

**Quantifying and monetising externalities in Kenya's green bean value chain:
implications for stakeholder and policy actions**

Supplementary Materials

Supplementary Table 1

Summary of empirical studies of negative externalities in food value chains.

Authors	Countries	Value chains	Externalities	Dimension of externalities	Methods	Findings
Ngowi, et al. [34]	Tanzania	Cabbage, onion and tomato	Health impacts from pesticide exposure	Health externality	Cost-of-illness model	Farmers were estimated to spend between 0.018 USD and 116 USD annually on health due to pesticide exposure
Ilari, et al. [25]	Italy	Frozen green bean	Climate change through GHG emissions and air pollution	Environmental externalities	Life cycle assessment (LCA)	One tonne of frozen green beans revealed 700 kg CO ₂ -eq GHG emissions, 0.19 kg C ₂ H ₄ -eq for photochemical oxidation, 3.5 kg SO ₂ -eq for acidification and 1.7 kg PO ₄ ³⁻ -eq (eutrophication)
Lloyd, et al. [38]	Canada	Cranberry and tomato production	Climate change through GHG emissions	Environmental externality	Non-steady-state static chamber	One hectare of cranberry and tomato production emitted approximately 2,700 kg CO ₂ -eq and 11,000 kg CO ₂ -eq, respectively
Esmailzadeh, et al. [37]	Taiwan	Onion production	Scarce blue water use and air pollution	Environmental externalities	LCA	Producing one tonne of onions required 136 m ³ of blue water for irrigation and emitted at least 0.00002 kg CFC11-eq (trichlorofluoromethane) as ozone layer-depleting emissions
Wainaina, et al. [40]	Ethiopia	Coffee	Water pollution	Environmental externality	Cost of treating wastewater	The cost of treating wastewater from coffee processing was estimated at 5,354 USD annually
			Health impacts from water pollution	Health externality	Cost-of-illness model	The cost of treating diseases caused by wastewater from coffee processing was estimated at 54.19 USD per person per dosage in 2017
Macharia [28]	Kenya	Vegetable sub-sector (cabbage, kale and potato)	Water pollution Health impacts from pesticide exposure	Environmental Externality Health externality	Deposit-refund system (DRS) Cost-of-illness model	Estimated substantial annual average costs related to human health (0.65 million USD), livestock loss (2.46 million USD) and pollution control through DRS for empty pesticide containers (0.06 million USD). The externalities amounted to 3.17 million USD per year

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Bergman, et al. [41]	Kenya	Tea	Environmental externalities (Air, soil and water pollution) Social externalities (child labour, gender inequality and low income) GHG emissions	Environmental and social externalities Environmental externalities	True Price methodology LCA	External costs per tonne of green leaf tea totalled 1,200 USD in 2015–770 USD from cultivation, 50 USD from transportation, 330 USD from processing and 50 USD from packaging Given a retail price of 380 USD per tonne of green leaf tea in Kenya, the true price of one tonne was 1,590 USD, accounting for the environmental and social externalities One tonne of green beans at the farm gate had a global warming potential of 89.3 to 565 kg CO ₂ -eq and 8,170 to 8,890 kg CO ₂ -eq at market gate
Kleih, et al. [3]	Kenya	Green bean	Air pollution and pesticide exposure effects on health	Health externalities	Disability-adjusted life years (DALYs)	Health externalities at free-on-board ranged from 0.0017 to 0.0031 DALYs and 0.015 to 0.016 DALYs at market-gate
Basset-Mens, et al. [19]	Kenya	Green bean	Climate change through GHG emissions	Environmental externality	LCA	It was estimated that transporting one tonne of fresh green beans from Kenya to the United Kingdom emitted 8,000 kg CO ₂ -eq
Impact Institute [42]	Kenya	Rose	Gender discrimination, underpayment, social security and health and safety	Social externalities	Social impact scan	The social costs of producing one rose stem summed to 0.039 USD in 2020—gender discrimination (0.021 USD), underpayment (0.010 USD), lack of social security (0.007 USD) and employee health and safety (0.001 USD)
Impact Institute [43]	Kenya	Coffee	Climate change, fossil fuel depletion, land use, water use, soil pollution and water pollution	Environmental externalities	True Price methodology	Environmental costs per tonne of coffee totalled 1,578.14 USD in 2022—air pollution (205.66 USD), GHG emissions (64.94 USD), fossil fuel depletion (21.65 USD), land use (508.73 USD), water use (10.82 USD), soil pollution (10.82 USD) and water pollution (768.48 USD)

Source: Authors' compilation based on references indicated in the table.

Supplementary Table 2

Environmental characterisation factors used in the analysis.

Externalities	Footprint indicators in standard units	Characterisation factors	References
Air pollution	Particulate matter formation (kg PM _{2.5} -eq)	1 kg PM ₁₀ -eq = 0.28011 kg PM _{2.5} -eq	Arendt, et al. [68]
	Photochemical oxidant formation from NO _x emissions (kg NO _x -eq)	1 kg NMVOC = 0.29 kg NO _x -eq	Huijbregts, et al. [36]
Water pollution	Freshwater eutrophication (kg P-eq)	1 kg PO ₄ ³⁻ -eq = 0.33 kg P-eq to freshwater	Huijbregts, et al. [36]
	Marine eutrophication (kg N-eq)	1 kg NO ₃ -eq = 0.33 kg N-eq to marine water	Huijbregts, et al. [36]
Soil pollution	Freshwater ecotoxicity (kg 1.4-DB-eq)	1 kg CTU-eq = 0.001017 kg 1.4-DB-eq emitted to freshwater	Arendt, et al. [68]
Land occupation	Land occupation (MSA*ha*yr)	1 ha of annual crop = 0.0000888 MSA	Huijbregts, et al. [36]
Land transformation	Land transformation (MSA*ha)	1 ha = 0.0000888 MSA	Huijbregts, et al. [36]

Source: Authors' compilation based on references indicated in the table.

Supplementary Table 3

Monetised environmental footprints in US dollars for all fresh green beans across the value chain in Kenya in 2022.

Footprint indicator	Production (a)	Domestic packhouses (b)	Domestic trade and port (c)	Domestic consumption (d)	Food loss and waste (e)	Total external costs per indicator (a+b+c+d+e)	
						Mean external costs	95% confidence intervals
GHG emissions	5,616,485.81	1,339,848.35	707,837.01	34,615.89	337,964.61	8,036,751.67	7,490,748.55–8,582,754.79
Terrestrial ecotoxicity	42.56	16.87	10.46	0.54		70.42	52.24–88.61
Marine ecotoxicity	2,787.28	1,365.76	580.42	29.69		4,763.16	2,287.63–7,238.69
Particulate matter formation	3,176,594.51	1,556,527.02	551,246.71	84,602.71		5,368,970.96	4,402,086.23–6,335,855.70
Photochemical oxidant formation (NMVOC emissions)	162,912.13	47,373.96	19,573.83	4,506.15		234,366.06	216,948.85–251,783.27
Photochemical oxidant formation (NOx emissions)	167,758.07	48,783.13	20,156.07	4,640.19		241,337.46	223,402.16–259,272.76
Acidification	1,504,190.02	556,971.17	340,819.29	20,922.93		2,422,903.40	1,789,482.93–3,056,323.87
Ozone layer-depleting emissions	224.61	15.13	6.39	1.47		247.61	218.60–276.61
Ammonia emissions	1,979,882.46					1,979,882.46	1,898,400.82–2,127,500.32
Freshwater eutrophication	5,973,166.67	1,040,163.00	560,571.43	34,413.53		7,608,314.62	5,660,634.66–9,555,994.59
Marine eutrophication	6,187,313.65	500,929.96	142,559.84	19,709.40		6,850,512.85	4,635,354.90–9,065,670.80
Freshwater ecotoxicity	127,164.89					127,164.89	91,270.20–163,059.59
Land occupation by green beans	2,752.76					2,752.76	2,752.76–2,752.76
Land transformation	11.79					11.79	10.93–12.65
Scarce blue water use	52,689,544.35	1,027,276.90		50,518.39		53,767,339.63	52,619,571.28–54,915,107.98
Soil organic carbon loss	224,084.11					224,084.11	126,343.70–321,824.52
Total average external costs across the value chain stages						86,869,473.86	

Source: Authors' calculations.

Supplementary Table 4

In-country and air-freighting external costs (US dollars) of all green beans from Kenya in 2022.

Description of GHG emissions	Mean external costs	95% confidence intervals
Total in-country environmental costs	86,869,473.86	79,159,566.44–94,645,517.51
Total GHG emission costs of air-freighted green beans	39,270,152.42	36,396,508.98–42,143,795.86
Total environmental costs (in-country plus air-freighting costs)	126,139,626.28	115,556,075.42–136,789,313.37
Total health costs	966,220.80	575,645.97–1,356,795.63
Total social costs	36,197,052.34	36,197,052.34–36,197,052.34
Total external costs	163,302,899.42	152,328,773.73–174,343,161.34

Source: Authors' calculations.