land

Supplementary material

Supplementary material of the paper "Territorial inequalities, ecological and material footprints of the energy transition. Case study of The Cantabrian-Mediterranean Bioregion".

Regarding materials results show the average between high intensity material and low intensity material scenarios.

Table S1. Low material intensity scenario and high material intensity scenario for wind turbines [81], [12].

Material	t/GW	t/GW
Concrete	194,800	413,000
Steel	85,600	172,100
Polymers	3,680	4,600
Glass/carbon composites	6,160	8,400
Al	400	1,600
B	-	6
Cr	376	580
Cu	760	7,000
Dy	1	17
Fe	14,400	20,800
Mn	624	800
Mo	79	119
Nd	6	183
Ni	89	440
Pr	-	35
Tb	-	7
Zn	4,400	5,500

Table S2. Low material intensity scenario and high material intensity scenario for PV [81], [12].

Material	t/MW	t/MW
Concrete	49	61
Steel	54	68
Plastic	7	9
Glass	37	46
Al	6	8
Ag	0	0
Cu	4	5
Si	1	6

Table S3. Use of materials in CSP [12].

Material	t/GW
Ag	14.2
Al	9,644
Cr	2,800
Cu	2,480
Fe	547,200

Mn	3,480
Mo	142
Ni	1,284
Ti	15
V	2
Zn	950

Table S4. Use of materials in hydropower [13].

Material	t/MW
Cu	1.05
Mn	0.20
Ni	0.03
Al	3.40
Cr	1.50
Mg	0.10
Mo	0.25
Zn	0.40

Table S5. Use of materials in bioenergy [13].

Material	t/MW
Cu	2.27
Ti	0.40
Al	3.90
Cr	0.00
Co	0.00
Ni	0.02
Zn	0.16
Steel	5.82

Table S6. Low material intensity scenario and high material intensity scenario for railway infrastructures [83], [84].

Material	t/km	t/km
Cu	11	20
Concrete	2,111	2,111
Steel	437	437
Al	4.38	4.38
Sn	0.18	0.18

Table S7. Low material intensity scenario and high material intensity scenario for trains [83], [84].

Material	t/train	t/train
Cu	3.50	34.53
Al	90.13	90.13
Steel	367.80	367.80

Table S8. Low material intensity scenario and high material intensity scenario for electrical transmissions lines based on current grid planning [38]. Material requirements for substations have been obtained from [85].

Material	t/GW	t/GW
Cu	980	9,844
Al	1,588	5,076
Steel	587	1,722

Table S9. Low material intensity scenario and high material intensity scenario for technology installation in homes and distribution lines. Demand management has been considered in the low material intensity scenario.

Technology	Material	kg/unit	kg/unit
Heat pump	Cu	1.68	14.07
EV	Cu	4.30	18.11

Table S10. Low material intensity scenario for electromobility in g/unit.

Material	Electric bike and Electric scooter[1]	Electric motorcycle[2]	Electric vehicle[3] [80]	Electric bus[4]	Electric light-duty truck[5]	Electric heavy-duty truck[6]
Ag	0.13	1.36	34.67	61.65	57.41	63.33
Al	776.83	6,018.76	161,464.68	473,985.13	194,535.64	420,830.07
As	0.01	0.05	0.88	4.51	1.36	2.67
Au	0.01	0.10	2.41	4.40	4.12	4.37
B	0.07	0.99	42.34	67.74	45.16	95.97
Ba	22.31	108.97	1,634.15	9,330.81	2,223.94	5,175.87
Be	0.00	0.00	0.05	0.08	0.06	0.07
Bi	0.52	2.60	34.50	213.10	51.94	118.56
Cd	0.00	0.01	0.24	0.48	0.32	0.45
Ce	0.00	0.01	0.14	0.94	0.20	0.51
Co	0.21	293.82	2,378.55	1,205.90	581.08	1,378.00
Cr	28.13	270.78	6,534.84	21,201.35	8,574.10	20,449.82
Cu	123.09	1,507.33	44,024.94	85,357.98	58,930.41	94,495.68
Dy	0.08	1.05	44.18	70.78	47.73	99.60
Er	-	-	-	-	-	-
Eu	0.00	0.00	0.00	0.00	0.00	0.00
Fe	11,756.20	61,474.94	899,775.17	5,348,064.61	1,387,791.77	3,362,505.31
Ga	0.00	0.01	0.50	0.88	0.74	1.04
Gd	0.00	0.00	0.00	0.01	0.00	0.00
Ge	0.00	0.00	0.01	0.01	0.01	0.01
Hf	-	-	-	-	-	-
Hg	0.00	0.00	0.02	0.08	0.04	0.09
Ho	-	-	-	-	-	-
In	0.00	0.00	0.09	0.14	0.14	0.14
Ir	0.00	0.00	0.00	0.00	0.00	0.00

La	0.05	0.26	3.67	20.84	4.74	11.37
Li	20.36	344.99	5,795.08	32,002.41	14,817.58	37,037.48
Lu	-	-	-	-	-	-
Mg	17.29	109.82	2,339.42	7,708.20	3,486.16	5,458.22
Mn	227.97	595.64	7,139.10	27,942.23	7,372.37	17,606.17
Mo	7.39	40.13	559.19	3,328.94	870.98	2,106.55
Nb	2.98	15.37	198.23	1,291.62	309.90	766.10
Nd	1.15	15.95	719.65	1,078.47	726.88	1,517.96
Ni	5.65	2,364.98	19,998.10	11,444.78	5,179.86	12,091.34
Os	-	-	-	-	-	-
Pb	0.30	2.77	11,561.68	215.52	148.13	213.04
Pd	0.00	0.02	0.42	0.64	0.62	0.65
Pr	0.01	0.18	6.87	9.00	7.76	10.54
Pt	0.00	0.00	0.06	0.10	0.07	0.11
Re	-	-	-	-	-	-
Rh	0.00	0.00	0.00	0.00	0.00	0.00
Ru	0.00	0.00	0.04	0.07	0.05	0.08
Sb	0.41	3.53	129.99	224.98	122.90	197.11
Sc	-	-	-	-	-	-
Se	0.00	0.03	0.58	1.16	1.13	1.15
Sm	-	-	-	-	-	-
Sn	1.50	14.43	392.53	696.41	574.84	670.71
Sr	2.74	17.38	326.28	1,180.53	551.19	810.74
Ta	0.04	0.41	11.51	17.59	17.09	18.22
Tb	0.00	0.05	2.24	3.58	2.39	5.08
Te	0.00	0.00	0.03	0.04	0.04	0.04
Ti	13.25	68.66	1,359.72	5,817.63	1,519.82	3,500.93
Tl	0.00	0.00	0.00	0.00	0.00	0.00
Tm	-	-	-	-	-	-
V	1.92	10.30	146.42	857.82	219.88	535.90
W	0.08	0.41	5.24	33.92	8.04	18.72
Y	0.00	0.01	0.10	0.20	0.20	0.20
Yb	0.00	0.00	0.00	0.00	0.00	0.00
Zn	40.65	259.41	4,380.02	18,182.39	6,257.96	12,308.97
Zr	0.04	0.30	6.23	17.82	10.48	15.48

[1] LMO battery. [2] NMC battery. [3] 60% NMC 811; 30% LiO; 10% LFP batteries. [4] 75% LFP; 20% LIO; 5% NCM batteries. [5-6] 75% LFP; 20% LIO; 5% NCM batteries [13].

Table S11. High material intensity scenario for electromobility in g/unit.

Material	Electric bike and Electric scooter[1]	Electric motorcycle[2]	Electric vehicle[3] [80]	Electric bus[4]	Electric light-duty truck[5]	Electric heavy-duty truck[6]
Ag	0.13	1.36	34.67	61.65	57.41	63.33
Al	776.83	6,018.76	161,464.68	473,985.13	194,535.64	420,830.07
As	0.01	0.05	0.88	4.51	1.36	2.67
Au	0.01	0.10	2.41	4.40	4.12	4.37
B	0.10	1.34	57.24	91.58	61.06	129.74
Ba	22.31	108.97	1,634.15	9,330.81	2,223.94	5,175.87
Be	0.00	0.00	0.05	0.08	0.06	0.07

Bi	0.52	2.60	34.50	213.10	51.94	118.56
Cd	0.00	0.01	0.24	0.48	0.32	0.45
Ce	0.00	0.01	0.14	0.94	0.20	0.51
Co	0.28	397.21	3,215.56	1,630.26	785.56	1,862.92
Cr	28.13	270.78	6,534.84	21,201.35	8,574.10	20,449.82
Cu	166.40	2,037.75	59,517.26	115,395.34	79,667.95	127,748.59
Dy	0.10	1.42	59.73	95.69	64.52	134.64
Er	-	-	-	-	-	-
Eu	0.00	0.00	0.00	0.00	0.00	0.00
Fe	11,756.20	61,474.94	899,775.17	5,348,064.61	1,387,791.77	3,362,505.31
Ga	0.00	0.01	0.50	0.88	0.74	1.04
Gd	0.00	0.00	0.00	0.01	0.00	0.00
Ge	0.00	0.00	0.01	0.01	0.01	0.01
Hf	-	-	-	-	-	-
Hg	0.00	0.00	0.02	0.08	0.04	0.09
Ho	-	-	-	-	-	-
In	0.00	0.00	0.09	0.14	0.14	0.14
Ir	0.00	0.00	0.00	0.00	0.00	0.00
La	0.05	0.26	3.67	20.84	4.74	11.37
Li	27.52	466.39	7,834.37	43,264.02	20,031.86	50,070.92
Lu	-	-	-	-	-	-
Mg	17.29	109.82	2,339.42	7,708.20	3,486.16	5,458.22
Mn	308.19	805.25	9,651.34	37,775.06	9,966.70	23,801.76
Mo	7.39	40.13	559.19	3,328.94	870.98	2,106.55
Nb	2.98	15.37	198.23	1,291.62	309.90	766.10
Nd	1.55	21.57	972.90	1,457.99	982.67	2,052.13
Ni	7.64	3,197.21	27,035.41	15,472.18	7,002.65	16,346.27
Os	-	-	-	-	-	-
Pb	0.30	2.77	11,561.68	215.52	148.13	213.04
Pd	0.00	0.02	0.42	0.64	0.62	0.65
Pr	0.02	0.24	9.29	12.16	10.49	14.25
Pt	0.00	0.00	0.06	0.10	0.07	0.11
Re	-	-	-	-	-	-
Rh	0.00	0.00	0.00	0.00	0.00	0.00
Ru	0.00	0.00	0.04	0.07	0.05	0.08
Sb	0.41	3.53	129.99	224.98	122.90	197.11
Sc	-	-	-	-	-	-
Se	0.00	0.03	0.58	1.16	1.13	1.15
Sm	-	-	-	-	-	-
Sn	1.50	14.43	392.53	696.41	574.84	670.71
Sr	2.74	17.38	326.28	1,180.53	551.19	810.74
Ta	0.04	0.41	11.51	17.59	17.09	18.22
Tb	0.00	0.05	2.24	3.58	2.39	5.08
Te	0.00	0.00	0.04	0.05	0.05	0.06
Ti	13.25	68.66	1,359.72	5,817.63	1,519.82	3,500.93
Tl	0.00	0.00	0.00	0.00	0.00	0.00
Tm	-	-	-	-	-	-
V	1.92	10.30	146.42	857.82	219.88	535.90
W	0.08	0.41	5.24	33.92	8.04	18.72
Y	0.00	0.01	0.10	0.20	0.20	0.20
Yb	0.00	0.00	0.00	0.00	0.00	0.00

Zn	54.96	350.70	5,921.35	24,580.74	8,460.12	16,640.48
Zr	0.04	0.30	6.23	17.82	10.48	15.48

[1] LMO battery. [2] NMC battery. [3] 60% NMC 811; 30% LiO; 10% LFP batteries. [4] 75% LFP; 20% LIO; 5% NCM batteries. [5-6] 75% LFP; 20% LIO; 5% NCM batteries [13].

Table S12. Reserves and resources considered in tons [33]

Material	Reserves	Resources
Ag	530,000	1,308,000
Al	28,000,000,000	75,000,000,000
As	1,180,000	11,000,000
Au	54,000	100,000
B	380,000,000	410,000,000
Ba	740,000,000	2,000,000,000
Be	100,000	400,000
Bi	370,000	680,000
Cd	500,000	7,500,000
Ce	31,700,000	31,700,000
Co	7,600,000	120,000,000
Cr	570,000,000	12,000,000,000
Cu	880,000,000	6,350,000,000
Dy	2,600,000	2,980,000
Er	-	-
Eu	244,333	244,333
Fe	160,000,000,000	800,000,000,000
Ga	5,200	1,000,000
Gd	1,235,000	3,622,143
Ge	2,500	440,000
Hf	-	-
Hg	94,000	600,000
Ho	-	-
In	11,000	47,100
Ir	2,000	2,000
La	6,000,000	22,600,000
Li	22,000,000	89,000,000
Lu	-	-
Mg	2,400,000,000	12,000,000,000
Mn	1,500,000,000	1,030,000,000
Mo	16,000,000	20,000,000
Nb	17,000,000	17,000,000
Nd	8,750,000	16,700,000
Ni	95,000,000	300,000,000
Os	-	-
Pb	-	-
Pd	33,000	46,000
Pr	2,000,000	4,800,000
Pt	33,000	50,000
Re	-	-
Rh	7,000	7,000
Ru	6,000	6,000

Sb	2,000,000	4,300,000
Sc	-	-
Se	100,000	172,000
Sm	2,900,000	2,900,000
Sn	4,900,000	76,200,000
Sr	6,800,000	1,000,000,000
Ta	140,000	317,060
Tb	566,104	566,104
Te	11,080	31,000
Ti	750,000,000	2,000,000,000
Tl	-	-
Tm	-	-
V	24,000,000	63,000,000
W	3,700,000	7,000,000
Y	-	-
Yb	1,900,000	1,900,000
Zn	250,000,000	1,900,000,000
Zr	75,000,000	235,029,851

Table S13. Type of vehicle and activity in Reference scenario with electric equivalents.

Vehicle type	Bus	Heavy-duty truck	Light-duty truck	Van	Car	Motorbike
km/year [68], [69]	52,951	47,543	14,844	14,467	12,266	2,903
Vehicles [67]	30,440	139,165	1,068,211	1,128,644	11,290,645	1,622,591
kWh/100 km combustion vehicle [63], [69]	478	546	71	67	64	42
kWh/100 km electric vehicle	106	138	12	29	17	6

Table S14. Energy consumption by technology in land transport.

Consumption in by technology kWh / 100 km[1]	Bus	High duty Truck	Light duty Truck	Van	Electric vehicle	Motorbikes	Train[2]
Electric	106	138	29	29	17	6	3.2
Combustion	478	546	71	67	64	42	7.6

[1] Energy consumption for freight transportation, truck 0.296 kWh/tkm; train 0.1925 kWh/tkm [41]. In the efficient scenario, we have considered a 50% cargo change from high duty trucks to trains, 9% reduction demand in trucks for sharing loads in Van and light duty trucks [40]. It may be higher, but a deeper study must be performed.
[2] Final energy consumption in Train transportation with diesel lines is 943 GWh and with electric lines 2,672 GWh.

Table S15. Vehicles considered for each scenario

Scenario	Bus	High duty Truck	Light duty Truck	Van	Electric vehicle	Motorbikes

Reference Scenario Bioregion vehicles	30,440	139,165	1,068,211	1,128,644	11,290,645	1,622,591
Trend Scenario	37,337	170,694	1,310,222	1,416,124	14,166,521	2,048,613
Efficient Scenario	37,337	34,139	1,310,222	1,416,124	2,821,971	2,048,613

Table S16. Assumption for demand increase and consumption increase [50].

Assumptions	Bus	High duty Truck	Light duty Truck	Van	Electric vehicle	Motorbikes
Demand increase	1.15	1.51	1.51	1.51	1.44	1.40
Vehicles increase	1.23	1.23	1.23	1.25	1.25	1.26

Table S17. Energy sources in Residential Sector. Reference scenario in GWh [62], [63], [64]

Energy source	Heating[1]	Cooling	Hot water	Cooking[2]	Lighting and appliances
Electricity	5525	1751	5603	6969	55171
Natural gas	14760	0	13635	3474	0
Carbon	649	0	51	95	0
Oil	22865	0	7043	2172	0
Renewable energy	28963	26	3453	309	0

[1] 80% energy reduction considered for electrified heating with heat pumps.
[2] 49% energy reduction considered for electrified cooking with induction.

Table S18. Heat demands along the year

Month	%
1	13.31%
2	12.28%
3	11.32%
4	8.06%
5	6.46%
6	5.33%
7	4.79%
8	4.50%
9	4.91%
10	7.09%
11	10.22%
12	11.74%

Table S19. Energy sources in service sectors. Reference scenario units in GWh [62], [63], [64]

Subsector	Coal	Oil	Natural Gas	Electricity	Renewable Energy	Waste no renewable
Offices	0	4686	13811	34794	312	0

Health	0	2052	2215	5235	52	0
Trade	0	2169	7382	20611	26	0
Hospitality and Restoration	0	271	805	5772	216	0
Education	0	4723	1064	3385	63	0
Other Services	0	621	1738	4830	56	56

Table S20. Reference scenario. Energy demands in Aragon [55] in GWh

Aragon	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity	Total
Industry	857.6	203.7	4,004.7	3,479.9	4,020.9	-	5,201.7	17,768.5
Transport	12,959.0	-	286.5	-	-	-	472.7	13,718.2
Primary	3,753.3	-	203.7	61.2	229.2	-	333.6	4,581.0
Households	425.4	-	1,115.3	1,751.4	-	-	2,029.1	5,321.2
Services	222.2	-	374.2	778.3	-	-	1,988.5	3,363.2
Total	18,217.5	203.7	5,984.4	6,070.8	4,250.1	-	10,025.5	44,752.1

Table S21. Reference scenario. Energy demands in Balearic Islands [56] in GWh

Balearic Islands	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity	Total
Industry	160.8	211.5	25.6	28.0	-	22.0	219.2	667.2
Transport	7,999.5	-	-	-	-	-	5.9	8,005.4
Primary	1,079.5	-	1.5	-	-	-	91.2	1,172.2
Households	620.8	-	62.9	353.7	-	-	2,477.5	3,514.9
Services	646.8	-	-	484.1	-	-	2,821.5	3,952.4
Total	10,507.4	211.5	89.9	865.8	-	22.0	5,615.4	17,312.0

Table S22. Reference scenario. Energy demands in Catalonia [57] in GWh

Catalonia	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity	Total
Industry	4,335.7	243.1	1,346.8	19,851.2	-	1,000.2	16,232.0	43,008.9
Transport	52,845.6	-	3,108.7	330.3	-	-	1,044.4	57,328.9
Primary	1,895.7	-	139.6	133.7	-	-	386.1	2,555.1

Households	3,772.8	-	1,053.7	10,303.0	-	-	10,205.3	25,334.8
Services	2,608.6	-	435.0	4,367.1	-	67.5	14,488.7	21,966.7
Total	65,458.3	243.1	6,083.7	34,985.4	-	1,067.6	42,356.5	150,194.5

Table S23. Reference scenario. Energy demands in Valencian Community [58] in GWh

Valencian Community	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity	Total
Industry	2,733.1	11.6	1,732.9	19,317.4	-	-	7,222.2	31,017.2
Transport	36,192.6	-	1,895.7	162.8	-	-	1,453.8	39,704.8
Primary	3,326.2	-	23.3	58.2	-	-	686.2	4,093.8
Households	1,791.0	-	1,337.5	2,163.2	-	-	7,536.2	12,827.9
Services	395.4	-	407.1	1,849.2	-	-	7,594.4	10,246.0
Total	44,438.2	11.6	5,396.3	23,550.8	-	-	24,492.8	97,889.7

Table S24. Reference scenario. Energy demands in Navarre [61] in GWh

Navarre	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity	Total
Industry	125.4	990.8	786.9	4,070.2	-	-	2,649.2	8,622.6
Transport	8,384.0	-	552.0	29.7	-	-	38.6	9,004.2
Primary	948.6	-	9.4	132.6	-	-	148.6	1,239.2
Households	446.8	-	247.5	2,183.1	-	-	1,507.6	4,384.9
Services	21.0	-	22.9	218.3	-	-	343.1	605.4
Total	9,925.8	990.8	1,618.7	6,633.8	-	-	4,687.1	23,856.2

Table S25. Reference scenario. Energy demands in Basque Country [59], [60] in GWh

Basque Country	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity	Total
Industry	1,651.5	279.1	2,186.4	7,943.3	186.1	-	8,268.9	20,515.3
Transport	22,457.5	-	1,639.8	-	-	-	174.5	24,271.8
Primary	383.8	-	11.6	11.6	11.6	-	46.5	465.2
Households	976.9	-	535.0	3,209.9	-	-	2,616.8	7,338.5
Services	302.4	-	221.0	1,174.6	-	-	3,430.9	5,128.8
Total	25,772.1	279.1	4,593.9	12,339.4	197.7	-	14,537.5	57,719.7

Table S26. Reference scenario. Energy demands in Cantabria in GWh

Cantabria	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity	Total
Industry	278.6	149.2	348.2	1,014.6	-	-	1,591.1	3,381.7
Transport	3,978.1	-	258.4	9.7	-	-	127.5	4,373.7
Primary	321.6	-	13.4	7.4	-	-	67.7	410.1
Households	226.9	-	150.3	370.4	-	-	1,054.5	1,802.0
Services	118.5	-	50.4	164.6	-	-	1,226.2	1,559.7
Total	4,923.8	149.2	820.6	1,566.7	-	-	4,067.0	11,527.2

Table S27. Reference scenario. Energy demands in La Rioja in GWh

La Rioja	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity	Total
Industry	210.8	11.2	260.3	794.6	-	-	636.7	1,913.6
Transport	3,010.0	-	193.2	7.6	-	-	51.0	3,261.8
Primary	243.4	-	10.0	5.8	-	-	27.1	286.3
Households	171.7	-	112.3	290.1	-	-	421.9	996.0
Services	89.7	-	37.7	128.9	-	-	490.6	746.9
Total	3,725.6	11.2	613.5	1,227.0	-	-	1,627.4	7,204.6

Table S28. Electricity balance. Reference scenario in GWh [66]

Energía	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Demand	10,109	4,942	25,457	3,906	43,840	1,621	4,844	14,955
Renewable generation	12,329	122	4,488	640	8,245	1,073	3,197	739
Electricity imports	-7,997	1,427	6,347	2,100	888	-171	-1,767	8,788
Conventional generation	5,713	3,393	14,622	996	34,708	719	3,414	5,429

Table S29. Renewable energy resources by autonomous community

	Biomass [75]	**Biogas** [74]	**Wind resource**[1] [42]	**Roof PV**[2] [76]

Unit	GWh	GWh	km2	km2
Aragon	15,214	2,430	11,850	76
Balearic Islands	2,263	298	550	37
Cantabria	2,451	652	750	14
Catalonia	15,018	3,817	3,875	255
Valencian Community	6,879	1,746	2,250	190
Navarre	6,030	515	3,600	37
Basque Country	4,520	313	975	56
La Rioja	1,883	240	925	18

[1]Land area with an average speed higher than 6 m/s respecting protected areas. [2] Katalin et al. [77] estimate an available building area of 462 km2 with an energy production of 65,244 GWh/year for Spain

Table S30. Nameplate Capacity by technology and autonomous community in Reference scenario [66]

MW 2020	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Hydro	1,338.3	-	641.9	98.9	1,922.1	52.4	237.7	177.7
Pumped hydro	219.1	-	1,512.0	360.6	439.8	-	-	-
Nuclear	-	-	1,063.9	-	3,032.8	-	-	-
Coal	-	241.2	-	-	-	-	-	-
Fuel/gas	-	742.5	8.0	-	-	-	-	-
Combined-cycle	1,869.7	822.9	2,853.5	-	3,788.2	784.7	1,222.3	1,968.1
HidroWind	-	-	-	-	-	-	-	-
Wind	4,284.0	3.6	1,243.0	35.3	1,271.2	448.1	1,302.3	154.3
PV	1,098.2	103.3	364.4	2.2	279.9	98.8	163.4	50.2
CSP	-	-	49.9	-	24.3	-	-	-
Others renovables	6.7	2.1	12.6	12.9	63.8	3.6	42.7	27.4
Cogeneration	514.2	11.5	451.4	280.7	983.9	22.9	151.5	445.1
No renowable waste	49.9	37.4	63.1	5.0	32.4	-	-	59.0
Renovable waste	-	37.4	-	5.0	27.2	-	-	46.8

Table S31. Full load hours considered by autonomous community and technology*

Technology	Full load hours	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country	Average
Hydro	REE [66]	1,903.07	-	684.04	2,324.33	1,809.21	2,917.14	2,147.22	2,178.68	1,903.07
Wind	Atlas [42]	2,150	2,250	2,175	2,475	2,350	2,175	2,275	2,400	2,281
	REE [66]	2,267	1,673	2,157	2,065	2,402	2,176	2,206	2,133	2,135
	Average	2,209	1,961	2,166	2,270	2,376	2,176	2,241	2,267	2,208
PV	PVGIS [73]	1,614	1,536	1,652	1,176	1,568	1,397	1,367	1,150	1,433

	REE [66]	1,371	1,145	1,444	1,015	1,355	1,447	1,708	1,226	1,339
	Average	1,493	1,340	1,548	1,095	1,461	1,422	1,537	1,188	1,386

* We have considered that by 2,050 there will be a full load hour increase, considering 2,600 full load hours in wind technology and 1,590 in PV technology as average values for the Bioregion. 2,910 full load hour for CSP and 2,300 full load hour for biomass and biogas power plants used upon request.

Table S32. 2030 Bioregion electricity balance. Trend scenario in GWh

	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Electricity Demand	11,122	6,286	28,307	4,446	49,147	1,779	5,309	17,320
Renewable generation	30,056	561	6,785	2,082	9,682	1,935	6,985	1,174
Electricity imports	-23,346	3,803	7,738	1,324	18,982	-1,433	-5,308	9,775
Conventional generation	4,412	1,922	13,784	1,039	20,483	1,278	3,632	6,371

Table S33. 2030 Bioregion electricity balance. Balanced scenario in GWh

	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Demand	11,122	6,286	28,307	4,446	49,147	1,779	5,309	17,320
Renewable generation	13,857	4,735	15,381	3,409	31,473	1,560	4,028	11,972
Electricity imports	-7,257	-371	-1,672	-263	-2,903	-1,059	-2,352	-1,023
Conventional generation	4,521	1,922	14,598	1,300	20,578	1,278	3,632	6,371

Table S34. 2050 Trend scenario. Energy demands in the Bioregion in GWh

Sector	Oil	Coal	Renewable energy	Natural gas	Heat	Waste	Electricity
Industry	2,499	1,250	30,543	0	4,286	1,250	74,699
Transport	0	0	0	0	0	0	78,680
Primary	11,952	0	2,001	0	116	0	2,890
Households	0	0	4,857	0	0	0	36,562
Services	0	0	1,761	0	0	0	40,030
Total	14,451	1,250	39,162	0	4,402	1,250	232,861

Table S35. 2050 Bioregion electricity balance. Trend scenario in GWh

	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Demand	22,406	9,844	49,438	7,457	91,261	3,996	12,448	35,500
Renewable generation	173,468	4,695	31,496	9,583	27,114	8,397	29,758	925
Electricity imports	-151,062	5,149	17,942	-2,126	64,148	-4,401	-17,311	34,575
Conventional generation	0	0	0	0	0	0	0	0

Table S36. 2050 Bioregion electricity balance. Balanced scenario in GWh

	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Demand	22,406	9,844	49,438	7,457	91,261	3,996	12,448	35,500
Renewable generation	76,001	10,670	50,199	7,632	84,572	9,390	21,087	25,885
Electricity imports	-53,595	-826	-761	-174	6,689	-5,394	-8,639	9,615
Conventional generation	0	0	0	0	0	0	0	0

Table S37. 2050 Efficient scenario. Bioregion electricity balance. Trend scenario in GWh

	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Demand	18,971	7,807	39,516	6,354	76,763	3,182	10,207	29,456
Renewable generation	143,456	3,892	26,684	7,697	23,249	7,092	24,767	909
Electricity imports	-124,485	3,915	12,832	-1,343	53,514	-3,910	-14,560	28,547
Conventional generation	0	0	0	0	0	0	0	0

Table S38. 2050 Efficient scenario. Bioregion electricity balance. Balanced scenario in GWh

	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Demand	18,971	7,807	39,516	6,354	76,763	3,182	10,207	29,456
Renewable generation	52,508	8,341	45,176	6,397	77,977	7,073	17,083	23,189
Electricity imports	-33,537	-535	-5,661	-43	-1,214	-3,891	-6,875	6,267
Conventional generation	0	0	0	0	0	0	0	0

Table S39. Nameplate Capacity by PV or wind technology and autonomous community in MW for scenarios

Technology	Scenario	Aragon	Balearic Islands	Valencian Community	Cantabria	Catalonia	La Rioja	Navarre	Basque Country
Wind	2020 [66]	4,284	4	1,243	35	1,271	448	1,302	154
	2026 REE [38]	8,649	4	1,515	549	2,134	594	2,256	154
	2030 Trend	9,689	4	1,580	672	2,340	629	2,484	154
	2030 Balanced	4,284	1,284	3,636	855	6,697	448	1,302	3,036
	2050 Trend	34,610	4	3,133	3,606	7,267	1,462	7,930	154
	2050 Balanced	18,262	2,098	9,000	1,622	15,500	2,567	5,219	3,900
	2050 efficient. Trend	28,452	4	2,749	2,881	6,049	1,256	6,584	154
	2050 efficient. Balanced	10770	1603	9000	1337	15500	1863	4156	3900
FV	2020 [66]	1,098	103	364	2	280	99	163	50
	2026 REE [38]	2,838	203	845	2	368	196	351	52
	2030 Trend	4,017	271	1,171	2	427	261	479	54
	2030 Balanced	1,200	1,544	4,371	1,028	8,050	300	200	3,650
	2050 Trend	41,720	2,438	11,594	2	2,334	2,363	4,552	97
	2050 Balanced	7,168	2,770	13,756	2,022	25,001	1,181	3,535	9,667
	2050 efficient. Trend	34,470	2,021	9,590	2	1,968	1,959	3,769	89
	2050 efficient. Balanced	6201	2203	10992	1711	20925	955	2909	7972

In order to validate the model, Figure S1 shows the electrical power system of the Bioregion for the 2050 scenario compared with those proposed by Jacobson [5] and the European Commission [45] for Spain. Comparatively, hydropower production is lower in our model because of the Bioregion's hydrological characteristics. In addition, thermal power production from renewable sources is lower when considering the Bioregion's renewable biomass and biogas production capacities. Thus, we have modelled a higher overproduction, which is the ratio of energy production to energy demand, due to the lower availability of manageable energy.

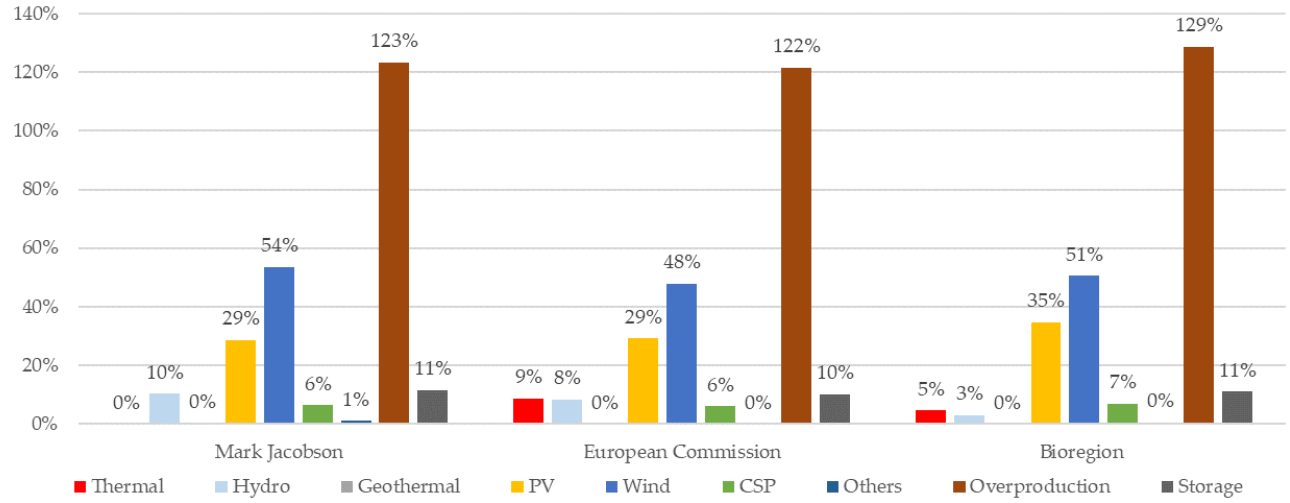

Figure S1. Comparative analysis of the electrical system for the 2050 scenario based on studies from Jacobson [5] and the European Commission [45] carried out for Spain, with respect to that of the Bioregion.

Scenario	Wind MW	FV MW	CSP MW	Pumped Hydro MW	Bioenergy (thermal) MW	Train km	Trains uds	New transportation lines (new RES MW)	e-bikes e-scooter uds	Electric motorbikes uds	Electric cars uds	Electric Bus uds	light duty truck uds	high duty truck uds	Batteries for storage NMC 50% - LFP 50% in kWh (5 hours of storage)	New heat pumps	Electric vehicles uds
2030	12801.2951 4	18183.5866 1	100.1	15341.413 3	0	8903.645	356.1458	280700.49924	19545679.63	39532 9.1658	16819671.101	7416.445457	26025 9.8168	0	54599 76.23	23656 97.193	16819671.101
2050	49424.6321 9	62940.3596 6	6897.41	56067.79452 5	6000	17807.29	7122.916	109134.1065	58637 03.888	20486 12.528	15582645.61	37336.50815	13102 2.374	17069 3.5069	29065 444.73	40926 56.144	15582645.61
2050 Efficient	39387.7972	51706.9889 4	5694.435313	4202.497319	4964.678392	17807.29	5553 5.836	88064.97153	58637 03.888	20486 12.528	42380952.92	37336.50815	13102 2.374	85346.75344	24050097.57	40926 56.144	42380952.92