Supplementary Materials: Bioenergy from Low-Intensity Agricultural Systems: An Energy Efficiency Analysis

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Table S1. Conversion factors for estimating energy inputs and energy outputs of baseline options.

Energy Inputs	
Fossil fuel supply chain [1,2]	
Calorific energy per litre of diesel (MJ·L^{-1})	32.0–35.0
Calorific energy per litre of gasoline (MJ·L^{-1})	35.7–45.1
Energy for fractional distillation of fossil fuel into diesel, gasoline etc. (MJ·L^{-1})	2.3
Total energy cost of diesel used (MJ·L^{-1})	34.3–37.3
Total energy cost of gasoline used (MJ·L^{-1})	38–47.4
Direct energy for farm operations [3]	
Energy for ploughing (MJ·ha^{-1}·a^{-1})	319.2–1550.0
Energy for harrowing (MJ·ha^{-1}·a^{-1})	72.2–1464.7
Energy for ridging (MJ·ha^{-1}·a^{-1})	34.2–843.7
Energy for sowing (MJ·ha^{-1}·a^{-1})	34.2–1019.1
Energy for fertilizer application (MJ·ha^{-1}·a^{-1})	178.6–488.2
Energy for pesticide spraying (MJ·ha^{-1}·a^{-1})	72.2–578.3
Energy for liming (MJ·ha^{-1}·a^{-1})	178.6–488.2
Energy for combined harvesting (MJ·ha^{-1}·a^{-1})	247.0–976.4
Total direct energy for farm operations (MJ·ha^{-1}·a^{-1})	1136.2–7408.6
Indirect energy for farm operations [1,4]	
Energy for fertilizer production (N-Nitrogen) (MJ·kg^{-1})	43.0–65.3
Energy for fertilizer production (P-Phosphorus) (MJ·kg^{-1})	4.8–32.0
Energy for fertilizer production (K-Potassium) (MJ·kg^{-1})	5.3–13.8
Energy for lime production (MJ·kg^{-1}·a^{-1})	0.6–1.8
Energy for pesticide production (herbicides) (MJ·kg^{-1})	237.3–422.0
Energy for pesticide production (insecticides + fungicides) (MJ·kg^{-1})	237.3–422.0
Quantity of lime (kg·ha^{-1}·a^{-1})	270–699
Quantity of herbicides applied (kg·ha^{-1})	2.1–4.7
Quantity of insecticides applied (kg·ha^{-1})	0.2–1.1
Quantity of fungicides applied (kg·ha^{-1})	0.2–1.1
Energy for lime production (270 − 699 kg·ha^{-1}·a^{-1} × 0.6 − 1.8 MJ·kg^{-1}·a^{-1}) (MJ·ha^{-1}·a^{-1})	162.0–1258.2
Energy for pesticide production (herbicides-2.1 − 4.7 kg·ha^{-1} × 237.3 − 422.0 MJ·kg^{-1}) = 498.3 − 1983.4 MJ·ha^{-1}·a^{-1}	498.3–1983.4
Energy for pesticide production (insecticides + fungicides) × 237.3 − 422.0 MJ·kg^{-1} × 2) = 47.5 − 464.2 × 2 MJ·ha^{-1}·a^{-1}	95.0–928.4
Total energy for transportation of inputs and co-products (MJ·kg^{-1}·km^{-1}·a^{-1})	0.0048–0.0058
Energy for human labour (MJ·ha^{-1}·a^{-1}) (for eight farm operations)	1.5–10.3
Energy for plant operations (ethanol) [5,6]	
Energy for wet milling operations (MJ·t^{-1})	3795.2–4886.0
Energy for human labour (MJ·a^{-1})	365.0–803.0
Total energy for plant operation (ethanol) (MJ·ha^{-1}·a^{-1})	4174.7–61075.0
Energy for plant operations (biogas) [7]	
Energy for wet oxidation (MJ·t^{-1})	5.0
Energy for biogas plant operation (MJ·t^{-1})	193.0
Energy for human labour (MJ·a^{-1})	365.0–803.0
Total energy for plant operation (biogas) (MJ·ha^{-1}·a^{-1})	217.8–2475.0
Energy outputs	
Energy from maize grain ethanol [8–10]	
Volume of ethanol per ton of maize (L·t^{-1})	378.0–435.0
Calorific energy per litre of ethanol (MJ·L^{-1})	21.1–23.4
Total energy from maize ethanol (MJ·t^{-1})	7975.8–10179.0
Energy from maize grain biogas [4]	
Volatile solids (%)	93.0–95.0
Volume of biogas per ton of maize (m^3·t^{-1})	560.0
Calorific energy per m^3 of biogas (MJ·m^{-3})	21.0–25.0
Total energy from maize biogas (MJ·t^{-1})	10936.8–13300.0

Table S2. The individual differences in values of NEG and EROEI (for maize ethanol and maize biogas production systems), as a result of the adoption of different agronomic factor options across different agro-climatic zones.

Agro-Climatic Zones	**Tropics**				**Sub-Tropics**				**Temperate**			
Energy efficiency indicator	**NEG (in GJ·ha⁻¹)**		**EROEI**		**NEG (in GJ·ha⁻¹)**		**EROEI**		**NEG (in GJ·ha⁻¹)**		**EROEI**	
Biofuel	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**
Agronomic factor category: Farm power options												
Baseline: Four wheel drive > 50 HP tractor (Initial value)	2.4–42.2	9.6–138.5	1.3–1-7	4.4–9.5	5.2–28.4	16.9–123.1	1.3–1.8	4.0–11.7	4.6–34.6	16.4–127.8	1.3–1.7	4.1–9.6
Two wheel drive 20–49 HP tractor	↓ 3.2–5.7 ↓	↓ 3.2–5.7 ↓	↓ 0.3–0.6 ↓	↓ 3.0–3.7 ↓	↓ 3.2–5.7 ↓	↓ 3.2–5.7 ↓	↓ 0.2–0.4 ↓	↓ 1.7–5.7 ↓	↓ 3.2–5.7 ↓	↓ 3.2–5.7 ↓	↓ 0.3–0.4 ↓	↓ 1.9–4.3 ↓
Single axle riding type 10–20 HP tractor	↓ 0.4–5.0 ↑	↓ 0.4–5.0 ↑	0.0–0.1 ↓	↓ 0.2–0.5 ↓	↓ 0.4–5.0 ↑	↓ 0.4–5.0 ↑	0.0–0.1↑	↑ 0.6–0.7 ↓	↓ 0.4–5.0 ↑	↓ 0.4–5.0 ↑	0.0–0.1 ↑	↓ 0.5–1.0 ↑
Ordinary single axle < 9 HP tractor	↓ 0.1–3.5 ↓	↓ 0.1–3.5 ↓	↓ 0.2–0.5 ↓	↓ 2.4–2.8 ↓	↓ 0.1–3.5 ↓	↓ 0.1–3.5 ↓	↓ 0.1–0.3 ↓	↓ 0.9–4.3 ↓	↓ 0.1–3.5 ↓	↓ 0.1–3.5 ↓	↓ 0.1–0.3 ↓	↓ 1.2–3.2 ↓
Man	↑ 6.4–85.0 ↑	↑ 2.5–27.8 ↑	0.0–0.1 ↑	↑ 1.7–2.1 ↑	↑ 9.2–96.8 ↑	↑ 2.8–40.5 ↑	0.0–0.1 ↑	0.0–3.2 ↑	↑ 9.7–88.5 ↑	↑ 3.3–33.1 ↑	↑ 0.1–0.2 ↑	↑ 1.4–1.5 ↑
Ox	↑ 0.3–6.0 ↑	↑ 1.4–11.3 ↑	↑ 0.1–0.1 ↑	↑ 0.5–1.0 ↑	↑ 0.3–6.0 ↑	↑ 1.6–11.2 ↑	0.0–0.1 ↑	↑ 0.6–0.7 ↑	↑ 0.3–6.0 ↑	↑ 1.6–11.1 ↑	0.0–0.1 ↑	↑ 0.4–1.2 ↑
Buffalo	↑ 0.4–6.2 ↑	↑ 0.4–6.2 ↑	↓ 0.1–0.1 ↑	↑ 0.7–1.3 ↑	↑ 0.4–6.2 ↑	↑ 0.4–6.2 ↑	0.0–0.1 ↑	↑ 0.7–0.9 ↑	↑ 0.4–6.2 ↑	↑ 0.4–6.2 ↑	0.0–0.1 ↑	↑ 0.5–1.3 ↑
Horse	↑ 0.6–6.8 ↑	↑ 0.6–6.8 ↑	0.0–0.2 ↑	↑ 1.3–2.1 ↑	↑ 0.6–6.8 ↑	↑ 0.6–6.8 ↑	0.0–0.1 ↑	↑ 0.9–1.4 ↑	↑ 0.6–6.8 ↑	↑ 0.6–6.8 ↑	0.0–0.2 ↑	↑ 1.0–1.4 ↑
Donkey	↑ 0.5–6.4 ↑	↑ 0.5–6.4 ↑	↓ 0.1–0.1 ↑	↑ 1.0–1.6 ↑	↑ 0.5–6.4 ↑	↑ 0.5–6.4 ↑	0.0–0.1 ↑	↑ 0.8–1.0 ↑	↑ 0.5–6.4 ↑	↑ 0.5–6.4 ↑	0.0–0.1 ↑	↑ 0.7–1.3 ↑
Mule	↑ 0.4–6.1 ↑	↑ 0.4–6.1 ↑	↓ 0.1–0.1 ↑	↑ 0.7–1.2 ↑	↑ 0.4–6.1 ↑	↑ 0.4–6.1 ↑	0.0–0.1 ↑	↑ 0.7–0.8 ↑	↑ 0.4–6.1 ↑	↑ 0.4–6.1 ↑	0.0–0.1 ↑	↑ 0.5–1.2 ↑
Camel	↑ 0.5–6.3 ↑	↑ 0.5–6.3 ↑	↓ 0.1–0.2 ↑	↑ 1.1–1.8 ↑	↑ 0.5–6.3 ↑	↑ 0.5–6.3 ↑	0.0–0.1 ↑	↑ 0.8–1.2 ↑	↑ 0.5–6.3 ↑	↑ 0.5–6.3 ↑	0.0–0.1 ↑	↑ 0.8–1.3 ↑
Agronomic factor category: Seed sowing options												
Baseline: Native seeds (Initial value)	2.4–42.2	9.6–138.5	1.3–1-7	4.4–9.5	5.2–28.4	16.9–123.1	1.3–1.8	4.0–11.7	4.6–34.6	16.4–127.8	1.3–1.7	4.1–9.6
Hybrid seeds	↓ 3.8–7.1 ↓	↓ 3.8–7.1 ↓	↓ 0.3–0.5 ↓	↓ 2.5–4.0 ↓	↓ 2.2–2.7 ↓	↓ 2.2–2.7 ↓	↓ 0.1–0.3 ↓	↓ 0.7–6.2 ↓	↓ 2.2–3.7 ↓	↓ 2.2–3.7 ↓	↓ 0.2–0.3 ↓	↓ 1.4–4.2 ↓
GMO seeds	↓ 0.3–2.2 ↓	↓ 0.3–2.2 ↓	↓ 0.1–0.2 ↓	↓ 0.5–0.6 ↓	↓ 0.3–1.3 ↓	↓ 0.3–2.2 ↓	0.0	↓ 0.3–0.6 ↓	↓ 0.3–2.2 ↓	↓ 0.3–2.2 ↓	0.0–0.1 ↓	↓ 0.4–0.5 ↓
Agronomic factor category: Fertilizer options												
Baseline: Synthetic fertilizer (Initial value)	2.4–42.2	9.6–138.5	1.3–1-7	4.4–9.5	5.2–28.4	16.9–123.1	1.3–1.8	4.0–11.7	4.6–34.6	16.4–127.8	1.3–1.7	4.1–9.6
Animal manure	↑ 0.4–7.6 ↑	↑ 0.3–5.7 ↑	0.0–0.1 ↑	↑ 0.8–1.8 ↑	↑ 0.5–20.4 ↑	↑ 0.3–18.5 ↑	↑ 0.1–0.2 ↑	↑ 1.4–1.7 ↑	↑ 1.0–13.2 ↑	↑ 0.8–11.3 ↑	↑ 0.1–0.2 ↑	↑ 1.3–3.3 ↑
Biogas digestate	↑ 0.4–8.8 ↑	↑ 0.4–6.9 ↑	0.0–0.1 ↑	↑ 0.9–2.2 ↑	↑ 0.5–21.6 ↑	↑ 0.3–19.7 ↑	↑ 0.1–0.2 ↑	↑ 1.7–1.9 ↑	↑ 1.0–14.4 ↑	↑ 0.9–12.6 ↑	↑ 0.1–0.3 ↑	↑ 1.4–3.7 ↑

Table S2. *Cont.*

Agro-Climatic Zones	**Tropics**				**Sub-Tropics**				**Temperate**			
Energy efficiency indicator	**NEG (in GJ·ha⁻¹)**		**EROEI**		**NEG (in GJ·ha⁻¹)**		**EROEI**		**NEG (in GJ·ha⁻¹)**		**EROEI**	
Biofuel	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**	**Maize Ethanol**	**Maize Biogas**
Agronomic factor category: Tillage options												
Baseline: Mouldboard with pesticide application (initial value)	2.4–42.2	9.6–138.5	1.3–1-7	4.4–9.5	5.2–28.4	16.9–123.1	1.3–1.8	4.0–11.7	4.6–34.6	16.4–127.8	1.3–1.7	4.1–9.6
Mouldboard without pesticide application	↑ 0.2–0.5 ↑	↑ 0.2–0.5 ↑	0.0–0.1 ↓	↑ 0.1–0.3 ↑	↑ 0.2–0.5 ↑	↑ 0.2–0.5 ↑	0.0	↑ 0.1–0.4 ↑	↑ 0.2–0.5 ↑	↑ 0.2–0.5 ↑	0.0	↑ 0.1–0.3 ↑
Chisel	↑ 0.2–1.2 ↑	↑ 0.2–1.2 ↑	0.0–0.1 ↓	↑ 0.4–0.5 ↑	↑ 0.2–1.2 ↑	↑ 0.2–1.2 ↑	0.0	↑ 0.2–0.5 ↑	↑ 0.2–1.2 ↑	↑ 0.2–1.2 ↑	0.0	↑ 0.3–0.4 ↑
Disk	↑ 0.4–2.4 ↑	↑ 0.4–2.4 ↑	↓ 0.1–0.1 ↑	↑ 0.7–0.8 ↑	↑ 0.4–2.4 ↑	↑ 0.4–2.4 ↑	0.0	↑ 0.3–0.7 ↑	↑ 0.4–2.4 ↑	↑ 0.4–2.4 ↑	0.0–0.1 ↑	↑ 0.4–0.6 ↑
Ridge plant	↑ 0.4–2.7 ↑	↑ 0.4–2.7 ↑	↓ 0.1–0.1 ↑	↑ 0.7–0.9 ↑	↑ 0.4–2.7 ↑	↑ 0.4–2.7 ↑	0.0	↑ 0.3–0.7 ↑	↑ 0.4–2.7 ↑	↑ 0.4–2.7 ↑	0.0–0.1 ↑	↑ 0.4–0.6 ↑
Stubble and mulch	↓ 0.1–2.8 ↑	↓ 0.1–2.8 ↑	0.0–0.1 ↓	↓ 0.2–0.2 ↑	0.0–2.6 ↑	0.0–2.6 ↑	0.0	0.0–0.3 ↑	↑ 0.1–2.5 ↑	↑ 0.1–2.5 ↑	0.0–0.1 ↑	↑ 0.1–0.5 ↑
Strip till	↑ 0.3–3.8 ↑	↑ 0.3–3.8 ↑	↓ 0.1–0.1 ↑	↑ 0.6–1.1 ↑	↑ 0.3–3.8 ↑	↑ 0.3–3.8 ↑	0.0–0.1 ↑	↑ 0.5–0.6 ↑	↑ 0.3–3.8 ↑	↑ 0.3–3.8 ↑	0.0–0.1 ↑	↑ 0.4–0.7 ↑
No till	↑ 0.2–3.4 ↑	↑ 0.2–3.4 ↑	↓ 0.1–0.1 ↑	↑ 0.5–1.0 ↑	↑ 0.2–3.4 ↑	↑ 0.2–3.4 ↑	0.0–0.1 ↑	↑ 0.4–0.5 ↑	↑ 0.2–3.4 ↑	↑ 0.2–3.4 ↑	0.0–0.1 ↑	↑ 0.4–0.7 ↑
Agronomic factor category: Irrigation options												
Baseline: Rain-fed (Initial value)	2.4–42.2	9.6–138.5	1.3–1-7	4.4–9.5	5.2–28.4	16.9–123.1	1.3–1.8	4.0–11.7	4.6–34.6	16.4–127.8	1.3–1.7	4.1–9.6
Surface	↓ 0.2–9.6 ↑	↓ 0.2–33.4 ↑	↓ 0.1–0.2 ↓	↓ 1.3–1.6 ↑	↓ 0.2–18.3 ↑	↓ 0.2–55.3 ↑	↓ 0.1–0.1 ↑	↓ 0.8–2.1 ↑	↓ 0.2–12.1 ↑	↓ 0.2–39.9 ↑	↑ 0.1–0.2 ↓	↓ 1.1–1.7 ↑
Sprinkler	↓ 3.9–5.7 ↑	↓ 3.9–29.5 ↑	↓ 0.2–0.5 ↓	↓ 2.6–2.7 ↓	↓ 3.9–14.4 ↑	↓ 3.9–51.4 ↑	↓ 0.1–0.2 ↓	↓ 1.2–2.8 ↓	↓ 3.9–8.2 ↑	↓ 3.9–36.0 ↑	↓ 0.1–0.3 ↓	↓ 1.5–1.9 ↓
Drip	↓ 3.1–7.8 ↑	↓ 3.1–31.7 ↑	↓ 0.2–0.4 ↓	↓ 2.3–2.4 ↓	↓ 3.1–16.6 ↑	↓ 3.1–53.5 ↑	↓ 0.1–0.2 ↓	↓ 1.1–1.9 ↓	↓ 3.1–10.4 ↑	↓ 3.1–38.1 ↑	↓ 0.1–0.2 ↓	↓ 1.2–1.4 ↓
Agronomic factor category: Co-product reintegration												
Non-reintegration of co-products	2.4–42.2	9.6–138.5	1.3–1-7	4.4–9.5	5.2–28.4	16.9–123.1	1.3–1.8	4.0–11.7	4.6–34.6	16.4–127.8	1.3–1.7	4.1–9.6
Reintegration of co-products	↑ 9.6–305.3 ↑	↑ 0.2–26.1 ↑	↑ 1.6–3.4 ↑	↑ 0.2–0.5 ↑	↑ 15.8–300.4 ↑	↑ 0.3–25.6 ↑	↑ 2.0–2.8 ↑	↑ 0.2–0.6 ↑	↑ 15.8–305.6 ↑	↑ 0.3–25.3 ↑	↑ 1.8–3.0 ↑	↑ 0.1–0.6 ↑
Agronomic factor category: Maximum transport distances												
10–20 km	2.4–42.2	9.6–138.5	1.3–1.7	4.4–9.5	5.2–28.4	16.9–123.1	1.3–1.8	4.0–11.7	4.6–34.6	16.4–127.8	1.3–1.7	4.1–9.6
21–800 km	↓ 24.2–27.4 ↓	↓ 3.8–83.7 ↓	0.0–0.5 ↓	↓ 0.8–3.4 ↓	↓ 6.8–41.5 ↓	↓ 11.7–60.8 ↓	0.0–0.5 ↓	↓ 1.2–3.0 ↓	↓ 15.0–32.6 ↓	↓ 12.0–68.7 ↓	0.0–0.5 ↓	↓ 0.8–3.0 ↓

↓ before or after values in a range indicates decrease in NEG or EROEI OR negative effects on NEG or EROEI OR negative difference in NEG or EROEI as a result of the adoption of a particular agronomic factor; ↑ before or after values in a range indicates increase in NEG or EROEI OR positive effects on NEG or EROEI OR positive difference in NEG and EROEI as a result of the adoption of a particular agronomic factor; 0.0 values in a range indicates no effects on NEG or EROEI OR no difference in NEG OR EROEI as a result of the adoption of a particular agronomic factor; ↓ before values in a range indicates decrease in NEG or EROEI at lower limit of the range; ↓ after values in a range indicates decrease in NEG or EROEI at upper limit of the range as a result of the adoption of a particular agronomic factor; ↑ before values in a range indicates increase in NEG or EROEI at lower limit; ↑ after values in a range indicates increase in NEG or EROEI at upper limit of the range as a result of the adoption of a particular agronomic factor.

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