Luke
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SuR IWAR

Incorporating Biogenic Carbon in Life Cycle Assessment: A Case Study of Forest-Based Bioethanol in Finland

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BUSINESS FINLAND NESTE PAPTIC fortum For a cleaner world WOODLY SULAPAC

Introduction

- Forest-based bioethanol is perceived as a promising contender for global transportation sector

- Mitigate GHG emissions
- Enhance energy security,
- Reduce reliance on fossil fuels
- Operate as a renewable resource

- Concerns regarding their environmental sustainability and effectiveness in addressing various issues

- Lack of a universally recognized and comprehensive methodological framework for incorporating biogenic carbon emissions

Introduction

- Biogenic carbon (C) emissions and removals
  - C related to land use and land use change (LULUC)
    - Carbon stocks in living biomass
    - Dead organic matter (DOM)
    - Soil carbon (SOC)
  - Short-cycle C associated with the storage and emissions from biobased products

- Biogenic C emissions and removals affect the non-atmospheric reservoirs

- A novel methodological framework is presented to include biogenic C in life cycle assessment with a case study forest-based bioethanol produced from forest residue in Finland.

Methodological framework

- A mass-balanced based approach with temporal allocation for a fixed time period to allocate the net LULUC

- $$GHG_{LULUC,i} = \Delta C_{t,a} \times \frac{44}{12} \text{ (kg } CO_2 \text{ eq.)} \qquad (1)$$

    - $GHG_{LULUC,\,i}$ is the life cycle GHG emissions of product i,
    - $\Delta C_{t,a}$ represents the changes in carbon stock at time t and area a
    - $\Delta C_{t,a}$ is the changes in carbon stock between time T0 and T1 over area a (i.e., $\Delta C_{T1,a} - \Delta C_{T0,a}$)

Methodological framework (Cot’d)

- $$\Delta C_{t,a} = \frac{\Delta C_{LB,t,a} + \Delta C_{DOM,t,a} + \Delta C_{SOC,t,a}}{Harvested\ biomass} \text{ (kg C/m}^3\text{)} \qquad (2)$$

  - $\Delta C_{LB,t,a}$ is the carbon stock change in living biomass contents at time t and area a,
  - $\Delta C_{DOM,t,a}$ is the net carbon stock change in dead organic matter contents at time t and area a,
  - $\Delta C_{SOC,t,a}$ is the net carbon stock change in soils contents per unit time t and area a.

Allocation of C stock changes to products

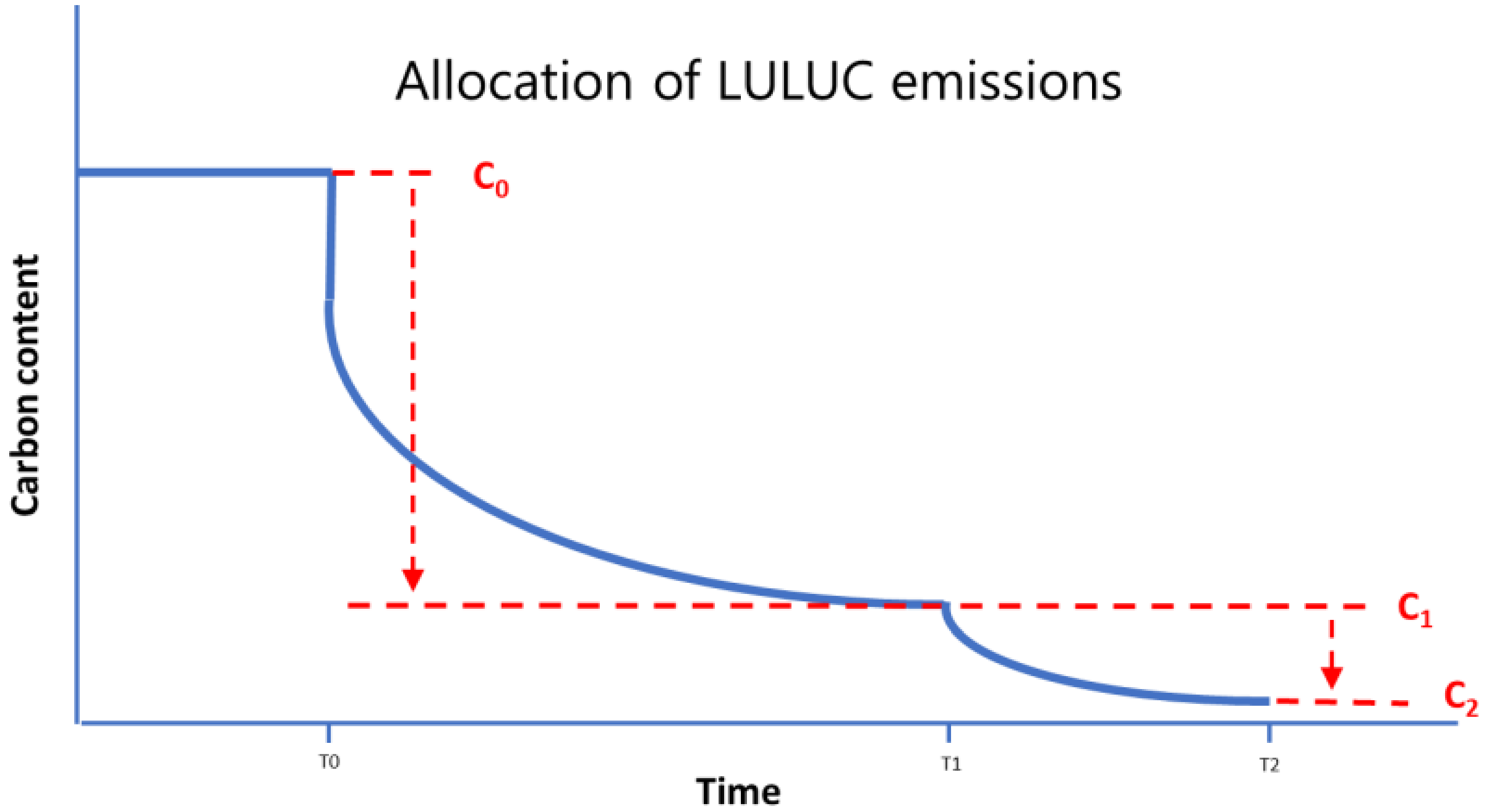

Figure 1: Allocation of C stock changes to forest products

(Leinonen, 2022)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES		ACTIVITY DATA			CHANGES IN CARBON STOCK AND NET CO_2 EMISSIONS/REMOVALS FROM SOILS										
Land-use category	Subdivision[1]	Total area[2] (kha)	Area of mineral soil (kha)	Area of organic soil (kha)	Carbon stock change in living biomass[3] [4]			Net carbon stock change in dead wood[4]	Net carbon stock change in litter[4]	Net carbon stock change in soils [4] [5] [6]		Net CO_2 emissions/ removals [4] [7]	Removals of wood	ΔC	LULUC
					Gains	Losses	Net change			Mineral soils	Organic soils				
					(kt C)							(kt C)	(mil. m3./yr)	(Kg C/ m3)	(Kg CO2/ m3)
National		21849.26	15891.72	5957.54	-	-	7888.75	-	-	1420.42	-1031.55	8277.62	68.98	120	-440.03
Uusimaa		544.00	397.12	146.88	-	-	232.17	-	-	35.55	-25.43	242.29	3.03	80	-293.68
Varsnais-Suomi		617.00	450.41	166.59	-	-	198.09	-	-	40.32	-28.85	209.57	2.88	73	-266.63
Satakunta		539.00	393.47	145.53	-	-	115.87	-	-	35.23	-25.20	125.90	2.93	43	-157.55
Kanta-Häme		360.00	262.80	97.20	-	-	187.01	-	-	23.53	-16.83	193.71	2.38	81	-298.69
Pirkanmaa		992.00	724.16	267.84	-	-	461.57	-	-	64.83	-46.38	480.02	5.91	81	-297.92
Päijät-Häme		402.00	293.46	108.54	-	-	201.07	-	-	26.27	-18.79	208.55	2.84	73	-269.44
Kymenlaakso		323.00	235.79	87.21	-	-	109.48	-	-	21.11	-15.10	115.49	1.94	59	-217.94
South Karelia		417.00	304.41	112.59	-	-	196.39	-	-	27.25	-19.49	204.14	2.48	82	-301.46
Etelä-Savo		1094.00	798.62	295.38	-	-	298.41	-	-	71.50	-51.15	318.76	6.39	50	-182.80
Pohjois-Savo		1394.00	1017.62	376.38	-	-	740.81	-	-	91.10	-65.17	766.75	7.68	100	-366.16
North Karelia		1636.00	1194.28	441.72	-	-	889.49	-	-	106.92	-76.48	919.92	6.96	132	-484.70
Central Finland		1346.00	982.58	363.42	-	-	576.59	-	-	87.97	-62.93	601.63	6.84	88	-322.61
South Ostrobothnia		980.00	715.40	264.60	-	-	471.16	-	-	64.05	-45.82	489.39	3.82	128	-470.24
Ostrobothnia		526.00	383.98	142.02	-	-	245.38	-	-	34.38	-24.59	255.16	2.41	106	-388.37
Central Ostrobothnia		363.00	264.99	98.01	-	-	147.82	-	-	23.72	-16.97	154.57	1.06	146	-534.19
North Ostrobothnia		2900.00	2117.00	783.00	-	-	920.16	-	-	189.52	-135.58	974.11	7.68	127	-464.95
Kainuu		1802.00	1315.46	486.54	-	-	539.74	-	-	117.77	-84.24	573.26	3.81	151	-551.84
Lapland		6661.00	4862.53	1798.47	-	-	1393.45	-	-	435.32	-311.40	1517.36	4.92	309	-1131.97
Åland		90.00	65.70	24.30	-	-	-17.04	-	-	5.88	-4.21	-15.37	0.40	-39	141.21
2016		21876.35	15910.18	5966.17	37215.56	-29935.36	7280.20	IE,NA	IE,NA	1843.99	-1398.75	7725.44	70.00	110	-404.67
2017		21868.82	15904.68	5964.14	37379.13	-30837.43	6541.70	IE,NA	IE,NA	1837.95	-1318.83	7060.82	72.40	98	-357.59
2018		21861.71	15899.67	5962.04	37446.85	-33213.04	4233.81	IE,NA	IE,NA	1561.35	-1121.04	4674.13	78.20	60	-219.16
2019		21854.99	15895.28	5959.71	37514.56	-31257.90	6256.66	IE,NA	IE,NA	1497.51	-1080.44	6673.73	72.90	92	-335.67

Changes of forest C stock in Finland

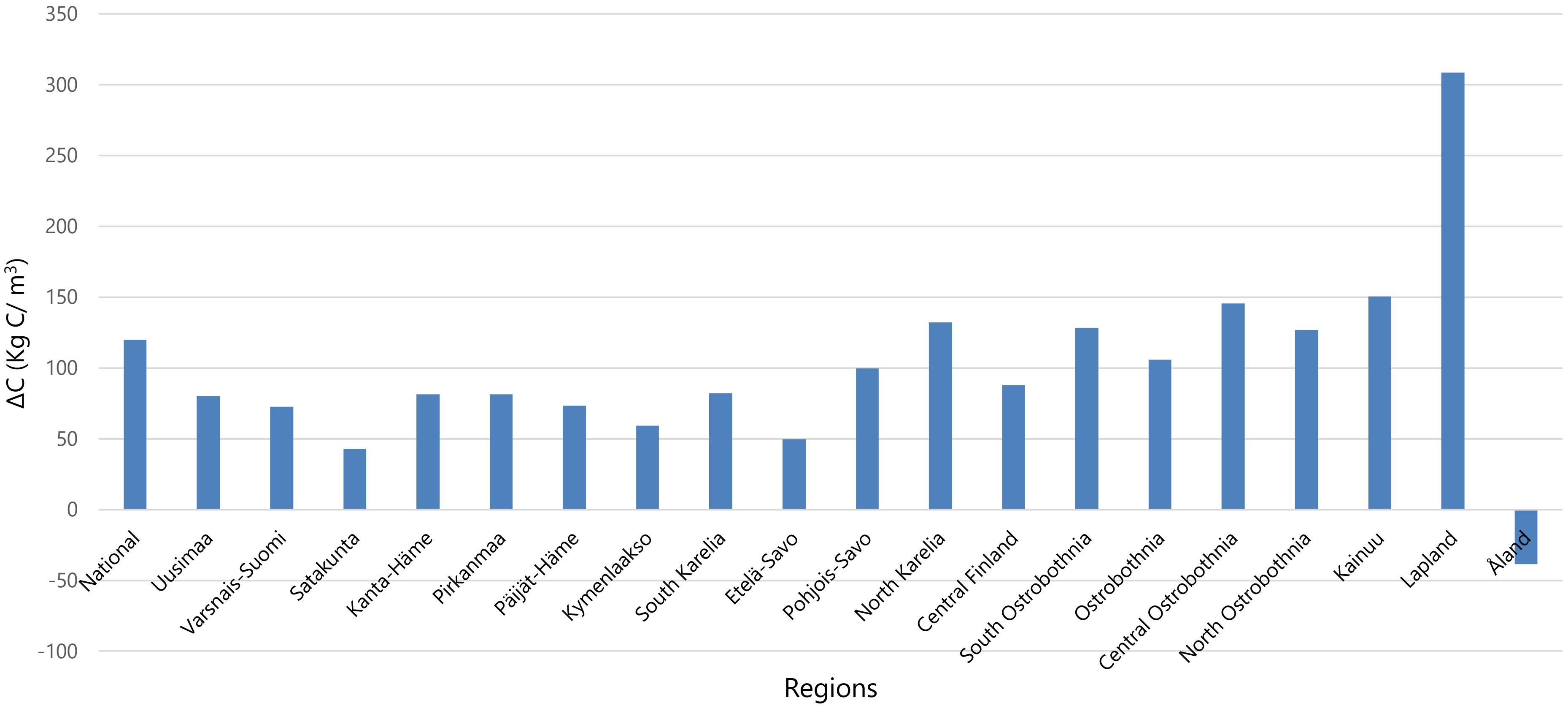

Figure 2: Changes in C stock in different regions of Finland (year 2020).

System boundaries

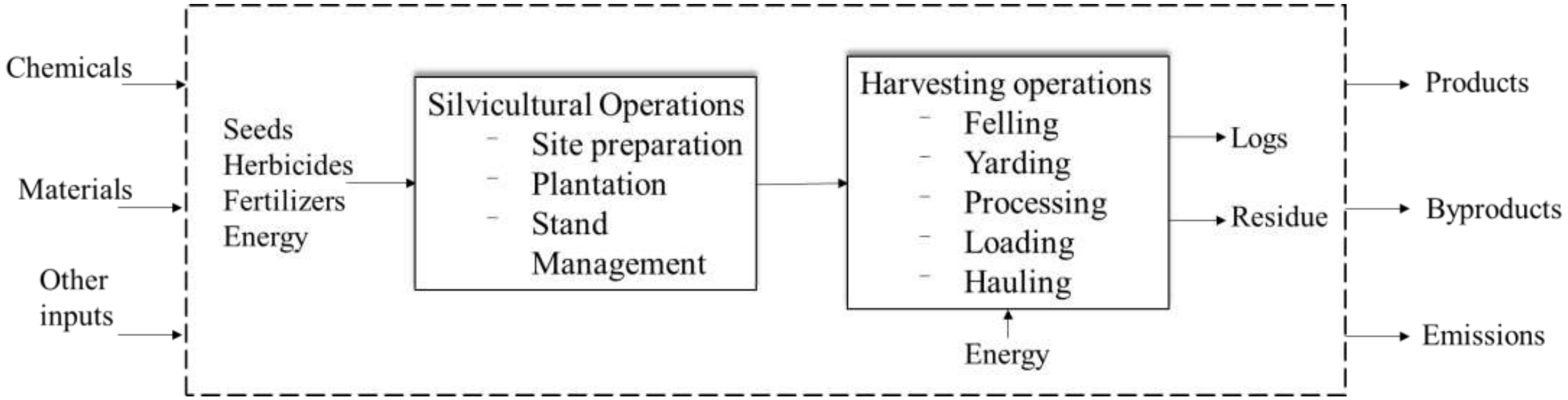

Figure 3: Product system for forest farming.

System boundaries (cont'd)

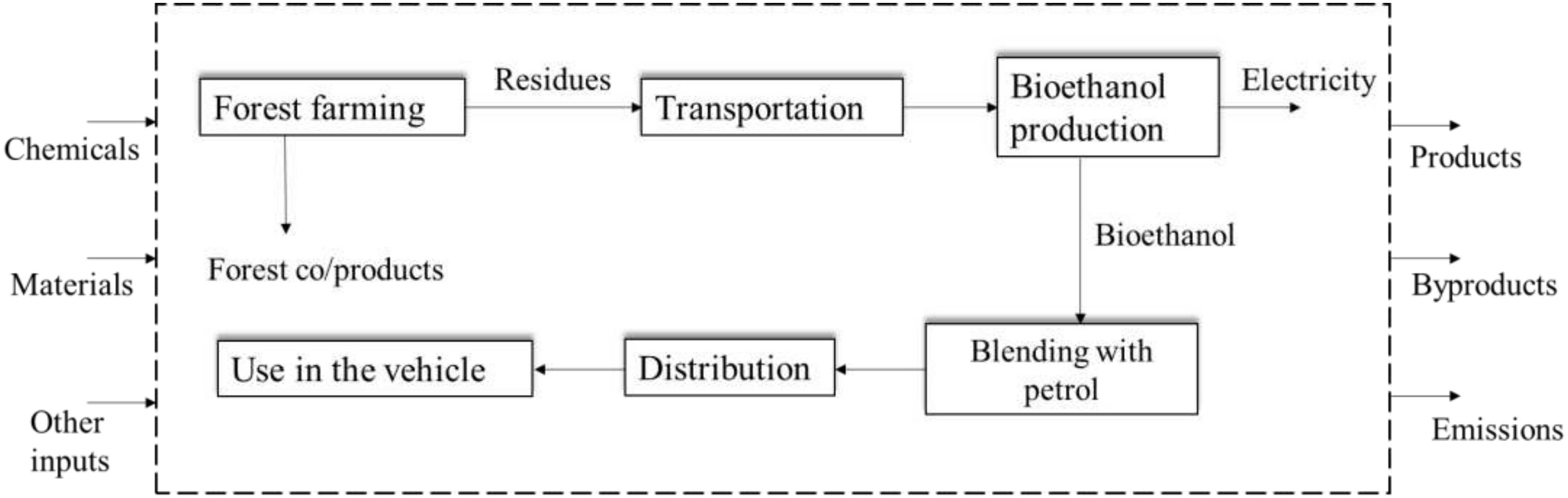

Figure 4: Product system and system boundaries for forest based E20 and E85 use.

Bioethanol production

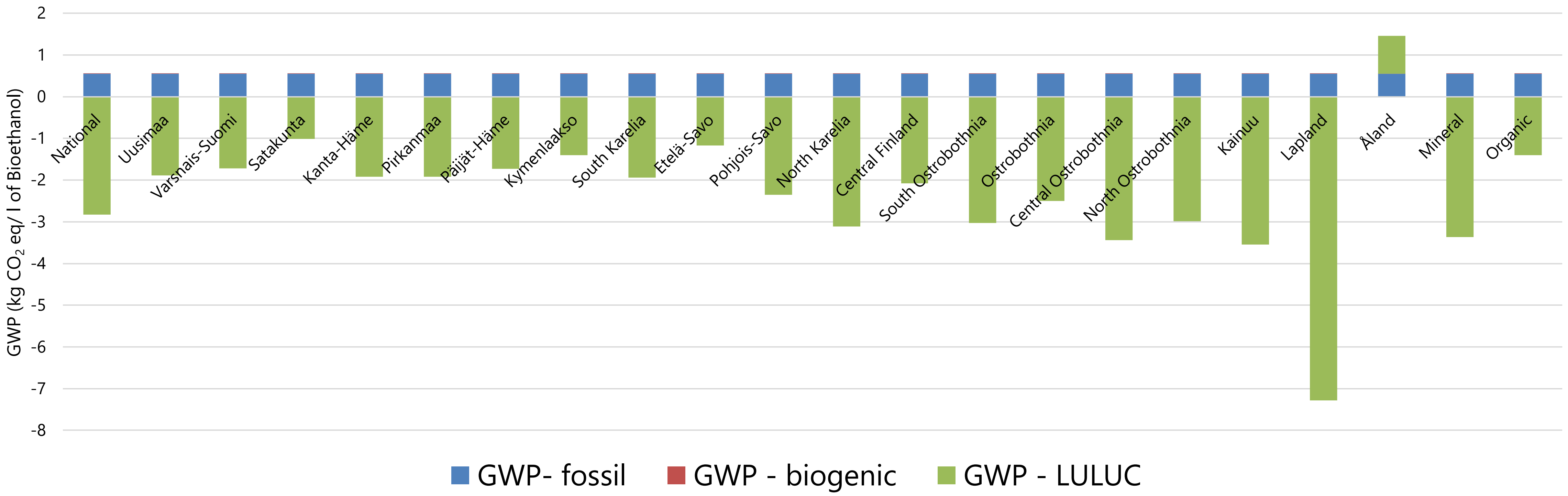

Figure 5: Life cycle GHG emissions of bioethanol production with raw materials from different regions of Finland (year 2020).

GWP of different fuels uses

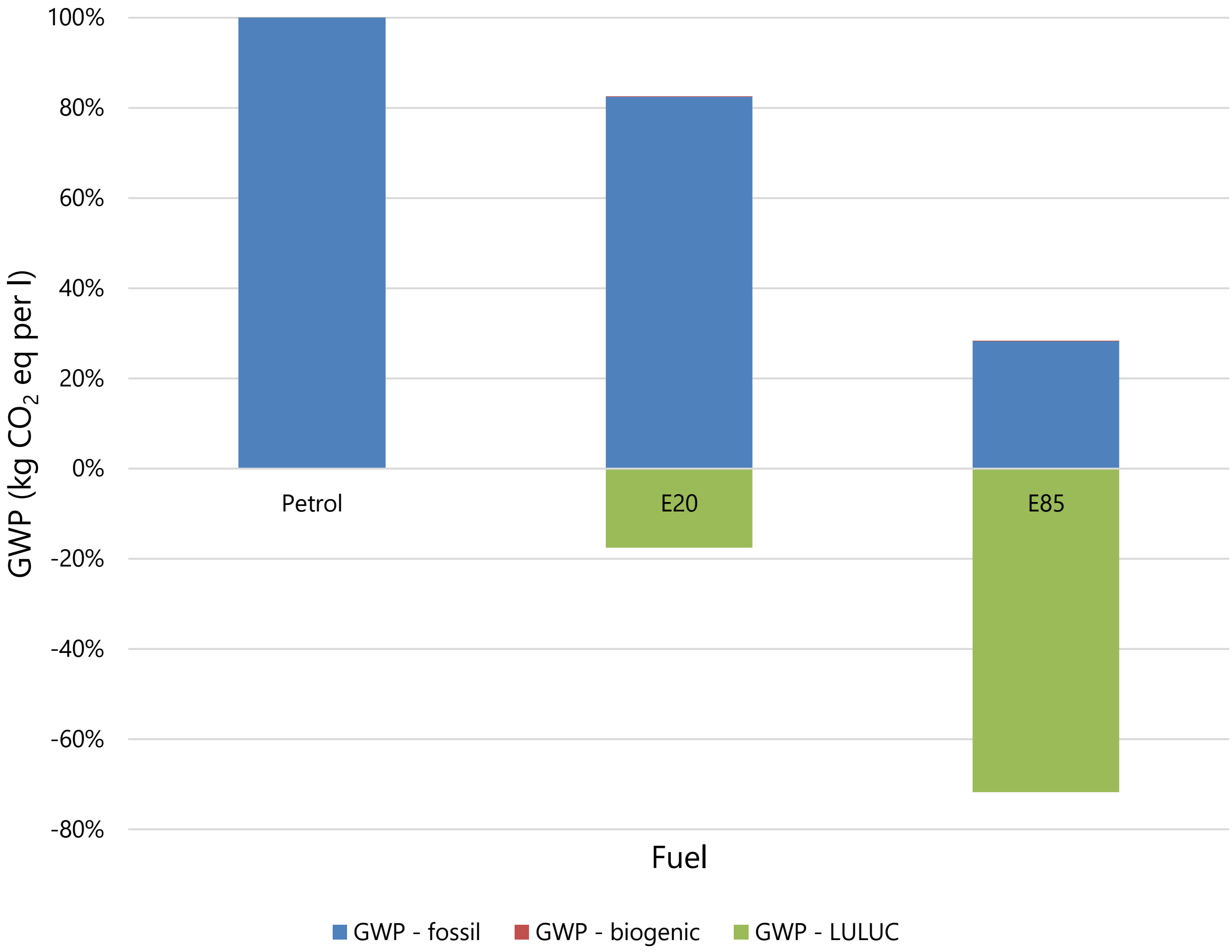

Figure 6: Contribution analysis of different Fuels (year 2020).

GWP of different fuels uses

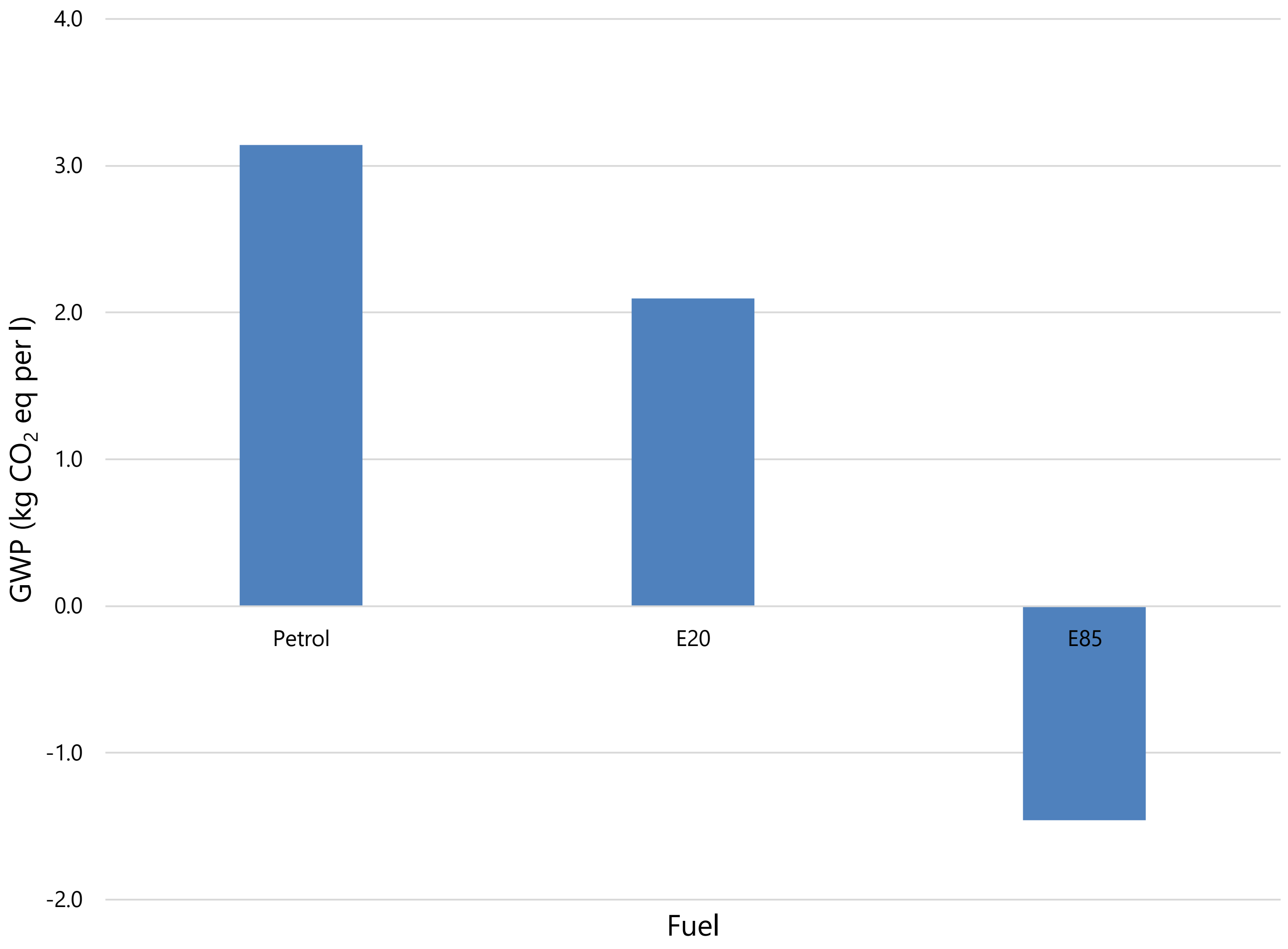

Figure 7: Life cycle GHG emissions from different fuels (year 2020).

GWP in different years

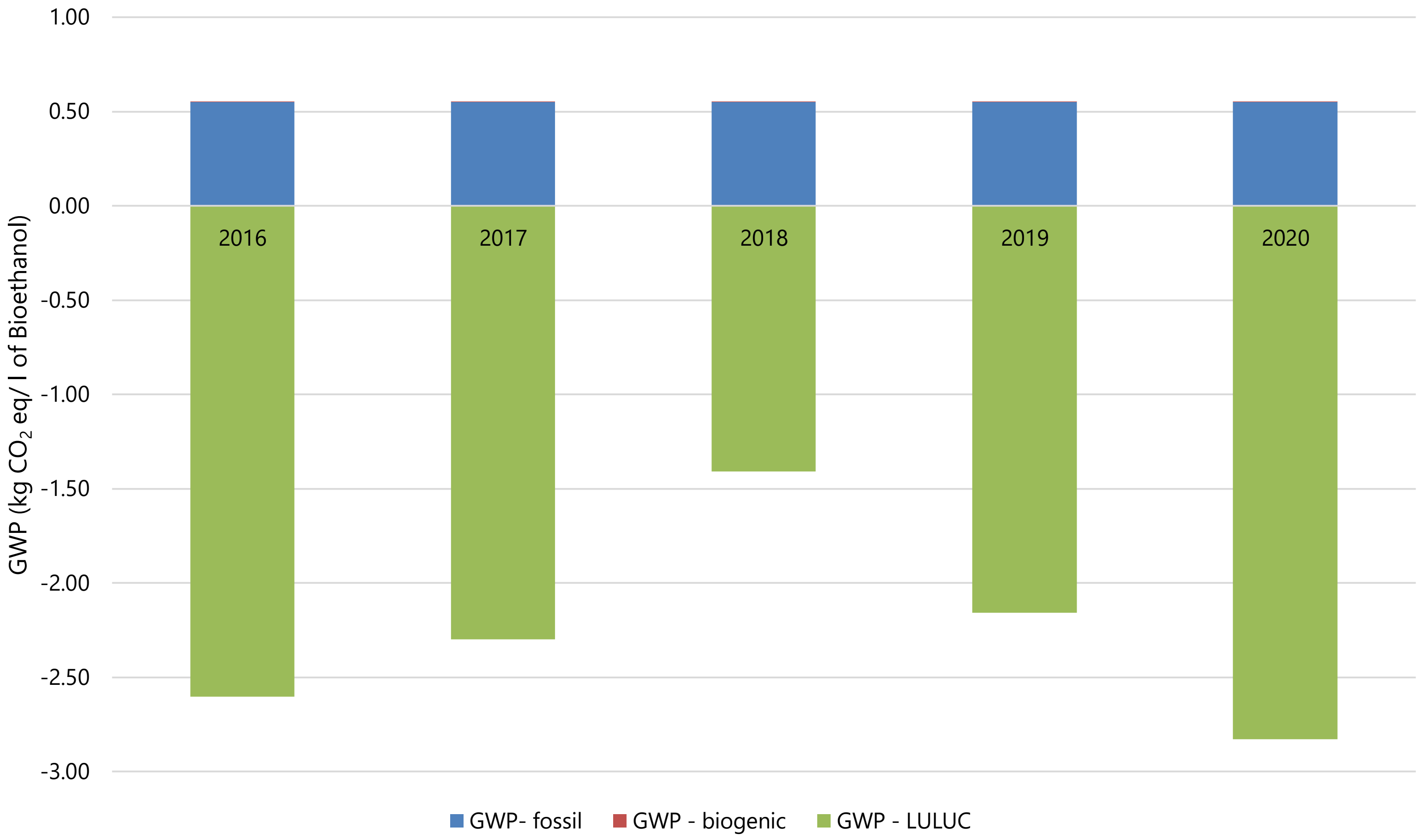

Figure 7: Life cycle GHG emissions of bioethanol production in different years.

Conclusion

Critical Role of Carbon Stock Changes: Carbon stock changes in LULUC play a decisive role in bioethanol's life cycle GHG impacts.

Carbon Sequestration: Forest-based bioethanol production fosters carbon sequestration, driven by vigorous biomass growth in Finnish forests.

Dominance of Carbon Stock Changes: Sequestration from carbon stock changes outweighs fossil impacts from bioethanol's production.

Regional Sequestration Potential: Variable sequestration potential of bioethanol's production, spanning -2 to 13 times fossil impacts, across regions.

Dynamic Sequestration Potential: Sequestration potential fluctuates based on living biomass, ranging from 5 times the total impacts of bioethanol production in 2020 to 3 times in 2020.

Comparative GHG Impacts: E20 and E85 use exhibit 33% and 164% lower life cycle GHG impacts than petrol, respectively.

These findings underscore the pivotal role of carbon stock dynamics in shaping the environmental footprint of bioethanol and highlight the significant potential for emissions reduction offered by bioethanol as a sustainable alternative to conventional fossil fuels.

You can find us online

https://www.luke.fi/en/projects/biolca

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