A comparative environmental assessment of the use of bamboo in toilet tissue manufacturing

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Introduction

PURPOSE

This research was carried out to assess the comparative advantages of using bamboo as a raw material in the production of toilet tissue. Toilet paper traditionally produced from virgin forest has been described as one of the world's most wasteful products, destroying forests for the sake of a single use prior to immediate disposal. Bamboo paper production in China has been suggested as a less environmentally damaging option for tissue paper applications than conventional forestry, while also helping to support rural communities.

The benefits of bamboo for paper making are claimed as:

- it avoids the need to deplete and replant conventional forests which can take up to a century to regenerate
- it is faster growing than other sources, indeed one of the world's fastest growing plants
- bamboo production and harvesting can be a sustainable process for rural farming communities
- it is less damaging in terms of biodiversity loss
- and potentially has a lower carbon footprint than conventional paper manufacture.

This document examines these claims by means of a literature review and a data-driven environmental impact analysis following Life Cycle Assessment (LCA) principles. Both literature and data are thin due to the emerging nature of both bamboo for this purpose and the unavailability of emissions figures for a value chain which starts in the mountains of central China. To some extent, published data, and claims based on it, are also somewhat contradictory. Acknowledging such gaps in available data, the work is based on a pragmatic adaptation of LCA methodology, with an emphasis on greenhouse gas (GHG) emissions, carbon sequestration, biodiversity and sustainability.

SCENARIO

The present document considers the case study of bamboo toilet tissue produced by the Chitianhua factory operated by the Chishui Newland Import and Export Trading Co, located in Chishui, Guizhou Province, China. The central and western regions of China are rich in bamboo resources, accounting for about 40% of the country's bamboo forest area (paperandpulpingmachine.com, 2020). Bamboo in these forested areas are characterised by manual cultivation, a short rotation cutting period, rapid regeneration, and a large biomass. Four to five tonnes of harvested bamboo is needed for every tonne of paper produced. According to the International Network for Bamboo and Rattan (INBAR, 2015), Chishui is one of the focal areas of development for the bamboo sector. From the farms near Chishui, bamboo is taken to the chips mill and then on to the paper pulp factory where it is processed to become tissue paper. According to Chen et al (2019), the Chitianhua operation is a good example of bamboo pulping and paper production utilising efficient modern processes and sound environmental practices including the use of 100% renewable hydro-electricity.

Chishui is located some 1,100km inland from the coast. After processing, bamboo products are trucked to Chongqing Port on the Yangtse River from where they are taken by riverboat to Shanghai, a journey of some

some 2,250km, for onward shipping around the world. The scenario considered here takes the UK as the final destination.

For comparison, the research also looks at toilet tissue produced from virgin pulp from forest sources as well as that produced in the UK from recycled fibre (RCF).

THE PROBLEM AND ISSUES ARISING

The destruction of virgin forests to make paper has long been considered wasteful and it may be argued that toilet paper is one of the world's most wasteful products. Its production from virgin pulp contributes to deforestation, especially of the boreal forests of Scandinavia, Russia and Canada, and thus to biodiversity loss and climate change. Alternative sources of raw materials exist but major manufacturers have been reluctant to take them up, arguing consumer preferences for soft white tissue. Alternatives include both recycled and alternative plant fibres. One such alternative is bamboo, although for European use it must be imported from China.

This paper seeks to assess the relative environmental impacts of bamboo versus these traditional sources, and to provide a meaningful measure of the its environmental costs. Even with sourcing from as far away as China, relative environmental benefits may accrue due to the complex international trade in both virgin and recycled pulp within and outside EU states. To achieve this, it will be necessary to attempt to assess the full Scope 3 value chain in LCA terminology, since the bulk of GHG emissions are incurred outside the UK importer's sphere of activity.

Because absolute figures may be hard to interpret, it will be advantageous to make comparisons with conventional toilet tissue as commonly available in the UK, made from both virgin and recycled pulp sources. To counterbalance the negative emissions factor from shipping, it will be necessary to demonstrate that the environmentally positive nature of bamboo harvesting is significantly greater than the use of RCF. Paradoxically, the UK exports large amounts of RCF to China, as well as importing from Europe to supply British producers. This significantly complicates the comparison. Furthermore, while the impacts of the 2020 global supply chain disruption are yet to fully play out, China has been reported as intending to prohibit its import of RCF from 2021.

An apparent absence of standard reporting procedures is a further complication. For example, Zhao et al (2019) quote at sector level as follows: 'Carbon emissions mainly occurred in fuel combustion in CHP and diesel combustion in material transportation, reaching 6.78 million tons and 790,000 tons of carbon, respectively'. Tesco, by contrast, has reported its emissions on a '*reductio ad absurdam'* claim stated as 1.1g/sheet for its recycled fibre toilet rolls (theguardian.com, 2009).

MARKET CONSIDERATIONS

The largest producers of toilet tissue appear to favour the use of virgin pulp and have reduced the RCF content over time (DEFRA, 2O12). This appears to reflect consumer preferences but may also be a response to a fragmented market for recyclable materials in general. These companies include Kimberley-Clark, Proctor & Gamble, and Essity (formerly SCS). Wepa claims to be the the biggest supplier of 100% recycled household paper in the UK.

The only companies currently selling bamboo toilet tissue in the UK are CheekyPanda and the New Zealand based Whogivesacrap. Pricing is competitive. CheekyPanda prices at 37.5p/100 sheets; WGAC at 22.5p/100 sheets, against Tesco's range of 17-40p/100 sheets. Although both parties promote the environmental benefits of their bamboo product, they seem to avoid quoting emissions factors.

RESEARCH OBJECTIVES

Hypothesis: that toilet paper produced from bamboo, even though shipped to the UK from China, has relative environmental benefits compared with tissue made from the more conventional practice of Scandinavian forest logging.

METHODOLOGY

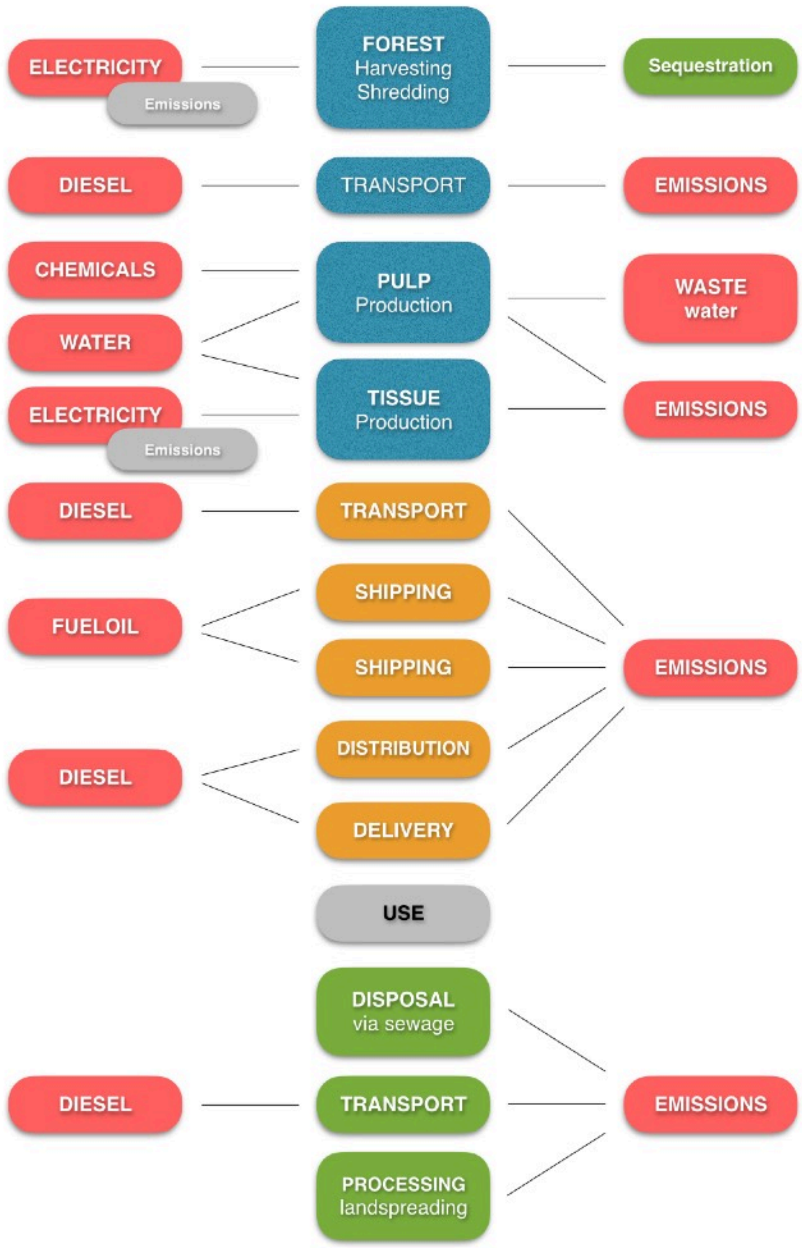
It was anticipated that primary data would not be fully available and that previously published work might provide both qualitative and quantitative material. A preliminary review confirmed that a full LCA covering the full range of environmental impacts would require unreasonable assumptions to be made. Accordingly, the assessment was confined to the global warming potential using GHG emissions measures. This effectively represents the carbon footprint of the value chain as shown in the system map below.

Quantitative data has been gathered from the producer's representative in China, supplemented by data extracted from selected published sources and emissions factors published by the UK Government (DEFRA, 2020). Qualitative materials have been derived from an internet search and a comprehensive literature review.

System boundary

SCOPE

This work encompasses so far as possible LCA Scopes 1,2 and 3 as defined by ISO 14040 and PAS 2050. This is illustrated by the Value Chain Map below.



ASSUMPTIONS

There are gaps in the available data and it has been necessary to make some assumptions. Based on data from the literature review, they are considered reasonable.

Functional unit (FU):

- there is significant variability in the specification of toilet tissue rolls and in the units chosen for reporting purposes. Across a number of manufacturers, weight per roll ranges from 115-135g, and number of sheets 160-200. For present purposes, a functional unit of one carton containing 48 rolls and weighing 6.58kg has been used, for reporting purposes converted per roll of 115g / 160 sheets.

Forestry and harvesting:

- indigenous bamboo forests harvested by hand by rural farmers and allowed to regrow
- hydro-electric powered on-site shredding
- 5-ton diesel truck to pulping factory

Pulping and processing:

- separate processes sharing the same site
- hydro-electric powered
- recycled 'black liquor' utilised in pulping (Zhao et al, 2019)
- chemical inputs, solid waste and waste water treatment are not accounted for
- cardboard used for packaging is included in the FU.

Distribution:

- 40ft container from the factory to Felixstowe port in the UK, 68.6m3, 7.3696te, 1120 cartons each containing 48 rolls
- typical distance from port to depot 200km
- typical delivery distance from depot to user 100km
- possible retail stage not accounted for.

Disposal:

- via the sewage system, anaerobic decomposition and processing into sludge
- 80% used for farm 'landspreading'
- 20% incinerated.

Where primary data is unavailable, emissions factors have been taken from DEFRA 2020.

Literature review

Extant published work falls into several relevant areas: bamboo as a sustainable forest crop; paper production; paper and the environment; and applicable LCA methods. We have also examined marketing related claims by a range of producers.

PURPOSE AND APPROACH

The main purpose of the literature review is to establish to what extent previous authors have conducted research in relevant and related topics. This also provides an ability to confirm the degree of agreement or otherwise between researchers and to provide a benchmark against our own work. The approach taken has been to conduct internet searches for key terms, identify the most cited authors and to carry out forward and backward searches from the various bibliographies and authors.

These searches have revealed a substantive cross section of work while also exposing some gaps. A number of the works discovered are more than five years old which, in a rapidly evolving discipline such as emissions mitigation, may lead to inaccuracies in modelling present day processes. A majority of works found relate to bamboo as a crop. There are fewer which describe the applicable industrial processes and almost none which precisely covers the specific topic of the present work. Those that do cover tissue production or the use of bamboo have limitations as will be described. This does, of course, validate the need for the present work.

In attempting to measure environmental impacts numerically, secondary research such as this risks turning out to be of limited value. It is illuminating how few extant papers have published actual hard data of the sort the present research seeks, while those that have confirm the difficulty in interpretation in a meaningful way.

The world's forests are not only an important carbon sink but actively remove around a fifth of the carbon dioxide that humans add to the atmosphere. This means that forests are an important component in climate change, and deforestation is considered to be one of the most important sources of carbon emissions (Yiping et al, 2010). As one of the fastest growing plants, bamboos are widely considered to have high ability to capture and sequester atmospheric carbon, and consequently to mitigate climate change (Elavinamannil et al, 2016). This rapid growth has been remarked upon by several authors who assert that bamboo has a greater potential than other types of forest to regenerate after harvesting and to maintain carbon sequestration levels (Rebelo & Buckingham, 2015). Song et al (2011) praise the ecological benefits of bamboo 'including carbon sequestration, water and soil conservation, its benefits for socioeconomic development, and its potential to mitigate climate change'. Chen et al (2019) suggest advantages of a 3-5 year growth cycle as well as self-reproduction and low cost in maintenance and regeneration. This compares with decade scale growth patterns for tree species.

Troya & Xu (2014) go further:

> 'Bamboo grows much faster than timber tree species, it requires less intensive management and expertise. It can be harvested annually without depletion and deterioration of the soil; it can grow on marginal land not suitable for agriculture and regenerates easily; it is easier to harvest and transport than timber tree species since with bamboo such activities don't require specialized equipment or vehicles'.

Van der Lugt & Vogtländer (2015) say that as bamboo products are increasingly perceived as 'green' and environmentally friendly, it is important to have an effective way to evaluate and verify these claims. Indeed Bowyer et al (2014) claim a degree of misinformation, pointing rather to a decline in biodiversity, soil and water loss, decreased soil fertility, and water pollution due to intensive management using inorganic fertilizers and pesticides. But while they also suggest that bamboo can be an invasive plant species, others disagree (Rebelo & Buckingham 2015; Yuen et al, 2017). The latter highlight 'the considerable potential of bamboo to sequester carbon' but advise appropriate management of bamboo stands throughout their growth cycle.

The ecological benefits of bamboo as a crop accrue from managed harvesting from virgin bamboo forests rather than where bamboo has replaced trees, which according to Zaninovich et al (2017) is sometimes the case following selective logging. Effective management practices include maintaining tree species, selective clearance of undergrowth and conservative fertilisation which can result in sustainable bamboo cultivation without compromising productivity (Yiping & Henley, 2010).

Van der Lugt & Vogtländer (2015) conclude that 'in terms of annual yield of the end product, combined with the biodiversity of the area, it can be concluded that bamboo is one of the best performing renewable resources around'.

PAPER PRODUCTION

While there are some authors who have written on pulp and paper production, published documents tend to focus on specific aspects and locations. The present research has failed to find work specific to the relative environmental impacts of bamboo tissue paper, but it has been possible to make inferences from work relating to bamboo paper products in general, to paper making in general, and to comparisons of virgin and recycled pulp.

The major production processes include forest tending and harvesting, material transportation, material preparation, pulping, alkali recovery, and papermaking itself (Zhao et al, 2019). In terms of energy consumption, steam from combined heat production (CHP) is used as the main energy source for process heating systems, and electricity for machine-driven systems. In general, the sector meets a large number of its energy needs through on-site power generation. A variety of fuels are typically used including coal, wood residues and 'black liquor' (a by-product of paper making) to self-produce energy. Carbon emissions of the pulp and paper industry are closely related to carbon intensity of the used energy sources and to energy efficiency.

Masternak-Janus & Rybaczewska-Błażejowska (2015) describe the life cycle processes as including wood logging, the pulp and chemicals making processes, the tissue paper production, and, finally, the use and disposal of tissue paper.

There have been efforts to switch towards cleaner energy sources in many countries such as Sweden (Ericsson et al, 2011), the UK (Dept for Business, Energy & Industrial Strategy, 2017) and in newer production facilities in China. Older facilities in China and, for example, Poland, still rely on fossil fuels (Masternak-Janus & Rybaczewska-Błażejowska, 2015). Differences in practices which influence energy consumption and emissions between production plants and between countries are marked (Lopes et al, 2003; Ericsson et al, 2011; Man et al, 2019). This is one reason why it can be difficult to develop meaningful comparative data relating to a specific process in a single country.

Diverse works agree that papermaking using recycled fibre results in some 30% lower emissions than the used of virgin forest pulp (Gemechu et al, 2013; Masternak-Janus & Rybaczewska-Błażejowska, 2015; Chen & Forbes, 2016). However, according to DEFRA (2012), the use of recycled fibre to produce toilet tissue in the UK is low (50-60%). This is claimed to be due to consumer preferences. There is little evidence this is changing, but there may be an emerging 'green' niche market segment.

PAPER AND THE ENVIRONMENT

In the context of sustainability, the literature is dominated by interest and campaigning groups. In particular, two important reports highlight the threat to boreal forests in Canada and Scandinavia. In 'Wiping away the boreal', Greenpeace (2017) explain that the widespread practice of industrial clearcut logging has dramatically fragmented Sweden's forest landscapes, with large areas of old-growth forest being cleared and replaced by faster growing non-native timber plantations. The report identifies Essity (SCA Hygiene) as one of the drivers of boreal forest destruction in Sweden and Russia. The company is Europe's largest producer of consumer tissue and the second largest in the world (after Kimberley-Clark).

'The issue with tissue: how Americans are flushing forests down the toilet', published by the Natural Resource Defence Council (Skene & Vinyard, 2019), states that a majority of tissue products are made from wood pulp which drives the degradation of forests around the world. Wastefulness is exacerbated by everyday consumption which facilitates a 'tree-to-toilet pipeline' in which centuries-old trees are 'hewn from the ground, converted into tissue pulp, rolled into perforated sheets or stuffed into boxes, and flushed or thrown away'. In Canada, the report says, more than 90% of logging is done by clearcutting. Clearcut forests can take more than a century to return to their pre-logging condition and some never do.

Because forests store and sequester carbon, tissue products made from virgin fibre have a higher carbon footprint than those made from other materials. And yet, these authors note, recycled content and alternative fibres are readily available. Tissue products made from bamboo release 30% less greenhouse gas emissions than tissue made from virgin wood. Yet large companies still adhere to decades old tissue formulas which have taken a devastating toll on forests. Procter & Gamble and Kimberly-Clark, it states, do not yet incorporate Scope 3 emissions into their greenhouse gas emissions reduction strategy.

Bamboo production, like the production of many alternative alternative fibre plants, often lacks robust supply chain monitoring, and bamboo plantations are sometimes grown in recently deforested areas. Producers and consumers should ensure it is sustainably sourced and certification is indicated on the products. The primary source of such certification is the Forest Stewardship Council (FSC) but Crumbie (2019) states that 'it is impossible to be sure that a product carrying an FSC logo really does come from a forest source that is environmentally acceptable, socially beneficial and economically sustainable'. This is because the FSC itself does not carry out eco-audits of forestry operations or timber companies. Rather this is done by private certification companies who are accredited by the FSC, and who are contracted and paid directly by the companies seeking certification. For this reason, toilet paper made using virgin wood pulp, even if FSC certified, cannot be considered a sustainable product.

LCA METHODS AND FACTORS

Van der Lugt & Vogtländer (2015) suggest that Life Cycle Assessment (LCA) methodology is an effective way to evaluate and verify claims about the environmental benefits of bamboo as a raw material. LCA is based on a range of environmental indicators which, besides the Global Warming Potential (carbon footprint), include acidification, eutrophication, smog, dust, toxicity, depletion, land-use and waste. The authors explain however that while the carbon footprint, expressed as kg of $CO2$ equivalent, can be easily understood and explained, other measures including other polluting emissions present greater challenges both in data collection and interpretation.

In the case of bamboo, biogenic $CO2$ sequestered during the growth of a stem may be legitimately included in an LCA if it has an end of life value. In the present case, the carbon stored in the tissue product is retained for agricultural 'landspreading' purposes, which leads over time to an increase in sequestration which may therefore be counted as a credit in LCA calculations.

This 'cradle-to-grave' approach which covers the whole product life cycle from the raw material extraction through the manufacturing and use stage to disposal is an important feature of LCA (Masternak-Janus & Rybaczewska-Błażejowska, 2015), and requires the collection and quantification of inputs and outputs for a given product or process system throughout its life cycle.

Zdilla et al (2014) list pre-harvest burning, soil tillage, nitrogen applications, fertilizer use, energy use, transportation, processing inputs, irrigation and land use change as elements to be considered as impacting emissions. An LCA can help identify and eliminate 'hot spots' to help achieve carbon neutrality within the scope of production. They suggest that carbon emitted from land use changes or crop management, including soil emissions, must be accounted for.

Madsen (2007), Ingwersen et al (2016) and Favero et al (2017) have produced LCA analyses for tissue manufacturers in the USA, each coming to the same non-committal conclusion that there is little provable environmental benefit in using recycled fibre as a raw material. European authors cited earlier contradict this. Zhao et al (2019) describe a Chinese case study based on an energy supply which included external fossil fuel coal and internal biomass fuel black liquor. Carbon emissions were found to occur mainly in fuel combustion in CHP and diesel combustion in material transportation.

Schultz & Suresh (2018) present supporting documentation for an online LCA calculator based on US data the results of which are included below for comparison purposes. Their results seem significantly higher than others.

MARKETING CLAIMS

Supporting the claim made by Skene & Vinyard for NRDC (2019) that large manufacturers are failing to adopt environmentally responsible strategies, Kimberly-Clark's 2018 Sustainability Report (Kimberley Clark, 2019) claims for their Andrex brand of toilet tissue that it is: 100% recyclable, uses less water than in 2005, is landfill free, and is made from sustainably sourced fibre (100% FSC certified). The recyclable claim, however, puts the onus on the consumer and depends on local recycling practices. The landfill claim is spurious since (at least in the UK), most toilet tissue ends up in sewage sludge recycled to agricultural land (OFWAT, 2010). And the value of FSC certification has been called into question (Crumbie, 2019).

The most rigorous work on tissue LCA, carried out for Kimberley-Clark, is more than a decade old (Madsen, 2007), while the scope of a more recent study carried out for Proctor & Gamble is restricted to a particular paper product made in the USA (Ingwersen, 2017). Neither study presents primary data.

Essity (Essity, 2020), also mentioned above, stakes its environmental responsibility on carbon credits and emissions allowances under which it has 24 production facilities in the EU offsetting rather than reducing their carbon footprint.

Another company, Nova Tissue, flags its partnership with a tree charity while claiming their product is 'made from responsibly sourced trees converted at a zero-emissions paper mill and then manufactured and wrapped in plastic-free, 100% home compostable packaging'. The product has 45% more paper compacted onto it leading to a claim that there are 30% less delivery trucks on the roads.

WEPA (UK) claims sustainability as one of its core values and states that the company is 'committed to minimising the environmental impact of its operations by meeting all legal requirements and meeting industry standards wherever possible'.

It may be noted that many of these claims, made for marketing purposes, are vague and non-committal in terms of tangible environmental benefits. Numerical measures of emissions or other commonly used LCA factors are almost entirely absent.

OBSERVATIONS

It is an interesting phenomenon of the extant literature that claims are repeated from one work to another without substantiation and that claims are made which contradict others. This is particularly notable in regard to bamboo growth rates, the benefit of recycled fibre over virgin and the overall value of bamboo as a sustainable plantation crop.

Furthermore, there is evidence of fabrication of data and plagiarism. A report by the Italian company Hygenia is entitled 'Life Cycle Assessment products single-use bamboo paper' whose grammatical inaccuracy could be forgiven except for the fact it was almost entirely copied and pasted from a 2010 LCA report on textile and single use tablecloths in restaurants carried out by Ente Bilaterale del Sistema Industriale Integrato di Servizi Tessili e Medici Affini. It contained nothing specific to bamboo products at all.

A report released by Kimberley-Clark entitled 'Life Cycle Assessment of Alternative Fibers with Supplemental Analyses' appears in certain search results. It is substantially similar to 'Life cycle and market review of the major alternative fibers for paper production' (Favero et al, 2017), and has since been taken down from the company's website. The Favero et al paper, as well as the 2007 LCA carried out for Kimberley-Clark (Madsen, 2007), conclude similarly: 'We are not convinced that any type of alternative fiber reviewed here has inherently low environmental impact compared to moderate to low impact standard wood fibers'. A further study carried out for Proctor & Gamble (Ingwersen et al, 2016) also fails to provide any substantive conclusion other than 'making the product drives much of the relevant impacts on the environment'.

These observations are disappointing given the high profile of the organisations studied and the apparent rigour of the analyses.

CONCLUSIONS

While insights can be gained into bamboo as a sustainable source of raw material and into tissue paper production processes, none of the documents examined provides information specific to the case in hand. It will be necessary therefore to compare such data as is available in the literature with published databases and primary data so far as it is available. Some data has become apparent which can be used to both include in calculations as well as to cross check findings.

Data analysis

PRIMARY DATA (Chishui Newland Import and Export Trading Co, personal communication)

Weight/bulk of product unit roll/carton:

- total factory production 30,000 te/yr
- 68.6 m3, 7369.6 kg, 48 rolls per carton, 1120 cartons per load
- shipped in 40ft container (67.7 m3)
- carton 6.58kg
- roll (plus pro rata carton) 0.137kg
- @200 sheets per roll: 0.68g/sheet / @160 sheets per roll 0.86g/sheet

Factory power consumption from utility bills:

- six month total: 323,925
- annualised: 647,850
- annual production: 30,000 te
- energy per tonne: 21.5 kWh / te

Factory to Chongqing port: 180km

Chongqing to Shanghai: 2,250km

Shanghai to Felixstowe: 22.000km

Disposal via sewage system: 80% landspreading, 20% incineration (OFWAT, 2010)

SECONDARY DATA

Hydropower plants:

- a typical GHG emission factor is 15 g CO2 equivalent/kWh (Gagnon & Van der Vate 1997)
- carbonbrief.org gives hydro as 97g CO2e/kWh
- Baldwin (2006) gives 10 gCO2eq/kWh (non-alpine reservoir storage)
- Scherer & Pfister (2016) offer an allocated median of 84.0 kgCO2e/MWh. For the Three Gorges dam, the figure is 153.8
- reasonable average 51.5 gCO2e/kWh.

Process data (Zhao et al, 2019):

- cultivation and harvesting 0.07 GJ / m3 @ 380 kg/m³ = 184 MJ/te @ 0.277778 MJ/kWh = 51.1 kWh/te
- pulping processes total 519 kWh/te
- papermaking processes total 212 kWh/te

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BAMBOO TOILET TISSUE DATA and emissions calculations

Process stage	Functional unit (FU) = 1 carton, 6.58kg, 48 rolls per carton				
	Raw data	Assumptions	Factor, kg/unit	kgCO2e/FU	% of total
Plantation	Not included	Sequestration			
Harvesting	4te bamboo/1te paper 51.1 kWH/te	Manual Shredding	0.0515/kWh	0.0693	1%
Local transport of stems	30km by road	100% laden 5-ton truck	0.25642/te.km	0.4049	7%
Pulping	Steam: 1474 kWh/te Power: 519 kWh/te	Zhao et al data, assumed all hydro electricity	0.0515/kWh	0.6754	12%
Tissue factory	21.5 kWh/te (See note)	100% hydro electricity	0.0515/kWh	0.0073	< 1%
Local transport of product	180 km by road 7.37te	Full 40ft container Full 15 ton truck	0.12125/te.km	0.2872	5%
Riverboat to Shanghai	2,250km by ship 7.37te	500 TEU container ship	0.036806/te.km	0.5449	10%
Shipping to UK	22,000km by ship 7.37te	20,000 TEU container ship	0.012674/te.km	1.8347	34%
Distribution	200km, 7.37te	to depot by truck	0.25642/te.km	0.3374	6%
Storage		Not accounted for			0%
Delivery	100km, 6.58kg	1 carton to user by van	0.62001/te.km	0.8159	15%
Use	Not accounted			0.0000	0%
Disposal	80% compost	Composting organic waste	10.2039/te	0.0537	1%
	20% combustion	Incinerating	21.3538/te	0.0281	1%
Transport	100km	Landspreading	0.62001/te.km	0.4080	7%
TOTAL emissions		per carton		5.4668	100%
		per kg		0.8308	
		per roll		0.1139	
		per sheet		0.0007	

Note: Primary data supplied by the factory. See Discussion and Sensitivity Analysis.

RESULTS

Source	Date	Country	Roll spec.	FU	Virgin	Recycled	Bamboo
Cheeky Panda	2016	China/UK	115g / 200 sheets	One roll	400	200	138
Tesco	2009	UK	See notes	One roll	288	176	
Madsen (K-C)	2007	EU	160 rolls, 26000 sheets, 34g/m2	One roll	368	464	
EPN (Schultz)	2018	USA	115g	One roll	1360	410	
Essity (excludes Scope 3)	2018	EU	Based on gross production data	One roll	101		
Present case	2020	China/UK	115g / 200 sheets	One roll			114

Notes:

- CheekyPanda data (Chen & Forbes, 2016) confuses virgin and recycled between their chart and their commentary. Figures may be reversed.
- Tesco: assumed sheet size 10x12cm, 160 sheets.
- Madsen data: recycled fibre at only 20%.
- Gemechu et al data presented as kgCO2e/kg tissue and converted to FU.
- EPN Paper Calculator assumes logged forest loss and disposal to landfill.
- Essity excludes Scope 3 emissions and is calculated from their published gross production/emissions data.
- Order of magnitude checks:
  - Calculations made by Van de Vugt et al (2015) relating to bamboo production for other purposes than tissue paper give an emissions figure of 1.2 kgCO2e / kg of product. This would translate to 138 gCO2e for a 115g roll, the same as given by CheekyPanda above.
  - Paper scope 3 factor 952.68 kgCO2e per tonne = 0.95268/kg = 110 gCO2e per 115g roll (DEFRA 2020).

DISCUSSION and SENSITIVITY ANALYSIS

Harvesting and pulping figures have been taken from Zhao et al (2019) which is based on a macro scale view of Chinese paper making operations much of which uses fossil fuels as opposed to the 100% hydroelectric claimed for the Chishui operation.

Paper making energy figures from Chishui are taken directly from the company’s utility bills but these seem understated compared to other sources. Zhao’s figures appear to be almost ten times higher for this stage. But inserting this into the emissions calculation would only raise the emissions per roll equivalent from 114g to 115g.

It seems counterintuitive that the production stages account for such a small percentage of the total. Shipping and other transport stages account for the greatest levels of emissions. This may explain why the figures for virgin pulp produced tissue are higher because their sources of raw materials, even including recycled fibre, involve multiple transport stages both within Europe and to and from China (DEFRA, 2012).

The bamboo figures do not take account of the carbon sequestration potential, a legitimate component in LCA analysis since the value chain end of use does not destroy the embodied carbon. Vogtländer (2010) has suggested a sequestration credit of -0.6085 kgCO2e/kg, which for the FU would calculate as a carbon credit of 4.0039 kgCO2e. Accounting for this would reduce the net emissions per roll from 114 to 31 kgCO2e.

The present research has referenced published data from several countries, and it may be noted that there are significant variations in the mix of energy sources, efficiencies and emissions factors. Examples include (Deodar, 2014):

tissue production emissions per country teCO2e/te

- China 1.169 - UK 1.38 - USA 1.548

electricity emissions factors by country, kg CO2/MWh

- UK 440 - USA 500 - China 620.

The following chart explores the impact of the most important variables.

Variable	Scenario	FU	gCO2e/roll
	Base case	One roll	114
Production energy	10x production energy data		115
	100x production energy data		129
Hydropower factor	Factor doubled to 103gCO22e/kWh		130
Worst case	100x production Hydropower factor doubled		160
Best case	Base case plus sequestration factor		31

Due to the uncertainties noted, a figure of 132 gCO2e/roll may be considered safe to use, based on the 10x production factor (due to doubts over the validity of primary data provided) and a doubling of the hydropower emissions factor (due to wide variations in published data noted above).

There is a high degree of confidence due to the predominant influence of transport components whose emissions factors are well accepted.

LCA LIMITATIONS

This paper has followed LCA principles but specific data is not available to consider the full range of impacts which include waste disposal, effluents, water use, ecological integrity of landscape, biodiversity impacts, use of fertilizer and pesticides.

LCAs may be used to identify 'hot spots' in a value chain in order to make improvements and savings. The hot spots include the various transport elements but comparisons with other similar products manufactured in the UK suggest that these too are influenced by extended supply chains.

Conclusions

The results show that that the scenario examined offers the lowest full scope emissions between the products compared, especially if carbon sequestration credits are included. The hypothesis is thus considered proven: that toilet paper produced from bamboo, even though shipped to the UK from China, has relative environmental benefits compared with tissue made from the more conventional practice of Scandinavian forest logging. The environmental value of well managed bamboo plantations has been established.

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