Supplementary Material

Soil carbon modelling in *Salix* biomass plantations: variety determines carbon sequestration and climate impacts

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Table S1 Parameters used to model SOC changes in ICBM [46,58,60]

	k_Y	k_O	r_e	h_a	h_b	i_a	i_b
Green fallow	0.8	0.0085	1	0.17	0.39	0.72	0.86[1]
Salix[2]	0.8	0.0085	1	0.17	0.39	-	-

[1]belowground biomass input adjusted for 20cm soil depth
[2]Above and belowground input for *Salix* varieties calculated based on yield levels and biomass allocation

Table S2 Initial values of aboveground (Y_a) and belowground (Y_b) young pool, and old pool (O) used in the ICBM calculation. The initial SOC stock was divided between the different pools (Y_a, Y_b and O) by using the ratio of each individual pool to the total SOC pool at steady state.

	Y_a	Y_b	O
Green fallow	0.31	0.62	27.92
Salix	0.31	0.62	27.92

Table S3 Values used to calculate the biomass allocation between the different pools (stems, leaves, fine roots and coarse roots) at stages of growth as a percentage of their 3-year net primary production [61].

	Annual biomass allocation (% of 3-year total accumulation)			
Year	Stems (S)	Leaves (L)	Fine Roots (F)	Coarse Roots (C)[1]
n.1	11%	13%	19%	24%
n.2	47%	39%	38%	49%
n.2	41%	48%	42%	26%

[1] Coarse roots include the stumps and cuttings

Table S4 The nitrogen (N) content in leaf litter was calculated according to the abscission leaf N content by variety and fertilization as reported by Weih and Nordh, 2002[41] . (Suffixes F0 and F+ denotes unfertilized and fertilized treatments)

Salix variety and treatment	Abscission leaf N concentration
Björn F0	1.04%
Björn F+	1.15%
Gudrun F0	0.66%
Gudrun F+	0.65%
Jorr F0	1.38%
Jorr F+	1.22%
Loden F0	0.94%
Loden F+	0.89%
Tora F0	0.90%
Tora F+	0.88%
Tordis F0	0.84%
Tordis F+	0.93%

Table S5 The nitrogen (N) content of roots was calculated from the dataset by Manzoni et al., 2021[57]. As data for individual varieties included in our study are unavailable, mean root N-content of *Salix* cultivated in low nutrient (F0) and high nutrient (F+) conditions were calculated. *Salix* grown under low frequency watering were excluded from the calculation.

	Mean N-content of roots		
	mg N/g dry wt.	Std dev.	% dry wt.
	13.02	5.0	1.30%
Salix_F0	8.35	1.3	0.83%
Salix_F+	17.6	2.1	1.76%

Table S6 Energy input and emissions associated with production of pesticides, cutting, fertilizer and fossil fuels

Input	Amount	Energy [MJ/ha]	CO_2 [g/ha]	CH_4 [g/ha]	N_2O [g/ha]	Reference
Pesticide						
- Roundup	5 l/ha	481.38	11958	0.4374	3.6693	(Ahlgren, 2004; Nilsson and Bernesson, 2008)
- Cougar	1 l/ha	118.86	2952.6	0.108	0.906	
Cuttings	18000 /ha	1120.98	1014369	158.40		Adapted from Nilsson and Bernesson, 2008
Fertilizer		Energy [MJ/kg]	CO_2 [g/kg]	CH_4 [g/kg]	N_2O [g/kg]	Adapted from GaBi Database
- N (Ammonium Nitrate based)	100 kg/ha	35.2	2839	8	2	("GaBi Process data set: AN," 2018)
- P	14 kg/ha	7.79	489	1	0	("GaBi Process data set: TSP," 2018)
- K	47 kg/ha	5.54	342	0	0	("GaBi Process data set: KCl," 2018)
Fuel production			CO_2	CH_4	N_2O	
Diesel			[g/MJ]	[g/MJ]	[g/MJ]	
			5.78	0.0338	0.0000555	(Öman et al., 2011)
Natural Gas			5.53	0.275	2.6E-12	(Gode et al., 2011)

Table S7 Data used to estimate emissions and energy usage for operations in the biomass procurement chain

Operation	Diesel [MJ/ha]	Energy [MJ/ha]	CO_2 [g/ha]	CH_4 [g/ha]	N_2O [g/ha]	Reference
Field Preparation						
- Plowing	1870	1870	154000	129.8	0	(Börjesson, 2006; Nilsson and Bernesson, 2008)
- Harrowing	262	286	81400	68.2	0	
Planting	660	55000	46.2	0.00		(Börjesson, 2006)
Fertilizer Application	28.1	30.6	2186.4	0.95	0.0016	(Nilsson and Bernesson, 2008)
Stump Removal	674.5	735.2	52464	22.8	0.0374	(Nilsson and Bernesson, 2008)
Harvest & Chipping	Harvest with self-propelled forage, Claas Jaguar 695					(Nilsson and Bernesson, 2008)
	Capacity [ton/h]				24.4	
	Fuel Consumption [l/h]				40.0	
Field Transport	Forwarding with Tractor 4WD, 100kW Capacity					(Nilsson and Bernesson, 2008)
	Capacity [ton/h]				11.4	
	Fuel Consumption [l/h]				19.0	
Road Transport	Capacity [ton/load]				34.6	(Baky et al., 2009)
	Fuel Consumption [l/km]				0.58	(Andersson and Frisk, 2012)
	Load rate [% of distance]				54%	
Incineration	Emission factors in large scale heating plant (50-300 MW)					(Paulrud et al., 2010)
	N_2O [g/GJ]				6	
	CH_4 [g/GJ]				11	

Table S8 Data used to model emissions and energy for the reference case

Green Fallow	Annual Yield (tons/ha)	4.8	Based on Aronsson et al., 2009
	N-content	2.81%	(Phyllis 2, 2009)
Annual mowing of green fallow	Mower-conditioner (Valtra 6600 tractor)		
	Fuel Consumption (kg/h)	12.9	(Lindgren et al., 2002)
	Cutting rate (ha/h)	2.53	
Natural Gas (NG) combustion	CO_2 [g/MJ]	56.8	(Gode et al., 2011)
	CH_4 [g/MJ]	0.001	
	N_2O [g/MJ]	0.0001	
Energy efficiency of NG heat plant	Heat efficiency	90%	(Börjesson et al., 2010)
	Flue gas heat recovery efficiency	10%	
	Total efficiency	100%	

References

1. Ahlgren, S., 2004. Environmental impact of chemical and mechanical weed control in agriculture - a comparing study using Life Cycle Assessment (LCA) methodology. SIK, Göteborg.
2. Andersson, G., Frisk, M., 2012. Skogsbrukets transporter 2010 (Forestry transports in 2010) (No. 791–2013). Skogsforsk, Uppsala.
3. Andrén, O., Kätterer, T., 1997. ICBM: The Introductory Carbon Balance Model for exploration of soil carbon balances. Ecological Applications 7, 1226–1236. https://doi.org/10.1890/1051-0761(1997)007[1226:ITICBM]2.0.CO;2
4. Andrén, O., Kätterer, T., Karlsson, T., 2004. ICBM regional model for estimations of dynamics of agricultural soil carbon pools. Nutrient Cycling in Agroecosystems 70, 231–239. https://doi.org/10.1023/B:FRES.0000048471.59164.ff
5. Aronsson, H., Stenberg, M., Rydberg, T., 2009. Kväve- och fosforutlakning från lerjord vid odling av två-årig grönträda med olika putsningsfrekvens (Report No. 111), Ekohydrologi (0347-9307). Dept. of Soil and Environment, Uppsala.
6. Baky, A., Forsberg, M., Rosenqvist, H., Jonsson, N., Sundberg, M., 2009. Skördeteknik och logistik för bättre lönsamhet från små odlingar av Salix (Harvest and logistics for better profitability from small cultivations of Short Rotation Willow Coppice) (No. Projekt E06-643). VÄRMEFORSK Service AB, Stockholm.
7. Börjesson, P., 2006. Livscykelanalys av Salixproduktion, IMES/EESS Report. Department of Environmental and Energy Systems Studies, Lund university.
8. Börjesson, P., Tufvesson, L., Lantz, M., 2010. Life Cycle Assessment of Biofuels in Sweden, (LUTFD2/TFEM--10/3061--SE + (1-88); Lund University. Department of Technology and Society. Environmental and Energy Systems Studies.
9. GaBi Process data set: Ammonium nitrate (AN, 33.5% N); from ammonia and nitric acid, including primary production; production mix, at plant; 33.5 % nitrogen content (en) [WWW Document], 2018. . GaBi Process data set: (AN, 33.5% N). URL http://gabi-documentation-2018.gabi-software.com/xml-data/processes/c2c4ebba-358f-493e-83ba-71bffe847e9a.xml (accessed 10.14.20).
10. GaBi Process data set: Potassium chloride (KCl/MOP, 60% K2O); shaft mining and beneficiation, including primary production; production mix, at plant; 60% potassium content (en) [WWW Document], 2018. . GaBi Process data set: (KCl/MOP, 60% K2O). URL http://gabi-documentation-2018.gabi-software.com/xml-data/processes/a2a8695e-968c-4341-922c-a007c8a8c56d.xml (accessed 10.14.20).
11. GaBi Process data set: Triple superphosphate (TSP, 46% P2O5); rock phosphate acidulation with phosphoric acid, including primary production; production mix, at plant; 46 % phosphate content (en) [WWW Document], 2018. . GaBi Process data set: (TSP, 46% P2O5). URL http://gabi-documentation-2018.gabi-software.com/xml-data/processes/8d0007f0-9ad8-43b0-86e4-ebe6e9f9d0e6.xml (accessed 10.14.20).
12. Gode, J., Martinsson, F., Hagberg, L., Öman, A., Höglund, J., Palm, D., 2011. Uppskattade emissionsfaktorer för bränslen, el, värme och transporter (Estimated emission factors for fuels, electricity, heat and transport in Sweden) (No. A08-833), Miljöfaktaboken 2011. VÄRMEFORSK Service AB, Stockholm.
13. Kätterer, T., Bolinder, M.A., Andrén, O., Kirchmann, H., Menichetti, L., 2011. Roots contribute more to refractory soil organic matter than above-ground crop residues, as revealed by a long-term field experiment. Agriculture, Ecosystems & Environment 141, 184–192. https://doi.org/10.1016/j.agee.2011.02.029
14. Lindgren, M., Petterson, O., Hansson, P.-A., Norén, O., 2002. Jordbruks- och anläggningsmaskiners motorbelastning och avgasemissioner : samt metoder att minska bränsleförbrukning och avgasemissioner (Engine load pattern and engine exhaust gas emissions from off-road vehicles and methods to reduce fuel-consumption and engine exhaust gas emissions), JTI-rapport. JTI Institutet för Jordbruks- och Miljöteknik, Uppsala.

15. Manzoni, S., Lindh, M., Hoeber, S., Weih, M., 2021. Salix biomass and nitrogen content measured in a pot experiment, Uppsala, Sweden, 2018 – 2019. Dataset version 1.0. Bolin Centre Database. https://doi.org/10.17043/manzoni-2021-salix-1
16. Nilsson, D., Bernesson, S., 2008. Pelletering och brikettering av jordbruksråvaror: en systemstudie (Processing biofuels from farm raw materials : a systems study), Rapport (Institutionen för energi och teknik, SLU), 001. Institutionen för energi och teknik, SLU, Uppsala.
17. Öman, A., Hallberg, L., Rydberg, T., 2011. LCI för petroleumprodukter som används i Sverige (No. B1965), IVL Rapport. IVL Svenska Miljöinstitutet AB, Stockholm.
18. Paulrud, S., Fridell, E., Stripple, H., Gustafsson, T., 2010. Uppdatering av klimatrelaterade emissionsfaktorer, SMED Rapport. SMHI, Norrköping.
19. Phyllis 2, 2009. Phyllis2 - Green grass (#3193) [WWW Document]. Phyllis2, database for biomass and waste. URL https://phyllis.nl/Biomass/View/3193 (accessed 10.14.20).
20. Rytter, R.-M., 2001. Biomass production and allocation, including ®ne-root turnover, and annual N uptake in lysimeter-grown basket willows. Forest Ecology and Management 16.
21. Weih, M., Nordh, N.-E., 2002. Characterising willows for biomass and phytoremediation: growth, nitrogen and water use of 14 willow clones under different irrigation and fertilisation regimes. Biomass and Bioenergy 23, 397–413. https://doi.org/10.1016/S0961-9534(02)00067-3