processes

MDPI

Supplementary Materials

Synthesis of European Union Biorefinery Supply Networks Considering Sustainability Objectives

Sanja Potrč [1], Lidija Čuček [1,*], Mariano Martin [2] and Zdravko Kravanja [1]

[1] Faculty of Chemistry and Chemical Engineering, University of Maribor, Smetanova ulica 17, 2000 Maribor, Slovenia; sanja.potrc@um.si

[2] Department of Chemical Engineering, University of Salamanca, 37008, Salamanca, Spain; mariano.m3@usal.es

* Correspondence: lidija.cucek@um.si; Tel.: +386 222 94 455

Supplementary material consists of:

- Part A: Data for regional plan
- Part B: Hectare yields and harvesting periods for raw materials
- Part C: Data related to eco-profit calculation
- Part D: Data related to technologies and transportation cost
- Part E: Data for social calculations
- Part F: Mathematical model of EU-27 biorefinery supply network

Part A. Data for regional plan

The data for the regional plan shown in Table A1 are collected with Google Maps [1].

Table A1. Data for regional plan

Nodes/items	Location i_{edge}		Location i		Location m		Location n		Location j		Area (km²)
	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	
1	37.0727	-8.9024	38.1259	-8.1079	38.1475	-8.0319	38.1259	-8.1079	38.7329	-9.1503	30,696.67
2	39.0533	-9.3621	39.8170	-8.1299	39.7917	-8.1857	39.8170	-8.1299	41.1704	-8.6370	30,696.67
3	42.0330	-8.6370	41.2943	-8.0090	41.3108	-7.9165	41.2943	-8.0090	41.5661	-8.4063	30,696.67
4	37.2128	-7.3516	37.4487	-6.3940	37.4138	-6.2749	37.4487	-6.3940	40.4219	-3.6821	36,097.86
5	36.6243	-5.2844	37.2828	-4.6692	37.2527	-4.5980	37.2828	-4.6692	41.3881	2.1718	36,097.86
6	36.9323	-4.1343	37.3352	-2.6367	37.4051	-2.5644	37.3352	-2.6367	39.4728	-0.3764	36,097.86
7	38.6169	-7.1445	39.1982	-5.8887	39.1982	-5.7504	39.1982	-5.8887	37.4182	-5.9884	36,097.86
8	38.7883	-5.4746	39.3006	-4.2627	39.2493	-4.1563	39.3006	-4.2627	41.6534	-0.8900	36,097.86
9	38.4622	-0.8164	39.5549	-1.6919	39.5379	-1.6167	39.5549	-1.6919	36.7240	-4.4235	36,097.86
10	40.0108	-6.8150	40.8969	-6.1743	40.8221	-6.1650	40.8969	-6.1743	37.9932	-1.1302	36,097.86
11	39.7748	-4.8594	40.5806	-3.3179	40.5639	-3.2207	40.5806	-3.3179	43.2587	-2.9238	36,097.86
12	39.8423	-2.3325	40.5138	-0.7690	40.5138	-0.6939	40.5138	-0.7690	38.3470	-0.4913	36,097.86
13	42.1634	-8.7925	43.0046	-7.9321	42.9966	-7.9133	43.0046	-7.9321	37.8895	-4.7801	36,097.86
14	42.0167	-6.8150	42.6824	-5.7129	42.6865	-5.7961	42.6824	-5.7129	41.6570	-4.7235	36,097.86
15	41.9186	-4.0025	42.5045	-2.6147	42.4721	-2.6604	42.5045	-2.6147	42.2468	-8.7126	36,097.86
16	41.7057	-2.1568	42.1145	-0.0220	42.0656	-0.0457	42.1145	-0.0220	43.5438	-5.6645	36,097.86
17	39.6099	2.4358	39.6226	2.9883	39.6057	3.0415	39.6226	2.9883	39.5824	2.6418	36,097.86
18	39.5040	8.5220	40.8803	9.1626	40.8720	9.2817	40.8803	9.1626	39.3003	9.1279	37,667.50
19	45.1665	6.9966	45.5679	8.4595	45.5217	8.4138	45.5679	8.4595	41.9595	12.4678	37,667.50
20	44.1270	7.8205	44.7623	8.8110	44.7623	8.7434	44.7623	8.8110	45.4674	9.1845	37,667.50
21	45.8977	13.2588	46.1950	11.8872	46.1798	11.7756	46.1950	11.8872	40.8512	14.2691	37,667.50
22	43.8345	12.5649	44.6843	11.7334	44.6608	11.6877	44.6843	11.7334	45.0740	7.6855	37,667.50
23	41.9350	12.5615	42.6663	12.8320	42.5693	12.8193	42.6663	12.8320	38.1165	13.3614	37,667.50

Table A1 - continuation. Data for the regional plan

Nodes / items	Location i_{edge}		Location i		Location m		Location n		Location j		Area (km²)
	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	
24	40.0444	15.7729	40.6640	16.0840	40.6556	16.0117	40.6640	16.0840	44.4063	8.9462	37,667.50
25	36.8093	14.8466	37.6666	14.3481	37.6316	14.4765	37.6666	14.3481	44.4975	11.3392	37,667.50
26	45.5217	13.6855	46.0427	14.6558	45.9970	14.5205	46.0427	14.6558	46.0599	14.5080	20,273.00
27	41.1952	22.6504	40.3130	21.6211	40.3198	21.5419	40.3130	21.6211	37.9615	23.7288	32,989.25
28	39.1812	20.8393	38.9594	21.8408	39.0448	21.7177	38.9594	21.8408	40.6640	22.9268	32,989.25
29	38.0913	21.2129	37.3003	22.2803	37.3352	22.3306	37.3003	22.2803	38.2641	21.7183	32,989.25
30	40.9301	26.2539	41.1290	24.3896	41.1787	24.2885	41.1290	24.3896	39.6818	22.4104	32,989.25
31	41.4427	22.9800	42.0982	23.5767	42.0656	23.5518	42.0982	23.5767	42.7067	23.3003	27,719.75
32	42.0003	27.6601	42.3585	26.2134	42.2610	26.2336	42.3585	26.2134	42.1715	24.7285	27,719.75
33	44.1586	22.6411	43.3731	23.6426	43.3571	23.6628	43.3731	23.6426	43.2062	27.9107	27,719.75
34	43.6122	28.3760	43.4848	26.5869	43.4529	26.5852	43.4848	26.5869	42.5050	27.4637	27,719.75
35	43.9137	22.8262	44.5748	23.6865	44.6374	23.5513	44.5748	23.6865	44.4343	26.1048	26,487.89
36	44.1664	27.0669	44.4965	25.7300	44.5435	25.6508	44.4965	25.7300	46.7925	23.5923	26,487.89
37	43.9454	28.5830	44.9026	28.1030	44.9337	27.9897	44.9026	28.1030	45.7579	21.2358	26,487.89
38	46.0885	20.3213	45.9206	22.3624	45.9512	22.5405	45.9206	22.3624	47.1589	27.5907	26,487.89
39	45.9206	25.9902	46.1189	24.3896	46.1342	24.4521	46.1189	24.3896	44.1664	28.6269	26,487.89
40	45.6908	28.1216	46.3166	27.0483	46.3469	26.9131	46.3166	27.0483	44.3553	23.7710	26,487.89
41	46.6645	21.3540	47.3239	22.9395	47.2941	23.0019	47.3239	22.9395	45.7369	25.6167	26,487.89
42	46.5589	23.6611	47.3537	25.1807	47.3239	25.0995	47.3537	25.1807	45.3985	28.0117	26,487.89
43	47.9899	25.8144	47.0851	27.2021	47.0851	27.3086	47.0851	27.2021	45.1356	26.0781	26,487.89
44	46.9052	16.2124	46.9503	17.1606	46.8977	17.1260	46.9503	17.1606	47.5320	19.0266	31,009.33
45	45.9512	18.4097	47.2643	19.4458	47.2419	19.4770	47.2643	19.4458	47.5469	21.6304	31,009.33
46	46.6645	21.2441	47.9311	21.4014	47.9163	21.4216	47.9311	21.4014	46.2634	20.1472	31,009.33
47	48.3270	17.0693	48.6474	18.4351	48.5893	18.3894	48.6474	18.4351	48.1514	17.0930	24,517.50
48	49.0523	22.3867	48.9225	20.3687	48.8936	20.3999	48.9225	20.3687	48.7127	21.2458	24,517.50
49	47.2941	9.6865	47.2196	11.4258	47.2121	11.4131	47.2196	11.4258	48.2466	16.3569	27,957.00
50	47.0252	12.2793	47.3239	13.6011	47.3239	13.7202	47.3239	13.6011	47.0626	15.4231	27,957.00
51	47.1150	15.1357	48.3584	15.5127	48.3489	15.5549	48.3584	15.5127	48.3270	14.2805	27,957.00
52	49.1673	15.0478	49.7671	13.4912	49.7387	13.4675	49.7671	13.4912	50.0783	14.4233	39,433.50

Table A1 - continuation. Data for the regional plan

Nodes / items	Location i_{edge}		Location i		Location m		Location n		Location j		Area (km²)
	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	
53	49.4967	18.2558	49.7671	16.2598	49.7458	16.2580	49.7671	16.2598	49.1961	16.6096	39,433.50
54	43.4210	-1.6514	43.7552	-0.2637	43.7632	-0.3423	43.7552	-0.2637	48.8647	2.3384	42,895.13
55	42.6178	2.9189	43.4050	2.0435	43.3731	2.0527	43.4050	2.0435	43.3412	5.3359	42,895.13
56	44.3867	-1.1900	45.5525	0.3296	45.5140	0.3169	45.5525	0.3296	45.7982	4.8525	42,895.13
57	44.5905	1.5786	45.3521	3.1421	45.3444	3.1184	45.3521	3.1421	43.6122	1.4028	42,895.13
58	43.1491	6.2368	44.4965	5.7129	44.5357	5.6233	44.4965	5.7129	43.7552	7.2475	42,895.13
59	48.5312	-4.6177	48.1954	-2.6807	48.2100	-2.7483	48.1954	-2.6807	47.2046	-1.5635	42,895.13
60	45.9970	-1.0801	47.2345	-0.7910	47.2494	-0.7048	47.2345	-0.7910	48.6184	7.6870	42,895.13
61	45.9817	0.1284	46.9353	1.5601	46.9203	1.5144	46.9353	1.5601	43.6122	3.8857	42,895.13
62	45.4755	2.0400	45.7675	3.9990	45.8288	4.0742	45.7675	3.9990	44.8403	-0.6187	42,895.13
63	45.3367	7.0735	45.5371	6.1743	45.5833	6.0830	45.5371	6.1743	50.6599	3.0525	42,895.13
64	49.5395	-1.3877	48.3562	-0.2637	48.4486	-0.3209	48.3562	-0.2637	48.1221	-1.7612	42,895.13
65	49.0811	0.7217	48.0340	2.1313	48.0928	2.2158	48.0340	2.1313	49.2678	4.0615	42,895.13
66	48.7489	3.2705	47.6802	4.8779	47.7098	4.8965	47.6802	4.8779	49.5109	0.0845	42,895.13
67	50.9584	2.3696	49.6249	2.3950	49.6961	2.5015	49.6249	2.3950	45.4909	4.3472	42,895.13
68	49.9229	4.2812	48.7489	5.8008	48.7213	5.9051	48.7489	5.8008	43.1170	5.9072	42,895.13
69	49.6605	5.6343	50.3875	5.2480	50.3665	5.2827	50.3875	5.2480	51.2138	4.3928	15,264.00
70	51.0828	2.6333	50.8753	4.0303	50.8822	3.9643	50.8753	4.0303	51.0414	3.7117	15,264.00
71	53.3571	6.7861	52.9089	6.1709	52.9222	6.0957	52.9089	6.1709	52.3756	4.8872	20,771.50
72	51.3031	4.0395	51.9578	5.2920	51.9578	5.2278	51.9578	5.2920	51.9036	4.4587	20,771.50
73	49.5537	6.5005	49.9229	7.4268	49.9371	7.3354	49.9229	7.4268	52.5229	13.3559	27,463.23
74	47.8132	7.9287	48.4875	9.0967	48.5039	8.9175	48.4875	9.0967	53.5534	10.0161	27,463.23
75	47.7393	12.7627	48.4146	11.7773	48.4146	11.8398	48.4146	11.7773	48.1221	11.5762	27,463.23
76	49.2678	8.2803	49.9654	8.9209	50.0783	8.9417	49.9654	8.9209	50.9446	6.8960	27,463.23
77	49.4253	9.6426	50.1910	11.1841	50.1530	10.9929	50.1910	11.1841	50.1206	8.6977	27,463.23
78	50.7225	6.2588	51.4266	7.3608	51.5087	7.3892	51.4266	7.3608	48.7779	9.1592	27,463.23
79	51.0828	8.7417	51.7814	9.4043	51.7765	9.2910	51.7814	9.4043	51.2344	6.7641	27,463.23
80	51.2482	12.3232	51.8629	11.2061	51.9046	11.1488	51.8629	11.2061	51.5771	7.4453	27,463.23
81	51.2344	14.8061	51.9849	13.6230	52.0119	13.7075	51.9849	13.6230	51.4677	16.6096	27,463.23

Table A1 - continuation. Data for the regional plan

Nodes / items	Location i_{edge}		Location i		Location m		Location n		Location j		Area (km²)
	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	
82	53.5925	7.0718	53.2389	8.4814	53.3702	8.4659	53.2389	8.4814	53.0544	6.9839	27,463.23
83	53.8396	12.0376	53.1599	10.7446	53.2089	10.8170	53.1599	10.7446	51.0276	8.7856	27,463.23
84	52.8559	13.9712	53.7747	13.2275	53.8143	13.3559	53.7747	13.2275	51.3443	13.7515	27,463.23
85	53.7227	10.8071	54.3421	9.5142	54.4061	9.4228	54.3421	9.5142	52.3890	12.3672	27,463.23
86	55.0658	8.6538	56.0475	9.0088	56.0945	8.8735	56.0475	9.0088	55.6900	9.7524	14,364.67
87	56.4261	10.4556	56.9450	9.9316	57.0166	9.9941	56.9450	9.9316	56.1456	12.6089	14,364.67
88	55.0154	12.1035	55.5162	11.7993	55.5783	11.9717	55.5162	11.7993	55.4290	10.1919	14,364.67
89	55.4664	13.9272	56.1700	13.6890	56.2067	13.8613	56.1700	13.6890	59.2883	10.3677	37,524.58
90	57.9732	11.7739	57.4449	14.3262	57.5394	14.4765	57.4449	14.3262	57.6924	18.0141	37,524.58
91	60.8342	12.5210	59.6011	12.8760	59.6455	12.7627	59.6011	12.8760	55.5908	11.9717	37,524.58
92	60.4572	18.0581	59.3220	16.7651	59.4004	16.6079	59.3220	16.7651	59.8448	12.9824	37,524.58
93	61.3335	16.9375	60.8235	14.2603	60.8770	14.0371	60.8235	14.2603	59.6455	17.6406	37,524.58
94	63.2237	12.1255	63.0450	15.7764	63.1047	15.6191	63.0450	15.7764	59.2883	16.4761	37,524.58
95	64.3209	20.8706	64.6427	17.1826	64.7085	17.0034	64.6427	17.1826	58.4132	15.2016	37,524.58
96	67.1444	16.3882	66.2580	16.9629	66.2492	16.7837	66.2580	16.9629	56.0352	15.6191	37,524.58
97	65.8478	23.6391	65.9823	21.1597	66.0448	20.9805	65.9823	21.1597	57.7862	12.6748	37,524.58
98	68.5443	18.2558	67.8092	19.0503	67.9004	18.8508	67.8092	19.0503	58.5969	14.1250	37,524.58
99	67.1785	23.3974	67.6008	22.1045	67.6218	21.8721	67.6008	22.1045	55.7395	16.2124	37,524.58
100	68.3749	22.4306	68.4557	21.0498	68.5202	20.8926	68.4557	21.0498	63.8794	13.1802	37,524.58
101	68.9899	21.0903	68.5524	23.3130	68.6085	23.1084	68.5524	23.3130	60.1634	20.2080	33,814.50
102	68.8556	28.3413	69.5191	27.1802	69.5959	26.9756	69.5191	27.1802	60.2180	24.9355	33,814.50
103	67.4581	29.3301	67.9004	27.8833	67.9417	27.7226	67.9004	27.8833	61.5017	24.6059	33,814.50
104	65.9106	24.3423	66.8524	24.7852	66.9128	24.9541	66.8524	24.7852	60.3378	23.7490	33,814.50
105	66.3992	29.3301	67.1700	27.5977	67.1290	27.7105	67.1700	27.5977	65.0072	25.0234	33,814.50
106	64.8583	29.5498	65.2291	28.3008	65.2668	28.2024	65.2291	28.3008	60.4464	25.4629	33,814.50
107	62.1758	21.5737	63.2831	23.5986	63.3218	23.8554	63.2831	23.5986	62.2781	22.2768	33,814.50
108	62.9152	31.4175	63.0749	28.2129	63.1336	28.1621	63.0749	28.2129	62.8952	25.7485	33,814.50
109	60.2180	24.4741	61.1538	23.0493	61.2280	23.2402	61.1538	23.0493	60.9731	27.6821	33,814.50
110	61.4808	29.3520	61.1856	26.7847	61.2702	26.6240	61.1856	26.7847	60.8770	25.6606	33,814.50

Table A1 - continuation. Data for the regional plan

Nodes / items	Location i_{edge}		Location i		Location m		Location n		Location j		Area (km²)
	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	Lat	Lon	
111	59.3724	27.8267	59.2659	26.0596	59.3444	26.1660	59.2659	26.0596	59.4339	24.7378	22,614.00
112	57.6219	27.2664	58.2517	26.4551	58.2517	26.3857	58.2517	26.4551	58.3902	26.7153	22,614.00
113	56.1761	28.1013	56.4625	27.2021	56.4625	27.2646	56.4625	27.2021	56.9450	24.1225	21,529.67
114	56.2434	25.6184	57.2315	25.4224	57.3028	25.4848	57.2315	25.4224	55.8753	26.5395	21,529.67
115	56.4078	23.3772	57.1243	22.0166	57.1601	22.0791	57.1243	22.0166	56.4868	21.0024	21,529.67
116	56.0229	21.1470	55.7889	22.1924	55.8136	22.2768	55.7889	22.1924	54.6992	25.2651	21,766.67
117	54.9524	25.7612	55.4664	25.1587	55.5038	25.1992	55.4664	25.1587	54.9019	23.9248	21,766.67
118	54.2074	25.0581	54.5466	24.1479	54.5975	24.3203	54.5466	24.1479	55.7271	21.1562	21,766.67
119	53.8914	14.6743	53.8655	15.9521	53.9819	15.9169	53.8655	15.9521	52.2009	21.0024	34,742.78
120	54.7880	17.9482	53.8007	18.9844	53.8561	18.9370	53.8007	18.9844	50.1065	19.9038	34,742.78
121	52.9354	23.7490	53.6186	21.7529	53.6817	21.9473	53.6186	21.7529	51.7542	19.4424	34,742.78
122	51.9036	14.8061	52.5095	15.8423	52.5431	15.9707	52.5095	15.8423	51.1104	17.0254	34,742.78
123	51.3031	20.9145	52.2009	19.0942	52.2547	18.9590	52.2009	19.0942	52.4024	16.9155	34,742.78
124	51.0138	23.6611	51.8629	21.8628	51.9443	21.7715	51.8629	21.8628	54.3293	18.6514	34,742.78
125	50.0924	18.1020	51.0414	16.2817	51.1380	16.3662	51.0414	16.2817	53.4357	14.5205	34,742.78
126	49.7103	20.3432	50.7643	18.9844	50.8337	19.1348	50.7643	18.9844	53.1336	18.0141	34,742.78
127	49.3824	22.6064	50.5972	22.2803	50.6251	22.1450	50.5972	22.2803	51.2344	22.5405	34,742.78
128	52.2413	-7.4522	52.1605	-8.9429	52.2682	-8.8584	52.1605	-8.9429	53.3440	-6.2437	35,136.50
129	53.2915	-6.5073	53.5925	-8.1958	53.6446	-8.1113	53.5925	-8.1958	51.8765	-8.5069	35,136.50
130	34.9670	32.3640	34.9330	32.8589	34.9895	33.0955	34.9330	32.8589	35.1783	33.3650	9,251.00
131	45.2364	13.6449	44.6922	15.4741	44.7293	15.3258	44.6922	15.4741	44.6824	15.3645	28,297.00
132	45.2170	19.0611	45.5353	17.5835	45.5430	17.6714	45.5353	17.5835	45.4254	17.6521	28,297.00

Part B. Hectare yields and harvesting periods for raw materials

Table B1. Hectare yields (in 1,000 t/(km²·year)) and harvesting periods for raw materials.

Raw material/ Country	Corn grain[a]	Wheat[b]	Corn Stover[c]	Wheat straw[d]	Miscanthus[e]	Forest residue[a]	Algae[f]	Cooking oil[f]
Austria	1.00	0.50	0.60	0.51	1.00	0.007	0.00	$8.17 \cdot 10^{-5}$
Belgium	1.15	0.85	0.69	0.87	2.70	0.008	0.00	$28.50 \cdot 10^{-5}$
Bulgaria	0.42	0.33	0.25	0.34	0.00	0.016	0.00	$5.29 \cdot 10^{-5}$
Croatia	0.58	0.45	0.35	0.46	1.50	0.016	0.00	$6.31 \cdot 10^{-5}$
Cyprus	0.00	0.18	0.00	0.18	1.00	0.000	1.52	$10.30 \cdot 10^{-5}$
Czech Republic	0.70	0.50	0.42	0.51	2.00	0.016	0.00	$10.80 \cdot 10^{-5}$
Denmark	0.54	0.72	0.32	0.73	2.13	0.018	0.00	$10.70 \cdot 10^{-5}$
Estonia	0.00	0.28	0.00	0.29	1.50	0.001	0.00	$2.35 \cdot 10^{-5}$
Finland	0.00	0.34	0.00	0.35	0.14	0.011	0.00	$1.30 \cdot 10^{-5}$
France	0.88	0.70	0.53	0.71	2.03	0.014	0.10	$8.50 \cdot 10^{-5}$
Germany	0.92	0.74	0.55	0.75	2.58	0.024	0.00	$19.00 \cdot 10^{-5}$
Greece	1.05	0.26	0.63	0.27	1.20	0.001	0.00	$6.80 \cdot 10^{-5}$
Hungary	0.58	0.40	0.35	0.41	0.83	0.011	0.00	$8.92 \cdot 10^{-5}$
Ireland	0.00	0.83	0.00	0.84	1.50	0.005	0.00	$7.93 \cdot 10^{-5}$
Italy	0.90	0.35	0.54	0.36	1.71	0.018	0.76	$16.90 \cdot 10^{-5}$
Latvia	0.00	0.33	0.00	0.34	1.50	0.014	0.00	$2.83 \cdot 10^{-5}$
Lithuania	0.44	0.37	0.26	0.38	1.50	0.006	0.00	$4.50 \cdot 10^{-5}$
Netherlands	1.16	0.84	0.70	0.87	2.70	0.003	0.00	$33.60 \cdot 10^{-5}$
Poland	0.60	0.39	0.36	0.40	1.79	0.009	0.00	$10.20 \cdot 10^{-5}$
Portugal	0.63	0.15	0.38	0.15	1.70	0.011	0.51	$9.76 \cdot 10^{-5}$
Romania	0.34	0.27	0.20	0.28	0.00	0.011	0.00	$7.64 \cdot 10^{-5}$
Slovakia	0.56	0.40	0.34	0.41	1.20	0.010	0.00	$9.32 \cdot 10^{-5}$
Slovenia	0.71	0.45	0.43	0.46	2.20	0.035	0.00	$8.21 \cdot 10^{-5}$
Spain	1.00	0.30	0.60	0.30	0.92	0.002	0.98	$7.76 \cdot 10^{-5}$
Sweden	0.00	0.59	0.00	0.60	0.40	0.008	0.00	$1.76 \cdot 10^{-5}$

Harvesting periods: [a] September – November, [b] May – July, [c] October – November, [d] June-July, [e] November – February, [f] January – December

Part C. Data related to eco-profit calculation

Table C1. Eco-cost coefficients of raw materials (in €/kg)

Raw material	Eco-cost coefficient
Corn grain	0.290
Wheat	0.100
Corn stover	0.205
Wheat straw	0.100
Miscanthus	0.050
Forest residue	0.041
Cooking oil	0.282
Algae	0.000
Methanol	0.150

Table C2. Eco-cost coefficients of products (in €/kg)

Product	Eco-cost coefficient
Bioethanol	0.297
Me-diesel	0.400
Et-diesel	0.400
FT-diesel	0.455
Green gasoline	0.473
Gasoline	1.260
Diesel	1.260
Hydrogen	0.000
HydrogenNG	0.410

Table C3. Eco-cost coefficients of pre-treatment for various raw materials (in €/kg)

Raw material	Eco-cost coefficient
Corn grain	0.420
Wheat	/
Corn stover	/
Wheat straw	/
Miscanthus	/
Forest residue	0.030
Cooking oil	/
Algae	/

Eco-cost of waste treatment is 0.013 M€/kt and of transport 0.000048 M€/(kt·km).

Part D. Data related to technologies and transportation cost

Table D1. Data related to technologies for bioethanol, FT-diesel and hydrogen production [2].

Technology	Biochemical conversion of lignocellulosic biomass	Dry-grind process	Gasification and catalytic synthesis	Gasification and syngas fermentation	FT-diesel and green gasoline production	Hydrogen production
Main product	Bioethanol	Bioethanol	Bioethanol	Bioethanol	FT-diesel	H_2
Investment cost (M$)	169	86	335	260	216	148
Capacity (kt/y)	183.97	183.97	183.97	183.97	193.06	60
Biofuel yield (kg/kg_{wet})	0.28	0.32	0.20	0.33	0.19	0.11
Production cost ($/gal)*	0.80	1.24	0.41	0.81	0.72	0.68
Water consumption (gal/gal)	1.66	1.5	0.36	1.59	0.15	-
Energy consumption (MJ/gal)	-10.2	23.3	-9.5	27.2	-62.0	-3.84

*production costs include cost for raw materials, utilities, equipment, chemicals and other costs

Table D2. Data related to technologies for biodiesel production [2].

Technology	Oil extraction	Transesterification of WCO with MeOH	Transesterification of WCO with EtOH	Transesterification of AO with MeOH	Transesterification of AO with EtOH
Main product	Algal oil (AO)	Biodiesel	Biodiesel	Biodiesel	Biodiesel
Investment cost (M$)	93	17	17	17	17
Capacity (kt/y)	243.25	239.84	239.84	229.85	229.85
Biofuel yield (kg/kg_{wet})	0.5	0.96	0.96	0.96	0.96
Production cost ($/gal)*	0.24	0.66	0.66	0.42	0.42
Water consumption (gal/gal)	0	0.33	0.33	0.60	0.60
Energy consumption (MJ/gal)	1.2	1.94	1.94	1.94	1.94

*production costs include cost for raw materials, utilities, equipment, chemicals and other costs

Table D3. Costs of the storage, pre-treatment and biomass deterioration percentage (after [2]).

	Corn grain	Wheat	Corn stover	Wheat straw	Miscanthus	Forest residues	Algal oil	Waste cooking oil
Storage (M$/kt) – dry	0.017	0.017*	0.011	0.011	0.011	0.010	0.010*	0.010*
Drying (M$/kt)	0.016	0	0	0	0	0	0	0
Chipping (M$/kt)	0	0	0	0	0	0.015	0	0
Mechanical cleaning (M$/kt)	0	0	0	0	0	0	0	0.030
Additional treatment (M$/kt)	0	0	0	0	0	0	0	0.060
Oil extraction (M$/kt)	0	0	0	0	0	0	0.131**	0
Harvesting loss (%)	3	3	5	5	5	5	0*	0*
Deterioration (%/month)	0.5	0.5	0.5	0.5	0.5	0.5	0*	0*

*assumed

**cost for algal oil production, including algae growing, harvesting and oil extraction

Table D4. Operating costs of the processing technology (after [2]).

Technology	Operating cost ($/gal*)
Biochemical conversion of lignocellulosic biomass	$0.4911 - 0.013 \cdot \frac{c_{\text{Steam}}^{\text{cost}}}{c_{\text{Steam}}^{\text{cost},0}} + 0.3166 \frac{c_{\text{Miscanthus}}^{\text{cost}}}{c_{\text{Miscanthus}}^{\text{cost},0}}$
Dry-grind process	$0.3582 + 0.0908 \cdot \frac{c_{\text{Steam}}^{\text{cost}}}{c_{\text{Steam}}^{\text{cost},0}} + 0.791 \frac{c_{\text{Cereal}}^{\text{cost}}}{c_{\text{Cereal}}^{\text{cost},0}} - 0.178 \frac{c_{\text{DDGS}}^{\text{cost}}}{c_{\text{DDGS}}^{\text{cost},0}}$
Gasification and syngas fermentation	$0.4578 + 0.2744 \cdot \frac{c_{\text{Steam}}^{\text{cost}}}{c_{\text{Steam}}^{\text{cost},0}} + 0.3425 \frac{c_{\text{Lignocellulosic}}^{\text{cost}}}{c_{\text{Lignocellulosic}}^{\text{cost},0}} - 0.4514 \frac{c_{\text{H}_2}^{\text{cost}}}{c_{\text{H}_2}^{\text{cost},0}}$
Gasification and catalytic synthesis	$0.6249 - 0.0248 \cdot \frac{c_{\text{Steam}}^{\text{cost}}}{c_{\text{Steam}}^{\text{cost},0}} + 0.4436 \frac{c_{\text{Lignocellulosic}}^{\text{cost}}}{c_{\text{Lignocellulosic}}^{\text{cost},0}} - 0.636 \frac{c_{\text{H}_2}^{\text{cost}}}{c_{\text{H}_2}^{\text{cost},0}}$
Gasification, FT synthesis and hydrocracking	$0.608 + 0.411 \frac{c_{\text{Lignocellulosic}}^{\text{cost}}}{c_{\text{Lignocellulosic}}^{\text{cost},0}} + 0.0298 \frac{c_{\text{H}_2}^{\text{cost}}}{c_{\text{H}_2}^{\text{cost},0}} - 0.323 \cdot \frac{c_{\text{Steam}}^{\text{cost}}}{c_{\text{Steam}}^{\text{cost},0}}$
Gasification and hydrogen production	$0.4336 - 0.0215 \cdot \frac{c_{\text{Steam}}^{\text{cost}}}{c_{\text{Steam}}^{\text{cost},0}} + 0.3166 \frac{c_{\text{Lignocellulosic}}^{\text{cost}}}{c_{\text{Lignocellulosic}}^{\text{cost},0}}$
Oil extraction	$0.122 + 0.005 \cdot \frac{c_{\text{Steam}}^{\text{cost}}}{c_{\text{Steam}}^{\text{cost},0}}$
Transesterification of waste cooking oil with methanol	$0.1288 + 0.629 \frac{c_{\text{Oil}}^{\text{cost}}}{c_{\text{Oil}}^{\text{cost},0}} - 0.201 \frac{c_{\text{Glycerol}}^{\text{cost}}}{c_{\text{Glycerol}}^{\text{cost},0}} + 0.098 \frac{c_{\text{Methanol}}^{\text{cost}}}{c_{\text{Methanol}}^{\text{cost},0}} + 0.0096 \cdot \frac{c_{\text{Natural gas}}^{\text{cost}}}{c_{\text{Natural gas}}^{\text{cost},0}}$
Transesterification of algal oil with methanol	$0.108 + 0.418 \frac{c_{\text{Oil}}^{\text{cost}}}{c_{\text{Oil}}^{\text{cost},0}} - 0.218 \frac{c_{\text{Glycerol}}^{\text{cost}}}{c_{\text{Glycerol}}^{\text{cost},0}} + 0.110 \frac{c_{\text{Methanol}}^{\text{cost}}}{c_{\text{Methanol}}^{\text{cost},0}} + 0.0095 \cdot \frac{c_{\text{Natural gas}}^{\text{cost}}}{c_{\text{Natural gas}}^{\text{cost},0}}$
Transesterification of waste cooking oil/algal oil with ethanol	$0.1435 + 0.426 \frac{c_{\text{Oil}}^{\text{cost}}}{c_{\text{Oil}}^{\text{cost},0}} - 0.201 \frac{c_{\text{Glycerol}}^{\text{cost}}}{c_{\text{Glycerol}}^{\text{cost},0}} + 0.162 \frac{c_{\text{Ethanol}}^{\text{cost}}}{c_{\text{Ethanol}}^{\text{cost},0}} + 0.0096 \cdot \frac{c_{\text{Natural gas}}^{\text{cost}}}{c_{\text{Natural gas}}^{\text{cost},0}}$

*for gasification and hydrogen production instead of gal, kg is used

Table D5. Transportation cost (after [2]).

Raw material	Distance fixed cost ($/t)	Distance variable cost ($/(t·km))	Product	Distance fixed cost ($/t)	Distance variable cost ($/(t·km))
Corn grain	6.3	0.07*	**Bioethanol**	3.86	0.05
Wheat	6.3*	0.07*	**Biodiesel**	3.86*	0.05*
Corn stover	8.5	0.255	**FT-diesel**	3.86*	0.05*
Wheat straw	8.5	0.255	**Hydrogen**	-	0.8
Miscanthus	8.5	0.255	**Green gasoline**	3.86*	0.05*
Forest residue	10	0.348	**DDGS**	6.3*	0.07*
Algal oil	3.86*	0.05*	**Glycerol**	6.3*	0.07*
Waste cooking oil	3.86*	0.05*			

*assumed

Part E. Data related to social-profit calculation

The data for salaries in each EU Member State are presented in Table E1 and are calculated from national currencies to €.

Table E1. Gross and net wages in EU Member States [3].

Country	Average gross salary (€/month)	Average net salary (€/ month)
Austria	4,261.00	2,885.00
Belgium	3,401.00	2,170.00
Bulgaria	690.00	535.00
Croatia	1,183.00	782.00
Cyprus	1,992.00	1,658.00
Czech Republic	1,320.00	1,005.00
Denmark	5,179.00	3,263.00
Estonia	1,389.00	1,193.00
Finland	3,194.00	2,458.00
France	2,957.00	2,225.00
Germany	4,012.00	2,439.00
Greece	1,060.00	890.00
Hungary	1,204.00	824.00
Ireland	3,300.00	2,564.00
Italy	2,595.00	1,878.00
Latvia	1,081.00	801.00
Lithuania	1,318.00	834.00
Netherlands	2,855.00	2,152.00
Poland	1,308.00	943.00
Portugal	1,276.00	1,038.00
Romania	1,148.00	702.00
Slovakia	1,219.00	917.00
Slovenia	1,897.00	1,234.00
Spain	2,244.00	1,806.00
Sweden	3,380.00	2,509.00

For the calculation of social-profit also next data are considered:
- number of unemployed people at EU level: 15,475,000 [4];
- social transfer for unemployed people: 500 €/month;
- social transfer for employed people: 50 €/month.

Data related to number of employees for construction and operation of involved processes are taken from the Jobs and Economic Development Impact (JEDI) model [5], where construction time of 3 years and the life span of the plant of 20 years are assumed.

Part F. Mathematical model for EU-27 biorefinery supply networks

The modelling with respect to mass and energy balances, as well as production and conversion constraints is represented by equations (F1) - (F8).
The production rate of the considered raw materials (*pi*) in supply zone *i* (level 1 (L1)) and in month *tp* was calculated as the product of the hectare yield (*HY*) and the available area (*A*) of *pi* in zone *i* and in month *tp* using Eq. (F1):

$$q_{i,pi,tp}^{m,\mathrm{L1}} = HY_{i,pi,tp} \cdot A_{i,pi,tp} \quad \text{(F1)}$$

Produced raw materials *pi* are then transported to the storage and pre-treatment facilities at zone *m* (level 2 (L2) (Eq. (F2)):

$$q_{i,pi,tp}^{m,\mathrm{L1}} = \sum_{m} q_{i,m,pi,tp}^{m,\mathrm{L1,L2}} \quad \text{(F2)}$$

Furthermore, each *pi* is stored or applied to the pre-treatment technology *t* at L2; also the harvesting losses (*HL*) for each *pi* are included into calculations (Eq. (F3):

$$\sum_{m} q_{i,m,pi,tp}^{m,\mathrm{L1,L2}} \cdot (1 - HL_{pi}) = \sum_{pi,t} q_{m,pi,t,tp}^{m,\mathrm{T,L2}} \quad \text{(F3)}$$

At the L2 each *pi* is converted into the intermediate product (*pm*) using conversion factor ($f^{\mathrm{conversion}}$) of pretreatment technology *t*:

$$q_{m,pi,t,tp}^{m,\mathrm{T,L2}} \cdot f_{pi,pm,t}^{\mathrm{conversion,T,L2}} = q_{m,pi,pm,t,tp}^{m,\mathrm{T,L2}} \quad \text{(F4)}$$

The intermediate product *pm* is further sent to the zone *n* at level 3 (L3):

$$\sum_{m} q_{m,n,pm,tp}^{m,\mathrm{L2,L3}} = \sum_{pm,t} q_{n,pm,t,tp}^{m,\mathrm{T,L3}} \quad \text{(F5)}$$

where conversion technologies *t* are applied.

Intermediate products *pm* are at L3 converted into the main products *pp* using conversion factor (f^{CON}), which are specified for each raw material and technology *t*:

$$q_{n,pm,t,tp}^{m,\mathrm{T,L3}} \cdot f_{pm,pp,t}^{CON,\mathrm{T,L3}} = q_{n,pm,pp,t,tp}^{m,\mathrm{T,L3}} \quad \text{(F6)}$$

It is also assumed that the pre-processing facilities and conversion technologies operate between minimum and maximum capacities – details are presented in Supplementary material from Čuček et al. [2].

Eq. (F7) represents the losses of energy and materials due to transportation and distribution over the distance ($D_{m,n}^{\mathrm{L2,L3}}$) between location of pre-treatment facility at L2 (location *m*) and production plant at L3 (location *n*), where the losses are defined as $(1 - L_{poutpin}^{\mathrm{trans}})^{D_{m,n}^{\mathrm{L2,L3}}}$:

$$q_{n,m,t,tt,poutpin,tp}^{m,\mathrm{T,L3,L2}} \cdot (1 - L_{poutpin}^{\mathrm{trans}})^{D_{m,n}^{\mathrm{L2,L3}}} = q_{n,m,t,tt,poutpin,tp}^{m,\mathrm{net,T,L3,L2}} \quad \text{(F7)}$$

Note, that also the losses of recycled materials and energy between two different plants al L3 (one at location *n* and other at location *nn*) are calculated using the same equation.

Net flow-rates of the main products at demand location *j* at Level 4 (L4) are calculated as the flow-rates of the same products from technology *t* at the location *n*, deducted by losses related to distribution (Eq. (F8)):

$$q_{n,t,j,pp,tp}^{m,\mathrm{T,L3,L4}} \cdot (1 - L_{pp}^{\mathrm{trans}})^{D_{n,j}^{\mathrm{L3,L4}}} = q_{n,t,j,pp,tp}^{m,\mathrm{net,T,L3,L4}} \quad \text{(F8)}$$

For details on the modelling of intermediate storage facilities at L2 and L3, transport cost, storage, pretreatment, operating and investment costs, please refer to Čuček et al. [2].

Demand

Four equations that consider the demand for food and biofuels are added to the model.

The demand for wheat ($Dem_{\text{wheat},j}$)and corn grain ($Dem_{\text{corn},j}$) is defined with Eq. (F9) and Eq. (F10) and should be satisfied in each zone, while the demand for gasoline and diesel substitutes (Eq. (F11) - (F14)) should be satisfied on the country level in order to meet the EU renewable target in transport in each Member State:

$$Dem_{\text{wheat},j} = \sum_{m}\sum_{tp} q^{m,\text{L2,L4}}_{m,j,tp,\text{wheat}} \tag{F9}$$

$$Dem_{\text{corn},j} = \sum_{m}\sum_{tp} q^{m,\text{L2,L4}}_{m,j,tp,\text{corn}} \tag{F10}$$

$$Dem_{\text{biodiesel},country} = \frac{HHV_{\text{et-diesel}}}{HHV_{\text{diesel}}} \cdot \sum_{n}\sum_{t}\sum_{tp} q^{m,\text{L3,L4}}_{n,t,country,\text{et-diesel},tp} + \frac{HHV_{\text{me-diesel}}}{HHV_{\text{diesel}}} \cdot \sum_{n}\sum_{t}\sum_{tp} q^{m,\text{L3,L4}}_{n,t,country,me\text{-diesel},tp} + \frac{HHV_{\text{FT-diesel}}}{HHV_{\text{diesel}}} \cdot \sum_{n}\sum_{t}\sum_{tp} q^{m,\text{L3,L4}}_{n,t,country,\text{FT-diesel},tp} \tag{F11}$$

$$Dem_{\text{biodiesel},country} = (0.14 - share^{\text{current}}_{\text{biofuels},country}) \cdot Dem_{\text{diesel},country} \tag{F12}$$

$$Dem_{\text{gasoline\_substitutes},country} = \frac{HHV_{\text{ethanol}}}{HHV_{\text{gasoline}}} \cdot \sum_{n}\sum_{t}\sum_{tp} q^{m,\text{L3,L4}}_{n,t,country,\text{ethanol},tp} + \frac{HHV_{\text{green\_gasoline}}}{HHV_{\text{gasoline}}} \cdot \sum_{n}\sum_{t}\sum_{tp} q^{m,\text{L3,L4}}_{n,t,country,\text{green\_gasoline},tp} \tag{F13}$$

$$Dem_{\text{gasoline\_substitutes},country} = (0.14 - share^{\text{current}}_{\text{gasoline\_substitutes},country}) \cdot Dem_{\text{gasoline},country} \tag{F14}$$

Demand for all products is defined in kt/y. In equations (F11) - (F14) symbols represent:
HHV_{fuel} – the higher calorific value for diesel, gasoline, bioethanol, green gasoline, biodiesel and FT-diesel in MJ/kg,
$q^{m,\text{L3,L4}}_{n,t,country,\text{biofuel},tp}$ – the flow rate of all types of biofuel produced from technology *t* at L3 (plant *n*) to demand location *country* at L4 at month period *tp*,
0.14 – the target of renewable energy in transport sector by 2030 (14%) and
$Dem_{\text{substitutes},country}$ – the demand for gasoline and diesel substitutes, which is defined as the difference between the target share (14%) and current share of renewables in each country ($share^{\text{current}}_{\text{substitutes},country}$), multiplied with total diesel and gasoline consumption within the country.

In scenarios 1 and 2, equations (F11) – F(14) are applied as presented, while in Scenarios 3 and 4, production of gasoline and diesel substitutes is greater than the demand. For these scenarios, inequalities (≥) are applied to Equations (F11) – F(14).

Economic Profit

Economic Profit is defined as a difference between Income and Outcome (Eq. (F15)).

$$P^{\text{Economic}} = Income - Outcome = \sum_{n}\sum_{(p,t)}\sum_{j}\sum_{tp} q^{m,\text{net,L3,L4}}_{n,t,j,p,tp} \cdot c^{\text{price}}_{p,tp} + \sum_{m}\sum_{j}\sum_{pd}\sum_{tp} q^{m,\text{L2,L4}}_{m,j,pd,tp} \cdot c^{\text{price}}_{pd,tp} - \left(\sum_{i}\sum_{pi}\sum_{tp} q^{m,\text{L1}}_{i,pi,tp} \cdot c^{\text{cost}}_{pi} + \sum_{m}\sum_{t}\sum_{pbuy}\sum_{tp} q^{m,\text{buy,L2}}_{m,t,pbuy,tp} \cdot c^{\text{cost}}_{pbuy} + \sum_{n}\sum_{t}\sum_{pbuy}\sum_{tp} q^{m,\text{buy,L3}}_{n,t,pbuy,tp} \cdot c^{\text{cost}}_{pbuy} + c^{\text{tr}} + c^{\text{spod}}\right) \quad \text{(F15)}$$

Income represents the revenues (R) from selling products (1. term) and direct products (2. term). Outcome is calculated as the sum of costs for: a) raw materials (c^{cost}_{pi}) – 3. term, b) purchased materials (c^{cost}_{pbuy}) that are needed at L2 (pretreatment) and L3 (biorefineries) – 4. and 5. Term, c) transportation cost (c^{tr}) and d) storage, pretreatment, operating costs, and annual depreciation cost (c^{spod}). The details about calculation of transportation and operating, pretreatment and storage costs are already presented in Supplementary material from Čuček et al. [2].

Eco Profit

Eco cost (EC) is defined using Eq. (F16) and consists of eco cost of raw materials (term 1), products (term 2), technologies (term 3), pretreatment (term 4), transport (term 5) and additional land use (term 6):

$$EC = \sum_{i,m,tp} q^{B}_{i,m,pi,tp} \cdot ecc^{B}_{pi} + \sum_{n,t,j,tp} q^{B}_{n,t,j,pp,tp} \cdot ecc^{B}_{pp} + \sum_{n,m} INV_{n,m,t} \cdot ecc^{B}_{t} + \sum_{n.t.tp} q^{L2,L3}_{n,pm,t,tp} \cdot ecc^{B}_{pretreat} + \left(\sum_{i,pi,m,tp} q^{R}_{i,m,pi,tp} \cdot D^{L1,L2}_{i,m} \cdot ecc^{B}_{tr} + \sum_{m,pm,n,tp} q^{R}_{m,n,pm,tp} \cdot D^{L2,L3}_{m,n} \cdot ecc^{B}_{tr} + \sum_{n,t,j,pp,tp} q^{R}_{n,t,j,pp,tp} \cdot D^{L3,L4}_{n,j} \cdot ecc^{B}_{tr}\right) + ecc_{\text{land}} \cdot \sum_{i} A_{i,piland} \quad \text{(F16)}$$

where:

$q^{B}_{i,m,pi,tp}$ – mass flow-rate of raw materials (pi) that burden the environment at month (tp) from L1 to L2 (i,m),

ecc^{B}_{pi} – eco-cost coefficient of raw materials that burden the environment,

$q^{B}_{n,t,j,pp,tp}$ – mass flow-rate of products (pp) that burden the environment from technology t (plant n) in month (tp) to demand sites (j),

ecc^{B}_{pp} – eco-cost coefficient of products that burden the environment,

$INV_{n,m,t}$ – investment costs for storage and preprocessing facilities (m) and technologies t at L3 (plant n)

ecc^{B}_{t} – eco-cost coefficient of technologies that burden the environment,

$D^{L1,L2}_{i,m}$ – distance between harvesting sites (i) and pre-treatment and storage facilities (m),

$D^{L2,L3}_{m,n}$ – distance between facilities at L2 (m) and technologies at L3 (n),

$D^{L3,L4}_{n,j}$ – distance between technologies at L3 (n) and demand sites (j),

ecc^{B}_{tr}, ecc_{land} – eco-cost coefficient of transport and additional land use, respectively, and

$A_{i,piland}$ –additional are used for cultivation of raw materials.

Eco Benefit (*EB*) is calculated using Eq. (F17):

$$EB = \sum_t \sum_{i \in R} q_{m_i}^{\mathrm{R_{UNB}}} \cdot ebc_{i,t}^{\mathrm{R_{UNB}}} + \sum_t \sum_{j \in P} q_{m_j}^{\mathrm{P_{UNB}}} \cdot f_j^{\mathrm{S/P_{UNB}}} \cdot ebc_{j,t}^{\mathrm{S}} \quad \text{(F17)}$$

where:

$q_{m_i}^{\mathrm{R_{UNB}}}$ – mass flowrate of raw materials that mainly unburden the environment,

$q_{m_j}^{\mathrm{P_{UNB}}}$ – mass flowrate of products that mainly unburden the environment,

$ebc_{i,t}^{\mathrm{R_{UNB}}}$ – eco benefit coefficient for raw materials that mainly unburden the environment,

$ebc_{j,t}^{\mathrm{S}}$ – eco-benefit coefficient for products that unburden the environment,

$f_j^{\mathrm{S/P_{UNB}}}$ – substitution factor, which is defines as the ratio of the quantity of conventional product (S) and product from renewable sources ($\mathrm{P_{UNB}}$).

Eco profit is then the difference between Eco Benefit and Eco Cost.

Social Profit

Social profit is defined using Eq. (F18):

$$P^{\mathrm{Social}} = SS + SU - SC = \sum_t N_t^{\mathrm{Jobs}} \left(s_t^{\mathrm{Gross}} - s_t^{\mathrm{Net}} \right) + \sum_t N_t^{\mathrm{Jobs}} \cdot c_s^{\mathrm{unemployed,\ State}} - \sum_t N_t^{\mathrm{Jobs}} \cdot (c_s^{\mathrm{employed,\ State}} + c_s^{\mathrm{Company}}) \quad \text{(F18)}$$

where:

N_t^{Jobs} – new jobs created, related to technology *t*,

s_t^{Gross} and s_t^{Net} are gross and net salaries, respectively,

$c_s^{\mathrm{unemployed,\ State}}$ – average state social transfer for the unemployed,

$c_s^{\mathrm{employed,\ State}}$ – state social transfer for employees,

c_s^{Company} – the average company's social contribution per employee.

Sustainability profit (SP) is defined as a composite criterion and represents the sum of all three pillars of sustainability (economic, eco and social), which are defined on monetary basis. Therefore, SP is the sum of Economic Profit, Eco Profit and Social Profit.

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