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PavementLCM Resources

Harmonization of environmental databases for road pavement in EU

Deliverable 5.3

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Deliverable 5.3 - Harmonization of environmental databases for road pavement in EU

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Glossary

Data – sets of quantitative data or descriptive meta data prepared for use in LCA

Elementary flow - Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation

Environmental footprint (EF) – method based on LCA to quantify the environmental impact of products (goods and services). It is developed both for products – PEF and for organizations – OEF

Life Cycle Assessment (LCA) – compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

Life Cycle Inventory (LCI) – phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle

LCA database – set of methodologically and technically fully or mostly interoperable LCI data sets (and related data sets type such as flows and so on) stored in an electronic database

National LCA database – a database with authoritative information who is governmentally (co) led or is at least partly funded by the government

Sustainability (also sustainable development) – Economic, environmental and social development that meets the needs of the current generation without undermining the ability of future generations to meet their own needs

Sustainability Assessment – evaluates the social, environmental and economic impact on a product or a system

Executive Summary

The report is part of the project "Complete package for Life Cycle Management of green asphalt mixtures and road pavement'' (PavementLCM). The project has several goals, like, user friendly look-up tool for LCA, providing National Road Authorities (NRAs) with methodology and coping mechanisms for uncertainty of datasets and creating a roadmap towards data harmonization at EU level. This report focuses on the latter goal which is part of work package 5.3. "Roadmap towards data harmonization at an European level". The aim is to explore to what extent any kind of European, harmonized database would be desired by NRAs and what steps are necessary to develop the database.

Considering that creating a harmonized LCA database is a complex and intricate task that requires a lot of time and effort, then to arrive at it, several actions were undertaken beforehand to thoroughly look at the issue.

First, EU national database inventory was done to analyse the situation in EU and understand what are the main differences between them. These databases can be used as an example when attempting harmonization. Next, successful harmonization attempts were investigated to understand what can be learned from previous efforts. It helped in creating the steps of the roadmap, like ensuring strong leadership and creating workshops.

Afterwards, an Impact Effort Matrix was designed and main database differences were grouped based on their importance and implementation difficulty. The matrix provides a clear outline of the main problems that has to be overcome in order to achieve harmonization.

Finally, as the final part of the research, the roadmap was designed. There are many steps necessary to arrive at a harmonized database, but one of the most important ones is to establish a strong management team who can lead the process. Considering the amount of stakeholders involved in the process, it is important to have strong leadership and guidance in order for the data harmonization to succeed.

Another important step is workshop arrangement. During workshops the outline of the database have to be decided using already existing standards and the Impact Effort Matrix (**Fehler! Verweisquelle konnte nicht gefunden werden.**). A lot of stakeholders have to be present during the workshops to gain comprehensive knowledge of the needs and wishes of all involved parties. Finally, when the outline of the database is known, a technical manual of the main rules and outlook of the database has to be drawn to ensure consistency between the datasets.

Both the matrix and the roadmap can be used by NRAs and other involved parties to reach data harmonization as smoothly as possible. Next step in the research should be to organize a workshop for NRAs and other stakeholders to discuss the main findings and

recommendations.

Reading guide

The report consists of several chapters. Each chapter describes several findings during the research and in the end conclusions and recommendations are drawn and described,

First, concise background on sustainability and LCA is given (chapter 1). Afterwards, the drivers of harmonization and advantages and disadvantages of it were investigated to understand the main reasons for harmonization (chapter 2). The research design and main research questions are given in chapter 3.

In chapter 4 national EU database inventory was carried out. The main differences between national databases were established and described to grasp the magnitude of the problem and to understand how big are the differences.

Next, to learn from previous experiences, other harmonization attempts both in methodology and data were investigated (chapter 5).

Impact Effort Matrix where all the harmonized parts were placed based on their importance and implementation difficulty was created in chapter 6. The matrix is especially useful in understanding where the most attention has to be paid and which parts will be the most challenging to harmonize.

Finally a roadmap towards harmonized database was created based on the matrix and previously collected information (chapter 7). The step by step procedure gives a comprehensive guidance towards data harmonization.

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1. Background

This report is part of the PavementLCM project work package 5. It has several goals, like, harmonized framework and user friendly look-up tool for LCA, providing NRAs with methodology and coping mechanisms for uncertainty of datasets and creating a roadmap towards data harmonization at EU level. This report focuses on the latter goal which is work package 5.3. “Roadmap towards data harmonization at an European level”. The aim is to explore to what extent any kind of European, harmonized database would be desired by NRAs and what steps are necessary to develop this database.

1.1 Concept of sustainability

Currently, sustainability or sustainable development is one of the key topics for all development activities (Santos, Bressi, Cerezo & Lo Presti, 2019). Sustainable development was first introduced in the document “Our Common Future’’ provided by UN World Commission. There it was defined as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs '' (WCED, 1987). Currently sustainability is identified as a pathway to steer development towards a model that aims to improve and achieve a balance between economic, social and environmental systems for present and future generations. This definition also introduced the three main pillars of sustainability: economic, social and environmental (Gibson & Hassan, 2005). The pillars together with the main issues can be seen in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Even though sustainable development has been widely embraced by governmental institutions and other relevant organizations all over the world, it still faces many challenges. One of the biggest challenges is how to incorporate sustainability in different sectors to achieve its goals.

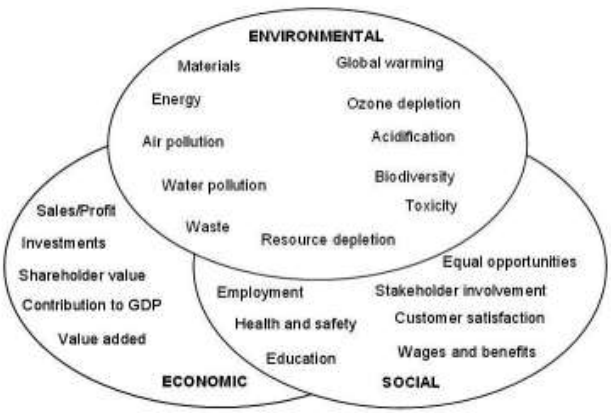

Figure 1 - Sustainability pillars (Lehtinen, Saarentaus, Rouhiainen, Pitts & Azapagic, 2011)

1.2 Sustainability in road construction

Road construction and pavements in particular are a significant challenge when it comes to achieving sustainability goals. Pavement life cycle (e.g. construction, maintenance, demolition) creates significant amount of waste and requires huge quantities of non-renewable resources and energy (Cruz, Gaspar & de Brito, 2019). Road pavement industry not only creates a significant environmental footprint but also impacts the other two sustainability pillars.

Examples of how road pavements can impact sustainability:

1. Environment: greenhouse gas emissions, air quality, water pollution
2. Social: safety, access, noise, comfort of driving
3. Economic: life cycle costs (e.g. construction, maintenance), accident costs (Hu, Shu & Huang, 2019)

Different private and public institutions have been tackling the issues of pavement sustainability and both literature and research on it has been growing significantly in recent years (Cruz, Gaspar & de Brito, 2019).

Even though road construction affects all three sustainability pillars and all of them are important, road sector is famous for its negative effect on environment, for example it is estimated that to produce one ton of hot-mix asphalt, an average energy consumption of 99 KWh (356 MJ) is required and 23.8 kg of CO_2 is generated. With the well-established threat of climate change upon us, practitioners, engineers and researchers have been seeking new solutions to save natural resources and reduce energy consumption and emissions (Hu, Shu & Huang, 2019). Taking it into account, this research will solely focus on environmental part of sustainability.

1.3 Sustainability assessment

Sustainability assessment (SA) is a process that directs decision making towards sustainability. In other words, it evaluates the social, environmental and economic impact of a product or a system (Bond, Morrison-Saunders & Pope, 2012). There are several tools, methodologies and techniques available for measuring sustainability with different advantages and disadvantages which can be used individually or in combination. However, life cycle techniques (e.g. life cycle costing, life cycle assessment) are the most common ones. European Commission for Standardisation defined SA as “combination of the assessments of environmental performance, social performance and economic performance taking into account the technical requirements and functional requirements of a civil engineering work or an assembled system (part of works), expressed at the civil engineering works level". EN 15643-5 standard "Sustainability of construction works - Sustainability assessment of buildings and civil engineering works - Part 5: Framework for the assessment of sustainability performance of civil engineering works" provides a system for the sustainability assessment of civil engineering works using a life cycle approach and using quantifiable indicators measured without value judgements.

There are different life cycle techniques, each appealing to a specific pillar of sustainability. Life Cycle Costing or Life Cycle Cost Analysis, evaluates the costs of an asset or its parts throughout its life cycle while fulfilling the performance requirements over a period of analysis (ISO, 2017) so it represents the economic pillar. Social Life Cycle Assessment on the other hand is a systematic process using the best available science to collect the best available data on and report about social impacts (positive and negative) in product life cycles from extraction to final disposal so it represents the social pillar. It is mostly used to increase knowledge, inform choices, and promote improvement of social conditions in product life cycles (Fortier, Teron, Reames, Munardy & Sullivan, 2019). However, as mentioned in paragraph 2.2., this Thesis focuses solely on the environmental aspect so life cycle approach on environment will be described in more detail.

Life Cycle Assessment (LCA) has been widely recognized as the most suitable tool for assessing the environmental performance for any kind of product or technology. It has broad range of use starting from policy documents like green public procurement used by governments till private companies using it in local projects (Maki consulting, 2014) and it is an important tool for stakeholders to deal with environmental aspects of their products/technology and to reach the objective of sustainable construction (Batouli, Bienvenu & Mostafavi, 2017).

LCA 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.

As main characteristics, it is important to mention that LCA: a) is an analytical method; b) follows an iterative step-wise procedure; and c) considers multiple potential environmental impacts of a product or service according to certain stages analysed or throughout its life cycle (Balaguera, Carvajal, Albertí & Fullana-i-Palmer, 2018). LCA methodology has four main steps (**Fehler! Verweisquelle konnte nicht gefunden werden.**): 1) goal and scope definition; 2) Life cycle inventory (LCI); 3) environmental impact assessment, and 4) interpretation of the obtained results.

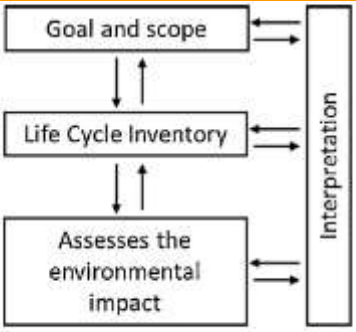

Figure 2 - LCA framework (ISO, 2006a,b)

When goal and scope have been defined and the purpose of the assessment has been described, next step begins. It involves data collection and quantification of inputs and outputs. Afterwards collected data are examined considering environmental and human health impacts. Final stage is the interpretation of the results in terms of significance, quality and so on. It also includes conclusion and recommendations on how to improve the process/product described in the goal and scope (Balaguera, Carvajal, Albertí & Fullana-i-Palmer, 2018).

1.4 Life cycle inventory (LCI)

This part of LCA takes the most effort and time and it is necessary to describe it in more detail. LCI can be defined as “phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle” (ISO, 2006a,b). The aim of LCI is to prepare an inventory of all processes involved in the life cycle of the product system, detailing all the important interactions with environment (Guinée et al. 2002). Collected data include energy inputs, raw material inputs, co-products, waste, emissions to air, water, soil and other environmental aspects. In **Fehler! Verweisquelle konnte nicht gefunden werden.**, examples of the product system for LCI is shown. It highlights the types of inputs and outputs, that the analysis may want to track.

Usually LCI phase takes up the most time and resources since data collection is one of the most important parts of LCI. There are two main types of data: primary and secondary. The primary data are collected in the field but the secondary data origin from databases and are used from background which are not specific for the defined product system. It is important to choose an appropriate database so the data would be as precise as possible (Koskela & Hiltunen, 2004).

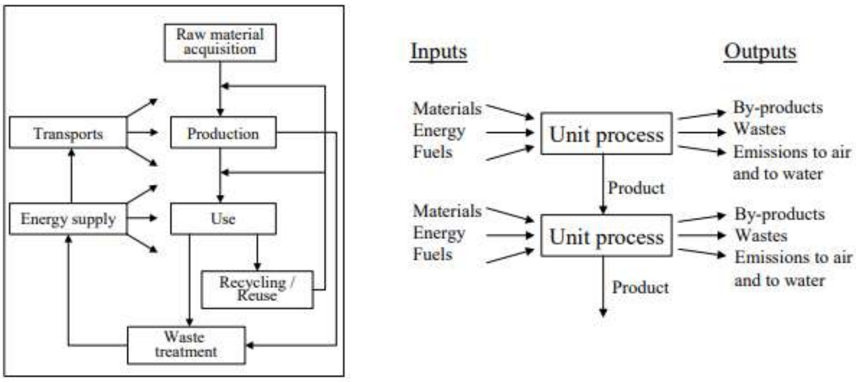

Figure 3 - Example of a product system in LCA (ISO, 2006a,b)

1.5 Sustainability databases – problem statement

As already mentioned outcome of the LCA is very much dependent on the availability and quality of the data. Reliable, comprehensive and high quality databases are crucial for LCI data input and the result of LCA. Information and communication technologies allow for smart and effective database solutions and to push LCA and sustainability 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, Japan, USA, have used this to their advantage and established centralised databases complementing or integrating databases developed by public or private sectors (Maki consulting, 2014). Building the databases has brought a real benefit and has helped to perform comprehensive LCA analysis. However, this multitude of "local" initiatives creates confusion, frustration and problems now, when sustainability has become a European/Global issue. Policy makers, road authorities 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, it can lead to double counting, unidentified data gaps, differences in allocation methodologies, resulting in divergent results for the same dataset. This furthermore leads to incomparability between the results since differences in databases will result in differences in the outcomes of LCA. It means that involved governments, LCA practitioners and other stakeholders have a very hard time transferring knowledge and learning from other countries since every country uses a different database and it makes it much more difficult to interpret the data. It also makes it more difficult for 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 is increasing in recent years. There are a lot of databases available, but their coverage of different materials, transport, waste management and so on 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 different 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.

2. Harmonization process and its advantages and disadvantages

Before attempting harmonization, it is important to understand what harmonization stands for and what can be gained from it. Harmony can be defined as “the combination or adaptation of parts, elements or related things, so as to form a consistent orderly whole” so 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 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 the 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 member state to amend its own domestic laws 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.

Standardization means creating uniform business processes across various divisions or locations. The expected results are processes that consistently meet their cost and performance objectives using a well-defined practice. Harmonization on the other hand, defines the extent of standards and how they fit together (Richen and Steinhorst, 2015).

Even though advancement of technology and globalisation 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 subject of standardization has been fiercely debated in the academic community and it has been in the centre of research for several decades since standardization among other things offers operational economies and the development of uniform practices (Griffith, Hu and Ryans, 2000).

2.1 LCA harmonization

LCA has been around since the 1960ties 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 a 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 almost 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 establishment of ISO (International Organisation for Standardization) 14040 series in 1997 led to a worldwide acceptance of LCA (Klopffer and Curran, 2014). Nevertheless, they still do not give specific details on methodological choices.

The ambiguity and the demand for environmental information has led to additional standards both under ISO and within other standardization bodies. There are many other LCA harmonization attempts as well, for example, LCA databases, tools and networks have been developed to help with the LCA assessment.

LCA development is still continuing till this day, and a lot of effort has been put to achieve international consensus on central parts of LCA methodology and standardization (Hauschild, Rosenbaum and Olsen, 2018).

The main drivers for harmonization are:

1. Health and safety – safe and healthy working conditions are a must. However, 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 a 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 has to be in place. Since it is a problem worldwide, harmonization on the main safety rules may take place.
2. Trade – for companies to be able to expand the market and trade internationally common rules are necessary. 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.
3. 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/method 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. EU has already created common rules for GPP.

There are also several advantages and disadvantages to LCA harmonization. The main advantages are:

1. Consistency between datasets would lead to more reliable LCA results. Databases have different structures, logic and datasets which consequently can lead to double counting, unidentified data gaps and other problems. Having a harmonized database would eliminate these issues.
2. Comparing performances between different studies becomes easier and more efficient transfer of knowledge can take place (Richen and Steinhorst, 2015). Diversity in databases and their structure furthermore leads to incompatibility between the results since differences in databases will result in differences in the outcomes of LCA.
3. It is easier for the beginners to start using LCA. Right now countries and companies who want to start using LCA are faced with a lot of information and has to make a lot of choices regarding database, methodology etc. Creating a harmonized database would eliminate all these choices and it would make LCA more accessible to new organizations.

There main disadvantages are:

1. Harmonized database could dampen the advancement of LCA. Using different perspectives and approaches may lead to new knowledge and it can be more useful in development of more comprehensive LCA analysis. 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). If only one method is used, the improvements of LCA can decrease.
2. Harmonized method may not be the best one. The number of different LCA databases shows how many variations there are. The decided outlook of the database may not be the best one, it may just be the one where the biggest consensus was reached.
3. It may put companies/organizations who already applies the standardized method into advantage over the organizations who uses different methods since they would have

to change their approach. If the harmonized database is created a lot of companies would have to change their approach based on the harmonized database and it would require extra human and financial resources.

It should also be considered to what extent the harmonization should be applied. Should it be on a national level so countries creating their own national databases or should it be on an EU level hence one harmonized database for the whole EU. A lot more stakeholders has to be involved to create an EU national database since more parties would be affected by the decision. However a harmonized database would make trading within EU easier since products would be more compatible. There are upsides and downsides to each of these decisions and it should be carefully considered.

Despite the disadvantages and difficulties, harmonization is still continuing.

3. Research design

3.1 Research objective and questions

Research objective is based on the PavementLCM project research goals and the background information described above. The objective therefore is:

Based on the needs, possibilities, challenges and characteristics of data harmonization, create a stepwise procedure that would lead to a harmonized database

To achieve the objective, following research questions are proposed:

1. *What are the main possibilities and challenges of data harmonisation in environmental databases in EU?*
    1. *What is the current state and main problems of environmental databases in EU?*
    2. *What are the lessons learned from other fields in data harmonization?*

2. *What are the necessary steps towards data harmonisation in environmental databases in EU?*
    1. *What are the most important parts that has to be harmonized?*
    2. *How data harmonisation can be achieved?*

3.2 Research methodology

The research will consist of 3 phases:

1. Inventory of road pavement sustainability databases in EU

In the first phase, the current situation of environmental databases will be examined, pointing out and classifying differences and similarities. Considering the large number of databases available and the time frame for the research, only EU database and other EU member state national LCA databases will be investigated.

National LCA database is a database with authoritative information who is governmentally (co) led or is at least partly funded by the government (Maki consulting, 2014).

Currently, there are six countries with National databases – Sweden, Netherlands, Belgium, UK, Germany and France. The design and structure of the databases will be investigated, e.g. main source of data, accessibility to the database, scope of the database. To be able to better compare the databases, information on road pavement products included in the databases will be compared like types of road pavement available, information given on it, and references.

After the inventory of databases, main differences will be drawn. Knowing the differences, will help in understanding the magnitude of the problem and will also give some insight into the creation of the matrix by showing the parts that differ and should be harmonized.

After the inventory of databases, some of the current LCA harmonization attempts will be looked upon.

Harmonization can be done in different ways, knowing what already has been done will provide information on the divergent possibilities of harmonization. This will be useful in understanding how to perform harmonization to achieve the best possible result. The knowledge will be then used to create a step-by-step roadmap towards data harmonization.

2. Creating and verifying the Impact Effort matrix and the roadmap

At the end of the first phase, the main problems of the harmonization will be known. Afterwards, based on the information gathered during the previous phases, an Impact Effort matrix will be created. The possible view of the matrix is visible in **Fehler! Verweisquelle konnte nicht gefunden werden.**. Based on the expert views and the literature research, the main parts that should be harmonized will be mapped out, depending on their importance and implementation difficulty.

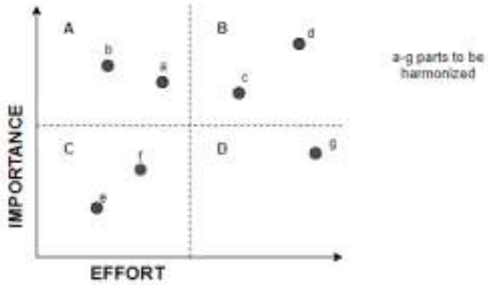

Figure 4 - View of the model

As a final step, based on the matrix and literature review, a roadmap towards data harmonization will be constructed. It will give detailed information on how to achieve data harmonization and will point out the most important parts for the process to run smoothly.

3. Conclusion and recommendations

In the final phase conclusions of the research will be drawn. Limitations and suggestions for further research will also be mentioned in this phase.

4. Inventory of databases

In this chapter inventory of databases is undertaken. Knowing the current state of LCA databases in Europe and understanding the main differences will show the magnitude of the harmonization problem and the main parts that has to be harmonized. This, together with the expert interviews will help to create a matrix where main differences will be mapped out based on their importance and difficulty.

4.1 National LCA databases

There is an enormous amount of information and data involved in LCA studies (Martínez-Rocamora, Solís-Guzmán & Marrero, 2016) which consequently means that there is a lot of LCA databases available. The precise number of different databases is unknown but most of the LCA softwares include one or several databases from external sources. When it comes to LCA software tools, then there are more than thirty available in the global market (Koskela and Hiltunen, 2004). SimaPro. Ecoinvent, GaBi are just a few examples.

Considering that the timeframe of the research is 6 months and the amount of databases available, only EU national databases will be investigated. A National LCA database is a database with authoritative information and is governmentally (co) led, or partly funded by the government (Maki consulting, 2014).

Another important reason for excluding commercial databases, is that National Road Agencies (NRAs) may not be in favour of data harmonization.

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 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 not want harmonization. So it is especially important to see the main differences between national databases to understand how much compromises would be necessary.

NRAs who do not use LCA may be more willing to support harmonization because it would make it easier for them to choose a database to work with. Industry and commercial companies are also more 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 important to understand the main differences between EU national databases to see to what extent they differ.

Even though the number of national databases has increased significantly in recent years, there are still many countries without a national database and with very limited knowledge of LCA (Frischknecht, 2005).

In Europe only a handful of countries have developed their own national databases (Table 1). Countries that have their own databases are: France, Germany, Sweden, Belgium, UK and Netherlands. The rest of the countries either do not have a national LCA database or uses different analysis, like LCC.

Table 1 National databases in EU

Country	Name of the database	Comments
Austria	-	Have their own database, but it's used for LCC not LCA
Belgium	Totem	
Bulgaria	-	
Croatia	-	
Cyprus	-	
Czechia	-	
Denmark	-	National database for food
Estonia	-	
Finland	-	
France	Ecorce Base Impacts Base Carbone INIES	
Germany	ProBas Ökobaudat	
Greece	-	
Hungary	-	

Ireland	-	Has a carbon calculator that is meant for personal and household use
Italy		
Latvia	-	
Lithuania	-	
Luxemburg	-	
Malta	-	
Netherlands	NMD	
Poland	-	
Portugal	-	
Romania	-	
Slovakia	-	
Slovenia	-	
Spain	-	
Sweden	CPM LCA	
United Kingdom	ICE	

After analysing questionnaire with representatives from ASFINAG, it became apparent that Austria has its own database, but it is used for LCC not for LCA. The database contains information about economic aspects like cost benefits, forecasting models and so on.

Even though Denmark is experienced in LCA assessment, there is only food LCA database available. During the TNO questionnaire with Vejdirectoratet (National road agency), it became apparent that Denmark mostly uses road LCA for economic and social analysis.

In Ireland, there is no extensive database, only a carbon calculator is available. It is meant for everyday use so everyone can see how their lifestyle affects environment ("Carbon Calculators: Environmental Protection Agency, Ireland", 2019).

4.1.1 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) (Totem-building.be, 2019).

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.

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 **Fehler! Verweisquelle konnte nicht gefunden werden.**.

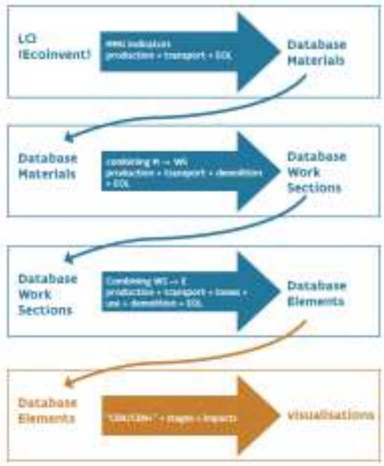

Figure 5 - Totem database overview (Allacker et al., 2018)

4.1.2 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

First one is Base Impacts – 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 ("Accueil - Base Impacts® - Accueil", 2019).

Base Carbone

The second database – 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 - Site Bilans GES", 2019).

Ecorce

The third database was developed by IFSTTAR together with French Ministry of Ecology and is dedicated specifically to roads ("ECORCE M", 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 LCI 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 M", 2019). The database itself 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 itself 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:

1. product specifications (raw materials, possible dangerous substances and so on).
2. product's functional unit and lifespan.
3. environmental profile (set of environmental indicators, calculated over product's life cycle).
4. 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.fr, 2019).

4.1.3 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 - Willkommen bei 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 itself contains information about building materials, construction, transport, energy and disposal processes (BBSR, 2019).

All datasets in Ökobaudat represent "Environmental product declarations" (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 2). Database itself is publicly available and free of charge.

Table 2 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 (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

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).

4.1.4 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:

1. Database with products and Item cards.

2. 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.
3. 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.
4. Database with disposal scenarios – waste scenario is entered together with the basic profiles ("Basisprofielendatabase en database met afdankscenario's - Nationale Milieu Database", 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:

1. Category 1 – brand data that is verified by a qualified, independent third party. Data is not available to public but can be accessed as LCI through calculating instruments like DuboCalc, GPR etc.
2. 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.
3. 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 (DuboCalc and so on). 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 are 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:

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

4.1.5 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 (**Fehler! Verweisquelle konnte nicht gefunden werden.**):

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 and so on), 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 and so on. 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, so on), 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 and so on.
6. *Administrative and general information* – information on organisation responsible for the data, identification number and so on.

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

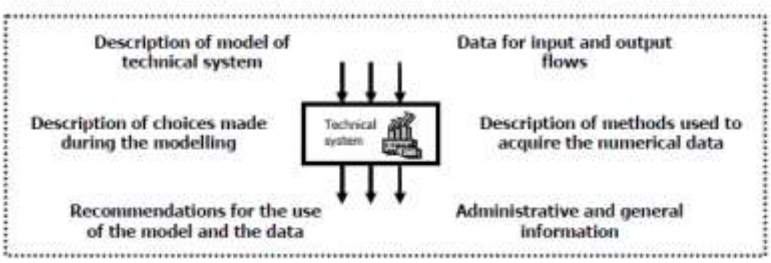

Figure 7 - Data documentation criteria (FlemStrom & Pallson, 2003)

4.1.6 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 | UK Construction Materials EPD/LCA Database | UK Ecolabel Centre", 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.org, 2019). In the beginning the database was relatively small but overtime it has been expanded and now it consists of over four hundred values of embodied energy and carbon (Hammond and Jones, 2008).

The database itself is accessible free of charge. It is basically an excel spreadsheet with a lot

of materials involved. There is information on asphalt provided as well. However, the information is quite poor and only GHG emissions are included (
Table 3).

Table 3 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**	**0.23**	**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	0.23	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	0.28	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: Low EE	Best EE Range - MJ/Kg: High EE	Specific Comments
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				

4.1.7 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.openlca.org, 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.jrc.ec.europa.eu, 2019).

4.1.8 Product environmental footprint (PEF) database

European Commission has launched PEF database with secondary data. Database is part of the 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. packaging) and transport services (Recanati and Ciroth, 2019). Information on road construction is not yet available. More detail can be found in chapter 7.3.4.

4.2 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 is meant for consumer goods and there is no information on construction included. Totem has information on construction materials but nothing on road pavement. Since road pavement materials are used for comparison of the databases, then Base impacts and Totem has to be excluded. Base Carbon and ICE only calculates greenhouse gasses so any other LCI is excluded, which 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 it 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 4 and Table 5. The differences are afterwards described in more detail.

Table 4. 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 5. 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		

4.2.1 Scope

Most of the databases cover craddle to grave scenarios. However, CPM LCA and Ökobaudat only covers craddle to gate when it comes to asroad pavement products.

The coverage of pavement categories is diverse as well. Ecorce is specifically designed for road construction. It is the only EU national database dedicated specifically for roads. In Ecorce, 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 (Figure 8).

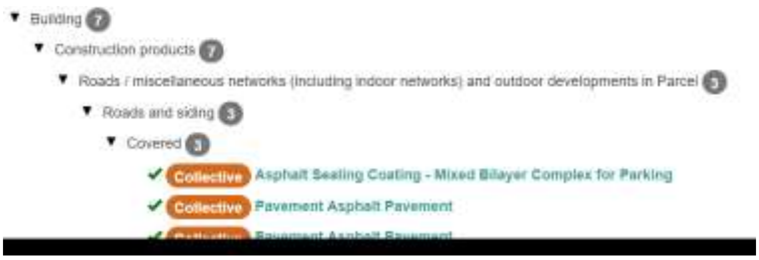

Figure 8 - Road pavement in INIES (HQE-GBC, 2019)

In Sweden, the data on pavement is very limited. When searching in the database in class ‘’construction’’ very few processes appear (**Fehler! Verweisquelle konnte nicht gefunden**

werden. 109) and there is only one type of asphalt available which is the average asphalt used in Sweden.

#	Name of process	Technical scope	Product or service	Date Completed	Report			CPM Quality
					SPINE HTML	ILCD XML More info	ISO/TS 14048 HTML	
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

Figure 9 - Construction processes included in the CPM LCA (Cpmdatabase.cpm.chalmers.se, 2019)

German database ProBas is almost just as poor as CPM LCA when it comes to road pavement (**Fehler! Verweisquelle konnte nicht gefunden werden.** 10), only asphalt and cement are provided as road pavement materials.

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	

Figure 10 - Road pavement accessible in ProBas (Probas.umweltbundesamt.de, 2019)

The relatively new German database Ökobaudat has more asphalt pavement categories included (Figure 11), so it is way more extensive than ProBas and CPM LCA.

Name	Languages	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	

Figure 12 - Road pavement in Ökobaudat (BBSR, 2019)

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

4.2.2 Access and licence

All the national databases are free of charge except for NMD. To be able to use it, it is necessary to acquire a licence for the tool that incorporates the database (DuboCalc, SimaPro and so on). 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.

4.2.3 Data sources and verification

Data sources and verification methods differs greatly. NMD uses other databases like SimaPro or Ecoinvent (category 3 data). Also any company or involved stakeholder can provide data for the database as long as the data is verified according to Verification protocol.

In Ecorce, the 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 itself 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 in the database 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. 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 chapter 4.1.5.

4.2.4 Environmental impact categories

Considering that in EN 15804 "Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products" (EN 15804) main impact categories are given then the databases were compared based on the information available there. 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 has more indicators available than in EN 15804 but considering that at least EN 15804 indicators should be included then they were not listed.

4.2.5 Structure of the database

The structure of the databases is completely divergent. 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 but in CPM LCA, extensive information on boundaries is provided. There are differences even in categories of datasets. For example, asphalt in CPM LCA database is under "Construction" but in Ökobaudat it is under "Mineral building products".

4.3 Summary

To sum up, main challenges in data harmonization are:

1. *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.
2. *Categories* –what type of road pavement materials are included in the database?
3. *Territory* – what territory the database should cover, should it include country specific materials or should it be more generic?
4. *Accessibility 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.
5. *Source of the data* – right now there are various sources – industry, academic papers, existing comercial databases and so on. Even though there can be different sources of data, it is important to agree what sources to use for eah specific data so there is no overlap.
6. *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 qualitaty data can be found in the database.
7. *Data modelling* – structure of the database, treatment of data gaps, and other modelling aspects has to be defined and consensus has to be reached

5. Harmonisation attempts in LCA

In this chapter several harmonization attempts both in LCA methodology and databases will be described. LCA databases and methodology are interrelated and by investigating harmonisation attempts in LCA methodology, the knowledge and approach can be transferred to data as well. Reviewing harmonization attempts in Europe and other places in the world, will also give a well needed insight into the LCA harmonization process and will help in establishing the harmonized database and the matrix by providing information and tips on the process. Since in the previous chapter EU member state databases were reviewed then here a database from US will be looked upon to see how they achieved data harmonization and if their approach differs from EU.

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 will be analysed. Furthermore, to gain better insight into the diverse harmonization attempts, each chosen network/harmonization effort is different and represents specific parts of LCA or is meant for distinct parties.

First harmonization attempts in methodology are analysed. ISO standards as the only global international standards on LCA are described first, then Environmental Product Declarations, EPLCA in EU, InData and Life cycle initiative are investigated. Afterwards, data harmonization attempts in food sector and LCA database in USA are examined. Finally, at the end of the chapter lessons learned both from methodology and data harmonization are drawn to see what knowledge can be gained from previous experiences.

5.1 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 (**Fehler! Verweisquelle konnte nicht gefunden werden.** 12). 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).

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.

Figure 13 - Members of ISO (ISO, 2019)

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 etc. 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.

5.2 Environmental product declarations (EPDs)

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.com, 2019). EPDs are used both externally for marketing purposes and internally for the improvement of product manufacturing, or process efficiency (Designingbuildings.co.uk, 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 NEN-EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products (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).

5.3 European Platform on Life Cycle Assessment (EPLCA)

The 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. The European Commission (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.

5.3.1 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 (chapter 5.3.2.), and 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 (Sala et al., 2012)

The structure of the ILCD Handbook is shown in Figure 14.

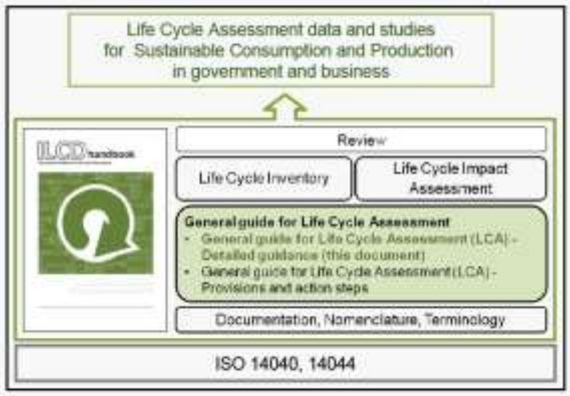

Figure 15 - ILCD handbook content (JRC-IES, 2010)

5.3.2 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), see chapter 5.3.4.

The network itself is non-centralised and composed by nodes (developer/owner dataset 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 Figure 14 (LCDN, 2019). In this network reliable datasets are available and the party using it can be assured that they are in good quality.

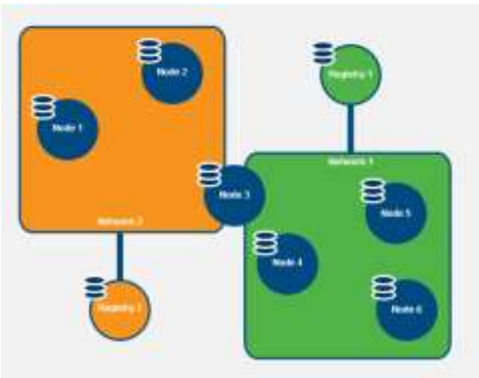

Figure 16 - Structure of the network (LCDN, 2019)

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.

5.3.3 Resource directory

Resource directory is a repository that consists of:

1. *Services and tools* – information on available softwares and databases.
2. *Documents and studies* – reports, methodologies, scientific papers etc. about different Life Cycle approaches
3. *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 on 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 is quite extensive information available on databases and tools, but the documents and studies on LCA are very poor. There are only couple of studies available, nothing newer than 2011 and only descriptions of the studies are accessible, 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.

5.3.4 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. In this chapter 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 – Product Category Rules (PCR) (SimaPro, 2019). The EF platform is meant to provide comparable and reliable environmental information (e.g. guidelines, general requirements, best practices for LCA development) for consumers, investors and other stakeholders. (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.

5.4 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 ("Resources — 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.

5.5 Life Cycle Initiative

The Life Cycle Initiative is a public-private, multi-stakeholder partnership enabling 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. The main purpose of Life Cycle initiative is to support decisions and policies towards a 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.org, 2019).

5.6 Data harmonization attempts

LCA is being used in almost all the possible fields and industries. In some industries LCA is more common and advanced, in some not so much. LCA in food sector is widespread and there has been several attempts at harmonization so first LCA advances in food sector will be investigated. Afterwards national database in USA will be examined to see how it was established overseas.

5.6.1 Harmonization in food sector

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 the 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. The effort led to a harmonized methodology for environment assessment – ENVIFOOD Protocol (Protocol). The Protocol is meant as a complementary guidance document to PEF guide. In Figure 15, 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, then 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) participated in the process.

Several other organizations has 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.

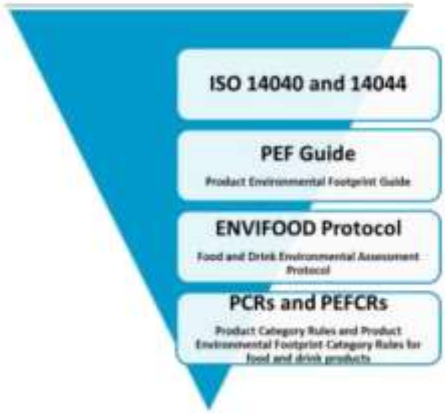

Figure 17 - Food and drink guidance documents (Saouter et al., 2014)

Similar organization to LEAP is the 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 (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.

5.6.2 National LCI database in USA

Since several EU national databases were investigated in the previous chapter, the database in USA will not be described in detail. However, the reasons for the database creation are analysed thoroughly since they give a much needed insight on the database success factors. The work on the database was carried out by the 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 (Figure 16) and to analyse the most important factors for the database to be successful (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

Figure 18 - 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 the demand for sustainability are the main reasons for data harmonization and database creation (**Fehler! Verweisquelle konnte nicht gefunden werden.**17).
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 analysis. These two factors are the most important ones, when determining success of the database (Figure 18).**Fehler! Verweisquelle konnte nicht gefunden werden.**

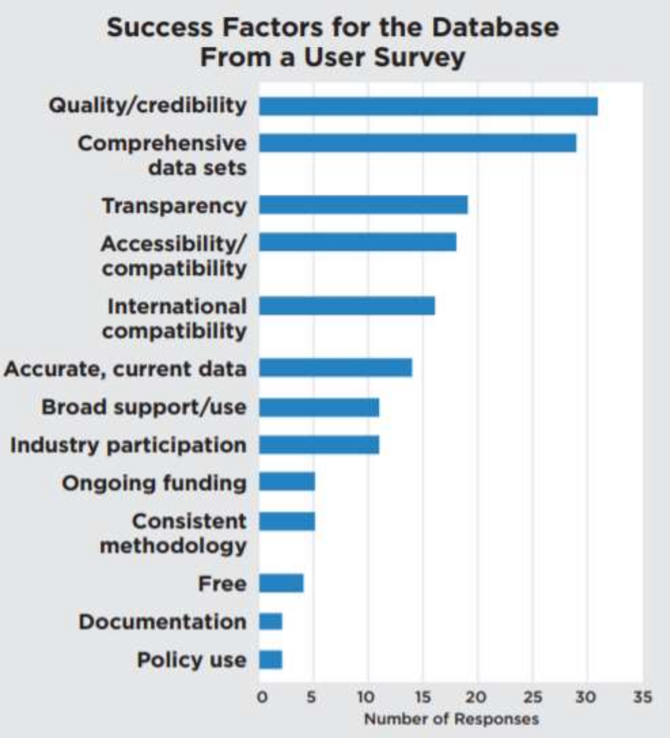

Figure 19 - Success factors for the database (US department of Energy, n.d.)

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

The database involves some information on asphalt pavement as well. However, after the interview with A. A. Butt it became clear that Federal Highway Administration is planning to start working on national pavement database for USA soon and work on pavement database in California is almost finished but unfortunately not yet available online.

5.7 Lessons learned

There has been variety of attempts to harmonize LCA, in many industries. The attempts differ in scope, methodology and application. There are attempts to harmonize methodology, databases, standards, etc. It 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 paths were analysed in this chapter. First one was development of different networks and LCA methodology harmonization in general and the second was data harmonization in other industries.

5.7.1 Lessons learned from networks

Several LCA platforms and networks were described in this chapter. Each of the networks had a different aim and purpose. For example, the EPLCA network is meant for LCA practitioners to guide them through the LCA process with more concrete examples and instructions. InData is quite new and has not 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 LCA projects in industry.

It shows that harmonization can be attempted on different levels and even though the purpose is the same, the means and information varies greatly. When attempting to harmonize databases, the scope of the database is important. 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 consistent 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 the 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 data 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 also the links to the existing studies does not work. This means that part of the Resource Directory is redundant and the initial effort has been wasted. When planning for the database harmonization, it is necessary to look ahead in terms of funding and means so there are enough human resources and budget to keep it up-to-date.

5.7.2 Lessons learned from data harmonization

After analysing data harmonization in food sector and in USA database several things has become clear.

First, it has become apparent that teamwork is crucial to achieve success. Since LCA is used by companies, practitioners, governments and other stakeholders, they should 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 from all sides.

Even if several databases or guidelines are being established, they all should be compatible with each other. In food sector, there are many parties creating 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 were all created based on one model.

It is also important to understand all the possible benefits and drawbacks of harmonization beforehand. 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.

5.8 Summary

To sum up, main lessons learned are:

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

6. The Impact Effort Matrix

To understand what are the main difficulties in database harmonization, an Impact Effort Matrix was created (**Fehler! Verweisquelle konnte nicht gefunden werden.**). It shows how important it is to harmonize each part of the database and how much of an effort it would take. The harmonized parts were derived from the database inventory. They are:

Data modelling:

1. Structure of the database – naming, categorizing, storing and so on).
2. Treatment of data gaps
3. Common Elementary flow list – naming, categorizing, using, storing.
4. Documentation requirements – common documentation requirements like geographical validity of data, time representativeness and so on.

Quality of the data:

5. 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.
6. 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:

7. Territory – what territory the database should cover so should it include country specific materials or should it be more generic.
8. 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.
9. 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:

10. Is license necessary.
11. Is it available on its own or is it accessible via tool.

Environmental impact categories:

12. Indicators that are used for environmental assessment, like depletion of raw materials, climate change, ozone layer depletion and so on.

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 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 other 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 could provide useful insight and input on the database harmonization and how the main harmonization parts fit into the matrix.

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 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 **Fehler! Verweisquelle konnte nicht gefunden werden.**.

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.

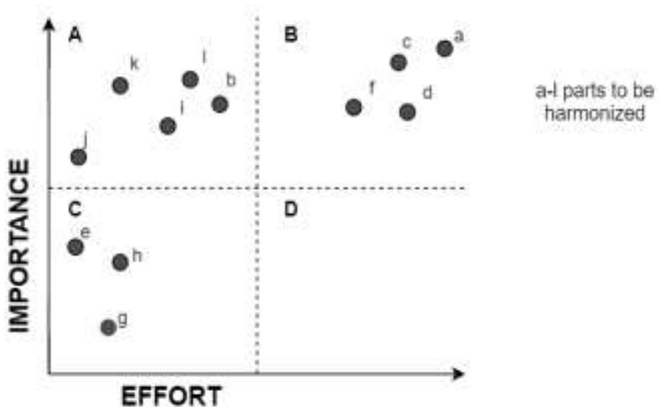

Figure 20 - The Impact Effort Matrix

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 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 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 because 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 materials.

7. The roadmap

After the matrix, the roadmap was consolidated. It is available in **Fehler! Verweisquelle konnte nicht gefunden werden.**. Each step 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 stages based on project management life cycle. The phases make up a path of the project from the very beginning till the end:

1. *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.
2. *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.
3. *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.
4. *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 18 can serve as a basis for the research. The main parts that should be harmonized are already given and mapped. Even though, there should not be too much variation on the parts that has to be harmonized (detailed list available in chapter 7), their placement in the matrix can change. Only two experts were involved in the creation of the matrix and input from wider range of stakeholders is necessary to make a complete overview.

However, the matrix 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 should 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 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 18) 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 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.

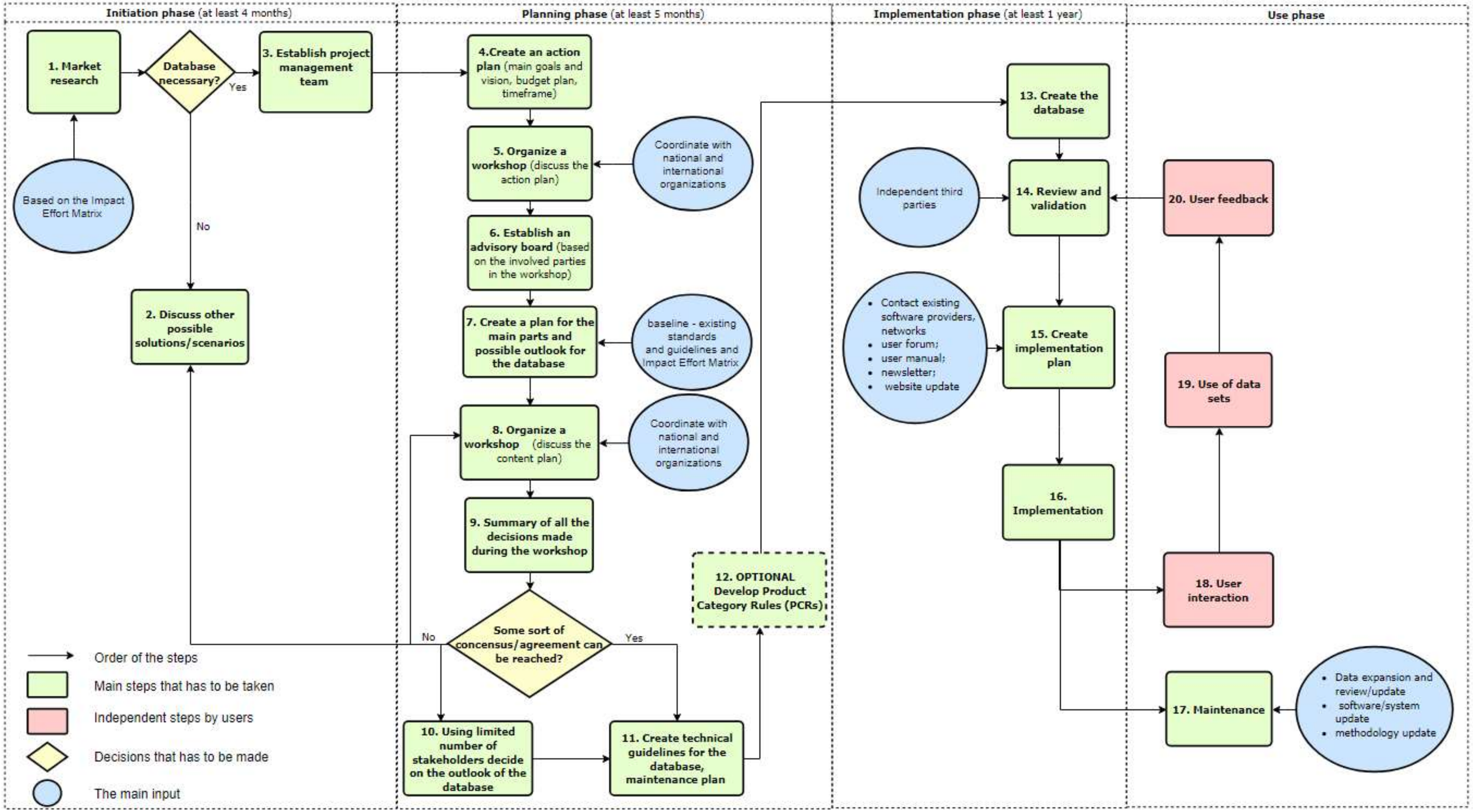

Figure 21 - The proposed roadmap for data harmonization

10. 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.
11. 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.
12. 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:

    1. Data collection
    2. Scope of the database (categories, system boundaries)
    3. Indicators
    4. Structure of the database
    5. Data verification protocols
    6. Documentation requirements
    7. Treatment of data gaps
    8. License creation
    9. 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 would 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.

10. 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.
11. The database development can begin. The most important part is to have consistent guidelines, so the database development goes as smoothly as possible.
12. 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 interests, it should be performed by an independent, qualified third party.

13. Implementation plan then 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.
14. Implementation procedure can begin.
15. Maintenance of the database. Amongst other things, data expansion, review, and update should be done.
16. 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.

8. Conclusion and recommendations

The main purpose of the research was to establish the primary steps that would lead to a harmonized database. Even though there are many steps necessary to arrive at the result, the most essential ones are:

1. 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 will fail due to the huge amount of stakeholders involved in the process.
2. To arrange workshops where the outline of the database is decided. Many stakeholders with different backgrounds has to participate in the workshops to gain comprehensive knowledge of the needs and wishes of all involved parties.
3. To create a technical manual of the main rules and outlook of the database to ensure consistency between the datasets.

The analysis of data harmonization also 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, data verification method etc., and 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) from many different countries has to be involved. To ensure that the database is implemented and used, their wishes and needs has to be acknowledged. It also has to be taken into account that not all parties may agree on data harmonization. Countries who already have their own national databases may not be in favor of harmonization since they already have established their own data and method of working.

Despite the challenges, harmonization is still continuing. There are several data harmonization attempts, such as the publication “Global guidance principles for LCA databases”, composed by UNEP and SETAC, or development of PEF database by EC.

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

Harmonization happens on a national scale as well, like database and tool development for one specific country.

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

However, before creating the database, it is important to examine the necessity for it. It can turn out that there is no apparent need for such a database, and other possible solutions has to be discussed. It also has to be investigated whether harmonization should be done on a national or a European level. Each has their advantages and disadvantages. The main difference is that if it is done on a national level, then knowledge transfer between countries would still be difficult since each country uses a different format of the database.

The Impact Effort matrix created during the research, is another important tool to ease data harmonization. It clearly points out the biggest challenges (e.g. data modelling) that has to be prioritized. This can help greatly during the discussions and workshops since it provides a clear outline of the main talking points.

Both the matrix and roadmap can be used by NRAs and other involved parties to achieve the goal as smoothly as possible.

As already mentioned, the main goal 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.

Next immediate stepts to continue the research should be:

1. present the main findings to NRAs and discuss the posibility of a harmonized database.
2. stakeholder analysis to identify all the involved parties and their significance in order to be able to understand their attitude towards harmonization.
3. Create 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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