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ASSESSMENT OF DATA QUALITY IN LIFE CYCLE INVENTORY (LCI) FOR FIBRE-REINFORCED POLYMER (FRP) COMPOSITES

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Assessment of Data Quality in Life Cycle Inventory (LCI) for Fibre-Reinforced Polymer (FRP) Composites

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GLOSSARY OF ABBREVIATIONS

LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
FRP	Fibre-Reinforced Polymer
ISO	International Organisation for Standardisation
DQG	Data Quality Goal
DQI	Data Quality Indicator
DQA	Data Quality Assessment
EE	Embodied Energy
CED	Cumulative Energy Demand
GWP	Global Warming Potential
EICF	Environmental Impact Classification Factor
GHG	Greenhouse Gases
EuCIA	European Composites Industry Association
EPD	Environmental Product Declaration

EXECUTIVE SUMMARY

Life Cycle Assessment (LCA) is increasingly being used as a tool to identify areas of potential environmental and human health impact of materials, technologies, and policies. Data quality and traceability within LCA is a significant issue that needs to be addressed in developing LCA as a decision support tool and its wider adoption within the composites industry. In response to current data quality standards, such as the ISO 14000 series, various entities within the LCA community have developed different methodologies to address and communicate the data quality of Life Cycle Inventory (LCI) data. LCI quantifies the inputs and outputs of a system, materials and data flows. Despites advances in this field, the LCA community is still hindered by the lack of reproducible data and documentation. As an initial attempt to address these issues, NPL has compiled this report following an investigation into data quality gaps that exist within LCI specifically for fibre-reinforced polymer (FRP) composites.

INTRODUCTION

Life Cycle Assessment (LCA) is a holistic concept or methodology used to identify the environmental consequences of a product or process or its operation throughout the entire life cycle, as well as opportunities to reduce the environmental burden. LCA is an environmental assessment method which, according to ISO 14040:2006(E), *“considers the entire life cycle of a product from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end-of-life treatment and disposal”* [1]. An LCA study has four phases as described below and shown schematically in Figure 1.

- **Goal and scope definition** – the goal states the intended application, the reasons for carrying out the study, the intended audience and end-use of the results. The scope defines the breadth, depth and detail of the study and states whether these are compatible and sufficient to address the stated goal. LCA is an iterative technique and as data and information are collected, various aspects of the scope may require modification to meet the original goal of the study.
- **Life Cycle Inventory (LCI)** – includes the identification and quantification of raw materials and energy inputs, emissions, water and land use, waste and other life-cycle inputs and outputs.
- **Impact Assessment** – consists of the qualitative and quantitative classification, characterisation and valuation of potential environmental impacts (e.g. global warming, acidification, aquatic and human toxicity etc.) based on the results of the inventory analysis.
- **Interpretation** – evaluation of results of an inventory and impact assessment which concludes the LCA by identifying potential improvements and recommendations.

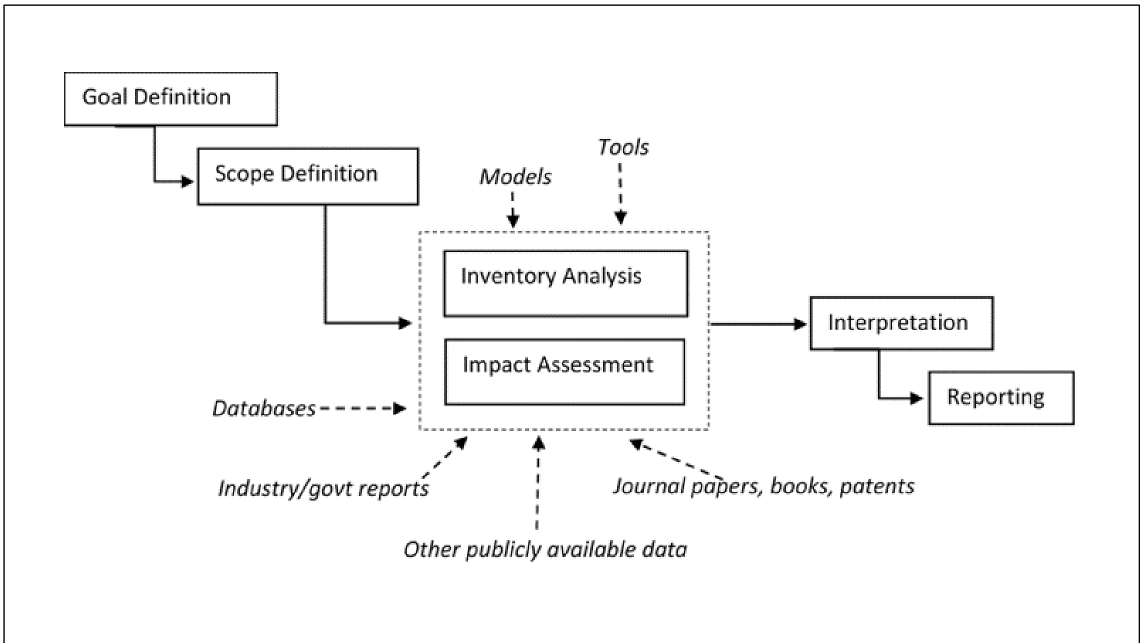

Figure 1 Phases of Life Cycle Assessment [1, 2]

LCA methodology is used by industry to serve a number of different purposes e.g. to support management decisions on production processes or product design or packaging, to support product environmental claims, to support technical policy and regulatory decisions and to compare the environmental impacts of alternative products or production processes. Most LCA approaches involve practitioners who compile inventories, with the aid of commercially available databases (GaBi, SimaPro, Ecoinvent), which provide international industrial life cycle inventory data on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services and transport services. The inventories can be built from these databases in combination with data available in the literature (journal articles, environmental product declarations, reports, other publicly available data). Life cycle interpretation and subsequent conclusions can be based on simple data assessment techniques (e.g. the lower the input/output quantities the lower the resulting environmental burden) or by following techniques to calculate the potential environmental impacts. The differences between and the lack of development in the impact assessment guidelines is beyond the scope of this study and is not addressed here.

A complete LCA study requires the acquisition and synthesis of significant amounts of data. Given, the data intensive nature of LCA and the importance of decisions that are made based on the LCA results, data quality and lack of traceability remain a critical concern. Outcomes of the LCA based on poor or inadequate data will potentially lead to incorrect decisions by industry and might have high-cost implications. They could also mislead the public perception about a process or a product and potentially result in invalid green claims of one product/process over an alternative. Data quality and traceability is a growing concern among the LCA community worldwide and this report aims to understand the scale of the problem among the FRP composites industry to provide some useful recommendations for increasing quality in data collection.

1 LIFE CYCLE ASSESSMENT (LCA) STANDARDS

The International Organization for Standardization (ISO) has developed internationally recognised standards covering LCA. They focus mainly on the process of performing an LCA, following a product's impact from cradle to grave. ISO 14040 [1] and ISO 14044 [2] are the international standards that define the practice of LCA. ISO 14040 describes the "principles and framework for LCA", while ISO 14044 specifies "requirements and guidelines" for LCA [1, 2].

The ten key categories addressing data quality are defined in ISO 14044 *Section 4.2.3.6 Data Quality.* The definitions of the different categories can be found in *Section 10 (Glossary of this Guidance)***.** ISO requires LCA practitioners to address the following data quality areas if the *"study is intended to be used in comparative sections that are intended to be released to the public"* [2].

1. Time related coverage
2. Geographical coverage
3. Technology coverage
4. Precision
5. Completeness
6. Representativeness
7. Consistency
8. Reproducibility
9. Source of data
10. Uncertainty of the information

ISO 14040 and ISO 14044 do not further define how these areas should be addressed and rather leave this task to the discretion of the individual. Some areas can only be addressed qualitatively through a description of the methodology used in the LCA study (e.g. consistency and reproducibility).

The assessment of data quality is a complete and a mandatory model, which is often overlooked. This could be due to number of factors, e.g. it is considered too complex for the average practitioner, it is time-consuming, and the users do not have the appropriate tools to analyse where the effort is needed.

2 DATA USED IN LIFE CYCE INVENTORY (LCI)

LCI datasets are comprised of data that varies depending on the primary or secondary nature of the data source, the type of data (e.g. measured, modelled or non-measured/estimated) and the level of aggregation (e.g. individual plant or industry average). It is important that practitioners recognise these characteristics among data sets and consider how their use may affect the outcome of the LCI.

2.1 PRIMARY AND SECONDARY DATA

Data used in LCIs can be categorised as primary (foreground) and secondary (background) data. Primary data are plant-specific, measured, modelled or estimated data that are directly accessed by the LCA practitioner or for which the practitioner has an input into the data collection process. This may include utility bills, inventory notes and other directly measured or collected information relevant to the process [3]. In most cases, primary data are preferred for use in LCI as they are specific to the product or process being evaluated. Companies conducting or commissioning LCIs have usually classified their primary data as proprietary. Under these circumstances, the data and the associated collection methods are unavailable to review. Consequently, verification of the data or measurement techniques is extremely difficult and the level of data quality will rely heavily on the reputation of the organisation providing the data.

Secondary data sources include data that were not collected specifically for use in LCI and for which the practitioner does not contribute to the data collection process. Secondary data sources can be more difficult to evaluate and they may not include an explanation of the data collection methods or data variability. Environmental impact audits and the Environmental Product Declarations (EPD) are popular sources of secondary data among LCA practitioners.

2.1.1 Data Types

A data type can be defined by the method used to generate the data. Data types generally include measured data, modelled/calculated data, sampled data and non-measured/estimated data.

Measured data are monitored either directly or by self-declaration (where an industry/person is measuring the data on behalf an organisation/LCA practitioner at a site(s)). Most of the time, self-declared data is not verified quantitatively by revisiting the sites to check the reported data. The magnitude of inaccuracies in reported data or units is significant and would directly impact the validity of LCA according to environmental audit experts [4]. The level of inaccuracies is often under-estimated in many cases and it is a very time-consuming task to review the data. Primary data collection for LCI database development in LCA usually relies on self-declared data from industry and the data is rarely verified (e.g. review of bills, monitoring consumption, raw materials, waste etc). Overall, it has been found that 80% of self-reported data at site level included inaccuracies with a magnitude that can significantly impact the LCA results [4].

Practitioners may use models to generate data for LCI, or they may rely on secondary sources that use a model to generate the data. Models can be used to simulate an industrial process or estimate emissions from a production process. However, practitioners are not always aware how these models are constructed or whether they have been validated to have high confidence in the data produced by these models. Validation refers to the degree to which the model has been checked against a standard or reference value to determine its accuracy. If the model's output equals or is close to the reference value, then the model is likely to generate relatively accurate results. The validation technique can also include using expert judgement or using the model to reproduce a historical data set. A model that is not validated (or verified) may produce results that in fact have very little relation to the true values. It is often easier to verify and validate primary modelled data than secondary modelled data because practitioners usually have access to their own models and can assess the accuracy of the model and results. Secondary data sources may provide neither the full model nor information regarding the author's verification and validation activities. These types of data include collation, calculation and manipulation activities linking measurements or recorded data in LCA.

Non-measured data include estimates based on experience professional judgement or other educated approximations. Approximated/estimated data (background data) may provide a quick idea of the outcome of the LCA. Many non-measured data sources do not describe the methods used to estimate the data or whether mathematical or other techniques were employed to compensate for missing data and data deficiencies. To assess the quality of these data requires reviewing the underlying evidence and assumptions. An analyst may make biased inferences using the data without sufficient understanding of the basis of estimates. Unless experts who developed the data can be consulted or there is adequate peer acceptance of the data source, the analyst may be unable to determine the extent of any potential bias.

2.2 DATA QUALITY IN LCA

Data quality should be addressed throughout the LCA modelling process. "Data Quality" can have various meanings, but it is often referred to as the degree of confidence an analyst has in a data source or data value based on the evaluation of data quality goals (DQGs), data quality indicators (DQIs) and the role of the data in an overall LCA in the guidelines [5].

All DQGs should be determined during the goal and scope phase of the LCA and should guide the data collection process. During inventory analysis, data quality should be assessed based on how well the data collected compares with the established DQGs. Interpretation of LCA results should include the interpretation of the data quality assessment (DQA).

2.2.1 Key data quality issues in LCA

Ideally, data of the highest possible quality for use in LCIs should consist of measured values with quoted ranges and standard errors. Data should be measured by an organisation using methods documented and approved by a standards organisation. In practice, most of the data used in LCIs does not fit this ideal and in some cases may not need to meet these stringent criteria. Therefore, assessing the quality and traceability of LCI data is paramount importance [6].

Key issues identified by LCA practitioners in the context of LCI include:

- a variety of data used in LCIs may vary by source, type and level of aggregation
- some key data may have a large amount of variability
- propagation of uncertainty
- use of non-parametric/outdated data
- use of data sources that are not developed for the purpose of LCA
- not being able to recognise which sources of data are high-risk
  e.g. calculation vs direct measurement, accuracy vs precision, uncertainty vs variance
- impossibility of tracing the data back to the source for review
- lack of transparency of sources of uncertainty between different datasets

Scientists and industry experts should work with the LCA community to improve data quality and data reviewing methods. Understanding and communicating data quality is essential to the scientific integrity of LCA as it is to other fields.

3 LCA FOR FRP COMPOSITES

An LCA with the scope of “cradle-to-grave” would seek to determine and evaluate every environmental impact incurred from the raw material acquisition, manufacturing, use and the end-of-life of a composite product. A “cradle-to-gate” analysis would focus on the environmental impacts from the raw material acquisition and manufacturing but not the use or disposal phase, which would apply to many composite materials that would be used to manufacture a product. Life Cycle Impact Assessment (LCIA) intended to convince the manufacturers (depending on the goal and scope of the study) that the FRP material or related product is environmentally sensitive and demonstrates to both customers and shareholders their commitment to sustainability.

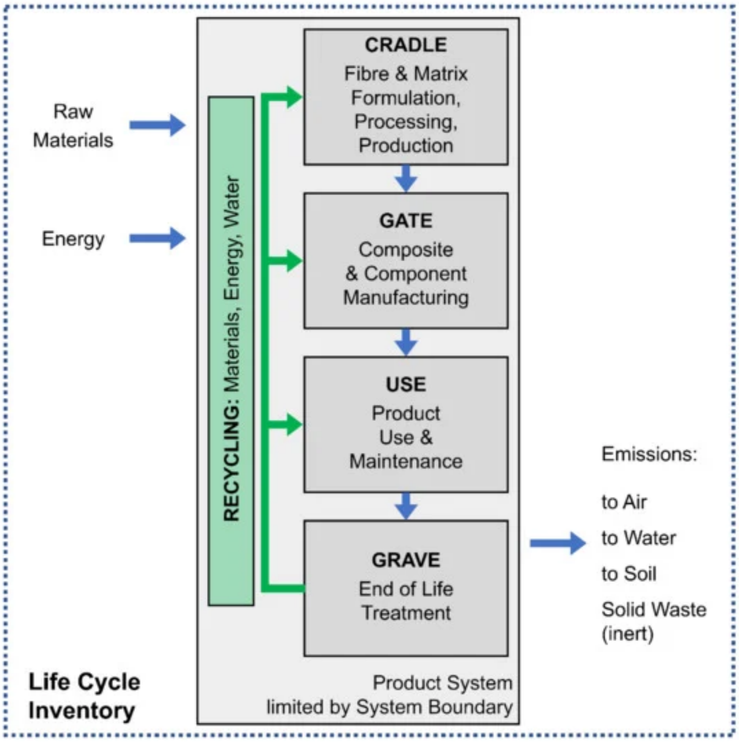

Figure 2 Schematic of LCA system for FRP composite [7, 8]

3.1 LCI FOR FRP COMPOSITES

Each LCA study starts with defining the goal, scope, and the functional unit of the study. The functional unit is required to establish a quantitative equivalent between two comparable products or processes. For example, environmental impacts arising from manufacturing 1 tonne of glass fibre can be directly compared to 1 tonne of carbon fire production. Inventory analysis is the key part of an LCA study which requires an intensive amount of data collection. LCA practitioners must determine all the possible inputs to and outputs from the functional unit that have an impact on the environment. Inputs include the upstream impacts of raw materials (e.g., sand for glass manufacture); the energy used to mine or extract the raw materials; the fuel costs to transport the raw materials to the manufacturing site; the energy used to transform the raw materials into the product (e.g., from natural gas or coal); and the energy use associated with any recycled materials in the product etc. Outputs include the downstream impacts of air pollutants (e.g., greenhouse gases), water pollutants, solid waste and any by-products that can be reused etc.

The life cycle of a glass fibre-reinforced composite component is shown in Figure 3.

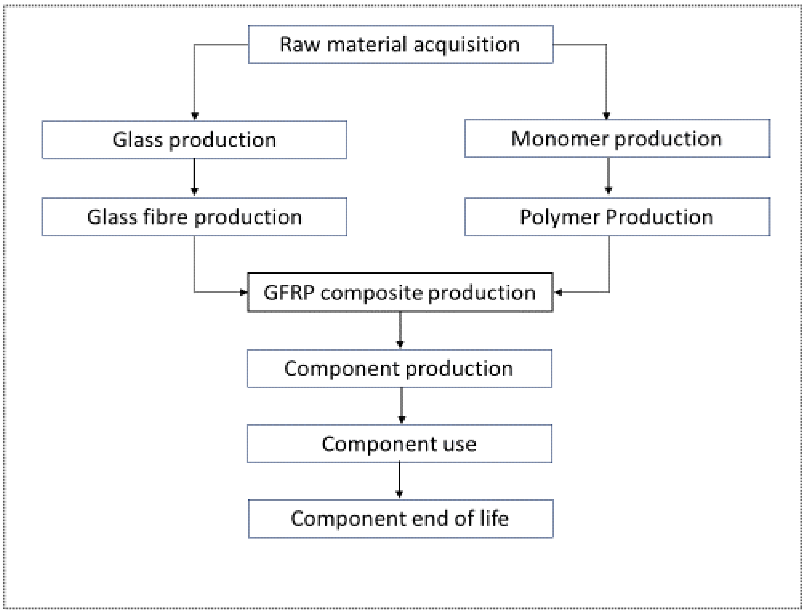

Figure 3 Life cycle of a glass fibre-reinforced composite component

3.2 DIFFERENCES IN DATA USED IN LCI

The **embodied energy** (EE) (measured in MJ/kg), of a material or a product is the primary energy associated with the manufacturing of a product which includes the energy used for extracting and processing raw materials, manufacturing, transportation, distribution, assembly, use and end-of-life according to the system boundaries set for the LCA study. There are variations in EE reported in the literature and LCA databases according to the cumulative energy demand (CED) method in which the energy is assessed as primary energy used for the manufacture, use and disposal of a product or which may be included with justification [3]. CED represents the primary energy used (both direct and indirect) during the life cycle of a product and is the sum of direct and indirect consumption of energy [3, 9]. Some research studies have failed to include renewable energy in their definition of EE. It was also found that the use of different sources and the failure to distinguish between primary and secondary could lead to errors in reporting as high as 40% EE [3, 10]. The poor understanding of EE and embedded energy definitions has also led to variation in data reported in the literature. The **embedded energy** of material is a property that can be directly measured, for example by incineration and not the energy associated within its life cycle of production.

Global warming potential (GWP) is an environmental impact classification factor (EICF) which is often discussed in LCIA related to greenhouse gas (GHG) emissions. GWP is calculated for each of the different GHG (CO_2, N_2O, CH_4 and volatile organic compounds (VOCs)) and expressed relative to CO_2 which is therefore defined as unity [11, 12]. Researchers have often found errors in primary energy reporting which is directly affecting GWP values of LCA studies. Some of them can be traced back to data sources to underpin the reasons causing the discrepancies such as use of more/less non-renewable energy sources in a certain location, but the others are more difficult to trace.

Differences in EE (reported as MJ per kg of fibre) and GWP (kg CO_2 equivalent per kg of fibre) are illustrated in Table 1 (glass fibre), Table 2 (carbon fibre) and Table 3 resin (epoxy, polyester and vinyl ester) production.

Table 1 LCA data for glass fibre production as per cradle-to-gate analysis

EE (MJ/kg)	GWP (kg CO_2e/kg)	Reference [3, 13]
45.6	2.5	Michaud 2016
31.6	2.16	EuCIA
28	1.54	Bath ICE database
45	2.6	Deng 2014

Table 2 LCA data for carbon fibre production as per cradle-to-gate analysis

EE (MJ/kg)	GWP (kg CO_2e/kg)	Reference [3, 13]
704	31	Deng 2014
286	22.4	Michaud 2016
1112	53	Verpoest 2014

Table 3 LCA data for resin (epoxy, polyester and vinyl ester) production as cradle-to-gate

Resin type	EE(MJ/kg)	GWP (kg CO_2e/kg)	Reference [3]
Epoxy	137.1	8.1	Plastics Europe 2005
Epoxy	76	4.7	Bricout 2017
Epoxy	135	6.8	EuCIA
Epoxy	137.1	5.7	Rankine 2006
U Polyester	87.8	3.79	EuCIA
UP DCPD based	77	2.93	EuCIA
UP DCPD based	90.2	3.06	Rietveld 2014
UP isophthalic acid based	91.7	4.13	EuCIA
VE Resin (BPA epoxy based)	121.5	5.97	EuCIA
Bisphenol-A VE	119.3	5.87	Rietveld 2014

The literature values for both EE and GWP have significant variability which may affect the LCA results depending on the chosen source of secondary data for glass fibre, carbon fibre and resin production. It was noted in the literature that the scarcity of available carbon production related data and the confidentiality of the few commercial carbon fibre suppliers hinders further research efforts in LCA [14]. Besides the need for a proper recycling strategy, the production of carbon fibres consumes substantially more energy than a comparable amount of steel or aluminium, leading to higher cost and related environmental impacts [15, 16].

4 SURVEY OF DATA USED IN LCA FOR COMPOSITES

Interviews were conducted with staff at the National Composite Centre (NCC), University of Plymouth and JCH Ecology Ltd to understand impact of data quality and lack of data traceability issues faced by LCA experts who work in the area of FRP composites from the. Subsequently, a survey (see Appendix 1) with specific questions about data used in LCA for composite materials and related products was compiled and shared widely among LCA practitioners, consultants, and researchers. The purpose of the consultation exercise was to understand the data sources, issues, and confidence among the LCA practitioners regarding

LCA for composite materials and related products. The survey was sent to academic institutes, consultation firms and industry. Due to time limitations of time, the survey was only live for a period of four weeks and 25 responses were received in total from Research and Technology organisation, universities (Plymouth, Cambridge, Chester, Portsmouth), LCA consultancy firm and an ex-UK government respondent. All the respondents were from the UK with varying degrees of experience in LCA.

The first survey question was set to capture the experience of the respondents in LCA of composite materials or related products. 64% of respondents had a reasonable knowledge in carrying out an LCA, whilst 12% had some background knowledge or interest in carrying out an LCA.

4.1 PRIMARY AND SECONDARY DATA

Unavailability or limited availability of life cycle inventory data is a common problem faced by many LCA practitioners, which is often overcome by making use of secondary data in combination with or without a sensitivity analysis. In some cases, LCA practitioners use primary data (foreground data) as well as secondary data (background data) from existing LCI databases or the literature. Secondary data is required to represent the context of the study and often includes data manipulation by expert judgements. From the responses of the survey, it was clear that most of the LCA practitioners (72%) use secondary data and only some (28%) have access to primary data or are involved in primary data measurement/collection (Figure 4).

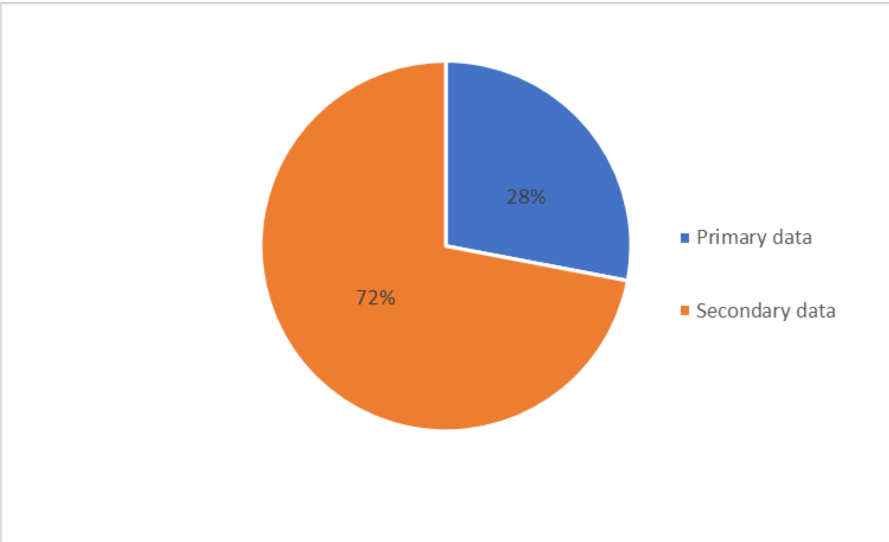

Figure 4 Proportion of primary and secondary data used in LCA for composites

4.2 DATA SOURCES

Respondents were given a list of secondary data sources to indicate which is most likely to be used in LCA studies for composites. The representation of secondary data sources used by practitioners is shown in Figure 5.

The findings of the survey and the interviews indicate that many LCA practitioners rely on commercial databases to compile their inventories. Existing LCI databases may be based on historic data with data for new technologies or processes not being available. The data that are available most likely originate from pilot projects and may lack representation. The second most used source of secondary data was literature such as journal articles, books and patents. The published literature may also lack information describing data collection, have limitations associated with data collection method, variability, reference to the original data source and the desired representativeness which may affect the LCI results. Other sources such as industry or government reports, other public data and trade associations data were also used by practitioners.

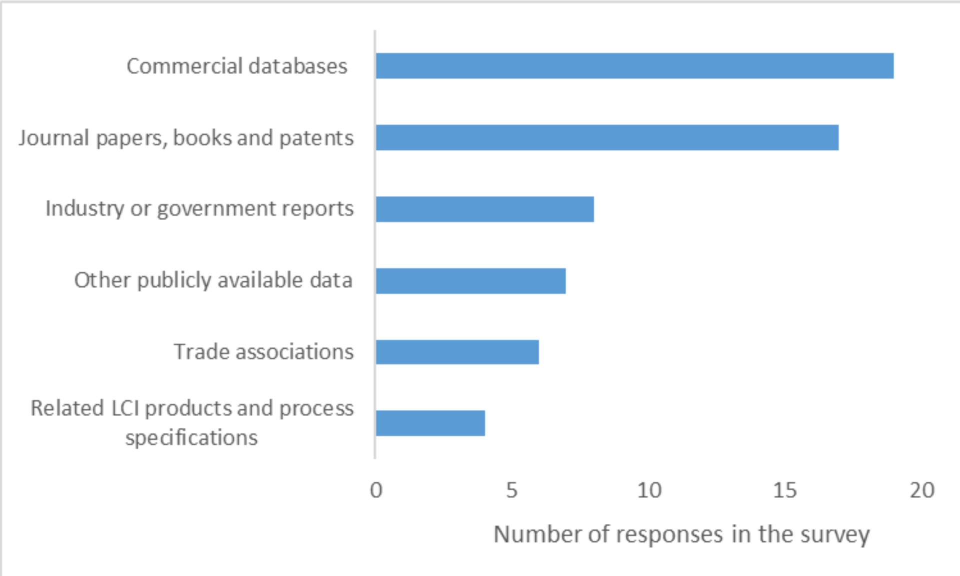

Figure 5 Breakdown of typical of secondary data sources used in LCA for composites

4.3 TYPES OF DATA

Most of the survey respondents felt their studies were mainly based on estimated data, data validated by inter-comparisons or non-verified data based on calculations. Some stated that they have used both verified and non-verified data based on measurements and calculations. LCA practitioners often find it difficult to differentiate between verified and non-verified data collected from secondary data sources due to lack of traceability and transparency.

One of the survey questions was on the most appropriate data practitioners would consider to be used in LCA. The options listed were measured, modelled, sampled, estimated/non-measured and calculated. The results of the responses are shown in Figure 6.

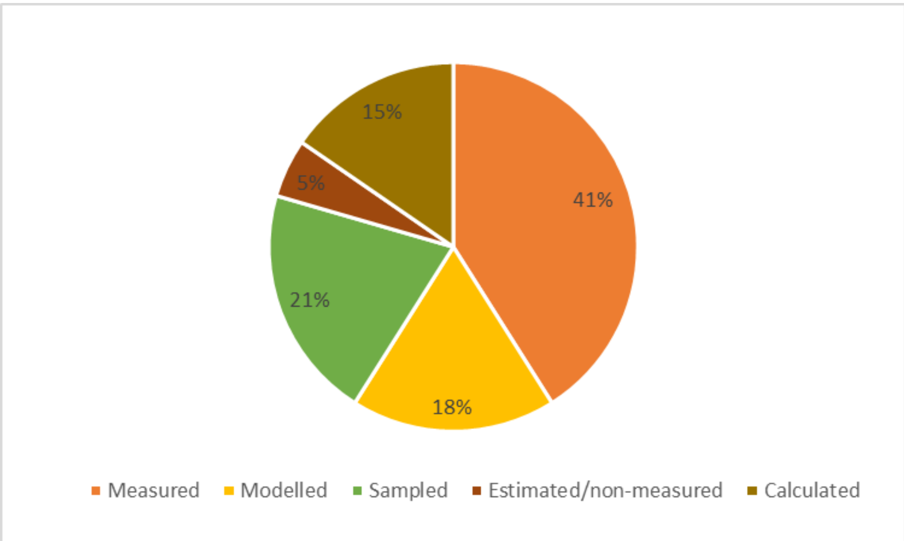

Figure 6 Proportion of most appropriate data to be used by LCA for practitioners for composites

41% of respondents felt that “measured” data was most appropriate to be used in LCA, while 54% thought “sampled”, “modelled” or “calculated” were most appropriate. Only 5% felt that “estimated” data was appropriate. LCA practitioners seem to have more confidence in using measured, modelled, sampled, or calculated data than estimated data.

4.4 PREFERRED CHOICE OF DATA

Respondents were asked to list 6 different data sources in order of their preference. The rankings were recorded as:

1. Direct measurement from relevant industry
2. Self-declared data from relevant industry
3. Modelled data
4. Suppler/association data
5. Laboratory test data
6. Estimated data

It was very clear that the preferred choice was for direct measurements (primary data) (93%) and that estimated data was the least preferred choice (73%). Practitioners often use their knowledge of the data source and its relevance or importance to the overall analysis to determine which data source is the most appropriate. When they were asked about the most appropriate data collection method, they preferred data collected from a relevant industry for adequate period than data based on literature, expert opinions or estimations.

None of the respondents chose to use unknown data collected from a small number of sites for a shorter period. LCA practitioners are very clear on which data they would like to use but limited data availability has driven them to use poor data sources. LCI data are generally collected on an iterative basis. After evaluating a data source, practitioners may determine that reviewing the existing data or collecting additional data is necessary. This can be done by reviewing techniques such as validation of data sources, sample tests on calculations, cross-checks with other sources and/or datasets and expert judgement. It was clear that many of the LCA practitioners have used more than one of these methods to review their data, but mostly by cross-checking with other sources and expert judgement.

4.5 CONCERN OVER DATA QUALITY AND FEEDBACK

When practitioners were asked to rate their concern over inaccuracies in and/quality of data used in LCAs which can invalidate the outcome of their studies (scores being 1 – not at all to 10 – extremely), 60% of respondents rated it as either 9 or 10 and the other 40% rated it as 7 or 8 as shown in Figure 7.

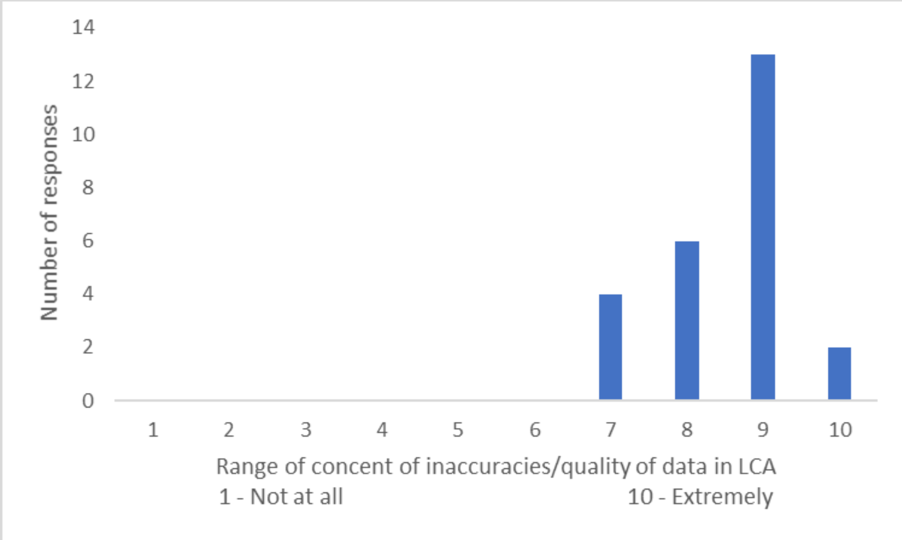

Figure 7 Representation of LCA practitioner's concern of inaccuracies/data quality

Some practitioners who completed the survey provided comments which provide additional context to the issues surrounding data quality and traceability.

*"I think that the myriad of data sources and lack of clarity surrounding an appropriate methodology is acting as a barrier for effective industry uptake of LCA for composites. Whilst examples of correct methodology practice should be sought by governing standards, there will also need to be a greater amount of relevant data provided by the material and equipment manufacturers. Pressure from end-users could also facilitate this - for example, car manufacturers. Without this information, comparisons with other materials will not be accurate, and this could block potential applications for composite materials. In addition, it will inhibit any innovation with the product development that is required to make it competitive with the increasingly environmentally-conscious marketplace". **(UK Research & Technology Organisation)***

*"A critical mass of primary and secondary data is needed to better understand the typical range of life cycle impacts (enabling better cross-comparisons), as well as for it to be useful as a tool to improve materials and their processes to minimise impacts. Also, standards are clear and available, so perhaps their wider enforcement/uptake (through legislation mandating EPDs and LCAs?) is critical". **(University of Cambridge)***

*"This is a very secretive industry who do not like to share data. No company wants to produce LCA data which is then a target for competitors to aim at". **(LCA Consultancy firm)***

*"The only area that is very clear is that the standards on process for LCA exist and they follow through to defining how to make a claim. What is missing, is the databases of material data that has been measured and verified and can be used which is relevant to the processes and procurement methods of the various sectors". **(UK Research & Technology Organisation)***

*"ISO14040/44 is too vague in respect of issues like (a) goal and scope definition and (b) handling allocation between primary and by-/co-products. There should be a rationale to avoid practitioners "forgetting" key environmental impacts?". **(University of Plymouth)***

5 RECOMMENDATIONS FOR FUTURE WORK

This report attempts to understand the data quality and lack of traceability in the life cycle inventory data for LCA of FRP composites. The high-level study was conducted by not limiting to any specific composite material or product purposely to understand the full scale of the problem among LCA practitioners within the composites industry. Following an intensive literature search and several interviews with experts to assess the data quality gaps, a survey with specific questions was sent to LCA practitioners with experience in compiling LCAs for composites. Recommendations are drawn by combining the findings from literature, interviews and the survey.

5.1 DATA COLLECTION

Most of the LCI databases contain their own industrial datasets which include measured data. These data are typically measured and supplied (self-declared primary data) by a manufacturing site/factory which are rarely verified by reviewing bills or monitoring consumption. Environmental audits have shown that the quality of self-reported data is poor with many inaccuracies that can significantly impact LCA results [4].

Recommendations on improving primary data collection:

- Introduce a review process on measured data to eliminate any errors (units, conversions, calculations etc) before including data in databases,
- Adding information on the sources of data (company/site name, location, date, how data is calculated or measured) within the available datasets to increase traceability,
- Combining the data used in environmental audits with LCA data for comparison,
- Minimise the errors during data collection by providing a set of guidelines/standards for measurements (e.g. how to measure the energy used for a process in terms of renewable and non-renewable energy usage), reviewing the collected data by an experienced person/auditor and providing training in data collection/measurements.

o EXISTING DATA

A systematic quality control process to understand the weak data and a good understanding of the data flow pathway in LCI play a key role in improving the data quality. Unfortunately, the available ISO standards [1,2] do not provide any information on how this process should be completed by either LCA practitioner or an external reviewer. Sometimes it is not feasible to trace the data back to the sources to review the data and the data flow pathway may not be robust. The fundamental question for the practitioner is “how did this data reach this study”. The existence of adequate, consistent, and representative data is a decision factor which relies on the technological and methodical decision taken by the practitioner.

Recommendations to enhance the quality of existing data:

- Improve the transparency of existing datasets by introducing a pedigree schema for data sources (for example, how are data calculated, measured or averaged, any assumptions made, any national or regional sources used).
- Develop practical approaches (data review, comparisons etc) to fill the data gaps in existing databases and in new data collected.
- Increase the accessibility of LCA data for composites among companies, practitioners a third parties to identify the weak data types.
- Compile and tabulate guidelines for LCA practitioners to determine if key data points (e.g. energy used to produce 1 tonne of glass fibre in Europe) sit within a “reasonable range”
- Develop, promote, and agree on quality assurance systems for LCA approaches.
- Introduce a qualitative documentation criterion (for example metadata such as age, origin, scope) to the existing datasets.
- Develop a verified and traceable industrial dataset for composite manufacture (for example, fibre production, resin production, composite production etc) which can be

used for comparison of any new or existing dataset which can be international, national, or regional.
- Develop peer-review protocol for key data components in LCA (e.g. energy data)

    - OTHER RECOMMENDATIONS

As most LCA studies are based on secondary data, it is important for practitioners to use representative data. However, this will depend on several factors such as availability, experience of the practitioners and the experience of the external reviewer. Inventory data collected from scientific articles, patents, interviews, and unpublished laboratory results are far from representative and such data may require curation to represent the goal and scope of the LCA study [17]. In this context, using assumptions is unavoidable and will not allow comparable system boundaries. This will obviously contribute to significant uncertainties in the LCA results as most of the studies carried out are based on secondary data. It will be extremely difficult for a practitioner to find highly relevant data among secondary sources. A mismatch between primary and secondary data can be avoided by clear definition of the goal and scope of the study.

Other recommendations to improve the secondary data used in LCA for FRP composites include:

- Collect, organise, and statistically characterise the existing and available data on LCA for FRP composites.
- Promote mechanisms for company databases on energy use to be accessible to LCA practitioners.
- Encourage the composites industry and raw materials manufacturers to carry out Environmental Product Declarations- EPDs which provide data that can be used in LCI (The primary purpose of an EPD according to ISO14025 [18] is for business-to-business communication and business-to-consumer communication [19]).
- Cooperation between and within ith trade associations to provide accurate aggregated data information on LCI (for example industrial secrecy leads LCA practitioners to use historic and non-verified data for carbon fibre production).
- Develop a structure and design of peer-reviewed online platform for dissemination of information about data quality or transparency issues in LCA for FRP composites (for example new databases, reports, workshops).

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7 APPENDIX -1

Survey of data used in LCA for composites by LCA Practitioners/Consultants (MS FORMS)

The survey will take approximately 4 minutes to complete.

The purpose of this consultation exercise is to understand the data quality and the measurement gaps that may exist within the LCA framework for composites. This is to inform a research study conducted by the National Physical Laboratory, with no commercial interest. I really appreciate your input in this study and if you would like more information about this study or consultation exercise, please contact: nilmini.dissanayake@npl.co.uk

Question 1. Have you conducted or intend to carry out LCA studies relating to composite materials or products?
Answers: Yes
No
May be

The following questions (no.2 -10) refer to LCA studies for composite materials and related products.

Question 2. Which of the following type of data is most likely to be used?
Answers: Primary Data
Secondary Data

Question 3. Which of the following types of data do you find most appropriate to be used? (select all that apply)
Answers: Measured
Modelled
Sampled
Estimated/non-measured
Calculated

Question 4. Please list the following data sources commonly used in LCA in the order of your preference.
Answers: Direct measurement from relevant industry/plants
Self-declared data from relevant industry/plants
Supplier/Association data
Laboratory test data
Modelled data
Estimated data

Question 5. Which of the following sources of secondary data is most likely to be used? (select all that apply)
Answers: Commercial databases
Industry or government reports
Journal papers, books and patents
Related LCI product and process specifications
Trade associations
Other publicly available data

Question6. Which of the following data collection methods do you consider to be the most appropriate? (select all that apply)
Answers: From relevant industry for adequate period

Unknown data from small number of sites for short period
Based on literature values
Based on expert opinions
Estimations

Question 7. Which of the following types of data are most likely to be used? (select all that apply)
Answers: Verified data based on measurements
Verified data based on calculations
Non-verified data based on measurements
Non-verified data based on calculations
Validated data by intercomparisons
Estimated data

Question 8. Which of the following methods of data review have you used? (select all that apply)
Answers: Validation of data sources
Sample tests on calculations
Cross-check with other sources or data sets
Expert judgement

Question 9. How concerned are you about the inaccuracies/quality of data used in LCAs which can invalidate the outcome?
Answers: Scale of 1-10
1 – Not at all
10- Extremely

Question 10. Which of the following need to be addressed to improve the quality of data used? (select all that apply)
Answers: Data collection (primary data)
Data set providers (secondary data)
Users who combine both primary and secondary data
QA process/Data updates/revisions
Standards governing LCA process

Question 11. Any additional comments
Question 12. Name
Question 13. Email address
Question 14. Organisation
Question 15. Country
Question 16. Years of experience in LCA