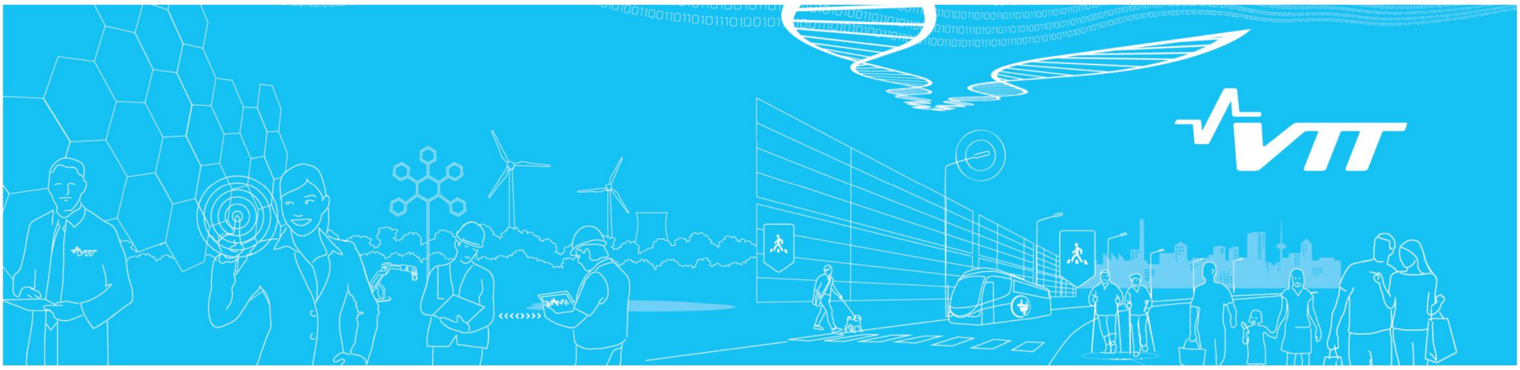

CUSTOMER REPORT

VTT-CR-04462-14 | 3.10.2014

Environmental performance of future digital textile printing

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Confidentiality: Public

Report's title

Environmental Performance of Future Digital Textile Printing

Customer, contact person, address	Order reference
Printscorpio, Tommi Helminen	Digitex textile printing project
Project name	**Project number/Short name**
Digitex	83282 Digitex

Summary

Overall aim of Digitex research was to develop textile products with better environmental performance and new kind of resource efficient business models. The research consisted of new kinds of models and product concepts, by which it is possible to do unique and/or short-run production in order to avoid overproduction.
Consequently, environmental performance of two textile printing types was evaluated based on life cycle assessment approach. The two evaluated textile printing methods were digital printing and screen printing. The initial aim was to find out from the environmental perspective when to print with digital printing and when with screen printing. The results or environmental performance evaluation are presented in this report.
Environmental impacts were evaluated using Life Cycle Assessment (LCA), using cradle-to-gate approach. It means that all the life cycle stages after printing plant were excluded from the scope. Also non-comprehensive Water Availability Footprint (WAF) with gate-to-gate approach was assessed where focus was in textile printing house production's water consumption, its quality and its scarcity.
The results of the study indicate that digitally printed textile has smaller environmental impacts than a textile printed with screen printing in all the studied impact categories. Mainly this is due to the fact that screen printing needs more printing dyes both in a test drive and in actual printing process. This in turn means that screen printed fabric needs more after wash which consumes energy, surfactant and water. With the help of several sensitivity analyses the broader understanding of the carbon footprint of printing methods was made. The sensitivity analyses strengthened the conclusion that digital printing is more environmental friendly printing method than screen printing. However, there are other aspects – such as money, production time and people's work time required - too to be considered when a choice of printing method is done.
Cotton production had biggest environmental impacts along the textile product life cycle. By choosing an environmental friendly base material, environmental impacts of printed products can be reduced. This possibility could be further considered and current development of new materials and technologies should be followed.
Water Availability Footprint results show that the difference between digital printing and screen printing is very small due to very good availability of water in Finland. The significance of water consumption would increase if the textile manufacturing occurred in a location with high scarcity of water.
Obviously there is the need of primary data from different manufacturers in the life cycle of textile printing product e.g. more precise information about different materials such as cotton as well as printing inks and chemicals are needed. The use of generic databases instead of actual measured figures for these processes increases the uncertainty of the results.

Espoo, 3.10.2014

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Distribution (customer and VTT)

Printscorpio, Tommi Helminen and VTT

Contents

1. Goal and scope of the study

The goal of the study is to evaluate the environmental impacts of digital textile printing, and to find out the pros and cons of digital printing from environmental point of view. In order to have a reference line and to assess whether digitally printed textile is performing well or not, similar product is printed with screen printing. In real life, digital printing and screen printing are used for different product types and are not comparable in that way. However, comparison of digital and screen printing gives valuable information about the environmental aspects of each printing technology.

The study is based on the life cycle assessment (LCA) methodology. The LCA is made following the principles of international life cycle assessment standards ISO 14040 and 14044. The study is carried out in VTT Technical Research Centre of Finland. The study is intended for internal communication, business-to-business communication and marketing purposes.

This report is a background report, listing the made assumptions, limitations of the study and explaining the assessment method. The report is not meant to be a scientific publication about the differences and environmental performance of digital and screen printing. The report is intended to support the power point presentation that is delivered to the customer (Printscorpio), presenting the results of the research work.

1.1 Functional unit

The functional unit of the study is 750m2 of printed textile. The initial goal was to study fabric printed with 5 colours, using three (3) different colourways. However, data for different reactive dyes was not accessible and only generic data for an average reactive dye was available in the PE database (Extension database: Textiles). For this reason only amounts of colourways are included in the assessment (stencil wash, scraping etc), and unfortunately the impacts ofof different colourways were not assessed in this study.

Figure 1. Fabric is printed with five colours, using three different colourways. All the other colours change but black remains. However, impacts of different colours could not be studied in the LCA due to lack of LCI data.

The coverage of the printing in this study was chosen to be 88%. The results of the study are affected of this decision and the results might look different with coverage of 25%, for example. However, it was decided that other coverage will not be studied in this research. The used coverage (88%) is very realistic and corresponds well to a real life printing jobs.

In the study the functional unit was 750 squaremeters (m^2), but in a report one can see also an unit of meters. If an unit of meter was used, it means a running meter of fabric and it equals to 1,5 squaremeters.

1.2 System boundary

This study evaluates the cradle-to-gate impacts of the studied product systems. This means that end of life processes are excluded from the study. In addition to that, “tailored finishing” was excluded because it differs from case-to-case, depending on the customer’s wishes. It is also reasonable to assume that impacts of the tailored finishing are negligible and therefore could be excluded from the study.

When life cycle impacts of a textile product are evaluated, consumer phase (washing) and disposal have also a contribution on environmental impacts (van der Velden et al 2014). Therefore, results of this study cannot be used as a comprehensive environmental impact assessment of digitally or screen printed textile products. However, the study gives good indication of the environmental impacts of textile production and printing.

Transportation for chemicals, other raw materials and cotton were included in the study. End of life treatment, mainly waste water treatment and hazardous waste treatment, for printing wastes was also included in the study.

1.2.1 Digitally printed textile

System boundary for digital printed product is presented in the following figure. The more detailed flowsheet is presented in appendix 1a.

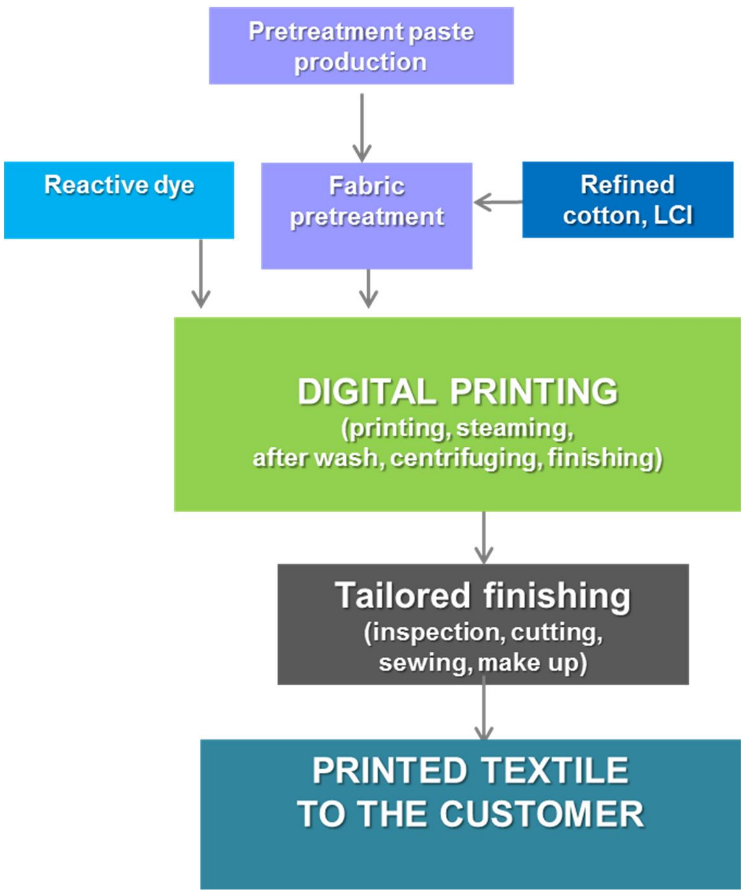


Figure 2. System boundary of digitally printed product. Tailored finishing was not included in the study.

1.2.2 Screen printed textile

System boundary for screen printed product is presented in the following figure. The more detailed flowsheet is presented in appendix 1b.

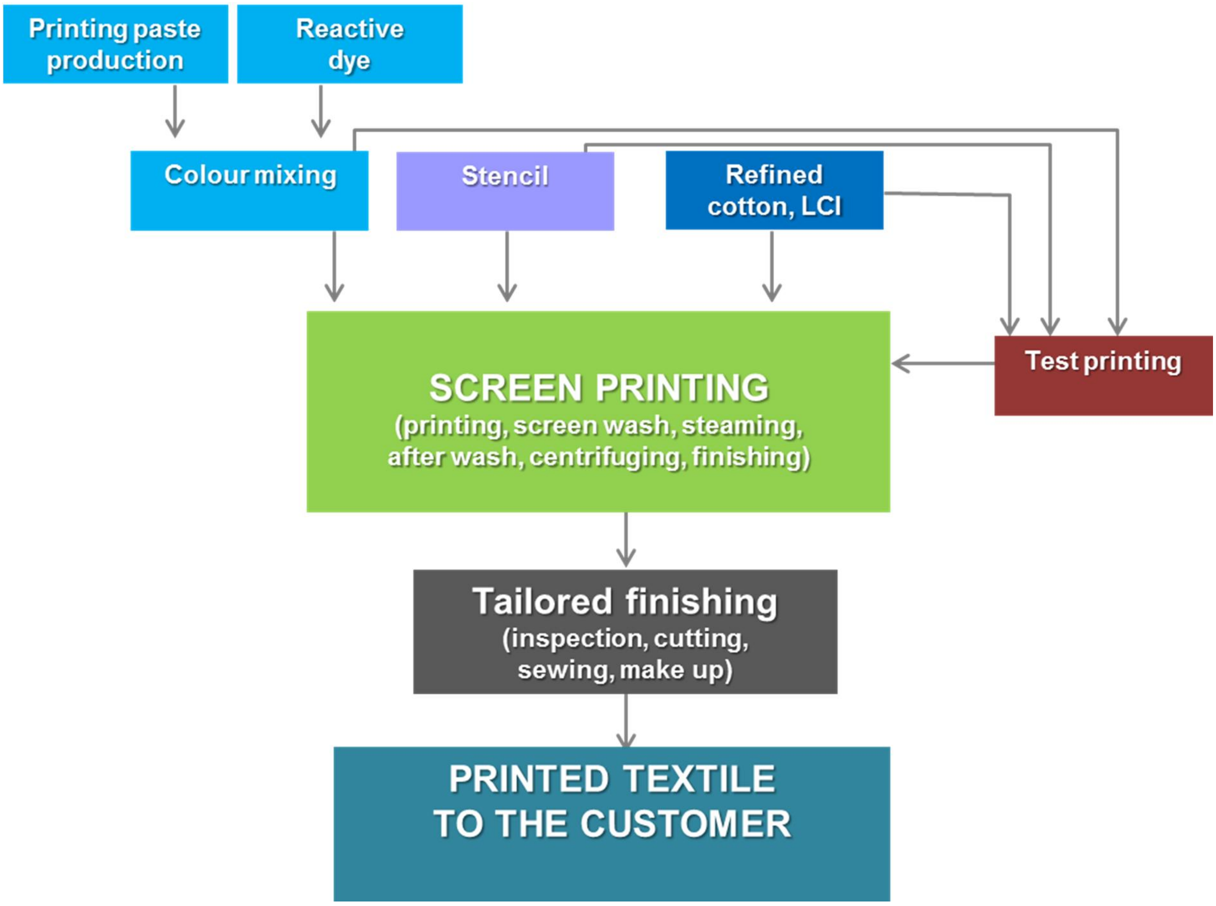


Figure 3. System boundary of screen printed product. Tailored finishing was not included in the study.

1.3 Test drive

Before the actual printing work can start, test drive needs to be done with both printing methods. In this study, test drive is assumed to be three meters, which corresponds to 4,5 square meters. Because of three colourways, test drive needs to be done three times. In screen printing, one meter is left empty between colourways whereas in digital printing all the colourways could be printed without empty meters.

Especially in screen printing test drive is time and resource consuming. The same five stencils are needed in test drive that are needed in actual printing job, and the consumption of printing dye is high when it is related to printed meters in test drive.

In this study a test drive was assumed to be 3 meters. However in reality, test drive might be longer than that and there is a possibility that it has to be done several times. Test drive has a clear contribution on results and if the size of test drive is increased or if it has to be made several times, the impact of test drive would grow further.

1.4 Cut off criteria and assumptions concerning used chemicals and other input materials

There are several chemicals used in the textile industry and printing houses, and mostly the amounts of used chemicals are rather small. Some of the used chemicals are very textile industry specific and therefore hardly found in life cycle inventory (LCI) databases. Some of the used chemicals were omitted from the study according to cut off criteria and for the chemicals that were to be included but specific LCI data was not found, corresponding data was searched from the LCI databases.

The LCI standards 14040-44 indicate that if an input material is less than 1% of the functional unit of the system it could be excluded from the study. However, not more than 5% in total shall be excluded. Based on this cut off criteria some of the minor chemicals used in the printing house were excluded from the study.

Any chemicals used in textile refinement are included in the cotton production LCI dataset and thus these chemicals are not listed in the following table. The following table (Table 1) explains the assumptions made in the study for the printing house chemicals.

Table 1.Assumptions related to chemicals used in the printing house. NA (not available) means that life cycle inventory information was not included in the study.

Chemicals used in printing plant	Screen printing	Digital printing	LCI data used for the chemical	Source
G333c	X		acetic acid	Ecoinvent 2.2
G101c	X		acetic acid	Ecoinvent 2.2
Polycol Z 514	X		NA	
SAATIGRAF CTS5	X		NA	
STRIP POWDER SSL02	X		NA	
CPS Screen cleaner	X		esterquat, coconut oil and palm kernel oil, at plant, tensides, RER, LCI	
Rapidoprint XRG	X	X	NA	
Sodium bicarbonate	X	X	Sodium bicarbonate (NaHCO3)	VTT Ecodata
Urea	X	X	urea	Ecoinvent 2.2
CHT ALGINAT NVS	X		CHT ALGINAT combined with PRISULON was assumed to be equivalent to Lyoprint rd-ht → LCI data for *solvents, organic*	Ecoinvent 2.2
PRISULON CR-F 50	X			
Reactive dye for digital printing (Reactive dye 15%, ethylene glycol 20%, processed water 65%)		X	Reactive dye	PE International
			Ethylene glycol	Ecoinvent 2.2.
Reactive dye for screen printing (Reactive dye 50%, sodium sulphate 50%)	X		Reactive dye	PE International
			Sodium sulphate	Ecoinvent 2.2.
Lyoprint air		X	Solvent, organic	Ecoinvent 2.2
Sodium carbonate		X	Sodium carbonate, NaCO3	VTT Ecodata
Lyoprint rd-ht		X	Solvent, organic	Ecoinvent 2.2
Antibacteria		X	NA	
Eriopon OS	X	X	Ethoxylated alcohols, unspecified	Ecoinvent 2.2.

1.5 Other input materials

In addition to chemicals there are other materials that are needed in printing processes. The following table lists materials, made assumptions and used data sources.

Table 2. Assumptions related to other input materials. NA (not available) means that life cycle inventory information was not included in the study.

Materials used in printing	Screen printing	Digital printing	LCI data used for the input material	Source
Recording HNS	X		NA	
Kiwobond Powergrip	X		NA	
Kiwodur Powergrip	X		NA	
Oracal sticker	X		NA	
Aluminum stencil	X		LCI for aluminium sheet	EAA 2008
Screen fabric	X		NA	

1.6 Energy profiles used in the study

1.6.1 Electricity

Electricity used in the printing house is assumed to be average Finnish grid electricity over five years (2007-2011). The average supply mix for Finnish grid electricity is presented in Figure 4.

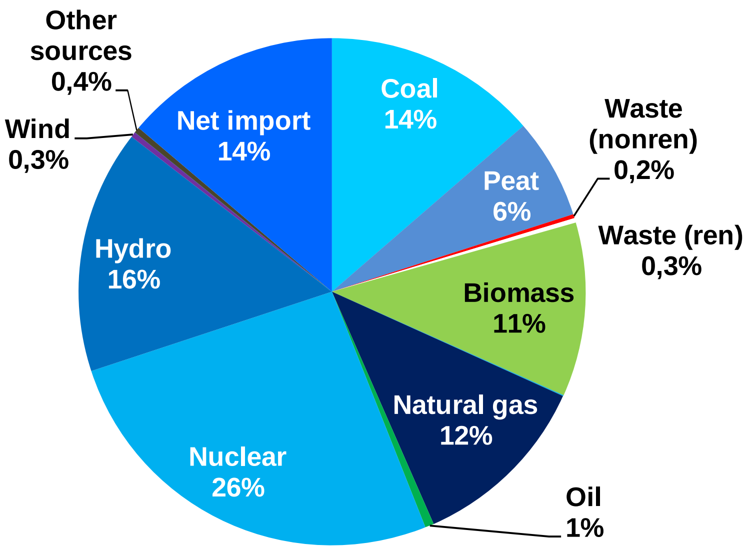


Figure 4. Average Finnish grid electricity (supply mix) for years 2007-2011.

Mostly LCI (cradle-to-gate) data is used for the chemicals, meaning that the data already includes assumptions about the used electricity as well as the emissions from electricity production. However, some chemicals used in the study do not include energy production and in those cases OECD average grid electricity for years 2007-2011 is used (Figure 5).

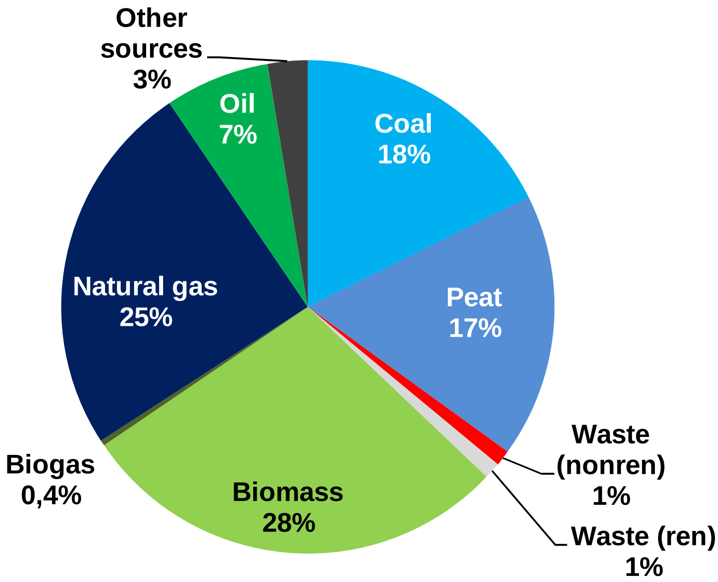


Figure 5. Average OECD Europe grid electricity production mix for years 2007-2011.

1.6.2 Propane

Propane is used for heat production in the printing plant. LCI data for propane production is sourced from Ecoinvent 2.2. Propane combustion is included in the LCI data Printscorpio has provided to VTT. Carbon dioxide emissions are calculated with the emission factor from Statistics Finland (Statistics Finland 2014), using the emission factor of 65 $kgCO_2/GJ_{fuel}$. Other emissions from propane combustion are assumed to be negligible and thus excluded from the study.

1.6.3 Light fuel oil

Light fuel oil is used for steam production in the printing plant. LCI data for light fuel oil production is sourced from Ecoinvent 2.2. Light fuel oil combustion is included in the LCI data Printscorpio has provided to VTT. Carbon dioxide emissions are calculated with the emission factor from Statistics Finland (Statistics Finland 2014), using the emission factor of 73 $kgCO_2/GJ_{fuel}$. Nitrogen oxides (NO_x) and particulate emissions (PM) from light fuel oil combustion are evaluated based on the emission limits (Government of Finland 2010) to small light fuel oil combustion plants (13g/kg_{fuel} and 1g/kg_{fuel} respectively). It is noted that the emissions do not equal to the exact amounts of emissions from Printscorpio plant but the evaluation gives a good indication of the NO_x and PM emissions.

1.7 Cotton

The fabric used in the printing is 100% cotton with grammage of 150g/m^2. Life cycle inventory information for cotton production and textile refinement are sourced from Ecoinvent 2.2. The following figure (Figure 6) presents the datasets used for Refined cotton fabric – module used in the study. The data in ecoinvent modules is calculated per kilogramme of cotton and it does not consider grammage at all. This generalisation might cause some error to the balance sheet of cotton. The grammage is taken into account in the life cycle model built in SULCA but it does not change the fact that the initial data for cotton fabric does not take into consideration the possible changes in emissions of different grammages.

The dataset represents global average of cotton production and refinement and therefore does not give exact values for the fabric used in Printscorpio. However, it was not reasonable to collect specific data for cotton because the focus in this study was in printing methods.

The average nature of the used data should however be kept in mind, especially when cotton causes most of the environmental impacts of printed textiles. Further discussion on the use of average LCI data can be found in scientific literature, i.e. Saxce et al (2014) discusses the representativeness and appropriateness of average LCI data for textile products.

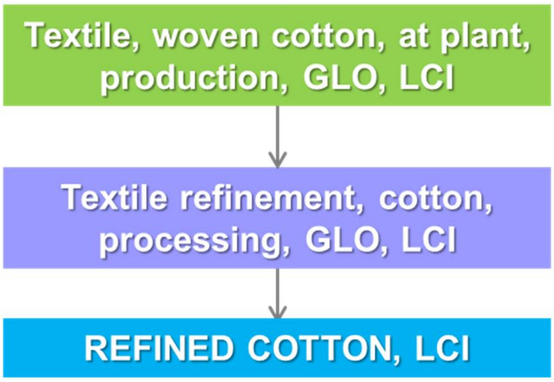


Figure 6. LCI dataset for refined cotton

Textile refinement includes processes of bleaching, washing, dying and drying. It should be noted that part of these processes (dyeing and maybe part of drying) could be taken into account now twice: once in textile refinement dataset and then in the printing house. Textile refinement causes 15% of the climate impact of the climate impact of cotton, and dying is only part of it. The issue of double counting was considered but it was decided that since printing house is on a focus in the study (not the cotton) and due to lack of information, textile refinement was included as such hence the amount of emissions that are double counted is not that significant. Van der Velden et al (2014) have evaluated the impacts of different life cycle stages during textile manufacturing and these results indicate also that even there is double counting in pre-treatment, the impact is not that significant.

1.8 Waste management

There are some waste flows from the printing plant. Waste is transported to hazardous waste treatment plant, 100 km away from Aitoo (with truck of 25t). There is a small amount of waste going to a landfill but the amount of landfilled waste is considered negligible and thus excluded from the study.

1.9 Waste water treatment

The Printscorpio textile printing house has an own water purification plant, which purifies waste water coming from Printiscorpio as well as waste waters from another company nearby. The water is purified and its' quality is measured regularly. Thus, the values used for water quality as well as to estimate the emission loads is based on average water quality measurements, which are done by protection organisation of Kokemäenjoki river. There are values measured in relation to incoming groundwater to textile printing manufacturing, the outgoing waste water to purification plant as well as the outgoing water from the purification plant. The average water use amount on daily bases is around 14m^3. The waste water sampling is done manually from sewer. The data used in this report is based on year 2013 average for measurements' data. The total efficiency of the purification system is for total phosphorus (P) and total nitrogen (N) around 98 percent and 85 percent, respectively.

2. Life cycle assessment – methodological framework

The examination of the environmental impacts in this study is based on life cycle assessment (LCA). LCA analyses the environmental aspects and potential impacts across the product life cycle from cradle to grave, including raw material acquisition, production, use, end-of-life treatment, recycling, and final disposal, by examining the physical chains of material flows. LCA assesses the environmental impacts of product systems in accordance with the stated goal and scope. (ISO 14040:2006)

The four phases of LCA are the goal and scope definition phase, inventory analysis, impact assessment and interpretation. ISO 14040 -standard addresses some requirements for carrying out LCA. The goal definition phase determines the goal of a study; the intended application, the reasons behind the study, the intended audience and if the results are intended to be used in comparative assertions in public. The scope includes information about the studied product system, the functions of product system, the functional unit, the system boundary, the allocation procedures, data requirements, assumptions, limitations, initial data quality requirements and type of critical review. (ISO 14040:2006). Figure 7 presents the four stages of LCA.

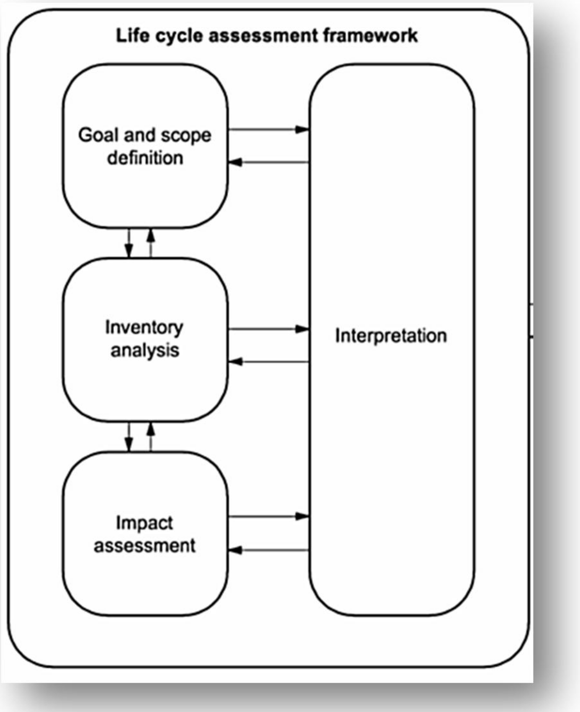


Figure 7. Four stages of LCA. (ISO 14040:2006)

Life cycle inventory (LCI) phase gives information about the inputs from the environment to the system and about the outputs to the environment from the studied system. Data for each unit process can be classified as follows:

- energy inputs, raw material inputs, ancillary inputs and other physical inputs;
- products, co-products and waste
- emissions to air, discharges to water and soil, and
- other environmental aspects.

After gathering the data, information is related to unit processes and to the reference flow of the functional unit. (ISO 14040:2006)

In the life cycle impact assessment (LCIA) phase, the significance of potential environmental impacts is evaluated using the LCI results. LCIA involves associating inventory data with specific environmental impact categories and category indicators. The mandatory elements in LCIA phase are (ISO 14040:2006):

– selection of impact categories, category indicators and characterization models
– assignment of LCI results (classification)
– calculation of category indicator results (characterization)

In addition, normalization, grouping and weighting can be done. In this study, none of the optional elements are included.

2.1 Partial carbon footprint

Carbon footprinting is a standardised method to evaluate the greenhouse gas emissions occurring during the product´s life cycle. Carbon footprint of a product presents the life cycle greenhouse gas emissions that are released as part of the process of creating, modifying, transporting, storing, using, providing, recycling or disposing of a product (ISO 14067). Since this study concentrates on cradle-to-gate carbon footprint (partial carbon footprint), emissions occurring after finishing the printed fabric are excluded from the study. All the greenhouse gas emissions mentioned in ISO 14067 were included in the carbon footprint calculation.

Greenhouse gas emissions were converted into carbon dioxide equivalents using global warming potentials of 100 years (Table 3 presents the GWP factors of the three most relevant greenhouse gases). From greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and dinitrogen oxide (N_2O) emissions have clearly the biggest contribution on carbon footprint. All the other greenhouse gas emissions have insignificant contribution on carbon footprint of digitally and screen printed products but are anyhow included in the calculation.

Table 3. Global warming potentials (GWPs) for different greenhouse gases (IPCC 2007).The same factors are used in ReCiPe impact assessment method and ISO 14067.

Greenhouse gas	**Global Warming Potential**
CO_2	1
CH_4	25
N_2O	298

2.2 ReCiPe and chosen impact categories

The life cycle impact assessment (LCIA) phase was performed by applying the ReCiPe Midpoint method (Goedkoop et al 2013). ReCiPe is an LCIA method, which offers results at both the midpoint and endpoint level. The midpoint-level assessment is used in this study, emissions and extractions of natural resources are converted into impact category indicator results for impact categories such as acidification, climate change and eutrophication. The endpoint-level assessment is not used in the study.

Altogether the ReCiPe impact assessment method includes eighteen midpoint indicators (Goedkoop et al. 2009). In this study, five of them were used (in addition to climate change). The studied environmental impact categories were:

- Fossil depletion [kg oil eq]
  - Use of fossil fuel resources lead to fossil resource depletion
- Terrestrial acidification [kg SO_2 eq]
  - Sulphur dioxide and nitrogen oxides to air have an impact on acidification of soil
- Particulate matter formation [kg PM10 eq]
  - Particle - , nitrogen and sulphurous emissions give rise to particulate matter formation, which in turn impacts on human health
- Freshwater eutrophication [kg P eq]
  - Phosphorus emissions cause freshwater eutrophication
- Marine eutrophication [kg N eq]
  - Nitrogen emissions to water and air cause marine eutrophication

Toxicity categories were not assessed in this study. Therefore no conclusions of toxicity could be drawn from the results.

3. Cradle-to-gate carbon dioxide emissions and carbon footprint

The cradle-to-gate carbon footprint was calculated for both of the printing methods, and with and without cotton. In addition, a question “*When to print with digital printing and when with screen printing from the climate change point of view?”* is studied from different view angles to find out as comprehensive answer as possible.

A strict one-by-one comparison of these two printing methods is not reasonable due to the different purposes of the printing methods. Therefore three sensitivity analyses were carried out to cover the differences in printing batch size, an impact of life time as well as differing amounts of printing batches. Nowadays there are no significant differences in quality or durability between products that are printed with screen or digital printing and thus products printed with these printing methods are comparable with each other.

In the following figures (Figure 8 without cotton and Figure 9 with cotton) cradle-to-gate carbon footprints are presented for both digital and screen printed textiles, calculated to represent the impact of the functional unit (750m^2).

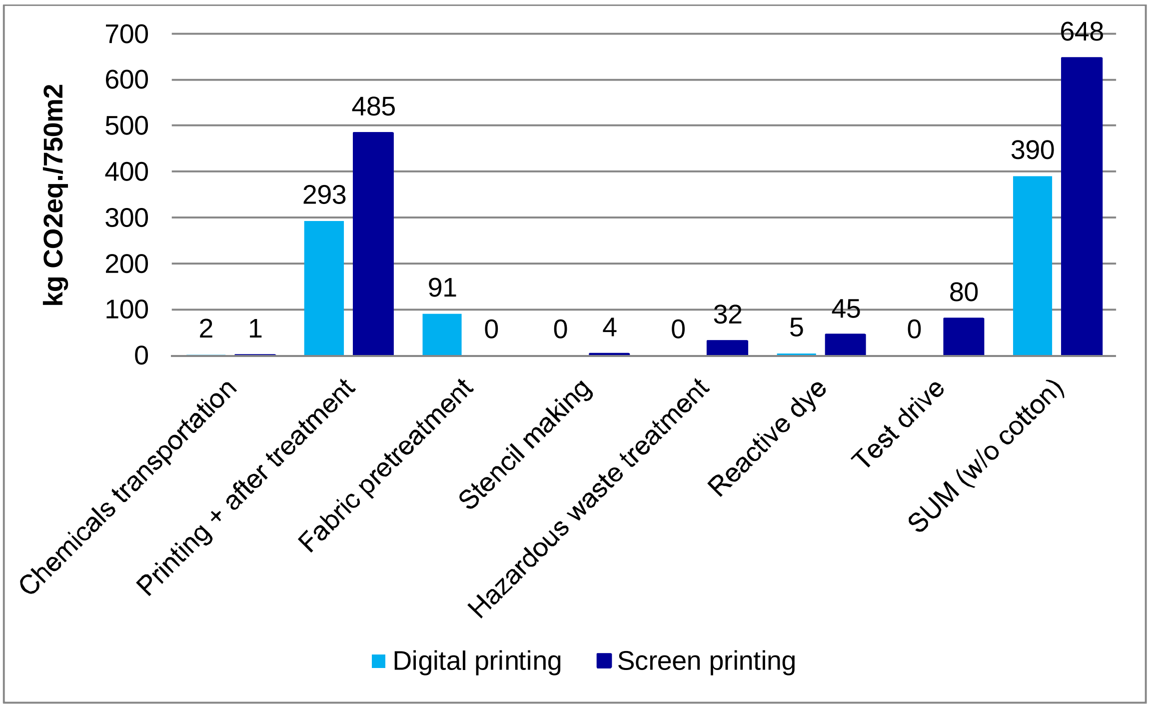


Figure 8. Cradle-to-gate greenhouse gas emissions from printing, emissions from cotton production are excluded [kg $CO_2eq/750m^2$].

Cotton production causes large amounts of greenhouse gas emissions. Cotton production consumes big amounts of water, fertilisers and pesticides and thus considerable amounts of carbon dioxide are emitted to the atmosphere. Cotton production and transportation cause circa 90% of the greenhouse gas emissions emitted during the production of a digital printed textile and about 85% of the greenhouse gas emissions of a screen printed textile.

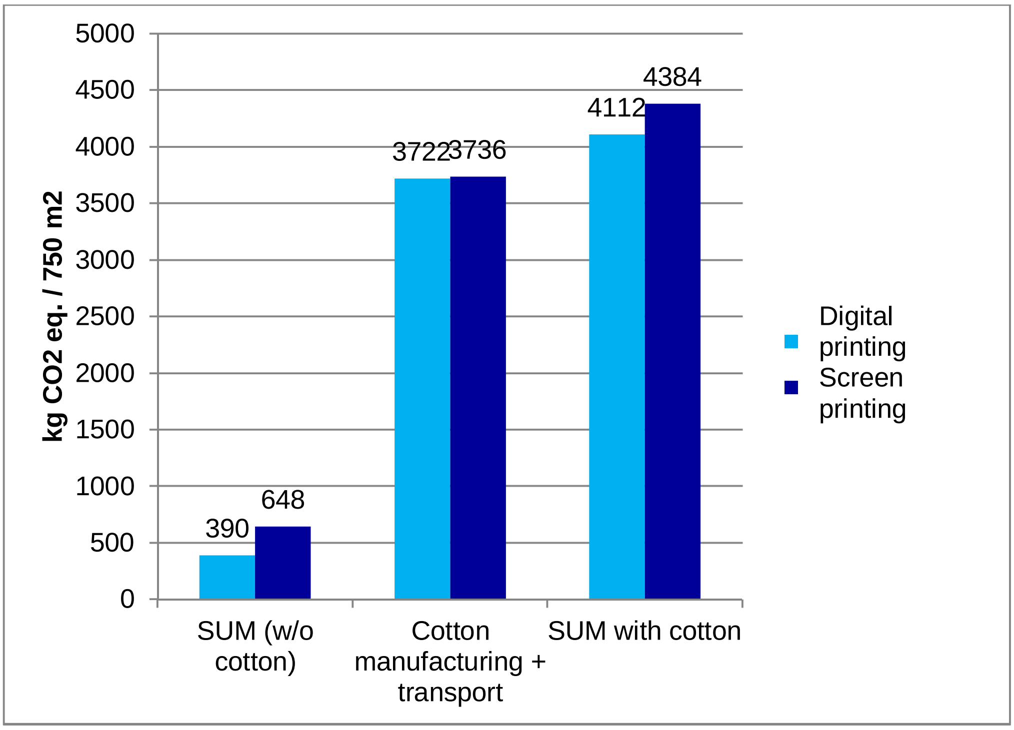


Figure 9. Cradle-to-gate greenhouse gas emissions from printing, cotton included [kg $CO_2eq/750m^2$].

3.1 Digital printing

The Figure 10 presents the greenhouse gas emissions from digital printing processes. It can be seen that after wash, finishing and fabric pre-treatment are the main contributors to greenhouse gas emissions. In finishing and fabric pre-treatment propane is used for steam production, whereas in after wash light fuel oil is used for steam production.

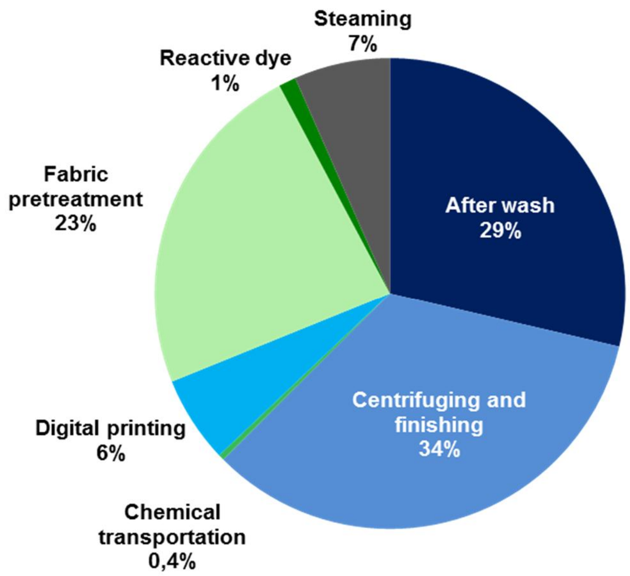


Figure 10. Greenhouse gas emissions [kg CO_2eq] from raw material production and printing processes (cotton and transports excluded).

Next figure (Figure 11) shows that cotton production causes most of the greenhouse gas emissions. Fabric pre-treatment (including chemical manufacturing), reactive dye manufacturing and printing (including after treatment) have a total share of about 10% of the cradle-to-gate greenhouse gas emissions whereas cotton production and transportation causes circa 90% of the total greenhouse gas emissions.

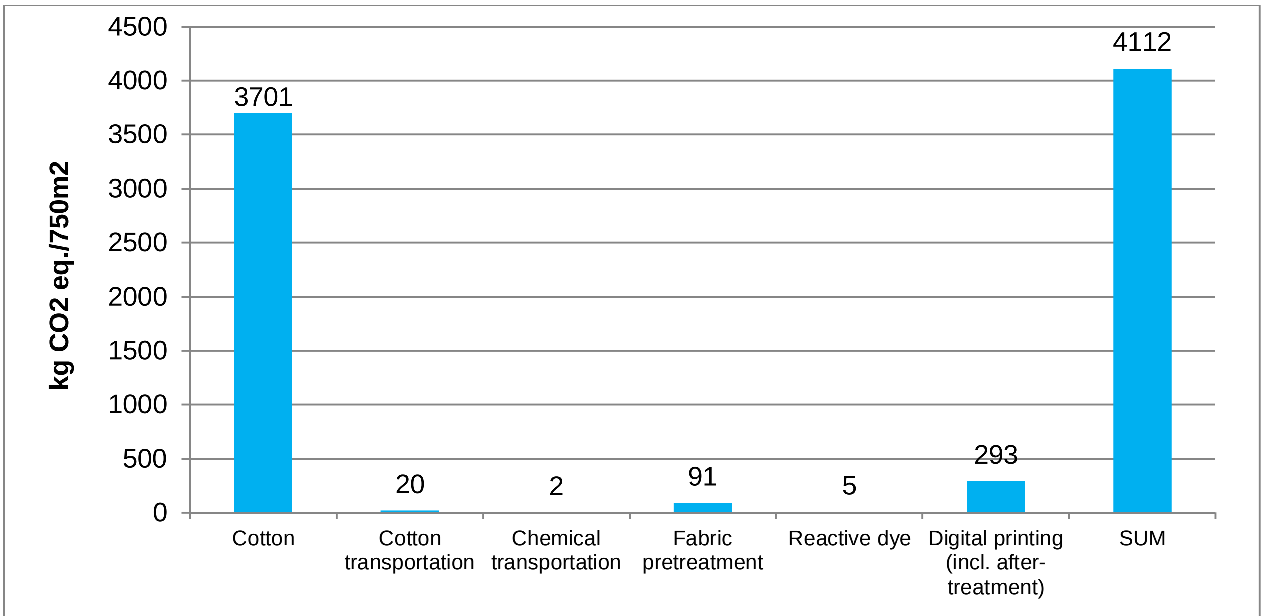


Figure 11. Greenhouse gas emissions of digitally printed product (kg CO_2eq./750m^2)

3.2 Screen printing

The Figure 12 presents the greenhouse gas emissions from screen printing processes. It can be seen that after wash and finishing are the main contributors to carbon dioxide emissions, causing more than half of the CO_2 emissions from printing. Propane is used for steam production in finishing, whereas in after wash light fuel oil is used for steam production, both fuels contributing to greenhouse gas emissions. In addition, test drive has a remarkable contribution on greenhouse gas emissions.

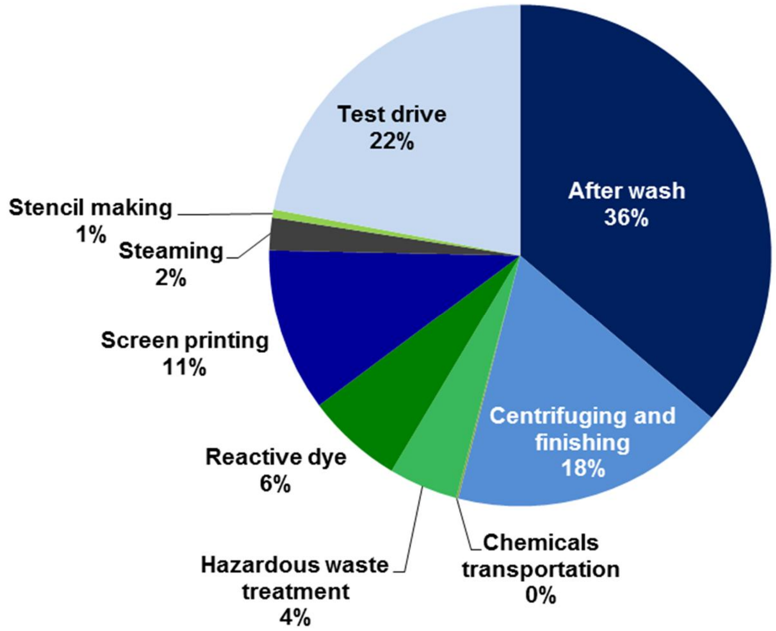


Figure 12. Cradle-to-gate carbon dioxide emissions [kg CO_2] from raw material production and printing processes (cotton and transports excluded).

Screen printing (including chemical manufacturing), reactive dye manufacturing and printing have a total share of about 10% of the cradle-to-gate greenhouse gas emissions whereas cotton production and transportation causes circa 90% of the total greenhouse gas emissions.

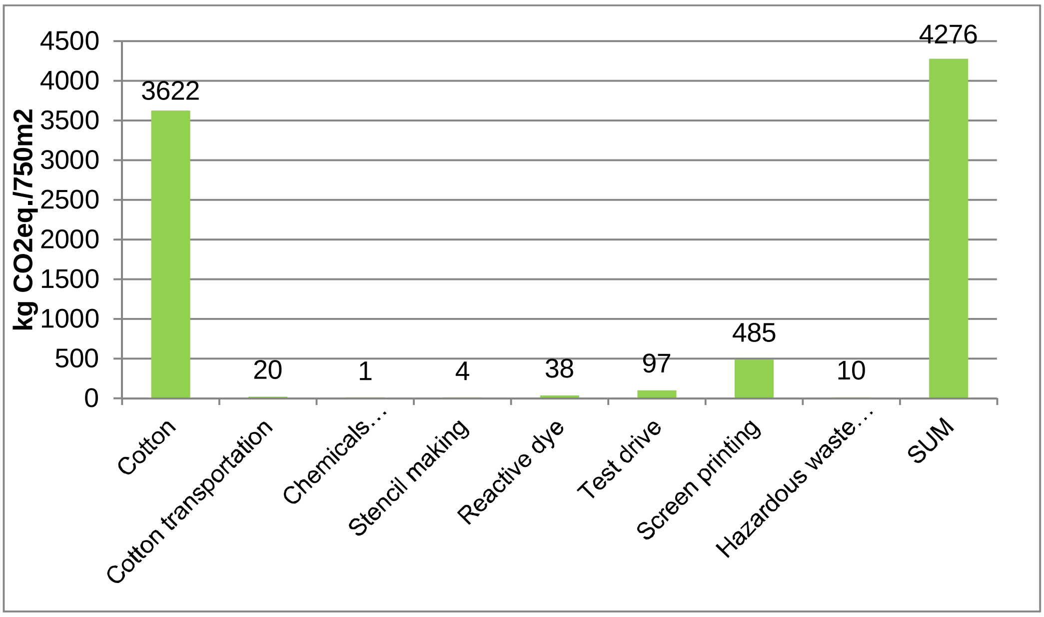


Figure 13.Greenhouse gas emissions of screen printed product (kg CO_2eq./750m^2)

3.3 Sensitivity analyses

In this study, certain assumptions were made in order to carry out the life cycle assessment. Functional unit was set to represent 750m^2 printed fabric. In the basic case the assumption was that the durability of both products is the same. In reality, batch size depends on the customer orders, life time of a product might differ (although nowadays not that much because of the differences in durability of print quality) and different printing methods are used for different batch sizes. Therefore it was essential to evaluate the significance and uncertainty of made assumptions and decisions. Sensitivity analyses were carried out for greenhouse gas emissions and were studied with the following scenarios:

1. Differences in printed amounts (batch size from 1m2 to 750m^2)
2. Differences in life time (how much longer should screen printed product last in order to achieve the level of digitally printed product)
3. Differences in printing batches (five small batches of 150m^2)

3.4 Differences in printed amounts

Generally screen printing is more suitable for bigger printing batches whereas digital printing suits better for smaller batches. This is mainly due to the fact that when using screen printing, a resource consuming test drive is needed and it is not reasonable to start printing job with screen printing if the printing batch is small. Digital printing is more flexible and faster, and does not require a resource consuming test drive. Therefore digital printing is more suitable for smaller printing batches.

When greenhouse gas emissions are considered and the life time not taken into account, it seems that digitally printed product has smaller climate impact, no matter how many meters are printed. The sensitivity analysis indicates that digital printing is the more favourable method also when bigger amounts are printed. However, the results of this sensitivity analysis do not include other aspects related to printing method decision, such as economic grounds, printing quality, requirements for printing etc.

The calculation was made only for greenhouse gas emissions but the conclusion is valid for other studied impact categories too (except water availability footprint).

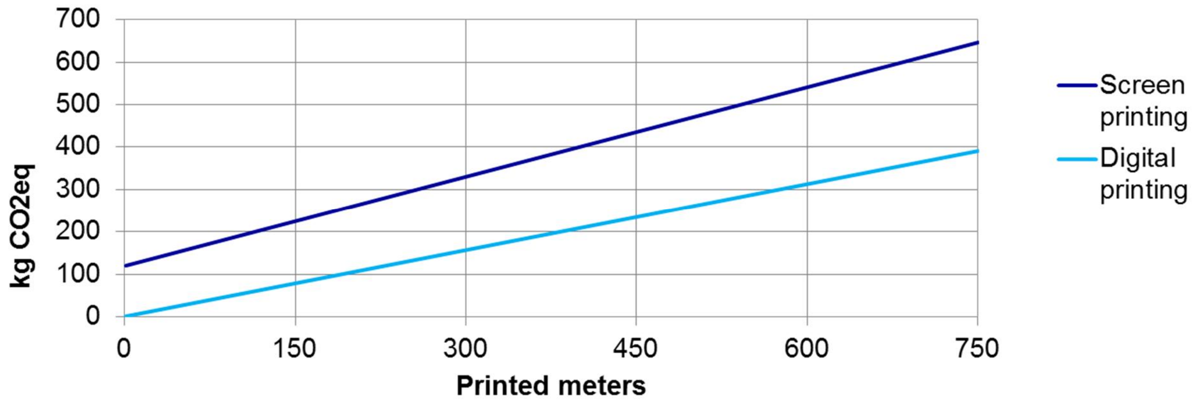


Figure 14. Screen printing has bigger greenhouse gas emissions also with big printing batches.

3.5 Differences in life time

When different products, or as in this case products with different printing methods are compared, it is essential to include quality aspects in the assessment. Nowadays there are no remarkable differences in durability of printing quality between screen and digital printing. And if there are some, it is unlikely that it is the reason for product disposal.

However, impacts of the life time are important to include in the assessment, even though there are no remarkable differences between printing methods. According to the results of this sensitivity analysis, it seems that if the life time of screen printed product is 5% longer than of the digitally printed product, screen printed product reaches the level of climate impacts caused by digital printing. All in all, by increasing the life time of a product, environmental impacts can be significantly reduced, assuming that purchase of a new product is avoided by that. And since cotton causes most of the environmental impacts of printed textiles, it is not reasonable to use cotton for products with short life time.

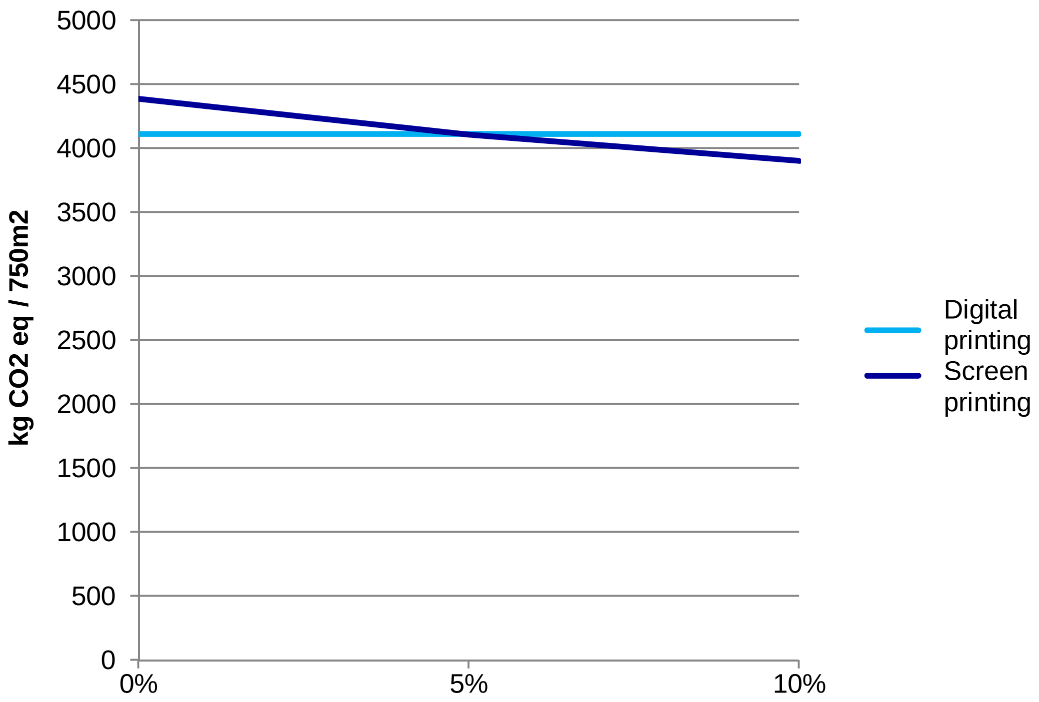


Figure 15. When it is assumed that appearance of screen printed product lasts longer than the appearance of digitally printed product, the climate change impact decreases.

3.6 Smaller printing batches

Digital printing is a well suited method for small printing batches. It is also known that screen printed is unlikely used for small printing batches due to heavy preparations (test drive) and because the shorter the batch is the more it consumes materials and energy (related to printed amounts). The third sensitivity analysis changes the functional unit from 750m^2 to 150m^2 and increases the amount of printing batches to five.

When a batch size of 150m^2 is considered (Figure 16), digital printing has 15% smaller greenhouse gas emissions. It can be seen that digital printing causes less greenhouse gas emissions when small batches are printed.

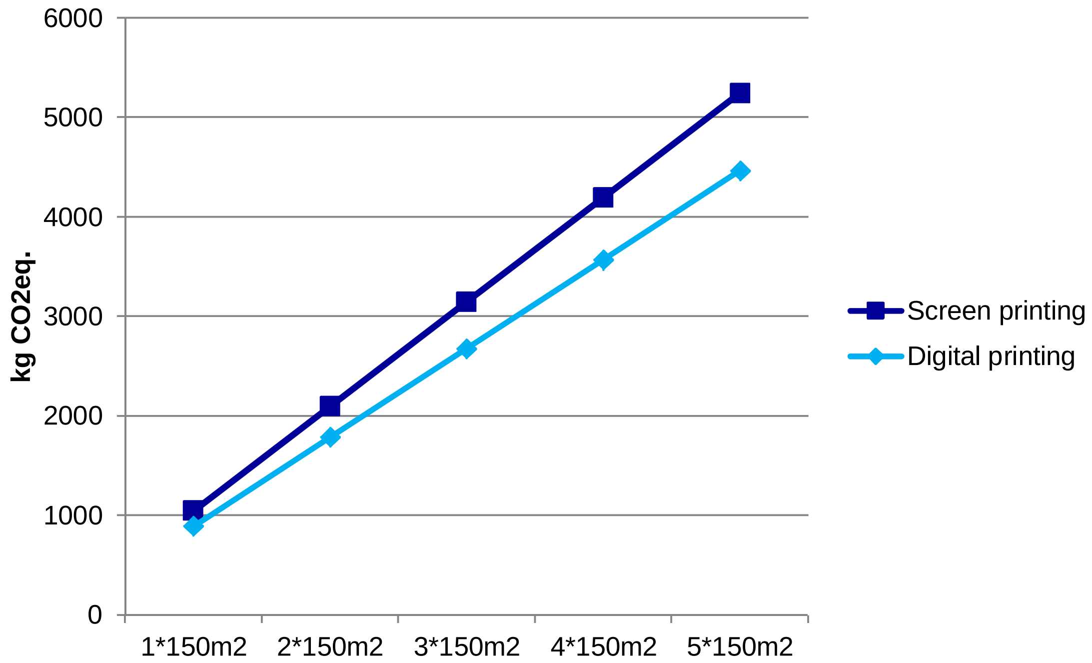


Figure 16. When smaller batches are printed screen printing has bigger greenhouse gas emissions than digital printing.

4. Other studied environmental impact categories

In addition to carbon footprint, other impact categories were studied too. This chapter shortly presents the results for other studied impact categories and in the end, the presented impact categories are shown in the same figure (results weighted to become comparable) to see which of the studied impact categories is the most important.

The following impact categories were studied using the ReCiPe method:

- Fossil depletion [kg oil eq]
- Terrestrial acidification [kg SO_2 eq]
- Particulate matter formation [kg PM10 eq]
- Freshwater eutrophication [kg P eq]
- Marine eutrophication [kg N eq]

In all of the studied impact categories, cotton production caused the biggest impacts. Impacts from digital printing varied between 2-10% of the total impacts, whereas impacts from screen printing varied between 5-15% of total impacts.

4.1 Fossil depletion

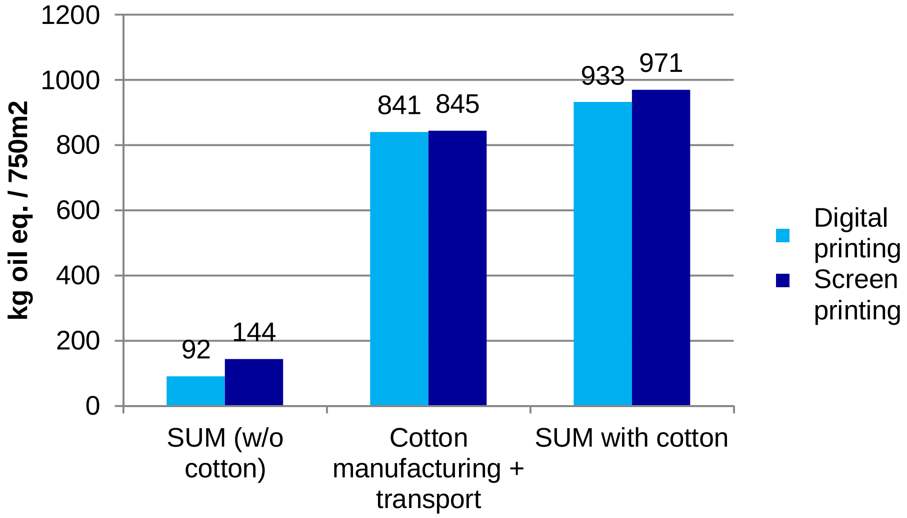


Figure 17. Fossil depletion [kg P eq./750m²]

Light fuel oil and propane combustion in the printing plant are the main contributors in the fossil depletion category when cotton is excluded from the numbers.

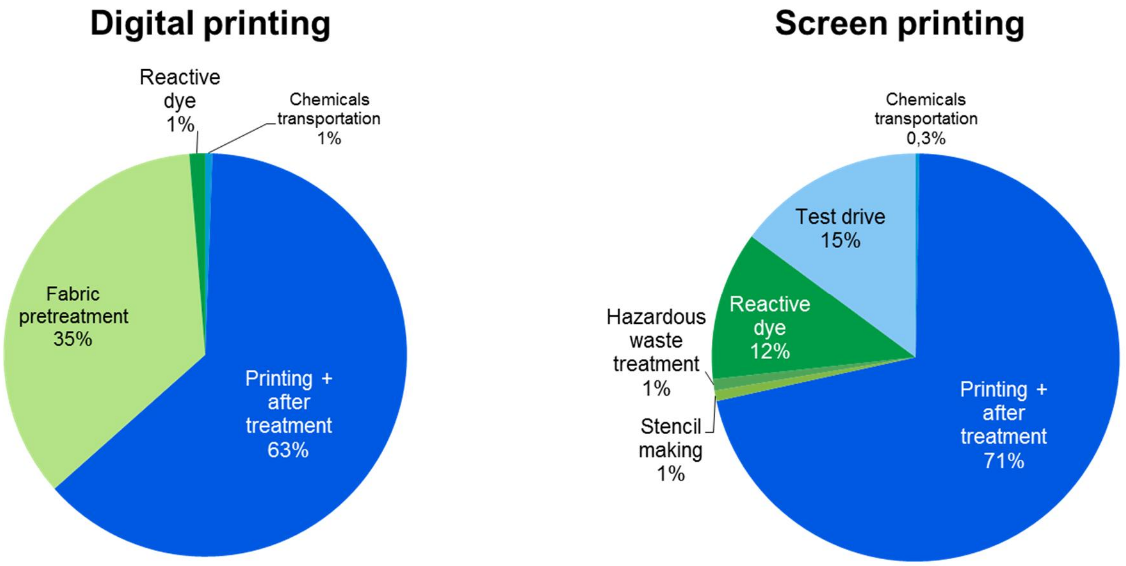


Figure 18. Fossil depletion impacts of printing, cotton not included.

4.2 Terrestrial acidification

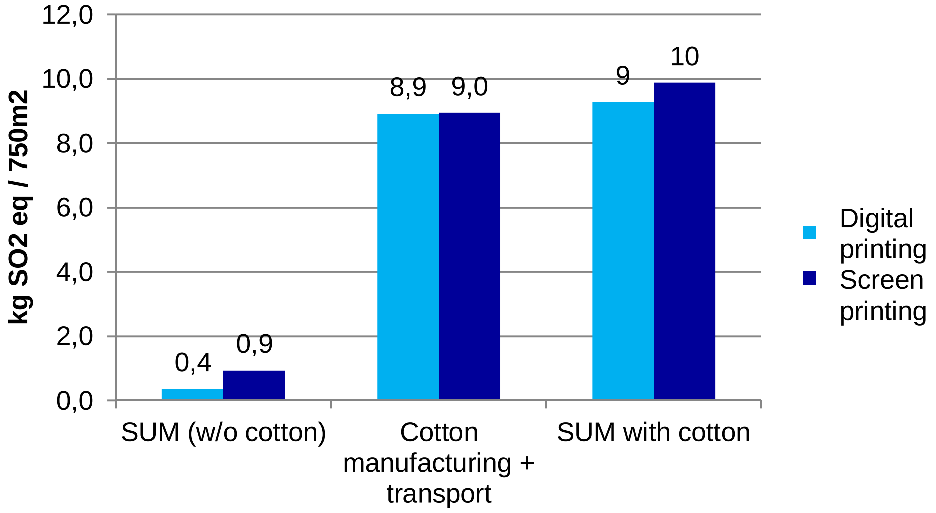
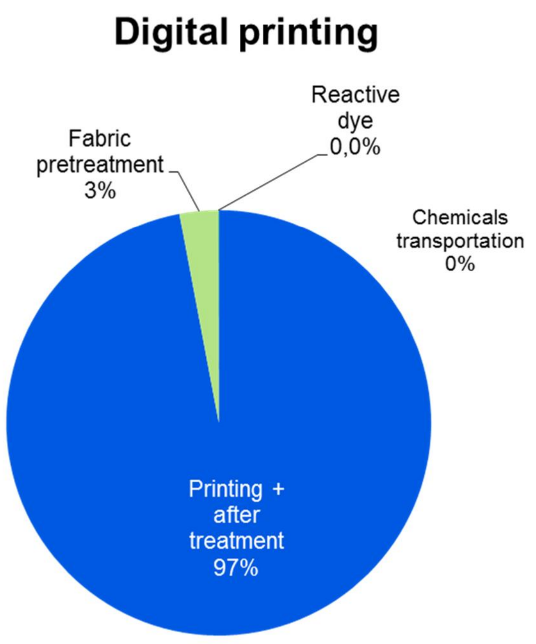


Figure 19. Terrestrial acidification [kg SO_2 eq/750m^2]

Light fuel oil combustion and electricity usage in the printing plant are the
main contributors in the terrestrial acidification category when cotton is excluded from the numbers.



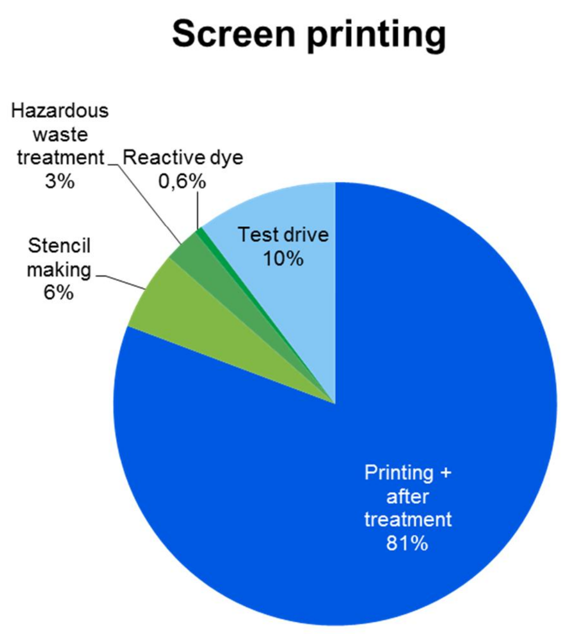


Figure 20. Terrestrial acidification impacts of printing, cotton excluded.

4.3 Particulate matter formation

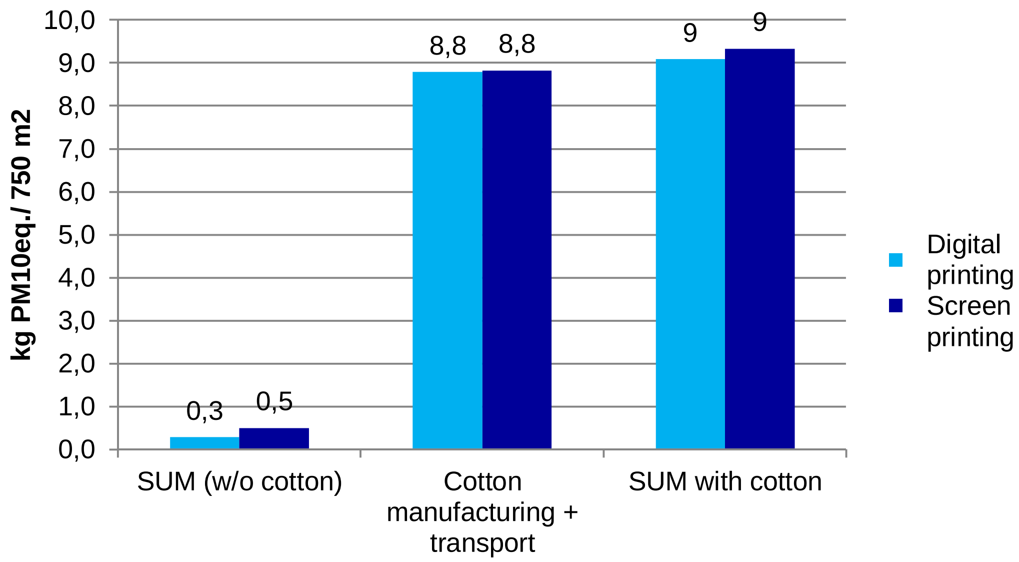
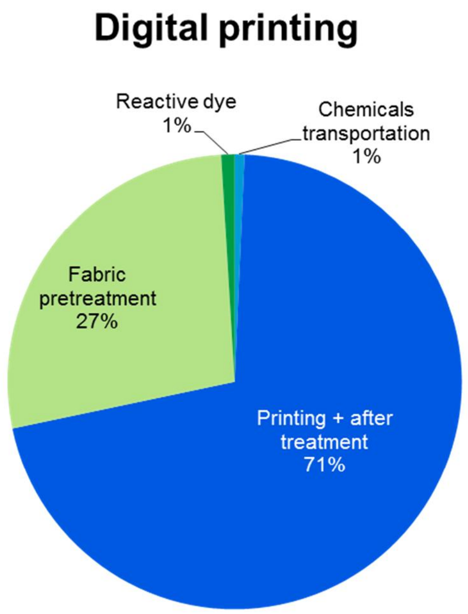


Figure 21. Particulate matter formation [kg PM10eq./750m^2].

Light fuel oil combustion and electricity use in the printing plant are the main contributors in the particulate matter formation category when cotton is excluded from the numbers.



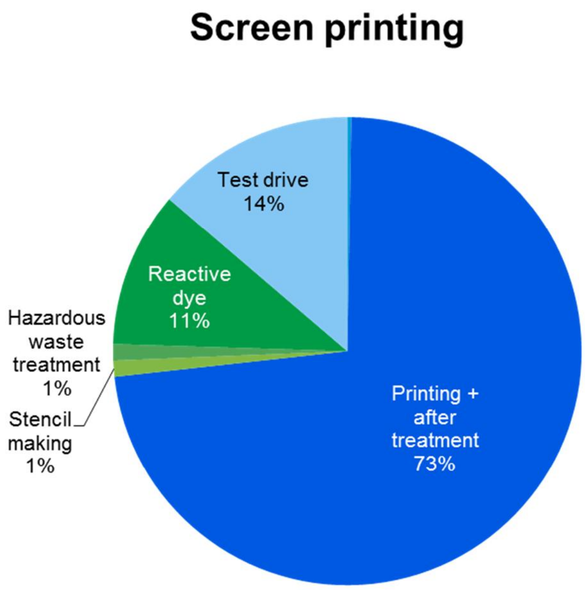


Figure 22. Impacts on particulate matter formation of printing, cotton excluded.

4.4 Freshwater eutrophication

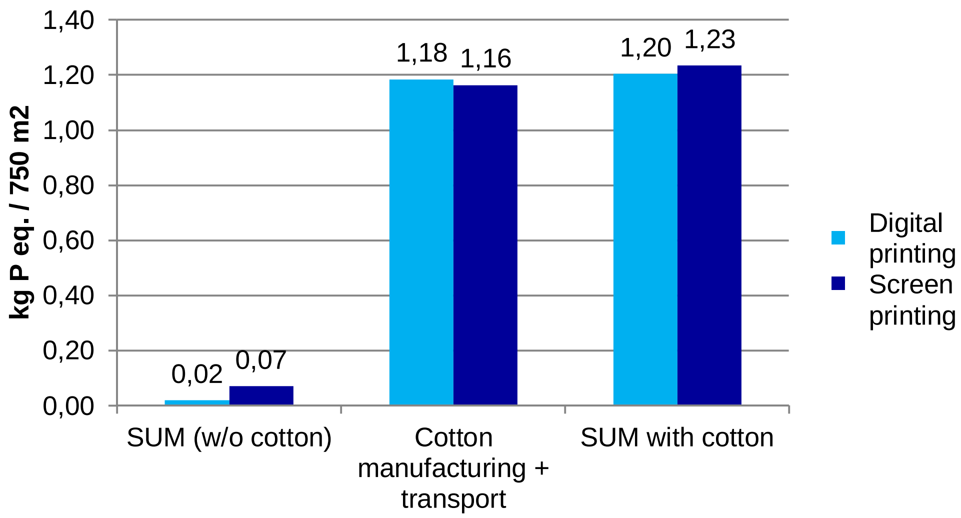


Figure 23. Freshwater eutrophication [kg P eq./750m²]

Urea production and sufractant production are the main contributors in the freshwater eutrophication impact category when cotton is excluded from the numbers. However the use of generic databases for urea and surfactant data instead of actual measured figures increase the uncertainty of the results.

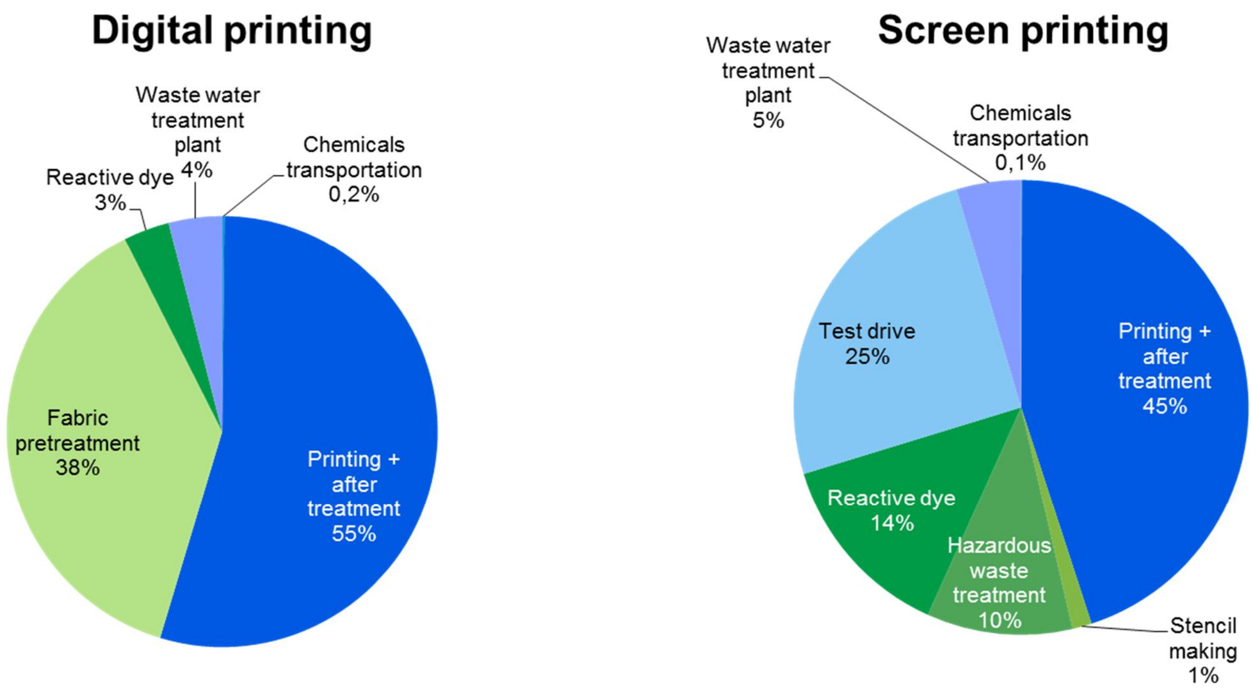


Figure 24. Freshwater eutrophication impacts of printing, cotton excluded.

4.5 Marine eutrophication

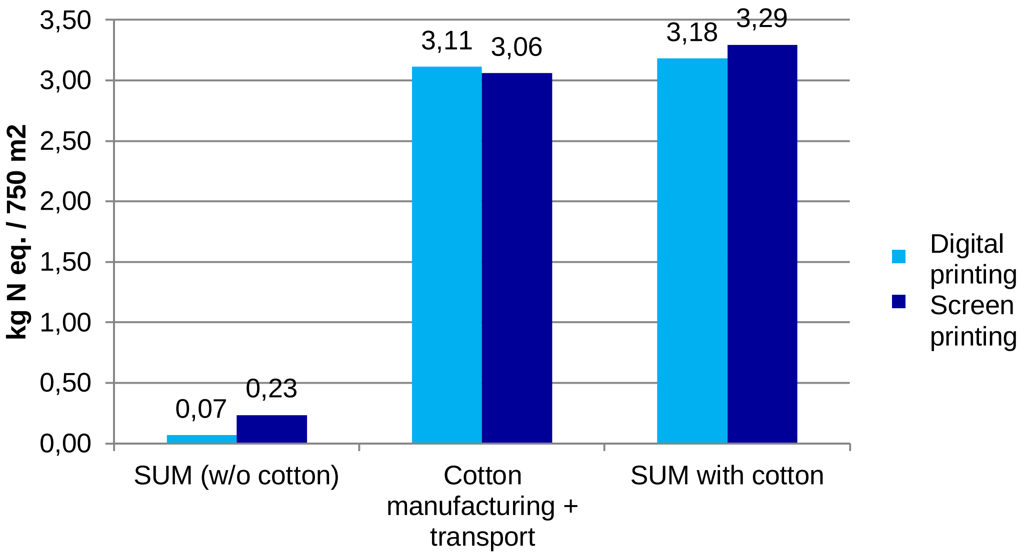


Figure 25. Marine eutrophication [kg N eq./750m²].

Waste water emissions from printing plant processes, light fuel combustion in printing plant and surfactant production are the main contributors in the marine eutrophication category when cotton is excluded from the numbers. However the use of generic databases for these processes instead of actual measured figures increase the uncertainty of the results.

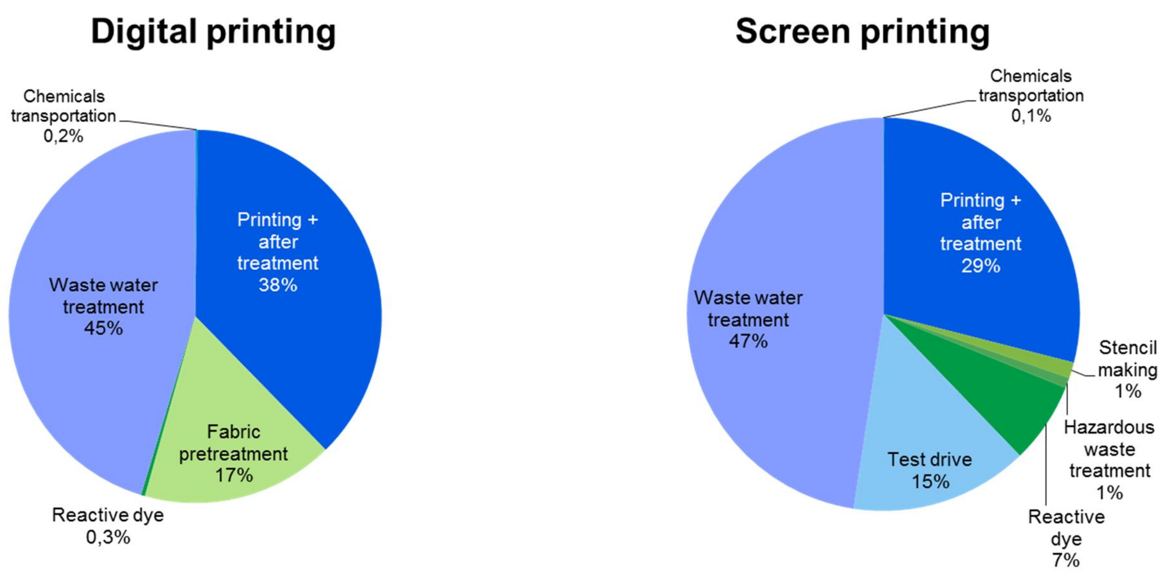


Figure 26. Marine eutrophication impacts of printing, cotton excluded.

5. Partial water availability footprint

Companies in Finland as well as globally have taken steps towards more efficient water management and water efficiency. Some big companies use the GRI reporting which offers general guidelines for water management. However the GRI reporting is as such quite a heavy tool for a SME company to evaluate the performance. In addition, GRI does not include requirements for quantification impacts in relation to water use. Thus, such tool like

Water Availability Footprint can be practical and beneficial in evaluating performance as well as to communicate in B-2-B and B-2-C situations.

According to couple of scientific articles several issues could be highlighted. Chapagain et al 2006 reveals the aspects related to water footprint of cotton consumption by an assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. The consumption of a cotton product is connected to a chain of impacts on the water resources in the countries where cotton is grown and processed. About 84% of the water footprint of cotton consumption in the EU25 region is located outside Europe. Consequently EU25 is very much dependent on the water resources in other continents, particularly water in Asia. In the article blue water use refers to withdrawal of ground-or surface water for irrigation with watering system or processing. Several rough average estimates are given, because the actual water requirements vary considerably among various techniques used. Among these values presented is virtual water content of cotton products at different stages of production with the global average of the blue water. For the final cotton textile virtual water content of blue water is 4917 m^3/ton (i.e. litre/kg) and for cotton fabric 4781 m^3/ton respectively. Thus the share of virtual blue water content for cotton fabric is 97 percent from the final textile's blue water content. The difference of values is 136 litres/kg. These water volumes do not yet include the volume of water necessary to dilute the fertiliser-enriched return flows from the cotton plantations and the polluted return flows from the processing industries. The result indicates the strong significance of cotton as a raw material. (Chapagain et al 2006)

The industrial water footprint assessment and need of improvement is discussed in the article of Gu et al 2014. As an example the need to more precise evaluating of the wastewater discharged from industrial activities, which significantly influences local aquatic environments, is presented. Also energy consumption is seen crucial in industrial enterprises, and further studies on water-energy relationship are necessary to support the assessment of industrial water footprints. Hoekstra et al 2011 introduced water footprint to quantify and map water use. Boulay et al. 2013 presents the common grounds and differences among water footprint methodologies developed by the Water Footprint Network (WFN) and life cycle assessment (LCA) community. The later started to frame the main concepts in the forthcoming international standard on water footprint (ISO 14046).

Water Footprint is a recently standardized method, which was published in July 2014 (ISO 14046 Water footprint – Principles, requirements and guidelines.) Water footprint evaluates the impacts of water use based on life-cycle approach. The goal is to enhance water sustainability from the human use point of view.

5.1 Water footprint methodology

Water footprint assesses how a product /process /organization contribute to pressure on water availability. Water availability footprint (WAF) is calculated by using a stress method introduced by Boulay et al. (2011), which measures the potential impacts on water stress caused by water consumption and degradation associated with a product. Three aspects of water footprint are accounted for

- Quantity
- Quality
- Location

5.2 Partial water availability footprint with Gate-to –gate approach

The goal of the study was to assess potential impacts related to water use associated with functional unit of production of 750m^2 printed textile, design with 5 colours, 3 colourways in the printing house with Gate-to-gate approach for digital and screen printing.

The form of this study is water availability footprint, focusing on consumptive and degradative use of water from human use point of view.

The focus is in the textile printing house where the producer has direct possibilities to influence on water use as well as to follow water quality information. The textile printing house infrastructure is excluded from the study as well as the raw material acquisition and production.

The cotton production is known to be water intensive so the evaluation of different textile materials from the point of view of their water footprint would be very beneficial in the future. Chapagain et al 2006 study reveals that the cotton product is connected to a chain of impacts on the water resources in the countries where cotton is grown and processed, and it estimates that withdrawal of ground- or surface water for irrigation or processing requires worldwide over 100 Gm^3 of water per year in relation to consumption of cotton products.

Other included impact categories in this study in relation to water use are fresh water eutrophication and marine water eutrophication. They were evaluated with cradle-to-gate approach and are presented among the LCA results reported in previous chapters.

Water availability footprint is evaluated based on water balance (water consumption at textile printing processes), water quality and water availability.

The water balance volumes are based on two specific cases: digital and screen textile printing of this study. The water volumes consumed are evaluated and estimated case specific and included are all significant phases of textile printing production where water is consumed. In certain phases e.g. where the steam is used the loss related to consumption of steam is included as well as the ionized water loss. However the preparing losses of steam are not included while these are estimated to be very small.

The quality is based on average water quality measured by water protection organisation of Kokemäenjoki river; incoming groundwater to textile printing manufacturing and outgoing water from Printscorpio’s purification plant. Data average is from year 2013.

The water availability situation describes the generic availability at Finland (Boulay et al. 2011) from human use point of view.

5.3 Partial Water Availability Footprint results

Water availabitly footprint (WAF) is formed based on water balance, water quality and water availability (country and location dependent) .Below in Table. 4 the water availability footprint results are presented. This approach is non-comprehensive evaluation of water footprint according ISO-standard 14046, because only part of the life-cycle is included through gate-to-gate approach, which is important to notice.

The difference in water balance is clear; the screen printing has higher water consumption than digital printing mainly due to after washing. The water availability at Finland is in very good level, consequently the WAF results are near each other with the difference of 62 Liters.

Table 4. Water availability footprint of the screen printing and digital printing

Case	Water balance, litres	Quality OUT Surface water	WAF Litres/ 750m^2
Digital	6369	2d	196
Screen	17196	2d	257

New-types of technological solutions to reduce water consumption in washing are in consideration in the future in order to tackle the higher water consumption at textile screen printing process (with gate-to-gate approach) where the main reason is after washing.

The average output values for water quality of textile printing facility is influenced by nitrogen emissions while all the other quality parameters have decreased during ten years period. It was assumed that the quality of effluent water from both textile printing methods were the same, because only average water quality measurements were available and the separation of quality parameters was not possible to do. The quality was assumed to be the same in both methods, which however is unlikely so.

The water quality parameters used were five: BOD, pH, N, P and suspended solids (mg/l). According to Boulay water quality categorisation, the groundwater used in Printscorpio has quality level 1, and purified water quality coming out after Printscorpio and own purification plant are 2d, respectively. The classification is presented in the Figure 27. Average water quality before Printscorpio textile printing plant and purification plant and after purification plant based on Bouley at al 2011. Figure 27 below.

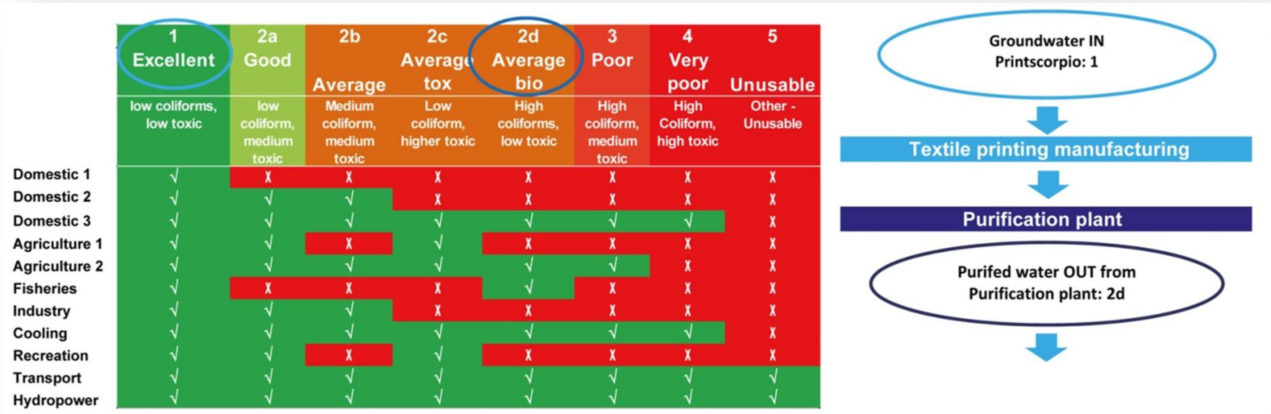


Figure 27. Average water quality before Printscorpio textile printing plant and purification plant and after purification plant based on Bouley at al 2011.

As discussed, water availability footprint results are very near each other for both printing methods due to very good availability of water at Finland (a competitive advantage). The significance of water consumption would increase, if the textile manufacturing would occur in a location with high scarcity of water. The importance of good quality water lies under its critical role in sustaining life and importance in social acceptance among community rather than in the economic value while it is not an expensive resource in Finland.

6. Conclusions and summary

A partial life cycle assessment with cradle-to gate approach gave information about environmental performance of the Printscorpio textile printing, focusing on digital printing and screen printing. The case study included several environmental impact categories: Carbon Footprint, Fossil depletion, Terrestrial acidification, Particulate matter formation, Freshwater eutrophication and Marine eutrophication.

6.1 Screen printing versus digital printing

When the life time and usability of printed textile product is assumed to be the same for both printing methods, digitally printed textile product has slightly smaller environmental impacts than screen printed textile product. Screen printing is more dye, energy and water consuming whereas digital printing needs fabric pretreatment, which in turn requires raw materials and energy and causes environmental impacts. When the life time and usability of printed product is assumed to be the same for both printing methods, digitally printed product has slightly smaller impacts than screen printed product in studied environmental impact categories.

When smaller printing batches are studied, digital printing causes less greenhouse gas emissions than screen printing. Digital printing is better for small batches also because of the flexibility of the system and fewer amounts of production waste.

Test drive is needed before actual printing work can start. In screen printing test drive is a rather heavy process with high dye consumption. This study includes one test drive of 3 meters. However in reality, test drive might be longer and there might be a need for several test drives before actual printing work can start.

When comparing products with each other it is essential to include quality and durability aspects in the assessment. Nowadays there are no significant differences in quality between the studied printing methods and thus these aspects were not included in the comparison.

There is still obvious need of primary data from different manufacturers in the life cycle of textile printing product e.g. more precise information about different materials; base material as well as printing inks and chemicals are needed.

6.2 Cotton

Cotton production (cultivation, fabric production and refinement) causes most of the environmental impacts of digital and screen printed textiles. Cotton dominates the results, and with different base fabric (e.g. wood fibre based fabrics) results and conclusions might be partly different.

By prolonging the life time of a textile product, and thus avoiding a purchase of a new product, environmental impacts can be reduced remarkably. Since cotton production has big environmental impacts, it is also not sustainable or recommendable to use cotton for products with short life time.

On a global level, environmental impacts of cotton production need to be decreased. For tackling problems related to cotton production, new technologies and materials are currently developed for textile purposes. It is recommendable to follow the development of new base materials and consider if at some printing works an alternative fabric can be used instead of cotton.

6.3 Partial water availability footprint

In addition to environmental impacts studied with ReCiPe, aim was to focus on the textile printing processes and their water balance, where there is possibility to directly influence on water consumption as well as to follow water quality parameters due to own purification plant. The Water Availability Footprint with gate-to-gate approach was assessed and it is according ISO14046 standard a non-comprehensive water footprint. The actual water consumption at textile printing process is much higher for screen printing where the main reason was after washing. From the average water quality parameters it could be seen that the quality is influenced by nitrogen emissions while all the other quality parameters have decreased during ten years period. However, Water Availability Footprint results indicated that the difference between digital printing and screen printing is very small due to very good availability of water at Finland. The Water Availability Footprint result for screen printing of the textile product case is 257 litres and the Water Availability Footprint result for digital printing of the textile product is 196 litres. Thus, the difference is 62 Litres of water.

References

Boulay, A-M, Bulle, C, Bayart, J-B, Deschenes, I.,Margini, M.,2011. Regional characterization of freshwater use in LCA: modelling direct impacts on human health. Environ.Sci.technol.5(20), 8948-8957.

Boulay, A. M., Hoekstra, A. Y., & Vionnet, S. (2013). Complementarities of water-focused life cycle assessment and water footprint assessment. Environmental science & technology, 47(21), 11926-11927.

Chapagain, A. K., Hoekstra, A. Y., Savenije, H. H. G., & Gautam, R. (2006). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological economics, 60(1), 186-203.

de Saxcé, M., Rabenasolo, B., Perwuelz, A. 2014. Assessment and improvement of the appropriateness of an LCI data set on a system level – application to textile manufacturing. International Journal of Life Cycle Assessment 19:950–961

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., van Zelm, R. 2013 ReCiPe A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. http://www.lcia-recipe.net

Government of Finland. 2010. Valtioneuvoston asetus polttoaineteholtaan alle 50 megawatin energiantuotantoyksiköiden ympäristönsuojeluvaatimuksista. 445/2010

Global reporting initiative (GRI): https://www.globalreporting.org/reporting/reporting-framework-overview/Pages/default.aspx

Gu, Y., Xu, J., Wang, H., & Li, F. (2014). Industrial Water Footprint Assessment: Methodologies in Need of Improvement. Environmental science & technology.

Hoekstra., A. Y.; Chapagain., A. K.; M. M. Aldaya; Mekonnen, M.M.(2011) The Water Footprint Assessment Manual; Earthscan: Earthscan LLC: Washington, DC.

ISO/TS 14067:2013 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification and communication

Kokemäenjoen vesistön vesiensuojeluyhdistys ry, Yhteenveto jätevesitutkimuksista vuodelta 2013, Printscorpio oy jätevedet 2013 (4.2.2014) ja jaksoraportti, yhdistelmätaulukko 16.1.2013. Luottamuksellinen.

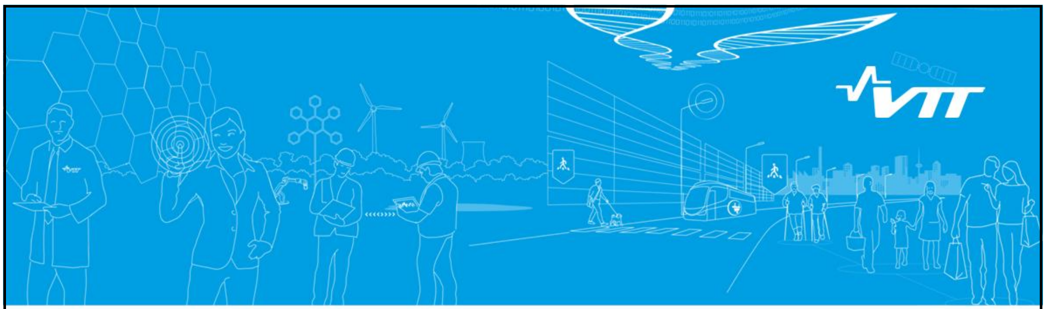
Statistics Finland. 2014. Fuel classification. http://www.stat.fi/tup/khkinv/khkaasut_polttoaineluokitus.html

van der Velden, N.M., Patel, M.K., Vogtländer J.G. 2014. LCA benchmarking study on textiles made of cotton, polyester, acryl, or elastane. International Journal of Life Cycle Assessment 19:331-356.

APP. A Main results on Power Point

Digitex PPT results

Power Point Results in PDF-format:



Environmental performance of future digital textile printing – Case study Printscorpio

1.10.2014
Marjukka Kujanpää, Minna Nors & Elina Saarivuori
VTT Technical Research Centre of Finland

Aim of the study

- Evaluate environmental impacts of digital textile printing
- Evaluate environmental impacts of screen printing
- Find out when to print with digital printing and when with screen printing when their environmental performance are considered
- Environmental impacts are evaluated using
  - **Life Cycle Assessment (LCA)** with **cradle-to-gate** approach → end of life excluded from the assessment
  - **Water Availability Footprint (WAF)** with **gate-to-gate** approach → focus is in textile printing house production's water consumption, it's quality and it's scarcity.

Aim of the study

Results of the study are calculated both with and without environmental impacts caused in cotton production in order to find out the role of the cotton and relate it with the printing process impacts, but also to assess the impacts of printing processes separately.

Three sensitivity analysis to test the significance of made assumptions

1. Differences in printing batch size
2. Differences in life time of a printed product
3. Differences in printing batch amounts

Life Cycle Assessment (LCA)

- LCA studies potential environmental impacts created during a life cycle of a product (from cradle to grave),
- Impacts are calculated per **functional unit**
- LCA consists of four phases
  1. **Goal and scope** sets the goal for the study and defines the system boundary
  2. **Inventory analysis** maps all the elementary flows from and to the environment
  3. **Impact assessment** characterizes the emissions from the inventory and results to environmental impacts, depending on the chosen method
  4. **Interpretation** discusses the results of the study, conclusions are made
- LCA is a standardized method, following standards ISO14040-44

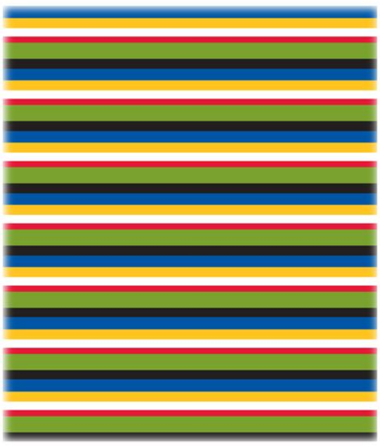
Functional unit

750m² printed textile

design with **5** colours

3 colourways

88% coverage



Environmental impacts are calculated using ReCiPe method

- ReCiPe is currently one of the most often used LCIA methods
- This study is based on version 1.07, updated in 2012
- Used method: ReCiPe Midpoint Europe H
- In this study, normalisation and weighting are excluded

www.lcia-recipe.net:

- ReCiPe uses an environmental mechanism as the basis for the modelling. An environmental mechanism can be seen as a series of effects that together can create a certain level of damage to for instance, human health or ecosystems.
- ReCiPe was created by RIVM, CML, Pre Consultants and Radboud Universiteit Nigmegen.

Assumptions

- Aluminum for stencil is primary aluminum. Stencils are recycled after use 100%, recycling is taken into account by using open loop allocation.
- Assumptions for dyes:
  - Screen printing dye paste 50% reactive dye, 50% sodium sulphate
    - Excess dye is scraped from stencils from which 20% is used again in a printing process
  - Digital printing dye paste: 10% reactive dye, 20% ethylene glycol, 70% water
- Test drive for screen printing is assumed to be 3 meters = 4,5m^2, and it is done for all colourways, 1m left empty in between colourways
- Test drive for digital printing is 3 meters = 4,5m^2, can be printed in a row without empty meters in between
- In both printing methods, 2 meters of fabric is left unprinted when printing starts and after printing

Assumptions - cotton

- Cotton transportation from Pakistan, cotton manufacturing global average
- The inventory of the cotton includes data about cotton production (soil cultivation, fertilisation, application of pesticides, irrigation, harvest, ginning and related transport to the ginning plant and farm), yarn production, weaving and refinement (bleaching, washing, dying and drying).
    - Generic data with global averages was used in this study. The used data does not represent the specific fabric that is used in Printscorpio but gives good indication of cotton production.
    - Textile refinement causes 15% of the greenhouse gas emissions **caused by cotton**. Data of textile refinement includes also dying and drying, and it should be noted that some of these emissions might be double counted; first at the textile refinement and then at printing house. However, the overall impact of double counted emissions is not remarkable.

Limitations

Data availability

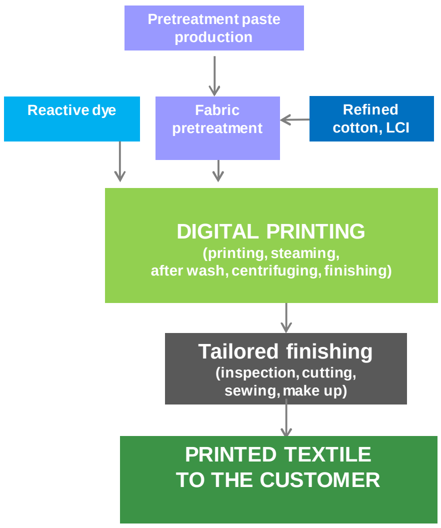
- Data for reactive dye is sourced from database and only one generic dataset was found for a reactive dye. Therefore differences between different colouring options could not be assessed
- The impacts of some minor printing process-specific chemicals and materials were left out due to data availability reasons
    - Cut off criteria 1% (if a flow is less than 1w-% of the functional unit it can be exluded, however no more than 5w-% altogether should be excluded)

Data sources and quality

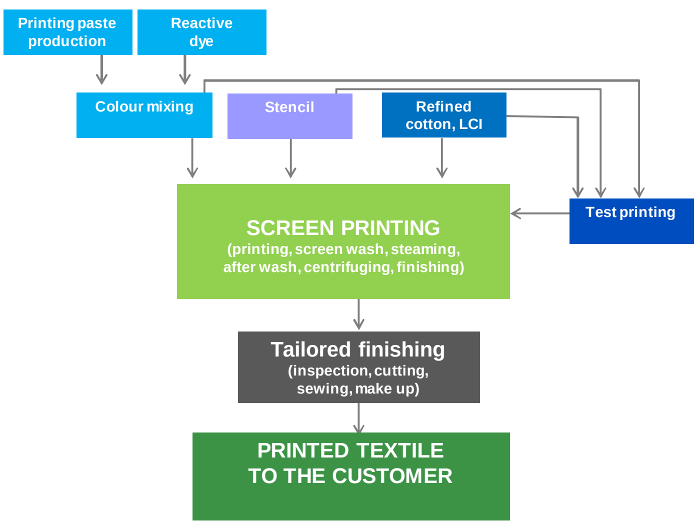
- Data for printing processes is sourced from Printscorpio and represents actual and specific printing data
- Data for downstream processes (chemicals, cotton) is sourced from life cycle inventory (LCI) databases and thus represents aggregated and generic data
- Cotton

- Detailed tables of chemicals and materials included and excluded are listed in the research report " Environmental performance of future digital textile printing **– case study Printscorpio**"

System boundary – digital printing



System boundary – screen printing



Carbon Footprint

Cradle-to-gate CO_2 emissions and carbon footprint

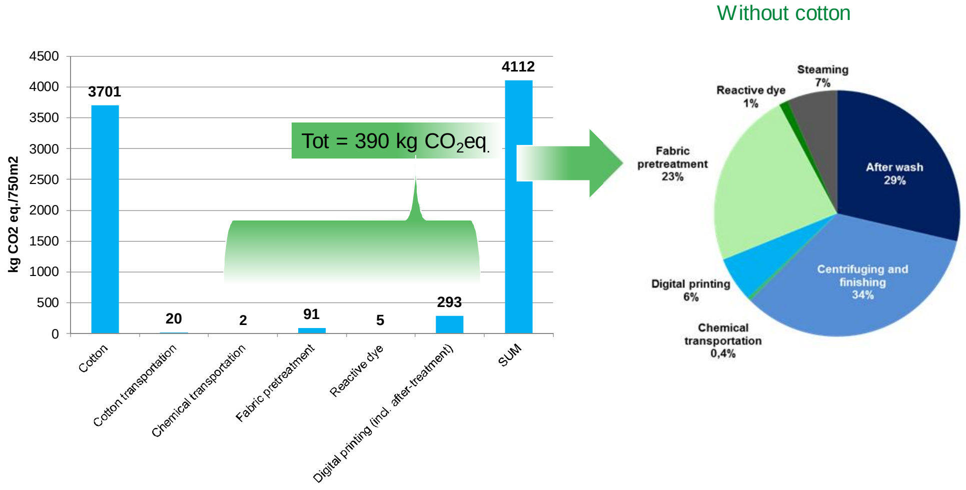
Carbon footprint

- Part of the life cycle assessment, focusing only on greenhouse gas emissions (e.g. carbon dioxide, methane and nitrous oxide)
- Greenhouse gas emissions are calculated and characterized to carbon dioxide equivalents (CO_2eq.) with the following factors:

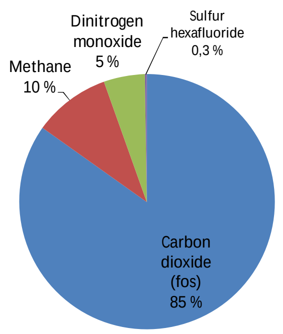
1kg CO_2 = 1 kg CO_2eq.
1kg CH_4 = 25 kg CO_2eq.
1kg N_2O = 298 kg CO_2eq.

- Only fossil greenhouse gas emissions are included, biogenic carbon is excluded (both emissions and carbon sequestration)
- Offsets (compensating) are not included
- Based on LCA standards and Carbon footprint standard ISO 14067

Digital printing - cradle-to-gate carbon footprint of digitally printed textile [kg CO_2eq / 750m²]

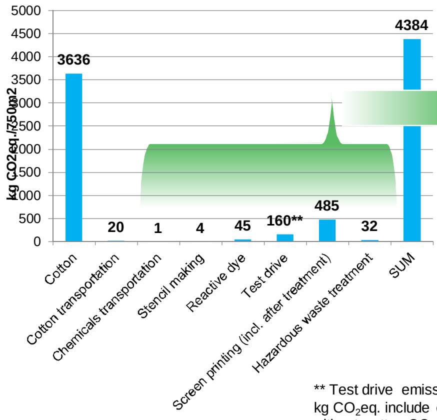


Digital printing - Greenhouse gas emissions from cradle-to-gate assessment of digitally printed product [kg CO_2eq/750m²]



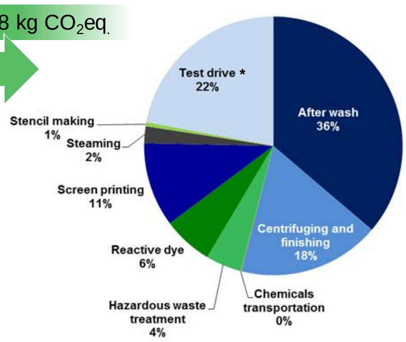
- Carbon dioxide (CO_2) is the dominant greenhouse gas originating from the cradle-to-gate life cycle of a digitally printed product (cotton is included)
- Methane (CH_4) and dinitrogen monoxide (N_2O) emissions originate from cotton cultivation and production
- Sulfur hexafluoride (SF_6) emissions come from the use of grid electricity

Screen printing - Cradle-to-gate carbon footprint of screen printed textile [kg CO_2eq/750m^2]



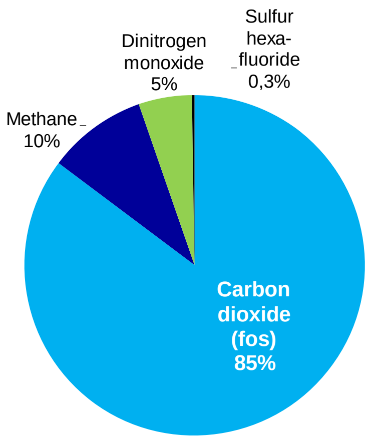
Without cotton
*cotton emissions omitted from test drive

Tot* = 648 kg CO_2eq.



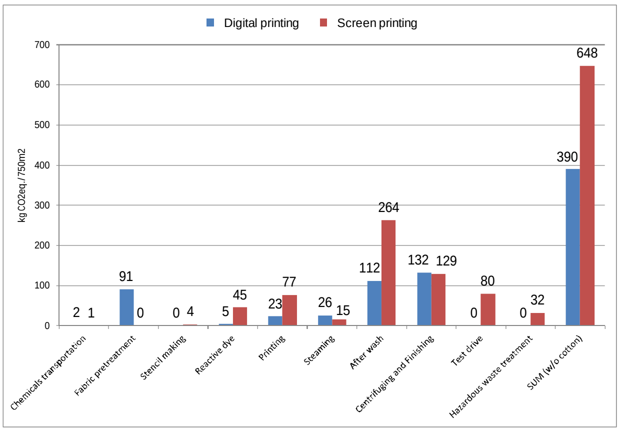
** Test drive emissions of 160 kg CO_2eq. include cotton, without cotton CO_2eq. emissions of test drive are 80 kg CO_2eq.

Screen printing - Greenhouse gas emissions from cradle-to-gate assessment of screen printed product [kg CO_2eq/750m^2]



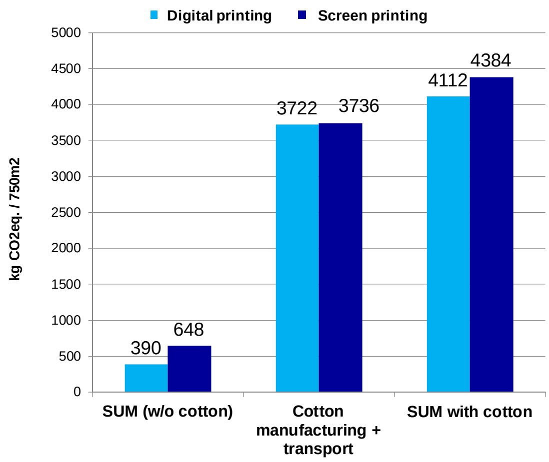
- Carbon dioxide (CO_2) is the dominant greenhouse gas originating from the cradle-to-gate processes of a digitally printed product (cotton is included)
- Methane (CH_4) and dinitrogen monoxide (N_2O) emissions originate from cotton cultivation and production
- Sulfur hexafluoride (SF_6) emissions come from the use of grid electricity

Cradle-to-gate greenhouse gas emissions from printing, excluding cotton [kg CO_2eq / 750m^2]



- The biggest difference in greenhouse gas emissions from printing is caused by amounts of printing dye used – dye usage in screen printing is remarkably higher
- The impacts are visible especially in after wash – screen printed textile needs more washing than digitally printed textile and thus the need for light fuel oil and surfactant is bigger

Cradle-to-gate carbon footprint of 750m^2 printed textile [kg CO_2eq / 750m^2]



Although cotton dominates the climate impacts, it does not mean that greenhouse gas emissions from printing processes are irrelevant!

Sensitivity analyses

- Sensitivity of greenhouse gas emissions is studied with the following scenarios:

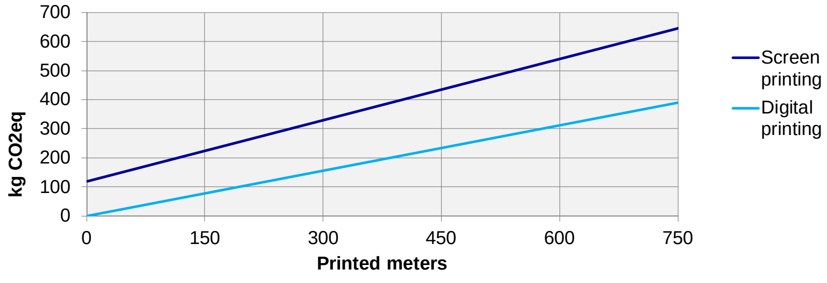
  1. Differences in **printed amounts** (batch size from 1m^2 to 750m^2)
  2. Differences in **life time** (how much longer should screen printed product last to achieve the same level of greenhouse gas emissions than digitally printed product)
  3. Differences in **printing batches** (five small batches of 150m^2)

1. Sensitivity analysis - differences in batch size

- In this study the functional unit is 750m^2 printed textile, meaning that the studied batch is 750m^2
- However, size of a printing batch varies depending on the customer order and thus the sensitivity of the batch size was studied
- Tendency is that batch sizes get smaller and smaller
- Printing requires a test drive, which size is independent of needed printing amounts
  - Especially with screen printing test drive is time and raw material consuming

Cradle-to-gate carbon footprints of printed textiles when printing amounts are from 1 m^2 to 750m^2 [kg CO_2eq/m^2]

Digital printing contributes to less greenhouse gas emissions, independent from a printing batch size. This is because all in all screen printing needs more energy and raw materials, and the test drive is heavier with screen printing.



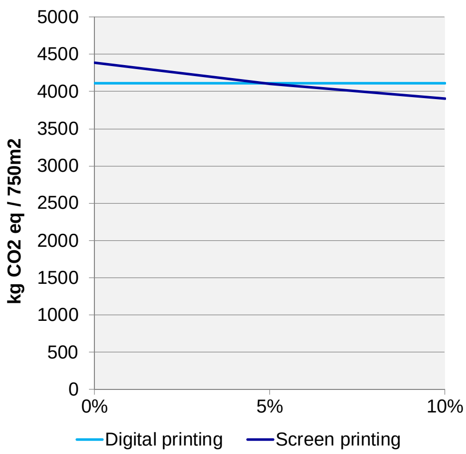
Evaluation of environmental impact such as Carbon Footprint is based on linear calculation. However, in real life there is also other factors, which have influence on textile manufacturing procedure of each job and on decisions of a textile printing method - for instance break even point from the economic point of view!

2. Sensitivity analysis - differences in life time

- In this study the functional unit is 750m^2 printed textile, printing quality and durability is excluded from the scope
- Sensitivity of the life span of printing is carried out to include durability and quality aspects to the life cycle assessment
- This sensitivity analysis studies how long should a screen printed product last longer in order to have a same climate change impact than digital printed product

Sensitivity analysis - differences in life time

- By prolonging the life time of a textile product, environmental impacts can be reduced remarkably
- Especially because cotton production is resource intensive. However, it's harmful environmental impacts can be decreased by using it for products with longer life time.
- When comparing different products or technologies, quality aspects should be included in the comparison
  - Nowadays, differences in durability between screen and digitally printed products are insignificant and are seldom a reason for disposal

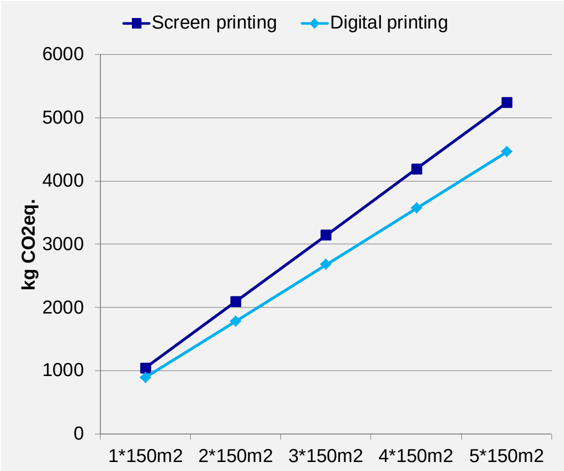


Screen printed product should last circa 5% longer in order to reach the same level of climate impact than digitally printed textile product causes.

3. Sensitivity analysis – smaller printing batches

- The current tendency in textile printing is to do small batches. Thus, digital printing is known to be more suitable for smaller printing batches whereas screen printing is used for bigger printing batches. The change from one batch to another is more efficiently done in digital textile printing than in screen printing. Typically printing batches can be around 400m – 500m, and as said tendency is towards even smaller batches.
- Screen printing needs a test drive, regardless of the size of a printing batch
  - Test drive in this study is assumed to be 3 meters = 4,5m^2
- In order to find out the significance of the printing batch size and amount of small printing batches, the size of a printing batch was decreased to correspond 150 printed square meters and the amount of printing batches was increased to five.

Sensitivity analysis – smaller printing batches



* Cotton and cotton transportation are included in the numbers

- When one 150m² printing batch is considered, difference in greenhouse gas emissions is 156 kg CO_2eq, whereas the difference is fivefold (779kg CO_2eq) with five smaller printing batches.
- Without cotton, the difference with one 150m² printing batch would be 61kg CO_2eq and with five 150m² printing batches 304kg CO_2eq.
- Sensitivity analysis indicates that when greenhouse gas emissions are considered it is more favourable to use digital printing for small printing batches.
- Evaluation of Carbon Footprint is based on linear calculation. However, in real life there is also other factors, which have influence on textile manufacturing procedure of each job and a decision of which textile printing method to use
- for instance overall productivity and production time.

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Other included impact categories

Fossil depletion [kg oil eq]

- Use of fossil fuel resources lead to fossil resource depletion

Terrestrial acidification [kg SO_2 eq]

- Sulphur dioxide and nitrogen oxides to air have an impact on acidification of soil

Particulate matter formation [kg PM10 eq]

- Particle -, nitrogen and sulphurous emissions to air affect on particulate matter formation, which in turn impacts on human health

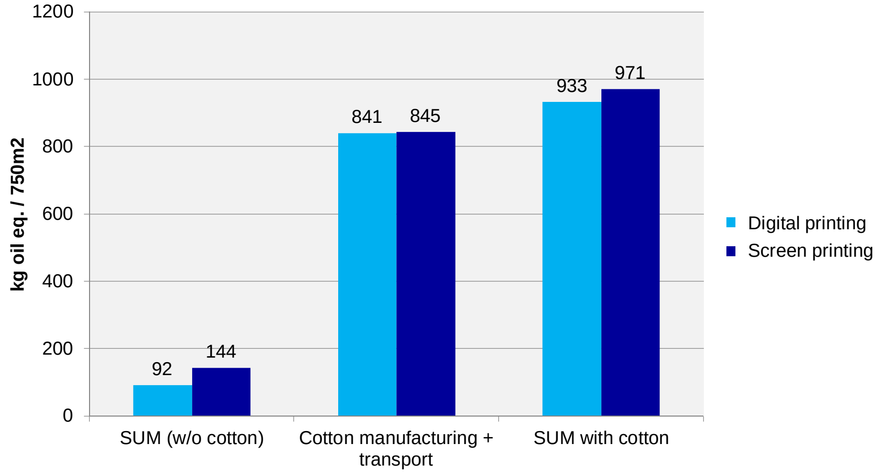
Freshwater eutrophication [kg P eq]

- Phosphorus emissions cause freshwater eutrophication

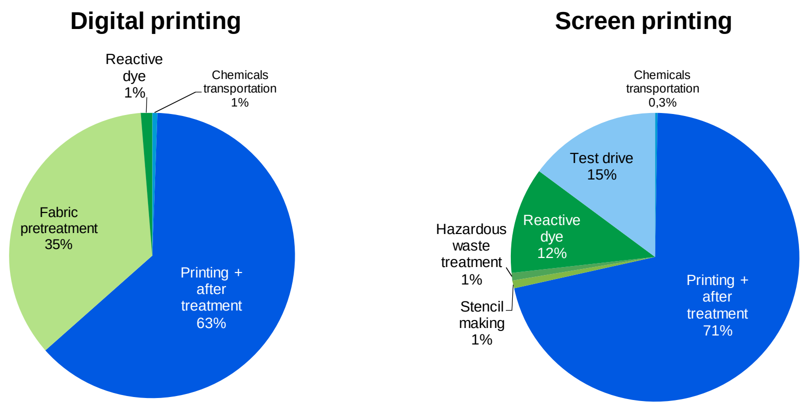
Marine eutrophication [kg N eq]

- Nitrogen emissions to water and air cause marine eutrophication

Cradle-to-gate impacts on fossil depletion [kg oil eq./750m^2]



Cradle-to-gate impacts on fossil depletion, cotton excluded [kg oil eq. /750m^2]



Light fuel oil and propane combustion in the printing plant are the main contributors in the fossil depletion category when cotton is excluded from the numbers.

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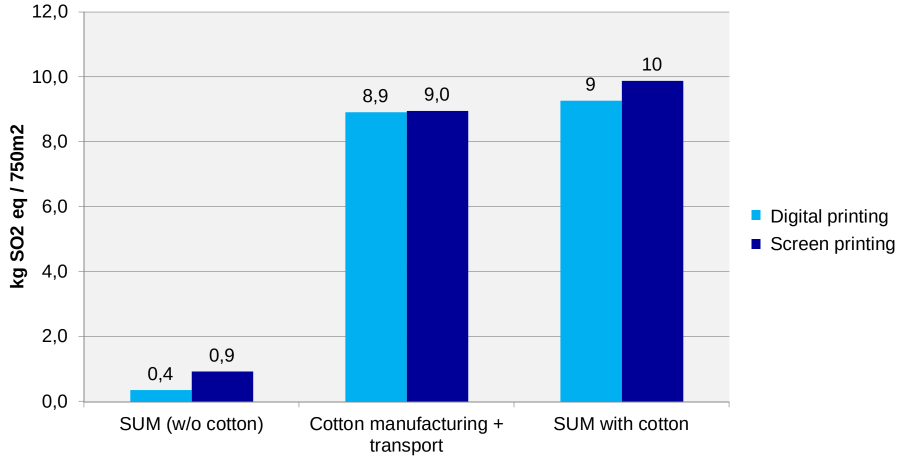
Cradle-to-gate impacts on terrestial acidification [kg SO_2 eq/750m^2]



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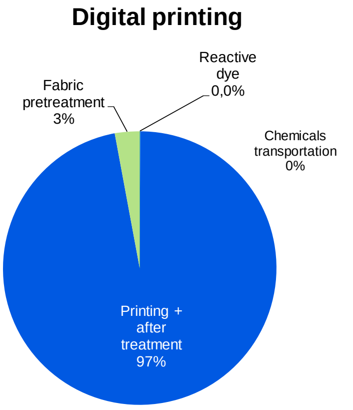
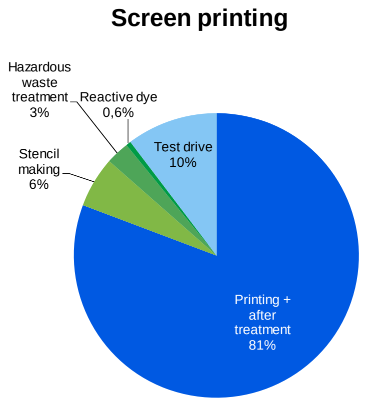
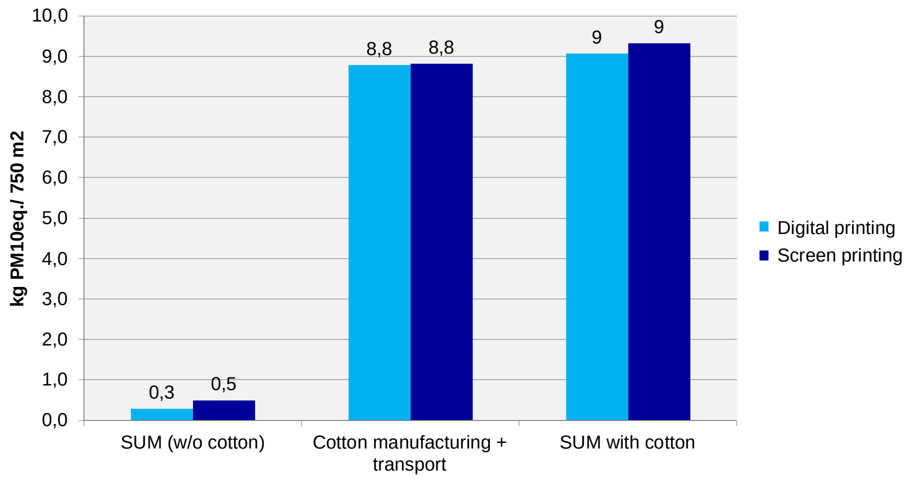
Cradle-to-gate impacts on terrestrial acidification, cotton excluded [kg SO_2 eq/750m^2]



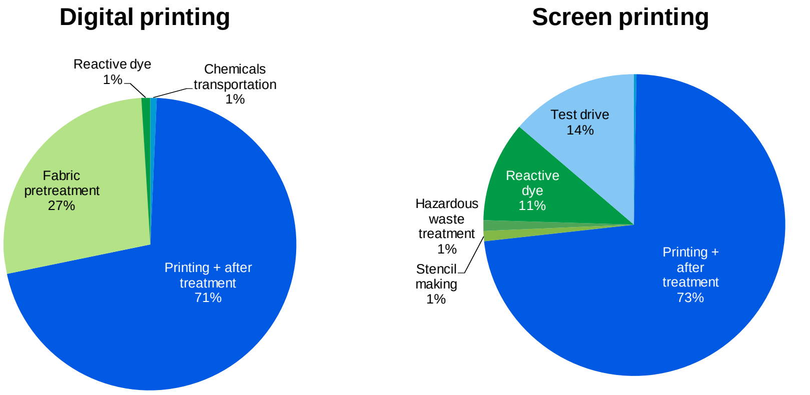


Light fuel oil combustion and electricity usage in the printing plant are the main contributors in the terrestrial acidification category when cotton is excluded from the numbers.

Cradle-to-gate impacts on particulate matter formation [kg PM10 eq/750m^2]



Cradle-to-gate impacts on particulate matter formation [kg PM10 eq. /750m²]



Light fuel oil combustion and electricity use in the printing plant are the main contributors in the particulate matter formation category when cotton is excluded from the numbers.

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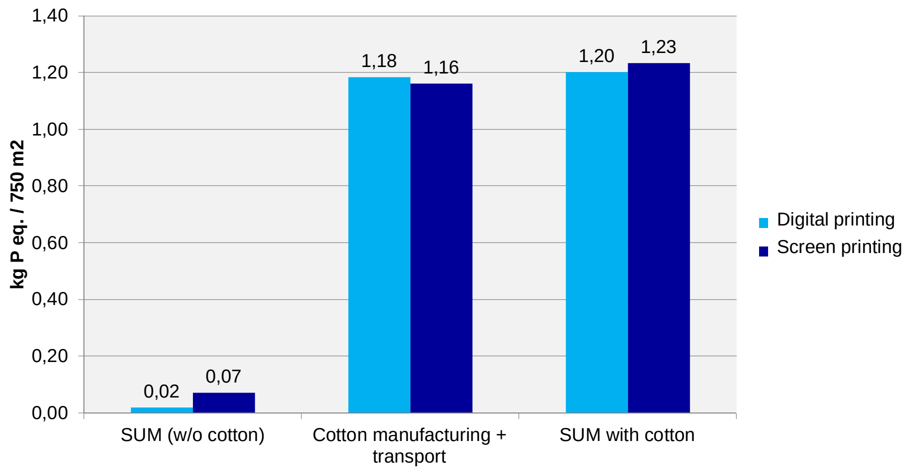
Cradle-to-gate impacts on freshwater eutrophication [kg P eq/750m²]



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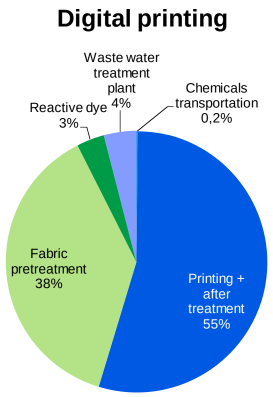
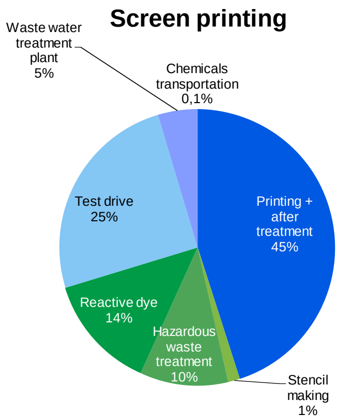
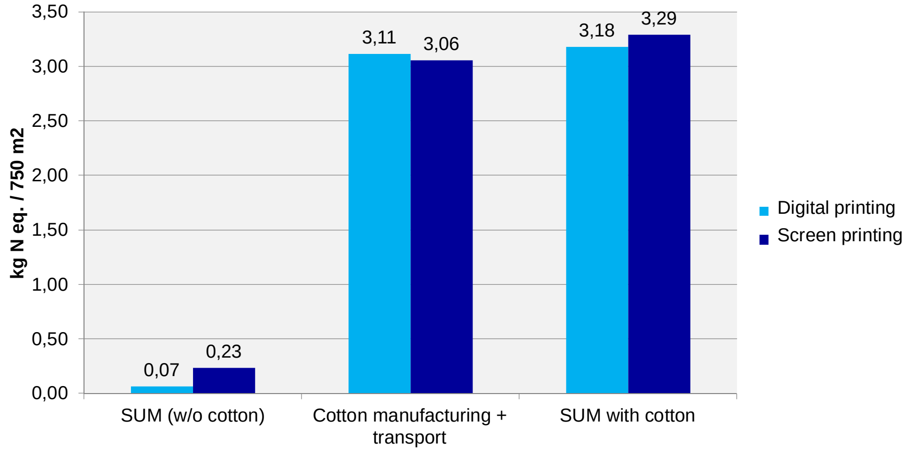
Cradle-to-gate impacts on freshwater eutrophication [kg P eq/750m²]



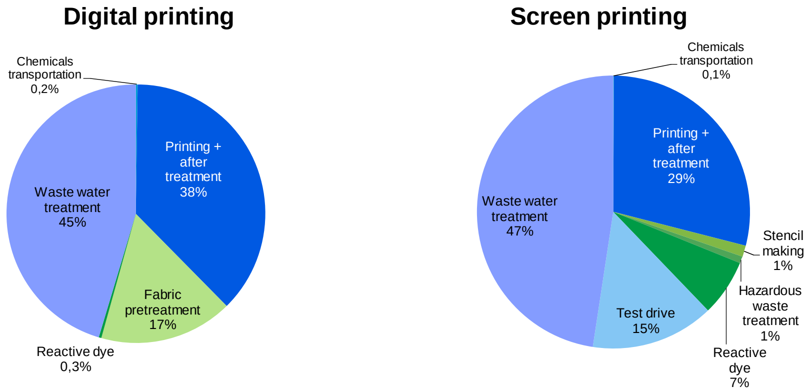


Urea production and surfactant production are the main contributors in the freshwater eutrophication impact category. However the use of generic databases for urea and surfactant data instead of actual measured figures increase the uncertainty of the results.

Cradle-to-gate impacts on marine eutrophication [kg N eq/750m²]



Cradle-to-gate impacts on marine eutrophication [kg N eq]



Waste water emissions from printing plant processes, light fuel combustion in printing plant and surfactant production are the main contributors in the marine eutrophication category. However the use of generic databases for these processes instead of actual measured figures increase the uncertainty of the results.

WAF

Water Availability Footprint with gate-to-gate approach (balance, quality, availability);
Non-comprehensive approach according ISO14046 Water Footprint standard

Water footprint

- Water footprint evaluates the impacts of water use based on life-cycle approach
- Ultimate goal is to enhance water sustainability
- Water Footprint is recently standardized method (on July 2014), following standard ISO14046

Water availability footprint methodology (Boulay et al. 2011)

- Assesses how a product /process /organization contributes to pressure on water availability
- In accordance with ISO 14046 standard
- Accounts for three (3) aspects of water footprint:
  - Quantity
  - Quality
  - Location

Water availability footprint of the study (1/4)

- The goal was to assess potential impacts related to water use associated with functional unit of production of 750m^2 printed textile, design with 5 colours, 3 colourways in the printing house with **gate-to-gate** approach for digital and screen printing.
- The form of this study is water availability footprint, focusing on consumptive and degradative use of water from human use point of view.
- The focus is in the textile printing house where the producer has direct possibilities to influence on water use. The textile printing house infrastructure is excluded from the study as well as the raw material acquisition and production. The cotton production is known to be water intensive.
- Other included impact categories in relation to water are fresh water eutrophication and marine water eutrophication presented earlier with Cradle-to-gate approach.

Water availability footprint steps (2/4)

- Water availability footprint is evaluated based on water balance (water consumption at textile printing processes), water quality and water availability.
- The water balance volumes are based on two cases: specific for digital and screen textile printing of this study.
- The quality is based on average annual (2013) water quality measured by water protection organization of Kokemäenjoki river; incoming groundwater and outgoing water from Printscorpio's purification plant.
- The water availability situation describes the generic water availability in Finland (Boulay et al. 2011) from human use point of view.

Water Availability Footprint results – Gate-to-gate (3/4)

- Below is presented Water Availability Footprint
- The difference in Water balance is clear, the screen printing has higher water consumption than digital printing mainly due to after washing.
- However, the water availability at Finland is on very good level, consequently the WAF results are near each other with the difference of 62 liters.

Case	Water ~~balance~~ consumption, litres	Quality OUT Surface water	WAF Litres/ $750m^2$
Digital	6369 *	2d	**196** *
Screen	17196	2d	**257**

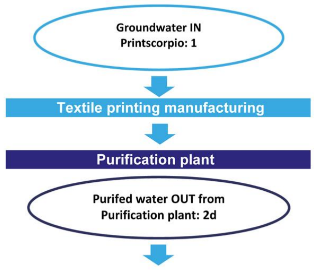
**Difference 10827 litres*

**Difference 62 litres / $750m^2$*

Water quality of the WAF (4/4)

- The water quality parameters used were five: BOD, pH, N, P and Suspended solids (mg/l)
- Groundwater used in Printscorpio has quality level 1, Purified water quality coming out after Printscorpio and own purification plant is 2d

	1 Excellent	2a Good	2b Average	2c Average tox	2d Average bio	3 Poor	4 Very poor	5 Unusable
	low coliforms, low toxic	low coliform, medium toxic	Medium coliform, medium toxic	Low coliform, higher toxic	High coliforms, low toxic	High coliform, medium toxic	High Coliform, high toxic	Other - Unusable
Domestic 1	√	x	x	x	x	x	x	x
Domestic 2	√	√	√	x	x	x	x	x
Domestic 3	√	√	√	√	√	√	√	x
Agriculture 1	√	√	x	√	x	x	x	x
Agriculture 2	√	√	√	√	√	√	x	x
Fisheries	√	x	x	x	√	x	x	x
Industry	√	√	√	x	x	x	x	x
Cooling	√	√	√	√	√	√	√	x
Recreation	√	√	x	√	x	x	x	x
Transport	√	√	√	√	√	√	√	√
Hydropower	√	√	√	√	√	√	√	√



(Boulay et al. 2011)

Conclusions and summary (1/4)

- When the life time and usability of printed textile product is assumed to be the same for both printing methods, digitally printed textile product has slightly smaller environmental impacts than screen printed textile product.
- When comparing products with each other it is essential to include quality and durability aspects in the assessment. Nowadays there are no significant differences in quality between the studied printing methods and thus these aspects were not included in the comparison.
- By prolonging the life time of a textile product, and thus avoiding a purchase of a new product, environmental impacts can be reduced remarkably.

Conclusions and summary (2/4)

- Screen printing is more dye, energy and water consuming whereas digital printing needs fabric pretreatment, which in turn requires raw materials and energy and causes environmental impacts
- When smaller printing batches are studied, digital printing causes less greenhouse gas emissions than screen printing. Digital printing is better for small batches also because of the flexibility of the system and fewer amounts of production waste.
- Test drive is needed before actual printing work can start. In screen printing test drive is rather a heavy process with high dye consumption. This study includes one test drive of 3 meters. However in reality, test drive might be longer and there might be a need for several test drives before actual printing work can start.
- There is still obvious need of primary data from different manufacturers in the life cycle of textile printing product e.g. more precise information about different materials; base material as well as printing inks and chemicals are needed.

Conclusions and summary (3/4)

- Cotton production (cultivation, fabric production and refinement) causes most of the environmental impacts of digital and screen printed textiles
  - Cotton dominates the results – results and conclusions might be partly different with different base fabric (e.g. wood fibre based fabrics)
- Since cotton production has big environmental impacts, it is not sustainable nor recommendable to use cotton for products with short life time
- By choosing an environmentally friendly base material, environmental impacts of printed products can be reduced. This possibility could be further considered.
- On a global level, environmental impacts of cotton production need to be decreased. For tackling problems related to cotton production, new technologies and materials are currently developed for textile purposes.

Conclusions and summary (4/4)

- The water consumption at textile printing process (with gate-to-gate approach) is much higher for screen printing where the main reason is after washing. There are new-type of technological solutions to reduce water consumption in washing.
- Water quality of textile printing facility is influenced by nitrogen emissions while all the other quality parameters have decreased during ten years period.
- Water Availability Footprint results show that the difference between digital printing and screen printing is very small due to very good availability of water at Finland (a competitive advantage). The significance of water consumption would increase, if the textile manufacturing would instead occur in an area of high water stress.
- From the economic point of view good quality water is not an expensive resource in Finland, but its the importance lies under it's critical role in sustaining life and importance in social acceptance among community.

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