Cigarette Smoking: An assessment of tobacco’s global environmental footprint across its entire supply chain

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Abstract

While the health effects of cigarette smoking are well recognised and documented, the environmental impacts of tobacco are less appreciated and often overlooked. Here we evaluate tobacco’s global footprint across its entire supply chain, looking at resources needs, wastes and emissions of the full cradle-to-grave life cycle of cigarettes. The cultivation of 32.4 Mt of green tobacco used for the production of 6.48 Mt of dry tobacco in the six trillion cigarettes manufactured worldwide in 2014, were shown to contribute almost 84 Mt CO₂ eq emissions to climate change – approximately 0.2% of the global total, 490,000 tonnes 1,4 dichlorobenzene eq to ecosystem ecotoxicity levels, over 22 billion m³ and 21 Mt oil eq to water and fossil fuel depletion respectively. A typical cigarette was shown to have a water footprint of 3.7 litres, a climate change contribution of 14 g CO₂ eq, and a fossil fuel depletion contribution of 3.5 g oil eq. Tobacco competes with essential commodities for resources and places significant pressures on the health of our planet and its most vulnerable inhabitants. Increased awareness as well as better monitoring and assessment of the environmental issues associated with tobacco should support the current efforts to reduce global tobacco use as an important element of sustainable development.
INTRODUCTION

Every year six trillion cigarettes are produced and 5.8 trillion consumed by one billion smokers worldwide. Although smoking prevalence has been dropping in high-income countries, global cigarette consumption has continued to grow, largely as a result of the increasing uptake of smoking by young people in developing regions. While the health effects of smoking are now well established, the impacts of tobacco on the environment are less appreciated. These range from the use of scarce arable land and water for tobacco cultivation, use of harmful chemicals on tobacco farms, deforestation, carbon emissions from manufacture and distribution processes, to the production of toxic waste and non-biodegradable litter. Furthermore, incorrect disposal of cigarette butts has been linked to numerous domestic and wildland fires with devastating results.

Over and above its direct impact on human health, the scale of the damage caused by tobacco to the natural world and natural resources is largely unknown. Although some tobacco companies produce sustainability reports and life cycle assessments (LCA), the assumptions and the methodologies used in these studies are not always transparent and often partially reported. Most of these assessments are limited to manufacturing processes and producers’ immediate supply chains, omitting integral preceding stages such as tobacco growing, curing, distribution, and product disposal, and thus substantially underestimate the actual environmental costs of cigarette smoking.

From tobacco cultivation, curing, processing, cigarette manufacturing, distribution, to use and final disposal, the tobacco industry’s supply chain is global and extensive. To understand all the environmental impacts of cigarette smoking, it is essential to consider tobacco’s entire supply chain. In this paper, we therefore present a systematic and transparent assessment of...
the environmental impacts of cigarettes, quantifying the environmental footprint of smoking across the global tobacco supply chain. A cumulative mass balance model was produced using Material Flow Analysis (MFA), an established analytical method for quantifying flows and stocks of materials and substances; while the environmental footprint of cigarette smoking was captured from cradle-to-grave using Life Cycle Assessment (LCA) - a well-established and internationally standardised method for assessing the potential environmental and health impacts of goods and services.  

METHODOLOGY

A global cigarette production and consumption conceptual model was developed to calculate the resource needs and environmental emissions of the global tobacco supply chain (Figure 1). Data were obtained from a range of secondary sources, including industry and market research reports, peer reviewed studies, and a number of Ecoinvent datasets available in SimaPro 8. Wherever possible, production- and/or consumption-weighted global average amounts were used and when necessary, representative global values of input and output flows were extrapolated from regional or company-specific data available (see Supporting Information for the full list of assumptions and data sources).

Material Flow Analysis was used to quantify the flows of natural resources and materials at the different stages of cigarette production and consumption, capturing both inputs (direct and indirect) and outputs. Additionally, due to a lack of data, selected direct inputs were also excluded (Figure 1). A cumulative mass balance model was produced based on typical mass flows per tonne of output tobacco at each stage in the supply chain, as well as the losses in tobacco mass across stages, all calculated through MFA (See Supporting Information for the
The environmental impacts associated with global tobacco production and consumption were quantified through LCA, using the SimaPro 8 software\textsuperscript{21} and the ReCiPe Midpoint (H) methodology.\textsuperscript{22} The base year, scope, system boundaries, functional unit, and impact categories are summarised in Table 1, and a full description of the inputs, sources, and the assumptions used are reported in Supporting Information, together with the limitations and the uncertainty associated with these factors.

Sensitivity analysis was carried out to evaluate how varying key assumptions used in the primary analysis could influence the total impact assessment outcomes and to identify the inputs where variation has the most impact on key outputs (see Supporting Information).
Figure 1. Conceptual framework and system boundaries of global cigarette production and consumption.
Table 1. Life cycle assessment (LCA) study scope and system boundaries of global cigarette production and consumption

<table>
<thead>
<tr>
<th>Study features</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processes included</td>
<td>Tobacco cultivation, curing, primary processing, cigarette manufacturing, distribution, use and disposal, plus transportation and waste management activities at every process stage.</td>
</tr>
<tr>
<td>Representative product</td>
<td>Cigarette sticks including manufactured and roll your own sticks containing 1g and 0.75g of tobacco and accounting for 98.35% and 1.65% production respectively*</td>
</tr>
<tr>
<td>Functional unit</td>
<td>A tonne of produced and consumed tobacco, equivalent to 1 million cigarette sticks**</td>
</tr>
<tr>
<td>Scope</td>
<td>Global cigarette production and consumption in one year</td>
</tr>
<tr>
<td>Base year</td>
<td>2014</td>
</tr>
<tr>
<td>Mass flows allocated to tobacco</td>
<td>100%</td>
</tr>
<tr>
<td>Types of resource flows included in the analysis</td>
<td>Key direct and indirect inputs and outputs</td>
</tr>
<tr>
<td>Types of resource flows excluded from the analysis</td>
<td>Office supplies, cleaning products, chemicals and additives used in production and manufacturing processes, smoking accessories</td>
</tr>
<tr>
<td>Issues excluded from impact analysis</td>
<td>Smoking-related fires, second-hand smoke, unsustainably sourced wood in curing, incorrectly disposed post-consumer waste that ends up in the environment (instead, all waste is assumed to be treated or deposited at landfill sites)</td>
</tr>
<tr>
<td>Impact categories considered</td>
<td>Climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity (excluding the health impacts of direct and second-hand smoking, as well as occupational exposure), terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion, and fossil fuel depletion.</td>
</tr>
</tbody>
</table>

*The assumption that the average tobacco weight of 1g in a typical manufactured cigarette (based on the PMI reported tobacco weight23) was tested in the sensitivity analysis by substituting it with 0.75g.

**The environmental impacts of a tonne of produced and consumed tobacco are equivalent to the impacts of a million smoked cigarette sticks

RESULTS

It was calculated that a total of 32.4 Mt of green tobacco leaf were cultivated on 4 million hectares of land, producing the 6.48 Mt of dry tobacco used to manufacture six trillion
cigarette sticks across 500 factories worldwide. However, tobacco cultivation was found to be concentrated primarily in low- and middle-income regions - nine of the top ten tobacco producing countries were developing and four of those (India, Zimbabwe, Pakistan, and Malawi), low-income food-deficit countries. In most of these countries, the majority of all tobacco produced is destined for exports with less than 20% consumed locally (Figure 2).

![Map of tobacco consumption and production worldwide.](image)

**Figure 2.** Annual tonnage of tobacco in cigarette production and consumption for countries with over 1,000 tonnes of tobacco flows in year 2014.\(^{24-27}\)

The total material inputs for the global production of six trillion cigarette sticks in 2014 amounted to 27.2 Mt. The energy inputs exceeded 62 million GJ, the water inputs came to over 22,000 Mt, the total arable land input to 4 million hectares and the transportation of tobacco products reached 24.5 billion tkm of freight (Table 2, Figure 3). The total outputs in addition to six trillion cigarettes included 25 Mt of solid waste, nearly 22,000 Mt of water, of which 55 Mt was wastewater from the processing and manufacturing stages and the rest was mainly losses to soil, water bodies and air from irrigation at the farming stage as well as almost 84 Mt CO\(_2\) eq emissions to air (Net of CO\(_2\) absorption by tobacco plants at the farming stage).
### Table 2. Summary annual mass flows in the global tobacco supply chain

<table>
<thead>
<tr>
<th>Stage</th>
<th>Inputs</th>
<th>Unit</th>
<th>Inputs per tonne of output tobacco</th>
<th>Total output tobacco at each stage (Mt)</th>
<th>Total Inputs (millions)</th>
<th>Inputs per tonne of tobacco produced for consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WATER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cultivation</td>
<td>tonne</td>
<td></td>
<td>678</td>
<td></td>
<td>32.4</td>
<td>21978.1</td>
</tr>
<tr>
<td>- Processing</td>
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<td></td>
<td>7.59</td>
<td></td>
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<td>45.4</td>
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<tr>
<td>- Manufacturing</td>
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<td></td>
<td></td>
<td></td>
<td>5.98</td>
<td>22038.2</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cultivation</td>
<td>MJ</td>
<td></td>
<td>8.59</td>
<td></td>
<td>32.4</td>
<td>278.3</td>
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<tr>
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<td>MJ</td>
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<td>277</td>
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</tr>
<tr>
<td>- Cultivation</td>
<td>tonne</td>
<td></td>
<td>0.03</td>
<td></td>
<td>32.4</td>
<td>1.07</td>
</tr>
</tbody>
</table>

**Note:** The table provides a summary of annual mass flows in the global tobacco supply chain, including inputs for water, energy, and material resources at different stages (cultivation, processing, manufacturing).
<table>
<thead>
<tr>
<th>Stages</th>
<th>Unit</th>
<th>Quantity</th>
<th>TRANSPORT</th>
<th>LAND</th>
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<td>6.48</td>
<td>32.4</td>
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<td>6.48</td>
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<td>5.98</td>
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<td>- Distribution</td>
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<td>tonne</td>
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<td><strong>27.2</strong></td>
<td><strong>32.4</strong></td>
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<tr>
<td>TRANSPORT</td>
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<td>32.4</td>
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<td>tkm</td>
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<td>LAND</td>
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</tr>
<tr>
<td>- Cultivation</td>
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<td>32.4</td>
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<tr>
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<td>- Manufacturing</td>
<td>m²</td>
<td>0.53</td>
<td>5.98</td>
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## WASTE and EMISSIONS

<table>
<thead>
<tr>
<th>Stages</th>
<th>Unit</th>
<th>Waste and emissions per tonne of output tobacco</th>
</tr>
</thead>
<tbody>
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<td>SOLID WASTE</td>
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<tr>
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</tr>
<tr>
<td>- Processing</td>
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</tr>
<tr>
<td>- Manufacturing</td>
<td>tonne</td>
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<tr>
<td>- Use &amp; Final Disposal*</td>
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<table>
<thead>
<tr>
<th>Stages</th>
<th>Unit</th>
<th>Waste and emissions per tonne of produced and consumed tobacco</th>
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</thead>
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<td>40077.7</td>
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<td>6702.0</td>
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## WASTE WATER & WATER EMISSIONS

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<th>Unit</th>
<th>Waste and emissions (tonne)</th>
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<tr>
<td>- Curing</td>
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<table>
<thead>
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<th>Stages</th>
<th>Unit</th>
<th>Total output tobacco at each stage (Mt)</th>
<th>Total waste and emissions (millions)</th>
<th>Waste and emissions per tonne of produced and consumed tobacco</th>
</tr>
</thead>
<tbody>
<tr>
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<td>tonne</td>
<td>32.4</td>
<td>19.4</td>
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</tr>
<tr>
<td>- Processing</td>
<td>tonne</td>
<td>5.98</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>- Manufacturing</td>
<td>tonne</td>
<td>5.98</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td>- Use &amp; Final Disposal*</td>
<td>tonne</td>
<td>5.78</td>
<td>4.1</td>
<td>0.6</td>
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<tr>
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<td>tonne</td>
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<table>
<thead>
<tr>
<th>Stages</th>
<th>Unit</th>
<th>Waste and emissions (tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cultivation</td>
<td>tonne</td>
<td>32.4</td>
</tr>
<tr>
<td>- Curing</td>
<td>tonne</td>
<td>6.48</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stages</th>
<th>Unit</th>
<th>Total output tobacco at each stage (Mt)</th>
<th>Total waste and emissions (millions)</th>
<th>Waste and emissions per tonne of produced and consumed tobacco</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cultivation</td>
<td>tonne</td>
<td>32.4</td>
<td>21844.5</td>
<td>3652.9</td>
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<tr>
<td>- Curing</td>
<td>tonne</td>
<td>6.48</td>
<td>25.9</td>
<td>4.3</td>
</tr>
<tr>
<td>Stages</td>
<td>Unit</td>
<td>2013</td>
<td>2014</td>
<td>2015</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>- Processing (waste water)</td>
<td>tonne</td>
<td>7.61</td>
<td></td>
<td></td>
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<td>- Manufacturing (waste water)</td>
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<td>1.50</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>tonne</strong></td>
<td><strong>21925</strong></td>
<td><strong>3666.4</strong></td>
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</table>

**EMISSIONS TO AIR**

<table>
<thead>
<tr>
<th>Stages</th>
<th>Unit</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cultivation</td>
<td>t CO₂ eq</td>
<td>0.64</td>
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<td></td>
</tr>
<tr>
<td>- Curing</td>
<td>t CO₂ eq</td>
<td>6.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Processing</td>
<td>t CO₂ eq</td>
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<td></td>
</tr>
<tr>
<td>- Manufacturing</td>
<td>t CO₂ eq</td>
<td>2.63</td>
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<td></td>
</tr>
<tr>
<td>- Distribution</td>
<td>t CO₂ eq</td>
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<td></td>
</tr>
<tr>
<td>- Use &amp; Final Disposal*</td>
<td>t CO₂ eq</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>t CO₂ eq</strong></td>
<td><strong>84</strong></td>
<td><strong>14.0</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Note: amounts for the Use & Final Disposal stage refer to consumed tobacco as opposed to produced tobacco in the preceding stages. It includes all post-consumer waste but assumes it is all treated or deposited at landfill sites.
## Total material and energy inputs for annual cigarette production of 6 trillion cigarettes

<table>
<thead>
<tr>
<th>Component</th>
<th>Input</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour excluded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation to farm</td>
<td>Mln tkm</td>
<td>405</td>
</tr>
<tr>
<td>Agric-l Machinery use</td>
<td>Mln ha</td>
<td>3.20</td>
</tr>
<tr>
<td>Pesticides</td>
<td>Mt</td>
<td>0.16</td>
</tr>
<tr>
<td>Fertilisers</td>
<td>Mt</td>
<td>0.900</td>
</tr>
<tr>
<td>Seeding production</td>
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<td></td>
</tr>
<tr>
<td>Land, Mln m²</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Peat Moss, Mln m³</td>
<td>19.4</td>
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</tr>
<tr>
<td>Energy, Mln MJ</td>
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<td></td>
</tr>
<tr>
<td>Planting process</td>
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<td></td>
</tr>
<tr>
<td>Machinery, fuel, Mt</td>
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</tr>
<tr>
<td>Shed, Mln m²</td>
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</tr>
<tr>
<td>Transport to processing</td>
<td>Mln tkm</td>
<td>648</td>
</tr>
<tr>
<td>Energy for processing (coal)</td>
<td>Mln MJ</td>
<td>82.71</td>
</tr>
<tr>
<td>Heat &amp; power co-generation unit</td>
<td>Mln units</td>
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</tr>
<tr>
<td>Curing barn</td>
<td>Mln m²</td>
<td>0.84</td>
</tr>
<tr>
<td>Fuel for flue-curing (68% of all tobacco)</td>
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</tr>
<tr>
<td>Wood</td>
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<td>Coal</td>
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<tr>
<td>Cardboard boxes for shipping</td>
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<td>Cardboard boxes</td>
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<tr>
<td>Tobacco shipping</td>
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<td></td>
</tr>
<tr>
<td>By road, Mln tkm</td>
<td>598.0</td>
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<td>By sea, Mln tkm</td>
<td>16730</td>
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<tr>
<td>Tobacco storage facilities</td>
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<td></td>
</tr>
<tr>
<td>Land, Mln m²</td>
<td>2.58</td>
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<tr>
<td>Transport, Mln tkm</td>
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<td>Energy/electricity, Mln MJ</td>
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<td>Building, Mln m³</td>
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<td>Construction materials, Mt</td>
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<tr>
<td>Cigarette cartons</td>
<td>Mt</td>
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</tr>
<tr>
<td>Manufacturing plant</td>
<td>Mln m²</td>
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</tr>
<tr>
<td>Energy, Mln MJ</td>
<td>60203</td>
<td></td>
</tr>
<tr>
<td>Cigarette packs with</td>
<td>Mt</td>
<td></td>
</tr>
<tr>
<td>Accessory materials, e.g. lighters</td>
<td>Mt</td>
<td>0.145</td>
</tr>
<tr>
<td>Shipping by air (1%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipping by marine transport (17%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipping by truck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unused</td>
<td>Mt</td>
<td>0.2</td>
</tr>
<tr>
<td>Other non-tobacco cigarette ingredients</td>
<td>Mt</td>
<td>0.62</td>
</tr>
<tr>
<td>Cigarette Filters</td>
<td>Mt</td>
<td>1.02</td>
</tr>
<tr>
<td>Shipping by marine transport</td>
<td>Mln tkm</td>
<td>5421</td>
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<tr>
<td>Shipping by air</td>
<td>Mln tkm</td>
<td></td>
</tr>
<tr>
<td>Shipping by truck</td>
<td>Mln tkm</td>
<td>598</td>
</tr>
</tbody>
</table>

### Material and Energy Inputs

**Labour**

*Excluded*

**Transportation to farm**

| Mln tkm | 405 |

**Liming tobacco soils**

| Mt | 0.16 |

**Agric-l Machinery use**

| Mln ha | 3.20 |

**Pesticides**

| Mt | 0.0063 |

**Fertilisers**

| Mt | 0.900 |

**Seeding production**

- Land, Mln m²: 0.15
- Peat Moss, Mln m³: 19.4
- Energy, Mln MJ: 278

**Planting process**

- Machinery, fuel, Mt: 0.0105
- Shed, Mln m²: 0.00004

**Transport to processing**

| Mln tkm | 648 |

**Energy for processing (coal)**

| Mln MJ | 82.71 |

**Heat & power co-generation unit**

| Mln units | 0.00016 |

**Curing barn**

| Mln m² | 0.84 |

**Fuel for flue-curing (68% of all tobacco)**

- Wood: 8.05
- Coal: 13.04

**Cardboard boxes for shipping**

| Mt | 0.990 |

**Cardboard boxes**

| Mt | |

**Tobacco shipping**

- By road: 598.0 Mln tkm
- By sea: 16730 Mln tkm

**Tobacco storage facilities**

- Land: 2.58 Mln m²
- Transport: 1.1 Mln tkm
- Energy/electricity: 1571 Mln MJ
- Building: 0.24 Mln m³

**Processing facilities**

- Construction materials: 1.0 Mt
- Electricity/heat inputs: 0.006 Mln MJ
- Land: 71 Mln m²

**Cigarette cartons**

| Mt | 0.10 |

**Manufacturing plant**

| Mln m² | 3.15 |

**Energy/electricity**

| Mln MJ | 60203 |

**Cigarette packs with accessories, e.g. lighters**

| Mt | 0.145 |

**Shipping by air (1%)**

**Shipping by marine transport (17%)**

**Shipping by truck**

**Unused**

| Mt | 0.2 |

**Other non-tobacco cigarette ingredients**

| Mt | 0.62 |

**Cigarette Filters**

| Mt | 1.02 |

**Shipping by marine transport**

| Mln tkm | 5421 |

**Shipping by air**

| Mln tkm | |

**Shipping by truck**

| Mln tkm | 598 |

**Unused**

| Mt | 0.2 |

**Use & Final disposal**

| Mt | 5.78 |

---

### Total Tobacco Output

- **Cultivation**
  - Flue/fire - curing (68%):
    - Mt: 32.4
  - Air/sun - curing (32%):
    - Mt: 6.48

- **Primary processing & trading**
  - Mt: 5.98

- **Manufacturing**
  - Mt: 5.98

- **Distribution**
  - Mt: 5.98

- **Use & Final disposal**
  - Mt: 5.78
Figure 3. Total annual input, waste and emission flows across the global tobacco supply chain.
The global tobacco supply chain also contributed over 19 Mt of 1,4-dichlorobenzene equivalent (1,4-DB eq, used as a reference unit in LCA to characterise the effects of toxic substances on human health and ecosystems) to human toxicity, and nearly 500,000 t 1,4-DB eq to freshwater and marine ecosystems’ ecotoxicity levels respectively. Tobacco drives almost 21 Mt oil eq in fossil fuel depletion, nearly 3.3 Mt Fe eq in metal depletion, and over 22.2 billion m³ in water depletion. Its terrestrial acidification potential was found to be in excess of 450,000 Mt SO₂ eq, while the total land use and transformation is almost 5.3 million hectares (Table 3). The activities accounting for the highest contribution across all impact categories were tobacco farming, cigarette manufacturing, and curing (Figure 4).

Table 3. Total annual environmental impacts of the global tobacco supply chain

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Farming (Millions)</th>
<th>Curing (Millions)</th>
<th>Processing (Millions)</th>
<th>Cigarette Manufacturing (Millions)</th>
<th>Distribution (Millions)</th>
<th>Use &amp; Disposal (Millions)</th>
<th>TOTAL (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO₂ eq</td>
<td>20849</td>
<td>44674</td>
<td>1073</td>
<td>15720</td>
<td>386</td>
<td>870</td>
<td>83572</td>
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<tr>
<td>Terrestrial acidification</td>
<td>kg SO₂ eq</td>
<td>119</td>
<td>240</td>
<td>11</td>
<td>78</td>
<td>2.4</td>
<td>2.9</td>
<td>453</td>
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<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>6.8</td>
<td>0.6</td>
<td>0.3</td>
<td>8.3</td>
<td>0.03</td>
<td>0.3</td>
<td>16</td>
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<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>11</td>
<td>3.7</td>
<td>0.4</td>
<td>4.3</td>
<td>0.2</td>
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<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>7107</td>
<td>4865</td>
<td>590</td>
<td>6286</td>
<td>52</td>
<td>534</td>
<td>19435</td>
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<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>24</td>
<td>1.5</td>
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<td>4.5</td>
<td>0.1</td>
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<td>185</td>
<td>43</td>
<td>14</td>
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<tr>
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<td>304</td>
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</tbody>
</table>

**Diagram:**

- **1. Tobacco farming**
- **2. Tobacco curing**
- **3. Tobacco processing**
- **4. Cigarette Manufacturing**
- **5. Cigarette Distribution**
- **6. Cigarette Use & Disposal**

**Legend:**

- Climate Change
- Terrestrial acidification
- Freshwater eutrophication
- Marine eutrophication
- Human toxicity
- Terrestrial ecotoxicity
- Freshwater ecotoxicity
- Marine ecotoxicity
- Agricultural land
- Urban land occupation
- Natural land transformation
- Water depletion
- Metal depletion
- Fossil depletion
Figure 4. Environmental impacts contribution of the global tobacco supply chain stages across the full life cycle of cigarette production and consumption

The sensitivity analysis showed variability in the environmental impact results in the range of ±10% across most categories (Table 4). LCA results were most sensitive to changes in parameters such as the rate of agrochemicals application on farms, type of fuel use in flue-curing, and the energy use in cigarette manufacturing. The relative contributions of the different stages in the supply chain remained largely unchanged with farming, curing and manufacturing still driving most of the environmental impacts. The uncertainty in the LCA results driven by geographical variation was found to vary greatly by region and depending on the practices adopted, particularly in the climate change, terrestrial ecosystems’ health and fossil fuel depletion categories (see Supporting Information).

Table 4. Upper and lower percent variance established in the sensitivity analysis compared to the total impact assessment results

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Study results (millions)</th>
<th>variance</th>
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<td>kg CO₂eq</td>
<td>83572</td>
<td>± 8%</td>
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<td>kg SO₂eq</td>
<td>453</td>
<td>±7%</td>
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<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>16</td>
<td>±12%</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>21</td>
<td>±10%</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>19435</td>
<td>±7%</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>36</td>
<td>±19%</td>
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<td>Environmental Impact</td>
<td>Unit</td>
<td>Impact Measure</td>
<td>Impact Value</td>
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<td>--------------</td>
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<tr>
<td>Freshwater ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>489</td>
<td>±9%</td>
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<tr>
<td>Marine ecotoxicity</td>
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<td>±9%</td>
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<tr>
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<td>±6%</td>
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<tr>
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</tr>
<tr>
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<td>64</td>
<td>±6%</td>
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<tr>
<td>Water depletion</td>
<td>m³</td>
<td>22203</td>
<td>±8%</td>
</tr>
<tr>
<td>Metal depletion</td>
<td>kg Fe eq</td>
<td>3282</td>
<td>±4%</td>
</tr>
<tr>
<td>Fossil fuel depletion</td>
<td>kg oil eq</td>
<td>20813</td>
<td>±9%</td>
</tr>
</tbody>
</table>

Considering that the incorrectly disposed post-consumer waste, unsustainably sourced wood, wildland and domestic fires, and a number of the supply chain inputs were not included in the assessment, the reported impacts are likely to be underestimated.

**DISCUSSION**

Across the global tobacco supply chain, cultivation, curing, and manufacturing stand out as particularly resource-demanding and environmentally damaging stages. For tobacco farming, irrigation and fertiliser use together drive more than 70% of the environmental damage across most impact categories. At the curing stage, the direct burning of wood and coal accounts for more carbon emissions than all other stages combined, releasing at least 45 Mt CO₂ eq globally in a year (that is excluding the deforestation impacts driven by the unsustainably sourced wood). In cigarette manufacturing, the single most important driver of environmental impacts is energy use, which accounts for at least 60% contribution across more than half of all impact categories. The choice of energy source plays an important role in mitigating tobacco’s environmental footprint. For example, if coal dominates the energy mix, the carbon footprint of cigarette manufacturing may be higher by
as much as 35%, while the damage to freshwater and marine ecosystems would be at least 20% greater than the typical impacts estimated. However, comparisons of the levels of environmental damage are not clear-cut. For instance, although natural gas may have a lower carbon footprint than coal, it can lead to higher levels of land transformation and fossil fuel depletion.

The non-tobacco elements of cigarettes such as filters, cigarette paper, and packaging, all carry a burden on the environment too. More than 1 Mt of filters and about 2.15 Mt of packaging are estimated to be used by the tobacco industry in a year (excluding cardboard boxes for shipping). The resources used in the production of these elements and all the post-consumer waste that is created and which has to be treated or ends up contaminating the environment, further exacerbate tobacco’s environmental footprint.

Comparing the overall environmental footprint of tobacco to that of other crops - specifically those considered by WHO FCTC as potentially viable substitutes to tobacco in a number of developing countries and considering only the cradle-to-farm gate stages of crop production – we estimate that the nearly 1,300 m² of agricultural land used for the production of a tonne of green tobacco could produce about 6 tonnes of tomatoes or almost half a tonne of wheat in regions suitable for their cultivation (e.g. in Sub-Saharan Africa). Similarly, the water footprint of 670 m³ per tonne of tobacco is comparable to that of a tonne of rice and is between 5 and 8 times greater than that of tomatoes or potatoes (see Supporting Information).

A typical smoked cigarette stick was shown to have a water footprint of 3.7 litres, a fossil fuel use equivalent to 3.5 g oil, and a climate change impact of 14 grams of CO₂ eq emissions. Over a lifetime, a person smoking a pack a day for 50 years has a carbon footprint of 5.1 tCO₂ eq, which would require 132 tree seedlings grown for 10 years to offset. Their water footprint of 1,355 m³ is equivalent to almost 62 years’ supply for any three people’s basic hygiene and food hygiene needs, and the lifetime fossil fuel depletion of 1.3 tonne oil eq is comparable to the electricity use of an
average household in India for almost 15 years. Additionally, comparing the annual environmental footprint of such a smoker (7.3 kg tobacco per year) to the global average red meat (14.4 kg meat) and sugar (24.3 kg sugar) consumption per capita per year demonstrates that the resource depletion and pollution levels caused by cigarette use can be several times greater than or least as high as those driven by other typical consumer commodities. For instance, in one year a smoker contributes almost 5 times more to water depletion, nearly 2 and 10 times more to fossil fuel depletion than an average consumer of red meat and sugar respectively, and 4 times more to climate change than a sugar consumer (See supporting information).

The sector’s total annual contribution to climate change at 84 Mt CO$_2$ eq, makes up about 0.2% of the world’s total greenhouse gas (GHG) emissions. That is nearly as much as entire countries’ GHG emissions such as Peru and Israel and more than twice that of Wales. The annual fossil fuel depletion of 21 Mt oil eq driven by tobacco is comparable to the total primary energy consumption of New Zealand and Hungary. The sector’s contribution to metal depletion at 3.3 Mt Fe eq is at least as high as that caused by 8% of the USA’s annual mine production of iron ore, while its water depletion at 22,200 Mt is more than 2.5 times the annual water supply to the entire population of the UK. With almost 90% of tobacco leaf production and the majority of cigarette consumption now concentrated in the less developed regions, the environmental burden and the many risks associated with tobacco are largely borne by lower-income countries. Thus, for example, while Malawi and Tanzania are among the top 10 tobacco growing countries, they consume less than 5% of the tobacco they produce. At the same time, in the UK, Canada, Portugal, and Austria, with no or very little domestic tobacco leaf or cigarette production, smoking cigarettes, literally means burning other countries’ resources.

As the industry claims to have already delivered some improvements in efficiency in parts of the supply chain, benefits from further improvements appear unlikely, particularly in light of the
increasing levels of global production and consumption. For instance, a 24% reduction in carbon and water footprints between 2010 and 2015 were reported by one manufacturer, and a 47% reduction in carbon footprint from the 2000 baseline for another. However, these values cover only a limited part of the tobacco supply chain. Moreover, aggressive tobacco marketing in developing countries means that globally, total tobacco consumption is growing, and so therefore will its environmental impacts. It is highly unlikely that any efficiency improvements could potentially outweigh the benefit that cuts in absolute production and consumption would deliver across the board. For example, a drop in cigarette smoking to the 1970-level of 3.26 trillion sticks per year would almost half tobacco’s global footprint across all impact categories, while potential efficiency improvements may only lead to incremental reductions across selected categories. In contrast, should cigarette consumption be allowed to reach the predicted 9 trillion sticks by 2025, this could result yearly in agricultural land use of 7.9 million hectares, water and fossil fuel depletion of 34 billion m³ and 5 Mt oil eq respectively, and annual CO₂ eq emissions reaching almost 130 Mt.

In a world facing enormous pressures on natural resources, tobacco competes with commodities that are essential for humanity and adds significant pressures on the health of our planet and its most vulnerable inhabitants. For example, the world’s top cigarette consuming country – China – harvests over 3 Mt of tobacco leaves using over 1.5 million hectares of arable land and significant fresh water resources – while habitats suffer from water scarcity and nearly 134 million of its people are undernourished. Given also the devastating health and negative social and economic effects of the global tobacco epidemic, the primary goal of tobacco control and resource management policies should be to significantly reduce if not eliminate cigarette production and consumption, protecting not only human health but also the environment and societies’ right to sustainable development. To do so effectively, it is important that governments mandate systematic and extensive reporting from the tobacco industry on the environmental impacts of their operations...
that should then be communicated to consumers on top of the health impacts of cigarette smoking. The introduction of better monitoring and assessment of the environmental issues associated with tobacco, will keep consumers informed and further support tobacco control and resource management policies.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

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SUPPORTING INFORMATION AVAILABLE

Methods, the full list of assumptions and data sources are available in Supporting Information. Additional figures and tables are provided
REFERENCES


3. Leppan, W., Lecours, N. & Buckles, D. *Tobacco control and tobacco farming: separating myth from reality.* Ottawa, Canada: International Development Research Centre (IDRC); 2014.


Cigarette Smoking: An assessment of tobacco’s global environmental footprint across its entire supply chain

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Pages: 44
Figures: 5
Tables: 12
1. METHODOLOGY

1.1. Information about the key model parameters and data gaps

The two main challenges in producing an evaluation of the resource needs and environmental emissions of the global tobacco supply chain were (1) the limited availability of data for the whole sector and (2) the need to construct an assessment at a global scale considering the large spatial and other variability in data.

Material Flow Analysis was used to quantify the flows of natural resources and materials at the different stages of cigarette production and consumption, capturing both inputs (direct and indirect) and outputs. For example, not only was the energy and material use at manufacturing facilities analysed but so were the inputs required for the construction of these facilities. However, selected indirect materials and processes, e.g. office supplies and smoking accessories were excluded from the study. Additionally, due to a lack of data, selected direct inputs were also excluded.

Outlined below is information about the key parameters used in the material and energy flow estimates for each stage in the tobacco supply chain, as well as the inputs and processes excluded from the study analysis. The exact resource and material input values used in LCA are listed in table 1 below.

**Forming and Curing**

- The total annual arable land used for tobacco cultivation was 4 million hectares (based on FAO-reported data \(^1\) for year 2014);
- The average tobacco yield value adopted for the analysis was 2.5 tonnes of dry unmanufactured tobacco per hectare \(^2,3\);
- For the purpose of the material flow estimates in tobacco seedling production at the cultivation stage, the process of and the resource use in the planting and transplanting of tobacco seedlings were equated to those of tomatoes \(^2,4,5\);
- Due to a lack of data on the production of green tobacco (all industry and independent reports refer to dry tobacco weight), the tobacco weight prior to curing had to be estimated. It was calculated based on a fresh tobacco plant’s weight loss in curing of 80%. This choice was informed by a literature review that identified a weight loss of between 72.5% and 90% as a result of water content evaporation in curing \(^6-10\);
- Since very little reliable data is available on the illegal and unsustainable logging associated with tobacco curing, this study only analysed the impacts of sustainable wood use.
**Processing**

- Due to a lack of transparency on the material and energy flows at the processing stage, an existing Ecoinvent dataset for a typical sugar refinery in a global context was used to help guide the input selection in SimaPro. Additionally, given that 30% of tobacco processing is done by manufacturers\(^\text{11}\), it was concluded that the resources required for that one-third of processing are reported under the manufacturing stage (this was also confirmed by BAT in their response to the enquiry on the subject by ASH\(^\text{12}\)). Thus, the mass flows of energy, water and land use at the manufacturing stage were adjusted accordingly to avoid double-counting;

- Due to a lack of reliable data, no dry tobacco loss at the manufacturing and distribution stages is considered. Instead, all loss of dry tobacco in the supply chain is attributed to the processing stage where all the grading, stemming and shredding takes place\(^\text{13}\).

**Manufacturing**

- The average weight of tobacco contained in a cigarette and adopted for this study was 0.996 gram. It includes manufactured and “roll your own” (RYO) cigarettes and was estimated based on the following data:
  
  1. Manufactured cigarettes account for 98.35% of cigarette consumption and the weight of tobacco contained in them and adopted for the analysis is 1g. A literature review on the weight of tobacco in a manufactured cigarette demonstrated that it varies considerably by brand and by country. For simplification reasons it was therefore decided to adopt the weight of 1 gram per cigarette stick used by the European commission for tax purposes\(^\text{14}\) and by Euromonitor for conversion of RYO products to sticks\(^\text{15}\). A scenario analysis was conducted to test the robustness of this assumption;

  2. RYO cigarettes account for 1.65% of global cigarette consumption (estimated based on data reported by Euromonitor\(^\text{16}\)). The weight of tobacco in the RYO products is 0.75g per stick\(^\text{14}\).

**Distribution**

- Due to a lack of data on the exact transport distances involved in the distribution of tobacco products globally and the complexity of estimating those, the Ecoinvent default transport model for tobacco products was adopted\(^\text{17}\).
Cigarette use & final disposal

- The total number of cigarette sticks consumed in a year is 5.8 trillion sticks, based on the data reported for the year 2014\(^\text{18}\).
- Due to a lack of relevant datasets in SimaPro, the landfills considered in the post-consumer waste treatment were of a modern European type, i.e. with leachate and emissions monitoring and collection.

Resources and activities excluded due to lack of data:

- Any chemical substances used at the processing facilities, including organic and inorganic chemicals, lubricating oils, etc.;
- Additives and flavourings used in cigarette manufacturing, such as, for example, mint, sugars, and liquorice;
- Cellophane used in cigarette packaging;
- The equipment used at the processing and manufacturing facilities, i.e. the materials and energy required for the production of this machinery;
- Post-consumer cigarette waste that ends up in the environment – instead it had to be assumed that it is all treated in one way or another;
- Filter-less cigarette butts.

Consumption chain processes that were beyond the scope of this study:

- Natural processes such as oxygen uptake in combustion and water evaporation in post-curing processes;
- Labour, smoking accessories, cleaning products, office supplies and similar products used at various stages of the tobacco consumption chain.

2. RESULTS

2.1. Material Flow Analysis per tonne of output tobacco

The cultivation of one tonne of green tobacco leaf requires, on average, 678 m\(^3\) of water, 8.59 MJ of energy (for the production of tobacco seedlings), 30 kg of materials such as fertilisers and pesticides, 0.12 ha of land, and 12.5 tkm of transport from field to farm (Table S1). The resulting outputs include 0.6 tonnes of solid waste, 675 m\(^3\) of water, and 0.64 tCO\(_2\) eq in emissions per tonne of green tobacco. Producing a tonne of cured tobacco involves the use of 3.25 t of materials such as
wood and coal that serve as fuel, and a 100 tkm of transport to transfer it to processing facilities, while the resulting emissions equate to 6.89 t CO₂ eq per tonne of cured tobacco. At the primary processing stage, the key inputs include 7.59 t of water, 277 MJ of energy, and 2,900 tkm of transport to ship a tonne of processed tobacco by road, sea or, in some cases, by air, to the cigarette manufacturing facilities. The outputs at this stage comprise 80 kg of solid waste, 7.61 m³ of waste water and 0.18 tCO₂ eq emissions per tonne of processed tobacco.

Manufacturing one of the 6.48 million tonnes of dry tobacco into cigarettes requires over 10,000 MJ in energy and 630 kg of material inputs such as packaging and non-tobacco cigarette constituents. The resulting outputs include 200 kg of solid waste and 2.63 tCO₂ eq emissions per tonne of dry tobacco. The distribution of manufactured cigarettes to consumers involves 20 kg of materials in the form of cardboard boxes for shipping, and 1,019 tkm of freight transport per tonne of dry tobacco. The output at this stage in the form of emissions is 0.07 tCO₂ eq per tonne of tobacco. Finally, at the use and disposal stage, the analysed mass flows are limited to outputs in the form of solid waste at 0.7 t and emissions to air at 0.15 tCO₂ eq per tonne of smoked tobacco.
Table S1. Material flows per stage in the tobacco supply chain, per tonne of output tobacco

<table>
<thead>
<tr>
<th>1. TOBACCO CULTIVATION</th>
<th>Amount per tonne of green tobacco</th>
<th>Unit</th>
<th>Amount per tonne of green tobacco</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water 19</td>
<td>675</td>
<td>tonne</td>
<td>Nitrogen fertiliser 20</td>
<td>0.017*</td>
</tr>
<tr>
<td>Land (incl. transformation from forest) 21,22</td>
<td>0.123* ha a</td>
<td></td>
<td>Potassium fertiliser 20</td>
<td>0.005*</td>
</tr>
<tr>
<td>Land for tobacco seedlings 5,21,23</td>
<td>0.0046** m²</td>
<td></td>
<td>Phosphate fertiliser 20</td>
<td>0.006*</td>
</tr>
<tr>
<td>Peat Moss for seedlings 5,21,23</td>
<td>0.6** m³</td>
<td></td>
<td>Pesticides 24</td>
<td>0.0002**</td>
</tr>
<tr>
<td>Seedlings Irrigation 5,21,23</td>
<td>3.22** tonne</td>
<td></td>
<td>Lime 25</td>
<td>0.0052**</td>
</tr>
<tr>
<td>Energy for seedlings in greenhouses 5,21,23</td>
<td>8.59** MJ</td>
<td></td>
<td>Agricultural machinery (tillage, harrowing, harvesting) 21,25,26</td>
<td>0.099**</td>
</tr>
<tr>
<td>Agricultural machinery and fuel for planting 25</td>
<td>0.00032** tonne</td>
<td></td>
<td>Transport of harvest from field to farm 25</td>
<td>12.5**</td>
</tr>
<tr>
<td>Shed 25</td>
<td>0.0000012** m²a</td>
<td></td>
<td>Wastes and emissions</td>
<td></td>
</tr>
<tr>
<td><strong>Wastes and emissions</strong></td>
<td></td>
<td></td>
<td>CO₂ eq emissions ***</td>
<td>0.644</td>
</tr>
<tr>
<td>Water loss (from irrigation) 25</td>
<td>674* tonne</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid waste (residue crop, burnt) 25</td>
<td>0.6* tonne</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. TOBACCO CURING
<table>
<thead>
<tr>
<th>Inputs</th>
<th>Amount per tonne of cured tobacco</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curing barns (wooden) 27</td>
<td>0.13024*</td>
<td>m²</td>
</tr>
<tr>
<td>Wood (16% of tobacco produced) 21,29</td>
<td>7.77*</td>
<td>tonne</td>
</tr>
<tr>
<td>Wood-burning furnace (16% of tobacco produced) 31</td>
<td>0.1946 number of units</td>
<td></td>
</tr>
<tr>
<td>Transport of wood logs (16% of tobacco produced) 31</td>
<td>72.02 tkm</td>
<td></td>
</tr>
</tbody>
</table>

### Wastes and emissions

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Amount per tonne of cured tobacco</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content loss in plants 6-10</td>
<td>4</td>
<td>tonne</td>
</tr>
<tr>
<td>Solid waste (from shed construction) 32</td>
<td>0.084</td>
<td>tonne</td>
</tr>
</tbody>
</table>

### 3. PRIMARY PROCESSING

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Amount per tonne of processed tobacco</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Facilities - construction materials 25</td>
<td>0.1703** tonne</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Amount per tonne of processed tobacco</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport from processing to storage 33</td>
<td>0.18** tkm</td>
<td></td>
</tr>
<tr>
<td>Processing Facilities - energy for construction</td>
<td>0.00097**</td>
<td>MJ</td>
</tr>
<tr>
<td>Land</td>
<td>11.9**</td>
<td>m²</td>
</tr>
<tr>
<td>Energy for tobacco processing</td>
<td>13.8**</td>
<td>MJ</td>
</tr>
<tr>
<td>Heat &amp; Power generating unit</td>
<td>0.000027**</td>
<td>number of units</td>
</tr>
<tr>
<td>Water</td>
<td>7.59**</td>
<td>tonne</td>
</tr>
<tr>
<td>Tobacco storage facility – land</td>
<td>0.432**</td>
<td>m²</td>
</tr>
<tr>
<td>Energy for storage</td>
<td>263**</td>
<td>MJ</td>
</tr>
<tr>
<td>Storage building</td>
<td>0.04**</td>
<td>m³</td>
</tr>
<tr>
<td>Corrugated cardboard boxes for shipping</td>
<td>0.015*</td>
<td>tonne</td>
</tr>
<tr>
<td>Shipping by road (lorry)</td>
<td>100**</td>
<td>tkm</td>
</tr>
<tr>
<td>Shipping by sea (35% of processed tobacco)</td>
<td>2800**</td>
<td>tkm</td>
</tr>
<tr>
<td>Wastes and emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid waste</td>
<td>0.1517**</td>
<td>tonne</td>
</tr>
<tr>
<td>Tobacco waste</td>
<td>0.084*</td>
<td>tonne</td>
</tr>
<tr>
<td>Wastes and emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste water</td>
<td>7.607**</td>
<td>tonne</td>
</tr>
<tr>
<td>CO₂ eq emissions</td>
<td>0.179</td>
<td>t CO₂eq</td>
</tr>
</tbody>
</table>

### 4. MANUFACTURING

<p>| Inputs | Amount per tonne of manuf. tobacco | Unit |
| Water | 2.466* | tonne |
| Cigarette filters | 0.17 | tonne |
| Cigarette plug wrap | 0.04 | tonne |
| Inputs | Amount per tonne of manuf. tobacco | Unit |
| Cigarette packs – foil (excl. from LCA) | 0.037 | tonne |
| Cellophane (for cigarette packs &amp; cartons; excl. from LCA) † | 0.108 | tonne |
| Cigarette cartons (of 10 packs) | 0.0167* | tonne |</p>
<table>
<thead>
<tr>
<th>Inputs</th>
<th>Amount per tonne of distrib. tobacco</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cigarette paper</td>
<td>0.063</td>
<td>tonne</td>
</tr>
<tr>
<td>Cigarette packs, carton (of 20-sticks)</td>
<td>0.284</td>
<td>tonne</td>
</tr>
<tr>
<td>Wastes and emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste water</td>
<td>1.5*</td>
<td>tonne</td>
</tr>
<tr>
<td>Non-hazardous waste, landfill</td>
<td>0.0139*</td>
<td>tonne</td>
</tr>
<tr>
<td>Non-hazardous waste, recovery</td>
<td>0.1875*</td>
<td>tonne</td>
</tr>
<tr>
<td>Hazardous waste, landfill</td>
<td>0.0018*</td>
<td>tonne</td>
</tr>
<tr>
<td>Hazardous waste, recovery</td>
<td>0.0009*</td>
<td>tonne</td>
</tr>
<tr>
<td>CO₂ eq emissions</td>
<td>2.63</td>
<td>t CO₂eq</td>
</tr>
</tbody>
</table>

5. DISTRIBUTION

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Amount per tonne of distrib. tobacco</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing plant - land and building</td>
<td>0.527**</td>
<td>m²a</td>
</tr>
<tr>
<td>Energy</td>
<td>10076*</td>
<td>MJ</td>
</tr>
<tr>
<td>Wastes and emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazardous waste, landfill</td>
<td>0.0001*</td>
<td>tonne</td>
</tr>
<tr>
<td>Hazardous waste, incineration</td>
<td>0.0001*</td>
<td>tonne</td>
</tr>
<tr>
<td>Hazardous waste, unspecified treatment</td>
<td>0.0001*</td>
<td>tonne</td>
</tr>
<tr>
<td>Hazardous waste, recovery</td>
<td>2.63</td>
<td>t CO₂eq</td>
</tr>
<tr>
<td>Wastes and emissions</td>
<td>Amount per tonne of smoked tobacco</td>
<td>Unit</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Carbon dioxide, biogenic $^{52-54}$</td>
<td>0.05</td>
<td>tonne</td>
</tr>
<tr>
<td>Carbon monoxide, biogenic $^{52-54}$</td>
<td>0.02</td>
<td>tonne</td>
</tr>
<tr>
<td>Nitrogen monoxide $^{52-54}$</td>
<td>0.0005</td>
<td>tonne</td>
</tr>
<tr>
<td>Hydrogen sulphide $^{52-54}$</td>
<td>0.0001</td>
<td>tonne</td>
</tr>
<tr>
<td>Methane $^{52-54}$</td>
<td>0.002</td>
<td>tonne</td>
</tr>
<tr>
<td>Transport by road, uncontrolled conditions $^{50,51}$</td>
<td>97*</td>
<td>tkm</td>
</tr>
<tr>
<td>Transport by road with reefer cooling $^{50,51}$</td>
<td>3*</td>
<td>tkm</td>
</tr>
<tr>
<td>Transport by sea (17% of manuf. Tobacco) $^{50,51}$</td>
<td>5337</td>
<td>tkm</td>
</tr>
<tr>
<td>Wastes and emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ eq emissions $^{***}$</td>
<td>0.0646</td>
<td>t CO2eq</td>
</tr>
<tr>
<td>Substance</td>
<td>Mass Weight</td>
<td>Unit</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0.00007</td>
<td>tonne</td>
</tr>
<tr>
<td>Nitrogen, total</td>
<td>0.201</td>
<td>tonne</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.06</td>
<td>tonne</td>
</tr>
</tbody>
</table>

[no asterisk] – value directly referenced
*Calculated value;
**Equivalent used and adopted for tobacco.
***SimaPro output
† Researchers’ measurements

It was calculated that a total of 32.4 Mt of green tobacco leaf were cultivated on 4 million hectares of land, producing the 6.48 Mt of dry tobacco used to manufacture six trillion cigarette sticks across 500 factories worldwide (Figure S1).

* Nearly 500 factories documented and 200 more suspected but unconfirmed

Figure S1. Global cigarette production in numbers for year 2014

2.2 Life Cycle Assessment results per tonne of produced and consumed tobacco

Each stage in the tobacco supply chain carries an environmental footprint driven by the associated resource use and processes. For instance, farming enough tobacco to produce a tonne of dry
tobacco leaf results in 3.5 tCO₂ eq emissions (accounting for the CO₂ uptake as the crops grow) and 1.2 t 1,4-DB eq in human toxicity potential, requires more than 6,800 m² of agricultural land, and depletes the planet of over 3,600 m³ of water, 308 kg Fe eq of metal and almost 700 kg oil eq of fossil resources (Table S2).

At almost 7.5 tCO₂ eq emission per tonne of produced tobacco, curing results in more carbon emissions than all other stages in the supply chain combined. It also has the highest contribution to terrestrial acidification at 340 kg SO₂ eq per tonne of tobacco and drives most of the fossil depletion at 2 t oil eq per tonne of tobacco. That is excluding the impacts of the unsustainably sourced wood, which could not be analysed due to a lack of data. At the processing stage, the contribution to climate change is just under 180 kg CO₂ eq per tonne of produced tobacco and human toxicity potential amounts to 99 kg 1,4-DB eq with metal and fossil depletion of 56 kg Fe eq and 51 kg oil eq, respectively. Cigarette manufacturing activities contribute 13 kg SO₂ eq in terrestrial acidification and over 1 t 1,4-DB eq in human toxicity per tonne of produced tobacco. Manufacturing processes have the greatest impact on freshwater and marine ecosystem ecotoxicity levels across the supply chain at 36 and 33 kg 1,4-DB eq respectively. Cigarette distribution activities contribute 65 kg CO₂ eq emissions per tonne of tobacco, 8.7 kg 1,4-DB eq in human toxicity potential, and 21 kg oil eq in fossil depletion. Finally, cigarette use and disposal drives 1545 kg CO₂ eq emissions per tonne of tobacco, contributes 89 kg 1,4-DB eq to human toxicity levels, almost 5 kg 1,4-DB eq to freshwater ecotoxicity and 23 kg oil eq in fossil depletion. At this stage, sustainable waste treatment practices such as shipping packaging recycling and land restoration at the end of life of modern landfills offset some of the land occupation and transformation impacts (-3436 m²a per tonne of tobacco in agricultural land occupation) and some water depletion (-0.6 m³ per tonne of tobacco). As the incorrect disposal of the post-consumer cigarette waste was not included in the analysis, these are conservative estimates.
Table S2. Environmental impacts per tonne of produced and consumed tobacco

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Farming</th>
<th>Curing</th>
<th>Processing</th>
<th>Cigarette Manufacturing</th>
<th>Distribution</th>
<th>Cigarette Use &amp; Disposal</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO₂ eq</td>
<td>3486.5</td>
<td>7470.6</td>
<td>179.3</td>
<td>2628.7</td>
<td>64.6</td>
<td>145.4</td>
<td>13975.2</td>
</tr>
<tr>
<td>Terrestrial acidification</td>
<td>kg SO₂ eq</td>
<td>19.9</td>
<td>40.1</td>
<td>1.8</td>
<td>13.1</td>
<td>0.4</td>
<td>0.5</td>
<td>75.8</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>1.1</td>
<td>0.1</td>
<td>0.1</td>
<td>1.4</td>
<td>0.0</td>
<td>0.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>1.9</td>
<td>0.6</td>
<td>0.1</td>
<td>0.7</td>
<td>0.0</td>
<td>0.2</td>
<td>3.5</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>1188.4</td>
<td>813.5</td>
<td>98.7</td>
<td>1051.2</td>
<td>8.7</td>
<td>89.4</td>
<td>3249.9</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>4.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.8</td>
<td>0.0</td>
<td>1.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>30.9</td>
<td>7.3</td>
<td>2.4</td>
<td>36.2</td>
<td>0.3</td>
<td>4.8</td>
<td>81.8</td>
</tr>
<tr>
<td>Marine ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>30.2</td>
<td>8.8</td>
<td>2.7</td>
<td>33.2</td>
<td>0.3</td>
<td>4.0</td>
<td>79.3</td>
</tr>
<tr>
<td>Agricultural land occupation</td>
<td>m²a</td>
<td>6821.2</td>
<td>1368.3</td>
<td>47.1</td>
<td>534.4</td>
<td>57.9</td>
<td>-335.9</td>
<td>8493.0</td>
</tr>
<tr>
<td>Urban land occupation</td>
<td>m²a</td>
<td>215.9</td>
<td>79.6</td>
<td>16.0</td>
<td>23.8</td>
<td>2.1</td>
<td>-2.3</td>
<td>335.0</td>
</tr>
<tr>
<td>Natural land transformation</td>
<td>m²</td>
<td>9.4</td>
<td>0.7</td>
<td>0.1</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>10.8</td>
</tr>
<tr>
<td>Water depletion</td>
<td>m³</td>
<td>3631.3</td>
<td>21.6</td>
<td>2.4</td>
<td>57.2</td>
<td>1.0</td>
<td>-0.6</td>
<td>3712.9</td>
</tr>
<tr>
<td>Metal depletion</td>
<td>kg Fe eq</td>
<td>307.7</td>
<td>77.8</td>
<td>55.8</td>
<td>102.7</td>
<td>2.3</td>
<td>2.7</td>
<td>548.9</td>
</tr>
<tr>
<td>Fossil depletion</td>
<td>kg oil eq</td>
<td>696.2</td>
<td>2014.9</td>
<td>50.8</td>
<td>674.2</td>
<td>21.2</td>
<td>23.2</td>
<td>3480.5</td>
</tr>
</tbody>
</table>

Across the entire life cycle of cigarette consumption, tobacco farming has at least 40% contribution in over half of all impact categories, cigarette manufacturing shows at least 20% contribution in 9 out of 14 categories, and curing drives more than half of the impacts in the climate change, terrestrial acidification, and fossil depletion categories with the burning of coal being by far the main cause (Figure S2).
Figure S2. Environmental impacts contribution of the global tobacco supply chain stages across the full life cycle of cigarette production and consumption.
Even a single cigarette and one smoker carry an environmental footprint that is noteworthy (Table S3).

**Table S3.** Environmental impacts of one cigarette and over a smoker’s lifetime

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Per tonne of produced and consumed tobacco</th>
<th>Per cigarette stick*</th>
<th>Per smoker's lifetime**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO2 eq</td>
<td>13975.2</td>
<td>0.013975</td>
<td>5100.9</td>
</tr>
<tr>
<td>Terrestrial acidification</td>
<td>kg SO2 eq</td>
<td>75.8</td>
<td>0.000076</td>
<td>27.7</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>2.7</td>
<td>0.000003</td>
<td>1.0</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>3.5</td>
<td>0.000003</td>
<td>1.3</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>3249.9</td>
<td>0.003250</td>
<td>1186.2</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>6.1</td>
<td>0.000006</td>
<td>2.2</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>81.8</td>
<td>0.000082</td>
<td>29.9</td>
</tr>
<tr>
<td>Marine ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>79.3</td>
<td>0.000079</td>
<td>28.9</td>
</tr>
<tr>
<td>Agricultural land occupation</td>
<td>m2a</td>
<td>8493.0</td>
<td>0.008493</td>
<td>3099.9</td>
</tr>
<tr>
<td>Urban land occupation</td>
<td>m2a</td>
<td>335.0</td>
<td>0.000335</td>
<td>122.3</td>
</tr>
<tr>
<td>Natural land transformation</td>
<td>m2</td>
<td>10.8</td>
<td>0.000011</td>
<td>3.9</td>
</tr>
<tr>
<td>Water depletion</td>
<td>m3</td>
<td>3712.9</td>
<td>0.003713</td>
<td>1355.2</td>
</tr>
<tr>
<td>Metal depletion</td>
<td>kg Fe eq</td>
<td>548.9</td>
<td>0.000549</td>
<td>200.3</td>
</tr>
<tr>
<td>Fossil depletion</td>
<td>kg oil eq</td>
<td>3480.5</td>
<td>0.003480</td>
<td>1270.4</td>
</tr>
</tbody>
</table>

*Assuming 1g of tobacco contained in a cigarette

** a smoker consuming a pack of 20 cigarettes every day for 50 years

---

3. **SENSITIVITY ANALYSIS**

3.1. **Total environmental impact assessment outcomes**

Sensitivity analysis was carried out to evaluate how the key assumptions used in the primary analysis may have affected the total impact assessment outcomes and to identify the inputs whose variation has the most impact on key outputs. This was performed by using realistic ranges.
in input values, which were identified through the literature review as well as the data collected for the MFA and are presented below (Table S4). The input variations included, for example, the weight of tobacco in a typical cigarette stick, the rate of irrigation, land use, transport distances, types of packaging, water and energy use, and the uncertainty driven by geographical variation.

Table S4. Summary of the input value ranges used in the sensitivity analysis

<table>
<thead>
<tr>
<th>LCA input considered in sensitivity analysis</th>
<th>Input value per tonne of output tobacco</th>
<th>Input value range tested</th>
<th>Sources and description of the value ranges considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>CULTIVATION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation (automated)</td>
<td>675 m³</td>
<td>-8.5%</td>
<td>8.5% lower irrigation infrastructure assuming nearly zero infrastructure in African tobacco-growing regions&lt;sup&gt;21,55&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>675 m³</td>
<td>+8.5%</td>
<td>8.5% higher irrigation infrastructure</td>
</tr>
<tr>
<td>Transport of harvest</td>
<td>12.5 tkm</td>
<td>-8.5%</td>
<td>8.5% lower use accounting for African countries&lt;sup&gt;21,26&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>12.5 tkm</td>
<td>+8.5%</td>
<td>8.5% higher transport distances</td>
</tr>
<tr>
<td>Seedlings produced in greenhouses</td>
<td>2000 seedlings</td>
<td>-10%</td>
<td>10% lower use of unheated greenhouses and no use of heated greenhouses&lt;sup&gt;21,56&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2000 seedlings</td>
<td>+10%</td>
<td>10% higher use of unheated greenhouses and no use of heated greenhouses</td>
</tr>
<tr>
<td>Land use</td>
<td>0.123ha</td>
<td>+7.5%</td>
<td>7.5% higher land use (based on FAO reported land use prior to 2014&lt;sup&gt;21&lt;/sup&gt;)</td>
</tr>
<tr>
<td></td>
<td>0.123ha</td>
<td>-7.5%</td>
<td>7.5% lower land use</td>
</tr>
<tr>
<td>Agrochemicals</td>
<td>0.033 tonne</td>
<td>+30%</td>
<td>30% higher use (based on US application rates&lt;sup&gt;24&lt;/sup&gt;)</td>
</tr>
<tr>
<td></td>
<td>0.033 tonne</td>
<td>-30%</td>
<td>30% lower use of agrochemicals</td>
</tr>
<tr>
<td>Agric. Machinery use</td>
<td>0.099 ha</td>
<td>+7.5%</td>
<td>7.5% higher use – to account for the case of higher land use&lt;sup&gt;21&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.099 ha</td>
<td>-7.5%</td>
<td>7.5% lower use of agricultural machinery</td>
</tr>
<tr>
<td>CURING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal for curing</td>
<td>3.87 tonne</td>
<td>-15%</td>
<td>15% lower use due to higher calorific value (anthracite)&lt;sup&gt;30,57&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>3.87 tonne</td>
<td>+15%</td>
<td>15% higher use of coal due to lower calorific value</td>
</tr>
<tr>
<td>PROCESSING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing facilities</td>
<td>0.0000005 units</td>
<td>-20%</td>
<td>20% smaller. Hypothesised based on the comparison of the processes involved in tobacco processing and sugar refining&lt;sup&gt;58,59&lt;/sup&gt;</td>
</tr>
<tr>
<td>Water use in processing</td>
<td>0.000005 units</td>
<td>+20%</td>
<td>20% bigger processing facilities</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------</td>
<td>------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td></td>
<td>7.59 tonne</td>
<td>-20%</td>
<td>20% lower use. Hypothesised based on the comparison of the processes involved in tobacco processing and sugar refining&lt;sup&gt;58,59&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>7.59 tonne</td>
<td>+20%</td>
<td>20% higher water use</td>
</tr>
<tr>
<td>Shipping packaging</td>
<td>0.015 tonne</td>
<td>+67%</td>
<td>triple-corrugated cardboard boxes instead of single&lt;sup&gt;34&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.015 tonne</td>
<td>-67%</td>
<td>lighter cardboard boxes</td>
</tr>
<tr>
<td>Transport to manufacturers</td>
<td>2900 tkm</td>
<td>-29%</td>
<td>minimum distances in the estimated ranges, (Fisher, 2013). In the case of sea shipping, the amount only applies to exported tobacco, i.e. 35% of all tobacco leaf&lt;sup&gt;36&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2900 tkm</td>
<td>+141%</td>
<td>maximum distances in the estimated ranges&lt;sup&gt;35&lt;/sup&gt;</td>
</tr>
<tr>
<td>MANUFACTURING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing plant lifetime</td>
<td>50 years</td>
<td>+32%</td>
<td>additional 16-year service life&lt;sup&gt;60&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>50 years</td>
<td>-32%</td>
<td>Plant service life shorter by 16 years</td>
</tr>
<tr>
<td></td>
<td>2.47 tonne</td>
<td>+85%</td>
<td>PMI reported 4.59m3/tonne and assuming it does not include processing activities&lt;sup&gt;61&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2.47 tonne</td>
<td>-85%</td>
<td>85% lower water use</td>
</tr>
<tr>
<td>Energy use in manufacturing</td>
<td>10076 MJ</td>
<td>+30%</td>
<td>30% higher energy use based on CNTC reported data&lt;sup&gt;62&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>10076 MJ</td>
<td>-30%</td>
<td>30% lower energy use</td>
</tr>
<tr>
<td>DISTRIBUTION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution - packaging</td>
<td>0.024 tonne</td>
<td>+69%</td>
<td>triple-corrugated cardboard boxes instead of single&lt;sup&gt;34&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.024 tonne</td>
<td>-69%</td>
<td>lighter cardboard boxes</td>
</tr>
<tr>
<td>Distribution by air</td>
<td>1171 tkm</td>
<td>-100%</td>
<td>zero air shipping&lt;sup&gt;63&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>1171 tkm</td>
<td>+100%</td>
<td>twice as much air shipping</td>
</tr>
<tr>
<td>Distribution by sea</td>
<td>5337 tkm</td>
<td>+275%</td>
<td>maximum distances in the estimated ranges&lt;sup&gt;35&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>5337 tkm</td>
<td>-63%</td>
<td>minimum distances in the estimated ranges&lt;sup&gt;35&lt;/sup&gt;</td>
</tr>
<tr>
<td>Distribution by truck</td>
<td>100 tkm</td>
<td>+200%</td>
<td>maximum distances in the estimated ranges&lt;sup&gt;35&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>100 tkm</td>
<td>-50%</td>
<td>minimum distances in the estimated ranges&lt;sup&gt;35&lt;/sup&gt;</td>
</tr>
<tr>
<td>USE &amp; FINAL DISPOSAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions from smoking</td>
<td>0.35 tonne</td>
<td>-5%</td>
<td>minimum concentrations of CH4, NH3, NO&lt;sup&gt;52-54&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.35 tonne</td>
<td>+154%</td>
<td>maximum concentrations of CH4, NH3, NO&lt;sup&gt;52-54&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
The sensitivity analysis established that the possible variability in the environmental impact results is in the range of -10% and +10% across most categories, apart from a few exceptions (Table S5). LCA results were most sensitive to changes in such parameters as the rate of agrochemicals application in tobacco farming, the use of coal in flue-curing of tobacco leaf, and the energy use at the cigarette manufacturing stage. For example, a 30% change in agrochemical use indicated the highest potential variability in terrestrial ecotoxicity (±19% variance in results) and marine eutrophication (±10% variance), while a 15% change in the amount of coal used in tobacco curing showed a potential variability in climate change impact of ±8% and in fossil depletion of ±9%. A 30% change in energy use in manufacturing lead to a variance of ±12% in freshwater eutrophication and ±9% freshwater and marine ecotoxicity levels. The change in the relative contributions of the different stages in the global tobacco supply chain was not significant with the farming, curing and manufacturing stages still driving most of the environmental impacts in the supply chain for all parameter ranges tested.
Table S5. Total environmental impact assessment outcomes of sensitivity analysis compared to the main study results

<table>
<thead>
<tr>
<th>LCA input considered in sensitivity analysis</th>
<th>Input value range tested</th>
<th>Environmental impact results by impact category</th>
</tr>
</thead>
<tbody>
<tr>
<td>CULTIVATION</td>
<td></td>
<td>Climate Change</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kg CO2 eq</td>
</tr>
<tr>
<td>Irrigation (automated)</td>
<td>-8.5%</td>
<td>82805.5</td>
</tr>
<tr>
<td></td>
<td>-0.92%</td>
<td>-0.85%</td>
</tr>
<tr>
<td></td>
<td>+8.5%</td>
<td>84337.9</td>
</tr>
<tr>
<td></td>
<td>0.92%</td>
<td>0.85%</td>
</tr>
<tr>
<td>Transport of harvest</td>
<td>-8.5%</td>
<td>83300.0</td>
</tr>
<tr>
<td></td>
<td>-0.33%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>+10%</td>
<td>83811.8</td>
</tr>
<tr>
<td></td>
<td>0.29%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>+10%</td>
<td>83811.8</td>
</tr>
<tr>
<td></td>
<td>0.29%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>+7.5%</td>
<td>unvaried</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>-7.5%</td>
<td>unvaried</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Agrochemicals</td>
<td>+30%</td>
<td>85800.0</td>
</tr>
</tbody>
</table>
### Agric. Machinery use

<table>
<thead>
<tr>
<th>Change</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>+7.5%</td>
<td>No notable impact on results</td>
<td></td>
</tr>
<tr>
<td>-7.5%</td>
<td>No notable impact on results</td>
<td></td>
</tr>
</tbody>
</table>

### CURING

<table>
<thead>
<tr>
<th>Coal for curing</th>
<th>Change</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>-15%</td>
<td>76988.8</td>
<td>419.4</td>
<td></td>
</tr>
<tr>
<td>-15%</td>
<td>-7.88%</td>
<td>-7.49%</td>
<td>-0.16% -1.99% -3.06% -0.43% -1.02% -1.29% -0.34% -2.88% -0.81% -0.08% -1.26% -8.58%</td>
</tr>
<tr>
<td>+15%</td>
<td>90154.7</td>
<td>487.2</td>
<td>16.4 21.3 36.6 494.2 480.1 50960.7 2061.2 64.8 22221.3 3323.4 22598.5</td>
</tr>
<tr>
<td>+15%</td>
<td>7.88%</td>
<td>7.49%</td>
<td>0.16% 1.99% 3.06% 0.43% 1.02% 1.29% 0.34% 2.88% 0.81% 0.08% 1.26% 8.58%</td>
</tr>
</tbody>
</table>

### PROCESSING

<table>
<thead>
<tr>
<th>Processing facilities</th>
<th>Change</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20%</td>
<td>unvaried</td>
<td>unvaried</td>
<td>16.4 20.8 19356.9</td>
</tr>
<tr>
<td>+20%</td>
<td>unvaried</td>
<td>unvaried</td>
<td>16.4 20.9 19512.2</td>
</tr>
<tr>
<td>-20%</td>
<td>0</td>
<td>0</td>
<td>-0.25% -0.07% -0.40%</td>
</tr>
<tr>
<td>+20%</td>
<td>0</td>
<td>0</td>
<td>0.25% 0.07% 0.40%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water use in processing</th>
<th>Change</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20%</td>
<td>unvaried</td>
<td>unvaried</td>
<td>16.4 20.8 19356.9</td>
</tr>
<tr>
<td>+20%</td>
<td>unvaried</td>
<td>unvaried</td>
<td>16.4 20.9 19512.2</td>
</tr>
<tr>
<td>-20%</td>
<td>0</td>
<td>0</td>
<td>-0.25% -0.07% -0.40%</td>
</tr>
<tr>
<td>+20%</td>
<td>0</td>
<td>0</td>
<td>0.25% 0.07% 0.40%</td>
</tr>
</tbody>
</table>

### Shipping packaging

<table>
<thead>
<tr>
<th>Shipping packaging</th>
<th>Change</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>+67%</td>
<td>unvaried</td>
<td>unvaried</td>
<td>16.4 20.8 19356.9</td>
</tr>
<tr>
<td>-67%</td>
<td>unvaried</td>
<td>unvaried</td>
<td>16.4 20.9 19512.2</td>
</tr>
</tbody>
</table>

### Transport to manufacturers

<table>
<thead>
<tr>
<th>Transport to manufacturers</th>
<th>Change</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>-29%</td>
<td>unvaried</td>
<td>unvaried</td>
<td>16.4 20.8 19356.9</td>
</tr>
<tr>
<td>+141%</td>
<td>84000.0</td>
<td>460.0</td>
<td>16.5 21.0 19500.0</td>
</tr>
<tr>
<td>-29%</td>
<td>0.51%</td>
<td>1.48%</td>
<td>0.59% 0.74% 0.34% 0.28% 0.37% 0.64%</td>
</tr>
</tbody>
</table>

### MANUFACTURING

<table>
<thead>
<tr>
<th>Manufacturing plant lifetime</th>
<th>Change</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>+32%</td>
<td>83449.0</td>
<td>452.4</td>
<td>16.4 20.8 19386.2</td>
</tr>
<tr>
<td>-32%</td>
<td>83809.9</td>
<td>455.1</td>
<td>16.5 20.9 19528.4</td>
</tr>
<tr>
<td>Water use in manufacturing</td>
<td>+85%</td>
<td>0.29%</td>
<td>0.40%</td>
</tr>
<tr>
<td>----------------------------</td>
<td>------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td></td>
<td>-85%</td>
<td>No notable impact on results</td>
<td>No notable impact on results</td>
</tr>
<tr>
<td>Energy use in manufacturing</td>
<td>+30%</td>
<td>87400.0</td>
<td>471.0</td>
</tr>
<tr>
<td></td>
<td>-30%</td>
<td>4.58%</td>
<td>3.90%</td>
</tr>
<tr>
<td>Distribution</td>
<td>+69%</td>
<td>No notable impact on results</td>
<td>No notable impact on results</td>
</tr>
<tr>
<td>Distribution by air</td>
<td>-100%</td>
<td>No notable impact on results</td>
<td>No notable impact on results</td>
</tr>
<tr>
<td>Distribution by sea</td>
<td>+275%</td>
<td>No notable impact on results</td>
<td>No notable impact on results</td>
</tr>
<tr>
<td>Distribution by truck</td>
<td>+200%</td>
<td>No notable impact on results</td>
<td>No notable impact on results</td>
</tr>
<tr>
<td>USE &amp; FINAL DISPOSAL</td>
<td>-5%</td>
<td>No notable impact on results</td>
<td>No notable impact on results</td>
</tr>
</tbody>
</table>

**Notes:**
- Impact values have been rounded up;
- Highlighted in yellow are the minimum and maximum percent variances in each impact category;
- “Input Value Range” refers to the percent difference between the parameter value used in the main study and the alternative value used in the sensitivity analysis;
- “% variance” refers to the percent difference between the impact output established in the main study and that found in the sensitivity analysis;
- “Unvaried” refers to a variance that is below 0.25% in both sensitivity tests conducted for an input (if at least one sensitivity test produced a %variance above 0.25%, both variances are displayed).
- “No notable impact on results” - less than 1% across all impact categories
3.2. The weight of tobacco in a typical cigarette

The sensitivity test that used lower average weight of tobacco in a typical cigarette established that the overall environmental impacts of the global tobacco supply chain could be between 1% and 9% lower than the typical values across all categories except in natural land use and water depletion where no change was observed (Table S6). The relative contribution of the different stages remained generally unchanged.

Table S6. Comparison of the environmental impacts of a lower tobacco content in a manufactured cigarette (0.75g per stick) to the main study results (1g per stick)

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Main study results</th>
<th>Uncertainty test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO₂ eq</td>
<td>83572</td>
<td>-5</td>
</tr>
<tr>
<td>Terrestrial acidification</td>
<td>kg SO₂ eq</td>
<td>453</td>
<td>-4</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>16</td>
<td>-9</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>21</td>
<td>-7</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>19435</td>
<td>-6</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>36</td>
<td>-8</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>489</td>
<td>-9</td>
</tr>
<tr>
<td>Marine ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>474</td>
<td>-8</td>
</tr>
<tr>
<td>Agricultural land occupation</td>
<td>m²a</td>
<td>50788</td>
<td>-1</td>
</tr>
<tr>
<td>Urban land occupation</td>
<td>m²a</td>
<td>2004</td>
<td>-1</td>
</tr>
<tr>
<td>Natural land transformation</td>
<td>m²</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td>Water depletion</td>
<td>m³</td>
<td>22203</td>
<td>0</td>
</tr>
<tr>
<td>Metal depletion</td>
<td>kg Fe eq</td>
<td>3282</td>
<td>-3</td>
</tr>
<tr>
<td>Fossil depletion</td>
<td>kg oil eq</td>
<td>20813</td>
<td>-5</td>
</tr>
</tbody>
</table>
3.3. Geographical variation

To assess the uncertainty in the LCA results driven by geographical variation, the study’s impact assessment outcomes of a tonne of tobacco were compared to two hypothetical extremes – the least and the most environmentally damaging scenarios of producing and consuming a million cigarettes. This analysis confirmed that the environmental impacts can vary greatly by region and depending on the practices adopted, including the rates of irrigation, agrochemical application, sources of energy, transportation distances, etc. The variance is particularly noticeable across such categories as climate change potential, damage to terrestrial ecosystems and contribution to fossil depletion with an up to 90% difference in impact values across those categories (Table S7).

Table S7. Summary of the least and most environmentally damaging scenarios compared to the input parameters used in the main study

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Value used in the main study</th>
<th>Least damaging scenario description</th>
<th>Most damaging scenario description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Farming</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water use</td>
<td>675 m3</td>
<td>No mechanised irrigation infrastructure assumed. Water of natural origin, moderate water stress.</td>
<td>100% mechanised irrigation infrastructure assumed in an area with high water stress</td>
</tr>
<tr>
<td>Transport of harvest</td>
<td>12.5 tkm</td>
<td>assuming 4% mechanisation (representing lower income countries)</td>
<td>n/a</td>
</tr>
<tr>
<td>Seedling production</td>
<td>2000 seedlings</td>
<td>10% lower use of greenhouses, unheated efficient greenhouses</td>
<td>Heated greenhouses only</td>
</tr>
<tr>
<td>Planting on farm</td>
<td>0.264 tkm</td>
<td>4% mechanised (as opposed to 33%)</td>
<td>100% mechanised (as opposed to 33%)</td>
</tr>
<tr>
<td>Land use</td>
<td>0.123ha a</td>
<td>16% lower yield than average and the subsequent higher land use</td>
<td>60% higher yield and the subsequent lower land use</td>
</tr>
<tr>
<td>Agrochemicals</td>
<td>0.033 tonne</td>
<td>10% of average use</td>
<td>30% higher use</td>
</tr>
<tr>
<td><strong>Curing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal fuelled curing</td>
<td>3.87 tonne</td>
<td>no coal use</td>
<td>all curing done using coal</td>
</tr>
<tr>
<td>Process</td>
<td>Value</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>----------------</td>
<td>----------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Wood fuelled curing</strong></td>
<td>31064 kWh</td>
<td>all curing done using wood</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>no wood curing</td>
<td></td>
</tr>
<tr>
<td><strong>Transport to processing</strong></td>
<td>100 tkm</td>
<td>50 tkm (min value in the range)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>300 tkm (max value in the range)</td>
<td></td>
</tr>
<tr>
<td><strong>Processing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Transport to manufacturers (lorry + sea)</strong></td>
<td>2900 tkm</td>
<td>2050 tkm (lowest distances in the ranges identified)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7300 tkm (highest distances in the ranges identified and applied to exported tobacco only)</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Energy use</strong></td>
<td>10076 MJ</td>
<td>Predominantly gas-based energy mix (at least 50%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Predominantly coal-based energy mix (at least 50%)</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturing plant service life</strong></td>
<td>50 years</td>
<td>10 years longer service life</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td><strong>Distribution</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>by air</strong></td>
<td>1171 tkm</td>
<td>no air shipping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td><strong>by sea</strong></td>
<td>5337 tkm</td>
<td>no sea shipping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>highest in the ranges, 20000tkm</td>
<td></td>
</tr>
<tr>
<td><strong>by lorry</strong></td>
<td>100 tkm</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>highest in the ranges, 300 tkm</td>
<td></td>
</tr>
<tr>
<td><strong>Use &amp; disposal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Emissions from smoking</strong></td>
<td>0.35 tonne</td>
<td>lowest values in ranges (1% lower values than used in the main study)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Highest in the ranges (154% higher than used in the main study)</td>
<td></td>
</tr>
</tbody>
</table>

This analysis confirmed that the environmental impacts can vary greatly by region and depending on the practices adopted, including the rates of irrigation, agrochemical application, sources of energy, transportation distances, etc. The variance is particularly noticeable across such categories as climate change potential, damage to terrestrial ecosystems and contribution to fossil depletion with an up to 90% difference in impact values across those categories (Table S8, Figure S3).
Table S8. The environmental impacts of a tonne of produced and consumed tobacco established in the main study, the least and the most environmentally damaging scenarios

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Primary study results</th>
<th>Least damaging scenario</th>
<th>Most damaging scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO₂ eq</td>
<td>13975</td>
<td>3322</td>
<td>26219</td>
</tr>
<tr>
<td>Terrestrial acidification</td>
<td>kg SO₂ eq</td>
<td>76</td>
<td>25</td>
<td>179</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>3250</td>
<td>1563</td>
<td>5485</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>6</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>82</td>
<td>37</td>
<td>134</td>
</tr>
<tr>
<td>Marine ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>79</td>
<td>37</td>
<td>130</td>
</tr>
<tr>
<td>Agricultural land occupation</td>
<td>m²a</td>
<td>8493</td>
<td>12457</td>
<td>3976</td>
</tr>
<tr>
<td>Urban land occupation</td>
<td>m²a</td>
<td>335</td>
<td>216</td>
<td>430</td>
</tr>
<tr>
<td>Natural land transformation</td>
<td>m²</td>
<td>11</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Water depletion</td>
<td>m³</td>
<td>3713</td>
<td>3643</td>
<td>3901</td>
</tr>
<tr>
<td>Metal depletion</td>
<td>kg Fe eq</td>
<td>549</td>
<td>287</td>
<td>662</td>
</tr>
<tr>
<td>Fossil depletion</td>
<td>kg oil eq</td>
<td>3480</td>
<td>717</td>
<td>6481</td>
</tr>
</tbody>
</table>
3.4. Limitations

There is inevitably a degree of uncertainty in the study findings down to the large scope and data availability, as well as the limitations associated with the LCA approach, which originate in the assumptions adopted and the choices made, including that of the functional unit, spatial and time dimensions, and the environmental impact categories. Nevertheless, because of the scale of both resource needs and environmental impacts, the significance of the results is clear. Furthermore, as demonstrated by the sensitivity analyses, it is unlikely that the findings represent a significant overestimate of the impacts, in fact, the known exclusion of some items because of an absence of data means that the true burden is likely to be even higher than we report.
3. DISCUSSION

3.4. Comparing tobacco to other crops

Comparing the estimated environmental footprint of a tonne of cultivated tobacco to that of other crops (considering only the cradle-to-farm gate stages of crop production) demonstrates that the nearly 1,300 m² of agricultural land used annually for the production of a tonne of green tobacco could produce about 6 tonnes of tomatoes or almost half a tonne of wheat in regions suitable for their cultivation. Similarly, the water use of 670 m³ per tonne of tobacco is comparable to that of a tonne of rice and is between 5 and 8 times higher than what would be required to grow a tonne of fresh tomatoes or potatoes (Table S9).

Table S9. Comparison of the environmental impacts of a tonne of green tobacco to other crops

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Green tobacco</th>
<th>Coffee, green bean, arabica</th>
<th>Potato</th>
<th>Rice</th>
<th>Tomato, fresh grade</th>
<th>Wheat grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO2 eq</td>
<td>643.5</td>
<td>6753.5</td>
<td>186.3</td>
<td>1842.4</td>
<td>265.6</td>
<td>806.1</td>
</tr>
<tr>
<td>Terrestrial acidification</td>
<td>kg SO2 eq</td>
<td>3.7</td>
<td>112.9</td>
<td>1.8</td>
<td>7.3</td>
<td>2.6</td>
<td>8.0</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>0.2</td>
<td>2.4</td>
<td>0.3</td>
<td>0.5</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>0.3</td>
<td>58.2</td>
<td>2.2</td>
<td>11.1</td>
<td>2.3</td>
<td>5.4</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>219.3</td>
<td>2965.8</td>
<td>98.5</td>
<td>311.4</td>
<td>60.6</td>
<td>298.7</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>0.7</td>
<td>129.6</td>
<td>174.3</td>
<td>0.8</td>
<td>0.2</td>
<td>5.6</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>5.7</td>
<td>141.7</td>
<td>12.6</td>
<td>8.4</td>
<td>1.9</td>
<td>6.0</td>
</tr>
<tr>
<td>Marine ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>5.6</td>
<td>95.9</td>
<td>2.0</td>
<td>7.9</td>
<td>1.8</td>
<td>5.0</td>
</tr>
<tr>
<td>Agricultural land occupation</td>
<td>m²a</td>
<td>1259.0</td>
<td>10856.7</td>
<td>270.3</td>
<td>1546.3</td>
<td>356.5</td>
<td>3008.4</td>
</tr>
<tr>
<td>Urban land occupation</td>
<td>m²a</td>
<td>39.9</td>
<td>100.0</td>
<td>4.1</td>
<td>103.6</td>
<td>13.7</td>
<td>13.9</td>
</tr>
<tr>
<td>Natural land transformation</td>
<td>m²</td>
<td>1.7</td>
<td>1.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Water depletion</td>
<td>m³</td>
<td>670.2</td>
<td>572.0</td>
<td>80.5</td>
<td>663.3</td>
<td>125.6</td>
<td>245.6</td>
</tr>
<tr>
<td>Metal depletion</td>
<td>kg Fe eq</td>
<td>56.8</td>
<td>619.5</td>
<td>18.4</td>
<td>71.4</td>
<td>17.9</td>
<td>50.6</td>
</tr>
<tr>
<td>Fossil depletion</td>
<td>kg oil eq</td>
<td>128.5</td>
<td>1270.6</td>
<td>40.9</td>
<td>212.7</td>
<td>47.4</td>
<td>133.9</td>
</tr>
</tbody>
</table>

Dataset name in SimaPro: [Study results] Coffee, green bean (RoW) | coffee, green bean production, arabica | Alloc Def, U
Rice (RoW) | production Alloc Def, U
Tomato, fresh grade (RoW) | tomato, fresh grade, open field Alloc Def, U
Wheat grain (RoW) | wheat production Alloc Def, U

LCIA method used: ReCiPe Midpoint (H)/ World (H)
3.5. **Comparison of the environmental impacts of using alternative energy sources at cigarette manufacturing facilities**

The choice of energy source was found to play an important role in mitigating tobacco’s environmental footprint. For example, if coal dominates the energy mix, the carbon footprint of cigarette manufacturing may be higher by as much as 35%, while the damage to freshwater and marine ecosystems can be at least 20% greater than the typical impacts estimated assuming a mix of energy sources across the world. Often, however, the comparison of the levels of environmental damage among alternative resource types is not clear-cut. For instance, although switching to natural gas as the main energy source may be less damaging than coal in terms of the carbon emissions and the damage to aquatic ecosystems, it may, at the same time, lead to higher levels of land transformation and fossil depletion (Figure S4).

![Figure S4](image)

**Figure S4.** Comparison of environment impact contributions of manufacturing 1 million cigarettes at facilities with coal-based electricity supply in China, natural gas-based in Germany and a mix of energy sources (main study results).

3.6. **Comparison of the environmental impacts of an average smoker to other commodity consumers**
Comparing the annual environmental footprint of an average smoker (consuming 5,840 sticks in a year or just under a pack a day) to red meat and sugar consumption demonstrates that the resource depletion and pollution levels caused by cigarette use can be several times greater than or least as high as those driven by other popular consumer commodities (Table S10).
Table S10. Comparison of environmental impacts associated with smoking a pack of 20 cigarettes every day and a world average annual per capita consumption of red meat and sugar

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Cigarettes, smoker of 1 pack/day</th>
<th>Red meat, average consumer*</th>
<th>Sugar, average consumer*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO₂ eq</td>
<td>100</td>
<td>196</td>
<td>27</td>
</tr>
<tr>
<td>Terrestrial acidification</td>
<td>kg SO₂ eq</td>
<td>0.55</td>
<td>1.3</td>
<td>0.20</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>0.02</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>0.02</td>
<td>1.05</td>
<td>0.08</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>23</td>
<td>21</td>
<td>0.09</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>0.04</td>
<td>1.3</td>
<td>0.83</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>0.56</td>
<td>0.89</td>
<td>0.21</td>
</tr>
<tr>
<td>Marine ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>0.55</td>
<td>0.64</td>
<td>0.12</td>
</tr>
<tr>
<td>Agricultural land occupation</td>
<td>m²a</td>
<td>64</td>
<td>179</td>
<td>26</td>
</tr>
<tr>
<td>Urban land occupation</td>
<td>m²a</td>
<td>2.45</td>
<td>2.5</td>
<td>0.35</td>
</tr>
<tr>
<td>Natural land transformation</td>
<td>m²</td>
<td>0.08</td>
<td>0.41</td>
<td>0.33</td>
</tr>
<tr>
<td>Water depletion</td>
<td>m³</td>
<td>27</td>
<td>4.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Metal depletion</td>
<td>kg Fe eq</td>
<td>3.97</td>
<td>4.3</td>
<td>0.86</td>
</tr>
<tr>
<td>Fossil depletion</td>
<td>kg oil eq</td>
<td>25</td>
<td>13</td>
<td>2.6</td>
</tr>
</tbody>
</table>

*See sources in the table below
Table S11. The environmental impacts associated with the consumption of a tonne of tobacco, red meat and sugar

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit</th>
<th>Tobacco, (cradle-to-gate)</th>
<th>Red meat, average consumer (excl. preparation)</th>
<th>Sugar, average consumer (excl. packaging)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO2 eq</td>
<td>13,765</td>
<td>13,600</td>
<td>1,110</td>
</tr>
<tr>
<td>Terrestrial acidification</td>
<td>kg SO2 eq</td>
<td>75</td>
<td>92</td>
<td>8</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>3</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>3</td>
<td>73</td>
<td>3</td>
</tr>
<tr>
<td>Human toxicity</td>
<td>kg 1,4-DB eq</td>
<td>3,152</td>
<td>1,484</td>
<td>4</td>
</tr>
<tr>
<td>Terrestrial ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>5</td>
<td>89</td>
<td>34</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>77</td>
<td>62</td>
<td>9</td>
</tr>
<tr>
<td>Marine ecotoxicity</td>
<td>kg 1,4-DB eq</td>
<td>75</td>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>Agricultural land occupation</td>
<td>m2a</td>
<td>8,771</td>
<td>12,463</td>
<td>1,050</td>
</tr>
<tr>
<td>Urban land occupation</td>
<td>m2a</td>
<td>335</td>
<td>174</td>
<td>14</td>
</tr>
<tr>
<td>Natural land transformation</td>
<td>m2</td>
<td>11</td>
<td>28</td>
<td>13</td>
</tr>
<tr>
<td>Water depletion</td>
<td>m3</td>
<td>3,713</td>
<td>296</td>
<td>167</td>
</tr>
<tr>
<td>Metal depletion</td>
<td>kg Fe eq</td>
<td>544</td>
<td>298</td>
<td>35</td>
</tr>
<tr>
<td>Fossil depletion</td>
<td>kg oil eq</td>
<td>3,436</td>
<td>908</td>
<td>106</td>
</tr>
</tbody>
</table>

Source: Current study 25 68 70 71

LCIA method applied
Average annual consumption per person and source. 20 cigarette sticks per day, or 7.3 kg of tobacco per year (Average consumption is 5.8 kg tobacco)

Dataset description
Excl. tobacco distribution and use & disposal stages. Activity starts: from reception and storage of feed materials, and dairy herd housing. Activity ends with provision of milk at farm, ready-to-deliver. Live animals (culled cows and calves) sold for slaughter are by-products, as well as solid and liquid manure. Dataset includes transport of sugarcane to refinery and the processing of sugarcane to sugar. System boundary is at sugar refinery. Treatment of waste effluents is not included. Packaging is not included.
Tobacco production and consumption by country

Tobacco cultivation is concentrated primarily in low- and middle-income regions - nine of the top ten tobacco producing countries are developing and four of those (India, Zimbabwe, Pakistan, and Malawi), low-income food-deficit countries. In some of these countries, the vast majority of all tobacco produced is destined for exports with less than 20% consumed locally (Figure S5 and table S12).

Figure S5. Annual tonnage of tobacco in cigarette production and consumption for countries with over 1,000 tonnes of tobacco flows in year 2014.21,72,73
Table S12. Tobacco consumption and production by country, region, and income group for 2014

<table>
<thead>
<tr>
<th>Country Name</th>
<th>Country Income group</th>
<th>Region</th>
<th>Population ages 15-64, total</th>
<th>Cigarette consumption per adult (15y.o.+), sticks</th>
<th>Total tobacco production, tonnes</th>
<th>Total tobacco consumption, tonnes</th>
</tr>
</thead>
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REFERENCES


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