Willow Biomass Crops Are a Carbon Negative or Low-Carbon Feedstock Depending on Prior Land Use and Transportation Distances to End Users

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Supporting Information

Table S1. Comprehensive list of processes included in willow biomass production and the values for each parameter used in the LCA.

Step Number	**Activities**	**Operation Rate (h ha^{-1})**	**Material**	**Equipment**	**Literature Source or Life Cycle Inventory Name (From Ecoinvent 3.3 and USLCI Databases)**
1	Nursery production of planting stock	n/a			(Caputo et al. 2014)
2	Clear existing vegetation	1.5	n/a	Tractor, mower, bailer	Mowing, by motor mower; Haying; Baling; Bale loading.
3	Apply contact herbicide (post-emergent)	0.5	Glyphosate 2.24kg/ha; 2,4-D 0.56kg/ha	7.6m boom sprayer	Application of plant protection product, by field sprayer; Glyphosate; 2,4-dichlorotoluene
4	Soil amendments	0.5	Lime, 2 ton/ac for Grasslands	dry spreader	Lime spread by hydraulic loader and spreader.
5	Plow	2	n/a	1.45m moldboard plow	Tillage, ploughing.
6	Cross-disk	1.4	n/a	3.4m tandem harrow disk	Tillage, harrowing, by rotary harrow
7	Rock-picking	2 passes	n/a	Tractor	Diesel, combusted in industrial equipment/US

8	Repeat weed control	0.5	Glyphosate 2.24 kg/ha	same as step 3	Application of plant protection product, by field sprayer; Glyphosate;
9	Sow cover crop	0.3	5 bushels/ha of seeds	12.2m broadcaster	Rye seed, for sowing; Sowing.
10	Terminate cover crop	1.5	n/a	1.8m brush hog	Tillage, rolling
11	Plant	1	15,300 cuttings/ha	4 row Salix Maskiner Step planter and tractor	Planting
12	Pre-emergent herbicide for weed control	0.5	Oxyfluorfen (Goal) 1 lb/ac, Pendimethalin (Pendulum) 1.5 lb/ac	Same as step 3	Application by field sprayer; Pendimethalin;
13	Weed control	0.5	Aminopyralid (Stinger) 10 gram/ha, Fluazifop (fusilade) 12oz/ac	Same as step 3	Application by field sprayer;
14	Mow headlands	1.5	n/a	Same as step 2	Mowing, by rotary mower.
15	Coppice	1.5	n/a	Same as Step 2	Mowing, by rotary mower.
16	Fertilizer	0.5	100kgN/ha	7.6 m spreader and tractor	Urea, as N; Fertilising, by broadcaster;
17	Harvest	equation from Eisenbies et al. (2014)	n/a	Forage harvester, 10 ton tractors and wagons	Forestry harvester; equipment/US; Lubricating oil.
18	Load	n/a	n/a	Bucket loader	loader.
19	Transport chips	n/a	n/a	Truck	Transport, single unit truck, short-haul, diesel powered, Northeast/tkm/RNA
20	Eliminate Stools	4.5	n/a	mowing, herbicide, and 2.3 m brush hog	Mulching; Tillage, harrowing, by rotary harrow;

Table S2. Number and area of suitable parcels for willow biomass crop production for four different land cover classes in five counties in central and northern NY. The four land cover classes correspond to land classes in NLCD datasets.

County	Shrub		Grassland		Pasture		Cultivated Crop		Total	
	No. Parcels	Area (ha)	No. Parcels	Area (ha)	No. Parcels	Area (ha)	No. Parcels	Area (ha)	No. Parcels	Area (ha)
Jefferson	139	5,897	80	3,062	1,754	46,619	578	19,048	2,551	74,626
Lewis	49	2,207	37	992	927	17,021	402	8,870	1,415	29,091
Oneida	82	2,716	54	1,084	988	16,326	737	12,476	1,861	32,602
Oswego	72	1,851	8	216	599	10,168	234	4,645	913	16,880
St. Lawrence	67	2,952	112	2,931	2,119	36,386	680	15,311	2,978	57,580
Total	409	15,623	291	8,286	6,387	126,520	2,631	60,350	9,718	210,779

Table S3. Yield distribution of willow biomass crops for grassland and cropland land cover classes across five counties in central and northern NY. Yield was estimated based on average NCCPI value in each suitable parcel.

County	Yield (Mg ha^{-1} yr^{-1})					
	Grassland			Cropland		
	Minimum	*Mean*	*Maximum*	*Minimum*	*Mean*	*Maximum*
Jefferson	7.1	10.8	15.1	7.7	12.1	15.5
Lewis	6.6	9.7	13.9	7.0	10.8	14.4
Oneida	8.6	11.2	15.4	8.4	12.0	15.5
Oswego	7.6	10.1	13.2	8.0	11.3	18.82
St. Lawrence	7.0	11.1	13.4	7.3	11.6	13.5

Table S4. NCCPI value distributions in parcels suitable for willow biomass crops across five counties in central and northern NY. NCCPI values were derived from SSURGO soil data layer and averaged in each suitable parcel.

County	NCCPI values					
	Grassland			Cropland		
	Minimum	*Mean*	*Maximum*	*Minimum*	*Mean*	*Maximum*
Jefferson	0.08	0.36	0.69	0.11	0.46	0.74
Lewis	0.03	0.33	0.6	0.06	0.39	0.64
Oneida	0.19	0.41	0.72	0.18	0.45	0.72
Oswego	0.11	0.34	0.64	0.15	0.43	0.96
St. Lawrence	0.24	0.39	0.57	0.08	0.44	0.57

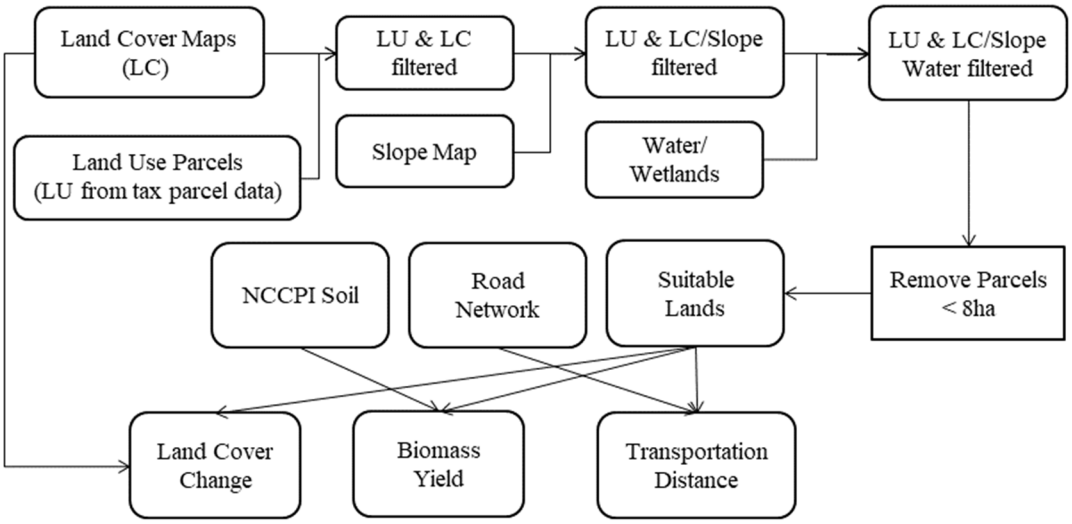

Figure S1. Data processing steps and data layers in GIS model for preparing inputs of LCA. Six datasets were processed for filtering criteria including land cover classes, land use types, slope, hydrography, and spatial continuity.

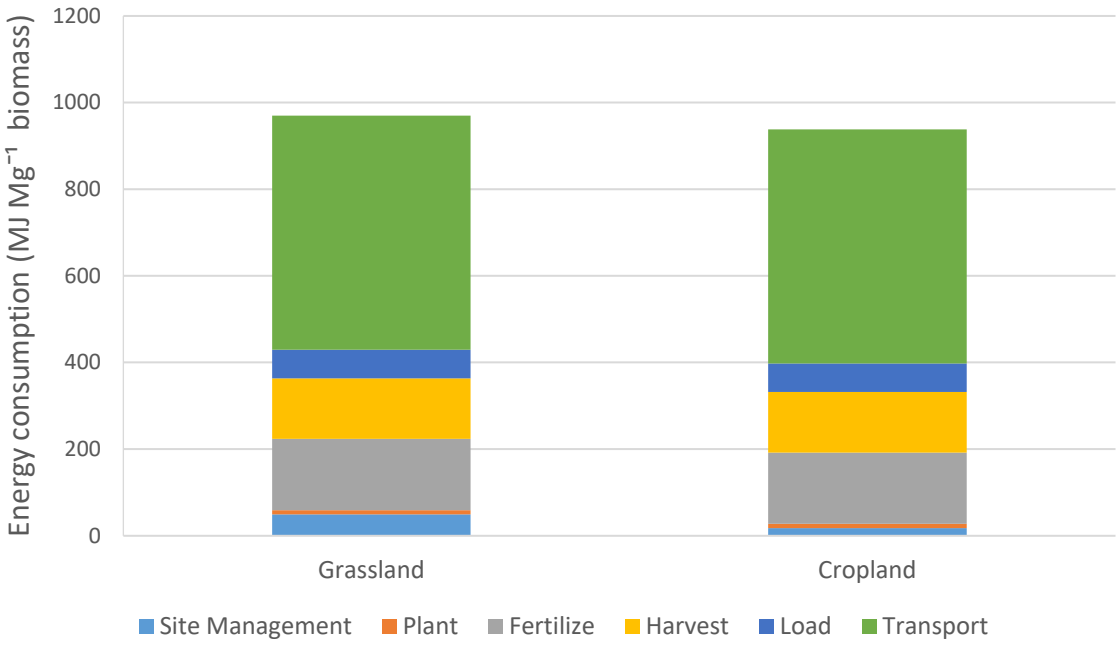

Figure S2. Energy consumption (MJ) of producing and delivering 1 Mg biomass in two land cover classes based on baseline parameters in Table 1. 1 Mg biomass is our functional unit defined for LCA in method section above and later can be used to compute energy balance between energy input and energy production in MJ/MJ. The difference between grassland and cropland are due to fewer steeps in the site preparation processes on cropland.

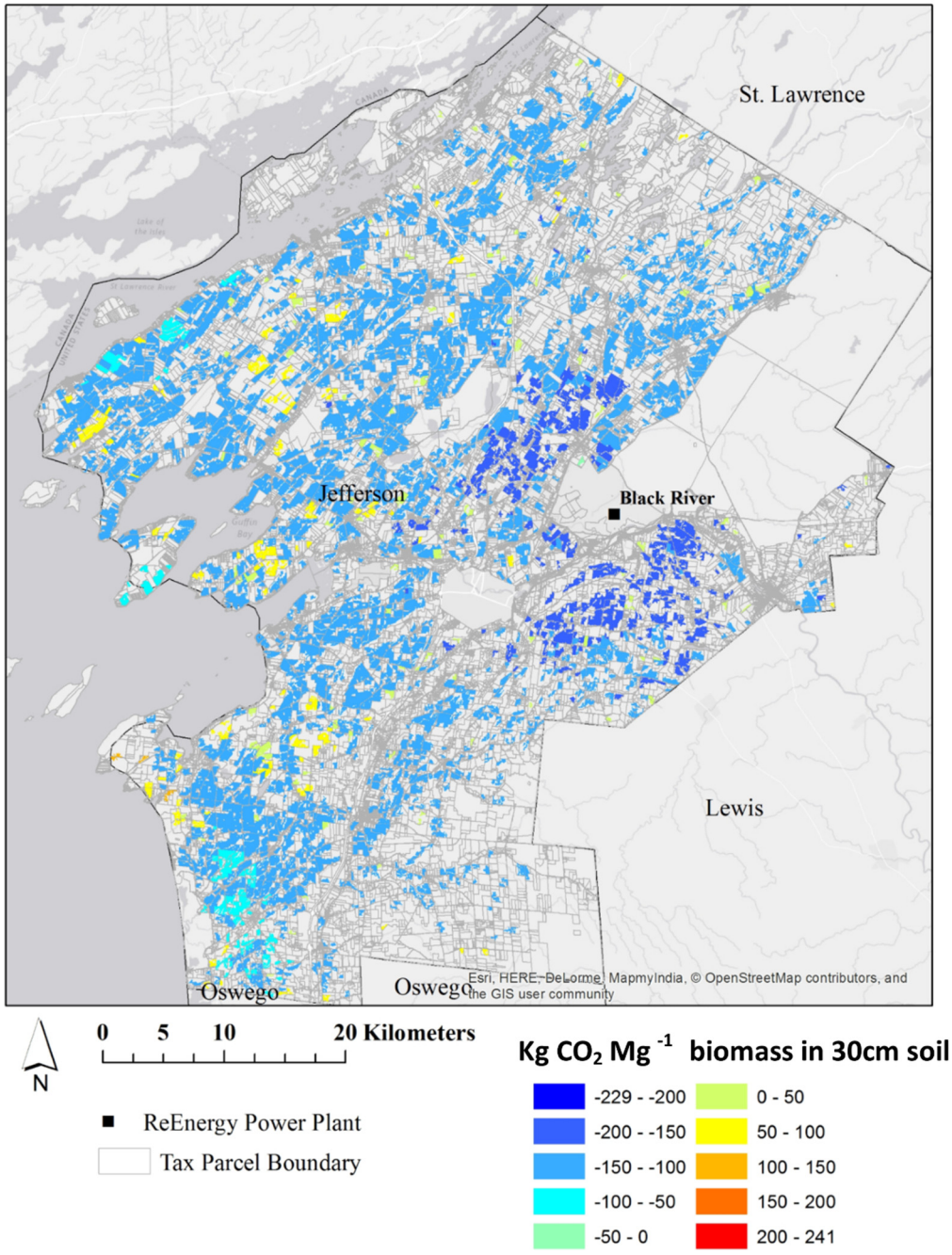

Figure S3. Geographical distributions of life cycle GHG emissions for willow biomass crops grown in Jefferson County, NY. The underlying polygons are tax parcels. Suitable parcels are color coded to represent GHG emission for each individual parcel. Black River is the end use facility that is closest to the fields in Jefferson County. The area northeast of Black River is the Fort Drum Army base so land is not available for willow production.

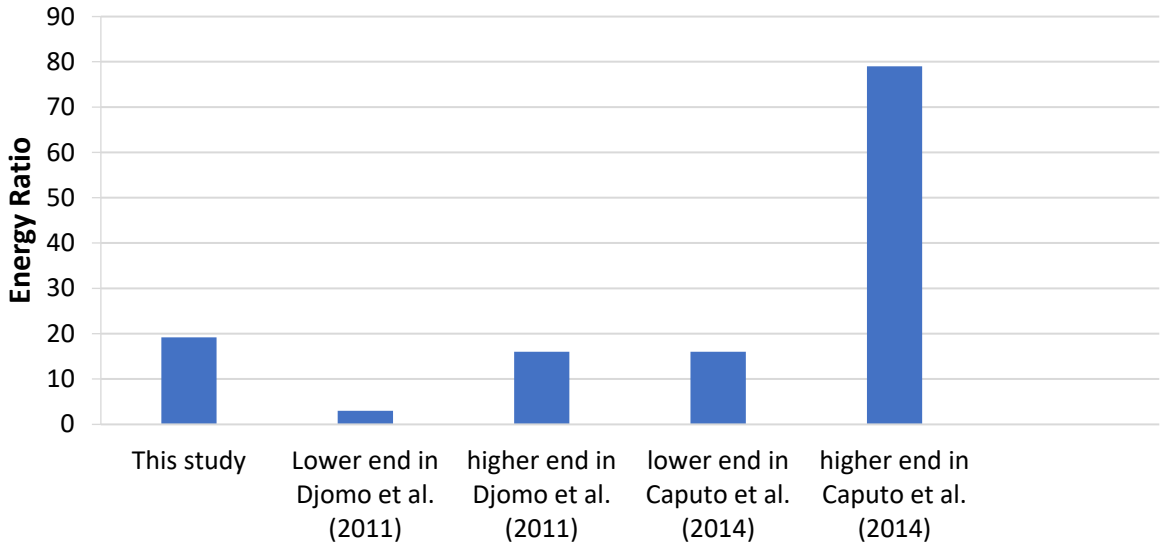

Figure S4. EROI for the base case scenario from this study compared to other studies of willow biomass crops.