EFFECT OF DIFFERENT TECHNOLOGICAL AND ENERGY SUPPLY RELATED MEASURES ON THE PRIMARY ENERGY DEMAND OF CFRP PRODUCTION

D. Wehner[1], A. Hohmann[2], B. Schwab[2], S. Albrecht[1], R. Ilg[1], K. Sedlbauer[1], P. Leistner[1], K. Drechsler[2]

[1]Fraunhofer Institute for Building Physics department life cycle assessment, Stuttgart, Germany
Email: daniel.wehner@ibp.fraunhofer.de, http://www.ibp.fraunhofer.de

[2]Fraunhofer Institute for Chemical Technology branch Functional Lightweight Design, Augsburg, Germany
Email: andrea.hohmann@ict.fraunhofer.de, Web Page: http://www.ict.fraunhofer.de/de/komp/fil.html

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Abstract

Carbon reinforced plastics (CFRP) are well-known for their excellent weight specific properties, resulting in energy reduction and emission savings during the use phase. Due to the required amount of raw materials and energy in the production phase, the holistic sustainability of these materials significantly depends on the manufacturing method, the achieved weight reduction and the respective application. One important key performance indicator to describe the sustainability of products over their whole life cycle is the primary energy demand (PED). The PED includes all sources of primary energy that have to be withdrawn from the environment in order to provide the function of a process, a product or a service. The presented study provides both manufacturers and users of CFRP with the means to effectively reduce the PED of CFRP production by investigating the effect of different technologically and energy supply related measures and their interdependencies along the process chain of CFRP production. The results show a great variance of the PED depending on particular, partly interdependent parameters in the process chains and highlight the importance of a detailed investigation of the state of the process chains subject to optimization.

1. Introduction

Carbon reinforced plastics (CFRP) are well-known for their excellent weight specific properties, resulting in energy reduction and emission savings during the use phase. Due to the required amount of raw materials and energy in the production phase, the holistic sustainability of these materials significantly depends on the manufacturing method, the achieved weight reduction and the respective application ([1] to [5]). Especially as there is a huge variety of manufacturing technologies and CFRP process chains, it is of high importance to understand the impacts on the environmental burden of CFRP production. This complexity has not been addressed by previous investigations; consequently there is a lack in reliable life cycle inventories (LCI) even for well-established composite technologies.

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2. Methodology

2.1. Goal of the Study

The goal of the study is to support the various actors involved in the production and CFRP structures in their efforts to energetically optimize the production of CFRP structures. Therefore, a comprehensive data collection for different CFRP process chains, process parameters and part complexities was conducted. Furthermore, different manufacturing scenarios were evaluated regarding their effect on the primary energy demand (PED) from non-renewable resources. This work shows the correlation between process parameter and energy demand, as well as ecological key performance indicators and energy saving potentials along the process chain.

2.2. System Boundaries and investigated scenarios

The study presents the results of the cradle-to-gate analysis of the primary energy demand (PED) from non-renewable resources of various CFRP production.

On the example of a the thermoset CFRP process chain two different preforming processes were investigated, a sequential 3D shaping process using a bindered non crimp fabric (NCF), which is activated by an infrared heating system and subsequently formed in a press, in addition to the material-efficient braiding technology. For the subsequent process step, the HP-RTM technology, the measurements have shown that either the heating of the tool or the press itself requires the main process energy, depending on the manufacturing conditions (press control, utilised capacity, tool size and temperature).

In total the following four production variants were analysed based on the combination of 7 different scenarios (also see Figure 1):

- **V1: Baseline**
  - sequential 3D shaping process (NCF, IR heating for binder activation, press forming)
  - HP-RTM technology (10min injection and curing at 120 °C)
  - energy-mix considering the worldwide production capacities for carbon fiber production
- **V2: Use of renewable energy resources**
  - Precursor production
  - Carbon fiber production
  - CFRP processing
- **V3: Technological improvements**
  - optimized energy use during carbon fiber production
  - reduction of material waste and energy consumption during preforming by introducing the braiding technology
  - reduction of curing time to 5min, recycling of material waste
- **V4: Combination of V2 and V3**

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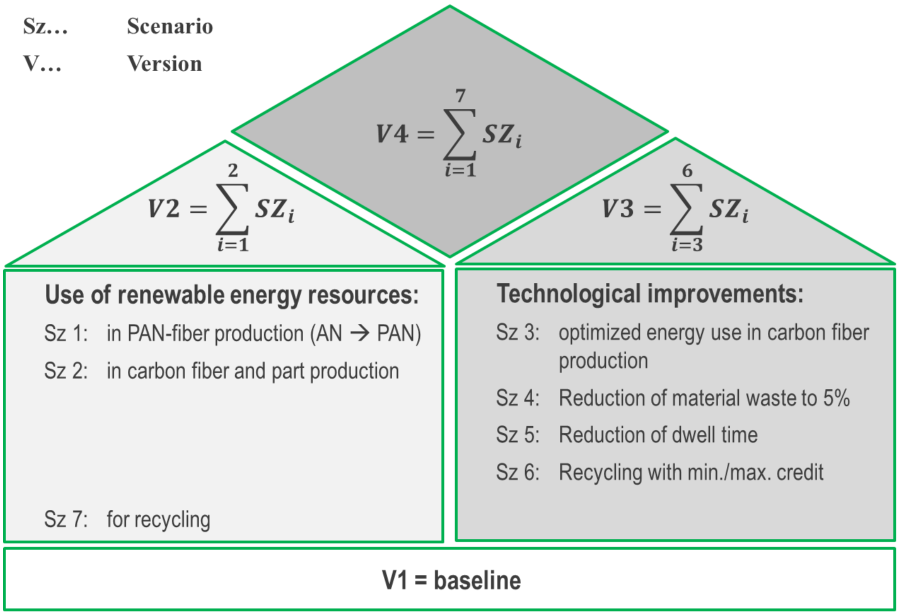

Figure 1. Overview of the analysed manufacturing scenarios.

2.3. Collection of process data

In order to provide reliable results process data was collected for several production processes and technologies.

Figure 2 shows the process chains subject of the analysis. For the analysis of the process steps carbon fiber- and matrix manufacturing, fabrication of NCF , finish and assembly literature data was used after verification with support from associated industry partners. For all other process steps specific technology analyses were carried out as described above and illustrated in Figure 2 using the methodology illustrated in Figure 3.

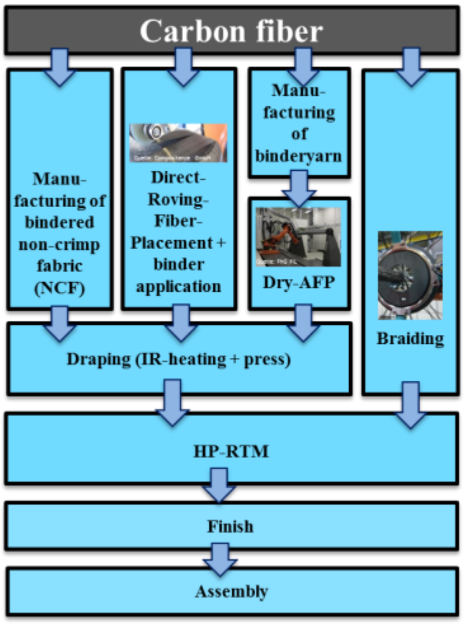

Figure 2. Analyzed production routes.

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Following the definition of process-specific boundary conditions (such as material, process pressures, temperature,…) a sensitivity analysis was performed in order to identfy relevant process parameters for further consideration. The effect of parameters such as the geometry, size and thickness of the component on energy and material flows was also examined. Consequently, the data was converted to the corresponding reference flow of the respective process, e.g. the energy demand per placed quantity of carbon fiber. Further details on data collection can be found in [6].

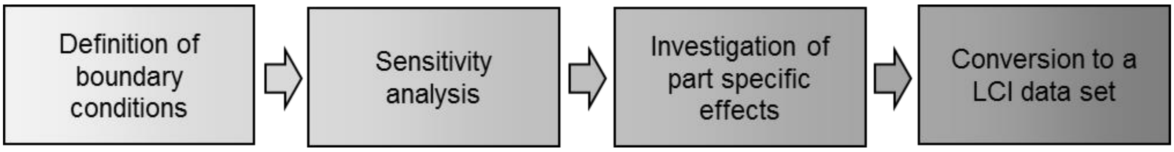

Figure 3. Procedure of analyzing individual processes.

2.4. Analysis of the Primary Energy Demand (PED)

The PED includes all sources of primary energy that have to be withdrawn from the environment in order to provide a product, a process or a service with its targeted functionality. The PED describes the use of primary energy sources which occur directly in nature, such as mineral oil (petroleum), natural gas, black coal (anthracite) and brown coal (lignite), uranium as well as renewable sources of energy. In refineries, power plants etc. the primary energy is converted according to the needs, i.e. to deliver energy (electricity, thermal energy, district heat, etc.) which can be used as a precursor in the form of thermal or electrical process energy. For instance, in order to determine the quantity of primary energy required by a technical system to satisfy its energy need, the upstream chains for preparing the primary energy sources must also be considered. The PED can be further divided into a share covered by non-renewables (e.g. black coal, mineral oil, etc.) and energy from renewable sources (e.g. solar energy, wind energy). Moreover, the PED includes the material use of energy sources. Due to societal relevance the focus of this study is placed on the analysis of the PED from non-renewable sources [6].

3. Results and Discussion

In the following the results of the process chain analysis of the alternative production variants V1 to V4 (also see chapter 2.2.) are shown and discussed.

Compared to the basline variant V1 material waste can be reduced by the use of braiding as an alternative preforming technology (investigated in V3 and V4). Figure 4 illustrates the changed material flow of variant V3 and V4 (reduced cutting waste) compared to the baseline variant V1. The investigations considered in Variant V2 have no impact on the material flow compared to variant V1.

As can be seen in Figure 4. The use of braiding as an alternative preforming technology changes both the number and type of process steps as well as the quantity of the cutting waste. With the use of the braiding process binder activation and draping is not necessary as it allows direct manufacturing of the 3D-geometry component. Moreover, compared to the baseline scenario, braiding reduces the cutting rate from 40% to approximately 5%.

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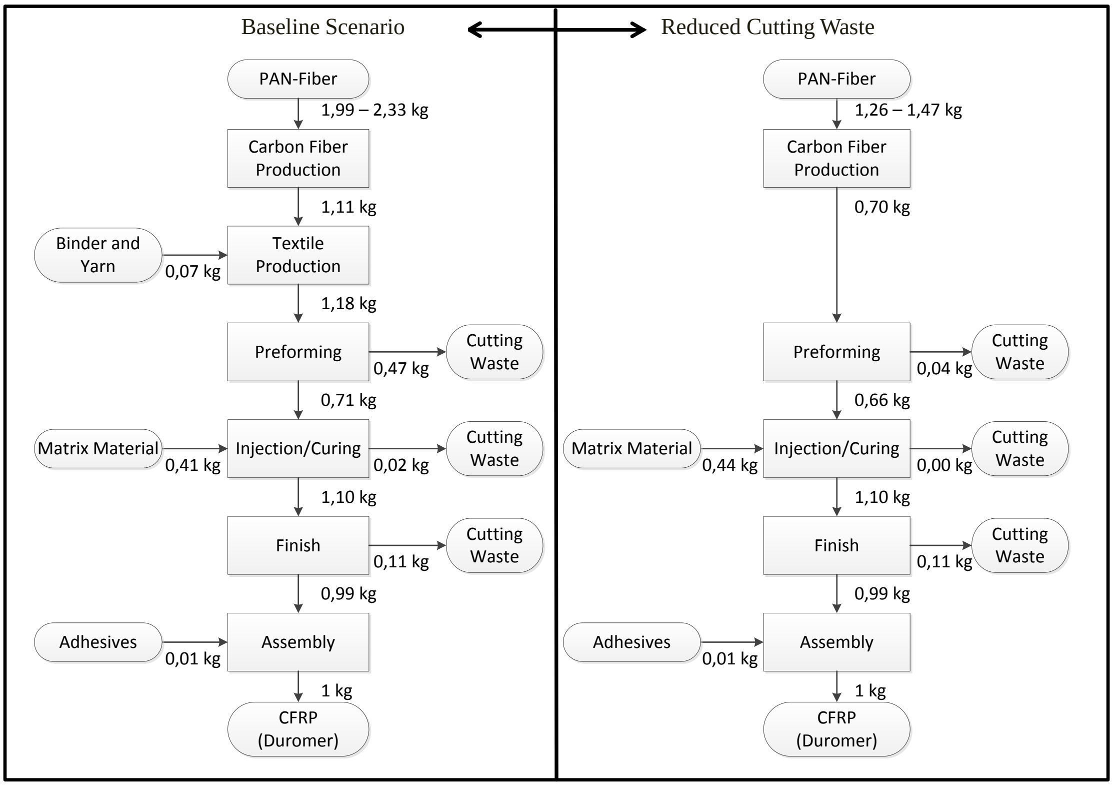

Figure 4. Material flows for the production of 1 kg thermoset-based CFRP.

Based on the determined process energies and material flows a cradle-to-gate analysis was performed using the GaBi professional software. The analysis of the baseline scenario V1, shows that the carbon fibre production requires the highest amount of PED. However 34% of this PED is needed for the carbon fibre production, which are wasted in the subsequent manufacturing process chain. To quantify possible PED reduction potentials, different scenarios were analysed (see Figure 5). Using electrical energy gained from renewable resources for fibre and part production (variant V2) results in a reduction of the PED from non-renewable resources of 42%, 60% of these total savings occur during fibre production.

Technological improvements (variant V3), e.g. the reduction of material waste from 40% to 5% (due to the use of the braiding technology) lead to similar reductions. The technological measures combined in variant V3 are however interdependent, which is why the various potentials for reduction cannot simply be added. For instance, the material-efficient preforming technologies have already minimized the amount of waste so effectively that a recycling process will hardly achieve any further reduction in the PED. The total reduction potential represented by the implementation of technological optimization measures is therefore equal to 49%.

Combining all investigated scenarios, a total PED (from non-renewable resources) saving of 68% compared to the baseline scenario can be achieved. Here further interdepencies occur. For instance, as the PED for the production of carbon fibers was reduced by using renewable energy, the primary energy credits that can be given for the recovery of carbon fibers are also reduced. In this variant, recycling of left-over cuttings to further reduce the primary energy demand for CFRP manufacturing will thus become increasingly irrelevant.

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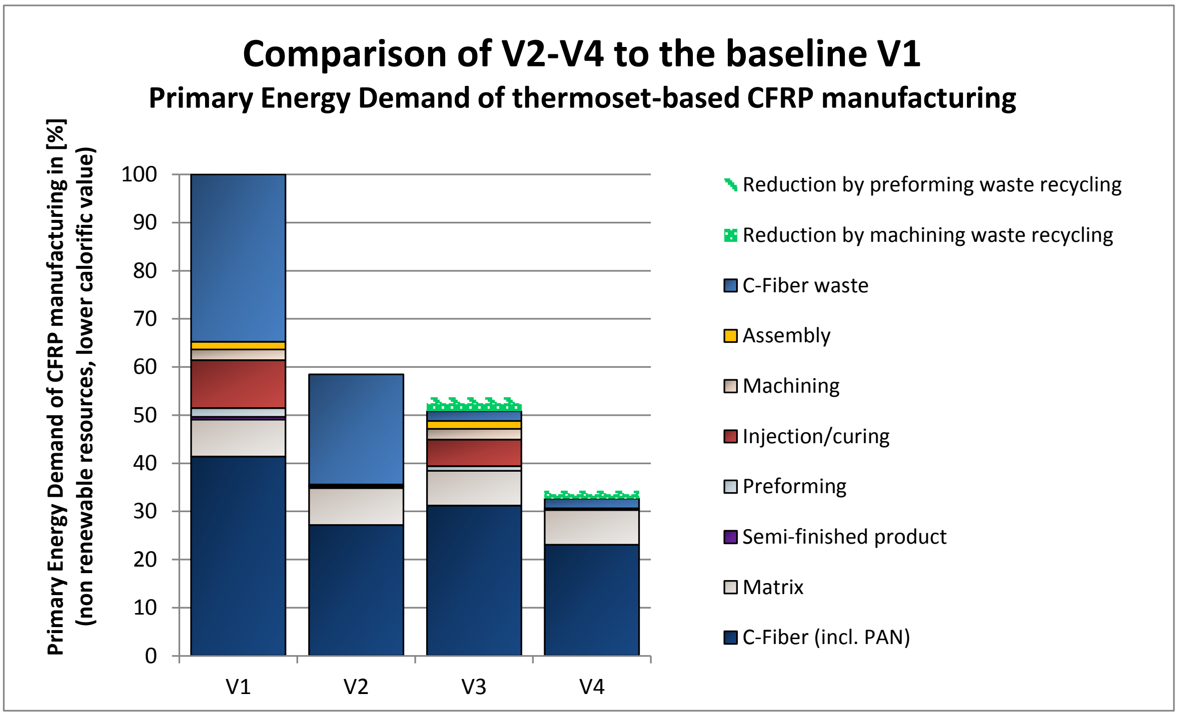

Figure 5. Primary energy demand in thermoset-based CFRP manufacturing.

4. Conclusions

The results of the presented study have shown the major levers for optimizing the energy use in CFRP manufacturing and processing as well as the interdependencies between individual parameters that have to be considered when optimizing particular process chains. In particular as the results show a great variance of PED depending on particular parameters it is advisable to pioratize optimization measures depending on the actual state of the process chain the measure is to be adopted in. The description of CFRP using a one-suits-all PED-dataset is not considered advisable. In order to facilitate the use of the results of the presented study a comperensive database will be developed amd made available to companies and research institutions to perform their own assessments and technical process optimizations.

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References

[1] J.R. Duflou. Environmental impact analysis of composite use in car manufacturing. *CIRP Annals - Manufacturing* Technology 58, p9–p12, 2015.

[2] S. Das. Life cycle assessment of carbon fiber-reinforced polymer composites. *International Journal Life Cycle Assessment 16*, p268–p282, 2011.

[3] L. Scelsi. Potential emissions savings of lightweight composite aircraft components evaluated through life cycle assessment. *eXPRESS Polymer Letters Vol.5*, p209–p217, 2011.

Excerpt from ISBN 978-3-00-053387-7

[4] R.A. Witik. Assessing the life cycle costs and environmental performance of lightweight materials in automobile applications. *Composites: Part A 42*, p1694–p1709, 2011.

[5] E-mobil BW GmbH. *LEICHTBAU IN MOBILITÄT UND FERTIGUNG: Ökologische Aspekte*. 2013.

[6] A. Hohmann. MAI ENVIRO: Vorstudie zur Lebenszyklusanalyse mit ökobilanzieller Bewertung relevanter Fertigungsprozessketten für CFK-Strukturen. Fraunhofer Verlag. ISBN 978-3-8396-0929-3

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