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APPLICATION OF PRODUCTION SIMULATION COMBINED WITH SITE-SPECIFIC DATA TO QUANTIFY THE ENVIRONMENTAL PERFORMANCE OF AGGREGATE PRODUCTS AT FIVE PILOT SITES

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ABSTRACT

Quantification of environmental performance is becoming a frequent request from downstream customers in the construction sector. Often, this information is provided through conducting a Life Cycle Assessment (LCA) where the results are used for communication purposes in the form of an Environmental Product Declaration (EPD). This misses an opportunity to use the LCA results for internal improvements to the production system from an environmental perspective. One way to increase the value of these LCA activities for aggregate producers is to connect the LCA to quarry operation simulations, allowing estimation of where environmental impacts occur in the process. Within the EU Horizon 2020 project, DigiEcoQuarry, work is being conducted to explore the improvement capabilities that digitalisation in the production process can bring for quarries across Europe. As part of this work, an industry-specific, online platform tool has been further developed and applied to five pilot sites to capture the environmental performance of the aggregates produced, connected to tailored simulation models of the plants. The simulation model helps capture the unique conditions at each pilot site and is complemented by real data on the site-specific consumption and production for one year to provide estimates of environmental performance across multiple environmental impact categories. The tool has now been applied at all five pilot sites in the project for the base year of 2019. The results illustrate the differences in performance created by the unique conditions at each site and highlight potential areas of improvement for the producers.

1 Introduction

A larger emphasis on sustainability is leading to higher demands on companies to report environmental performance publicly in Europe, as demonstrated by the upcoming Corporate Sustainability Reporting Directive (CSRD) from the EU (European Parliament, 2022). At a product-level, this can be achieved through producing an Environmental Product Declaration (EPD) from a Life Cycle Assessment (LCA) of the product (Konradsen et al., 2023). However, EPDs are resource intensive to produce and usually only provide value for the customer rather than the producer (Marzocchini et al., 2023; Papadopoulou, 2021).

EPDs are standardised documents used as a communication tool that companies can use to provide quantitative environmental information for business customers, thus providing more value for the customer (Marzocchini et al., 2023). Within the EPD, relative environmental performance in several environmental impact categories is given for the product, which is normalised to a functional or declared unit (Svensk Standard [SIS], 2019). For aggregates, a declared unit (DU) of 'impact per tonne aggregates' is commonly used (Papadopoulou et al., 2021). The generic process for producing an EPD is given in Figure 1, consisting of seven steps, and highlights the standardisation in the process. The standards provide prescriptive guidelines for producing an EPD and the underlying LCA, and are governed by the programme operator who hosts the EPD. There are many programme operators running across Europe; among them the EPD International System, based in Sweden, is globally recognised (Marzocchini et al., 2023).

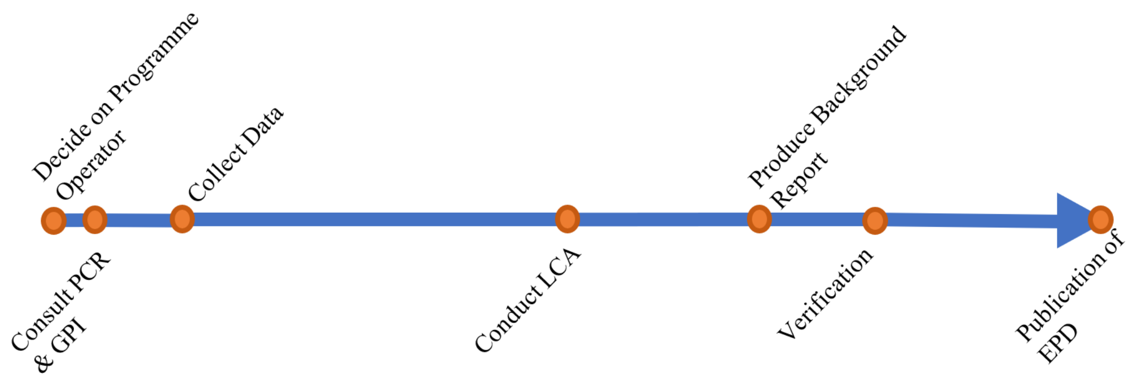

Figure 1: Overview of the generic process for producing an EPD.

Key international standards in the EPD framework are given in Figure 2, which include: standards on environmental declarations in general (ISO 14020:2000 and ISO 14025:2010), conducting an LCA (ISO 14040:2006 and ISO 14044:2006), instructions on LCA studies more specific to the programme operator (General Programme Instructions, GPI) and the product itself (Product Category Rules, PCR), and further guidelines on specific aspects related to methodology (Technical Reports, TR) or the products themselves (sub-PCR). An overview of the specific standards that are applicable for aggregate products under the International EPD System programme operator is shown in Figure 2.

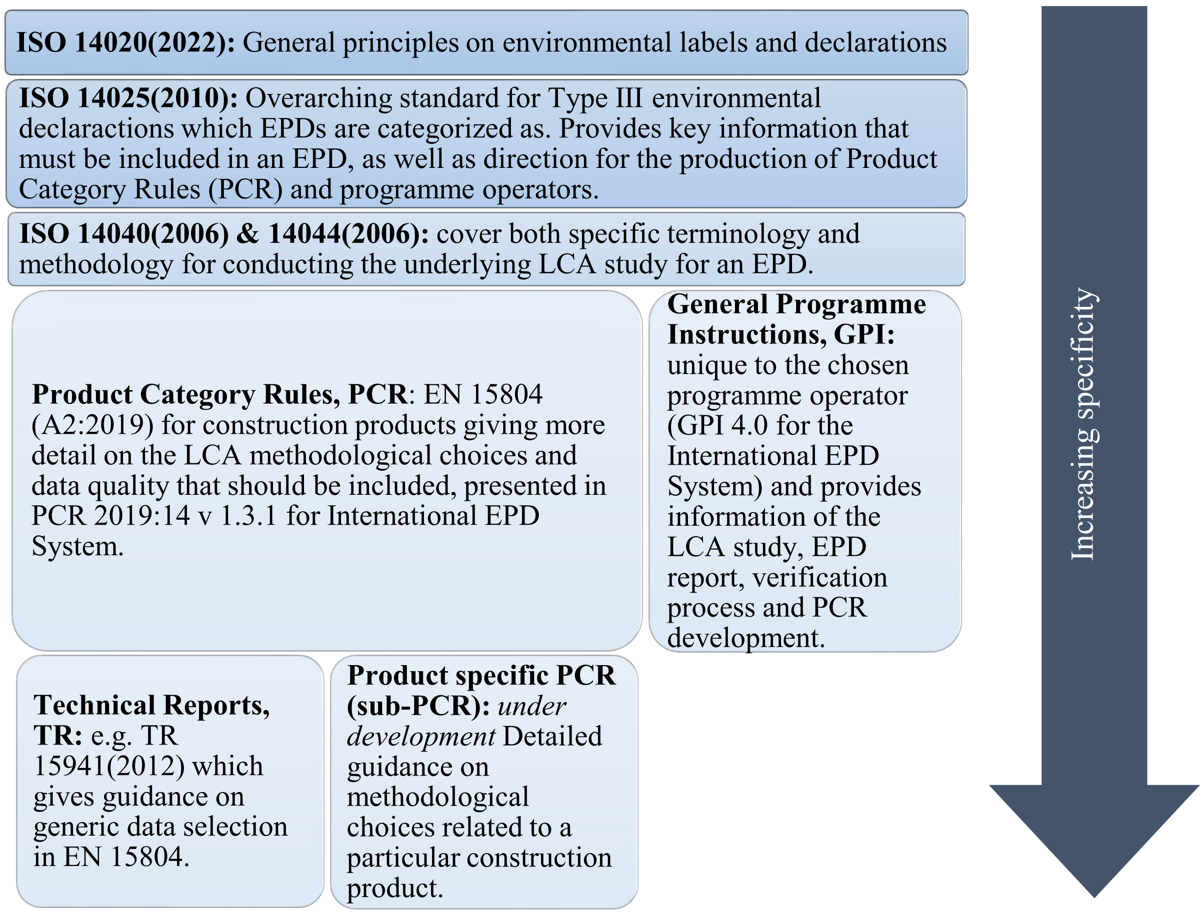

Figure 2: Overview of the hierarchy of standards applicable for the aggregate industry in conducting an EPD.

Each standard should be referred to for a detailed understanding of the prescriptive guidelines. The EN15804:2012+A2:2019 standard defines the system as multiple modules, depicted in Figure 3, specified for a generic aggregate production system. The modules cover site preparation and raw material extraction (A1), through transportation (A2), processing (A3), external transport (A4), construction (A5), use phase (B), and end-of-life of the product (C). The final module represents the benefits and loads beyond system boundaries (D).

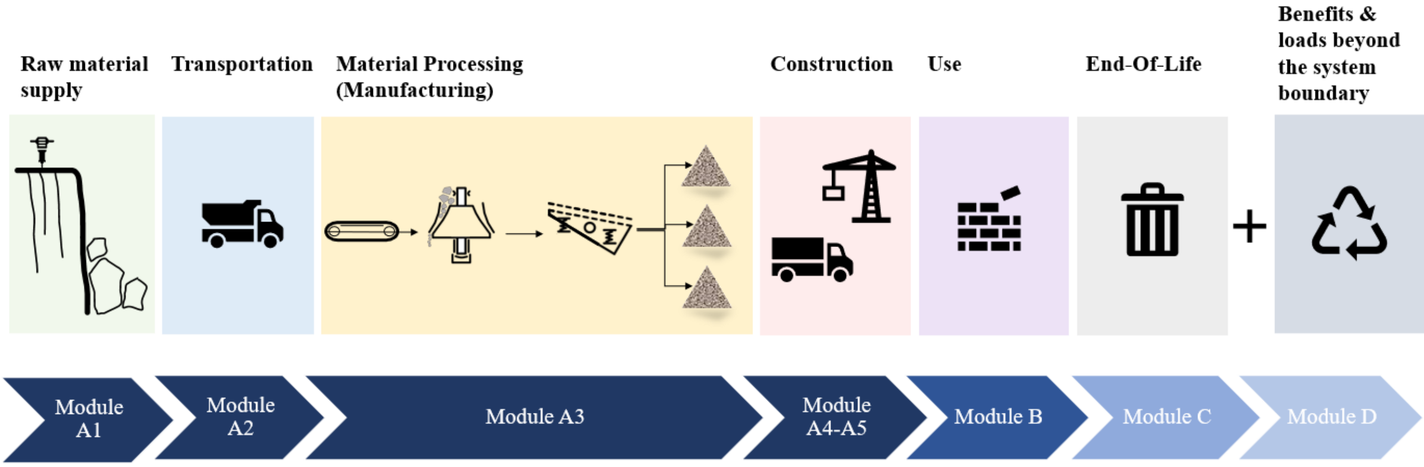

Figure 3: Flow diagram of life cycle activities for aggregates produced in a crushed rock facility and associated EN15804: 2012+A2:2019 nomenclature.

EPDs are seen to create value for customers by providing important environmental information (Marzocchini et al., 2023). However, this ignores the potential for the underlying LCA report to provide valuable insights into improved decision-making in the production system from an environmental perspective (Lee et al., 2022). To achieve this, incorporating production simulations with LCA has been suggested (Liu, 2022). With this goal in mind, work has been conducted on building an industry specific tool with integrated simulation and LCA capabilities for environmental assessment and EPD creation (Asbjörnsson et al., 2024). The tool is a web-based platform known as *Plantsmith* developed by Roctim AB (Roctim, 2023).

In this study, the tool has been applied to five pilot sites across Europe within the project DigiEcoQuarry[1], to understand the specific requirements of different aggregate production systems, and further improve the tool. New modules have been developed to meet these requirements before applying the tool to gain quantitative environmental results that can be used as part of an EPD for each site in the future.

2 Methodology

The LCA studies in the tool cover modules A1-A3, module C, and module D in line with the EN15804:2012+A2:2019 standard. To understand the individual needs of each site, the methodology shown in Figure 4 was followed in an iterative process. When modules needed to match the data collected were discovered to be missing in the tool, these were developed and implemented before the final drafts for documentation could be created. Site-specific historical data is also needed to provide high-quality results for the EPD: the same methodology as outlined in Figure 4 has also been followed for gaining the quantified environmental results for each site. The methodology consisted of six steps:

1. **Collection of yearly data on consumables and production**. High quality data can be collected from invoices, internal monitoring records, sensors, and sales data, among other sources.

[1] European Union Horizon 2020 project, grant no. 101003750. More information at digiecoquarry.eu.

Examples of lower quality data include estimations based on site conditions or data collected from other sites with similar characteristics.

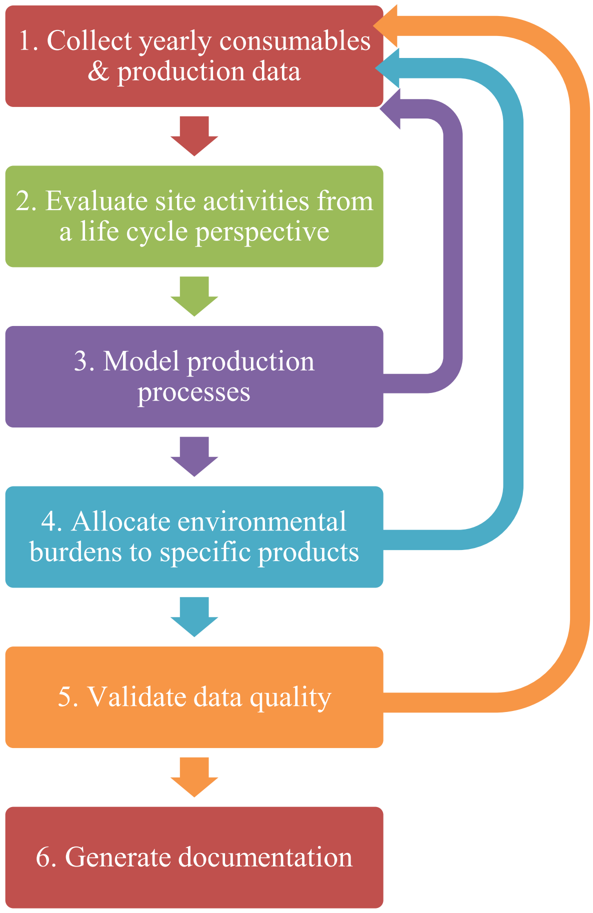

Figure 4: Methodology applied for historical data collection at individual pilot sites.

2. **Evaluation of site activities from a life cycle perspective**. Information is collected on the different activities related to the product, from its extraction to when the product leaves the factory gate. Activities after the product has left the control of the pilot site, i.e. transport to customers, construction, and the use phase have not been considered and no data collection has taken place. End-of-life and Module D activities have been estimated and modelled based on a likely scenario for unbound aggregates (NCC Industry AB, 2023).
3. **Modelling of production processes**. The information collected is then used to model the production process in the process simulation platform *Plantsmith*. For machinery that was not included in the tool at the beginning of the project and deemed relevant for the results, new models have been developed to achieve a more accurate representation of all the pilot sites included in the project.
4. **Allocation of environmental burdens to products**. Combining the data gathered in steps 1 and 2 with the model produced in step 3, the environmental burdens are allocated to the different products produced at each pilot site to give the total system inputs and outputs per product. The environmental profiles are then created using a modular LCA approach (Brondi & Carpanzano, 2011). LCA modules for each input or output have been created and stored in a database. These modules are normalised to the system inputs and outputs per product and summated to give the environmental profiles for each product. If an LCA module for an input or output was missing, this has been built and added to the tool.

5. **Validation of data quality**. All the data used for generating the models and allocating the environmental burdens is checked by the data suppliers (pilot sites) and assessed to see if any data gaps remain. At the same time, the quality of the data collected is evaluated. For new models, functionality is tested before implementation to ensure plausible results are obtained.
6. **Generate documentation**. Background LCA and EPD reports are autogenerated in Plantsmith and shared with the pilot sites to complete the interpretation phase; the final stage of the LCA methodology according to ISO 14040. If completed, the documents can be sent for third-party verification to gain and publish an EPD for the products. The templates used for the auto-generated reports have been built based on the facility type, which is inputted into Plantsmith during the modelling and added into the tool.

A new iteration of the process is triggered if a data gap analysis at the end of each step identifies missing information that prevents the process from progressing to the next step.

The generic steps for EPD creation shown in Figure 1 have been followed for the background LCA models used for EPD creation. The chosen Programme Operator for the tool is EPD International (EPD International, 2023). The operator has been chosen based on the previous development work conducted in the Sweden-based Vinnova project EPD Berg (reference number: 2019-00857) for the environmental simulation platform in Plantsmith. Within the EPD International system, the PCR for construction products, PCR 2019:14 version 1.2.5, which has been built on top of the standard EN15804:2012+A2:2019 (also applied in this project), has been followed and the GPI 3.0 for EPD International has been used. This was due to the work being conducted in Spring 2023: new updates to the standards have been released, which are in force from 2024, as shown in Figure 2. Currently, no sub-PCR is available for aggregate products under the International EPD System so no sub-PCR has been applied in this study. However, a sub-PCR is available for the EPD Norge programme (EPD Norge, 2022), and sub-PCRs for bound, and unbound aggregate applications are under development by the European Aggregates Association, UEPG, where the release date is estimated for 2024.

The historical data has been collected for the reference year of 2019, which was used to avoid capturing any anomalies associated with COVID-19 in the production process. It is important to note that the documentation generated is not verified, and, therefore, has not included the last two steps shown in Figure 2, and no published EPD is yet available for the pilot sites in the project.

2.1. Pilot Sites

The industry specific tool was applied at five pilot sites across five European countries encompassing three different types of aggregate extraction: three drill and blast quarries, one dredging quarry and one processing plant for excavated materials. A summary of the sites can be seen in Table 1 which uses the classification framework developed by Sánchez et al. (2024), where operation scale is related to the amount of product produced annually (small = under 200 000 tonnes, medium = 200 000 – 1 million tonnes, and large = over 1 million tonnes). The primary use for the aggregates produced by the sites is construction material. The size fractions each site produces varies, which should be considered in the analysis of results.

Table 1: Summary of pilot sites where the industry specific tool was implemented.

Site Reference	**Location**	**Extraction Method**	**Operation Scale**
Site 1	Portugal	Drill & Blast	Large
Site 2	Germany	Drill & Blast	Large
Site 3	Spain	Drill & Blast	Large
Site 4	Italy	Dredge	Medium
Site 5	France	Excavation	Small

2.2. Assumptions

Due to the availability of data and limitations of modelling the plants, some assumptions are made when using the tool. Information on general assumptions for all sites, along with the assumptions for each individual site, are given in the following sections.

2.2.1. General Assumptions

- The data collected for the background information originates from the Sphera Life Cycle Assessment (GaBi) 2021.2 database, where the region for electricity is the country-specific grid mix from 2018 and EU-28 for all other processes.
- The LCA module for foreground diesel consumption includes the production and consumption of 1 litre of diesel. Diesel consumption excludes transport between the refinery and the site of use. Diesel consumption is based on generic diesel combustion in a construction machine.
- The LCA module for the foreground use of explosives includes manufacturing, 300 kilometres transport distance to the site, consumption, and use of a custom detonator wire model based on the specification of an Orica detonator wire. 10g of detonator wire is estimated to be needed for every kilogram of explosive used. Background datasets in the GaBi 2021.2 database have been used for foreground emission estimates for the use of explosives based on ANFO explosives.
- Background transport is assumed to happen with EURO 4 trucks.
- All waste treatment processes include 150 kilometres of transport as a standard distance between the extraction and waste handling sites, except for inert waste rock which is assumed to be handled on site unless otherwise stated.
- Waste from ancillary materials has been divided into mixed waste for all non-hazardous materials, and hazardous waste for all hazardous materials. The disposal method is assumed to be incineration. Inert waste rock materials are considered to be disposed of as construction waste unless used in the restoration of the site itself.
- AdBlue is assumed to contain 32.5% urea and is modelled accordingly.
- Flocculants are assumed to be anionic dispersant and ethoxylate non-ionic mixtures and are modelled accordingly.
- Unit conversions are made using standardised values based on the density of the material in question. The conversion values used were as follows:
    - Diesel: 0.820 kg/l
    - Water: 0.997 kg/l
    - Oil: 0.825 kg/l
    - AdBlue: 1.088 kg/l
- No losses are experienced throughout the manufacturing process.
- Production conditions fluctuate throughout the year dependent on demand and site-specific conditions. Therefore, the steady-state conditions given in the Plantsmith model are assumed to be represent the average year scenario.
- The machinery selected within the model are technically representative of machinery found on site.
- Manufacturing of equipment and infrastructure were not included as it is assumed that they cause a nominal contribution to the impact.
- Transportation of staff members to and from the site were not included in compliance with PCR 2019:14.

- Any chemicals used for maintenance within the production process not classed as AdBlue (or equivalent) or flocculants have been summated and modelled using a generic dataset for chemicals. Similarly, metals are aggregated and modelled as steel.
- Power draw from machines that are not monitored or modelled are estimated based on site knowledge.
- Not all equipment is reflected in the model - any machine deemed to have an equal contribution to energy consumption for all products has been removed for simplicity.

2.2.2. Site-specific Assumptions: Site 1

- Products merged at storage are assumed to have an even split of the total mass when taken out at different stages of the process.
- Granulometry is estimated based on generic blast information similar to the site conditions.
- Missing datasets for water consumption have been taken from 2020 instead of 2019 and are assumed to be representative.

2.2.3. Site-specific Assumptions: Site 2

- Individual product fractions are not available and, therefore, have been modelled as aggregated products representing pre-crushing, primary, and secondary products as one group; and tertiary products as another.
- Granulometry is estimated based on generic blast information similar to the site conditions.
- All waste material is assumed to be used in restoration.

2.2.4. Site-specific Assumptions: Site 3

- Production data was only available at a group level, and, therefore, simulation data is assumed to be representative of individual product fractions within the product groups.
- Granulometry is estimated based on generic blast information similar to the site conditions.

2.2.5. Site-specific Assumptions: Site 4

- 80% of particles under 1mm from granulometry tests are assumed to fall out during extraction and fail to enter the system, remaining in the lake.
- Water content remains constant throughout the system at 5%.
- Waste rock material is assumed to be the difference in production and sales.
- Water recycled through the system has been excluded.

2.2.6. Site-specific Assumptions: Site 5

- Production data was only available at a group level, and therefore, simulation data is assumed to be representative of individual product fractions within the product groups.
- Electricity is shared between the production plant and the neighbouring cement plant and is estimated at 70% of the total share.
- Granulometry has been estimated based on simulated production and generic information on excavated material.
- Diesel consumption during extraction is conducted by the supplier of the material where no data is available at this time. The consumption has, therefore, been estimated based on a Volvo

L180H wheel loader carrying 11.66 tonnes in one load taking 7 minutes to excavate and move where:

$$F = \frac{F_e T_s}{vd}$$

Where F represents diesel consumption in litres/tonne, F_e represents the fuel efficiency in litres/hour, T_s represents the extraction time in hours, v represents the volume of the bucket in m^3, and d represents the bulk density of the material in tonnes/m^3.

- Diesel consumption in transport to and from the site is conducted by contractors where precise data is currently unavailable. Therefore, consumption has been estimated for source material and waste material using SBMI emission factors and the perfect combustion of diesel of 0.037kg/ton-km, based on a transport distance of 25km to site for incoming material, and 50km from the site for waste material.

3 Results

The results of the LCA give quantitative estimates for environmental impact in 38 different impact categories, based on the results of the Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA). The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks. The characterisation models included in the EF 3.0 have been used, in line with EN 15804:2019. The results for the 32 compulsory impact categories from the programme operator, EPD International, are given for each pilot site for Modules A1-A3 in Table 2. The results are displayed for the average of all products produced in 2019 for the declared unit of one tonne of aggregate product.

For a more comprehensive overview of the assessment, the results for six impact categories that connect with some of the main KPIs of the DigiEcoQuarry project have been chosen and are presented in Figure 5 for each pilot site for modules A1-A3. These include: GWP – total, AP, EP – marine, POCP, WDP, and Non-hazardous waste disposal (NHWD). All results have been benchmarked against the Spanish Sector EPD for natural aggregates (Federación De Áridos, 2022). This has been chosen due to its representation of over 300 quarries.

Lastly, the process resulted in the development of several new models for various components of the *Plantsmith* platform. To understand where new models have been developed, a schematic of the tool is presented in Figure 6 which shows the modular structure of the platform and how the different modules relate to different steps in the workflow for using the platform. Tool components that were developed based on the needs of the sites included: new LCA modules for flocculants, inert waste rock, and country-specific electricity; new report templates specified to the facility type, namely drill & blast facilities (crushed rock), dredging facilities, and natural gravel facilities; and new generic machine models for a HSI crusher, dredger, hydrocyclone, and pump. Models identified but deemed non-essential where already existing specifications could be used as proxies included: LCA modules for petrol and gas for which diesel was used as a proxy considering the small amounts consumed at the sites; and machine models for four-deck screens and vibrating screens where existing screen models were used as a proxy. The simulation modules for allocation were also updated and improved to distinguish between product allocation in A3 and lifecycle allocation between A1-A3.

Table 2: Results for all pilot sites for 32 compulsory impact categories according to EPD International for modules A1-A3

		Total for A1-A3 (Production including Extraction (A1), Transport (A2) and Manufacturing (A3))				
Indicator	**Unit**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**
Potential environmental impact for mandatory indicators according to EN 15804						
GWP-fossil	kg CO_2 eq.	1.46	3.91	2.01	2.64	1.07e+1
GWP-biogenic	kg CO_2 eq.	8.03e-3	2.86e-2	1.53e-3	4.74e-2	1.10e-1
GWP-luluc	kg CO_2 eq.	7.68e-3	1.84e-2	1.30e-2	5.63e-3	6.22e-2
GWP-total	kg CO_2 eq.	1.47	3.96	2.03	2.7	1.09e+1
ODP	kg CFC 11 eq.	1.59e-11	4.38e-11	1.35e-11	4.89e-9	6.01e-9
AP	mol H^+ eq.	8.35e-3	1.74e-2	1.19e-2	7.52e-3	5.48e-2
EP-freshwater	kg PO_4^{3-} eq.	1.09e-5	5.55e-5	1.55e-5	8.12e-5	2.70e-4
EP-freshwater	kg P eq.	3.64e-6	1.85e-5	5.17e-6	2.71e-5	9.00e-5
EP-marine	kg N eq.	3.73e-3	7.76e-3	5.34e-3	3.00e-3	2.45e-2
EP-terrestrial	mol N eq.	4.33e-2	8.85e-2	6.17e-2	3.29e-2	2.69e-1
POCP	kg NMVOC eq.	8.29e-3	1.57e-2	1.08e-2	7.31e-3	5.22e-2
*ADP-minerals & metals**	kg Sb eq.	4.33e-7	6.87e-7	3.43e-7	6.26e-6	8.50e-6
*ADP-fossil**	MJ	2.04e+1	5.18e+1	2.87e+1	3.83e+1	1.54e+2
WDP	m3	6.36e-1	2.15e+1	3.33e-1	8.63	1.79e+2
Potential environmental impact – additional mandatory and voluntary indicators						
GWP-GHG	kg CO2 eq.	1.43	3.85	1.97	2.62	1.05e+1
Use of resources						
PERE	MJ	4.64	1.56e+1	3.82	2.33e+1	1.19e+1
PERM	MJ	0	0	0	0	0
PERT	MJ	4.64	1.56e+1	3.82	2.33e+1	1.19e+1
PENRE	MJ	2.04e+1	5.19e+1	2.88e+1	3.83e+1	1.54e+2
PENRM	MJ.	2.05e-8	4.22e-12	4.19e-13	1.87e-5	2.31e-5

PENRT	MJ	2.04e+1	5.19e+1	2.88e+1	3.83e+1	1.54e+2
SM	kg	0	0	0	0	0
RSF	MJ	0	0	0	0	0
NRSF	MJ	0	0	0	0	0
FW	m^3	1.45e-2	5.07e-1	6.29e-3	2.04e-1	4.18
Waste production						
Hazardous waste disposed	kg	7.78e-8	3.26e-8	3.02e-9	1.31e-7	2.17e-6
Non-hazardous waste disposed	kg	5.52e+1	5.00e+2	6.17e+1	6.97e+1	2.22e+2
Radioactive waste disposed	kg	1.68e-4	1.45e-3	6.67e-4	1.26e-3	6.56e-3
Output flows						
Components for re-use	kg	0	0	0	0	0
Material for recycling	kg	0	0	0	0	0
Materials for energy recovery	kg	0	0	0	0	0
Exported energy, electricity	MJ	0	0	0	0	0
Exported energy, thermal	MJ	0	0	0	0	0
Acronyms	GWP = Global Warming Potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential; EP = Eutrophication Potential; POCP = Formation potential of tropospheric ozone; ADP = Abiotic Depletion Potential; WDP = Water Deprivation Potential, PERE = Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total use of renewable primary energy resources; PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM = Use of non-renewable primary energy resources used as raw materials; PENRT = Total use of non-renewable primary energy re-sources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non-renewable secondary fuels; FW = Use of net fresh water					
1	The indicator includes all greenhouse gases included in GWP-total but excludes biogenic carbon dioxide uptake and emissions and biogenic carbon stored in the product. This indicator is thus almost equal to the GWP indicator originally defined in EN 15804:2012+A1:2013.					
*	Disclaimer: The results of this environmental impact indicator shall be used with care as the uncertainties of these results are high or as there is limited experience with the indicator.					

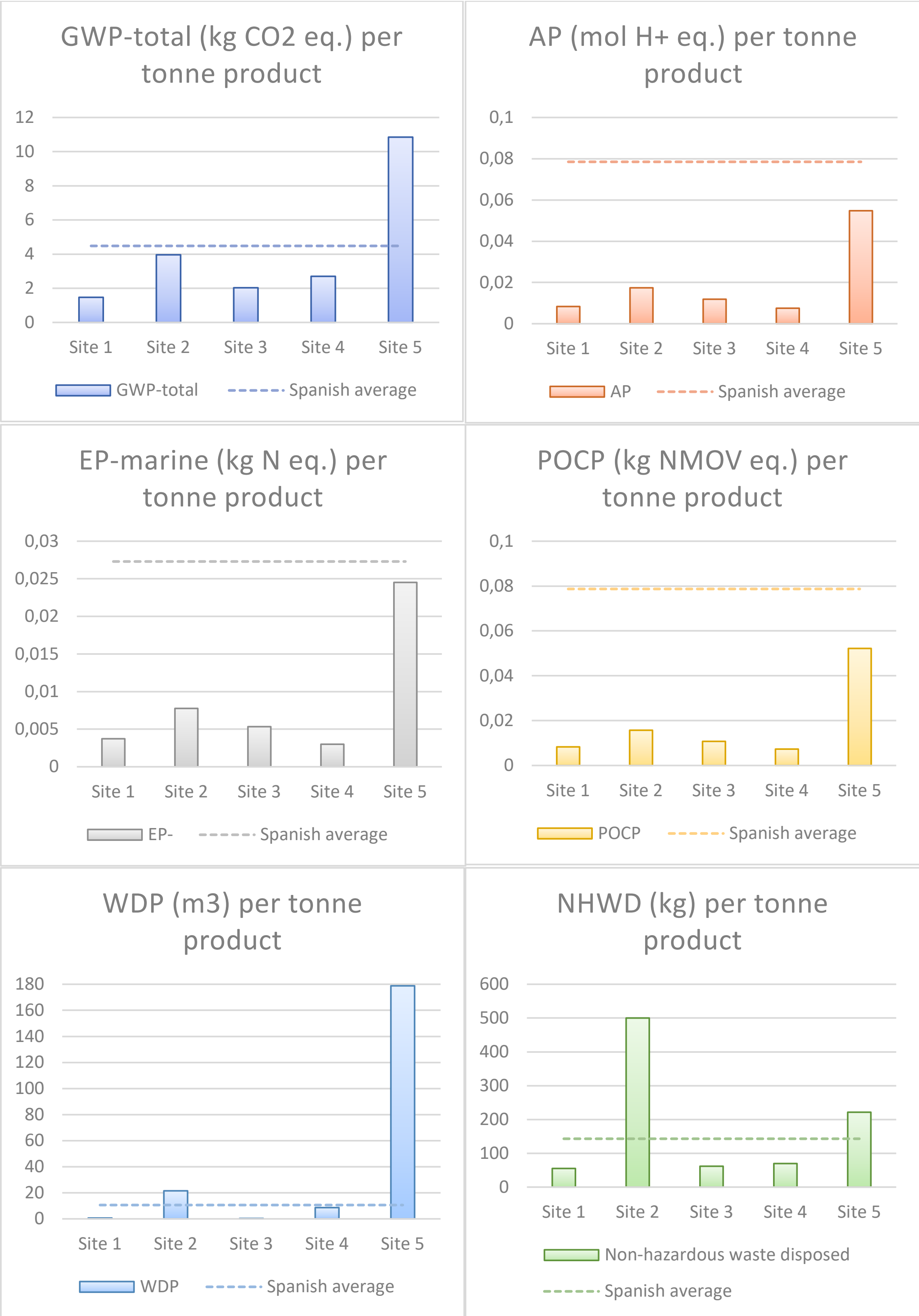

Figure 5: Results for all five pilot sites for module A1-A3 in six chosen impact categories: Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Photo-chemical Ozone Creation Potential (POCP), Water Depletion Potential (WDP), and Non-hazardous Waste Disposed (NHWD).

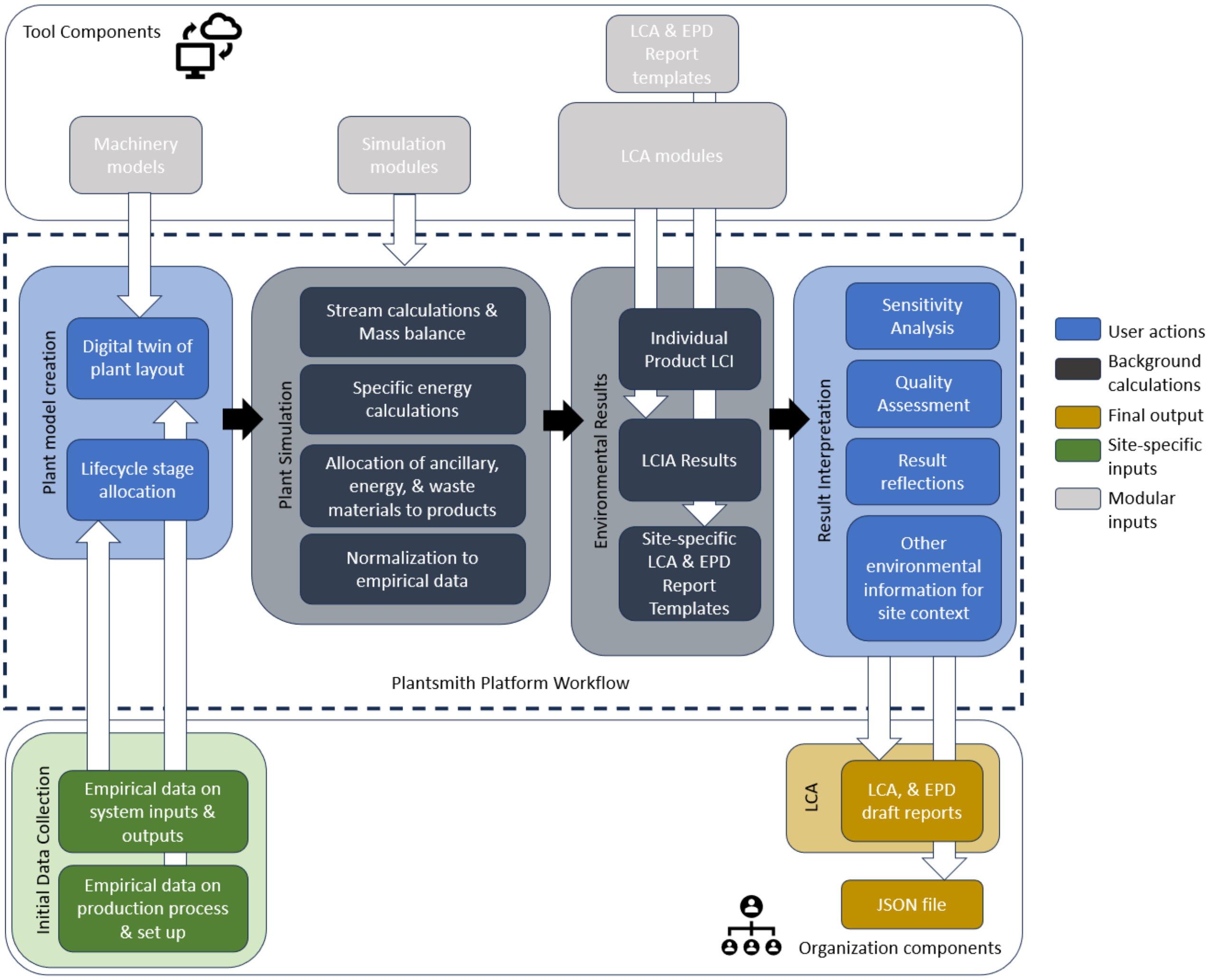

Figure 6: Schematic representation of the modular structure of the tool.

4 Discussion

Within the DigiEcoQuarry project, methodologies have been developed for conducting site-specific LCA studies, aimed at generating EPDs. These methodologies, integrated with process simulations, have been applied in all five pilot sites, resulting in the creation of product-specific EPD documentation for further interpretation. However, it is important to note that this EPD documentation has not yet undergone third-party verification and, as such, cannot currently be considered as valid EPDs. To achieve this, more work to support users in the ‘Interpretation phase’ of the Plantsmith workflow is recommended. Additionally, the process has identified certain gaps in environmental information not covered by the LCA, underscoring the need for a more comprehensive approach to understanding the specific environmental concerns at each site. To overcome this, the framework developed by Sánchez et al. (2024) has also been applied in the project to provide further contextual environmental information for each site, and it is recommended that future LCA studies be complemented by other methods to capture these concerns.

The results from creating the EPD documentation provide a benchmark for each quarry to evaluate improvement actions as the project progresses, thus allowing producers to gain more value from the assessment. Part of realising this extra value is ensuring that producers access and use this data. To utilise this information further for improvements, the project is providing monthly updates through a digital platform known as the IQS (Innovative Quarry System) to gather and present data related to the environmental performance of the products.

For most impacts, the pilot sites are below the Spanish average, suggesting that these operations are already applying best practices when it comes to environmental aspects. However, some differences can be country-related, especially considering that country-specific electricity mixes were used for the sites. For a more valid benchmarking of performance, further investigation is suggested for each site to compare with other quarries within their country. Water Depletion Potential and Non-Hazardous Waste Disposal are areas where some of the sites did not perform as well; however, these are both target areas for the project, and will be important to assess if better practices are realised in the project through the implementation of new technologies or awareness.

Significant variation can be seen between the sites within the six categories assessed. Examining the results for different sizes of quarries and types of quarries also shows a relevant variation in environmental performance at a product level. It can indicate that a similar effect for economies of scale can be seen for environmental savings in quarries, i.e. larger productions lead to efficiency gains and cost savings. The type and size of the quarry could also be an influencing factor when comparing the environmental performance of aggregate products, considering the significant variations seen. However, as the same division of pilot sites is seen for size and type, it is not possible to determine the individual contribution of each one of these factors. The small number of pilot sites involved in the project also means that no conclusions can be made at a broader level at this stage. Nevertheless, the results can help indicate what challenges are apparent for the different quarries, providing guidance for future actions in the upcoming phases of the project. It also suggests that comparing sites of different natures can be difficult due to the uniqueness of each operation.

The quality of the data also differs between sites; however, all sites have been able to provide site-specific information for both the system inputs and outputs and the production process, giving an overall high quality to the data. As the same methods and generic datasets have been used in creating the LCA modules, thus reducing variation due to methodological choices, the results between pilot sites can be more comparable than those for general EPDs (Konradsen et al., 2023). However, this may reduce the representativeness of the results compared to the reality at the site.

Certain assumptions due to limitations on the data and models themselves have been made which can affect the accuracy of the results. These should be considered before any further interpretations are made.

Site 5 is the only site where external transport occurs as part of A2 and also has some of the largest environmental impacts. This supports previous assessments that transport is a critical aspect of the environmental performance of aggregate production and should be considered carefully by consumers and city planning for production locations close to urban hubs. The inclusion of A4 in future assessments is encouraged to help provide more information for actors involved.

There is still room for improvement in the methodology and tool itself to increase the accuracy of the results, for example where proxy models have been used. When using the quantitative results on environmental performance to assess improvements in the production system, any changes in the methodology and tool should be evaluated separately to determine whether changes to environmental performance result from methodological changes or actions at the individual quarries.

5 Conclusions

Plant models were completed for all five pilot sites in the tool Plantsmith. Site-specific data collected by the pilot sites could be connected to the production models and provide estimates for 38 environmental impact categories. Documentation has then been provided to each pilot site for the identified product groups, based on their similar environmental impacts. This documentation can be the basis for creating an EPD, if further interpretation and verification steps are completed. Supporting producers through this interpretation step is an area identified for improvement in the tool.

The applied methodologies have identified challenges for the producers in data collection. Using digitalisation solutions within the DigiEcoQuarry project can be a way to overcome these challenges, and work has been conducted towards building and applying these solutions in the project. The process has also helped identify areas for improving the tool and methodologies. The knowledge gained from the development so far has helped define a modular structure to the tool which will help guide development within the coming phases of the project to maximise the benefit of solutions for the producers. The structure can also provide a framework for other industries in developing similar tools.

The quantitative environmental data obtained through the production of the EPD documentation can be used to identify and assess any improvements to the production system at specific sites and provide value for the producers. However, a clear distinction must be made between variations in the results that occur due to methodological changes in the tool and those as consequences of actions and solutions implemented at the quarries in later stages of the project.

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