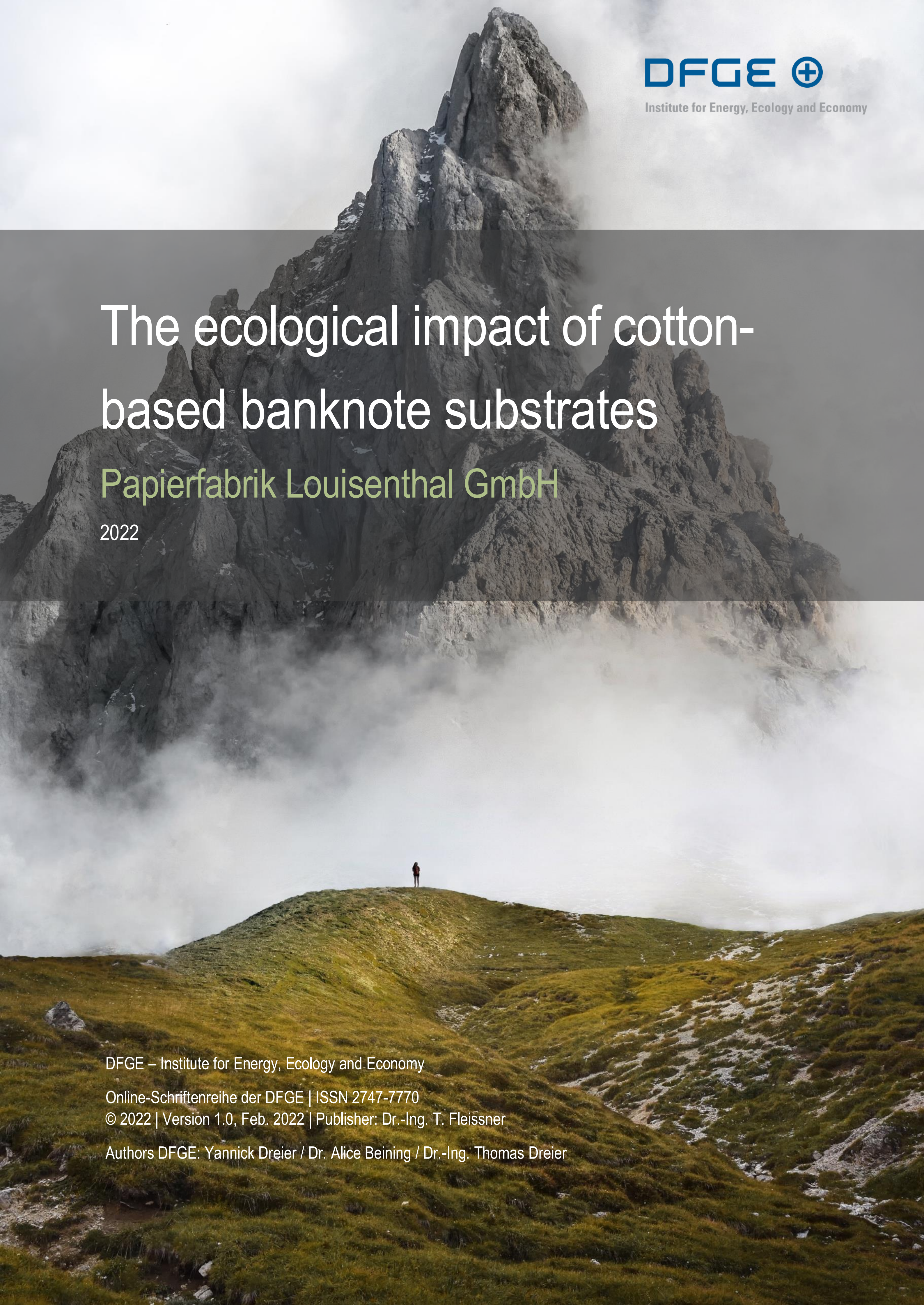

The ecological impact of cotton-based banknote substrates

Papierfabrik Louisenthal GmbH

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DFGE – Institute for Energy, Ecology and Economy

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Abbreviations

ATM	Automated Teller Machine
BN	Banknote
CO2e	Carbon dioxide equivalent
FU	Functional Unit
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change

1 Executive Summary

In order to find an optimum balance between security, durability and sustainability of banknotes Papierfabrik Louisenthal appointed DFGE – Institute for Energy, Ecology and Economy to conduct a study on the ecological impact of cotton banknote substrates. The project target was to compare the product carbon footprint and water consumption of three different banknote substrates – Standard cotton, Longlife^{TM} cotton and Hybrid^{TM}.

The different banknote substrates were assessed via a complete analysis considering the selected inventory boundaries. The study was based on the methodology of the Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard and the ISO 14040/44. All relevant processes of the considered life cycle stages were included. According to the intended application of the assessment, the life-cycle stage "End-of-Life" was excluded from the analysis. In order to allow accurate comparisons of the different banknote substrates, the results refer to an equivalent functional unit chosen for the analysis: „Provision and use of 1.000 banknotes over a period of 10 years".

The estimated total carbon footprint and water results per life cycle stage show cleary a different performance of the studied banknotes with a lower environmental impact of the Longlife^{TM} and Hybrid^{TM} substrate compared to the cotton standard. The assessement also revealed that the carbon footprint of the three substrates banknotes is mainly dominated by the life cycle phases: use, printing and cotton production. In terms of water use, only cotton production is relevant, while the other life cycles can be neglected.

The study showed that the product innovations offered by Papierfabrik Louisenthal allow the extension of the banknote circulation, with fewer banknotes having to be produced and transported over the entire life cycle and improving the sustainability performance of the whole banknote cash-cycle.

2 Introduction

As one of the leading manufactures of banknotes substrates and security features for banknotes worldwide Papierfabrik Louisenthal, a subsidiary of Giesecke + Devrient, strives to support the efforts of its customers enhancing sustainability within the cash cycle.

Among other things, the focus is on optimizing the process efficiency of plants, the use of raw materials and natural resources from the point of view of environmental responsibility. Inquiries about sustainability have increased steadily in recent years. At central banks sustainability of the cash cycle is becoming increasingly important, e.g., regarding the durability of banknotes and possible end-of-life scenarios, and there is a need for transparency as well as engagement on the part of the suppliers.

Against this background, there is also a need for a fact-based public discussion of the sustainability of banknote substrates and their classification in the context of competition. In the past, comparative analyses on the sustainability of cotton and polymer-based banknote substrates were carried out and published by the Bank of Canada, Bank of England and Banco de Mexico. More recent product-related developments, such as the Hybrid™ substrate, an innovative combination of cotton and polymer, have not yet been considered in the context of sustainability.

In order to provide Central Banks with a better understanding of Hybrid™'s performance and to help understand where the levers for reducing the carbon footprint of cotton-based banknote substrates lie, Papierfabrik Louisenthal decided to conduct a comparative product carbon footprint and water use analysis between different cotton-based banknote substrates: Standard cotton, Longlife™ and Hybrid™.

The different banknote substrates were assessed via a complete analysis considering the selected inventory boundaries. The calculation is based on the methodology of the Greenhouse Gas Protocol (GHG Protocol) Product Life Cycle Accounting and Reporting Standard and the ISO 14040/44. All relevant processes of the considered life cycle stages are included. According to the intended application of the assessment, the life-cycle stage "End-of-Life" was excluded from the analysis. The work was conducted by making use of DFGE's holistic TopDown approach[1], based on DFGE's project experiences and combined with mathematical methods.

[1] DFGE 2013

3 Methodology and Implementation

3.1 Impact Categories Studied

In the present study two impact categories are examined for comparison of the different banknote substrates – global warming potential and water use. Appropriate Life Cycle Impact Assessment (LCIA) methods were used in accordance with the applied standards – GHG Protocol Product Life Cycle Accounting and Reporting Standard[2] and ISO 14040/44[3]. Both impact categories were analyzed in a holistic cradle-to-grave approach considering the complete life cycle of banknotes.

Product Carbon Footprint (PCF)
The Global Warming Potential (GWP) is a measure of greenhouse gas emissions and determines the climate impact of a product. Besides carbon dioxide further greenhouse gases are taken into account. Their harmfulness in terms of climate change varies greatly, therefore the emitted amount of greenhouse gas is multiplied by a specific factor, the so-called Global Warming Potential (GWP, Unit CO_2e). The GWP is defined by the Intergovernmental Panel on Climate Change (IPCC) as an indicator fixed to a certain period of time, such as 100 years (GWP100).[4] The greenhouse gases covered and GWP100 values used by DFGE are available in the DFGE Knowledge Base.[5]

Water use
Water use is an indicator for the amount of water consumed during the life-cycle of a product. To quantify the impact, the following indicator is applied: m^3 water. The impact category indicators were calculated using ReCiPe developed by Goedkoop et al. 2013. The potential impacts were determined using results obtained from inventory analysis, at the midpoint level, adopting the hierarchism perspective.

3.2 Studied Products, Functional Unit and Reference Flow

Studied Products
The studied products are banknotes based on three different cotton substrates:
- **Standard banknote:** based on cotton comber noil
- **Longlife™ banknote:** based on cotton comber noil and treated with an additional coating
- **Hybrid™ banknote:** based on a core of cotton comber noil and covered with an additional polymer foil

To achieve a high level of comparability an average banknote – with the same security features and dimensions – was assumed to be produced with all three substrates. Data was mainly derived from a real customer order, resulting in a high percentage of primary data used in this study., Further data

[2] GHG Protocol 2011, Product Life Cycle Accounting and Reporting Standard
[3] ISO 14040:2006: Environmental management — Life cycle assessment — Principles and framework;
ISO 14044:2006: Environmental management — Life cycle assessment — Requirements and guidelines
[4] IPCC, 2007
[5] See DFGE 2015a

like the velocity of circulation was assumed based on previous studies and a conservative lifetime for each banknote was calculated.

Table 3-1 Banknote characteristics

	Standard BN	Longlife™ BN	Hybrid™ BN
Grammage [g/m²]:	94,0	94,0	104,0
Dimensions [mm]:	145 x 68	145 x 68	145 x 68
Security features:	Security thread	Security thread	Security thread
Lifetime [months]:	4,0	8,4	14,0
Velocity of circulation [months]:	6	6	6
Total circulation time [months]:	6	12	18

The different lifetimes have a significant impact on the overall results of this analysis, but in general there is a high uncertainty regarding the data on lifetime of banknotes. For this reason, a detailed sensitivity analysis with respect to the lifetime of all three banknote substrates was conducted.

Functional Unit and Reference Flow

According to ISO 14040/44, a functional unit is a quantified description of the function of a product that serves as the reference basis for all calculations regarding impact assessment. The functional unit for this analysis was chosen based on previous studies and the available data regarding the distribution and use phase. It was set to be:

> "Provision and use of 1000 banknotes over a period of 10 years, considering an average banknote life cycle in which banknotes are introduced into circulation only through an ATM"

Based on this definition and the banknote characteristics (total circulation time) the reference flow was defined. The reference flow describes the required number of banknotes per substrate to fulfill the functional unit.

Table 3-2 Reference Flow

	Total circulation time [months]	Reference flow [number of banknotes per functional unit]
Standard:	6,0	20.000
Longlife™:	12,0	10.000
Hybrid™:	18,0	6.667

3.3 Banknote Life Cycle and Boundary Setting

The following paragraphs give a brief overview of the assumptions and limitations regarding the banknote life cycle and describes the boundaries of the present study.

Cotton Production

All three substrates considered in this study are based on cotton, more precisely short-fibre by-products of the textile industry. The production of the required cotton fibres was calculated based on its origin and cultivation method distributing the environmental effects between the main product (long-fibre cotton) and the by-product (short-fibre cotton)

Banknote Production

During the banknote production there are three main processes – substrate production, (security-)thread production, printing process. To further increase the comparability of the different banknote substrates the thread production and the printing process are assumed to be the same for all three examined banknotes.

Thread and Substrate Production

The thread production and the substrate production site that produced the examined banknote paper is located in Gmund am Tegernsee. The main component for all three substrates is cotton comber noil. In a first step of the substrate production, the raw material is prepared and bleached through several processes[6]. The subsequent paper production takes place in several screening and drying processes. During these processes security elements, such as the security thread, are incorporated. In order to extend the lifetime and durability of the banknote the Longlife™ substrate is treated with an additional coating in an extra process. To increase the lifetime and durability of Hybrid™ banknotes the cotton paper core is covered from both sides by a very thin polymer foil. Finally, the three substrates are precut according to the specified sheet size and prepared for transportation to the printing works.

Printing

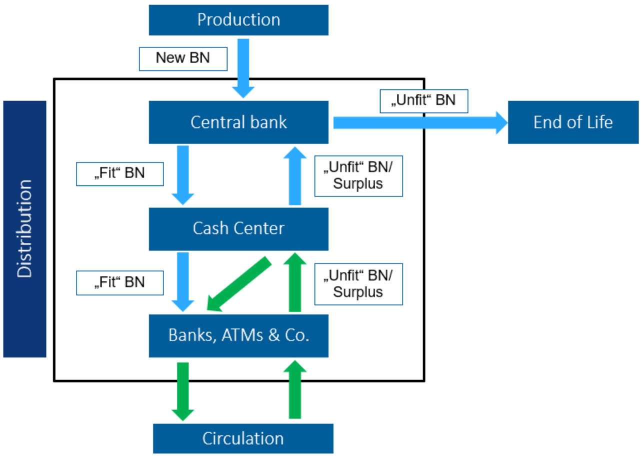
The printing works which printed the examined banknotes is located in Leipzig. The printing processes and the colors and chemicals used are identical for all substrates. The banknotes are printed in several process steps. The general design of the banknote is applied, additional security features are added, and the individual serial number of the banknote is imprinted. After printing processes, the sheets are cut into individual banknotes and then inspected separately by machine. The controlled banknotes are packed and in the next step distributed and put into circulation.

Distribution

The distribution of banknotes is identical for all three substrates and was modeled based on an average customer/country. The only differences arise from a different weight per banknote and a different lifetime per banknote (frequency of distribution).

The banknotes are transported by truck from the printing works in Leipzig either directly to the customers central bank or to the next harbor and are further transported by ship. Figure 3-1 explains the considered model for the distribution of banknotes and how they return to the customer's central bank. All distances were modeled based on an average customer/country and can easily be adjusted to a specific country.

Figure 3-1 Distribution model



[6] This is a standard and common procedure in the paper industry.

Use Phase

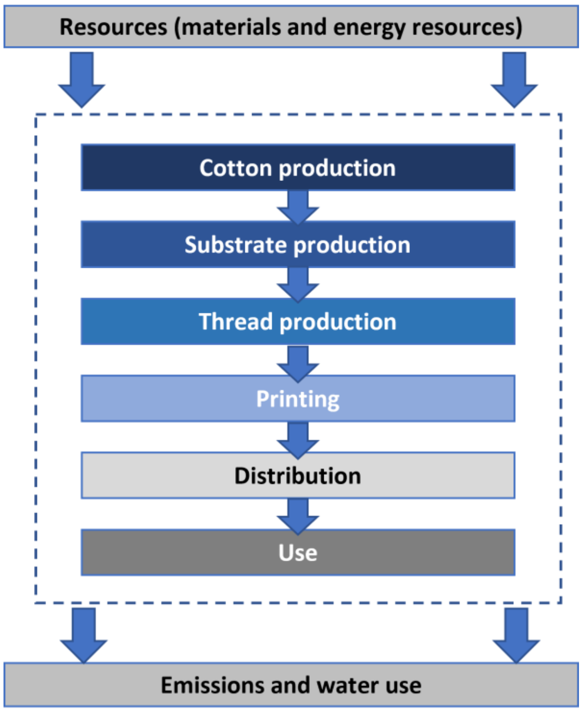
The use phase was also modeled for an average customer/country and is identical for all three substrates. It was assumed that the only impact during this life cycle stage comes from the ATM energy use. The data to calculate the energy use per transaction was acquired from previous studies conducted by the Bank of England[7].

End-of-Life

Since the study follows the cradle-to-grave approach all life cycle stages are included in this analysis. Due to a lack of information and the complex predictability, the end-of-life stage had to be excluded in the present calculation.

Figure 3-2 shows the process map containing attributable processes in the production, distribution and use of the studied products, and their assignment to the life cycle stages mentioned above:

Figure 3-2 Schematic process map for the studied products. Dashed line: Inventory boundary



[7] Source: Bank of England, 2017

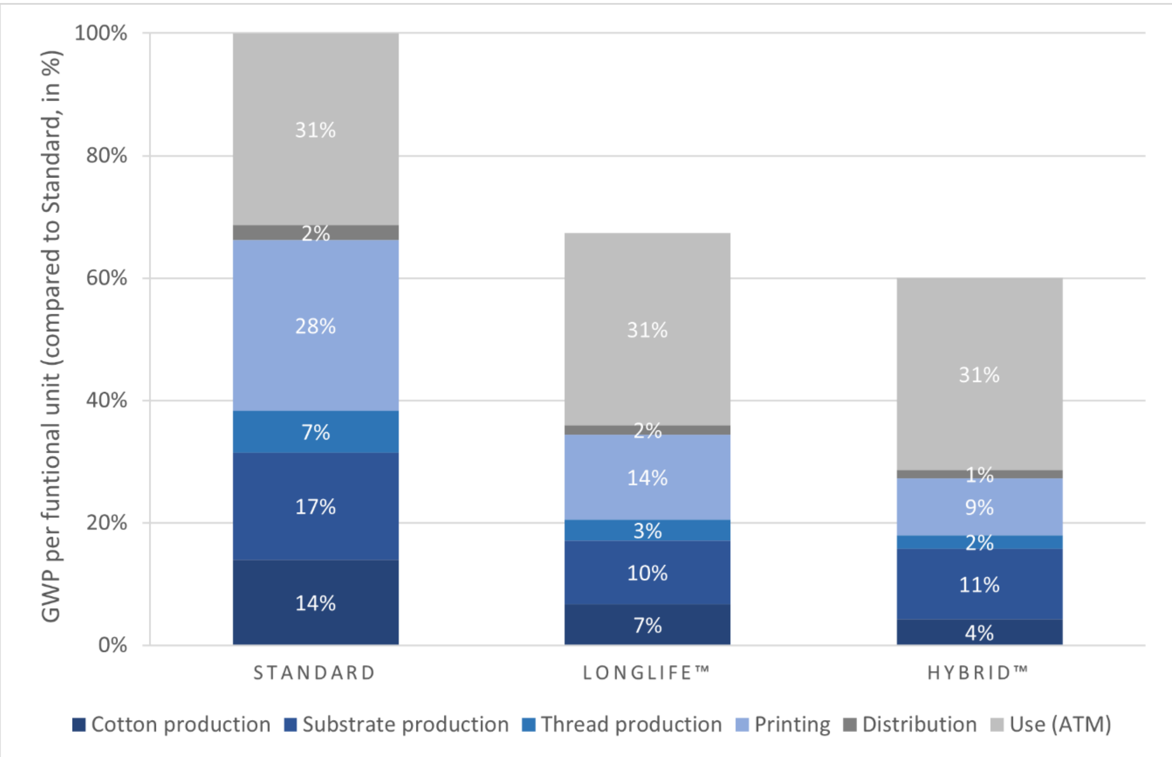
4 Study Results and Sensitivity Analysis

4.1 Global Warming Potential

The results of this analysis indicate that Hybrid™ banknotes have the lowest GHG emissions compared to Longlife™ and Standard banknotes looking at the whole cash-cycle (Figure 4-1). Upon this consideration, when compared with Standard banknotes, Longlife™ and Hybrid™ banknotes offer the highest potential to reduce the impact on global warming, with 30% and 40% lower GHG emissions than the Standard product for Longlife™ and Hybrid™ banknotes respectively. The main reason for these differences is the longer lifetime of the Longlife™ and Hybrid™ substrates. Due to their increased lifetime substantially less banknotes are required to provide the same function. Accordingly, fewer raw materials and less manufacturing proccesses are required as banknote lifespan increases.

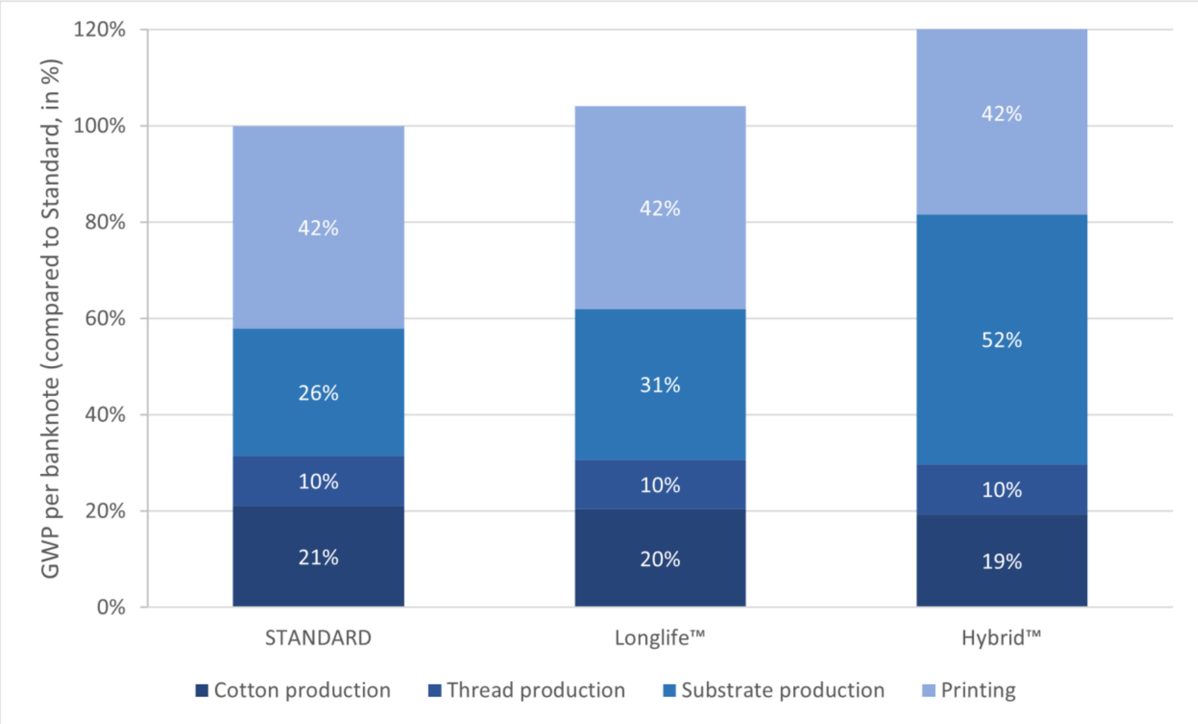
Figure 4-1 shows also the impact of different life cycle stages. The largest share arises from the use phase in connection with use of ATMs and is the same for all three substrates. The second largest position is represented by the printing process followed by cotton, substrate and thread production. The differences in these life cycle stages primary result from the different number of production cycles due to various lifetimes of the analyzed substrates. The distribution of the banknotes has only an exceedingly small impact because of a rather low velocity of circulation and short transportation distances assumed in this study. The larger the distribution area and the higher the velocity of circulation the higher the emissions in the distribution stage.

Figure 4-1 Top level results for GWP by life cycle stage (per functional unit)



In a second consideration it is useful to look at the manufacturing process of a single banknote to better work out what effects occur when considering the functional unit parameters (Figure 4-2). The analysis shows that for one banknote the Hybrid™ banknote has the highest carbon footprint. It's GWP per banknote is about 20% higher than that of a Standard banknote and about 16% higher than the Longlife™ banknote. These differences primary result from the additional coating for the Longlife™ substrate and the two polymer foils for the Hybrid™ substrate. In addition, figure 4-2 shows how the manufacturing-related emissions of a single banknote are distributed over the various stages of production. It is noticeable that the substrate production had the highest impact compared to other life-cycles for the Hybrid™ banknote, whereas the printing process has the highest emissions for the Standard and Longlife™ substrates. When interpreting the results, it should be considered that the data originated from a real customer with a banknote configuration which led to high printing efforts. A minimization of the impact of printing process can be expected as soon as the banknote specifications changes. Thread production has the lowest emissions footprint for all three substrates.

Figure 4-2 GWP of the manufacturing process of one banknote by life cycle stage

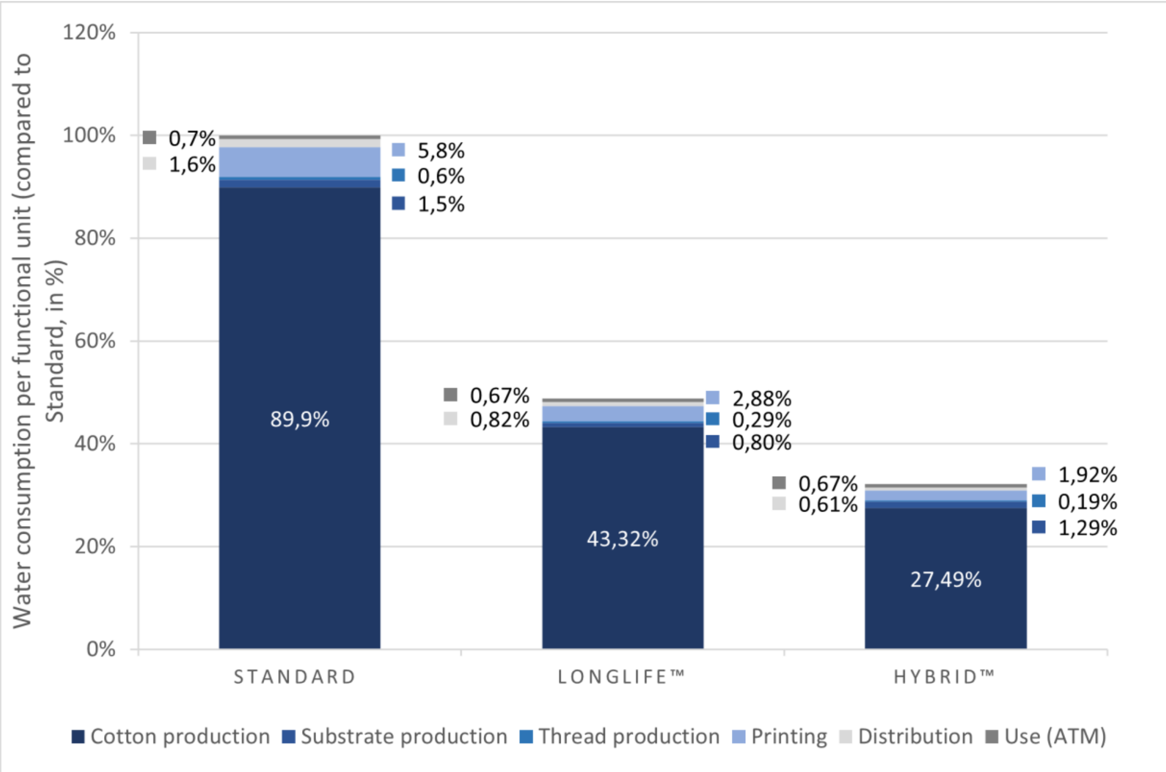


4.2 Water Use

The results of this analysis indicate that Hybrid™ banknotes have the lowest water use compared to Longlife™ and Standard banknotes, when considering the functional unit as described in chapter 2. Upon this consideration, Standard banknotes have the highest water use. Longlife™ banknotes need about 51% and Hybrid™ banknotes about 68% fewer water than the Standard product. The main reason for these differences is the amount of cotton required in the production of the banknotes required to satisfy the functional unit.

Figure 4-3 shows the water use per life cycle stage considering the chosen functional unit. Across all three substrates, the by far the largest share arises from the cotton production. The second largest position is represented by the printing process. The other life cycle stages – thread production, substrate production, distribution and use have only negligible impacts. Across all three substrates the impact of the cotton production is about the same (between 86% and 91%).

Figure 4-3 Top level results for water use by life cycle stage (per functional unit)



In a second consideration it is useful to look at the manufacturing process of a single banknote to better work out what effects occur when considering the functional unit parameters.

The analysis showed that considering the manufacturing process of a single banknote all three substrates have about the same water use. This category is dominated by the raw material production (cotton production). For the production of the Standard substrate, slightly more cotton is needed and therefore more water is used. The Hybrid™ substrate has the lowest water use for the production of one banknote.

Figure 4-4 Water use of the manufacturing process of one banknote by life cycle stage

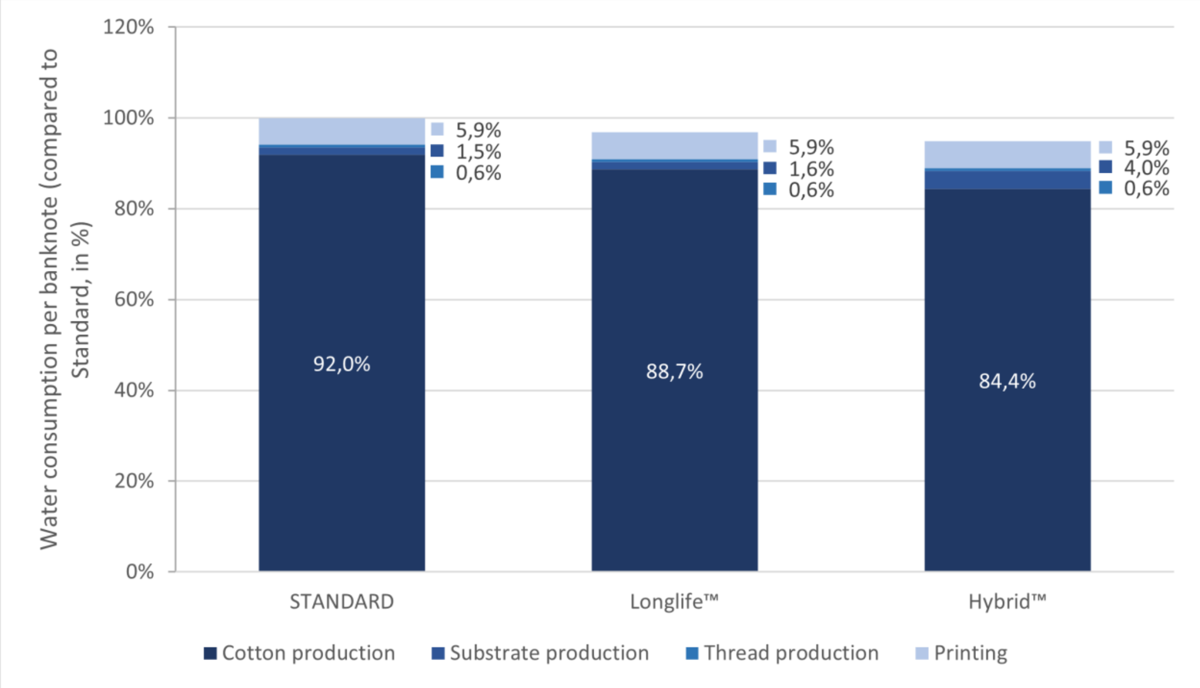


Figure 4-4 shows how the manufacturing-related water use of a single banknote is distributed over the various stages of production. It is noticeable that the cotton production has by far the highest water use across all three substrates. This is followed by the printing process and the substrate production. The water use during the substrate production is higher for the Hybrid™ banknote compared to the other banknotes based on cotton.

4.3 Sensitivity Analysis

Lifetime

The durability/lifetime of the analyzed banknotes is one of the most significant factors for the calculation of the global warming potential and the water use considering the given functional unit. But there is also a high uncertainty about the actual durability/lifetime of the three banknotes under certain climate and circulation conditions. For these reasons, a sensitivity analysis was conducted in order to show the influence of varying lifetimes on the global warming potential and water use of all three substrates.

The analysis indicates a significant influence of the banknote lifetime on the overall results of this study. There is an inverse relationship between the durability/lifetime of the banknotes and their global warming potential/water use. As the banknote lifetime increases, so the global warming potential/water use decreases. By doubling the lifetime from 6 to 12 months the global warming potential decreases by 30-35% and the water use by 45-50%.

To further explain this considerable influence the GWP and the water use of the Standard substrate with a lifetime of 6 months are compared with the Hybrid™ substrate at different lifetimes.

Table 4-1 Influence of the lifetime using the example of Standard vs. Hybrid™

Substrate:	Standard	Hybrid™				
Lifetime:	6 months	6 months	12 months	18 months	24 months	30 months
GWP (%):	100%	111%	74%	62%	55%	52%
Water use (%):	100%	94%	47%	32%	24%	20%

Alternative raw materials

All three substrates analyzed in this study are based on conventional cotton comber, which has an extremely high impact on the banknotes' water use. For this reason, a sensitivity analysis was conducted to evaluate the influence of alternative raw materials – such as organic cotton, flax fiber and cellulose fiber – on the global warming potential and water use of banknotes. All three alternatives are possible substrates for the production of banknotes.

The analysis indicates only a small influence of alternative raw materials on the global warming potential, but in terms of the water use a significant effect for all analyzed substrates can be observed. The highest reduction for both impact categories can be achieved by substituting cotton with irrigation by rainfed cotton production. By reducing the water consumption in cotton farming, the overall water use of a banknote could be reduced by 85-90%.

Table 4-2 Sensitivity analysis of the manufacturing process of one banknote by variation of the raw material – Standard Substrate

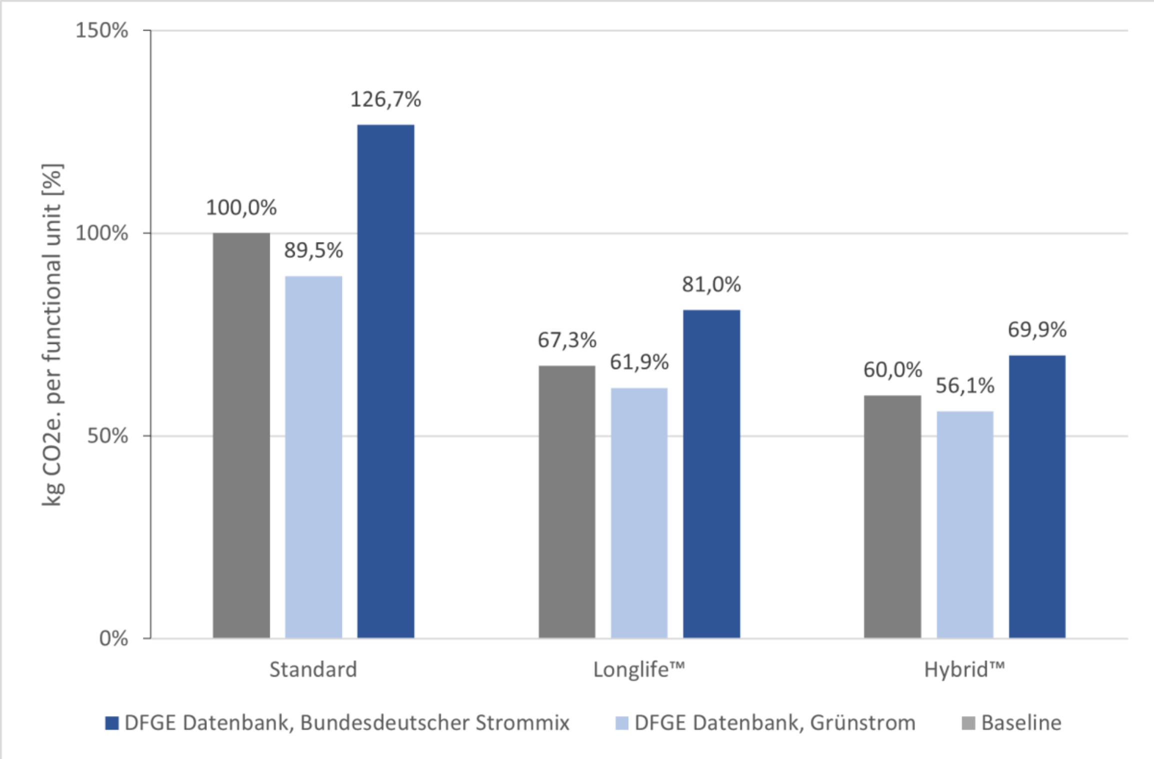
Raw material:	Irrigated cotton	Rainfed cotton	Cellulose fiber	Flax fiber
GWP [g CO2e/BN]:	100%	83%	95%	84%
Water use [l/BN]:	100%	8%	33%	17%

Electricity

The production of all three banknotes is associated with a high consumption of energy. Especially the printing processes requires a high amount of energy input. Therefore, a sensitivity analysis was conducted to analyze the effect of three different electricity mixes on the global warming potential of a single banknote. The basis scenario in this analysis is the current electricity mix for the production sites under study. The two alternative scenarios are the average electricity mix in Germany with a higher emission factor than the basis scenario and 100% green electricity with a lower emission factor. The two alternative scenarios are only considered for the thread production, substrate production and the printing processes (not the use phase).

As seen in Figure 4-5 by using the average electricity mix in Germany the global warming potential regarding the functional unit would be increased by more than 27% (Standard BN). On the other side using 100% green electricity would lead to reduction by up to 11% (Standard BN).

Figure 4-5 Sensitivity analysis of GWP per functional unit by variation of the electricity mix – PCF



5 Conclusion and Outlook

Interpretation of results

The results for the global warming potential clearly indicate a lower footprint for Hybrid™ and Longlife™ when considering the chosen functional unit. Looking at the manufacturing of a single banknote Hybrid™ and Longlife™ have slightly higher emissions compared to the Standard substrate. This is due to the additional coating for Longlife™ banknotes and the polymer foil for Hybrid™. These additional materials and processing steps lead to a higher durability and a longer lifetime of the respective banknotes. The higher the durability of a banknote the less often it must be replaced. Therefore, the better performance of Longlife™ and Hybrid™ per functional unit is primary based on their significantly longer lifetime and the associated lower number of production cycles.

A banknote's lifetime and therefore their overall carbon footprint highly depends on environmental and circulation conditions like climate and velocity of circulation. For this reason and the lack of insight into data, emission factors and calculation methods of previous studies, a comparison of results with these studies is very difficult. However, when simply considering the manufacturing of a single banknote all three substrates considered in the present study indicate a lower carbon footprint compared to the analyzed substrates in previous studies.

The results for the water use show nearly the same performance for all three substrates when considering the manufacturing of a single banknote. For the same reason as explained above the results per functional unit show significantly lower water use for Hybrid™ and Longlife™. This impact category is dominated by the raw material production of conventional cotton. The high water use associated with this life cycle stage can be reduced significantly by substituting irrigated cotton with rainfed production or alternative raw materials. Sensitivity analysis showed that water use could be reduced by up to 90%.

Table 5-1 Top level GWP and water use results

	Standard BN	**Longlife™ BN**	**Hybrid™ BN**
Per functional unit:			
GWP [kg CO2e/FU]:	207	140	124
Water use [m³/FU]:	26	13	9
Per manufacturing of a single banknote:			
GWP [g CO2e/BN]:	6,9	7,2	8,5
Water use [dm³/BN]:	1,3	1,3	1,2

Outlook

Through the above presented results, Papierfabrik Louisenthal can gain valuable insights into the composition of the described product's emissions balance, identify main emission sources and priority areas for improvement.

Based on the calculation and reporting framework established in this project, analyses for further Papierfabrik Louisenthal products can be conducted and will support Central Banks in decision making.

In the future a frequent monitoring of the inventory should be considered, to be able to compare the performance over time. Further the results can be used to set reduction targets and track their development.

Index and References

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Founded in 1999 as a spin-off of the technical University of Munich, the DFGE – Institute for Energy, Ecology and Economy provides consulting services in the field of sustainability. Our offer Sustainability Intelligence featuring calculation management, reporting solutions and strategy development aims at bundling the effort of taking part in several sustainability/CSR standards and rankings like CDP, UNGC, DJSI, EcoVadis or GRI as well as building overarching strategies, such as a sustainability strategy according to the SDGs. As the unique partner of the CDP for SBTs, DFGE provides its customers with comprehensive advice on climate strategy and helps them to operate climate-neutrally at product level or company-wide. To enable a future AI-based CSR management, DFGE researches in big data approach and machine learning. Our clients comprise international companies (DAX and fortune 500), SMEs, governmental organizations or territorial authorities.

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