

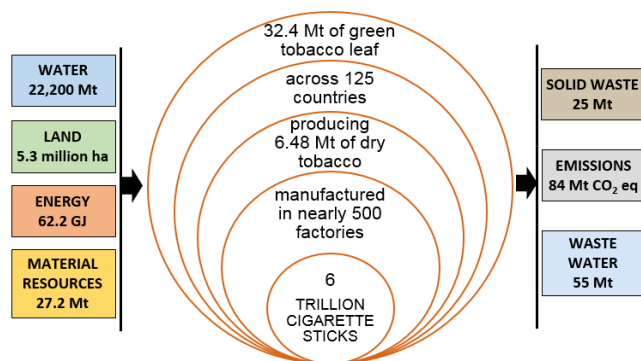
Cigarette Smoking: An assessment of tobacco's global environmental footprint across its entire supply chain

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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 worldwide¹. Although smoking prevalence has been dropping in high-income countries², global cigarette consumption has continued to grow, largely as a result of the increasing uptake of smoking by young people in developing regions³. 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 litter⁴⁻⁷. Furthermore, incorrect disposal of cigarette butts has been linked to numerous domestic⁸ and wildland fires with devastating results⁹.

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 reports¹⁰⁻¹⁴ and life cycle assessments (LCA),^{10,15,16} 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,^{17,18} 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.¹⁹ 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.²⁰

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

74 full list of the mass flows considered).

75 The environmental impacts associated with global tobacco production and consumption were
76 quantified through LCA, using the SimaPro 8 software²¹ and the ReCiPe Midpoint (H)
77 methodology.²² The base year, scope, system boundaries, functional unit, and impact
78 categories are summarised in Table 1, and a full description of the inputs, sources, and the
79 assumptions used are reported in Supporting Information, together with the limitations and
80 the uncertainty associated with these factors.

81 Sensitivity analysis was carried out to evaluate how varying key assumptions used in the
82 primary analysis could influence the total impact assessment outcomes and to identify the
83 inputs where variation has the most impact on key outputs (see Supporting Information).

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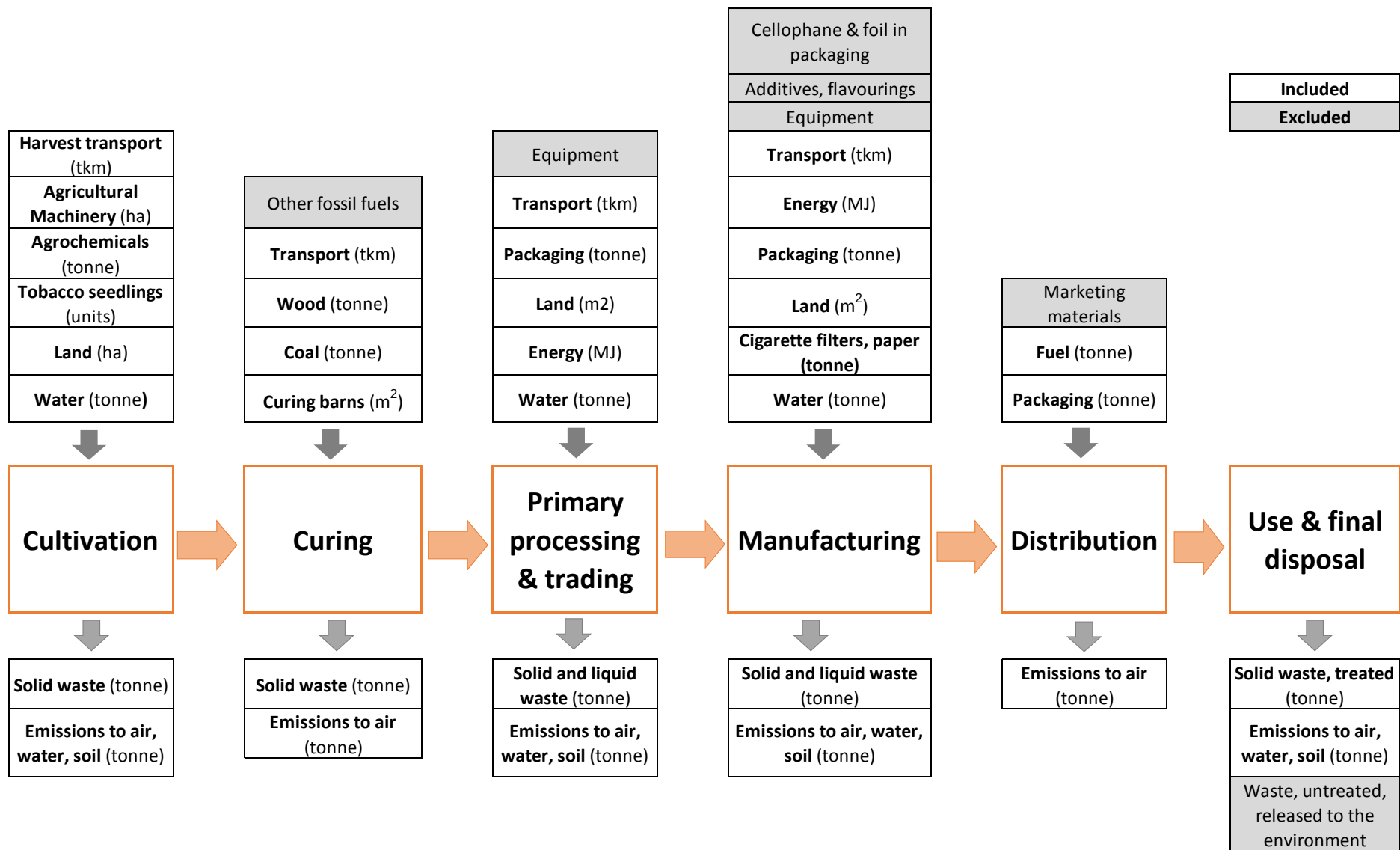


Figure 1. Conceptual framework and system boundaries of global cigarette production and consumption.

Table 1. Life cycle assessment (LCA) study scope and system boundaries of global cigarette production and consumption

Study features	Description
Processes included	Tobacco cultivation, curing, primary processing, cigarette manufacturing, distribution, use and disposal, plus transportation and waste management activities at every process stage.
Representative product	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*
Functional unit	A tonne of produced and consumed tobacco, equivalent to 1 million cigarette sticks**
Scope	Global cigarette production and consumption in one year
Base year	2014
Mass flows allocated to tobacco	100%
Types of resource flows included in the analysis	Key direct and indirect inputs and outputs
Types of resource flows excluded from the analysis	Office supplies, cleaning products, chemicals and additives used in production and manufacturing processes, smoking accessories
Issues excluded from impact analysis	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)
Impact categories considered	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.
*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).

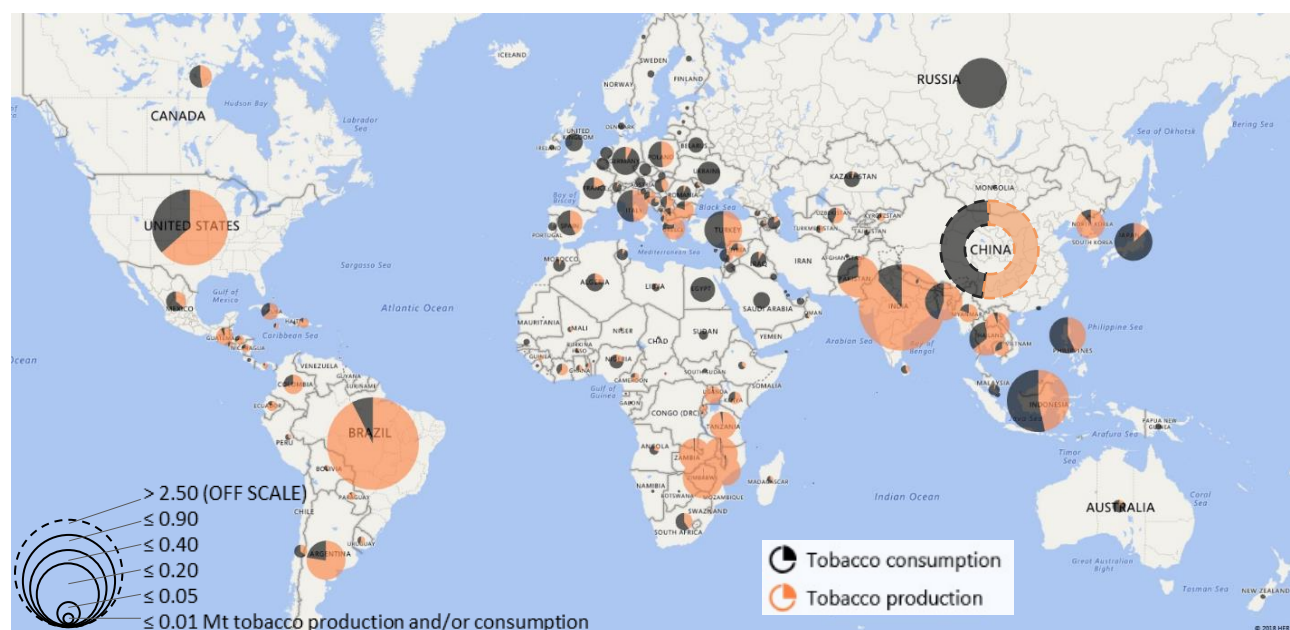


Figure 2. Annual tonnage of tobacco in cigarette production and consumption for countries with over 1,000 tonnes of tobacco flows in year 2014.²⁴⁻²⁷

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 CO₂ eq emissions to air (Net of CO₂ absorption by tobacco plants at the farming stage).

109 **Table 2.** Summary annual mass flows in the global tobacco supply chain

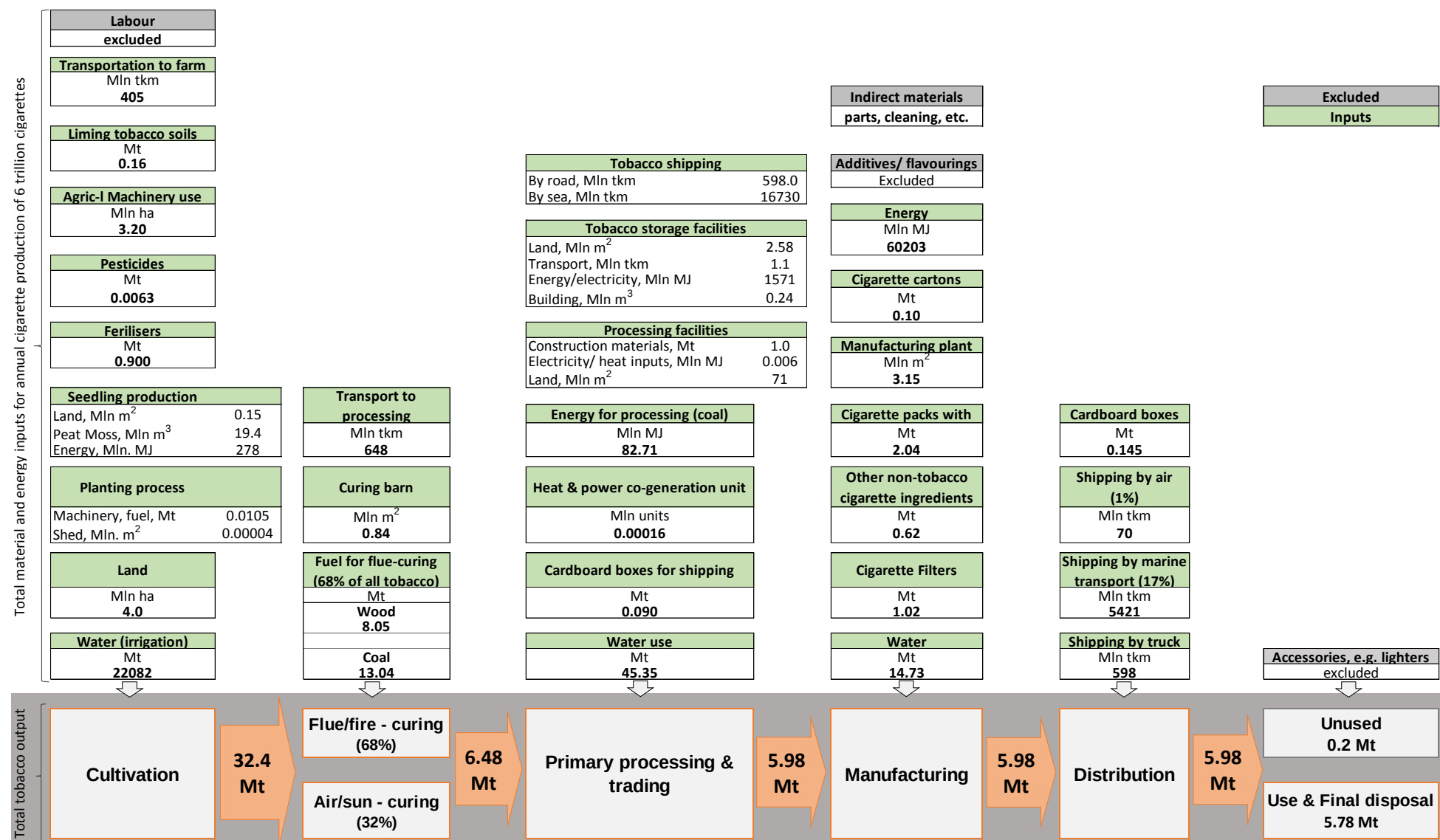
INPUTS		Unit	Inputs per tonne of <u>output</u> tobacco	Total output tobacco at each stage (Mt)	Total Inputs (millions)	Inputs per tonne of <u>tobacco produced for</u> <u>consumption</u>
WATER						
Stages	- Cultivation	tonne	678	32.4	21978.1	3675.3
	- Processing	tonne	7.59	5.98	45.4	7.6
	- Manufacturing	tonne	2.47	5.98	14.8	2.5
Total		tonne			22038.2	3685.3
ENERGY						
Stages	- Cultivation	MJ	8.59	32.4	278.3	46.5
	- Processing	MJ	277	5.98	1655.5	276.8
	- Manufacturing	MJ	10076	5.98	60253.6	10075.8
Total		MJ			62187.4	10399.2
MATERIAL RESOURCES						
Stage	- Cultivation	tonne	0.03	32.4	1.07	0.2

	- Curing	tonne	3.25	6.48	21.1	3.5
	- Processing	tonne	0.19	5.98	1.11	0.2
	- Manufacturing	tonne	0.63	5.98	3.78	0.6
	- Distribution	tonne	0.02	5.98	0.15	0.0
Total		tonne			27.2	4.5
TRANSPORT						
Stages	- Cultivation	tkm	12.5	32.4	405	67.7
	- Curing	tkm	100	6.48	648	108.4
	- Processing	tkm	2900	5.98	17342.0	2900.0
	- Distribution	tkm	1019	5.98	6093.6	1019.0
Total		tkm			24488.6	4095.1
LAND						
Stages	- Cultivation	m ²	1235	32.4	40000.2	6689.0
	- Curing	m ²	0.13	6.48	0.84	0.1
	- Processing	m ²	12.31	5.98	73.6	12.3
	- Manufacturing	m ²	0.53	5.98	3.15	0.5

<i>Total</i>		<i>m²</i>		<i>40077.7</i>		<i>6702.0</i>
WASTE and EMISSIONS		Unit	Waste and emissions per tonne of <u>output</u> tobacco	Total output tobacco at each stage (Mt)	Total waste and emissions (millions)	Waste and emissions per tonne of <u>produced and consumed</u> tobacco
SOLID WASTE						
Stages	- Cultivation	tonne	0.6	32.4	19.4	3.3
	- Processing	tonne	0.08	5.98	0.5	0.1
	- Manufacturing	tonne	0.2	5.98	1.2	0.2
	- Use & Final Disposal*	tonne	0.7	5.78	4.1	0.6
<i>Total</i>		<i>tonne</i>			25	4.2
WASTE WATER & WATER EMISSIONS						
Stages	- Cultivation (losses from irrigation)	tonne	674	32.4	21844.5	3652.9
	- Curing (losses from evaporation)	tonne	4.00	6.48	25.9	4.3

	- Processing (waste water)	tonne	7.61	5.98	45.5	7.6
	- Manufacturing (waste water)	tonne	1.50	5.98	9.0	1.5
Total		tonne			21925	3666.4
EMISSIONS TO AIR						
Stages	- Cultivation	t CO ₂ eq	0.64	32.4	20.9	3.5
	- Curing	t CO ₂ eq	6.89	6.48	44.6	7.5
	- Processing	t CO ₂ eq	0.18	5.98	1.1	0.2
	- Manufacturing	t CO ₂ eq	2.63	5.98	15.7	2.6
	- Distribution	t CO ₂ eq	0.07	5.98	0.4	0.1
	- Use & Final Disposal*	t CO ₂ eq	0.15	5.78	0.9	0.2
Total		t CO₂ eq			84	14.0

*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.



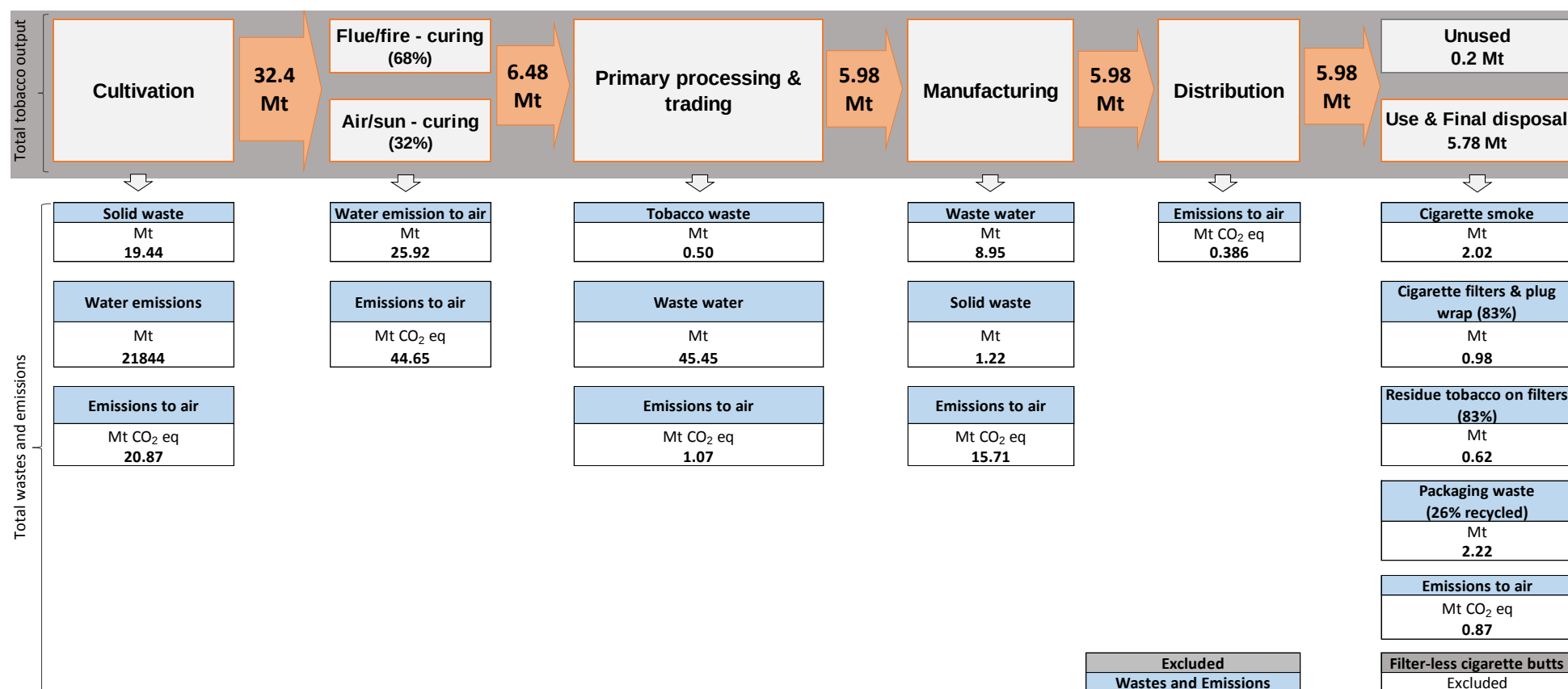


Figure 3. Total annual input, waste and emission flows across the global tobacco supply chain

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

Impact category	Unit	Farming	Curing	Processing	Cigarette Manufacturing	Distribution	Use & Disposal	TOTAL
		(Millions)						
Climate Change	kg CO ₂ eq	20849	44674	1073	15720	386	870	83572
Terrestrial acidification	kg SO ₂ eq	119	240	11	78	2.4	2.9	453
Freshwater eutrophication	kg P eq	6.8	0.6	0.3	8.3	0.03	0.3	16
Marine eutrophication	kg N eq	11	3.7	0.4	4.3	0.2	1.0	21
Human toxicity	kg 1,4-DB eq	7107	4865	590	6286	52	534	19435
Terrestrial ecotoxicity	kg 1,4-DB eq	24	1.5	0.2	4.5	0.1	6	36
Freshwater ecotoxicity	kg 1,4-DB eq	185	43	14	216	1.7	29	489

Marine ecotoxicity	kg 1,4-DB eq	181	53	16	199	2.1	24	474
Agricultural land occupation	m ² a	40791	8182	282	3196	346	-2009	50788
Urban land occupation	m ² a	1291	476	96	142	12	-14	2004
Natural land transformation	m ²	56	4.4	0.8	2.7	0.2	-0.1	64
Water depletion	m ³	21715	129	15	342	5.8	-3.5	22203
Metal depletion	kg Fe eq	1840	465	334	614	14	16	3282
Fossil fuel depletion	kg oil eq	4163	12049	304	4032	127	139	20813

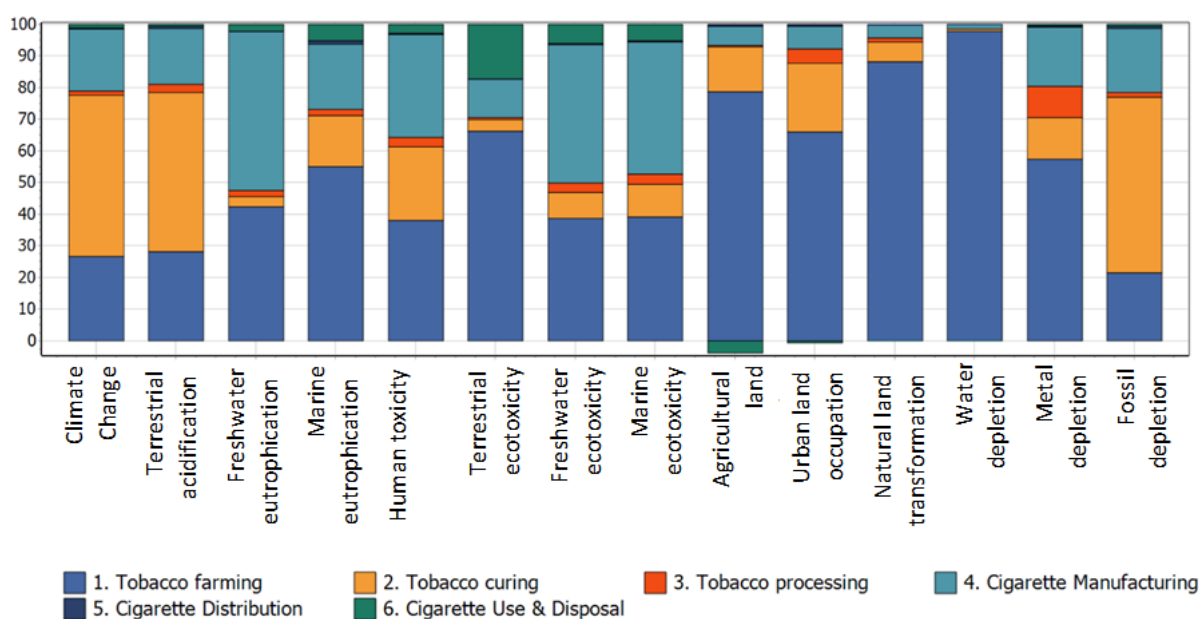


Figure 4. Environmental impacts contribution of the global tobacco supply chain stages across the full life cycle of cigarette production and consumption

The sensitivity analysis showed variability in the environmental impact results in the range of $\pm 10\%$ 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

Impact category	Unit	Study results	
		(millions)	variance
Climate change	kg CO ₂ eq	83572	$\pm 8\%$
Terrestrial acidification	kg SO ₂ eq	453	$\pm 7\%$
Freshwater eutrophication	kg P eq	16	$\pm 12\%$
Marine eutrophication	kg N eq	21	$\pm 10\%$
Human toxicity	kg 1,4-DB eq	19435	$\pm 7\%$
Terrestrial ecotoxicity	kg 1,4-DB eq	36	$\pm 19\%$

Freshwater ecotoxicity	kg 1,4-DB eq	489	±9%
Marine ecotoxicity	kg 1,4-DB eq	474	±9%
Agricultural land occupation	m ² a	50788	± 6%
Urban land occupation	m ² a	2004	±4%
Natural land transformation	m ²	64	±6%
Water depletion	m ³	22203	±8%
Metal depletion	kg Fe eq	3282	±4%
Fossil fuel depletion	kg oil eq	20813	±9%

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,^{4,28} 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 countries²⁹ 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 Africa²⁹). 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.³⁰ 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,³¹ 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.³² 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 meat³³) and sugar (24.3 kg sugar³⁴) 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 CO₂ 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.³⁵ 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.³⁶ 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,³⁷ 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.³⁸ 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,^{24,39} 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,¹³ and a 47% reduction in carbon footprint from the 2000 baseline for another.¹⁰ 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 ⁴⁰ 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 2025,⁴¹ 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.⁴² 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

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SUPPORTING INFORMATION

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

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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.

Farming 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 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 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 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 ¹⁴ and by Euromonitor for conversion of RYO products to sticks 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 ¹⁶). The weight of tobacco in the RYO products is 0.75g per stick.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 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 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 m³ 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 m³ of water, and 0.64 tCO₂ 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

1. TOBACCO CULTIVATION					
Inputs	Amount per tonne of green tobacco	Unit	Inputs	Amount per tonne of green tobacco	Unit
Water ¹⁹	675	tonne	Nitrogen fertiliser ²⁰	0.017*	tonne
Land (incl. transformation from forest) ^{21,22}	0.123*	ha a	Potassium fertiliser ²⁰	0.005*	tonne
Land for tobacco seedlings ^{5,21,23}	0.0046**	m ²	Phosphate fertiliser ²⁰	0.006*	tonne
Peat Moss for seedlings ^{5,21,23}	0.6**	m ³	Pesticides ²⁴	0.0002**	tonne
Seedlings Irrigation ^{5,21,23}	3.22**	tonne	Lime ²⁵	0.0052**	tonne
Energy for seedlings in greenhouses ^{5,21,23}	8.59**	MJ	Agricultural machinery (tillage, harrowing, harvesting) ^{21,25,26}	0.099**	ha
Agricultural machinery and fuel for planting ²⁵	0.00032**	tonne	Transport of harvest from field to farm ²⁵	12.5**	tkm
Shed ²⁵	0.0000012**	m ² a			
Wastes and emissions			Wastes and emissions		
Water loss (from irrigation) ²⁵	674*	tonne	CO ₂ eq emissions ***	0.644	tCO ₂ eq
Solid waste (residue crop, burnt) ²⁵	0.6*	tonne			
2. TOBACCO CURING					

	Amount per tonne of cured tobacco	Unit
Curing barns (wooden) ²⁷	0.13024*	m ²
Wood (16% of tobacco produced) ^{21,29}	7.77*	tonne
Wood-burning furnace (16% of tobacco produced) ³¹	0.1946	number of units
Transport of wood logs (16% of tobacco produced) ³¹	72.02	tkm
Wastes and emissions		
Water content loss in plants ⁶⁻¹⁰	4	tonne
Solid waste (from shed construction) ³²	0.084	tonne

3. PRIMARY PROCESSING

	Amount per tonne of processed tobacco	Unit
Processing Facilities - construction materials ²⁵	0.1703**	tonne

	Amount per tonne of cured tobacco	Unit
Coal (hard coal coke) (52% of tobacco produced) ²⁸	3.87*	tonne
Coal stove, 5-15 kW (52% of tobacco produced) ³⁰	0.0647	number of units
Transport of coal (52% of tobacco produced) ³⁰	3232.68	tkm
Transport of cured tobacco to processing facilities ²⁵	100**	tkm
CO ₂ eq emissions ^{***}	6.89	t CO ₂ eq

	Amount per tonne of processed tobacco	Unit
Transport from processing to storage ³³	0.18**	tkm

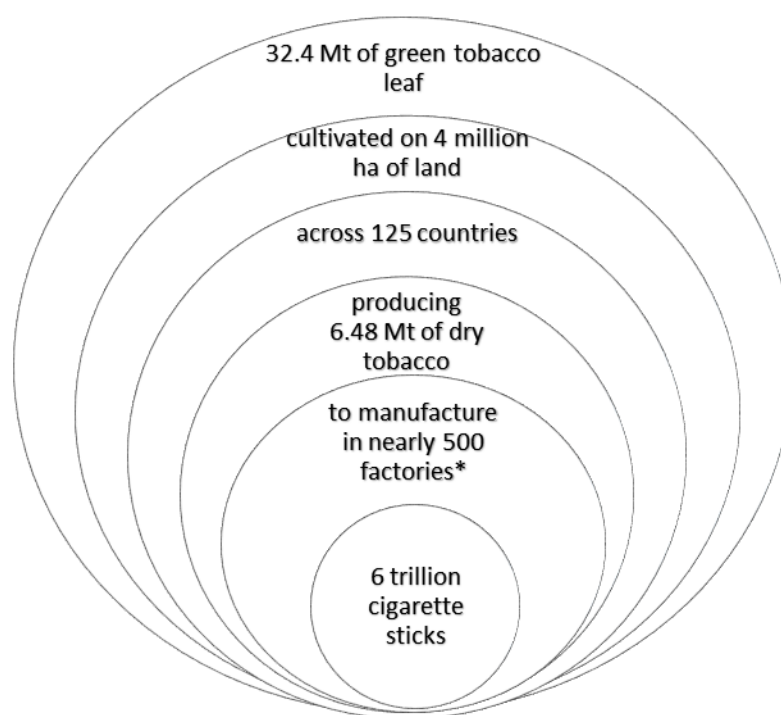
Processing Facilities - energy for construction ²⁵	0.00097**	MJ	Energy for storage ³³	263**	MJ
Land ²⁵	11.9**	m ²	Storage building ³³	0.04**	m ³
Energy for tobacco processing ²⁵	13.8**	MJ	Corrugated cardboard boxes for shipping ³⁴	0.015*	tonne
Heat & Power generating unit ²⁵	0.000027**	number of units	Shipping by road (lorry) ³⁵	100**	tkm
Water ²⁵	7.59**	tonne	Shipping by sea (35% of processed tobacco) ^{35,36}	2800**	tkm
Tobacco storage facility – land ³³	0.432**	m ²			
Wastes and emissions			Wastes and emissions		
Solid waste ²⁵	0.1517**	tonne	Waste water ²⁵	7.607**	tonne
Tobacco waste ^{22,37}	0.084*	tonne	CO ₂ eq emissions ^{***Error!} Bookmark not defined.	0.179	t CO ₂ eq
4. MANUFACTURING					
	Amount per tonne of manuf. tobacco	Unit		Amount per tonne of manuf. tobacco	Unit
Water ³⁸	2.466*	tonne	Cigarette packs – foil (excl. from LCA) ³⁹	0.037	tonne
Cigarette filters ^{40,41}	0.17	tonne	Cellophane (for cigarette packs & cartons; excl. from LCA) [†]	0.108	tonne
Cigarette plug wrap ⁴²⁻⁴⁴	0.04	tonne	Cigarette cartons (of 10 packs) ⁴⁵	0.0167*	tonne

Cigarette paper ⁴⁶	0.063	tonne	Manufacturing plant - land and building ^{47,48}	0.527**	m ² a
Cigarette packs, carton (of 20-sticks) ^{38,45}	0.284	tonne	Energy ³⁸	10076*	MJ
Wastes and emissions			Wastes and emissions		
Waste water ^{38,49}	1.5*	tonne	Hazardous waste, landfill ³⁸ Error! Bookmark not defined.	0.0001*	tonne
Non-hazardous waste, landfill ³⁸	0.0139*	tonne	Hazardous waste, incineration ³⁸ Error! Bookmark not defined.	0.0001*	tonne
Non-hazardous waste, recovery ³⁸ Error! Bookmark not defined.	0.1875*	tonne	Hazardous waste, unspecified treatment ³⁸	0.0001*	tonne
Non-hazardous waste, incineration ³⁸ Error! Bookmark not defined.	0.0009*	tonne	CO ₂ eq emissions ^{***}	2.63	t CO ₂ eq
Hazardous waste, recovery ³⁸	0.0018*	tonne			
5. DISTRIBUTION					
	Amount per tonne of distrib.			Amount per tonne of distrib.	
Inputs	tobacco	Unit	Inputs	tobacco	Unit

Transport by road, uncontrolled conditions ^{50,51}	97*	tkm	Transport by air (1% of produced tobacco) ^{50,51}	1171	tkm
Transport by road with reefer cooling ^{50,51}	3*	tkm	Fuel for transport ***	0.343	tonne
Transport by sea (17% of manuf. Tobacco) ^{50,51}	5337	tkm	Packaging, corrugated board ³⁴	0.0243*	tonne
Wastes and emissions			Wastes and emissions		
CO ₂ eq emissions ***	0.0646	t CO ₂ eq			
5. USE & FINAL DISPOSAL					
Wastes and emissions	Amount per tonne of smoked tobacco	Unit	Wastes and emissions	Amount per tonne of smoked tobacco	Unit
Carbon dioxide, biogenic ⁵²⁻⁵⁴	0.05	tonne	Water ⁵²⁻⁵⁴ Error! Bookmark not defined.	0.01	tonne
Carbon monoxide, biogenic ⁵²⁻⁵⁴	0.02	tonne	Argon ⁵²⁻⁵⁴	0.005	tonne
Nitrogen monoxide ⁵²⁻⁵⁴	0.0005	tonne	Hydrogen ⁵²⁻⁵⁴	0.00075	tonne
Hydrogen sulphide ⁵²⁻⁵⁴	0.0001	tonne	Cigarette butts, incl. residue tobacco (83% of smoked tobacco) ^{15,40,41}	0.205*	tonne
Methane ⁵²⁻⁵⁴	0.002	tonne	Residue tobacco in cigarette butts (83% of smoked tobacco) ¹⁵	0.108*	tonne

Ammonia ⁵²⁻⁵⁴	0.00007	tonne	Cigarette packaging waste ³⁴	0.36*	tonne
Nitrogen, total ⁵²⁻⁵⁴	0.201	tonne	Cardboard boxes waste ⁴⁵	0.024057*	tonne
Oxygen ⁵²⁻⁵⁴	0.06	tonne	CO ₂ eq emissions***	0.15	t CO ₂ eq
<i>[no asterisk] – value directly referenced</i> <i>*Calculated value;</i> <i>**Equivalent used and adopted for tobacco.</i> <i>***SimaPro output</i> <i>† Researchers' measurements</i>					

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 unconfirmed³⁷

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

Impact category	Unit	Farming	Curing	Processing	Cigarette Manufacturing	Distribution	Cigarette Use & Disposal	TOTAL
Climate Change	kg CO ₂ eq	3486.5	7470.6	179.3	2628.7	64.6	145.4	13975.2
Terrestrial acidification	kg SO ₂ eq	19.9	40.1	1.8	13.1	0.4	0.5	75.8
Freshwater eutrophication	kg P eq	1.1	0.1	0.1	1.4	0.0	0.1	2.7
Marine eutrophication	kg N eq	1.9	0.6	0.1	0.7	0.0	0.2	3.5
Human toxicity	kg 1,4-DB eq	1188.4	813.5	98.7	1051.2	8.7	89.4	3249.9
Terrestrial ecotoxicity	kg 1,4-DB eq	4.0	0.2	0.0	0.8	0.0	1.0	6.1
Freshwater ecotoxicity	kg 1,4-DB eq	30.9	7.3	2.4	36.2	0.3	4.8	81.8
Marine ecotoxicity	kg 1,4-DB eq	30.2	8.8	2.7	33.2	0.3	4.0	79.3
Agricultural land occupation	m ² a	6821.2	1368.3	47.1	534.4	57.9	-335.9	8493.0
Urban land occupation	m ² a	215.9	79.6	16.0	23.8	2.1	-2.3	335.0
Natural land transformation	m ²	9.4	0.7	0.1	0.5	0.0	0.0	10.8
Water depletion	m ³	3631.3	21.6	2.4	57.2	1.0	-0.6	3712.9
Metal depletion	kg Fe eq	307.7	77.8	55.8	102.7	2.3	2.7	548.9
Fossil depletion	kg oil eq	696.2	2014.9	50.8	674.2	21.2	23.2	3480.5

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).

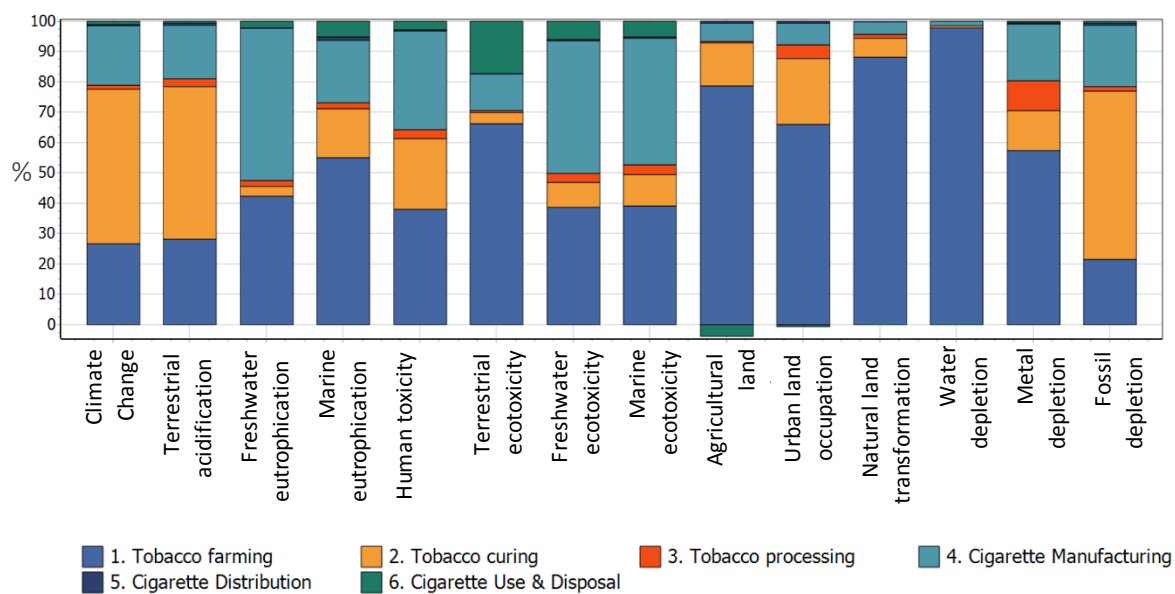


Figure S2. Environmental impacts contribution of the global tobacco supply chain stages across the full life cycle of cigarette production and consumption

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

Impact category	Unit	Per tonne of produced and consumed tobacco		
			Per cigarette stick*	Per smoker's lifetime**
Climate Change	kg CO ₂ eq	13975.2	0.013975	5100.9
Terrestrial acidification	kg SO ₂ eq	75.8	0.000076	27.7
Freshwater eutrophication	kg P eq	2.7	0.000003	1.0
Marine eutrophication	kg N eq	3.5	0.000003	1.3
Human toxicity	kg 1,4-DB eq	3249.9	0.003250	1186.2
Terrestrial ecotoxicity	kg 1,4-DB eq	6.1	0.000006	2.2
Freshwater ecotoxicity	kg 1,4-DB eq	81.8	0.000082	29.9
Marine ecotoxicity	kg 1,4-DB eq	79.3	0.000079	28.9
Agricultural land occupation	m ² a	8493.0	0.008493	3099.9
Urban land occupation	m ² a	335.0	0.000335	122.3
Natural land transformation	m ²	10.8	0.000011	3.9
Water depletion	m ³	3712.9	0.003713	1355.2
Metal depletion	kg Fe eq	548.9	0.000549	200.3
Fossil depletion	kg oil eq	3480.5	0.003480	1270.4
*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

LCA input considered in sensitivity analysis	Input value per tonne of output tobacco	Input value range tested	Sources and description of the value ranges considered
CULTIVATION			
Irrigation (automated)	675 m ³	-8.5%	8.5% lower irrigation infrastructure assuming nearly zero infrastructure in African tobacco-growing regions ^{21,55}
	675 m ³	+8.5%	8.5% higher irrigation infrastructure
Transport of harvest	12.5 tkm	-8.5%	8.5% lower use accounting for African countries ^{21,26}
	12.5 tkm	+8.5%	8.5% higher transport distances
Seedlings produced in greenhouses	2000 seedlings	-10%	10% lower use of unheated greenhouses and no use of heated greenhouses ^{21,56}
	2000 seedlings	+10%	10% higher use of unheated greenhouses and no use of heated greenhouses
Land use	0.123ha	+7.5%	7.5% higher land use (based on FAO reported land use prior to 2014 ²¹)
	0.123ha	-7.5%	7.5% lower land use
Agrochemicals	0.033 tonne	+30%	30% higher use (based on US application rates ²⁴)
	0.033 tonne	-30%	30% lower use of agrochemicals
Agric. Machinery use	0.099 ha	+7.5%	7.5% higher use – to account for the case of higher land use ²¹
	0.099 ha	-7.5%	7.5% lower use of agricultural machinery
CURING			
Coal for curing	3.87 tonne	-15%	15% lower use due to higher calorific value (anthracite) ^{30,57}
	3.87 tonne	+15%	15% higher use of coal due to lower calorific value
PROCESSING			
Processing facilities	0.000005 units	-20%	20% smaller. Hypothesised based on the comparison of the processes involved in tobacco processing and sugar refining ^{58,59}

	0.000005 units	+20%	20% bigger processing facilities
Water use in processing	7.59 tonne	-20%	20% lower use. Hypothesised based on the comparison of the processes involved in tobacco processing and sugar refining ^{58,59}
	7.59 tonne	+20%	20% higher water use
Shipping packaging	0.015 tonne	+67%	triple-corrugated cardboard boxes instead of single ³⁴
	0.015 tonne	-67%	lighter cardboard boxes
Transport to manufacturers	2900 tkm	-29%	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 ³⁶
	2900 tkm	+141%	maximum distances in the estimated ranges ³⁵
MANUFACTURING			
Manufacturing plant lifetime	50 years	+32%	additional 16-year service life ⁶⁰
	50 years	-32%	Plant service life shorter by 16 years
	2.47 tonne	+85%	PMI reported 4.59m3/tonne and assuming it does not include processing activities ⁶¹
	2.47 tonne	-85%	85% lower water use
Energy use in manufacturing	10076 MJ	+30%	30% higher energy use based on CNTC reported data ⁶²
	10076 MJ	-30%	30% lower energy use
DISTRIBUTION			
Distribution - packaging	0.024 tonne	+69%	triple-corrugated cardboard boxes instead of single ³⁴
	0.024 tonne	-69%	lighter cardboard boxes
Distribution by air	1171 tkm	-100%	zero air shipping ⁶³
	1171 tkm	+100%	twice as much air shipping
Distribution by sea	5337 tkm	+275%	maximum distances in the estimated ranges ³⁵
	5337 tkm	-63%	minimum distances in the estimated ranges ³⁵
Distribution by truck	100 tkm	+200%	maximum distances in the estimated ranges ³⁵
	100 tkm	-50%	minimum distances in the estimated ranges ³⁵
USE & FINAL DISPOSAL			
Emissions from smoking	0.35 tonne	-5%	minimum concentrations of CH4, NH3, NO ⁵²⁻⁵⁴
	0.35 tonne	+154%	maximum concentrations of CH4, NH3, NO ⁵²⁻⁵⁴

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 ($\pm 19\%$ variance in results) and marine eutrophication ($\pm 10\%$ variance), while a 15% change in the amount of coal used in tobacco curing showed a potential variability in climate change impact of $\pm 8\%$ and in fossil depletion of $\pm 9\%$. A 30% change in energy use in manufacturing lead to a variance of $\pm 12\%$ in freshwater eutrophication and $\pm 9\%$ 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

LCA input considered in sensitivity analysis		Environmental impact results by impact category													
		Climate Change	Terrestrial acidification	Freshwater eutrophication	Marine eutrophication	Human toxicity	Terrestrial ecotoxicity	Freshwater ecotoxicity	Marine ecotoxicity	Agricultural land occupation	Urban land occupation	Natural land transformation	Water depletion	Metal depletion	Fossil depletion
		kg CO2 eq	kg SO2 eq	kg P eq	kg N eq	kg 1,4-DB eq	kg 1,4-DB eq	kg 1,4-DB eq	kg 1,4-DB eq	m2a	m2a	m2	m3	kg Fe eq	kg oil eq
		%	%	%	%	%	%	%	%	%	%	%	%	%	%
		variance	variance	variance	variance	variance	variance	variance	variance	variance	variance	variance	variance	variance	variance
CULTIVATION															
Irrigation (automated)	-8.5%	82805.5	449.5	16.0	20.7	19109.1	unvaried	479.4	464.6	unvaried	1976.1	unvaried	20329.2	3185.7	20584.8
		-0.92%	-0.85%	-2.42%	-0.81%	-1.67%	0	-2.01%	-1.98%	0	-1.37%	0	-8.44%	-2.94%	-1.10%
	+8.5%	84337.9	457.1	16.8	21.0	19759.9	unvaried	499.0	483.4	unvaried	2031.1	unvaried	24077.3	3378.5	21041.8
		0.92%	0.85%	2.42%	0.81%	1.67%	0	2.01%	1.98%	0	1.37%	0	8.44%	2.94%	1.10%
Transport of harvest	-8.5%	No notable impact on results													
	+8.5%	No notable impact on results													
Seedlings produced in greenhouses	-10%	83300.0	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	1920.0	unvaried	unvaried	unvaried	unvaried
		-0.33%	0	0	0	0	0	0	0	0	-4.17%	0	0	0	0
	+10%	83811.8	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	2085.7	unvaried	unvaried	unvaried	unvaried
		0.29%	0	0	0	0	0	0	0	0	4.10%	0	0	0	0
Land use	+7.5%	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	53700	unvaried	68	unvaried	unvaried	unvaried
		0	0	0	0	0	0	0	0	5.73%	0	6.04%	0	0	0
	-7.5%	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	unvaried	47914.6	unvaried	60.4	unvaried	unvaried	unvaried
		0	0	0	0	0	0	0	0	-5.66%	0	-6.05%	0	0	0
Agrochemicals	+30%	85800.0	465.0	16.9	23.0	20100.0	43.2	506.0	490.0	51200.0	2040.0	65.1	22300.0	3429.5	21100.0

		2.67%	2.58%	3.03%	10.34%	3.42%	18.69%	3.43%	3.38%	0.81%	1.82%	1.22%	0.44%	4.49%	1.38%
	-30%	81349.3	441.3	15.9	18.7	18742.3	29.6	472.7	458.1	50411.0	1969.5	63.5	22151.4	3136.3	20488.6
		-2.66%	-2.66%	-3.14%	-10.13%	-3.56%	-18.64%	-3.38%	-3.34%	-0.74%	-1.70%	-1.23%	-0.23%	-4.44%	-1.56%
Agric. Machinery use	+7.5%	No notable impact on results													
	-7.5%	No notable impact on results													
CURING															
Coal for curing	-15%	76988.8	419.4	16.4	20.4	18840.5	36.2	484.2	467.9	50615.4	1946.0	63.8	22185.2	3240.8	19028.2
		-7.88%	-7.49%	-0.16%	-1.99%	-3.06%	-0.43%	-1.02%	-1.29%	-0.34%	-2.88%	-0.81%	-0.08%	-1.26%	-8.58%
	+15%	90154.7	487.2	16.4	21.3	20028.5	36.6	494.2	480.1	50960.7	2061.2	64.8	22221.3	3323.4	22598.5
		7.88%	7.49%	0.16%	1.99%	3.06%	0.43%	1.02%	1.29%	0.34%	2.88%	0.81%	0.08%	1.26%	8.58%
PROCESSING															
Processing facilities	-20%	unvaried	unvaried	16.4	20.8	19356.9	unvaried	487.4	472.1	unvaried	1988.3	unvaried	unvaried	3247.6	unvaried
		0	0	-0.25%	-0.07%	-0.40%	0	-0.37%	-0.41%	0	-0.76%	0	0	-1.05%	0
	+20%	unvaried	unvaried	16.4	20.9	19512.2	unvaried	491.0	475.9	unvaried	2018.8	unvaried	unvaried	3316.7	unvaried
		0	0	0.25%	0.07%	0.40%	0	0.37%	0.41%	0	0.76%	0	0	1.05%	0
Water use in processing	-20%	No notable impact on results													
	+20%	No notable impact on results													
Shipping packaging	+67%	No notable impact on results													
	-67%	No notable impact on results													
Transport to manufacturers	-29%	No notable impact on results													
	+141%	84000.0	460.0	16.5	21.0	19500.0	36.5	491.0	477.0	unvaried	2020.0	64.5	unvaried	unvaried	21000.0
		0.51%	1.48%	0.59%	0.74%	0.34%	0.28%	0.37%	0.64%	0	0.82%	0.29%	0	0	0.90%
MANUFACTURING															
Manufacturing plant lifetime	+32%	83449.0	452.4	16.4	20.8	19386.2	unvaried	487.6	472.7	unvaried	unvaried	unvaried	unvaried	3260.1	20786.8
		-0.15%	-0.20%	-0.22%	-0.18%	-0.25%	0	-0.32%	-0.28%	0	0	0	0	-0.67%	-0.13%
	-32%	83809.9	455.1	16.5	20.9	19528.4	unvaried	492.3	476.5	unvaried	unvaried	unvaried	unvaried	3324.9	20864.8

Water use in manufacturing		0.29%	0.40%	0.42%	0.35%	0.48%	0	0.63%	0.54%	0	0	0	0	1.30%	0.25%
	+85%	No notable impact on results													
	-85%	No notable impact on results													
Energy use in manufacturing	+30%	87400.0	471.0	18.4	21.6	20800.0	36.6	534.0	515.0	51000.0	2030.0	64.8	unvaried	3330.0	21800.0
		4.58%	3.90%	12.17%	3.62%	7.03%	0.56%	9.16%	8.66%	0.42%	1.32%	0.75%	0	1.46%	4.74%
	-30%	79788.0	435.6	14.4	20.0	18095.7	36.2	443.9	432.5	50595.6	1981.4	63.9	unvaried	3239.0	19863.1
		-4.53%	-3.90%	-12.37%	-3.82%	-6.89%	-0.50%	-9.25%	-8.75%	-0.38%	-1.11%	-0.72%	0	-1.31%	-4.57%
DISTRIBUTION															
Distribution - packaging	+69%	No notable impact on results													
	-69%	No notable impact on results													
Distribution by air	-100%	No notable impact on results													
	+100%	No notable impact on results													
Distribution by sea	+275%	No notable impact on results													
	-63%	No notable impact on results													
Distribution by truck	+200%	No notable impact on results													
	-50%	No notable impact on results													
USE & FINAL DISPOSAL															
Emissions from smoking	-5%	No notable impact on results													
	+154%	No notable impact on results													

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)

Impact category	Unit	Main study results	Uncertainty test
		(millions)	% Variance
Climate Change	kg CO ₂ eq	83572	-5
Terrestrial acidification	kg SO ₂ eq	453	-4
Freshwater eutrophication	kg P eq	16	-9
Marine eutrophication	kg N eq	21	-7
Human toxicity	kg 1,4-DB eq	19435	-6
Terrestrial ecotoxicity	kg 1,4-DB eq	36	-8
Freshwater ecotoxicity	kg 1,4-DB eq	489	-9
Marine ecotoxicity	kg 1,4-DB eq	474	-8
Agricultural land occupation	m ² a	50788	-1
Urban land occupation	m ² a	2004	-1
Natural land transformation	m ²	64	0
Water depletion	m ³	22203	0
Metal depletion	kg Fe eq	3282	-3
Fossil depletion	kg oil eq	20813	-5

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

Input parameters	Value used in the main study	Least damaging scenario description	Most damaging scenario description
Farming			
Water use	675 m3	No mechanised irrigation infrastructure assumed. Water of natural origin, moderate water stress.	100% mechanised irrigation infrastructure assumed in an area with high water stress
Transport of harvest	12.5 tkm	assuming 4% mechanisation (representing lower income countries)	n/a
Seedling production	2000 seedlings	10% lower use of greenhouses, unheated efficient greenhouses	Heated greenhouses only
Planting on farm	0.264 tkm	4% mechanised (as opposed to 33%)	100% mechanised (as opposed to 33%)
Land use	0.123ha a	16% lower yield than average and the subsequent higher land use	60% higher yield and the subsequent lower land use
Agrochemicals	0.033 tonne	10% of average use	30% higher use
Curing			
Coal fuelled curing	3.87 tonne	no coal use	all curing done using coal

Wood fuelled curing	31064 KWh	all curing done using wood	no wood curing
Transport to processing	100 tkm	50 tkm (min value in the range)	300 tkm (max value in the range)
Processing			
Transport to manufacturers (lorry + sea)	2900 tkm	2050 tkm (lowest distances in the ranges identified)	7300 tkm (highest distances in the ranges identified and applied to exported tobacco only)
Manufacturing			
Energy use	10076 MJ	Predominantly gas-based energy mix (at least 50%)	Predominantly coal-based energy mix (at least 50%)
Manufacturing plant service life	50 years	10 years longer service life	n/a
Distribution			
by air	1171 tkm	no air shipping	n/a
by sea	5337 tkm	no sea shipping	highest in the ranges, 20000tkm
by lorry	100 tkm	n/a	highest in the ranges, 300 tkm
Use & disposal			
Emissions from smoking	0.35 tonne	lowest values in ranges (1% lower values than used in the main study)	Highest in the ranges (154% higher than used in the main study)

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

Impact category	Unit	Primary study results	Least damaging scenario	Most damaging scenario
Climate Change	kg CO ₂ eq	13975	3322	26219
Terrestrial acidification	kg SO ₂ eq	76	25	179
Freshwater eutrophication	kg P eq	3	1	4
Marine eutrophication	kg N eq	3	2	5
Human toxicity	kg 1,4-DB eq	3250	1563	5485
Terrestrial ecotoxicity	kg 1,4-DB eq	6	3	8
Freshwater ecotoxicity	kg 1,4-DB eq	82	37	134
Marine ecotoxicity	kg 1,4-DB eq	79	37	130
Agricultural land occupation	m ² a	8493	12457	3976
Urban land occupation	m ² a	335	216	430
Natural land transformation	m ²	11	11	7
Water depletion	m ³	3713	3643	3901
Metal depletion	kg Fe eq	549	287	662
Fossil depletion	kg oil eq	3480	717	6481

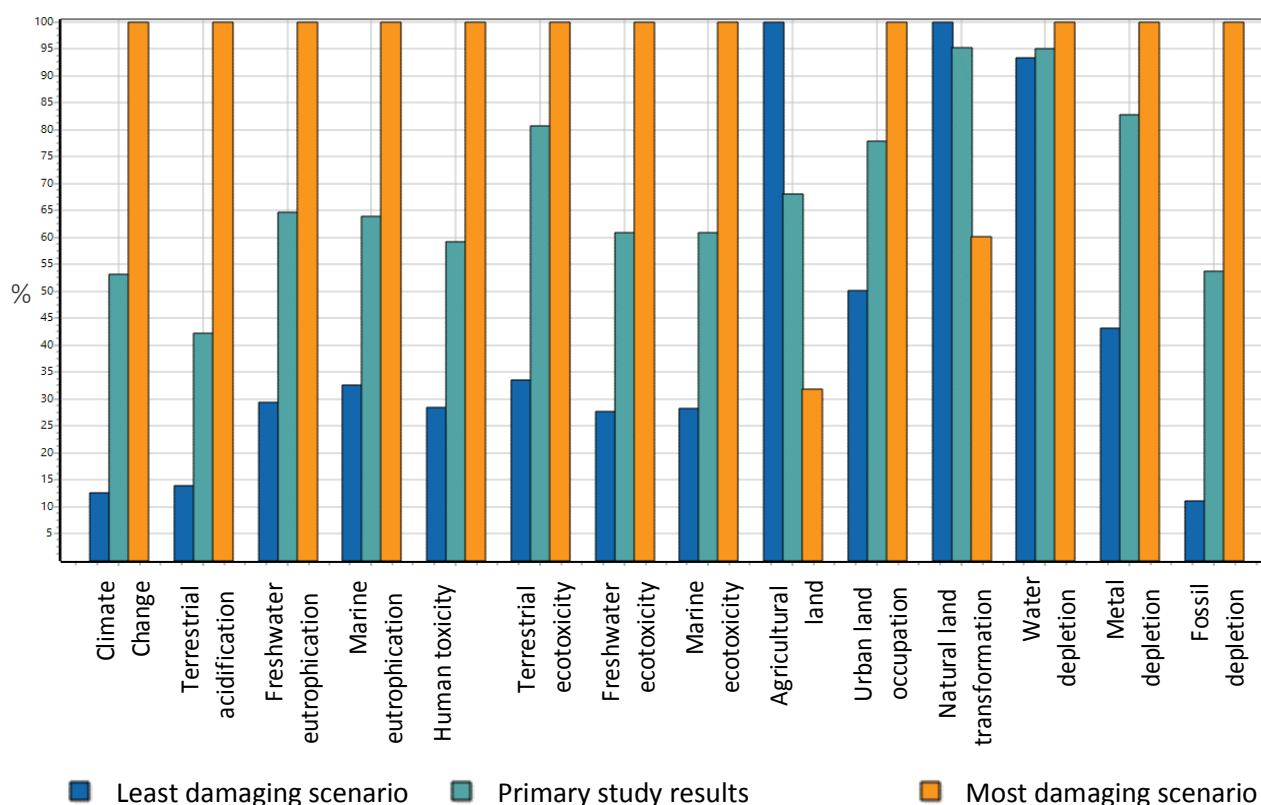


Figure S3. Comparison of the environmental impacts of a tonne of produced and consumed tobacco to the least and most environmentally damaging scenarios

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

Impact category	Unit	Green tobacco	Coffee, green bean, arabica	Potato	Rice	Tomato, fresh grade	Wheat grain
Climate Change	kg CO ₂ eq	643.5	6753.5	186.3	1842.4	265.6	806.1
Terrestrial acidification	kg SO ₂ eq	3.7	112.9	1.8	7.3	2.6	8.0
Freshwater eutrophication	kg P eq	0.2	2.4	0.3	0.5	0.1	0.6
Marine eutrophication	kg N eq	0.3	58.2	2.2	11.1	2.3	5.4
Human toxicity	kg 1,4-DB eq	219.3	2965.8	98.5	311.4	60.6	298.7
Terrestrial ecotoxicity	kg 1,4-DB eq	0.7	129.6	174.3	0.8	0.2	5.6
Freshwater ecotoxicity	kg 1,4-DB eq	5.7	141.7	12.6	8.4	1.9	6.0
Marine ecotoxicity	kg 1,4-DB eq	5.6	95.9	2.0	7.9	1.8	5.0
Agricultural land occupation	m ² a	1259.0	10856.7	270.3	1546.3	356.5	3008.4
Urban land occupation	m ² a	39.9	100.0	4.1	103.6	13.7	13.9
Natural land transformation	m ²	1.7	1.0	0.0	0.1	0.0	0.1
Water depletion	m ³	670.2	572.0	80.5	663.3	125.6	245.6
Metal depletion	kg Fe eq	56.8	619.5	18.4	71.4	17.9	50.6
Fossil depletion	kg oil eq	128.5	1270.6	40.9	212.7	47.4	133.9
Dataset name in SimaPro		[Study results]	Coffee, green bean {RoW} coffee green bean production, arabica Alloc Def, U ⁶⁴	Potato {RoW} production Alloc Def, U ⁶⁵	Rice {RoW} production Alloc Def, U ⁶⁶	Tomato, fresh grade {RoW} tomato production, fresh grade, open field Alloc Def, U ²³	Wheat grain {RoW} wheat production Alloc Def, U ⁶⁷
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).

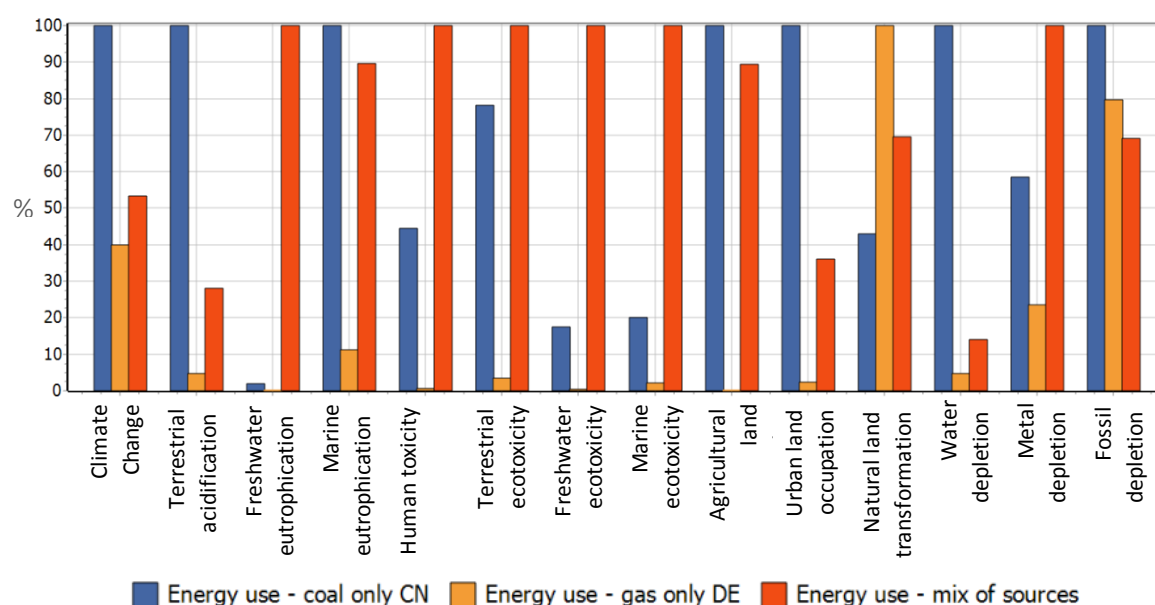


Figure S4. Comparison of environment impact contributions of manufacturing 1 million cigarettes at facilities with coal-based electricity supply in China, natural gas-based in Germany and a mix of energy sources (main study results).

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

Impact category	Unit	Cigarettes, smoker of 1 pack/day	Red meat, average consumer*	Sugar, average consumer*
Climate Change	kg CO ₂ eq	100	196	27
Terrestrial acidification	kg SO ₂ eq	0.55	1.3	0.20
Freshwater eutrophication	kg P eq	0.02	0.03	0.00
Marine eutrophication	kg N eq	0.02	1.05	0.08
Human toxicity	kg 1,4-DB eq	23	21	0.09
Terrestrial ecotoxicity	kg 1,4-DB eq	0.04	1.3	0.83
Freshwater ecotoxicity	kg 1,4-DB eq	0.56	0.89	0.21
Marine ecotoxicity	kg 1,4-DB eq	0.55	0.64	0.12
Agricultural land occupation	m ² a	64	179	26
Urban land occupation	m ² a	2.45	2.5	0.35
Natural land transformation	m ²	0.08	0.41	0.33
Water depletion	m ³	27	4.3	4.1
Metal depletion	kg Fe eq	3.97	4.3	0.86
Fossil depletion	kg oil eq	25	13	2.6
*See sources in the table below				

Table S11. The environmental impacts associated with the consumption of a tonne of tobacco, red meat and sugar

Impact category	Unit	Tobacco, (cradle-to-gate)	Red meat, average consumer (excl. preparation)	Sugar, average consumer (excl. packaging).
Climate Change	kg CO2 eq	13,765	13,600	1,110
Terrestrial acidification	kg SO2 eq	75	92	8
Freshwater eutrophication	kg P eq	3	2	0.2
Marine eutrophication	kg N eq	3	73	3
Human toxicity	kg 1,4-DB eq	3,152	1,484	4
Terrestrial ecotoxicity	kg 1,4-DB eq	5	89	34
Freshwater ecotoxicity	kg 1,4-DB eq	77	62	9
Marine ecotoxicity	kg 1,4-DB eq	75	45	5
Agricultural land occupation	m2a	8,771	12,463	1,050
Urban land occupation	m2a	335	174	14
Natural land transformation	m2	11	28	13
Water depletion	m3	3,713	296	167
Metal depletion	kg Fe eq	544	298	35
Fossil depletion	kg oil eq	3,436	908	106
Source:		Current study	⁶⁸	²⁵
LCIA method applied			ReCiPe Midpoint (H)	
Average annual consumption per person and source.		20 cigarette sticks per day, or 7.3 kg of tobacco per year (Average consumption is 5.8kg tobacco ⁶⁹)	14.4 kg/ capita ⁷⁰	24.3 kg/ capita ⁷¹
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 slaughtering 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).

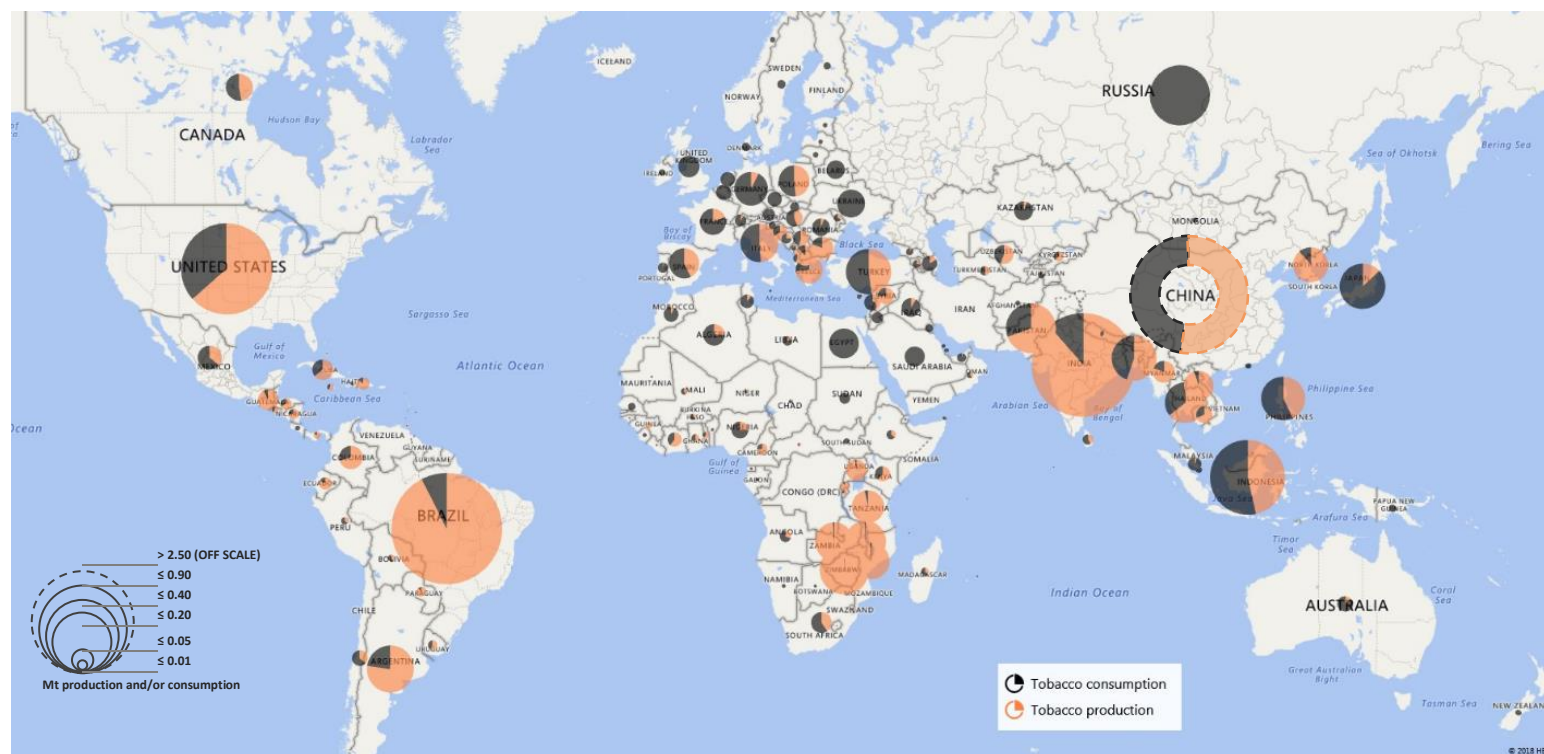


Figure S5. Annual tonnage of tobacco in cigarette production and consumption for countries with over 1,000 tonnes of tobacco flows in year 2014.^{21,72,73}

Table S12. Tobacco consumption and production by country, region, and income group for 2014

Country Name	Country Income group ^{21,72}	Special group (SIDS or LIC) ²¹	Region	Population ages 15-64, total ⁷³	Cigarette consumption per adult (15y.o.+), sticks ⁷⁴	Total tobacco production, tonnes ²¹	Total tobacco consumption, tonnes
	2014			2014	2014	2014	
China	UM		Asia	996046584	2249.79	2997050	2240896
Brazil	UM		Americas	141628142	491.78	862396	69650
India	LM	LIC and deficit food	Asia	846013020	110.93	720732	93848
United States of America	H		Americas	211378325	1082.87	397533	228895
Indonesia	LM		Asia	170545175	1322.3	196300	225512
Zimbabwe	L	LIC and deficit food	Africa	8575500	133.53	184003	1145
Pakistan	LM	LIC and food deficit	Asia	111907431	510.59	129878	57139
Argentina	H		Americas	27440753	1359.4	127085	37303
Malawi	L	LIC and deficit food	Africa	8879588	80.02	126348	711
Zambia	LM		Africa	8088061	164.55	112459	1331
Mozambique	L	LIC and deficit food	Africa	14007850	81.71	97075	1145
Bangladesh	LM	LIC & Deficit food	Asia	103669903	664.98	85000	68938
Democratic People's Republic of Korea	L	LIC and food deficit	Asia	17309412	609.67	80521	10553
Thailand	UM		Asia	48960244	895.24	79618	43831
Tanzania	L	LIC and food deficit	Africa	26958914	101.12	76910	2726
Turkey	UM		Asia	51215979	1580.91	74696	80968
Lao PDR	LM		Asia	4080625	835.51	63355	3409
Philippines	LM		Asia	63067209	1291.08	61418	81425
Italy	H		Europe	39035661	1442.87	53925	56323
Greece	H		Europe	7162507	2086.09	40940	14942
Poland	H		Europe	26612967	1396.06	34893	37153
Uganda	L	LIC	Africa	19149827	41.08	31770	787
Korea, Rep.	H		Asia	37193108	2072.57	30267	77085
Bulgaria	UM		Europe	4800771	1504.72	29996	7224
Spain	H		Europe	30946615	1264.74	29140	39139
Colombia	UM		Americas	32755499	359.39	28600	11772
Myanmar	LM		Asia	34507130	205.55	28600	7093
Guatemala	LM		Americas	9346487	189.5	27937	1771

Macedonia, FYR	UM		Europe	1470032	2732.23	27578	4016
Canada	H		Americas	24258899	1154.25	24841	28001
Yemen, Rep.	LM		Asia	14760999	388.23	23090	5731
Japan	H		Asia	78379970	1713	20000	134265
Cuba	UM	SIDS	Americas	8005323	1391.98	19800	11143
Iran, Islamic Rep.	UM		Asia	56075715	868.89	19039	48724
Uzbekistan	LM		Asia	20809283	572.84	15214	11920
Mexico	UM		Americas	81676066	329.26	15119	26893
Syrian Arab Republic	LM		Asia	11190794	458.63	14731	5132
Cambodia	L		Asia	9799868	644.99	13751	6321
South Africa	UM		Africa	35442305	537.03	12876	19034
Kenya	LM		Africa	25630264	256.57	10283	6576
France	H		Europe	41917948	992.81	9825	41617
Hungary	H		Europe	6747667	1758.63	9460	11867
Serbia	UM		Europe	4802321	1643.67	9341	7893
Croatia	H		Europe	2819112	1709.3	9164	4819
Dominican Republic	UM	SIDS	Americas	6580083	245.36	9163	1614
Ecuador	UM		Americas	10197616	190.98	9064	1948
Côte d'Ivoire	LM		Africa	12210626	477.01	9040	5825
Lebanon	UM		Asia	3799776	3023.15	9038	11487
Algeria	UM		Africa	25800849	1024.09	8707	26422
Germany	H		Europe	53327698	1480.04	6485	78927
Chile	H		Americas	12107339	929.55	6362	11254
Cameroon	LM	LIC and deficit food	Africa	11928208	184.17	5995	2197
Honduras	LM		Americas	5459894	489.01	5904	2670
Nicaragua	LM		Americas	3879978	487.84	5694	1893
Paraguay	UM		Americas	4165479	166	5616	691
Nigeria	LM		Africa	93635896	172.68	5307	16169
Rwanda	L	LIC	Africa	6372827	53.24	5106	339
Venezuela, RB	H		Americas	20106367	565.39	5047	11368
Kyrgyzstan	LM		Asia	3790251	682.83	4374	2588
Congo, Dem. Rep.	L	LIC	Africa	37297867	74.39	3908	2775
Sri Lanka	LM		Asia	13772602	322.44	3322	4441
Turkmenistan	UM		Asia	3592358	925	3209	3323

Uruguay	H		Americas	2190338	1135.16	3150	2486
Albania	UM		Europe	1996460	1177.42	3000	2351
Angola	UM		Africa	13596360	488.8	2969	6646
Azerbaijan	UM		Asia	6818152	2114.33	2858	14416
Panama	UM		Americas	2517900	224.27	2820	565
Ghana	LM		Africa	15534587	120.85	2490	1877
Guinea	L	LIC	Africa	6385656	14.96	2405	96
Nepal	L		Asia	17355470	83	2329	1441
Iraq	UM		Asia	19624851	1226.92	2306	24078
Ethiopia	L	LIC	Africa	52911554	75.8	2292	4011
Australia	H		Oceania	15598904	955.72	2064	14908
Togo	L		Africa	3976251	249.85	1893	993
Bosnia and Herzegovina	UM		Europe	2499199	2233.46	1812	5582
El Salvador	LM		Americas	3981742	280.35	1737	1116
Madagascar	L	LIC	Africa	13012354	205.82	1707	2678
Jamaica	UM		Americas	1913620	592.95	1609	1135
Kazakhstan	UM		Asia	11600105	2156.59	1603	25017
Mali	L		Africa	8392260	236.09	1548	1981
Tunisia	UM		Africa	7680759	1628.46	1444	12508
Romania	UM		Europe	13511662	1619.82	1405	21886
Moldova	LM		Europe	2643738	1114.11	1396	2945
Morocco	LM		Africa	22622915	671.12	1329	15183
Libya	UM		Africa	4166313	1332.77	1303	5553
Peru	UM		Americas	20178212	116.33	1300	2347
Burundi	L	LIC	Africa	5231333	97.73	1295	511
Armenia	LM		Asia	2017975	1545.13	1253	3118
Oman	H		Asia	2976014	576.55	1161	1716
Bolivia	LM		Americas	6418360	299.49	1133	1922
Switzerland	H		Europe	5521093	1633.86	997	9021
Burkina Faso	L		Africa	9111212	213.2	896	1943
Malaysia	UM		Asia	20820049	583.67	583	12152
Haiti	L		Americas	6477057	113.93	569	738
Tajikistan	LM		Asia	5148555	533.04	550	2744
Central African Republic	L	LIC	Africa	2381467	177.76	514	423

Niger	L	LIC	Africa	9046469	105.36	500	953
Congo, Rep.	LM		Africa	2642817	293.84	470	777
Fiji	UM	SIDS	Oceania	580843	617.69	455	359
Georgia	LM		Asia	2497565	1378.45	338	3443
United Arab Emirates	H		Asia	7739507	715.01	315	5534
Portugal	H		Europe	6805950	1112.8	228	7574
Trinidad and Tobago	H		Americas	948850	97.03	216	92
Samoa	LM	SIDS	Oceania	110145	54.21	212	6
Belgium	H		Europe	7292570	2353.28	183	17161
Chad	L		Africa	6739689	156.31	183	1053
Montenegro	UM		Europe	421507	4124.53	180	1739
Bhutan	LM		Asia	523784	155.09	174	81
Austria	H		Europe	5736127	1987.52	154	11401
Swaziland	LM		Africa	763530	427.08	151	326
Somalia	L		Africa	6816191	116.66	139	795
Cyprus	H		Asia	811526	1687.56	122	1369
Solomon Islands	LM		Oceania	326381	26.42	111	9
St. Vincent and the Grenadines	UM	SIDS	Americas	74348	338.29	103	25
Guyana	LM		Americas	494272	76.58	93	38
Costa Rica	UM		Americas	3268521	432.33	60	1413
Ukraine	LM		Europe	31422954	1853.66	50	58247
Sierra Leone	L		Africa	3853601	309.58	43	1193
Jordan	UM		Asia	5279573	1855.05	7	9794
Benin	L		Africa	5506483	122.1	5	672
Mauritius	UM	SIDS	Africa	891504	261.4	5	233
Israel	H		Asia	5026349	1346.21	4	6767
Slovak Republic	H		Europe	3853888	1617.59	3	6234
Puerto Rico	H		Americas	2359037	0	1	0
Russian Federation	H		Europe	101035287	2690.33	0	271818
Egypt	LM		Africa	56917392	1187.65	0	67598
United Kingdom	H		Europe	41744392	827.48	0	34543
Saudi Arabia	H		Asia	21682073	1395.14	0	30250
Belarus	UM		Europe	6628315	3830.62	0	25391
Czech Republic	H		Europe	7114159	2194.01	0	15609

Netherlands	H		Europe	11068561	1395.97	0	15451
Sudan	LM		Africa	20658679	427.75	0	8837
Sweden	H		Europe	6161002	831	0	5120
Denmark	H		Europe	3634215	1378.23	0	5009
Kuwait	H		Asia	2901402	1517.26	0	4402
Senegal	LM		Africa	7834611	503.9	0	3948
Papua New Guinea	LM		Oceania	4609145	826.13	0	3808
Finland	H		Europe	3492007	1083.41	0	3783
Slovenia	H		Europe	1397654	2637.03	0	3686
Ireland	H		Europe	3029345	953.66	0	2889
Singapore	H		Asia	3998397	651.63	0	2605
South Sudan	L		Africa	6243550	398.48	0	2488
Lithuania	H		Europe	1966503	1123.86	0	2210
New Zealand	H		Oceania	2958794	679.95	0	2012
Mongolia	UM		Asia	1982109	957.2	0	1897
Norway	H		Europe	3384343	556.04	0	1882
Hong Kong SAR, China	H		Asia	5376335	345.32	0	1857
Estonia	H		Europe	861757	1774.6	0	1529
Afghanistan	L		Asia	17117081	83.81	0	1435
Qatar	H		Asia	2024601	697.73	0	1413
Latvia	H		Europe	1316271	1041.18	0	1370
Namibia	UM		Africa	1405531	740.25	0	1040
Bahrain	H		Asia	1029523	968.68	0	997
Botswana	UM		Africa	1395455	448.81	0	626
Gabon	UM		Africa	1114175	559.05	0	623
Equatorial Guinea	H		Africa	671315	649	0	436
Malta	H		Europe	289355	1266.14	0	366
Mauritania	LM		Africa	2294015	134.92	0	310
Brunei Dar.	H		Asia	296452	1022.88	0	303
Djibouti	LM		Afro	578330	475.89	0	275
Liberia	L	LIC	Africa	2384228	104.36	0	249
Guinea-Bissau	L	LIC	Africa	954416	174.84	0	167
Gambia	L	LIC	Africa	992846	165.93	0	165
Comoros	L		Africa	431053	289.42	0	125

Iceland	H		Europe	217019	551.36	0	120
Lesotho	LM		Africa	1279825	87.69	0	112
Belize	UM		Americas	222102	400.1	0	89
Bahamas, The	H		Americas	271725	301.22	0	82
Barbados	H	SIDS	Americas	189305	333.09	0	63
Maldives	UM		Asia	289582	215.42	0	62
Seychelles	H	SIDS	Africa	64166	589.66	0	38
St. Lucia	UM		Americas	124178	231.55	0	29
Suriname	UM		Americas	362505	79.24	0	29
Antigua and Barbuda	H		Americas	67755	361.63	0	25
Grenada	UM		Americas	70485	224.33	0	16
Vanuatu	LM		Oceania	153019	76.2	0	12
Sao Tome and Principe	other		Africa	101780	110.65	0	11
Tonga	UM		Oceania	60517	81.07	0	5
Kiribati	LM		Oceania	67756	28.03	0	2
Andorra	H		Europe		0	0	0
Bermuda	H		Americas		0	0	0
Cabo Verde	LM		Africa	335552	0	0	0
Curacao	H		Americas	102951	0	0	0
Cayman Islands	H		Americas		0	0	0
Dominica	UM		Americas		0	0	0
Eritrea	L		Africa		113.58	0	0
Faroe Islands	H		Europe		0	0	0
Micronesia, Fed. Sts.	LM	SIDS	Oceania	63702	0	0	0
Gibraltar	other		Europe		0	0	0
Greenland	H		Americas		0	0	0
Guam	H		Oceania	105611	0	0	0
Isle of Man	H		Europe		0	0	0
St. Kitts and Nevis	H		Americas		0	0	0
Liechtenstein	H		Europe		0	0	0
Luxembourg	H		Europe	386181	0	0	0
Macao SAR, China	H		Asia	468857	0	0	0
St. Martin (French part)	H		Americas		0	0	0
Monaco	H		Europe		0	0	0

Marshall Islands	UM		Oceania		0	0	0
Northern Mariana Islands	H		Oceania		0	0	0
New Caledonia	H		Oceania	180344	0	0	0
Nauru	other		Oceania		0	0	0
Palau	UM		Oceania		0	0	0
French Polynesia	H		Oceania	189611	0	0	0
San Marino	H		Europe		0	0	0
Sint Maarten (Dutch part)	H		Americas		0	0	0
Turks and Caicos Islands	H		Americas		0	0	0
Tuvalu	UM		Oceania		0	0	0
British Virgin Islands	other		Americas		0	0	0
Virgin Islands (U.S.)	H		Americas	65532	0	0	0
Vietnam	LM		Asia	63747992	0	0	0
Kosovo	LM		Europe		0	0	0
Timor-Leste	LM		Asia	634478	0	0	0

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