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Life cycle assessment of a PA12 powder material for additive manufacturing

Report I-43/22

Prepared by:
S. Kilchert

Contributions:

Management:
M. Imbert

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Freiburg, Germany

Fraunhofer Institute for High-Speed Dynamics
Ernst-Mach-Institut, EMI
Director: Prof. Dr.-Ing. habil. S. Hiermaier

EMI Freiburg,
Ernst-Zermelo-Strasse 4, 79104 Freiburg, phone +49 761 2714-0
EMI Efringen-Kirchen,
Am Klingelberg 1, 79588 Efringen-Kirchen, phone +49 7628 9050-0
www.emi.fraunhofer.de

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Prepared by:

Sebastian Kilchert
Digital unterschrieben von Sebastian Kilchert
Datum: 2022.12.09 11:03:11 +01'00'

Dr. S. Kilchert
Research Fellow – Multi-Material-Structures

Management:

Mathieu Imbert
Digital unterschrieben von Mathieu Imbert
Datum: 2022.12.09 12:23:39 +01'00'

Dr. M. Imbert
Group Manager – Multi-Material-Structures

Martin Sauer
Digital unterschrieben von Martin Sauer
Datum: 2022.12.15 17:39:40 +01'00'

Dr. M. May
Head of Department – Materials and Simulation Methods

Frank Schaefer
Digital unterschrieben von Frank Schaefer
Datum: 2022.12.21 14:31:28 +01'00'

Prof. Dr.-Ing. habil. S. Hiermaier
Director of Ernst-Mach-Institut

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1 Critical review statement

LCA Critical Review Statement

Product Service

Mehr Wert.
Mehr Vertrauen.

Statement No.:	PSCR05022068
Issue Date:	07.11.2022
Client:	EOS GmbH, Robert-Stirling-Ring 1, 82152 Krailling / München
Reviewed by:	TÜV SÜD Product Service GmbH, Ridlerstraße 65, 80339 München (TÜV SÜD PS)
Review scope and objective:	TÜV SÜD PS has been engaged by EOS GmbH to undertake an independent third-party critical review. The review was conducted by: Senior verifier: Dr. Max Rehberger Verifier: Daniel Philipp Müller with the task to assess whether — the methods used to carry out the LCA are consistent with DIN EN ISO 14040:2021-02, DIN EN ISO 14044:2021-02 and DIN CEN ISO/TS 14071:2016-06, — the methods used to carry out the LCA are scientifically and technically valid, — the data used are appropriate and reasonable in relation to the goal of the study, — the interpretations reflect the limitations identified and the goal of the study, — the study report is transparent and consistent. The scope of TÜV SÜD PS's critical review covers the cradle-to-gate life cycle impact assessment (LCIA) claims on EOS's Polyamid 12 (PA 12) powder for additive manufacturing in "Life cycle assessment of a PA12 powder material for additive manufacturing." version 2.0 from 07.11.2022.

Description of the review process:
— the review was performed based on ISO 14044 6.2 (external experts),
— the review was performed at the end of the study,
— the review included an assessment of the LCI model,
— the review included an analysis of individual data sets,
— the reviewers' comments were provided and discussed through a critical review report. Implementation was rigorously checked by the reviewers.

Independence
EOS GmbH is responsible for the collection and fair presentation of the information presented. TÜV SÜD PS does not involve in manufacturing products, calculating potential environmental impacts, and preparing the LCA claims. The review activities are independent from EOS GmbH.

Conclusion
On the basis of the critical review report, the TÜV SÜD PS reviewers conclude that the study is in conformance with ISO 14040, ISO 14044. The verifier rated the overall quality of the report as high, its methods as scientifically and technically valid, and the used data as appropriate and reasonable. The study report is transparent and consistent, and the interpretation of the results reflects the goal and the identified limitations of the study.

Signed on behalf of	Max Rehberger Global Sustainability Services	Daniel Philipp Müller Sustainability Hub Germany
TÜV SÜD Product Service GmbH	Max Rehberger	Daniel Philipp Müller
	07.11.2022	07.11.2022

This critical review statement may only be quoted in full. Any use for advertising purposes must be granted in writing. This statement is the result of a single examination of the object in question and is not a generally applicable evaluation of other products. It is issued under the obligation of TÜV SÜDs Testing and Certification Regulation (tuvsud.com/tcr)

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Page 1 von 1

Creator: Daniel Philipp Müller
Date of document creation: 07.11.2022

Phone: +49 15120004773
E-Mail: danielphilipp.mueller@tuvsud.com

TÜV SÜD Product Service GmbH
Ridlerstraße 65
80339 Munich
Germany

2 Definitions

AM	Additive manufacturing
CED	Cumulative energy demand, methodology for impact assessment
EF	Environmental footprint, methodology for impact assessment
EMI	Fraunhofer EMI, contractor
EOS	AM machinery manufacturer, commissioner
GWP	Global warming potential (Climate change)
IPCC	International panel for climate change
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LS	Laser sintering (additive manufacturing process)
openLCA	Software for life cycle assessment
PA 12	Polyamide 12
ReCiPe	LCA methodology for impact assessment
SLS	Selective laser sintering

3 Summary

EOS, a German-based additive manufacturing machine manufacturer has commissioned an LCA report with the objective of assessing environmental footprints of PA 12 powder production. The life cycle assessment was conducted by the Fraunhofer EMI according to DIN EN ISO14040/44 standards.

PA12 powder is a polymer feedstock for additive manufacturing (3D printing). It is used as a feedstock material for laser sintering (LS), which allows the production of final products for the automotive industry, aerospace, medical applications, as well as functional prototypes and tools.

For the LCA, the function of the PA12 powder was defined as "polymer feedstock for laser sintering". The functional unit was then defined as "packaged quantity (1 kg) of polymer feedstock for additive manufacturing (laser sintering) of final products". Following the functional unit, a reference stream of 1 kg PA 12 powder was investigated. The system boundaries corresponded to a cradle-to-gate approach, i.e. the LCA corresponded to the production and blending of two types of PA 12 primary powders and the further homogenization of the powder, including transport between the production sites and transport packaging for intermediate and final delivery including disposal of transport packaging. Two types of transport packaging were considered for final delivery: cardboard box and big bag.

The product systems were modelled in openLCA, which is an open source framework for life cycle assessment. Life cycle impact assessment focuses on the determination of impact scores for the impact categories climate change, acidification, eutrophication, abiotic resource depletion, photochem. oxidant formation and land use.

The following impact scores were calculated for the reference flow considered:

Impact category – Impact indicator (cardboard / big bag)

- Climate change – incl. biogenic carbon – 5.70 / 5.75 kg CO2 eq.
- Climate change – excl. biogenic carbon – 5.60 / 5.65 kg CO2 eq.
- Acidification – 0.013 / 0.013 SO2 eq.
- Eutrophication – 0.0025 / 0.0027 kg PO4 eq.

- Abiotic resource depletion (elements) – 1.4E-05 / 1.4E-05 kg Sb eq.
- Abiotic resource depletion (fossil) – 113.9 / 114.6 MJ.
- Photochem. oxidant formation – 0.0017 / 0.0017 kg ethylene eq.
- Land use – 0.21 / 0.27 m² crop eq.

4 General statement

4.1 LCA practitioner and commissioner

This life cycle assessment (LCA) has been commissioned and financed by EOS. The LCA is carried out by Fraunhofer EMI. A critical review of the LCA according to DIN EN ISO 14040:2021-02 and DIN EN ISO 14044:2021-02 was performed by TÜV Süd [1, 2].

The investigated PA12 powder is a homogenized blend of two types of primary powders. The blending and homogenization of the powder is carried out by KVS on behalf of EOS. The supplier of both primary powders is confidential. The abbreviation PA 12 refers to polyamide 12 which is a thermoplastic, semi-crystalline and linearly structured polymer.

EOS provides responsible manufacturing solutions via industrial 3D printing technology to manufacturers around the world. Connecting high quality production efficiency with its pioneering innovation and sustainable practices, the independent company formed in 1989 will shape the future of manufacturing. Powered by its platform-driven digital value network of machines and a holistic portfolio of services, materials and processes, EOS is deeply committed to fulfilling its customers' needs and acting responsibly for our planet.

Fraunhofer EMI specializes in investigating physical-technical processes in materials, structures and components as they occur, for instance, during crash or impact. The Fraunhofer EMI research contributes to increased safety and security, resilience and sustainability in our society. Within the framework of cooperation with the Institute for Sustainable Systems Engineering of the Albert-Ludwigs-University Freiburg, the Fraunhofer EMI engineers' solutions for today's challenges in sustainable development with particular focus on the research areas sustainable materials and resilience.

The KVS (Kunststoff Vertrieb Dr. Schiffers GmbH u. Co. KG) is a company that produces customized powder mixtures for additive manufacturing for EOS. This enables fast, flexible and cost-effective manufacturing of products directly from 3D CAD data. KVS produces 86 % of the EOS materials offered in the EOS GmbH product portfolio from plastic. TÜV SÜD offers verification and certification services which represent third-party endorsement by a globally renowned organization. This includes a wide range of services related to sustainability such as lifecycle assessments (ISO 14040), product carbon

footprints, renewable resources verification, environmental impact assessment, etc.

The study commenced in October 2022 and was finished in 7th November 2022. This LCA report is in accordance with ISO 14040 and ISO 14044.

5 Goal definition

5.1 Intended application

The objective of the study is to determine the environmental footprints of a PA 12 powder for additive manufacturing. With this regard, this study is an LCA of a single product. The results of the study are intended to be disclosed to customers so that they have information on the environmental impact of the product offered. Additionally, EOS plans to offset carbon emissions and then certify the carbon neutrality of the investigated powder. For this purpose, the study provides the verified carbon footprint of the PA 12 powder.

5.2 Method assumptions and impact limitations

Impact assessment is based on characterization modelling methods from the CML v4.8 2016 and the ReCiPe Midpoint (H) 2016 methods.

Considered are climate change, acidification, eutrophication, resource use (elements), resource use (fossil), land use and photochem. oxidant formation. The impact categories were chosen to be consistent with existing LCIA data on the primary powder, which was provided by the powder manufacturer.

5.3 Reasons for carrying out the LCA study

EOS wants to position themselves as proactive company in the market in terms of environmental sustainability, with the aim of attracting customers who demand products with overall better environmental performance. EOS also intends in future to offer an additional option to the customers for the PA 12 powder to be climate neutral. In the LCA study, the footprints of the selected impact categories as well as the climate footprint that needs to be offset for climate neutrality will be determined.

5.4 Target audience

The target audience relates to both internal and external stakeholders. The results of the LCA study will primarily be communicated to customers.

5.5 Comparative assertions to be disclosed to the public

The environmental footprints determined in the LCA study are intended to be a certified assertion disclosed to the public.

6 Scope definition

6.1 Deliverables

The LCA study will provide environmental footprints for selected impact categories for the PA 12 powder. The deliverables include a detailed life cycle inventory (LCI) of both product systems and life cycle impact assessment results as well as an interpretation of the results.

At the request of the commissioners, the flow and process data from the life cycle inventory are not included in this report, but will be included in the supplemental information, which is confidential and will not be provided to customers.

6.2 Critical review needs

A critical review by third parties was carried out by TÜV SÜD.

Contact details:

Max Rehberger
TÜV SÜD Produkct Service GmbH
www.tuvsud.com/ps

6.3 Functional unit

The goal of the analysis in this study was to determine the environmental footprints of a PA 12 powder.

The function of the PA 12 powder was the use as feedstock for the additive manufacturing (AM) of polymer products.

Thus, the following functional unit was defined as:

- Packaged quantity (1 kg) of polymer feedstock for additive manufacturing (laser sintering) of final products".

The investigated reference flow was then 1 kg of PA 12 powder.

6.4 LCI modelling framework

EOS' introduction of environmentally friendly options for powder feedstocks is not expected to have large structural changes on the market. Thus, the decision context is micro-level, product or process-related decision support studies, i.e. situation A in the ILCD Guideline (EC-JRC 2010), suggesting that the attributional principle be chosen as LCI modelling framework.

The attributive principle implies that the systems are modelled depicting existing value chains, i.e. using current German electricity and heating mix. Secondary functions in upstream and downstream processes (e.g. fuel refining, waste incineration) are handled using allocation. I.e. the multifunctional processes in the background systems were allocated according to the allocation, cutoff by classification system model of the Ecoinvent 3.8 database. In the foreground system of this study, no allocation was necessary.

6.5 System boundaries and completeness requirements

In order to represent the functional unit and the reference flow of 1 kg of PA 12 powder (packaged) produced a cradle-to-gate approach was adopted. Thus, the use phase and the end-of-life of potential applications of the powder are not considered as these are attributed to the final product produced in the AM process.

The modeling of the process chains in this LCA considers in particular the further processing of the primary powders provided by suppliers. This "gate-to-gate" part of the LCA includes the mixing/homogenization process of the powder, the packaging of the primary powder, the transport from the powder supplier's site to the KVS site in Germany, and the transport packaging of the powder (to potential customers) modeled in detail.

The process chain of primary powder production is not modeled, instead already verified LCA results were used for its representation. It is noted that both types of primary powder are supplied by the same manufacturer/site. Also considered is the disposal of powder taken for quality assurance at the KVS and the disposal of the transport packaging.

The investigated product system is illustrated in Figure 6-1.

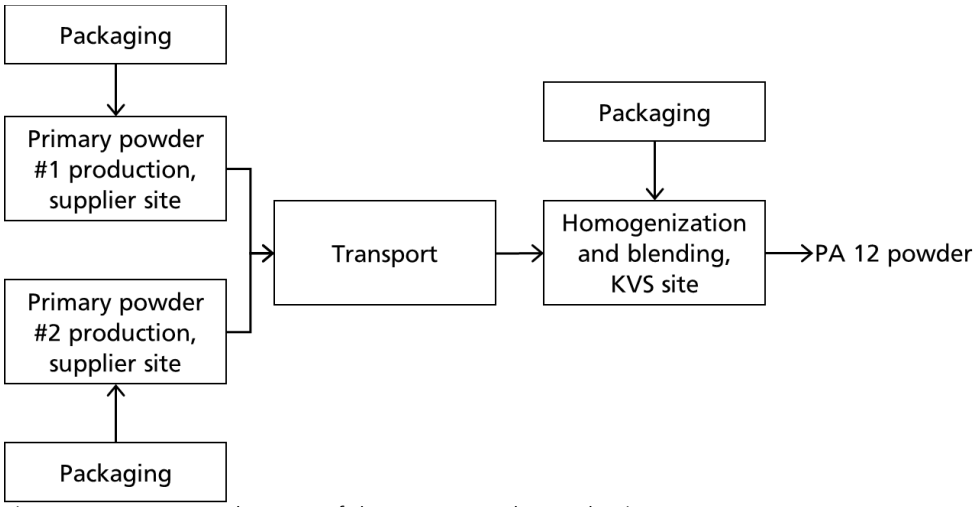

Figure 6-1: Foreground system of the PA 12 powder production.

All relevant processes in the upstream process chain were considered, including transport to the various production sites. Average markets for waste treatment were applied to the disposal of packaging.

Services, materials, and energy that are not directly associated with the product during its life cycle because they do not become the product, produce the product, or directly carry the product through its life cycle are defined as non-attributable processes.

These include:

- Corporate activities and services (e.g., research and development, servers, administrative functions)
- Transport of employees to and from work

Capital equipment such as buildings or machines, aside of data already integrated in aggregated unit processes of the background system was excluded.

Waste flows of the homogenization at the KVS site were cut-off, as the mass flow is estimated to be less than 0.01 % of the processed material. The low losses during processing in the KVS are due to the fact that only one mixing process takes place during blending/homogenization, which does not result in any major losses due to the removal of material or similar. However, approximately 0.2 % of the powder produced is removed for quality assurance and disposed afterwards. This mass flow was measured and has been taken into account in the blending/homogenization process. It is assumed that the disposed plastic waste is incinerated.

6.6 Representativeness of LCI data

Technological representativeness: The production technology for the primary PA 12 powder and the blending/homogenization at the KVS site correspond to the technologies used by EOS and the suppliers. The homogenization equipment at the KVS site in Ulm, Germany is based on simple manufacturing principles (e.g. mixing apparatus), for which no changes in near future are expected and which will be used in this form for a period of well over 10 years. The LCA data on the PA 12 powder was published in 2021 and is valid for a period of 5 years, after which an update will be published.

In general, the manufacturing technology represented is state of the art. It is expected that the machines used will meet a modern standard in the next five years.

Geographical representativeness: Blending/homogenization takes place at the KVS site in Ulm, Germany. The data for the KVS site was taken from available machine information and was based on machine runtime and performance. Environmental footprints for the production of the PA 12 powders were taken from LCA studies with critical review provided by the powder supplier, which considered local manufacturing. Where possible, background data (Ecoinvent) for manufacturing of intermediates and utilities were adapted to the local sites (EOS/KVS).

Temporal representativeness. LCI data are based on literature data from 2021 (LCA report of powder supplier, confidential) as well as the Ecoinvent database version 3.8. The data for the homogenization process should be representative frames from 2022 to 2032, i.e. a 10-year time horizon.

However, it should be noted that the environmental impact of the background manufacturing processes is likely to change due to future changes in the (national) electricity mixes. This may lead to a change of predicted environmental footprints. This applies in particular to the manufacturing technologies with high energy requirements (PA 12).

In summary, the data on the manufacturing of the product and the background processes for the environmental impacts are up-to-date and geographically representative, i.e. the production sites are located in the region for which the relevant Ecoinvent environmental datasets were selected. The dataset is current and representative of the current technology used in the processes used to manufacture the products.

6.7 Basis for impact assessment

Impact scores for a range of impact categories were calculated. The investigated impact categories were taken from the impact assessment methods CML v4.8 2016 and ReCiPe Midpoint (H) 2016.

Climate change (CML v4.8 2016): The category indicates the potential for global temperatures increase, due to emissions of CO2 and other greenhouse gases (GHGs) to air.

Acidification (CML v4.8 2016): This impact category gives an indication for the potential environmental damage to soils and water bodies due to the release of acidifying gases such as nitrogen oxides (NOx) and sulfur oxides (SOx).

Eutrophication (CML v4.8 2016): The Eutrophication reflects the enrichment of water bodies with nutritional elements. This enrichment of nutrition in water causes the rapid growth and reproduction of phytoplankton leading to algae bloom that consumes the oxygen in the water, leaving none for other marine or freshwater life and blocks sunlight from photosynthetic underwater plants.

Abiotic depletion, elements (CML v4.8 2016): This category gives the potential for depletion of abiotic resources. It specifically addresses the extraction of non-renewable, abiotic, natural resources, such as different minerals and metals (but not fossil fuels).

Abiotic depletion, fossil (CML v4.8 2016): This category gives the potential for depletion of abiotic resources. It specifically addresses the extraction of fossil fuels.

Photochem. oxidant formation (CML v4.8 2016): Photochem. ozone creation gives the indication of emissions to air that cause an increase in ground level ozone.

Agricultural land occupation (ReCiPe Midpoint (H)): The land use impact category reflects the damage to ecosystems due to the effects of occupation and transformation of land.

For reasons of consistency, the selection of the impact categories was limited to the impact categories that were also used in the LCA study on the production of the primary powder by the powder supplier.

For the impact category climate change, two global warming potential (GWP) values were reported. One considered the effect of biogenic carbon in the PA 12 primary powder production, whereas the second did not consider any effects.

The impact assessment methods used translate emissions and resource extractions into environmental impact scores for the investigated impact categories. Calculations have been done according to well researched impact assessment methods and there are no reasons to expect any omissions in these calculations. These LCIA results are relative expressions and do not predict the exceeding of thresholds, safety margins or risks.

Product systems were modelled in openLCA, which is an open source framework for life cycle assessment. The software provides access to life cycle inventory databases such as Ecoinvent and established LCIA methods.

7 Life cycle inventory analysis

This chapter gives an abbreviated summary of the life cycle inventory. For more detailed information on the process chain as well as flow and process data, please refer to the supplementary information available in the confidential part of the report.

7.1 LCI model setup

The flow diagram in Figure 7-1 illustrates the product system of the PA 12 powder production. A summary on the foreground processes depicted in the figure is given in Table 7-1.

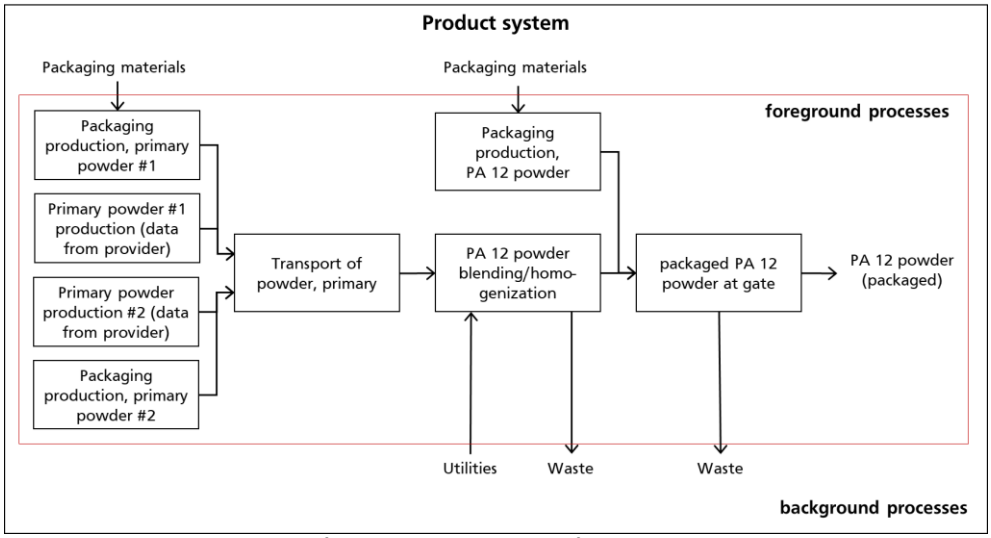

Figure 7-1: System boundaries for the product system of the PA 12 powder production.

The PA 12 primary powders are blended and homogenized at the KVS site in Ulm, Germany. The processing consists of blending, homogenization and screening of the primary powder materials supplied by the powder manufacturer. After homogenization, the PA 12 powder is either packed in cardboard boxes on a pallet or a big bag on a pallet, respectively.

Approximately 0.2 % of the powder produced is considered as losses, which is mainly due to the material removed for quality assurance. Losses in the mixing process itself are not considered, as they are estimated to be less than 0.01 % of the processed material.

The PA 12 powder will be used by potential customers to manufacture a "final product". The environmental impact of this "final product" is not taken into account, as the type of "final product" is determined by the customer and therefore cannot be clearly defined. The further use of the PA 12 powder, i.e. the additive manufacture of the "final product" from the powder raw material, is therefore outside the system boundary considered.

Table 7-1: Overview on foreground processes.

Process	Description	Data source
Primary powder production	Aggregated process for the primary powder production. Data was provided by the powder supplier.	LCA data provided by supplier.
Packaging production, primary powder	Process for the transport packaging in which the primary powder is shipped to the KVS site. Data was provided separately provided by the powder supplier.	Material quantities of packaging were measured.
Transport of powder, primary	Process for the transport of the primary powder from the supplier site to the KVS site.	Distances and mass transported were calculated.
PA 12 powder homogenization	Process for blending and homogenizing the powder. This process also considers the disposal of the powder used for quality assurance and the transport packaging (powder supplier -> KVS).	Utilities were calculated from machine data. Waste flow equals packaging mass.
Packaging production, PA 12 powder	Process for the transport packaging in which the PA 12 powder will be shipped to potential customers.	Material quantities of packaging were measured.
packaged PA 12 powder at gate	Process for the packaged PA 12 powder (at gate of factory) ready for delivery to customers. This process also considers the disposal of the transport packaging (KVS -> customer).	Waste flow equals packaging mass.

The powder is packed at the producer site and delivered to the KVS site by truck transport. This also includes the production of the transport packaging, which are paper bags lined with polyethylene film on a pallet.

For the disposal of transport packaging, disposal into the municipal waste system was considered (average market processes for waste treatment, incineration).

7.2 Data collection

Data used to model the life cycles inventory for the foreground system were collected from three sources:

- EOS, who provided machine data (from the machine specifications) used for the calculation of the power consumption of the blending/homogenization process and bills of materials for the transport packaging of the PA 12 powder (masses were measured for the study in 2022).

- Powder supplier, which provided LCA data on the primary powder manufacturing and bills of materials for the packaging. The LCA data was critically reviewed by TÜV Rheinland in 2021. The masses of the transport packaging were measured for the study in 2022

- Ecoinvent database for the background processes (Ecoinvent 3.8).

The supplier specific data on the material production of PA 12 powder consists of an LCA analysis with critical review carried out by the powder supplier in 2021.

Data for transport and waste treatment as well as material production for packaging were taken from the Ecoinvent database, while EOS and suppliers provided the bill of materials and distances.

All data meet the quality requirements given in section 6.6. While the data collection is summarized in this section, further information on the life cycle inventory and a list of all process units can be found in the supplementary information in the confidential part of the report.

8 Life cycle impact assessment

8.1 Characterized results

Life cycle inventory and life cycle impact were calculated using the openLCA 1.10.3 software and the Ecoinvent database. The life cycle impacts calculated for a reference flow of 1 kg of PA 12 powder are listed in characterized form in Table 8-1.

Table 8-1: Characterized life cycle impacts for the production of 1 kg of PA 12 powder.

Impact category	Unit	Value	Method
1 kg of PA 12 powder, cardboard option			
Climate change – incl. biogenic carbon	kg CO2 eq.	5.70	CML v4.8 2016
Climate change – excl. biogenic carbon	kg CO2 eq.	5.60	CML v4.8 2016
Acidification	kg SO2 eq.	0.013	CML v4.8 2016
Eutrophication	kg PO4 eq.	0.0025	CML v4.8 2016
Abiotic depletion, elements	kg Sb eq.	1.4E-5	CML v4.8 2016
Abiotic depletion, fossil	MJ	113.9	CML v4.8 2016
Photochem. oxidant formation	kg ethylene eq.	0.0017	CML v4.8 2016
Land use	m² crop eq.	0.21	ReCiPe 2016 (H)
1 kg of PA 12 powder, big bag option			
Climate change – incl. biogenic carbon	kg CO2 eq.	5.75	CML v4.8 2016
Climate change – excl. biogenic carbon	kg CO2 eq.	5.65	CML v4.8 2016
Acidification	kg SO2 eq.	0.013	CML v4.8 2016
Eutrophication	kg PO4 eq.	0.0027	CML v4.8 2016
Abiotic depletion, elements	kg Sb eq.	1.4E-5	CML v4.8 2016
Abiotic depletion, fossil	MJ	114.6	CML v4.8 2016
Photochem. oxidant formation	kg ethylene eq.	0.0017	CML v4.8 2016
Land use	m² crop eq.	0.27	ReCiPe 2016 (H)

The table shows the calculated values for the investigated impact categories and indicates the impact assessment method used for 1 kg of powder and two packaging options for the final product (cardboard box or big bag). It is noted that climate impacts (GWP) are reported both with and without biogenic carbon.

9 Life cycle interpretation

The present LCA study provides information of the environmental impact of the investigated PA 12 powder on a number of impact indicators (climate change, acidification, eutrophication, resource use, photochem. ozone creation and land use).

9.1 Contribution analysis

The results of the process contribution analysis are not reported here, as conclusions can be drawn from them regarding the confidential data of the suppliers. The analysis can be found in the confidential part of the report.

The contribution analysis evaluated the contribution of following process chains to the overall environmental impact.

- Primary powder production: Production of the primary powder at the primary powder manufacturing site including the associated supply chain. The supply chain was based on a cradle-to-gate analysis provided by the powder manufacturer.
- Blending/homogenization at KVS site: Electricity consumed during the homogenization process.
- Packaging of primary powder: Production of the transport packaging applied at the supplier site.
- Packaging of the PA 12 powder: Production of the transport packaging applied at the KVS site.
- Transport: Transport of the primary powder from the supplier site to the KVS site.
- Waste: Waste streams occurring in the foreground system (waste transport packaging (primary powder and PA 12 powder), waste powder after quality assurance).

In summary, the main driver of all impact scores is the primary powder production, which considerably exceeded the contribution of the other process chains. Other relevant contributions were observed for the process chains of packaging (primary powder and PA 12 powder), the homogenization process

and transport from supplier site to KVS. For quantitative statements, the reader is referred to the confidential report section.

9.2 Completeness and consistency checks

9.2.1 Completeness check

The cut-off rules have been consistently applied across the whole life cycle the PA 12 powder in order to ensure the completeness of the study (no significant cut off < 5 % of total mass and energy inputs/outputs). The loss of materials during the manufacturing processes at the KVU is very small (<0.1 % of total mass) and is not considered in this study. Increased primary powder material demand due to the additional powder used for quality assurance of each batch has been considered (~ 0.2 % additional material).

The data used for modelling the production of intermediates comes from LCA report with critical review (primary powder) and the Ecoinvent database (other), so it is assumed that completeness rules have been followed.

For transportation, the actual supply chain routes have been traced back to the suppliers and all relevant routes are included. Losses of goods due to transport (e.g. accidents, damage during transport, ...) have not been included.

The production and supply of the essential materials of the packaging of final product and intermediates have been modeled using average market processes from Ecoinvent.

Finally, capital goods for foreground processes were not considered. In general, the contribution of capital equipment can be 10–30 %, depending on the type of sector [3]. However, given that contribution to overall impact from the processing stages of the foreground system is below 5 %, the contribution of capital equipment of the foreground system is expected to be considerably less than 5 % to total impact score.

9.2.2 Consistency check

The objective of the consistency check is to determine whether the assumptions, methods and data used throughout the LCA process are consistent with the goal and scope of the study and for each alternative evaluated. In the following potential inconsistencies of the LCI and LCIA modelling are summarized.

The LCA model of the foreground system has taken into account the production of the primary powder and the homogenization process in detail, including the corresponding packaging and transport distances. It is possible

that a different level of detail has been used for the modeling of the manufacturing of the primary powder, which was taken from the LCA report was provided by the supplier.

Cut-off criteria were applied consistently across the product systems and the similar processes were omitted. Other assumptions, methods and data (have also been applied consistently to all processes).

10 Conclusions and limitations

10.1 Conclusions

The impact scores for the impact categories agricultural land occupation, climate change, acidification, freshwater eutrophication, resource use, water use, ozone depletion and cumulative energy demand have been calculated for the reference flow of 1 kg of PA 12 powder (see Table 8-1 on page 22):

Impact category – Impact indicator (cardboard / big bag)

- Climate change – incl. biogenic carbon – 5.70 / 5.75 kg CO2 eq.
- Climate change – excl. biogenic carbon – 5.60 / 5.65 kg CO2 eq.
- Acidification – 0.013 / 0.013 SO2 eq.
- Eutrophication – 0.0025 / 0.0027 kg PO4 eq.
- Abiotic resource depletion (elements) – 1.4E-05 / 1.4E-05 kg Sb eq.
- Abiotic resource depletion (fossil) – 113.9 / 114.6 MJ.
- Photochem. oxidant formation – 0.0017 / 0.0017 kg ethylene eq.
- Land use – 0.21 / 0.27 m² crop eq.

Main driver for the calculated impacts is the production of the PA 12 powder production. The blending/homogenization process itself demonstrated comparatively low contribution.

10.2 Limitations

The major limitations of the LCA are:

Due to the cradle to gate approach, the holistic perspective of LCA is limited. The use of the powder in additive manufacturing, the use of the additively manufactured product and the resulting waste streams are not taken into account.

Carbon footprints with and without carbon are provided in the report. When using these footprints further, care must be taken to avoid double counting.

When using the footprints that take into account the biogenic carbon benefit, it must be ensured that the life cycle assessment of the final product also takes into account the biogenic carbon emissions into the environment during disposal. On the other hand, when using the footprints without the biogenic carbon benefit, no climate impact due to biogenic carbon emissions should be calculated for the disposal of the final product.

The transport of the PA 12 powder (final product) from KVS to potential customer is not considered.

The production of the manufacturing equipment and infrastructure used at the KVS site was not included.

The level of detail in the LCA on the primary powder was unknown, as only the results of the impact assessment are published. It is possible that the level of detail differs between the primary powder LCA study and the present study.

The choice of investigated impact categories was limited to those published in the LCA study of the primary powder manufacturer.

The ecoinvent data have been simplified to a certain extent, e.g. they refer to average processes and therefore do not take into account any special local conditions, and in some cases only the most relevant inputs/outputs are taken into account (e.g. no goods losses are taken into account for transport processes).

11 Literature

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