

Deliverable D4.4

Report on multi-purpose laser processing and production strategy-decision tool

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Executive Summary

This deliverable presents the development of a decision-support tool aimed at optimizing multi-purpose laser processing strategies with a focus on environmental, economic, and technical aspects. The tool builds on the results of D4.1, D4.2, and D4.3, which provided insights into the environmental impacts and costs associated with the laser manufacturing technologies Laser Powder Bed Fusion (LPBF), Directed Energy Deposition (DED), and Laser Surface Texturing (LST).

The decision-support tool is designed to assist users in making informed decisions by providing recommendations to reduce material waste, improve energy efficiency, and minimize environmental impacts. The tool will be integrated into the DILAFACT software and will evolve over time, starting with a minimum viable solution that offers basic predictions of energy, gas, and material consumption. Future iterations will include more advanced features, such as Life Cycle Assessments (LCAs), Life Cycle Costing (LCC), and balancing trade-offs between cost, quality, and environmental impact.

A proof-of-concept for the minimum viable solution has been developed in Excel, demonstrating the feasibility of the tool's basic functionalities. However, the accuracy of predictions depends on user feedback to build and continuously improve an environmental database. Further development will focus on integrating the tool into DILAFACT, enabling multi-technology balancing and expanding its capabilities to support more complex decision-making when the DILAFACT software evolves.

This deliverable highlights the potential of the decision-support tool to promote sustainable and efficient laser manufacturing while adapting to the evolving needs of the DILAPRO project.

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List of Abbreviations

WP	Work Package
AM	Additive Manufacturing
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
DED	Directed Energy Deposition
LPBF	LPBF
UC	Use Case
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PL	Pilot Line
LST	Laser Surface Texturing

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1. Introduction

This deliverable is the final deliverable of WP4. It builds upon D4.1 to D4.3 and incorporates their results to give inputs to DILAFACT. The goal of this deliverable is to draft a decision support tool within DILAFACT to enable the user of the software to make environmentally conscious decisions.

D4.1 laid the groundwork for the LCA within DILAPRO, as goals were defined and systems were sketched out, as well as overviews of the different pilot lines were created.

D4.2 investigated methods to measure the environmental impact of the use cases and structured the data collection. Further definitions were made and definitions made in D4.1 were refined.

D4.3 contains the report on the LCAs and LCCs performed on four selected use cases within DILAPRO. Based on the results and a literature review, different recommendations for the pilot lines could be given. Most of the recommendations can likely be applied to similar manufacturing setups. Below is a short summary of the main findings of D4.3.

The main conclusion for LPBF was to utilize the build space and print as many parts as possible in the same build job, to be able to allocate consumables to as many parts as possible and thereby reduce the environmental impact per part. Additionally, the LCA revealed that PL3 had a higher material efficiency, while PL4 was able to produce parts with a significantly lower amount of gas. This led to different recommendations for those PLs. PL3 should investigate the sealings and whether printing with a lower gas consumption would still be possible. PL4 should consider installing a cyclone, similar to PL3, to reduce the amount of material that gets trapped in the filters. Based on the literature review, additionally, the introduction of higher layer heights should be considered, as it is directly related to the build time and therefore the energy and gas usage (Obeidi et al., 2024). Other methods to save material, for example, the design of lighter support structures could additionally reduce the amount of material wasted in LPBF. This shows that there are some recommendations, which are equipment based and some which are process based.

The laser surface texturing (LST) process itself had a rather low environmental impact. However, faster processing could potentially reduce energy consumption during the process, and the considerate use of isopropanol during ultrasonic cleaning, or its substitution with another alcohol with a smaller environmental impact, could further reduce the environmental impact. If feasible, the production of the semi-finished product should also be improved in terms of environmental impact, but that is outside the scope of DILAPRO.

For DED, there were again some equipment-based and some process-based recommendations. Installations like a powder switch can help to reduce powder waste. Gas usage should be carefully considered, and if possible, the use of shielding gas should be omitted. If shielding gas is required,

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proper sealing should be ensured. If a build plate is required, the design should be adapted so that the build plate can be reused. If a build plate is required, adapting the design in such a way that the build plate can be recycled should be considered. To reduce energy, and possibly gas consumption, trajectories should be optimized to reduce build times. Higher deposition rates could lead to additional savings in terms of energy and consumables.

Besides the processing with only one laser processing method, DILAPRO additionally wants to investigate multi-purpose laser processing. Multi-purpose laser processing refers to the usage of one or multiple lasers in a sequence to achieve different properties of a part. For example, a part could first be produced by laser-based AM technology and in a subsequent process step the surface could be altered using LST. Here, both, the use of different sets of laser processing equipment or the use of the same laser processing equipment for multiple processing steps could be possible, depending on the capabilities of available equipment. However, as the focus was first placed on the fundamental understanding of relations between parameters and environmental impacts, only single-purpose laser processing was analyzed by means of LCA and LCC within DILAPRO. Nevertheless, over the course of development to the DILAFACT software, the strategy decision support tool described in this deliverable should be able to develop further to balance between laser-based AM processing parameters and subsequent laser processing steps from an environmental and economical point of view. Here, an example could be the production of a part with a laser AM strategy with economic and environmental efficient process parameters and adding in a laser post-process such as laser shot peening to achieve the required surface quality. The tool would then evaluate and compare different production strategies, balancing the use of more environmentally friendly process parameters during the primary laser AM process (e.g., larger layer heights that reduce material and energy consumption) with the addition of a subsequent laser post-processing step, such as laser shot peening, to achieve the required surface quality. This comparison would consider the environmental and economic impacts of each option, enabling users to select the most sustainable and cost-effective strategy. The addition of traditional post-processing technologies would also be a valuable consideration for future development.

Based on the strategies identified above, this deliverable develops the framework for a decision-support tool for optimizing laser processing and production strategies from an environmental point of view. The tool is designed to optimize laser processing strategies by integrating environmental, economic, and technical considerations. Building on the findings of D4.1–D4.3, the tool provides actionable recommendations for reducing material waste, improving energy efficiency, and minimizing environmental impact. Initially, the tool focuses on individual additive manufacturing (AM) technologies, LPBF and DED, with LST as a potential add-on. In the future, as the DILAFACT software evolves to include additional techniques and capabilities, the tool will expand to incorporate multi-purpose laser processing strategies. This will enable users to explore

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environmental opportunities across combined processes, such as balancing LPBF production parameters with subsequent LST or thermal treatments. Further down the line, WP7 will also explore the possible addition of non-laser external post-processing technologies. Such integrations have the potential to further optimize resource use and environmental performance. The tool will thus scale and adapt to support increasingly complex and sustainability-focused decision-making for multi-purpose laser processing.

2. Methodology

D4.1 to D4.3 show that most laser processing technologies considered within DILAPRO, especially LPBF and DED, have a considerably high environmental impact. Additionally, due to non-optimized processing strategies, an additional cost in production might be added. However, there is potential for improvement, both in terms of equipment and in terms of processing strategies. These must be communicated clearly with the user of such technologies. At the same time, it should be easy for users to benchmark the environmental impact against the quality of a to-be-manufactured product.

The decision-support tool is designed to enable users to make informed decisions regarding laser processing and production strategies by integrating environmental, economic, and process optimization considerations. It builds on the findings from D4.1 to D4.3 and aims to provide a structured, user-friendly framework that supports the evaluation of trade-offs and the identification of optimal parameters for laser processing. The description of the development of the decision support tool will mainly use LPBF as an example, a central manufacturing technique in DILAPRO, to keep the deliverable comprehendible. However, the methodology developed in this deliverable is also applicable to DED and it will also lay the groundwork for how to consider the addition of other laser AM techniques and subsequent laser processing techniques, from an environmental point of view, and the benefits that may arise from this.

Due to the different processing methods of each laser-based AM technology, it was decided that separate tools should be developed for each technology. LST was mainly viewed as a post-processing strategy for AM based parts. Therefore, this will be considered as an add-on to the two main technologies DED and LPBF investigated within DILAPRO. However, it is expected that a similar methodology will be applicable when developing tools for strategy decision support within LST and other laser processing technologies.

One of the objectives of DILAPRO is to enable multi-purpose laser processing by combining different laser technologies. In future iterations of the decision support tool, it could become possible to balance the environmental impacts of optimizing processing parameters versus avoiding or minimizing post-processing steps, such as thermal laser surface treatment, LST, or heat treatment. However, since no tests or validations have been performed on this aspect within

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WP4, this deliverable instead sets the stage for further development in Task 7.1 by providing recommendations to guide the creation of this module.

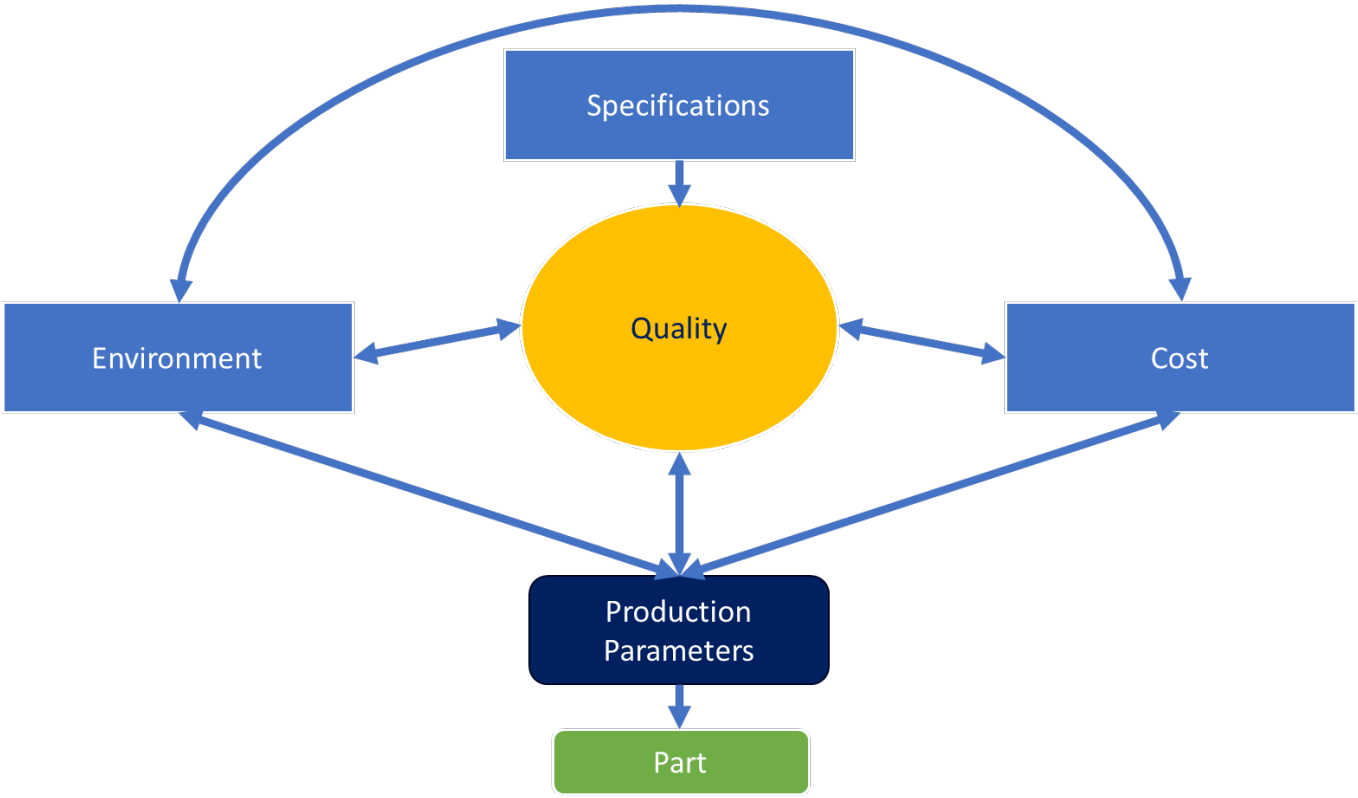


Figure 1 The "problem" addressed by the decision support tool: Quality, as defined by the specifications of the part will influence the range of the production/process parameters. This tool should help the user to find the sweet spot that balances environmental and financial impacts within this range, however, all factors and the process parameters will influence each other.

Figure 1 illustrates the problem that should be addressed by the decision-support tool. The concept of the tool is developed in a stepwise approach to ensure it is both robust and user-friendly. First, the key results of D4.1 to D4.3 were identified and split into process-based and equipment-based recommendations. While the software cannot make sure that certain equipment is in place or that the environmental impact is considered when making a purchasing decision, it could include e.g. energy and material usage predictions based on processing parameters when balancing environmental impacts, cost and quality.

Through multiple discussions amongst the project partners, different ideas of an output of the tool were developed. Minimum required capabilities and maximum desired capabilities were discussed and based on these, the framework in this deliverable was developed. However, the final capabilities and outputs will also depend on the capabilities and structure of the DILAFACT software developed in WP7 and the input the user is able to give.

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Potential users of the decision support tool were identified for systems development. The end users are overlapping with the users of DILAFACT software, which during the development phase will be represented by mainly the PL owners and consortium members of DILAPRO. The LASER community will also be exploited for this, especially during workshops. However, once the software has been launched, production engineers and decision makers in the production process are the potential end users. As the decision support tool aims to reduce environmental impacts of laser processing technologies, policy makers might be interested in its output as well.

Based on the desired outputs and capabilities, the required input was defined. Some of the desired features rely on the capabilities of the digital twin. Finally, the framework of the decision support tool was defined.

3. Desired capabilities and outputs of the decision support tool

3.1 Different output scenarios

To design the possible output of the decision support tool, the results of the LCA and LCC in D4.3 were summarized as follows:

1. Utilize the entire build space to save time and consumables/energy/material per part
2. Check sealing and gas usage
3. Implement powder recycling strategies such as powder switches or cyclones
4. Optimize laser paths or trajectory to reduce processing time and energy consumption
5. Choose semi-finished parts/powder considering the environmental impact
6. Use greater layer heights or deposition rates to increase efficiency
7. Powder or semi-finished part, energy consumption and gas consumption contribute the most to the finished part, excluding depreciation, maintenance, labor, etc. However, the percentages will vary depending on the technology
8. Simulations reduce scrap rates and therefore minimize material consumption.

It was identified that 1., 4., and 6. are processed based and could therefore be implemented in a process optimization strategy tool. Results 2., 3., and 5. are equipment based and cannot be implemented by a processing strategy optimization software. Result 7. indicates where the main impacts are and, hence, where efforts should be focused on. Result 8 supports the use of simulations in general but cannot be implemented into the decision support tool directly. These results were presented and discussed within WP4.

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Based on discussions with the PL owners and participants of WP4, different output scenarios were developed, with different capabilities regarding reporting and recommending, as shown in Figure 2. However, since DILAFACT aims to be developed as scalable software, these scenarios are also built on top of each other, so when developing further it should be possible to proceed from the minimum to the best-case solution.

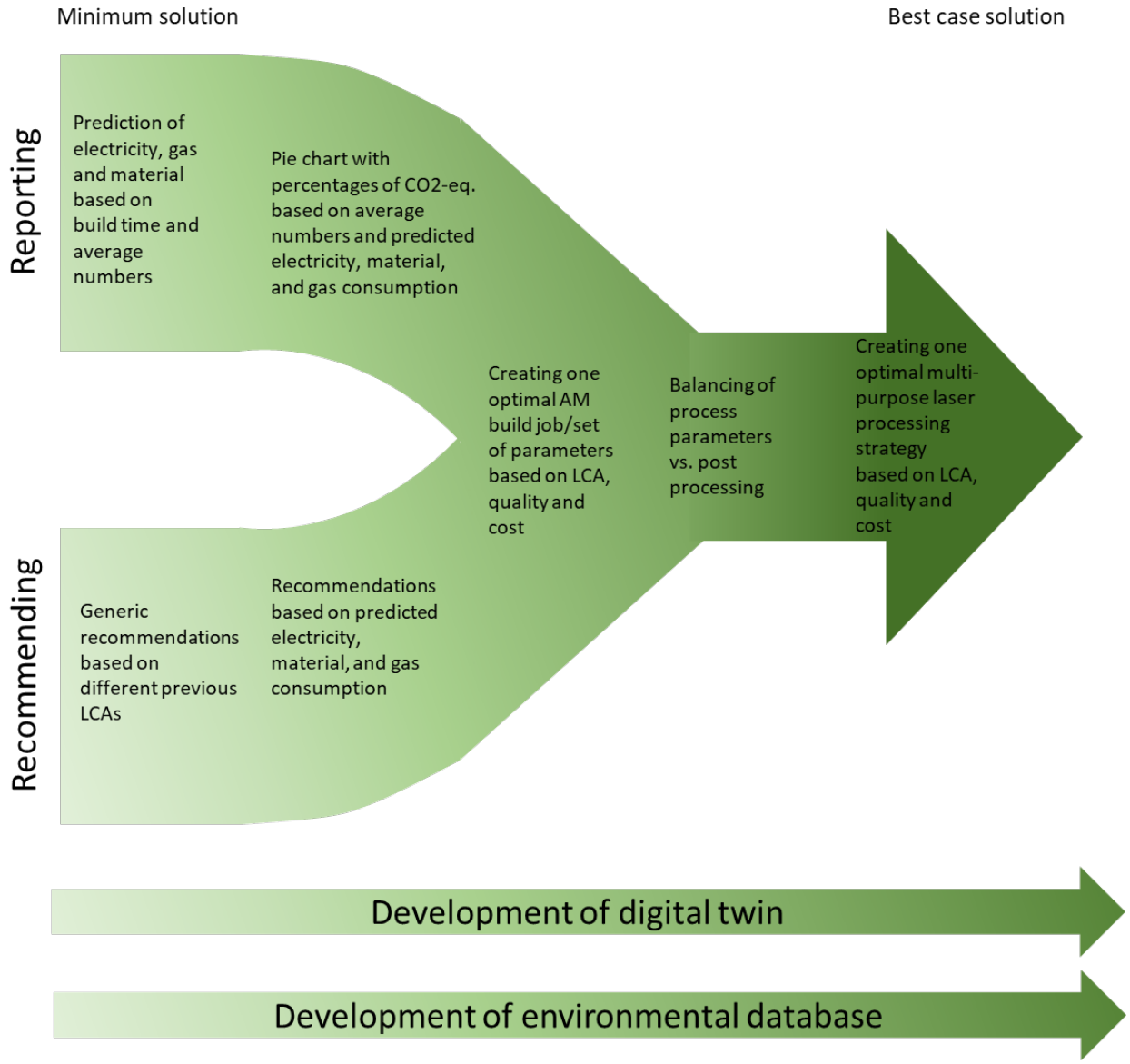


Figure 2 Different reporting and recommending capabilities of the environmental decision tool to develop over time depending on the development and capabilities of the digital twin and environmental database towards multi-purpose laser processing within the DILAFACT software.

The minimum viable solution should include pie charts of the contribution to the GWP of energy consumption, the material consumption and the gas consumption for visualization purposes. This could indicate where out of these three, the impact is the highest and where improvement

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therefore is expected to have the highest impact. However, these pie charts will not constitute a full LCA, and to avoid the users misinterpreting and misrepresenting the output as such, the pie charts will not contain any CO2e numbers but only percentages as they are only aimed at visualization. An example of this is given in Figure 3. Based on a predicted processing time and mass of material required for support structures, certification coupons and parts for different production parameters by the digital twin, the tool could be able to predict energy consumption, material consumption and gas consumption based on average values and e.g. the laser path. The predicted values could be used to predict the price of electricity, gas and material per part based on user inputs more precisely than in the minimum solution. For recommendations, this solution could be able to give general rules of thumb based on the LCA work in DILAPRO (see the eight points above), maybe in the form of a pop-up window. These rules could include both process- and equipment-based recommendations, like installing a better powder recycling system or investigating the impact of the semi-finished materials used in the process.

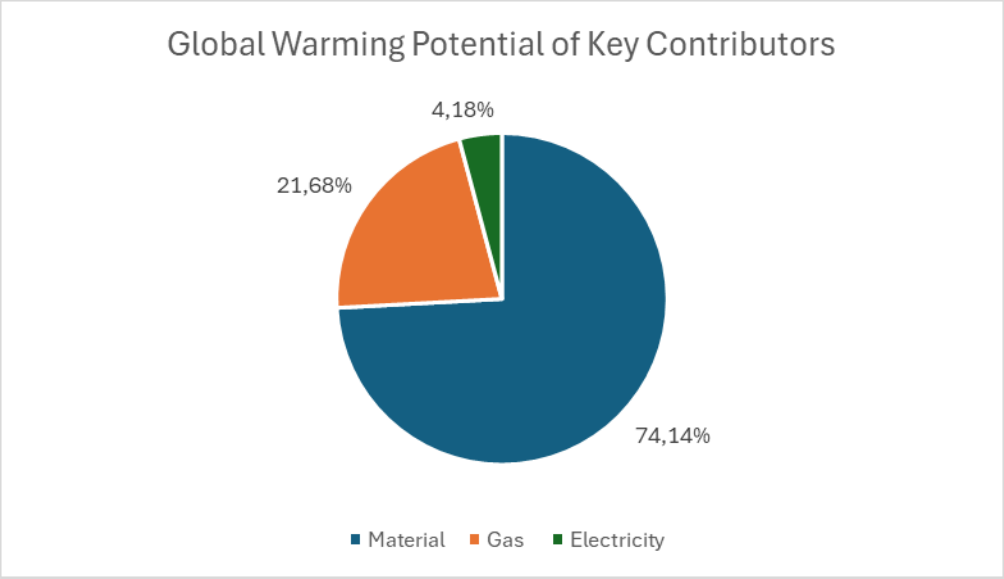


Figure 3 Example of potential visual feedback to the user in the simplest version of the decision support tool.

Intermediate solutions could be more detailed and therefore report on i.e. how much money or CO2-eq. could potentially be saved when implementing (some) of the strategies. Additional consumables, such as recoater lips or the build plate could also be considered. Later, the tool should be able to give more concrete recommendations on how to balance quality, cost, and environmental impacts on the specific use case. Additionally, in the cost module it should be accounted for those things and e.g. the depreciation of the machines. A development in the digital twin and the extension of an environmental database will additionally improve the predictions made by the tool. Maybe new, more precise strategies to predict, e.g. energy consumption by the laser path instead of purely average numbers, could increase the reliability

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of the tool. However, these developments are, as mentioned, highly dependent on how the digital twins and the environmental database develop.

In the best-case output scenario, the software would be able to perform LCAs and LCCs of several different production strategies, including balancing out processing parameters of the main laser-production strategy and potential laser post-processing strategies such as LST or laser peening (multi-laser processing). It should consider inputs by the user as well as inputs from the digital twin, simulations and databases to feed back into the software and define the proposed strategy, while balancing quality, cost and environmental impact. It would therefore find the optimal point for cost and environmental impact within the parameter interval defined by the specifications and quality requirements, and balance where i.e. post-processing is needed and where it can be avoided by optimizing the laser production strategy, while considering the environmental impact of both. A particularly interesting case of multi-purpose laser processing would be if it was possible to use the same laser for different applications, i.e. perform laser thermal treatment of a recent AM produced part. The output in this case would be one optimized laser processing strategy with the respective parameters and a brief overview of CO2-eq. numbers and contributors. Depending on the development of the digital twin, this could fully integrated solution could also consider the build space utilization and optimize the orientation of parts on the build plate. However, as the capabilities of the DILAFACT software are not fully defined yet, this is difficult to predict and develop. Furthermore, multi-purpose laser processing with one laser is a methodology under development and therefore requires further research. Within DILAPRO, for example, there are fatigue and hardness tests on LST processed parts planned. The results could give valuable insights into further development of the decision support tool. Another valuable addition to the strategy decision support tool could be the inclusion of traditional post-processing methods, such as traditional machining or heat treatment, enabling the user of the software to use equipment present in their workshop. This is, however, out of the scope of DILAPRO.

Additionally, the system boundaries of the analysis performed by the tool were discussed and agreed on. While the initial idea was to follow the system boundaries of the LCA in D4.3, some additional exclusions were made for the tool, to reduce the amount of data required and focus on the laser manufacturing process. Therefore, the transportation of products, consumables and semi-finished products to and from the production side should be excluded, as well as the impact of the semi-finished parts in LST and the powder in DED and LPBF. The tool will not be able to influence the impact of these and due to a lack of data and the use of generic data, the tool would not be able to compare powders/semi-finished parts from different manufacturers. The inclusion of especially powder manufacturing in the future would be most interesting, but requires that powder manufacturers start performing LCAs, which are currently not available. Next, it was decided to include testing for certification in the tool, despite only generic data being available,

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as this might be a valuable feature to showcase the impact of digital certification by means of DILACERT. Furthermore, similar to the LCA in D4.3, the process finalization will be included. In a later iteration, the post-processing might be included as well, and the tool will help balancing post-processing against optimized production strategies, as discussed above.

3.2 Identification of impacts on the desired outputs

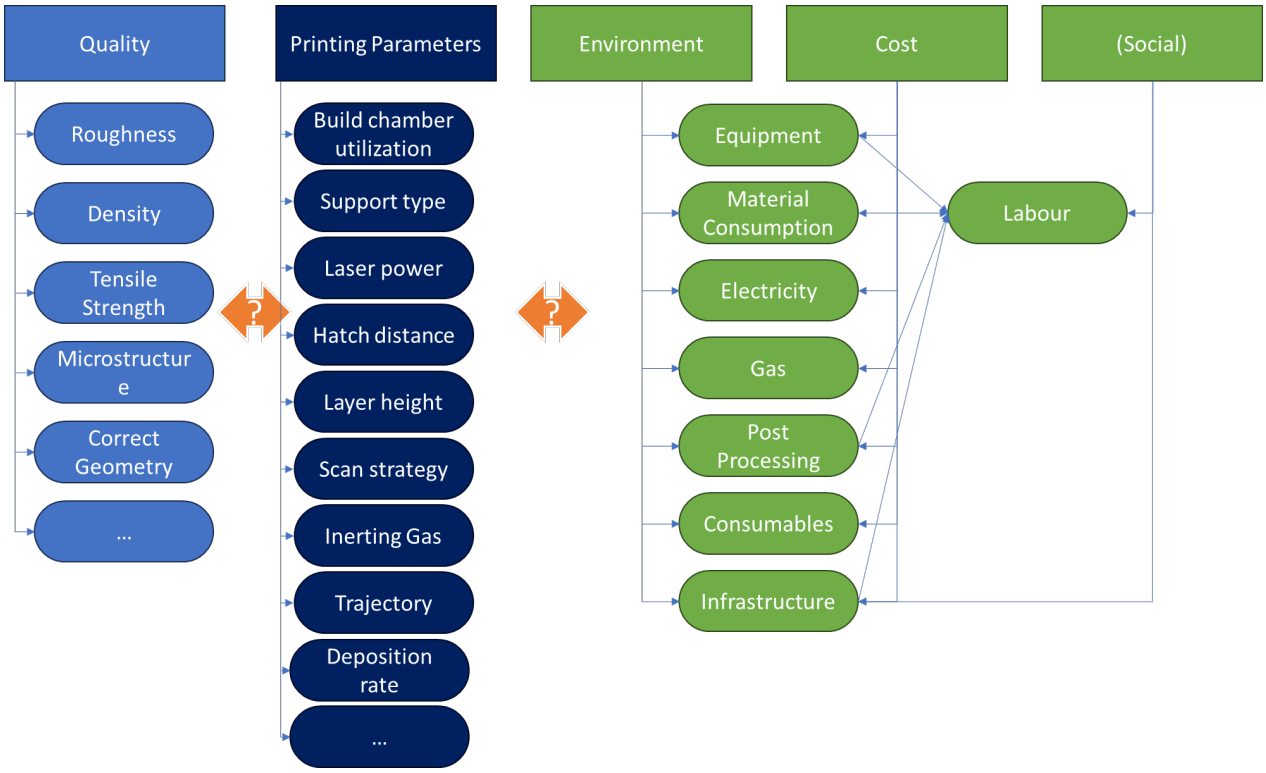


Figure 4 Flowchart of different factors defining quality and different impacts on sustainability for AM.

Figure 4 shows to the left in the light blue color different factors that define the quality of a product, which can be found in the use case descriptions of D1.1. These will be achieved by different printing parameters, shown in the middle in the dark blue color, in combination with post processing (which is not shown in the figure). These will in different ways be connected to different impacts, defining the sustainability of a product, which was uncovered in WP4 and is shown to the right of the figure in green. In terms of sustainability, the triple bottom line (environment, cost and social), is often discussed, but WP 4 mainly focused on cost and environmental impacts, as the social impacts are in this case mostly negligible. The different impacts on sustainability are highly interrelated, e.g. the choice of AM machine (equipment) will impact on gas usage and electricity consumption during printing. However, some of these interdependencies might be more complex. Additionally, trying to link the quality factors directly to one or multiple printing parameters and those directly to one or more sustainability impacts is nearly impossible. However, it was tried to identify some important links between printing

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parameters and sustainability impacts on the one hand and quality factors on the other hand based on the results and identified strategies of D4.3.

To keep this deliverable comprehensive, from here on the development is described based on LPBF as an example. However, similar principles can be used when developing strategy decision support tools for other laser processing technologies. Figure 5 gives an implication of possibly impacted quality, environmental and cost factors by the strategy of “filling up the build chamber”. Green ellipses indicate a positive influence on the environmental impact, while yellow ellipses indicate an unknown impact as discussed in the following. Overall, with better utilization of the space on the build platform, most consumables can be allocated to more parts, meaning the environmental impact per part should go down. However, filling up the build chamber can also lead to a change in the build orientation of the different parts, which might lead to a different roughness in certain areas, a different amount of required support structures and therefore change in material use and post-processing requirements, which also could affect the labor required. As microstructure in additively manufactured parts is anisotropic, a different build orientation might also affect the microstructure and therefore part properties.

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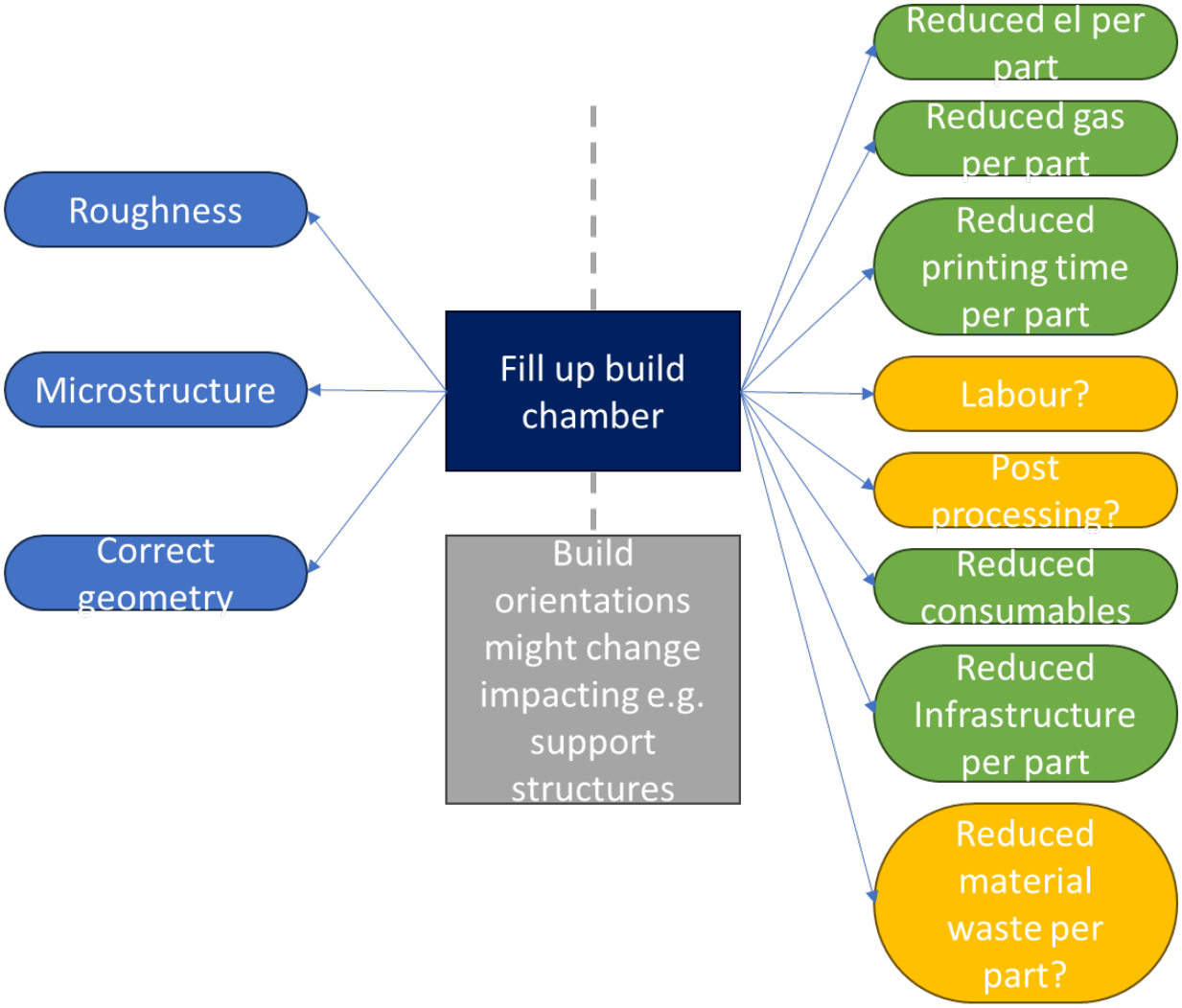


Figure 5 Implications of filling up the build chamber on quality, environment and cost.

Figure 6 shows an overview of the implications of an increased layer height or deposition rate on quality, environmental impact and cost. On the quality side, roughness values may increase, and the correct geometry might be harder to reach as the resolution could decrease. It is expected that a change in layer height or deposition rate might also affect density, tensile strength and microstructure. With an increase in layer height/deposition rate, the overall processing time decreases, which usually is directly linked to a reduction in gas usage and electricity (Obeidi et al., 2024). However, the effect this might have on labor, post-processing, consumables and the required infrastructure is unclear. E.g. labor and post-processing requirements might go up, due to bigger stair-step effects, making more post-treatment necessary. In severe cases, this might call for new equipment, thereby negatively impacting infrastructure. On the other hand, if no more post-processing is required, the infrastructure might be the same or its impact could be decreased, due to shorter processing times and therefore more favorable allocation. The

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investigation of the total electricity consumed by the process should also be interesting, e.g. if the energy saved in the printing process might require additional post-processing to reach the required quality it might stay the same or even increase.

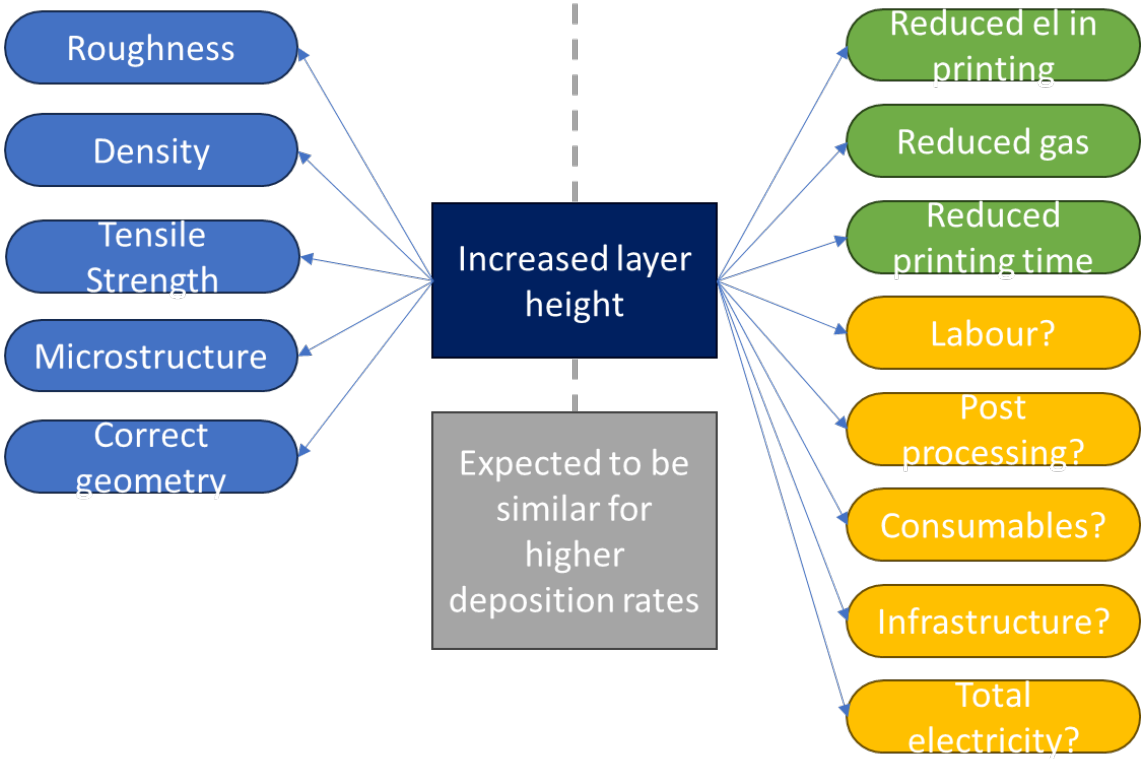


Figure 6 Implications of increased layer heights/deposition rates on quality, environment and cost.

Figure 7 gives an overview of the potential impacts of an optimized scanning strategy or trajectory. However, within WP4 no such tests were performed, so impacts are less understood than for the other strategies described. Here, further research is necessary.

This discussion shows how important a good interface or even integration of the tool and the digital twins and simulations within DILAFACT will be. The tool will depend on data input from both the user and the digital twin, and might give an output back to it, regarding the environmental assessment. The decision support tool itself will not be able to consider and simulate all the different implications of the quality on the sustainability. It will rather rely on process data delivered by the digital twin and the simulations and evaluate based on these, additional user inputs, and potentially an additional database.

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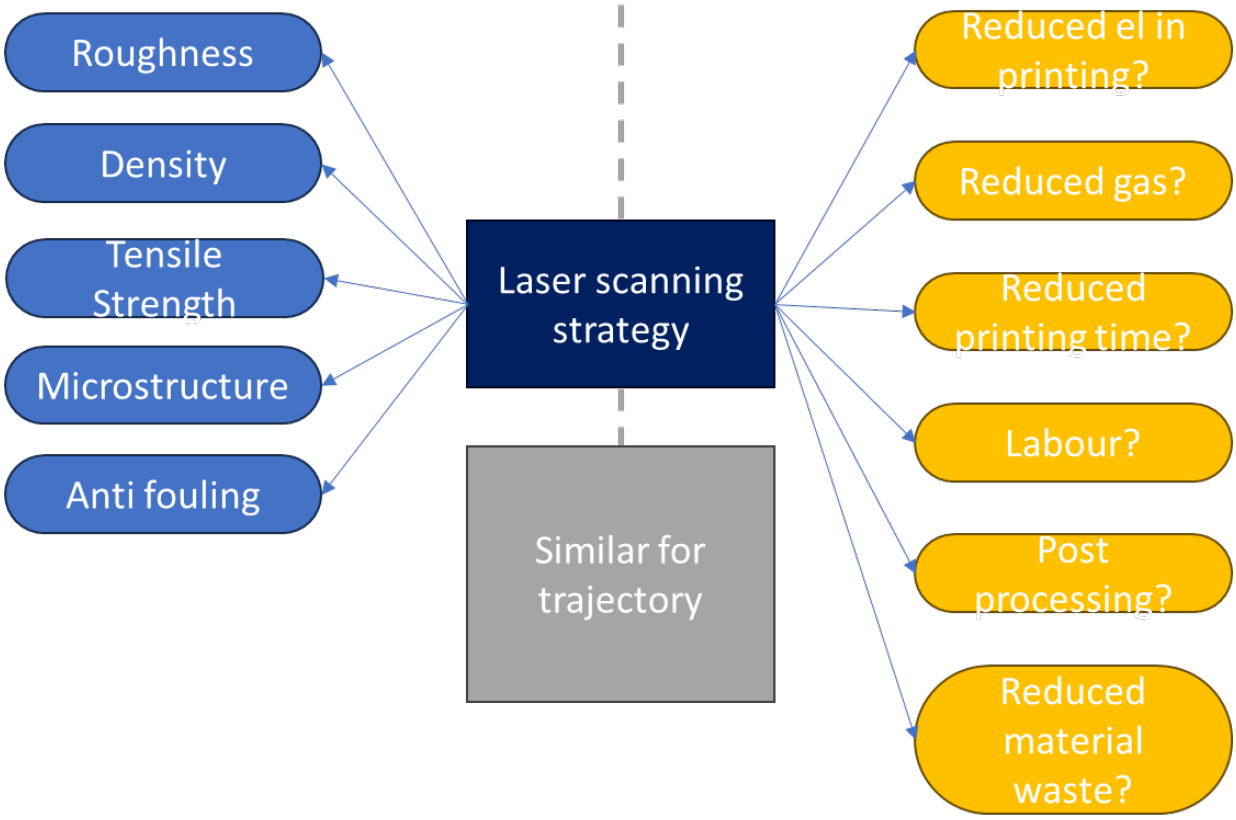


Figure 7 Implications of a changed trajectory/ laser scanning strategy on quality, environment and cost.

4. Required inputs to the tool

Already during the performance of the LCA and LCC it became obvious that data collection would pose the biggest challenge of an environmental decision support tool. Relevant data are often not collected and therefore not available, so proxies and industry averages must be used. Therefore, based on the example of LPBF, generic data that could be used instead of measured data to predict environmental impacts was generated. However, it is planned to ask the user for feedback on the predictions to improve the predictions and create a database.

Figure 8 shows the general data inputs and outputs of user, digital twin and decision support tool. It is expected that the user will supply the DILAFACT software with the geometry of the part, the quality requirements, and the number of required parts. Additionally, at this point, it is planned that the user will prepare a build job in a software like Magics by Materialise or ANSYS SpaceClaim+Additve. Based on this, DILAFACT software will find the build parameters which are needed to fulfil the quality requirements. The decision support tool is supposed to help find the ideal strategy in terms of environment and cost. To do so, the basic version of the tool would need to get the (expected) build time and the (expected) mass of the part plus support structures. In a potential future version, the digital twin could optimize part placement and orientation in

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the build space, including certification parts, as this could have great influence on build space utilization, which would influence the environmental impact. This would reflect on the build time and material consumption and hence on the energy and gas usage. However, in the currently planned version of the DILAFACT software, this is not planned as a capability.

In a later version of the decision support tool, consumables and equipment could be included to generate a more LCA-like result. This would require additional information from the user. As the LCAs and LCCs in D4.3 showed, the cost impact often follows the environmental impact, so where a high impact on global warming potential was found, usually also a high price was connected to the consumable or material.

In the best-case solution, the user would be asked to also give input on all available laser processing technologies, and whether the user would be interested in potential laser processing by external suppliers, so multi-laser processing can be implemented, and an optimal processing strategy could be found by the software, balancing quality, environmental impacts and costs.

The minimal version would predominantly focus on energy, gas, and material consumption. Based on the results of the LCA in D4.3 and values from literature, energy consumption and material consumption would be predicted so the user could decide for a configuration based on these values. After printing, the user will be asked to evaluate the energy, gas, and material consumption prediction, if possible, to improve the prediction for future builds. The cost calculations here will be similar to the cost calculations in D4.3 and be based solely on the costs of the energy, gas and material consumption, while, e.g., machine depreciation and labor will not be included.

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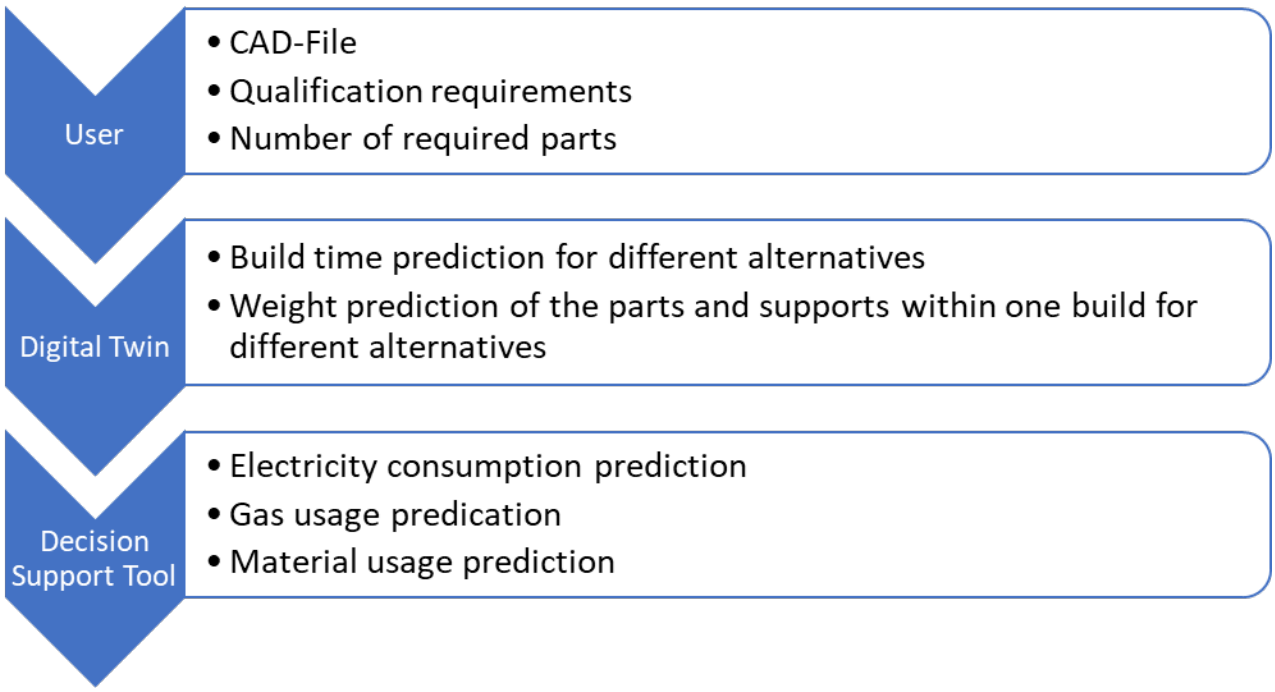


Figure 8 General overview of data presented by user, digital twin and decision support tool in the minimal version. In addition to this, a feedback loop will exist from the user to the decision support tool after printing.

5.Tool Framework

The tool will generally operate in four phases:

1. Input phase,
2. Processing phase,
3. Output phase,
4. Feedback phase.

In the first phase, the input phase, inputs from the user and the digital twin will be processed. Here, data, such as the material, the build time, the average energy consumption of the machine for the respective material, the number of parts in the build space, the expected mass of the parts and supports, whether a cyclone is used, and which machines are available are collected. Some of the data will be direct inputs from the digital twin, while others will be inputs from the user.

During the processing phase, the tool will, based on the inputs, predict the energy usage and material usage of the build job. Additionally, the tool will predict the energy used to produce one part in the specific build job configuration. This is, however, only working if there are only parts of the same geometry and in the same build orientation on the build plate. In a later version an improved algorithm might help to allocate energy and material to specific parts of different geometries, but as this is related to several factors, more research to understand the

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dependencies is necessary. Additionally, in a later version, the tool will balance cost, environmental impact and quality when using different processing parameters and different laser processes. By this, unnecessary post-processing might be avoided, or if it saves costs and reduces the environmental impact, the required quality might first be achieved by increased post-processing as compared to the original strategy.

The processing phase will be followed by the output phase. Here, the tool will present its predictions to the user and the user can easily compare the expected energy, gas, and material consumption per build job and per part for different configurations. The tool might additionally generate some more generic recommendations to the user on how to optimize for decreased environmental impact. In a later stage of the tool, this should be more advanced and get closer to a LCA, where based on the consumables, energy and raw materials, the environmental impact in categories such as global warming potential is calculated and made comparable for different multi-purpose laser processing strategies. An evaluation of the costs of the predicted energy, gas, and material usage is easily implementable; however, this will also need to advance as the tool advances from these basic calculations towards something closer to an LCC.

The last phase of the tool should be a feedback phase, where the user is requested to provide feedback on the predicted data and ideally providing the actual measured data. The tool will use the data to build up a database and improve its predictions.

6. Proof of concept for the minimum viable solution

As proof of concept of the minimum viable solution, an Excel sheet with the basic prediction functionalities of the minimum solution for LPBF was created. A simple version of such a tool based on the measured data from the LCA performed in D4.3 was built in Excel. This does not yet include the feedback collecting and database building phase and was only used to investigate the general functionality of such a tool.

An example of the inputs and outputs to this Excel tool is shown in Figure 9, Figure 10, and Figure 11. Figure 9 shows the necessary data inputs to the tool:

- The expected build time
- The expected weight of parts and supports
- The number of required tensile tests and density tests
- The number of parts on the platform excluding the certification coupons
- The time it takes to flood the build chamber with inert gas
- The prices of the three main consumables inert gas, material and electricity.

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Additionally, there are drop-down menus to select:

- The use of a cyclone (yes/ no)
- The type of material (Aluminum/ Steel/ Inconel)
- The type of inert gas (Nitrogen/ Argon)
- The location of production (Belgium/ Denmark/ Germany/ Ireland/ Italy/ Norway/ Portugal/ Spain/ Switzerland).

The expected build time, in combination with the flooding time, is used to calculate the amount of gas that is required for production. Additionally, the build time is used to predict energy consumption. The number of tensile and density tests is used to estimate the additional electricity required for testing those parts. The prices are used to predict the cost of the three consumables gas, electricity and material. With the number of parts per platform excluding the certification coupons the amount and cost of the consumed gas, material and electricity is distributed among those parts. When a Cyclone is used the material efficiency is increased and the predicted amount of material used is therefore lower, when “yes” is selected. The results for the shown example in Figure 9 are shown in Figure 10. To the left the overall result is given and to the right the result for one part is given, as in the example build job, four parts are built.

The type of material, type of inert gas and place of production will influence the graphical output of the tool, which is shown in Figure 11. Each of the selections is connected to a different number of kg CO2-eq. So, for example, producing the same part in Norway and Belgium will lead to different results regarding the contributions to the CO2-eq. pie chart, as Norwegian electricity has a lower global warming potential compared to Belgian electricity. As these calculations are rough estimates and are only aimed at giving an impression of where the impact is the highest, the total amount of CO2-eq. produced is not given. This will additionally prevent the user from misinterpreting the number or using it for advertising purposes.

To test the accuracy this tool was tested with the data of both LPBF build jobs presented in D4.3. However, the results were different and simply averaging the average consumption of the two machines leads to overestimating the energy for one machine while underestimating for the other machine. Additionally, when comparing estimations made by the tool to measurements from the PL5 and PL3 using different material compared to the initial measurements in D4.3, the results were off. Therefore, it was noted that different machines require different amounts of energy and gas and that the energy consumption of one machine type might also vary depending on the material which is being processed. Hence, the database building phase is important. Additionally, an improvement in the algorithm to calculate the predicted energy consumption could improve the accuracy of the predictions. In a future iteration this could for example be based on the laser path and energy consumption plus an addition for other consumers during the build job, rather than an average energy multiplied by the processing time.

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INPUT

(Expected) build time (h)	24
(Expected) weight of parts and supports (kg)	5
Number of required tensile tests	4
Number of required density tests	8
Number of parts per platform (excluding certification coupons)	4
Cyclone?	NO
Time for flooding of the build chamber (min)	10
Price Electricity (€/kWh)	0,26
Price Material (€/kg)	78
Price Interting Gas (€/kg)	1,6
Type of Material	Inconel
Type of Inerting gas	Argon
Place of production	Denmark

Figure 9 Input panel of the simple Excel tool.

OUTPUT

Expected total electricty consumption	184,71	kWh
Expected electricty consumption only printing	181,2	kWh
Expected material consumption	8,333333	kg
Expected Argonconsumption	9,3854	kg
Expected cost for electricity	48,0246	€
Expected cost for Material	650	€
Expected cost for Argon	15,01664	€

Expected el consumption per part	46,1775	kWh
Expected el consumtion only printing per part	45,3	kWh
Expected material consumption per part	2,083333	kg
Expected Argon consumption per part	2,34635	kg
Expected cost for electricty per part	12,00615	€
Expected cost for material per part	162,5	€
Expected cost for argon per part	3,75416	€

Figure 10 Output panel of the simple excel tool, showing the expected total consumption on the left and the expected consumption per part on the right.

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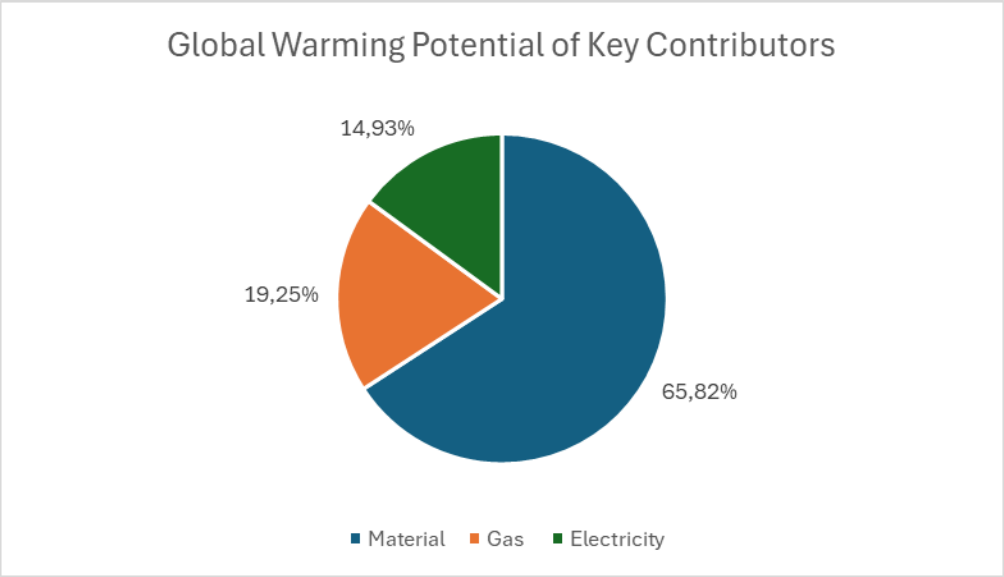


Figure 11 Graphical output of the simple excel tool.

7. Conclusion and Recommendations

Based on several discussions with the PL owners and project partners involved in WP4, different possible outputs and capabilities of the decision support tool were discussed. Many of the capabilities as well as possible further developments of the decision support tool highly depend on the development of DILAFACT software and the development of multi-purpose laser processing and are therefore hard to predict and plan for at this moment. The tool will need to develop and expand during the duration of the DILAPRO project and beyond, as not all relevant data is available, and not all interdependencies are clear yet and the DILAFACT software itself will develop over time and gain more capabilities. This report indicates potential developments which could be added to the tool as more data becomes available and the capabilities of the DILAFACT software become clearer. A relevant inclusion to enhance multi-purpose laser will be a balancing tool that enables the combination of several different laser processing technologies or traditional post-processing technologies where it makes sense, and an adaptation of the processing strategies to reduce environmental impacts. This will enable more complex decision-making considering the entire process of production and not only the main laser processing technology.

A seamless integration with the DILAFACT software will be crucial to make the use of the decision support tool as easy as possible and encourage DILAFACT users to consider environmental impacts in their production.

Feedback from the users of the software is crucial to build a database and make predictions more precise, especially in the minimal form of the decision support tool proposed in this report.

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