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Electronic Supplementary Material

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Title: **Climate regulation, energy provisioning and water purification: quantifying ecosystem service delivery of bioenergy willow grown on riparian buffer zones using life cycle assessment**

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S1. Methodology

S1.1 Skåne characteristics

Table S1.1. Key statistics for the Skåne region in 2014, based on data provided by SCB (2014)

	Unit	Value
Skåne land area	ha	1,096,881
Skåne arable land area	ha	434,506
Skåne grassland area	ha	169,443
River length	m	4,106,160
Lake perimeter	m	1,275,983
Max buffer length	m	9,488,303
Max arable buffer length	m	2,832,163
Max buffer area	ha	47,442
Paid buffer area	ha	1146 - 3437
Paid buffer length	m	1,910,000 - 5,728,333
Tile drainage area	ha	123,700
Share arable land drained	%	38%

S1.2. Baseline arable landscape

Key agronomic parameters for the baseline arable landscape summarised in Table 2 of the main paper are based on fertiliser recommendations (Jordbruksverket, 2014a) and other input data for European crop production sourced from Biograce v4d (EC, 2014). Crop residue N inputs were calculated using IPCC (2006) equations 11.7, 11.8 and values in Table 11.2, taking a representative crop for each crop category (i.e. wheat, grass, oil seed rape and sugar beet), and assuming that grass ley is ploughed-in every two years on average.

S1.3. Life cycle impact assessment method

The CML (2010) life cycle impact assessment method was used (Table S1.4).

Table S1.4. Environmental burden characterisation factors and indicators used to assess contributions to the four life cycle assessment impact categories considered in this study

Impact category	Abbreviation	Indicator	Characterisation factors (per kg)
Global warming potential	GWP	CO_2e	CO_2 1; N_2O 298; CH_4 25
Eutrophication potential	EP	PO_4e	NO_3 0.1; P 3.06; NH_3 0.35; NO_x 0.13; N 0.42
Acidification potential	AP	SO_2e	NH_3 1.6; NO_x 0.5; SO_x 1.2
Fossil resource depletion potential	FRDP	MJe	Hard coal 27.91; soft coal 13.96; natural gas (m^3) 38.84; crude oil 41.87.

S1.4. LCAD method

Direct on-farm emissions factors are displayed in Table S1.5, whilst burdens embodied in imported materials and counterfactual processes are summarised in Table S1.6. These emission factors are mostly as used in Styles et al. (2015a;b), but NO_3-N leaching rates have been updated based on Johnsson and Mårtensson (2002) data showing an average leaching rate of 45-51 kg N ha^{-1} yr^{-1} across annual arable crops in Skåne, which translates into an emission factor of 0.23 relative to average fertiliser- and residue-N inputs of 150 and 58 kg ha^{-1} yr^{-1}, respectively.

Table S1.5. Direct emission factors applied in the LCAD tool

Process	Unit	CO_2	CH_4	N_2O-N	NH_3-N	NO_x	NO_3-N	P
Fertiliser-N application	Fraction N			[1]0.01	[2]0.018		[3]0.23	
Crop residue N inputs	Fraction TN			[1]0.01			[3]0.23	
All P amendments	Fraction P							[4]0.01
Lime application	kg per kg lime	[1]0.44						
Tractor diesel combustion	kg per kg diesel	[5]3.05	[5]0.000044	[5]0.000048		[6]0.004		

[1]IPCC (2006); [2]Misselbrook et al. (2012); [3]Johnsson and Mårtensson (2002); [4]Withers, pers. comm. (2013); [5]DEFRA (2012); [6]Dieselnet (2013).

Table S1.6. Environmental burdens attributed to upstream and counterfactual processes in the LCAD tool (Styles et al., 2015a)

Input	Reference unit	Global warming potential kg CO_2e	Eutrophication potential kg PO_4e	Acidification potential kg SO_2e	Resource depletion potential MJe
Ammonium nitrate-N	kg N	6.10	0.0068	0.024	55.7
Triple superphosphate	kg P_2O_5	2.02	0.045	0.037	28.3
Potassium chloride K_2O	kg K_2O	0.50	0.00077	0.0017	8.32
Lime	kg $CaCO_3$	2.04	0.00040	0.00068	3.31
Crop protection products	kg active ingredient	10.1	0.033	0.097	174
Diesel (upstream)	kg	0.69	0.00089	0.0062	51.6
Electricity consumed	kWh_e	0.42	0.000064	0.000226	7.32
Oil heating	kWh_{th}	0.34	0.00011	0.00075	4.55
Transport	tkm	0.081	0.000067	0.0003	1.06

Data based on Ecoinvent (2014), DEFRA (2012), CFT (2012)

S1.5. Indirect land use change method

The agricultural frontier iLUC proposed in Styles et al. (2015b) is applied in this study. The global agricultural frontier is simplified in Table S1.5 into five dominant natural habitats from the five countries that exhibited the largest increase in agricultural land area between 2007 and 2012 (FAO Stat, 2014). Carbon stock change, N_2O emissions, N mineralisation and associated N leaching were all calculated based on relevant Tier 1 methods in IPCC (2006). Biomass C stock factors reported in Table S1.5 below are based on IPCC (2006) equations 2.15 and 2.16, above ground biomass values taken from Table 4.7 and below-to-above ground biomass ratios from Table 4.4 of IPCC (2006). Soil organic C was calculated based on IPCC Tier 1 methodology, based on SOC_{REF} values (Table 2.3) and cropland F_{LU} values (Table 5.5) from IPCC (2006), assuming low activity clay soils under relevant climatic conditions. In addition, soil N mineralisation following LUC was calculated according to equation 11.8, and N_2O-N and NO_3-N emissions calculated based on default IPCC (2006) emission factors of 0.01 and 0.3, respectively. These emissions contributed to global warming potential and eutrophication potential burdens for iLUC (Table S1.7).

Table S1.7. Key parameters of land use change at the global agricultural frontier

	Agricultural expansion 2007-2012 (M ha)	**Lost habitat**	**Soil organic C loss (kg ha^{-1} yr^{-1})**	**Soil N mineralisation (kg ha^{-1} yr^{-1})**	**Biomass C loss (kg ha^{-1} yr^{-1})**	**Global warming potential (kg CO_2e ha^{-1} yr^{-1})**	**Eutrophication potential (kg PO_4e ha^{-1} yr^{-1})**
Argentina	4.76	Temperate grassland	977	65	90	4215	8.6
Brazil	3.97	Tropical moist forest	1222	82	6570	28952	10.8
Indonesia	3.50	Tropical rain forest	1222	82	11378	47900	10.8
Thailand	2.06	Tropical dry forest	987	66	4710	21197	8.7
Angola	1.50	Tropical moist forest	1222	82	7810	33499	10.8
Weighted mean			1173	74.5	5638	**25117**	**9.9**

Reference list

CFT (2012). Available to download at the *Cool Farm Tool* homepage. Downloaded June 2012: http://www.coolfarmtool.org/

CML (2010). Characterisation Factors database available online from Institute of Environmental Sciences (CML), Universiteit Leiden, Leiden, 2010. Available at: http://cml.leiden.edu/software/data-cmlia.html (accessed 15 May 2012).

Defra (2010). Fertiliser Manual RB209. UK: TSO. Retrievable at http://www.defra.gov.uk/publications/2011/03/25/fertiliser-manual-rb209/

Defra (2012). 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting. London: Defra.

Dieselnet (2013). Non-road transport EU emission standards, available at: http://www.dieselnet.com/standards/eu/nonroad.php Last accessed 04.05.2013.

EC (2014). BioGrace Excel tool version 4d, downloaded from the BioGrace website September 2015: www.biograce.net

Ecoinvent (2014). Ecoinvent database version 3.1, accessed via SimaPro.

FAO Stat (2014). Statistics database: http://faostat3.fao.org/home/E Accessed 29.10.2014.

IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Johnsson, H. and K. Mårtensson. 2002. Kväveläckage från svensk åkermark (Nitrogen leaching from Swedish arable land). Report 5248, Swedish Environmental Protection Agency, Stockholm.

Jordbruksverket. (2014a). Jordbruksstatistisk årsbok 2014. Jönköping, Sweden

Jordbruksverket. (2014b). Riktlinjer för gödsling och kalkning 2015. Jönköping, Sweden

Misselbrook, T.H., Gilhespy, S.L., Cardenas, L.M. (Eds.) (2012). *Inventory of Ammonia Emissions from UK Agriculture 2011.* Defra, London.

SCB. (2014). Skane land data. Statistiska centralbyra˚n, Stockholm. http://www.scb.se. Accessed Nov 2014.

Styles, D., Gibbons, J., Williams, A.P., Stichnothe, H., Chadwick, D.R., Healey, J.R. (2015a). Cattle feed or bioenergy? Consequential life cycle assessment of biogas feedstock scenarios on dairy farms, Global Change Biology Bioenergy 7, 1034-1049.

Styles, D., Gibbons, J., Williams, A.P., Dauber, J., Urban, B., Stichnothe, H., Chadwick, D., Jones, D.L. (2015b). Consequential life cycle assessment of biogas, biofuel and biomass energy options in an arable rotation. Submitted to Global Change Biology Bioenergy 7, 1305-1320.

Withers P (2013). Personal communication, 22nd April 2013.