

Supplementary Materials: Environmental and Energy Performance of Ethanol Production from the Integration of Sugarcane, Corn, and Grain Sorghum in a Multipurpose Plant

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Table S1. Sugarcane production inventory (1.0 m³ hydrate ethanol).

	Unit	Quantity
Products		
Sugarcane, at farm	t	1.33 × 10 ¹
Inputs		
Natural Resources		
Carbon dioxide, in air	kg	6.13 × 10 ³
Transformation, from permanent crop, fruit	m ²	1.13 × 10 ²
Transformation, from forest	m ²	1.10 × 10 ³
Transformation, to arable	m ²	1.21 × 10 ³
Occupation, arable	m ² ·a	1.48 × 10 ³
Trinexapac-ethy (growth regulator)	kg	2.59 × 10 ⁻³
Sulfometuron metil (growth regulator)	kg	1.95 × 10 ⁻⁴
Etefon (growth regulator)	kg	9.68 × 10 ⁻³
Cobalt (foliar fertilizer)	kg	4.14 × 10 ⁻⁵
Molybdenum (foliar fertilizer)	kg	1.66 × 10 ⁻⁴
Anthropogenic Material Resources		
Urea, as N	kg	5.76 × 10 ⁰
Triple superphosphate, as P ₂ O ₅	kg	5.55 × 10 ⁰
Potassium chloride, as K ₂ O	kg	7.87 × 10 ⁰
Limestone, milled, loose, at plant	kg	8.52 × 10 ¹
Gypsum, mineral, at mine	kg	1.73 × 10 ¹
Glyphosate, at regional storehouse	kg	5.20 × 10 ⁻²
Herbicides, at regional storehouse	kg	7.86 × 10 ⁻²
2,4-D, at regional storehouse	kg	3.66 × 10 ⁻²
Propylene glycol, liquid, at plant	kg	3.28 × 10 ⁻⁴
Pyridine-compounds, at regional storehouse	kg	7.41 × 10 ⁻³
Fungicides, at regional storehouse	kg	4.62 × 10 ⁻³
Triazine-compounds, at regional storehouse	kg	7.41 × 10 ⁻³
Cyclic N-compounds, at regional storehouse	kg	2.96 × 10 ⁻²
Diuron, at regional storehouse	kg	8.56 × 10 ⁻³
Triazine-compounds, at regional storehouse	kg	8.56 × 10 ⁻³
Insecticides, at regional storehouse	kg	1.17 × 10 ⁻²
Diesel, at refinery	L	2.32 × 10 ⁰
Hydrate ethanol (95% ww), to storage	kg	1.61 × 10 ⁻¹
vinasse + ashes, at transportation	kg	2.41 × 10 ⁴
Filter cake, at transportation	kg	1.37 × 10 ³
Transport, lorry 7.5–16t, EURO3	tkm	1.88 × 10 ¹
Outputs		
Air emissions		
Carbon dioxide, fossil	kg	1.65 × 10 ¹
Carbon dioxide, biogenic	kg	2.43 × 10 ⁻¹
Carbon dioxide, land transformation	kg	1.02 × 10 ³
Dinitrogen monoxide	kg	3.57 × 10 ⁻¹
Nitrogen oxides	kg	3.64 × 10 ⁰
Ammonia	kg	4.13 × 10 ⁰
NMVOOC, unspecified origin	kg	1.99 × 10 ⁻²

Carbon monoxide, fossil	kg	1.26×10^{-2}
Carbon monoxide, biogenic	kg	1.28×10^{-2}
Sulfur dioxide	kg	2.35×10^{-3}
Sulfur oxides	kg	5.58×10^{-1}
Nitrogen dioxide	kg	7.18×10^{-3}
Methane, fossil	kg	3.00×10^{-4}
Methane, biogenic	kg	3.77×10^0
Benzene	kg	1.70×10^{-5}
Cadmium	kg	2.32×10^{-8}
Chromium	kg	1.16×10^{-7}
Copper	kg	3.96×10^{-6}
Nickel	kg	1.63×10^{-7}
Zinc	kg	2.32×10^{-6}
Benzopyrene, methyl-	kg	6.98×10^{-8}
Selenium	kg	2.32×10^{-8}
Benz[a]anthracene,12-methyl-	kg	1.86×10^{-7}
Benzo(a)fluoranthene	kg	1.16×10^{-7}
Cresol	kg	4.66×10^{-7}
Dibenz(a,h)anthracene	kg	2.32×10^{-8}
Fluoranthene	kg	1.05×10^{-6}
Phenanthrene	kg	5.81×10^{-6}
VOC, volatile organic compounds	kg	9.76×10^0
Particulates, <2.5 μm	kg	5.44×10^0
Particulates, <10 μm	kg	1.09×10^1
Water emissions		
Phosphorus	kg	4.35×10^{-3}
Cadmium	kg	1.71×10^{-10}
Nickel	kg	1.98×10^{-10}
Chromium	kg	1.40×10^{-9}
Emissions to Soil		
Cadmium	kg	1.71×10^{-6}
Nickel	kg	1.98×10^{-6}
Chromium	kg	1.40×10^{-5}
Glyphosate	kg	2.94×10^{-4}
Imazapic	kg	2.20×10^{-5}
2,4-D	kg	2.07×10^{-4}
Florasulam	kg	1.04×10^{-6}
Propylene glycol	kg	1.85×10^{-6}
Fipronil	kg	4.19×10^{-5}
Pyraclostrobin (prop)	kg	2.61×10^{-5}
Sulfentrazone	kg	1.91×10^{-4}
Hexazinone	kg	4.19×10^{-5}
Clomazone	kg	1.67×10^{-4}
Triazoxid	kg	1.91×10^{-4}
Isoxaben	kg	1.76×10^{-5}
Diuron	kg	4.84×10^{-5}
Triazine, 1,3,5-	kg	4.84×10^{-5}
Mesotrione	kg	4.84×10^{-5}
Pesticides, unspecified	kg	6.17×10^{-5}
Triflumuron	kg	4.22×10^{-6}
Trinexapac-ethyl	kg	1.46×10^{-5}
Sulfometuron methyl	kg	1.10×10^{-6}
Ethephon	kg	5.47×10^{-5}

Table S2. Sugarcane ethanol production inventory (1.0 m³ hydrate ethanol).

	Unit	Quantity
Products		
Hydrate ethanol (95%ww)	m ³	1.00 × 10 ⁰
Vinasse + ashes, at transportation	t	2.41 × 10 ¹
Filter cake, at transportation	t	5.63 × 10 ⁻¹
Bagasse at milling, surplus	t	5.63 × 10 ⁻¹
Inputs		
Natural Resources		
Water, well, in ground	t	2.26 × 10 ¹
Anthropogenic Material Resources		
Sugarcane, at farm	t	1.33 × 10 ¹
Transport, lorry 16–32t, EURO4	tkm	8.48 × 10 ⁻¹
Water transportation, at pipeline	tkm	2.26 × 10 ⁰
Outputs		
Air emissions		
Water		6.00 × 10 ⁰
Ethanol	kg	1.73 × 10 ⁰
Carbon dioxide, biogenic	t	3.80 × 10 ⁰
Carbon monoxide, biogenic	t	1.00 × 10 ⁻¹
Nitrogen oxides	kg	2.51 × 10 ⁰
Dinitrogen monoxide	kg	1.00 × 10 ⁻¹
Methane, biogenic	kg	7.53 × 10 ⁻¹
NMVOOC, unspecified origin	kg	1.25 × 10 ⁰
Particulates, <10 µm (stationary)	kg	2.27 × 10 ¹

Table S3. Corn production inventory (1.0 m³ hydrate ethanol).

	Unit	Quantity
Products		
Corn, at farm	t	2.77 × 10 ⁰
Inputs		
Natural Resources		
Carbon dioxide, in air	kg	3.51 × 10 ³
Transformation, from permanent crop	m ²	1.83 × 10 ¹
Transformation, from forest	m ²	1.76 × 10 ³
Transformation, to arable	m ²	1.78 × 10 ³
Occupation, arable, irrigated	m ² -a	1.83 × 10 ³
Anthropogenic Material Resources		
Maize seed organic, at farm	kg	4.62 × 10 ⁰
Urea, as N, at regional storehouse	kg	3.46 × 10 ¹
Triple superphosphate, as P ₂ O ₅ , at regional storehouse	kg	1.77 × 10 ¹
Potassium chloride, as K ₂ O, at regional storehouse	kg	1.77 × 10 ¹
Limestone, milled, loose, at plant	kg	7.39 × 10 ¹
Glyphosate, at regional storehouse	kg	1.08 × 10 ⁰
Atrazine, at regional storehouse	kg	5.92 × 10 ⁻¹
Insecticides, at regional storehouse	kg	2.28 × 10 ⁻²
Pyrethroid-compounds, at regional storehouse	kg	6.78 × 10 ⁻³
Organophosphorus-compounds, at regional storehouse	kg	5.59 × 10 ⁻²
Cyclic N-compounds, at regional storehouse	kg	1.38 × 10 ⁻²
Fungicides, at regional storehouse	kg	3.68 × 10 ⁻²
Diesel, at refinery	L	1.80 × 10 ¹
Electricity, diesel, at power plant	kWh	2.45 × 10 ⁰
Vinasse + ashes, at transportation	kg	7.66 × 10 ³
Transport, lorry 7.5–16t, EURO3	tkm	1.37 × 10 ¹
Outputs		
Air emissions		

Carbon dioxide, fossil	kg	1.11×10^2
Carbon dioxide, land transformation	kg	2.27×10^3
Dinitrogen monoxide	kg	1.15×10^0
Nitrogen oxides	kg	1.01×10^0
Ammonia	kg	1.25×10^1
NM VOC, unspecified origin	kg	5.42×10^{-2}
Carbon monoxide, fossil	kg	9.74×10^{-2}
Sulfur dioxide	kg	1.82×10^{-2}
Methane, fossil	kg	2.33×10^{-3}
Benzene	kg	1.32×10^{-4}
Cadmium	kg	1.80×10^{-7}
Chromium	kg	9.02×10^{-7}
Copper	kg	3.07×10^{-5}
Nickel	kg	1.26×10^{-6}
Zinc	kg	1.80×10^{-5}
Benzopyrene, methyl-	kg	5.42×10^{-7}
Selenium	kg	1.82×10^{-7}
Benz[a]anthracene,12-methyl-	kg	1.45×10^{-6}
Benzo(a)fluoranthene	kg	9.02×10^{-7}
Cresol	kg	3.60×10^{-6}
Dibenz(a,h)anthracene	kg	1.80×10^{-7}
Fluoranthene	kg	8.11×10^{-6}
Phenanthrene	kg	4.51×10^{-5}
Water emissions		
Phosphorus	kg	6.78×10^{-2}
Cadmium	kg	8.94×10^{-8}
Chromium	kg	4.59×10^{-7}
Emissions to Soil		
Cadmium	kg	8.94×10^{-4}
Chromium	kg	4.59×10^{-3}
Glyphosate	kg	1.08×10^0
Atrazine	kg	5.92×10^{-1}
Triasulfuron	kg	8.63×10^{-3}
Lambda-cyhalothrin	kg	6.78×10^{-3}
Lufenuron	kg	5.31×10^{-3}
Propiconazole	kg	5.59×10^{-2}
Diflubenzuron	kg	8.85×10^{-3}
Epoxiconazole	kg	1.38×10^{-2}
Pyraclostrobin (prop)	kg	3.68×10^{-2}

Table S4. Corn ethanol production inventory (1.0 m³ hydrate ethanol).

	Unit	Quantity
Products		
Hydrate ethanol (95% ww)	m ³	1.00×10^0
Wet Solid Soluble (SS)	t	9.78×10^{-1}
Vinasse + ashes, at transportation	t	6.37×10^0
Inputs		
Natural Resources		
Water, well, in ground	t	1.43×10^{-1}
Anthropogenic Material Resources		
corn, at farm	t	2.77×10^0
yeast, to fermentation	kg	2.95×10^{-1}
Wood chips, from industry, hardwood, burned in furnace 300 kW	t	1.65×10^0
Transport, lorry 16–32t, EURO4	tkm	2.93×10^0
water transportation, at pipeline	tkm	1.43×10^0
Outputs		

Air emissions		
Water	t	6.77×10^{-0}
Ethanol	kg	1.70×10^{-0}
Carbon dioxide, biogenic	t	3.34×10^{-0}
Carbon monoxide, biogenic	t	8.84×10^{-2}
Nitrogen oxides	kg	2.21×10^{-0}
Dinitrogen monoxide	kg	8.84×10^{-2}
Methane, biogenic	kg	6.63×10^{-1}
NM VOC, unspecified origin	kg	1.10×10^{-0}
Particulates, <10 μm (stationary)	kg	7.27×10^{-0}

Table S5. Grain sorghum production inventory (1.0 m³ hydrate ethanol).

	Unit	Quantity
Products		
Grain sorghum, at farm	t	2.82×10^{-0}
Inputs		
Natural Resources		
Carbon dioxide, in air	kg	3.92×10^{-3}
Transformation, from permanent crop	m ²	4.42×10^{-2}
Transformation, from forest	m ²	2.91×10^{-3}
Transformation, to arable	m ²	3.39×10^{-3}
Occupation, arable, irrigated	m ² -a	3.38×10^{-3}
Anthropogenic Material Resources		
Urea, as N, at regional storehouse	kg	1.40×10^{-1}
Limestone, milled, loose, at plant	kg	1.56×10^{-2}
Maize seed organic, at farm	kg	5.90×10^{-0}
Glyphosate, at regional storehouse	kg	1.04×10^{-0}
Atrazine, at regional storehouse	kg	9.88×10^{-1}
Insecticides, at regional storehouse	kg	2.01×10^{-2}
Pyrethroid-compounds, at regional storehouse	kg	1.58×10^{-2}
Diesel, at refinery	L	2.25×10^{-1}
Electricity, diesel, at power plant	kWh	3.33×10^{-0}
Transport, lorry 7.5–16t, EURO3	tkm	6.22×10^{-0}
Vinasse + ashes, at transportation	kg	7.96×10^{-3}
Outputs		
Air emissions		
Carbon dioxide, fossil	kg	9.28×10^{-1}
Carbon dioxide, land transformation	kg	4.14×10^{-3}
Dinitrogen monoxide	kg	9.68×10^{-1}
Nitrogen oxides	kg	1.16×10^{-0}
Ammonia	kg	3.33×10^{-0}
NM VOC, unspecified origin	kg	6.75×10^{-2}
Carbon monoxide, fossil	kg	1.22×10^{-1}
Sulfur dioxide	kg	2.28×10^{-2}
Methane, fossil	kg	2.91×10^{-3}
Benzene	kg	1.64×10^{-4}
Cadmium	kg	2.25×10^{-7}
Chromium	kg	1.13×10^{-6}
Copper	kg	3.84×10^{-5}
Nickel	kg	1.58×10^{-6}
Zinc	kg	2.25×10^{-5}
Benzopyrene, methyl-	kg	6.75×10^{-7}
Selenium	kg	2.25×10^{-7}
Benz[a]anthracene,12-methyl-	kg	1.80×10^{-6}
Benzo(a)fluoranthene	kg	1.13×10^{-6}
Cresol	kg	4.52×10^{-6}
Dibenz(a,h)anthracene	kg	2.25×10^{-7}

Fluoranthene	kg	1.01×10^{-5}
Phenanthrene	kg	5.62×10^{-5}
Water emissions		
Cadmium	kg	4.66×10^{-11}
Copper	kg	7.57×10^{-8}
Zinc	kg	8.67×10^{-8}
Lead	kg	1.01×10^{-9}
Chromium	kg	1.48×10^{-7}
Emissions to Soil		
Cadmium	kg	4.66×10^{-7}
Copper	kg	7.57×10^{-4}
Zinc	kg	8.67×10^{-4}
Lead	kg	1.01×10^{-5}
Chromium	kg	1.48×10^{-3}
Glyphosate	kg	1.04×10^{-0}
Atrazine	kg	9.88×10^{-1}
Thiamethoxam	kg	2.01×10^{-2}
Lambda-cyhalothrin	kg	1.58×10^{-2}

Table S6. Grain sorghum ethanol production inventory (1.0 m³ hydrate ethanol).

	Unit	Quantity
Products		
Hydrate ethanol from sorghum (95% ww)	m ³	1.00×10^{-0}
Wet Solid Soluble (SS)	t	1.02×10^{-0}
Vinasse + ashes, at transportation	t	6.64×10^{-0}
Inputs		
Natural Resources		
Water, well, in ground	m ³	1.46×10^{-1}
Anthropogenic Material Resources		
Grain sorghum, at farm	t	2.82×10^{-0}
yeast, to fermentation	kg	3.01×10^{-1}
Wood chips, from industry, hardwood, burned in furnace 300 kW	t	1.69×10^{-0}
Transport, lorry 16–32t, EURO4	tkm	3.13×10^{-0}
water transportation, at pipeline	tkm	1.46×10^{-0}
Outputs		
Air emissions		
Water	t	7.20×10^{-0}
Ethanol	kg	1.70×10^{-0}
Carbon dioxide, biogenic	t	2.53×10^{-0}
Carbon monoxide, biogenic	t	9.02×10^{-2}
Nitrogen oxides	kg	2.26×10^{-0}
Dinitrogen monoxide	kg	9.02×10^{-2}
Methane, biogenic	kg	6.77×10^{-1}
NM VOC, unspecified origin	kg	1.13×10^{-0}
Particulates, <10 um (stationary)	kg	7.42×10^{-0}