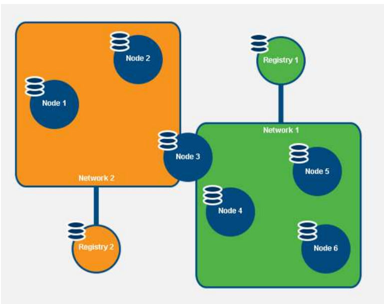
Picture 5 ILCD handbook content (JRC-IES, 2010)

Life Cycle Data Network (LCDN)

LCDN was launched in 2014 and its main purpose is to provide a globally usable infrastructure for the publications of LCA datasets from different stakeholders and organizations like industry, research groups, LCA projects etc.

Originally it was meant to host data compliant with ILCD entry level requirements but since 2018 a new entry has been added to host and share data packages in line with the Product and Organisation Environmental Footprint (PEF and OEF).

The network itself is non-centralised and composed by nodes (developer/owner dateset repository). For the developer/owner to be able to publish their datasets, they have to be compliant with ILCD entry level requirements and PEF/OEF. The structure of the network can be viewed in Picture . In this network reliable datasets are available and the party using it can be assured that they are in good quality(LCDN, 2019).



Picture 6 Structure of the network (LCDN, 2019)

However, currently, only Thinkstep nodes are available in the network. There are some from ELCD as well but they are not valid anymore – the link to the dataset does not work. Even though it would be a useful platform for LCA datasets, right now the information in the network is very restricted. This shows that creating a platform is only half of the work. If it is not properly maintained, then the use of it is very limited.

Resource directory

Resource directory is a repository that consists of:

- *Services and tools* – information on available softwares and databases.
- *Documents and studies* – reports, methodologies, scientific papers etc. about different Life Cycle approaches

- *Review registry* – information on skills of potential reviewers for Life Cycle studies and LCI datasets (Resource Directory, 2019).

It was built to keep an overview of Life Cycle approaches and keep track on the newest research and findings. Even though, the Resource directory would be a useful tool in LCA development, it has to be properly maintained. Currently, it is not happening. There are quite extensive information available on databases and tools, but the documents and studies on LCA are very poor. There is only couple of studies available, nothing newer than 2011 and only descriptions of the studies are available, the links to the studies does not work.
Resource directory has the same problem as LCDN – it is not properly maintained so the use is very limited.

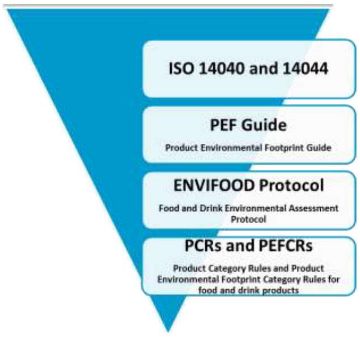
Environmental Footprint (EF)
EF is a method based on LCA to quantify the environmental impact of products (goods and services). It is developed both for products – PEF and for organisations – OEF. Abbreviation EF is used to describe both PEF and OEF.
The main goal of EF is to develop a standardized LCA methodology for the whole Europe by creating a general EF assessment method and specific rules for each product type – PCRs (SimaPro, 2019). The EF platform is meant to provide comparable and reliable environmental information (guidelines, general requirements, best practices for LCA development) for consumers, investors and other involved stakeholders. EF is supposed to give precise technical guidance on the choice of impact categories, type of data, quality requirements of data etc. (European Commission Joint Research Centre, 2013). However, because of data and methodological inconsistencies, the project is still on-going and is trying to come to a common solution.

InData
InData is an informal non-profit working group whose purpose is to establish an open web based international data network structure for LCA/EPD data, using a common data format and open source software. The site is meant mainly for construction products based on EPD and it provides access to different documentations and specifications, mainly on ILCD+EPD data format (InData, 2019).
Since the network is relatively new (it was developed in 2015), then still a lot of work has to be put into it. The purpose of the network – to provide information on EPD data and how to integrate EPD information into the existing ILCD data format is important, however, for now, not a lot of information is provided and mostly only small amount of documents can be accessed.

Life Cycle Initiative
The Life Cycle Initiative is a public-private partnership whose main goal is to facilitate the global use of credible life cycle knowledge by private and public decision makers. It is hosted by UN Environment and it is meant to be an interface between users and experts of Life Cycle approaches. Life Cycle initiative supports decisions and policies towards the shared vision of sustainability as a public good. The vision is to achieve Sustainable Development Goals and Nationally Determined Contributions for the Paris Agreement faster and more efficiently by using life cycle approaches. It supports and works together with global and local initiatives like Global LCA data network access and Europe's EF. It is not meant for private users, but it more works on a global level, supporting the industries (Lifecycleinitiative, 2019).

Harmonization in food sector
Food and its consumption has a significant impact on environment. Agriculture and food production are responsible for the third of global greenhouse emissions. Robust LCA can help in understanding this issue and decrease the impact on the environment. However, to be able to analyse the LCA studies, it is necessary to have consistency in data and methods (SimaPro, 2019). There have been several attempts to harmonize guidelines and data of LCA in food sector (Ponsioen and van der Werf, 2017). One of the latest attempts is the PEF initiative and European Food Sustainable Consumption and Production Round Table (RT) as part of PEF pilot phase. The RT is co-chaired by the EC and food supply chain partners and is supported by United Nations Environment Programme and European Environment Agency. RT's structure facilitates an open and result driven dialogue amongst the stakeholders along the food supply chain which can lead to further harmonization. RT performed an analysis on data, methodologies and guidelines for assessing environmental performance. It led to a harmonized methodology for environment assessment – ENVIFOOD Protocol (Protocol). The Protocol is meant as a complementary guidance document to PEF guide. In Picture , the documents currently available in PEF pilot stage on food and drinks are visible and it shows the hierarchy of the released documents and how with each document more detailed approach is achieved. It starts with ISO standards where the general concept is described, the LCA methodology further and in more detail is described in PEF guide. Protocol provides additional guidance specifically for food and drinks and finally, PCRs and PEFCRS specify the details even further on how LCA should be conducted at a product level (Saouter et al., 2014).

To establish the guidelines, RT organized different workshops, consultation moments, test period, feedback moments etc. To gain comprehensive insight into the process many stakeholders (e.g. governmental organizations, consulting agencies, research institutes etc.) participated in the process.
Several other organizations have been trying to improve and expand the availability of LCA data for food and drinks as well. For example, Food and Agricultural Organisation launched the Livestock Environmental Assessment and Performance initiative (LEAP) in 2012. The main objective of LEAP is to develop comprehensive guidance and methodology for environmental performance of livestock supply chains. LEAP not only has published several guidelines but also has a database on five main global feed-crops.



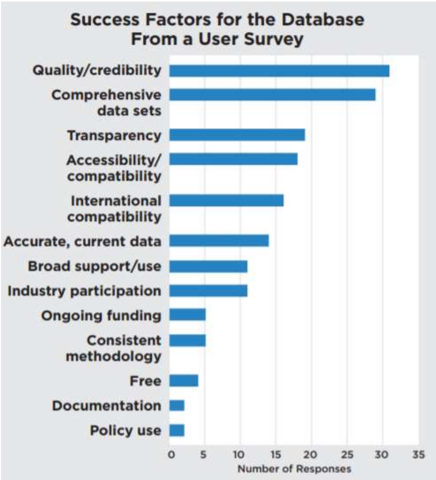
Picture 7 Food and drink guidance documents (Saouter et al., 2014)

Similar organization to LEAP is Global Feed LCA institute. Its goal is to develop a harmonized LCA database for livestock products compliant with the LEAP methodological guidelines.
Another organization in food industry is World Food LCI database. The database includes 900 primary products and processed food products at the global level. Similar to the previously mentioned initiatives, the aim is to provide a well-documented, reliable data to perform comprehensive and robust LCAs or EPDs (SimaPro, 2019).
The food industry provides an example on how to further develop guidelines and data requirements. Even though there are many organizations working on their own databases, they are all based on the same guidelines and are in line with each other so they can all be used together.

National LCI database in USA
Since several EU national databases were investigated in the previous chapter, then the database in USA will not be described in detail. However, the reasons for the database creation is analysed thoroughly since they give a much needed insight on the database success factors.
The work on the database was carried out by National Renewable Energy Laboratory (NREL) and the Athena Institute and the database was launched in 2003. During the design of the database and also after the database was released, several surveys were conducted to understand the need for the database (Picture) and to analyse the most important factors for the database to be successful (Picture).

Picture 8 Drivers for the LCI database in USA (US department of Energy, n.d.)

Since in USA just as in Europe LCA is becoming more and more popular, then the demand for consistent data and possibility to compare different LCA anlysis on products or systems is only growing. Another important reason to create the database was the limited access to USA data. When performing an LCA analysis, data from other countries were usually used, but this kind of data may be unreliable since conditions in each country vary.The third reason for the database was the drive for sustainability. Customers, governments and other stakeholders are becoming more and more avare of the environmental impacts so they demand more environmentaly friendly products. Industry on the other hand uses LCA for new product development, marketing, corporate management and goal setting to create more sustainable products (US department of Energy, n.d.). These three drivers – consistent data, need for USA specific data and demand for sustainability are the main reasons for data harmonization and database creation (Picture 8).Picture 8 Drivers for the LCI database in USA (US department of Energy, n.d.)



Picture 9 Success factors for the database (US department of Energy, n.d.)

The most important parts of the database itself are data quality and comprehensive datasets. The survey makes it clear that database users wants to be confident that the data is valid and want to have a clear picture of where the data came from, what it represents and what is the uncertainty. The database also has to be big enough to perform comprehensive LCA. These two factors are the most important when determining success of the database (Picture).

The current database has the main energy sources, transportation and materials. Together it has more than 2000 categories. The database is freely available online and the individual datasets or the whole database can also be downloaded if necessary.

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Appendix 4 Lessons learned from previous harmonization attempts

There have been a lot of attempts to harmonize LCA, in many industries. The attempts differ in scope, methodology and application. There are attempts to harmonize methodology, databases, standards, scientific studies and so on. This shows that data harmonization is just one part of LCA, there are many ways to attempt and perform harmonization. Even if harmonization is attempted in another part of LCA, the lessons are still interrelated so a lot can be gained from other experiences. Two main harmonization ways were analysed in Appendix 3. First one was development of different networks and LCA methodology harmonization in general and the second was data harmonization in other industries.

Lessons learned from methodology harmonization

Each of the networks had a different aim and purpose. For example, EPLCA network is meant for LCA practitioners, to guide them through LCA process with more concrete examples and instructions. InData is quite new and hasn't been completely established yet, but it provides general information and instructions on EPD data and how to use EPD together with ILCD but Life Cycle initiative is offering global and regional support for diverse projects in industry.

This shows that harmonization can be attempted on different levels and even though the purpose is the same, the means and information varies greatly. It shows how important is the scope of the database in the beginning. In the beginning it could start with fewer datasets and then slowly grow bigger.

Consistency is an important part as well. When EF pilot phase was taking place, there was no steady communication and each involved party worked independently which led to inconsistencies in data. This should be avoided at all costs. To launch a harmonization project, a strong leadership is necessary and an overview of the processes happening should be established. Considering that many involved parties can be competitors (for example, commercial databases), it is important to make sure that the same assessment and methodology is used. It directly translates to databases as well – there has to be consistency between data and flows, otherwise the database will not be useful.

Not only consistency within is necessary, but also between the networks and documents. For example, all of the networks mentioned are based on ISO standards. The database should also be based on already established standards to make it more compatible.

Another important lesson is to plan beyond the initial launch. For example, in the Resource Directory, there is supposed to be the latest studies and documents on LCA. However, the network is not being maintained properly and not only the studies are not being updated but the links to the existing studies does not work as well. This means that part of Resource Directory is redundant and the initial effort has been wasted. When planning for the database harmonization, it is important to look ahead in terms of funding and means so there are enough human resources to keep it up-to-date.

Lessons learned from data harmonization

It has become apparent that teamwork is crucial to achieve success. Since LCA is used by companies, practitioners, governments and other stakeholders, they should also all be involved in the harmonization process to be able to reach a comprehensive analysis and to guarantee that the issue is looked upon in depth and one parties agenda is not pushed forward.

Even if several databases or guidelines are being established, they all should be compatible with each other. In food sector, there are many parties who are developing databases, but they are all compatible with each other so the database users are able to gather data from all of the databases since they are all created based on one model.

In USA market research was done before creating the database. This way it can be established whether the database is actually necessary so there is no needless costs. It also surveyed involved parties to understand which parts of the database are the most important ones to be able to design the database compliant with the customer and stakeholder needs.

Appendix 5 Interview protocol

Date and time:

Interviewee (title and name):

Interviewer:

Introduction:

Thank you very much for agreeing to this interview. It should not take more than an hour. I am Zane and I'm writing my Master Thesis in TNO about data harmonization in environmental databases in EU. I have created a list of the main harmonization parts for the database. It would be of great help if you could provide your input in distributing them according to the effort it would take to implement them and importance.

Do you have any questions? If not then we could start by introducing ourselves.

A. Could you please tell a little bit about your background and work experience?

1. Briefly describe your current role at the company.

2. How long have you worked at your current job?

3. What is your academic degree?

4. How are you involved in LCA harmonization process?

B I will now show you a list of the main harmonization parts.

5. Could you please rate each part on the list them from 1-5 based on their importance and implementation difficulty (1-low; 5-high)?

Data modelling:

a) *Structure of the database* – naming, categorizing, storing and so on
b) *Treatment of data gaps*
c) *Common Elementary flow list* – naming, categorizing, using, storing
d) *Documentation requirements* – common documentation requirements like geographical validity of data, time representativeness and so on

Quality of the data:

e) *Source of the data* – main sources usually are industry, academic papers, existing commercial databases. The database can include all of the sources or only one of them. For example, in French Ecorce only Academic papers are used
f) *Verification method* – how and by whom data verification can be achieved. For example, Netherlands has verification protocol, but data in Ecorce is peer reviewed.

Scope of the database:

g) *Territory* – what territory the database should cover so should it include country specific materials or should it be more generic
h) *Categories* – what categories are included in the database so is it only for road pavement, or should it be more extensive and include more construction materials
i) *System boundaries* – product life cycle stages that database include, so should it only be cradle to gate or use stage and end of life stage should be included

Access to the database:

j) Is license necessary
k) Is it available on its own or is it accessible via tool

Environmental impact categories:

l) *Indicators* that are used for environmental assessment, like depletion of raw materials, climate change, ozone layer depletion and so

Appendix 6 The roadmap to data harmonization (draft version