Supplementary Material for:

**Flexible electricity generation, grid exchange and storage for the transition to a 100% renewable energy system in Europe**

Michael Child1\*, Claudia Kemfert2, Dmitrii Bogdanov1, Christian Breyer1

1 Lappeenranta University of Technology, Skinnarilankatu 34, 53850 Lappeenranta, Finland

2 German Institute for Economic Research (DIW) and Hertie School of Governance, Mohrenstrasse 58, 10117 Berlin, Germany

\* Email: Michael.Child@lut.fi

**Table A.1:** Technical and financial assumptions of all energy system components used in the energy transition from 2015 to 2050. Assumptions are taken from [1] and European Commission [2] and further references are individually mentioned.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Name of component |  |  | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | Reference |
| PV optimally tilted | Capex | €/kW | 1000 | 680 | 560 | 480 | 420 | 370 | 330 | 300 | [3], [4] |
| Opex fix | €/(kW a) | 15 | 10.2 | 8.4 | 7.2 | 6.3 | 5.6 | 5 | 4.5 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Lifetime | years | 30 | 30 | 35 | 35 | 35 | 40 | 40 | 40 |  |
| PV single-axis tracking | Capex | €/kW | 1150 | 750 | 620 | 530 | 465 | 410 | 365 | 330 | [3], [4] |
| Opex fix | €/(kW a) | 17.3 | 11.3 | 9.3 | 8 | 7 | 6.2 | 5.5 | 5 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Lifetime | years | 30 | 30 | 35 | 35 | 35 | 40 | 40 | 40 |  |
| PV prosumers | Capex | €/kW | 1360 | 1090 | 890 | 760 | 680 | 610 | 550 | 500 | [3], [4] |
| Opex fix | €/(kW a) | 20 | 16 | 13 | 11 | 10 | 9 | 8 | 8 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Lifetime | years | 30 | 30 | 35 | 35 | 35 | 40 | 40 | 40 |  |
| Wind onshore | Capex | €/kW | 1250 | 1150 | 1060 | 1000 | 965 | 940 | 915 | 900 | [5] |
| Opex fix | €/(kW a) | 25 | 23 | 21 | 20 | 19 | 19 | 18 | 18 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Lifetime | years | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |  |
| CSP (solar field. parabolic trough) | Capex | €/m2 | 270 | 240 | 220 | 200 | 180 | 170 | 150 | 140 | [6], [7] |
| Opex fix | % | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Lifetime | years | 25 | 25 | 25 | 25 | 30 | 30 | 30 | 30 |  |
| Geothermal power | Capex | €/kW | 5250 | 4970 | 4720 | 4470 | 4245 | 4020 | 3815 | 3610 | [2], [8] |
| Opex fix | €/(kW a) | 80.0 | 80.0 | 80.0 | 80.0 | 80.0 | 80.0 | 80.0 | 80.0 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Lifetime | years | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |  |
| Water electrolysis | Capex | €/kWH2 | 800 | 685 | 500 | 363 | 325 | 296 | 267 | 248 | [9], [10] |
| Opex fix | €/(kW a) | 32 | 27 | 20 | 12.7 | 11.4 | 10.4 | 9.4 | 8.7 |  |
| Opex var. | €/kWh | 0.0012 | 0.0012 | 0.0012 | 0.0012 | 0.0012 | 0.0012 | 0.0012 | 0.0012 |  |
| Lifetime | years | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |  |
| Methanation | Capex | €/kWCH4 | 492 | 421 | 310 | 278 | 247 | 226 | 204 | 190 | [9], [10] |
| Opex fix | €/(kW a) | 19.7 | 16.8 | 12.4 | 11.1 | 9.9 | 9 | 8.2 | 7.6 |  |
| Opex var. | €/kWh | 0.0015 | 0.0015 | 0.0015 | 0.0015 | 0.0015 | 0.0015 | 0.0015 | 0.0015 |  |
| Lifetime | years | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |  |
| CO2 direct air capture | Capex | €/tCO2 | 480 | 411 | 301 | 228 | 201 | 183 | 165 | 154 | [9], [10] |
| Opex fix | €/(tCO2 a) | 19.2 | 16.4 | 12 | 9.1 | 8 | 7.3 | 6.6 | 6.1 |  |
| Opex var. | €/tCO2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 |  |
| Lifetime | years | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |  |
| CCGT | Capex | €/kW | 775 | 775 | 775 | 775 | 775 | 775 | 775 | 775 | [11] |
| Opex fix | €/(kW a) | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Efficiency | % | 58 | 58 | 58 | 58 | 59 | 60 | 60 | 60 |  |
| Lifetime | years | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |  |
| OCGT | Capex | €/kW | 475 | 475 | 475 | 475 | 475 | 475 | 475 | 475 | [11] |
| Opex fix | €/(kW a) | 9.5 | 9.5 | 9.5 | 14.25 | 14.25 | 14.25 | 14.25 | 14.25 |  |
| Opex var. | €/kWh | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |  |
| Efficiency | % | 43 | 43 | 43 | 43 | 43 | 43 | 43 | 43 |  |
| Lifetime | years | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |  |
| Steam turbine (CSP) | Capex | €/kW | 760 | 740 | 720 | 700 | 670 | 640 | 615 | 600 | [10], [11] |
| Opex fix | €/(kW a) | 15.2 | 14.8 | 14.4 | 14 | 13.4 | 12.8 | 12.3 | 12 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Efficiency | % | 42 | 42 | 42 | 43 | 44 | 44 | 45 | 45 |  |
| Lifetime | years | 25 | 25 | 25 | 25 | 30 | 30 | 30 | 30 |  |
| Steam turbine (coal-fired PP) | Capex | €/kW | 1500 | 1500 | 1500 | 1500 | 1500 | 1500 | 1500 | 1500 |  |
| Opex fix | €/(kW a) | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Efficiency | % | 45 | 45 | 45 | 45 | 46 | 46 | 47 | 47 |  |
| Lifetime | years | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |  |
| Nuclear PP | Capex | €/kW | 6210 | 6003 | 6003 | 5658 | 5658 | 5244 | 5244 | 5157 | [2], [12]–[14] |
| Opex fix | €/(kW a) | 162 | 157 | 157 | 13 | 137 | 116 | 116 | 109 |  |
| Opex var. | €/kWh | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 |  |
| Efficiency | % | 37 | 37 | 37 | 38 | 38 | 38 | 38 | 38 |  |
| Lifetime | years | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |  |
| Biomass PP | Capex | €/kW | 3400 | 2900 | 2700 | 2500 | 2300 | 2200 | 2100 | 2000 |  |
| Opex fix | €/(kW a) | 238 | 203 | 189 | 175 | 161 | 154 | 147 | 140 |  |
| Opex var. | €/kWh | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |  |
| Efficiency | % | 36 | 37 | 40 | 43 | 45 | 47 | 48 | 48 |  |
| Lifetime | years | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |  |
| Biogas CHP | Capex | €/kW | 503 | 429 | 400 | 370 | 340 | 326 | 311 | 296 |  |
| Opex fix | €/(kW a) | 20.1 | 17.2 | 16.0 | 14.8 | 13.6 | 13.0 | 12.4 | 11.8 |  |
| Opex var. | €/(kWh) | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |  |
| Efficiency | % | 35 | 36 | 39 | 42 | 44 | 46 | 46 | 47 |  |
| Lifetime | years | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |  |
| Waste incinerator | Capex | €/kW | 5940 | 5630 | 5440 | 5240 | 5030 | 4870 | 4690 | 4540 |  |
| Opex fix | €/(kW a) | 267.3 | 253.35 | 244.8 | 235.8 | 226.35 | 219.15 | 211.05 | 204.3 |  |
| Opex var. | €/kWh | 0.0069 | 0.0069 | 0.0069 | 0.0069 | 0.0069 | 0.0069 | 0.0069 | 0.0069 |  |
| Efficiency | % | 27 | 31 | 32.5 | 34 | 35.5 | 37 | 29.5 | 42 |  |
| Lifetime | years | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |  |
| Biogas digester | Capex | €/kW | 771 | 731 | 706 | 680 | 653 | 632 | 609 | 589 |  |
| Opex fix | €/(kW a) | 30.8 | 29.2 | 28.2 | 27.2 | 26.1 | 25.3 | 24.3 | 23.6 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Efficiency | % | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |  |
| Lifetime | years | 20 | 20 | 20 | 20 | 25 | 25 | 25 | 25 |  |
| Biogas upgrade | Capex | €/(kW a) | 340 | 290 | 270 | 250 | 230 | 220 | 210 | 200 | [11] |
| Opex fix | €/kW | 27.2 | 23.2 | 21.6 | 20 | 18.4 | 17.6 | 16.8 | 16 |  |
| Opex var. |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Efficiency | % | 98 | 98 | 98 | 98 | 98 | 98 | 98 | 98 |  |
| Lifetime | years | 20 | 20 | 20 | 20 | 25 | 25 | 25 | 25 |  |
| Battery Li-ion | Capex | €/kWh | 600 | 300 | 200 | 150 | 120 | 100 | 85 | 75 |  |
| Opex fix | €/(kWh a) | 24 | 9 | 5 | 3.75 | 3 | 2.5 | 2.125 | 1.875 |  |
| Opex var. | €/kWh | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 |  |
| Efficiency | % | 96 | 96 | 96 | 96 | 96 | 96 | 96 | 96 |  |
| Lifetime | years | 15 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |  |
| Adiabatic compressed air energy storage (A-CAES) | Capex | €/kWh | 35.0 | 35.0 | 33.0 | 31.1 | 30.4 | 29.8 | 28.0 | 26.3 |  |
| Opex fix | €/(kWh a) | 0.46 | 0.46 | 0.43 | 0.40 | 0.40 | 0.39 | 0.36 | 0.34 |  |
| Opex var. | €/kWh | 0.0012 | 0.0012 | 0.0012 | 0.0012 | 0.0012 | 0.0012 | 0.0012 | 0.0012 |  |
| Efficiency | % | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 |  |
| Lifetime | years | 40 | 55 | 55 | 55 | 55 | 55 | 55 | 55 |  |
| Gas storage | Capex | €/kWh | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |  |
| Opex fix | €/(kWh a) | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |  |
| Opex var. | €/kWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
| Lifetime | years | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |  |
| HVDC Transmission (Underground or undersea cable) | Capex | €/(kW km) | 1.368 | 1.368 | 1.368 | 1.368 | 1.368 | 1.368 | 1.368 | 1.368 | [15] |
| Opex fix | €/(kW km) | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| Opex var. | €/(kW km) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lifetime | years | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| HVDC Transmission (Overhead) | Capex | €/(kW km) | 0.288 | 0.288 | 0.288 | 0.288 | 0.288 | 0.288 | 0.288 | 0.288 |
| Opex fix | €/(kW km) | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| Opex var. | €/(kW km) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lifetime | years | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| HVAC Transmission | Capex | €/(kW km) | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 | 0.458 |
| Opex fix | €/(kW km) | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| Opex var. | €/(kW km) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lifetime | years | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| AC/DC Converter station | Capex | €/(kW) | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 |
|  | Opex fix | €/(kW a) | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
|  | Opex var. | €/(kW) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | Lifetime | years | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |

**Table A.2:** Energy to power ratio of the storage technologies. Assumptions based on [1].

|  |  |  |
| --- | --- | --- |
| Technology | Energy /Power Ratio (h) | Self-Discharge(%/h) |
| Battery | 6 | 0 |
| A-CAES | 100 | 0.1 |
| Gas storage | 80·24 | 0 |
| TES | 8 | 0.2 |
| PHES | 8 | 0 |

**Table A.3:** Annual electricity demand and cumulative annual growth rate (CAGR) for all regions from 2015 to 2050.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Region | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |  |
| *TWh* | *TWh* | *TWh* | *TWh* | *TWh* | *TWh* | *TWh* | *TWh* | *CAGR* |
| Norway | 115 | 122 | 129 | 137 | 146 | 155 | 164 | 174 | 1.2% |
| Denmark | 32 | 30 | 31 | 32 | 34 | 36 | 39 | 42 | 0.8% |
| Sweden | 145 | 155 | 160 | 163 | 174 | 179 | 190 | 199 | 0.9% |
| Finland | 74 | 74 | 85 | 93 | 97 | 101 | 108 | 113 | 1.2% |
| Baltic | 26 | 26 | 28 | 33 | 33 | 35 | 36 | 38 | 1.1% |
| Poland | 152 | 173 | 181 | 186 | 193 | 202 | 216 | 221 | 1.1% |
| Iberia | 327 | 340 | 364 | 384 | 403 | 416 | 433 | 443 | 0.9% |
| France | 529 | 525 | 545 | 568 | 582 | 600 | 634 | 645 | 0.6% |
| Benelux | 206 | 205 | 195 | 197 | 203 | 216 | 225 | 231 | 0.3% |
| UK and Ireland | 356 | 340 | 351 | 365 | 383 | 414 | 438 | 448 | 0.7% |
| Germany | 544 | 533 | 531 | 540 | 544 | 557 | 563 | 580 | 0.2% |
| Czech Republic & Slovakia | 95 | 100 | 104 | 110 | 121 | 126 | 131 | 135 | 1.0% |
| Austria Hungary | 93 | 94 | 100 | 106 | 108 | 113 | 119 | 124 | 0.8% |
| Balkan West | 88 | 92 | 96 | 101 | 106 | 113 | 117 | 123 | 1.0% |
| Balkan East | 148 | 156 | 160 | 170 | 180 | 190 | 201 | 208 | 1.0% |
| Italy | 289 | 290 | 302 | 315 | 333 | 359 | 391 | 399 | 0.9% |
| Switzerland | 61 | 65 | 69 | 73 | 78 | 82 | 87 | 93 | 1.2% |
| Turkey, Cyprus | 274 | 382 | 425 | 469 | 520 | 573 | 611 | 649 | 2.5% |
| Ukraine, Moldova | 148 | 157 | 166 | 177 | 187 | 199 | 211 | 224 | 1.2% |
| Iceland | 17 | 18 | 19 | 20 | 22 | 23 | 24 | 26 | 1.2% |
| Europe total | 3718 | 3876 | 4041 | 4239 | 4445 | 4690 | 4941 | 5116 | 0.9% |

**Table A.4:** Residential Electricity Price (€/kWh). Based on [16], [17]

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Region | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| Norway | 0.1590 | 0.1843 | 0.2137 | 0.2477 | 0.2655 | 0.2791 | 0.2791 | 0.2933 |
| Denmark | 0.2640 | 0.2775 | 0.2916 | 0.3065 | 0.3221 | 0.3386 | 0.3386 | 0.3558 |
| Sweden | 0.1670 | 0.1936 | 0.2244 | 0.2602 | 0.2735 | 0.2874 | 0.2874 | 0.3021 |
| Finland | 0.1294 | 0.1501 | 0.1740 | 0.2017 | 0.2338 | 0.2606 | 0.2606 | 0.2739 |
| Baltic | 0.1083 | 0.1338 | 0.1589 | 0.1874 | 0.2182 | 0.2511 | 0.2513 | 0.2699 |
| Poland | 0.1420 | 0.1646 | 0.1908 | 0.2212 | 0.2565 | 0.2696 | 0.2696 | 0.2833 |
| Iberia | 0.1655 | 0.1918 | 0.2224 | 0.2578 | 0.2716 | 0.2855 | 0.2855 | 0.3001 |
| France | 0.1290 | 0.1495 | 0.1734 | 0.2010 | 0.2330 | 0.2649 | 0.2649 | 0.2784 |
| Benelux | 0.1891 | 0.2192 | 0.2539 | 0.2703 | 0.2841 | 0.2986 | 0.2986 | 0.3138 |
| UK and Ireland | 0.1511 | 0.1754 | 0.2036 | 0.2341 | 0.2643 | 0.2777 | 0.2778 | 0.2920 |
| Germany | 0.2330 | 0.2649 | 0.2784 | 0.2926 | 0.3075 | 0.3232 | 0.3232 | 0.3397 |
| Czech Republic & Slovakia | 0.1460 | 0.1696 | 0.1967 | 0.2281 | 0.2608 | 0.2740 | 0.2740 | 0.2879 |
| Austria Hungary | 0.1901 | 0.2203 | 0.2551 | 0.2716 | 0.2855 | 0.3001 | 0.3000 | 0.3153 |
| Balkan West | 0.0915 | 0.1107 | 0.1338 | 0.1598 | 0.1859 | 0.2103 | 0.2088 | 0.2318 |
| Balkan East | 0.1146 | 0.1387 | 0.1626 | 0.1881 | 0.2182 | 0.2490 | 0.2491 | 0.2702 |
| Italy | 0.2150 | 0.2492 | 0.2671 | 0.2808 | 0.2951 | 0.3101 | 0.3101 | 0.3260 |
| Switzerland | 0.1320 | 0.1530 | 0.1774 | 0.2057 | 0.2384 | 0.2657 | 0.2657 | 0.2793 |
| Turkey, Cyprus | 0.1443 | 0.1673 | 0.1939 | 0.2248 | 0.2602 | 0.2735 | 0.2735 | 0.2874 |
| Ukraine, Moldova | 0.0215 | 0.0275 | 0.0351 | 0.0448 | 0.0571 | 0.0729 | 0.0729 | 0.0918 |
| Iceland | 0.1070 | 0.1340 | 0.1553 | 0.1800 | 0.2087 | 0.2419 | 0.2419 | 0.2645 |

**Table A.5:** Commercial Electricity Price (€/kWh). Based on [16], [17]

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Region | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| Norway | 0.1180 | 0.1413 | 0.1696 | 0.1980 | 0.2187 | 0.2391 | 0.2621 | 0.2854 |
| Denmark | 0.1890 | 0.2081 | 0.2263 | 0.2465 | 0.2692 | 0.2946 | 0.3122 | 0.3282 |
| Sweden | 0.1180 | 0.1402 | 0.1676 | 0.1981 | 0.2156 | 0.2351 | 0.2570 | 0.2816 |
| Finland | 0.0918 | 0.1096 | 0.1311 | 0.1571 | 0.1860 | 0.2104 | 0.2299 | 0.2516 |
| Baltic | 0.0887 | 0.1126 | 0.1378 | 0.1661 | 0.1943 | 0.2249 | 0.2503 | 0.2689 |
| Poland | 0.1190 | 0.1436 | 0.1678 | 0.1945 | 0.2255 | 0.2476 | 0.2724 | 0.2863 |
| Iberia | 0.1332 | 0.1597 | 0.1856 | 0.2151 | 0.2358 | 0.2586 | 0.2821 | 0.2965 |
| France | 0.1000 | 0.1201 | 0.1445 | 0.1702 | 0.1973 | 0.2260 | 0.2477 | 0.2721 |
| Benelux | 0.1512 | 0.1794 | 0.2079 | 0.2290 | 0.2509 | 0.2754 | 0.2905 | 0.3054 |
| UK and Ireland | 0.1270 | 0.1627 | 0.1887 | 0.2177 | 0.2488 | 0.2693 | 0.2833 | 0.2978 |
| Germany | 0.1740 | 0.2031 | 0.2211 | 0.2412 | 0.2638 | 0.2891 | 0.3039 | 0.3194 |
| Czech Republic & Slovakia | 0.1305 | 0.1556 | 0.1806 | 0.2095 | 0.2410 | 0.2614 | 0.2798 | 0.2940 |
| Austria Hungary | 0.1572 | 0.1848 | 0.2144 | 0.2366 | 0.2595 | 0.2805 | 0.2948 | 0.3099 |
| Balkan West | 0.0841 | 0.1039 | 0.1271 | 0.1529 | 0.1774 | 0.2031 | 0.2289 | 0.2546 |
| Balkan East | 0.1004 | 0.1243 | 0.1484 | 0.1729 | 0.2006 | 0.2307 | 0.2572 | 0.2743 |
| Italy | 0.1780 | 0.2064 | 0.2283 | 0.2502 | 0.2749 | 0.2915 | 0.3064 | 0.3221 |
| Switzerland | 0.1080 | 0.1301 | 0.1558 | 0.1806 | 0.2094 | 0.2374 | 0.2609 | 0.2793 |
| Turkey, Cyprus | 0.1373 | 0.1596 | 0.1850 | 0.2145 | 0.2485 | 0.2686 | 0.2823 | 0.2967 |
| Ukraine, Moldova | 0.0215 | 0.0275 | 0.0351 | 0.0448 | 0.0571 | 0.0729 | 0.0918 | 0.1156 |
| Iceland | 0.0530 | 0.0670 | 0.1044 | 0.0900 | 0.1044 | 0.1210 | 0.1322 | 0.1390 |

**Table A.6:** Industrial Electricity Price (€/kWh). Based on [16], [17]

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Region | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| Norway | 0.0770 | 0.0983 | 0.1254 | 0.1482 | 0.1718 | 0.1992 | 0.2309 | 0.2625 |
| Denmark | 0.1130 | 0.1388 | 0.1609 | 0.1865 | 0.2162 | 0.2506 | 0.2687 | 0.2824 |
| Sweden | 0.0680 | 0.0868 | 0.1108 | 0.1360 | 0.1577 | 0.1828 | 0.2119 | 0.2457 |
| Finland | 0.0542 | 0.0691 | 0.0882 | 0.1126 | 0.1383 | 0.1603 | 0.1858 | 0.2154 |
| Baltic | 0.0697 | 0.0914 | 0.1166 | 0.1449 | 0.1705 | 0.1987 | 0.2307 | 0.2529 |
| Poland | 0.0960 | 0.1225 | 0.1448 | 0.1679 | 0.1946 | 0.2256 | 0.2615 | 0.2749 |
| Iberia | 0.1000 | 0.1276 | 0.1488 | 0.1725 | 0.1999 | 0.2318 | 0.2642 | 0.2776 |
| France | 0.0710 | 0.0906 | 0.1157 | 0.1393 | 0.1615 | 0.1872 | 0.2171 | 0.2516 |
| Benelux | 0.1136 | 0.1395 | 0.1619 | 0.1877 | 0.2176 | 0.2522 | 0.2673 | 0.2809 |
| UK and Ireland | 0.1291 | 0.1499 | 0.1737 | 0.2014 | 0.2334 | 0.2610 | 0.2747 | 0.2887 |
| Germany | 0.1150 | 0.1412 | 0.1637 | 0.1898 | 0.2200 | 0.2551 | 0.2681 | 0.2818 |
| Czech Republic & Slovakia | 0.1155 | 0.1416 | 0.1645 | 0.1909 | 0.2213 | 0.2488 | 0.2717 | 0.2854 |
| Austria Hungary | 0.1240 | 0.1493 | 0.1736 | 0.2016 | 0.2335 | 0.2609 | 0.2744 | 0.2884 |
| Balkan West | 0.0764 | 0.0971 | 0.1205 | 0.1459 | 0.1689 | 0.1959 | 0.2253 | 0.2532 |
| Balkan East | 0.0860 | 0.1099 | 0.1341 | 0.1577 | 0.1829 | 0.2124 | 0.2442 | 0.2647 |
| Italy | 0.1410 | 0.1635 | 0.1895 | 0.2197 | 0.2547 | 0.2730 | 0.2869 | 0.3015 |
| Switzerland | 0.0840 | 0.1072 | 0.1342 | 0.1556 | 0.1804 | 0.2091 | 0.2424 | 0.2650 |
| Turkey, Cyprus | 0.1312 | 0.1520 | 0.1762 | 0.2043 | 0.2368 | 0.2638 | 0.2773 | 0.2914 |
| Ukraine, Moldova | 0.0215 | 0.0275 | 0.0351 | 0.0448 | 0.0571 | 0.0729 | 0.0918 | 0.1156 |
| Iceland | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Table A.7:** Installed capacities for 2015 in units of MWth for CSP and MWel for all other technologies. Based on [18]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | PV optimal tilt | PV single-axis tracking | Wind Onshore | Wind Offshore | Run-of-River Hydro | Hydro Dam | CSP |
| Region / Unit | MWel | MWel | MWel | MWel | MWel | MWel | MWth |
| Norway | 13 | 0 | 1280 | 2 | 9191 | 20116 | 0 |
| Denmark | 655 | 0 | 3993 | 1271 | 9 | 0 | 0 |
| Sweden | 72 | 0 | 7651 | 212 | 5336 | 11496 | 0 |
| Finland | 19 | 0 | 1151 | 226 | 3434 | 0 | 0 |
| Baltic | 76 | 0 | 613 | 0 | 1119 | 70 | 0 |
| Poland | 28 | 0 | 4335 | 0 | 210 | 489 | 0 |
| Iberia | 6098 | 0 | 27888 | 7 | 5061 | 17691 | 2355 |
| France | 6149 | 0 | 9713 | 0 | 6077 | 12380 | 2 |
| Benelux | 4614 | 0 | 4451 | 1688 | 136 | 25 | 0 |
| UK and Ireland | 5808 | 0 | 14015 | 5238 | 796 | 1561 | 0 |
| Germany | 38636 | 0 | 37386 | 3320 | 3281 | 2091 | 2 |
| Czech Republic & Slovakia | 2900 | 0 | 289 | 0 | 899 | 2470 | 0 |
| Austria Hungary | 809 | 0 | 2608 | 0 | 5577 | 4938 | 0 |
| Balkan West | 385 | 0 | 1131 | 0 | 2536 | 5991 | 0 |
| Balkan East | 5299 | 0 | 8632 | 0 | 3275 | 8466 | 0 |
| Italy | 19251 | 0 | 9012 | 0 | 5367 | 9215 | 5 |
| Switzerland | 1062 | 0 | 73 | 0 | 4141 | 8132 | 0 |
| Turkey, Cyprus | 150 | 0 | 5046 | 0 | 7635 | 16457 | 0 |
| Ukraine, Moldova | 856 | 0 | 1115 | 0 | 2641 | 1988 | 0 |
| Iceland | 3 | 0 | 0 | 0 | 9 | 1943 | 0 |
| Europe total | 92881 | 0 | 140380 | 11965 | 66729 | 125521 | 2364 |

**Table A.8:** Assumed upper limits of installed capacities for generation technologies in units of GWth for CSP and GWel for all other technologies. Calculated according to [19]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | PV  optimal tilt | PV single-axis tracking | Wind  Onshore | Wind  Offshore | Hydro Run-of-River | Hydro  Reservoir/ Dam | CSP |
| Region / Unit | GWel | GWel | GWel | GWel | GWel | GWel | GWth |
| Norway | 1457 | 1457 | 109 | 100 | 14 | 30 | 2914 |
| Denmark | 194 | 194 | 14 | 101 | 0 | 0 | 388 |
| Sweden | 2026 | 2026 | 151 | 100 | 8 | 17 | 4053 |
| Finland | 1522 | 1522 | 114 | 100 | 5 | 0 | 3043 |
| Baltic | 788 | 788 | 59 | 100 | 2 | 0 | 1576 |
| Poland | 1407 | 1407 | 105 | 100 | 0 | 1 | 2814 |
| Iberia | 2689 | 2689 | 201 | 100 | 8 | 27 | 5377 |
| France | 2484 | 2484 | 185 | 100 | 9 | 19 | 4968 |
| Benelux | 336 | 336 | 25 | 102 | 0 | 0 | 672 |
| UK and Ireland | 1416 | 1416 | 106 | 105 | 1 | 2 | 2832 |
| Germany | 1607 | 1607 | 120 | 103 | 5 | 3 | 3213 |
| Czech Republic & Slovakia | 576 | 576 | 43 | 0 | 1 | 4 | 1151 |
| Austria Hungary | 796 | 796 | 59 | 0 | 8 | 7 | 1592 |
| Balkan West | 1281 | 1281 | 96 | 0 | 4 | 9 | 2562 |
| Balkan East | 2166 | 2166 | 162 | 100 | 5 | 13 | 4331 |
| Italy | 1358 | 1358 | 101 | 100 | 8 | 14 | 2715 |
| Switzerland | 186 | 186 | 14 | 0 | 6 | 12 | 371 |
| Turkey, Cyprus | 3568 | 3568 | 266 | 100 | 11 | 25 | 7135 |
| Ukraine, Moldova | 2868 | 2868 | 214 | 100 | 4 | 3 | 5737 |
| Iceland | 464 | 464 | 35 | 100 | 0 | 3 | 927 |
| Europe total | 29186 | 29186 | 2179 | 1612 | 100 | 188 | 58373 |

**Table A.9:** Estimation of bioenergy potential (TWhth) for Europe from 2015 to 2050. Based on [20], [21]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Region | Solid waste - MSW | Solid waste - biomass | Solid residues | Biogas | Bioenergy total |
| Norway | 0.9 | 1.7 | 8.5 | 1.4 | 12.5 |
| Denmark | 2.4 | 0.7 | 15.2 | 28.4 | 46.6 |
| Sweden | 2.0 | 69.7 | 48.3 | 8.4 | 128.5 |
| Finland | 2.5 | 58.1 | 36.5 | 14.8 | 112.0 |
| Baltic | 2.0 | 20.6 | 24.5 | 6.4 | 53.5 |
| Poland | 11.4 | 18.2 | 65.9 | 144.7 | 240.3 |
| Iberia | 10.9 | 28.3 | 47.3 | 93.2 | 179.8 |
| France | 11.9 | 25.8 | 148.0 | 149.5 | 335.2 |
| Benelux | 9.3 | 7.1 | 8.3 | 80.1 | 104.8 |
| UK and Ireland | 15.6 | 11.5 | 36.7 | 114.5 | 178.4 |
| Germany | 17.2 | 58.6 | 122.1 | 77.8 | 275.7 |
| Czech Republic & Slovakia | 2.9 | 23.1 | 37.0 | 35.5 | 98.5 |
| Austria Hungary | 2.9 | 25.0 | 57.0 | 39.4 | 124.3 |
| Balkan West | 2.3 | 0.6 | 21.4 | 5.4 | 29.8 |
| Balkan East | 7.5 | 16.7 | 82.6 | 52.2 | 159.0 |
| Italy | 14.4 | 7.5 | 38.6 | 85.0 | 145.6 |
| Switzerland | 1.1 | 1.8 | 5.6 | 2.2 | 10.7 |
| Turkey, Cyprus | 12.5 | 1.4 | 41.3 | 6.4 | 61.5 |
| Ukraine, Moldova | 4.4 | 1.4 | 42.9 | 11.2 | 60.0 |
| Iceland | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 |
| Europe total | 134.3 | 377.9 | 887.8 | 956.6 | 2356.6 |

**Table A.10:** Estimation of bioenergy gate fees and prices (€/MWh) for Europe from 2015 to 2050.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Solid waste – MSW gate fee | | | | | | | | Solid waste – Biomass | Solid residues | Biogas |
| Region | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | All years | All years | All years |
| Norway | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 15.2 | 0 |
| Denmark | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 6.2 | 0 |
| Sweden | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 15.0 | 0 |
| Finland | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 14.3 | 0 |
| Baltic | 17.3 | 18.1 | 19.2 | 20.2 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 10.3 | 0 |
| Poland | 17.5 | 19.7 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 7.7 | 0 |
| Iberia | 19.2 | 19.6 | 20.0 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 8.6 | 0 |
| France | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 6.9 | 0 |
| Benelux | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 7.7 | 0 |
| UK and Ireland | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 6.8 | 0 |
| Germany | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 8.5 | 0 |
| Czech Republic & Slovakia | 18.6 | 19.5 | 20.0 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 8.6 | 0 |
| Austria Hungary | 19.2 | 20.1 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 7.7 | 0 |
| Balkan West | 15.7 | 17.1 | 18.1 | 19.2 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 6.4 | 0 |
| Balkan East | 15.7 | 17.1 | 19.1 | 20.2 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 7.0 | 0 |
| Italy | 19.7 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 7.2 | 0 |
| Switzerland | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 14.7 | 0 |
| Turkey, Cyprus | 17.5 | 18.8 | 19.5 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 5.3 | 0 |
| Ukraine, Moldova | 10.7 | 11.5 | 12.9 | 14.9 | 17.5 | 19.2 | 20.3 | 20.3 | 0 | 5.3 | 0 |
| Iceland | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 0.0 | 0 |
| Europe total | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 0 | 15.2 | 0 |

**Table A.11:** Total European installed capacities of different electricity generation technologies from 2015 to 2050 [GW] for the Regions scenario.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | **2015** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| PV optimally tilted | 49 | 49 | 57 | 62 | 68 | 135 | 203 | 227 |
| PV single-axis tracking | 0 | 104 | 190 | 252 | 360 | 414 | 449 | 480 |
| PV prosumers | 54 | 127 | 355 | 584 | 781 | 974 | 1124 | 1268 |
| CSP | 2 | 2 | 3 | 3 | 3 | 2 | 0 | 0 |
| Wind onshore | 127 | 204 | 369 | 479 | 534 | 536 | 539 | 546 |
| Wind offshore | 8 | 8 | 8 | 7 | 5 | 0 | 0 | 0 |
| Geothermal power | 2 | 3 | 5 | 5 | 6 | 6 | 6 | 6 |
| Hydro RoR | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 |
| Hydro Dam | 126 | 131 | 140 | 146 | 154 | 155 | 156 | 156 |
| CCGT | 177 | 172 | 166 | 170 | 164 | 135 | 106 | 88 |
| OCGT | 96 | 98 | 131 | 143 | 139 | 135 | 120 | 132 |
| Steam turbine | 0 | 1 | 3 | 3 | 7 | 7 | 8 | 7 |
| Biomass PP | 20 | 20 | 35 | 43 | 49 | 51 | 55 | 59 |
| Waste incinerator | 8 | 8 | 7 | 7 | 6 | 6 | 5 | 6 |
| Biogas PP | 9 | 12 | 22 | 39 | 48 | 62 | 64 | 74 |
| Coal PP | 234 | 166 | 111 | 72 | 51 | 36 | 24 | 20 |
| Internal combustion gen. | 55 | 33 | 7 | 3 | 1 | 0 | 0 | 0 |
| Nuclear PP | 138 | 133 | 105 | 58 | 22 | 13 | 8 | 2 |

**Table A.12:** Total European installed capacities of different electricity generation technologies from 2015 to 2050 [GW] for the Area scenario.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| PV optimally tilted | 49 | 49 | 49 | 49 | 48 | 38 | 58 | 72 |
| PV single-axis tracking | 0 | 105 | 224 | 231 | 245 | 288 | 337 | 369 |
| PV prosumers | 54 | 127 | 355 | 584 | 781 | 974 | 1124 | 1268 |
| CSP | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 |
| Wind onshore | 127 | 246 | 435 | 508 | 570 | 580 | 585 | 597 |
| Wind offshore | 8 | 8 | 8 | 7 | 5 | 0 | 0 | 0 |
| Geothermal power | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| Hydro RoR | 67 | 67 | 67 | 67 | 67 | 67 | 67 | 67 |
| Hydro Dam | 126 | 126 | 139 | 141 | 143 | 145 | 145 | 146 |
| CCGT | 177 | 165 | 159 | 158 | 147 | 119 | 82 | 47 |
| OCGT | 96 | 101 | 105 | 102 | 101 | 91 | 72 | 77 |
| Steam turbine | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Biomass PP | 20 | 20 | 25 | 27 | 27 | 26 | 24 | 25 |
| Waste incinerator | 8 | 7 | 7 | 7 | 6 | 5 | 5 | 5 |
| Biogas PP | 9 | 11 | 13 | 19 | 22 | 24 | 37 | 62 |
| Coal PP | 234 | 166 | 111 | 72 | 51 | 36 | 24 | 20 |
| Internal combustion gen. | 55 | 33 | 7 | 3 | 1 | 0 | 0 | 0 |
| Nuclear PP | 138 | 133 | 105 | 58 | 22 | 13 | 8 | 2 |

**Table A.13:** Full Load Hours of generation and storage technologies from 2015 to 2050 (h) in the Regions scenario.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| PV optimally tilted | 1236 | 1236 | 1238 | 1241 | 1241 | 1340 | 1350 | 1375 |
| PV single-axis tracking | 1432 | 1931 | 1814 | 1727 | 1710 | 1693 | 1688 | 1668 |
| PV prosumers |  |  |  |  |  |  |  |  |
| CSP | 2069 | 2048 | 1999 | 1999 | 1998 | 1977 | 1310 | 1244 |
| Wind onshore | 2546 | 3091 | 3042 | 2993 | 3078 | 3153 | 3187 | 3178 |
| Wind offshore | 3960 | 3961 | 3963 | 3960 | 3968 | 3988 | 3146 | 3144 |
| Hydro ROR | 2907 | 2878 | 2878 | 2878 | 2878 | 2878 | 2878 | 2878 |
| Hydro dams | 2932 | 2936 | 2971 | 2988 | 2954 | 2960 | 2972 | 2977 |
| Geothermal | 5827 | 6257 | 6411 | 6256 | 6109 | 6018 | 6250 | 6497 |
| Battery prosumers (Residential) | 0 | 1560 | 1501 | 1446 | 1399 | 1357 | 1330 | 1307 |
| Battery prosumers (Commercial) | 0 | 1601 | 1530 | 1502 | 1458 | 1420 | 1379 | 1353 |
| Battery prosumers (Industrial) | 0 | 1664 | 1578 | 1548 | 1494 | 1444 | 1403 | 1371 |
| Battery prosumers (total) | 0 | 1581 | 1535 | 1499 | 1452 | 1408 | 1373 | 1345 |
| Battery system | 0 | 2087 | 2776 | 1856 | 1731 | 1677 | 1698 | 1657 |
| PHES | 571 | 1227 | 1527 | 1557 | 1558 | 1472 | 1534 | 1466 |
| TES | 8279 | 5067 | 5092 | 4169 | 5551 | 5506 | 4928 | 4402 |
| A-CAES | 0 | 1463 | 1518 | 1655 | 1956 | 1993 | 1910 | 2112 |
| Power-to-gas | 0 | 513 | 1346 | 42 | 2136 | 2699 | 3039 | 3012 |
| CCGT | 2377 | 2334 | 1327 | 1624 | 1833 | 2100 | 2503 | 2926 |
| OCGT | 2085 | 61 | 97 | 213 | 198 | 237 | 331 | 309 |
| Steam turbine | 5912 | 2953 | 2315 | 2538 | 2487 | 2475 | 2586 | 2607 |
| Biomass PP | 4865 | 7032 | 6953 | 6441 | 5811 | 5545 | 5353 | 5083 |
| Waste incinerator | 2775 | 3609 | 4744 | 5633 | 6545 | 7315 | 8216 | 8018 |
| Biogas CHP | 5255 | 4157 | 3935 | 2900 | 2318 | 1945 | 2095 | 1926 |
| Biogas upgrade | 0 | 8154 | 8112 | 8260 | 8147 | 7984 | 7921 | 7898 |
| Biogas digester | 8322 | 8322 | 8322 | 8322 | 8322 | 8322 | 8322 | 8322 |
| Coal PP | 4881 | 5424 | 3366 | 1977 | 1140 | 567 | 298 | 0 |
| Internal combustion gen. | 1147 | 4 | 138 | 1 | 26 | 0 | 0 | 0 |
| Nuclear PP | 7104 | 7446 | 7446 | 7446 | 7446 | 7446 | 7446 | 7446 |

**Table A.14:** Full Load Hours of generation and storage technologies from 2015 to 2050 (h) in the Area scenario.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| PV optimally tilted | 1236 | 1236 | 1236 | 1236 | 1238 | 1237 | 1359 | 1538 |
| PV single-axis tracking | 1432 | 1944 | 1855 | 1849 | 1848 | 1852 | 1849 | 1847 |
| PV prosumers | 1198 | 1239 | 1237 | 1232 | 1232 | 1227 | 1224 | 1219 |
| CSP | 2069 | 2068 | 2066 | 2066 | 2066 | 2067 | 1450 | 1281 |
| Wind onshore | 2553 | 3195 | 3365 | 3308 | 3431 | 3481 | 3502 | 3494 |
| Wind offshore | 3960 | 3960 | 3961 | 3959 | 3966 | 2847 | 2847 | 3253 |
| Hydro ROR | 2878 | 2878 | 2878 | 2878 | 2878 | 2878 | 2878 | 2878 |
| Hydro dams | 2902 | 2906 | 2974 | 2983 | 2995 | 3005 | 3012 | 3017 |
| Geothermal | 5612 | 5887 | 5905 | 6024 | 6044 | 5944 | 5694 | 5240 |
| Battery prosumers (Residential) | 0 | 1560 | 1501 | 1446 | 1399 | 1357 | 1330 | 1307 |
| Battery prosumers (Commercial) | 0 | 1601 | 1530 | 1502 | 1458 | 1420 | 1379 | 1353 |
| Battery prosumers (Industrial) | 0 | 1664 | 1578 | 1548 | 1494 | 1444 | 1403 | 1371 |
| Battery prosumers (total) | 0 | 1581 | 1535 | 1499 | 1452 | 1408 | 1373 | 1345 |
| Battery system | 0 | 7593 | 3007 | 2227 | 2020 | 2037 | 1970 | 1938 |
| PHES | 94 | 921 | 1731 | 1935 | 1990 | 1933 | 1729 | 1715 |
| TES | 8292 | 8032 | 8128 | 8419 | 8784 | 7186 | 5562 | 5767 |
| A-CAES | 0 | 1647 | 1680 | 1839 | 2135 | 2371 | 2569 | 2433 |
| Power-to-gas | 0 | 613 | 549 | 25 | 65 | 290 | 2285 | 2826 |
| CCGT | 2174 | 1537 | 1330 | 1613 | 1810 | 2256 | 2947 | 3705 |
| OCGT | 2085 | 38 | 95 | 314 | 366 | 412 | 419 | 529 |
| Steam turbine | 5916 | 5897 | 5116 | 4573 | 3938 | 3497 | 3085 | 3176 |
| Biomass PP | 4909 | 6984 | 7205 | 6725 | 7060 | 7115 | 7068 | 6811 |
| Waste incinerator | 2720 | 3584 | 4737 | 5625 | 6595 | 7382 | 8309 | 8219 |
| Biogas CHP | 5248 | 4185 | 5292 | 5277 | 4649 | 4400 | 3739 | 3074 |
| Biogas upgrade | 0 | 8322 | 8321 | 8322 | 8320 | 8306 | 8233 | 7675 |
| Biogas digester | 8322 | 8322 | 8322 | 8322 | 8322 | 8322 | 8322 | 8322 |
| Coal PP | 4953 | 5466 | 497 | 119 | 72 | 51 | 77 | 0 |
| Internal combustion gen. | 1147 | 1 | 1 | 1 | 2 | 0 | 0 | 0 |
| Nuclear PP | 7104 | 7446 | 7446 | 7446 | 7446 | 7446 | 7446 | 7446 |

**Table A.15:** Installed capacities of storage systems from 2015 to 2050 for the Regions scenario.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | Units | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| A-CAES storage | [GWh] | 0 | 25 | 143 | 149 | 149 | 149 | 213 | 214 |
| Battery RES | [GWh] | 0 | 63 | 195 | 311 | 403 | 482 | 535 | 581 |
| Battery COM | [GWh] | 0 | 28 | 165 | 281 | 372 | 446 | 509 | 555 |
| Battery IND | [GWh] | 0 | 9 | 169 | 328 | 449 | 558 | 651 | 718 |
| Battery System | [GWh] | 0 | 4 | 33 | 78 | 354 | 794 | 1189 | 1465 |
| Battery total | [GWh] | 0 | 103 | 561 | 999 | 1578 | 2280 | 2883 | 3320 |
| PHES storage | [GWh] | 388 | 388 | 392 | 392 | 392 | 392 | 396 | 396 |
| TES storage | [GWh] | 22 | 41 | 149 | 157 | 309 | 326 | 394 | 395 |
| A-CAES storage | [GWh] | 0 | 25 | 143 | 149 | 149 | 149 | 213 | 214 |
| PtSNG el. input | [GW] | 0 | 1 | 5 | 3 | 9 | 17 | 37 | 37 |
| Gas storage | [GWh] | 0 | 5570 | 16954 | 66564 | 96651 | 145504 | 193080 | 218042 |

**Table A.16:** Output of storage systems from 2015 to 2050 for the Regions scenario.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | Units | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| Battery SC output | [TWh] | 0 | 26 | 135 | 230 | 296 | 349 | 388 | 416 |
| Battery system output | [TWh] | 0 | 1 | 15 | 24 | 102 | 222 | 336 | 405 |
| Battery total output | [TWh] | 0 | 28 | 150 | 254 | 398 | 571 | 724 | 820 |
| PHES output | [TWh] | 28 | 60 | 75 | 76 | 76 | 72 | 76 | 73 |
| TES output | [TWh] | 4 | 5 | 18 | 16 | 41 | 43 | 46 | 41 |
| A-CAES output | [TWh] | 0 | 0 | 2 | 2 | 3 | 3 | 4 | 5 |
| Gas output | [TWh] | 0 | 217 | 348 | 521 | 548 | 548 | 547 | 537 |

**Table A.17:** Installed capacities of storage systems from 2015 to 2050 for the Area scenario.

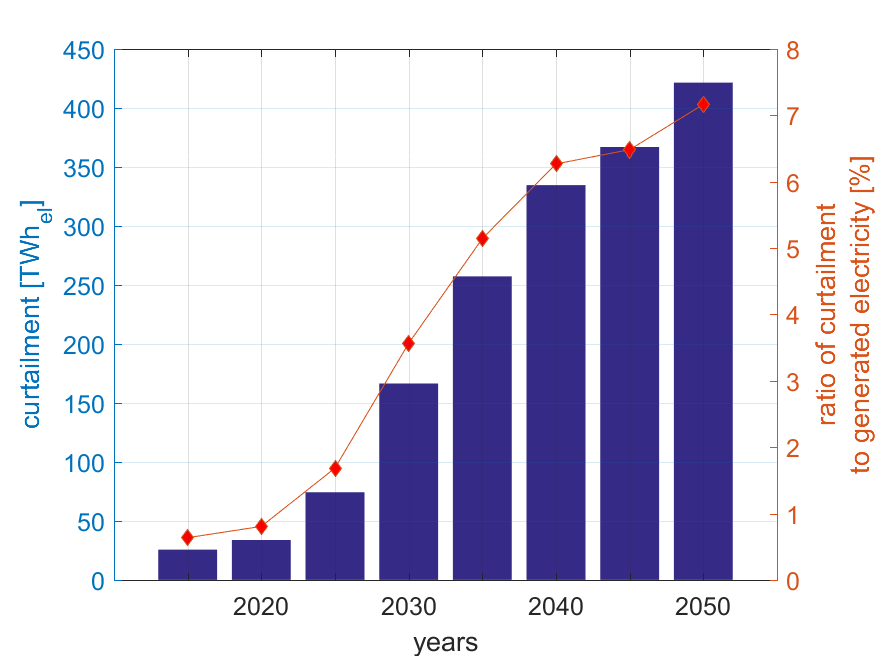
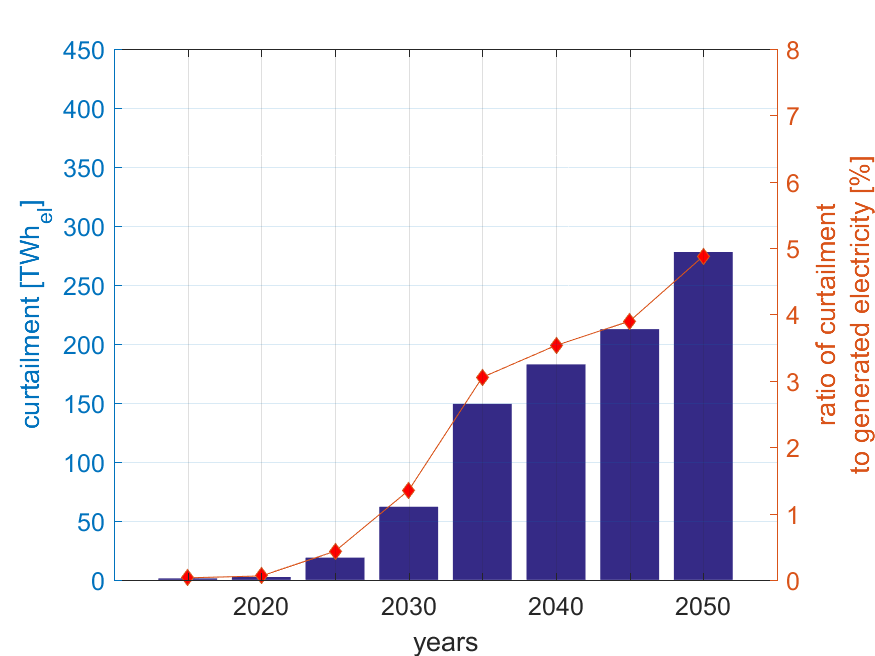
|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | Units | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| A-CAES storage | [GWh] | 0 | 1 | 2 | 5 | 6 | 11 | 14 | 16 |
| Battery RES | [GWh] | 0 | 63 | 195 | 311 | 403 | 482 | 535 | 581 |
| Battery COM | [GWh] | 0 | 28 | 165 | 281 | 372 | 446 | 509 | 555 |
| Battery IND | [GWh] | 0 | 9 | 169 | 328 | 449 | 558 | 651 | 718 |
| Battery System | [GWh] | 0 | 0 | 0 | 10 | 103 | 376 | 798 | 1023 |
| Battery total | [GWh] | 0 | 100 | 529 | 930 | 1327 | 1862 | 2492 | 2878 |
| PHES storage | [GWh] | 388 | 388 | 388 | 388 | 388 | 388 | 388 | 388 |
| TES storage | [GWh] | 22 | 23 | 23 | 26 | 29 | 41 | 22 | 23 |
| A-CAES storage | [GWh] | 0 | 1 | 2 | 5 | 6 | 11 | 14 | 16 |
| PtSNG el. input | [GW] | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 |
| Gas storage | [GWh] | 0 | 4594 | 47389 | 72122 | 99400 | 109887 | 141260 | 170638 |

**Table A.18:** Output of storage systems from 2015 to 2050 for the Area scenario.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Technology | Units | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| Battery SC output | [TWh] | 0 | 26 | 135 | 230 | 296 | 349 | 388 | 416 |
| Battery system output | [TWh] | 0 | 0 | 0 | 4 | 35 | 128 | 262 | 331 |
| Battery total output | [TWh] | 0 | 26 | 135 | 234 | 331 | 476 | 650 | 746 |
| PHES output | [TWh] | 5 | 45 | 84 | 94 | 97 | 94 | 84 | 83 |
| TES output | [TWh] | 4 | 4 | 5 | 5 | 6 | 7 | 3 | 3 |
| A-CAES output | [TWh] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gas output | [TWh] | 0 | 235 | 393 | 545 | 554 | 553 | 485 | 392 |

**Table A.19:** Amounts of renewable energy, storage discharge and curtailment. Shares are shown as percentage of total generation.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Storage technology | Unit | Scenario | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| Share of RE | % | Regions | 30.4 | 48.1 | 72.9 | 87.3 | 95.2 | 97.6 | 98.9 | 99.8 |
| Area | 30.5 | 51.6 | 80.8 | 90.4 | 96.6 | 98.1 | 98.9 | 99.8 |
| Storage discharge | TWhe | Regions | 29 | 90 | 237 | 340 | 500 | 675 | 848 | 940 |
| Area | 6 | 73 | 221 | 330 | 430 | 574 | 736 | 833 |
| Share of storage discharge | % | Regions | 0.7 | 2.2 | 5.5 | 7.6 | 10.8 | 13.8 | 16.5 | 17.7 |
| Area | 0.2 | 1.8 | 5.2 | 7.4 | 9.3 | 11.7 | 14.3 | 15.7 |
| PtG storage discharge | TWhe | Regions | 0 | 0 | 2 | 0 | 5 | 11 | 24 | 24 |
| Area | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| Curtailment | TWhe | Regions | 26 | 34 | 74 | 167 | 257 | 335 | 367 | 422 |
| Area | 1 | 2 | 19 | 62 | 149 | 183 | 213 | 278 |
| Share of curtailment | % | Regions | 0.6 | 0.8 | 1.7 | 3.6 | 5.1 | 6.3 | 6.5 | 7.2 |
| Area | 0 | 0.1 | 0.4 | 1.3 | 3.2 | 3.6 | 3.9 | 4.9 |

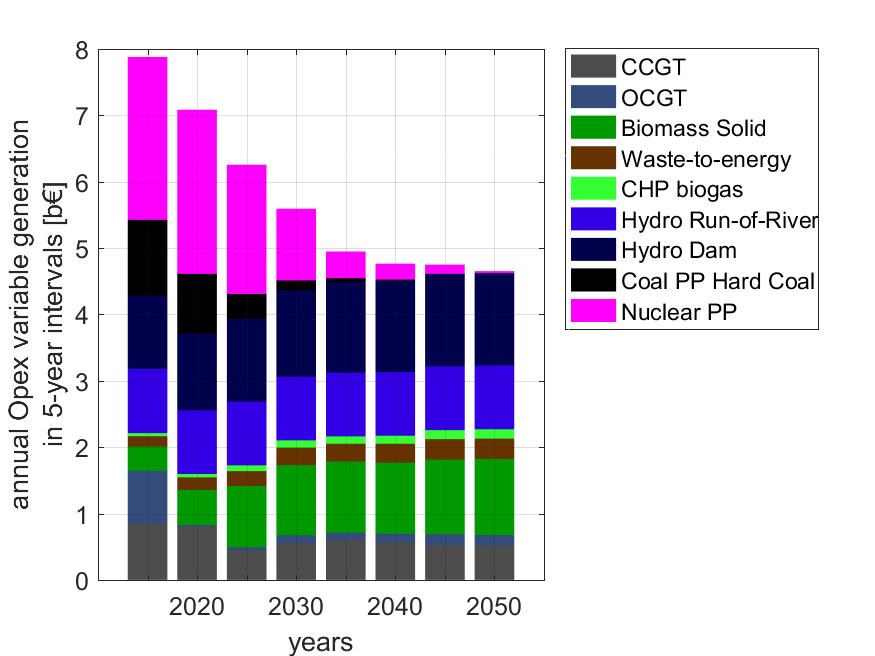
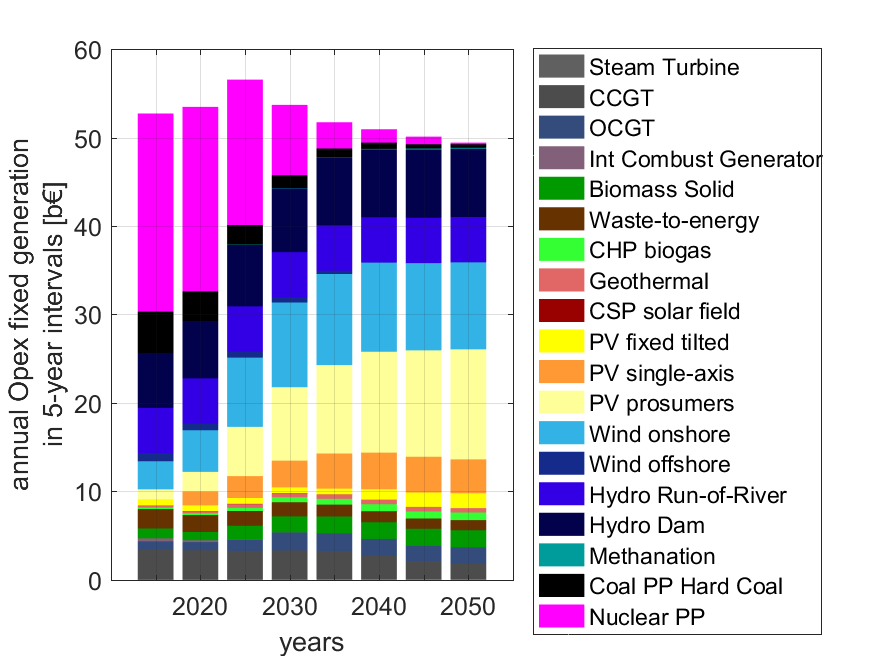
**Figure A.1.** Curtailed electricity from 2015 to 2050 for Europe for the Regions (left) and Area (right) scenarios.

**Table A.20:** Financial results from 2015 to 2050 for the Regions scenario.

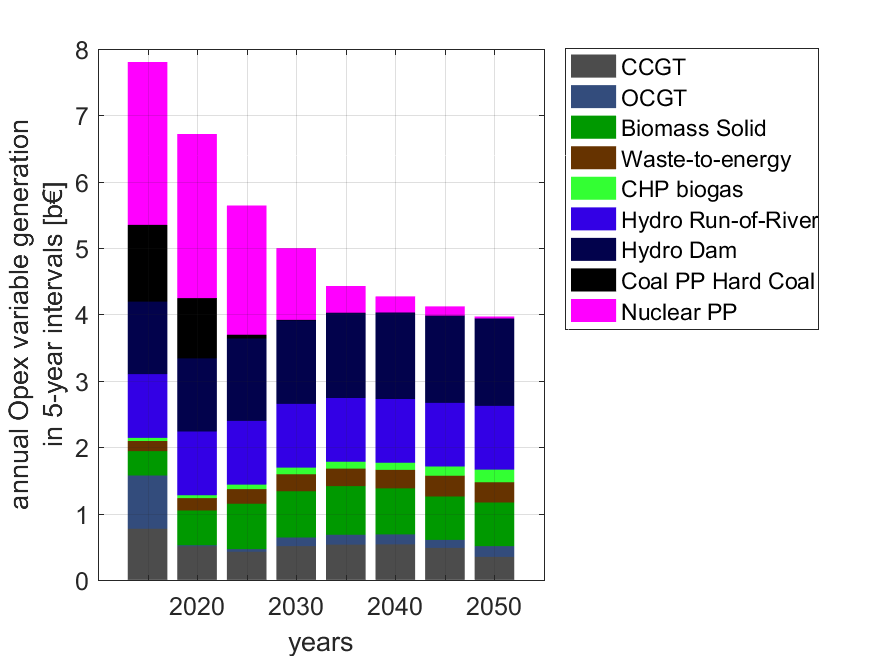
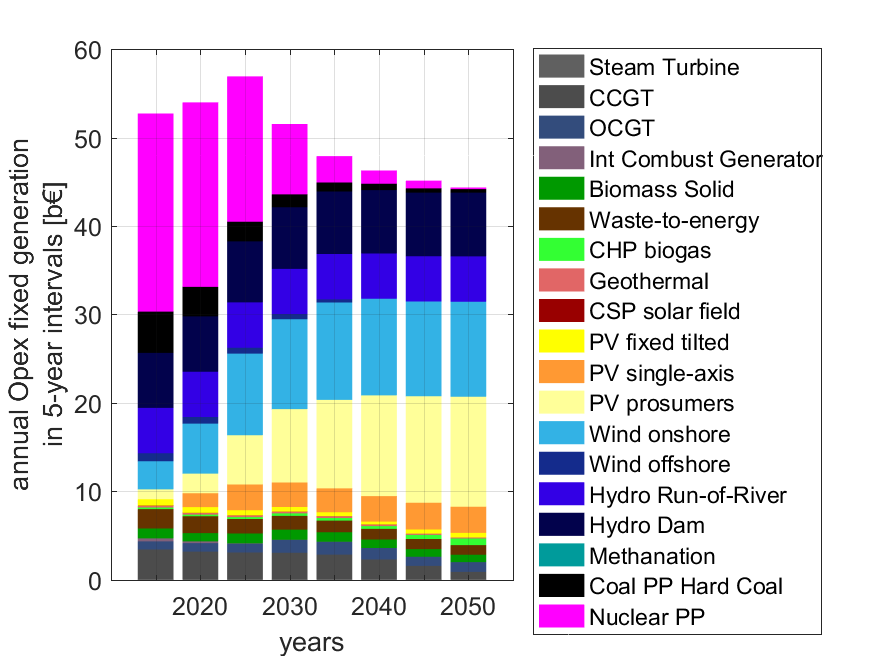
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | LCOE  [€/MWh] | LCOE primary  [€/MWh] | LCOC  [€/MWh] | LCOS  [€/MWh] | LCOT  [€/MWh] | Total annualized cost  [b€] |
| 2015 | 68.4 | 66.3 | 0.4 | 1.6 | 0 | 274 |
| 2020 | 65.8 | 58.9 | 0.5 | 6.4 | 0 | 276 |
| 2025 | 67.8 | 56.2 | 0.9 | 10.7 | 0 | 295 |
| 2030 | 66.3 | 51.2 | 1.8 | 13.3 | 0 | 302 |
| 2035 | 62.9 | 45.5 | 2.3 | 15.0 | 0 | 299 |
| 2040 | 59.9 | 41.5 | 2.6 | 15.8 | 0 | 299 |
| 2045 | 57.8 | 39.2 | 2.5 | 16.1 | 0 | 303 |
| 2050 | 55.8 | 37.3 | 2.5 | 16.0 | 0 | 302 |

**Table A.21:** Financial results from 2015 to 2050 for the Area scenario.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | LCOE  [€/MWh] | LCOE primary  [€/MWh] | LCOC  [€/MWh] | LCOS  [€/MWh] | LCOT  [€/MWh] | Total annualized cost  [b€] |
| 2015 | 68.5 | 66.4 | 0.0 | 1.5 | 0.5 | 274 |
| 2020 | 65.3 | 57.2 | 0.0 | 7.3 | 0.8 | 274 |
| 2025 | 64.3 | 51.1 | 0.2 | 10.5 | 2.5 | 280 |
| 2030 | 63.1 | 47.6 | 0.6 | 12.3 | 2.5 | 288 |
| 2035 | 58.9 | 41.7 | 1.2 | 13.2 | 2.8 | 281 |
| 2040 | 55.7 | 38.4 | 1.3 | 13.3 | 2.7 | 279 |
| 2045 | 53.4 | 36.6 | 1.3 | 13.0 | 2.5 | 280 |
| 2050 | 51.1 | 34.7 | 1.5 | 12.5 | 2.5 | 276 |

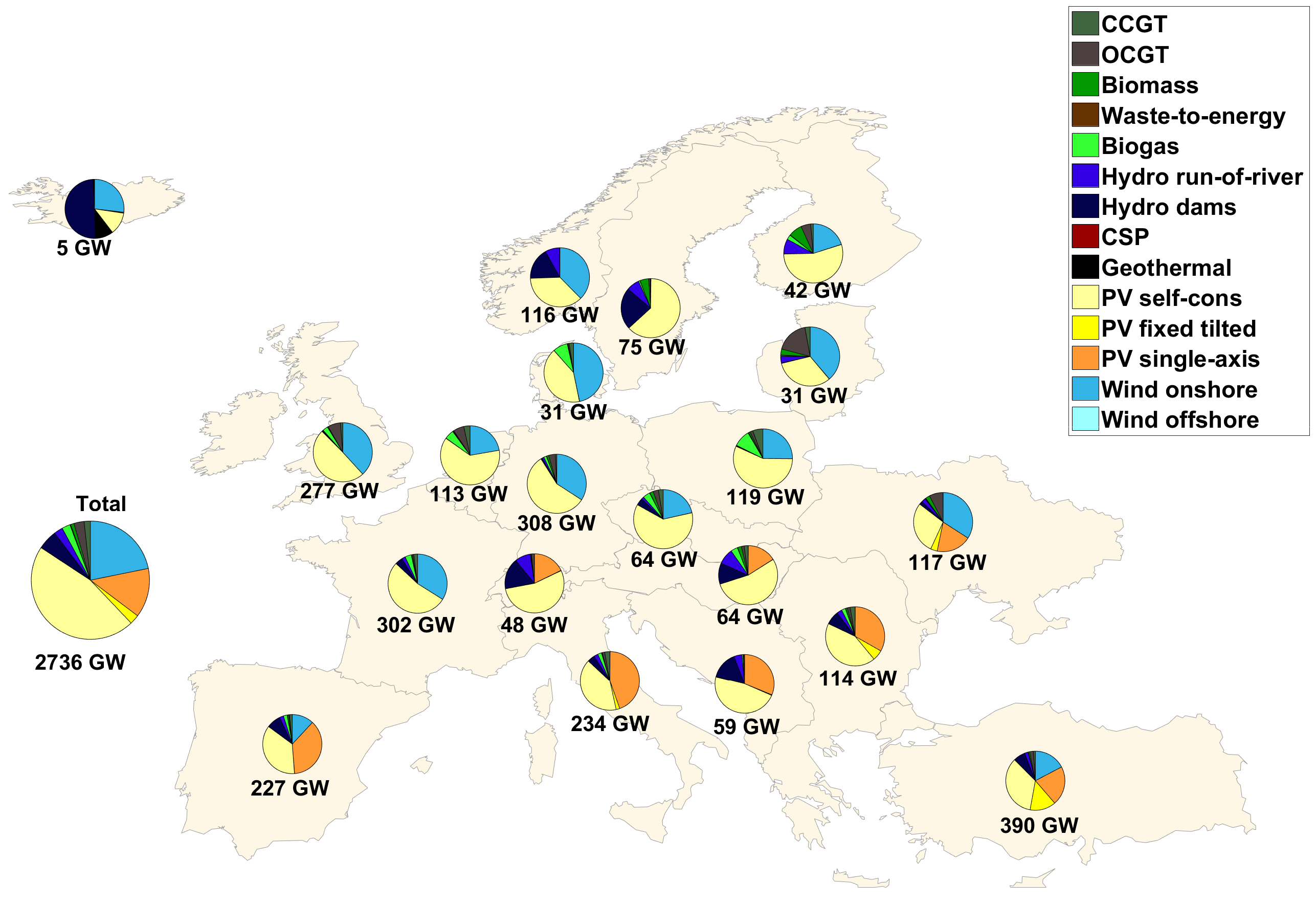
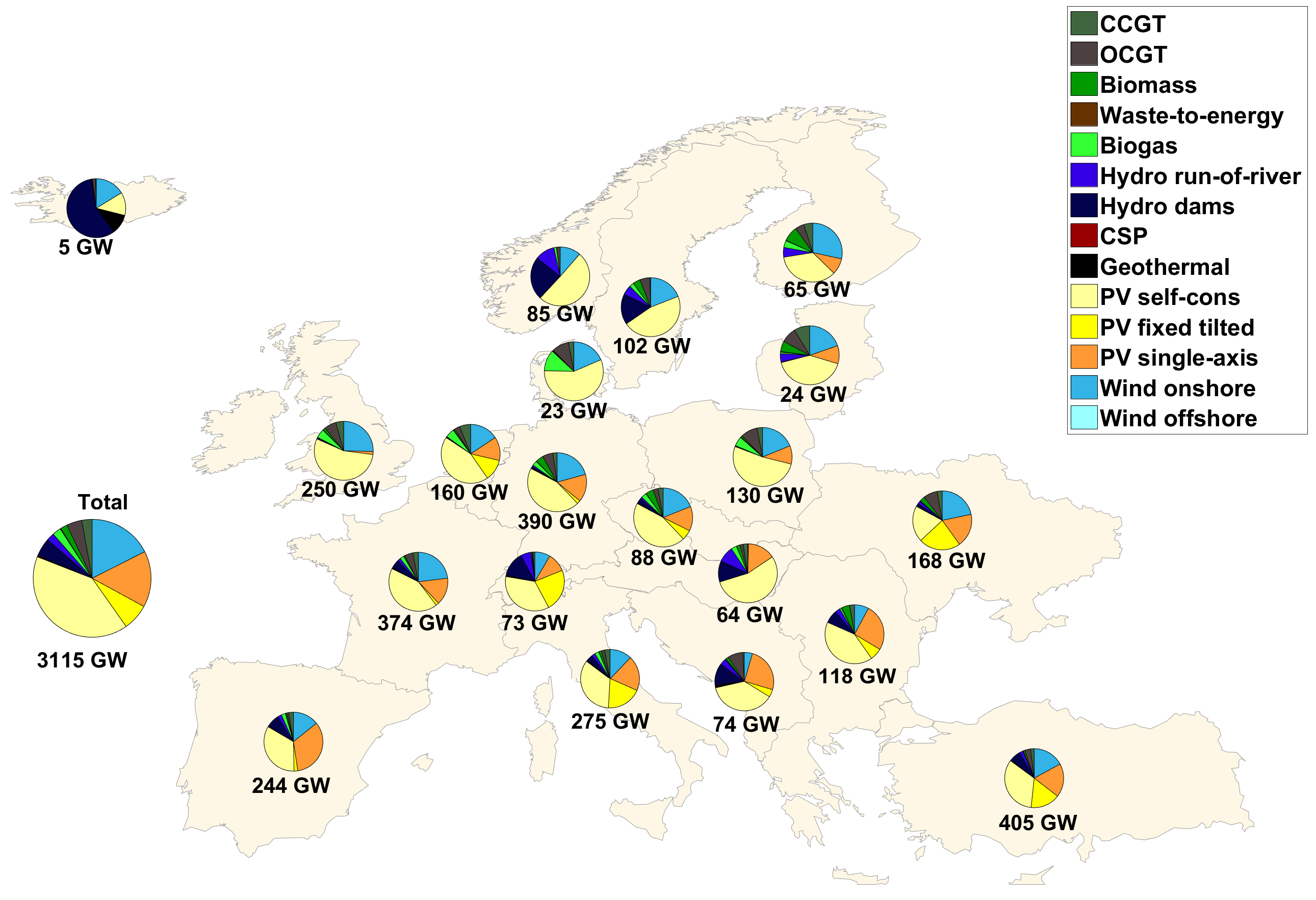


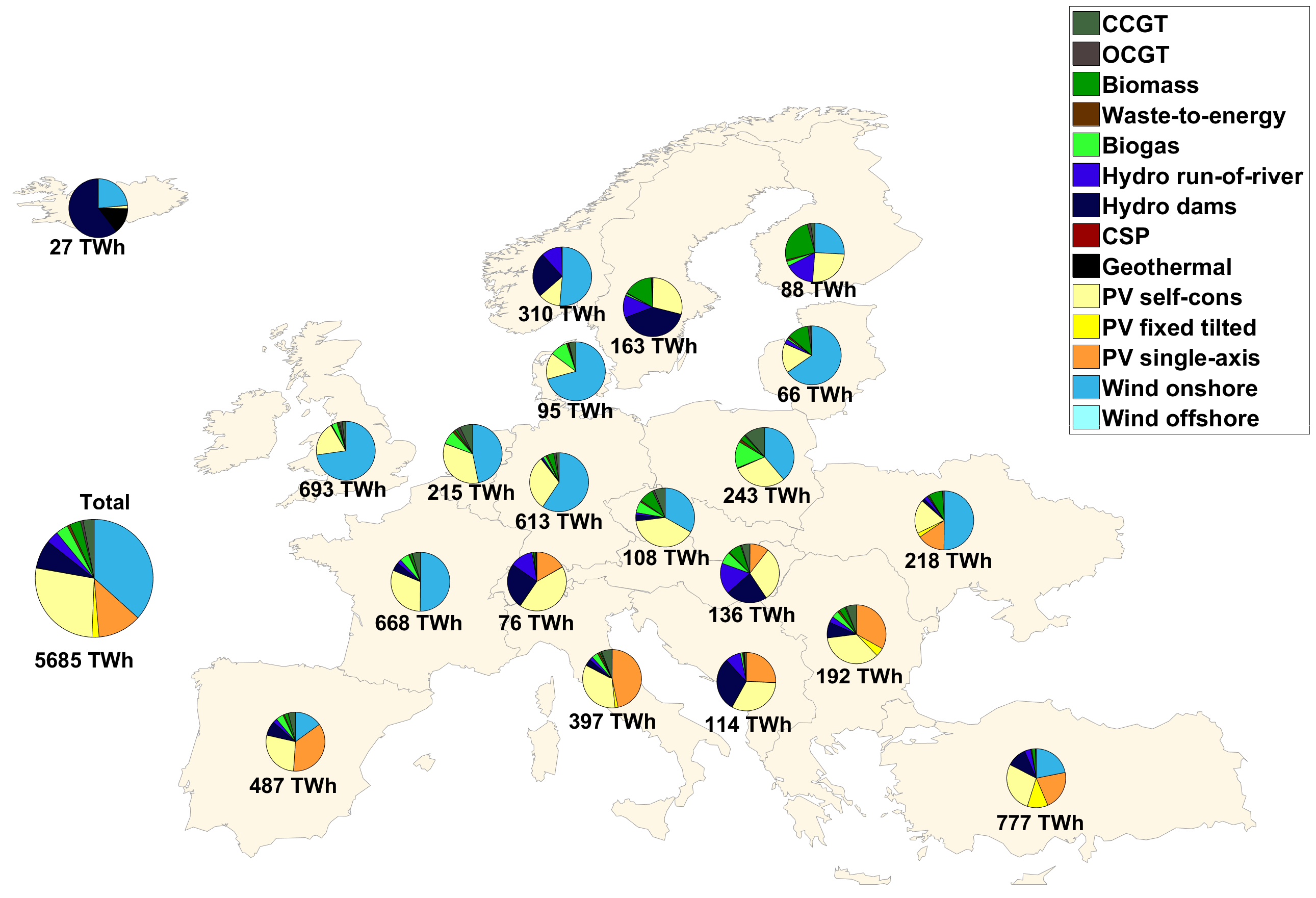
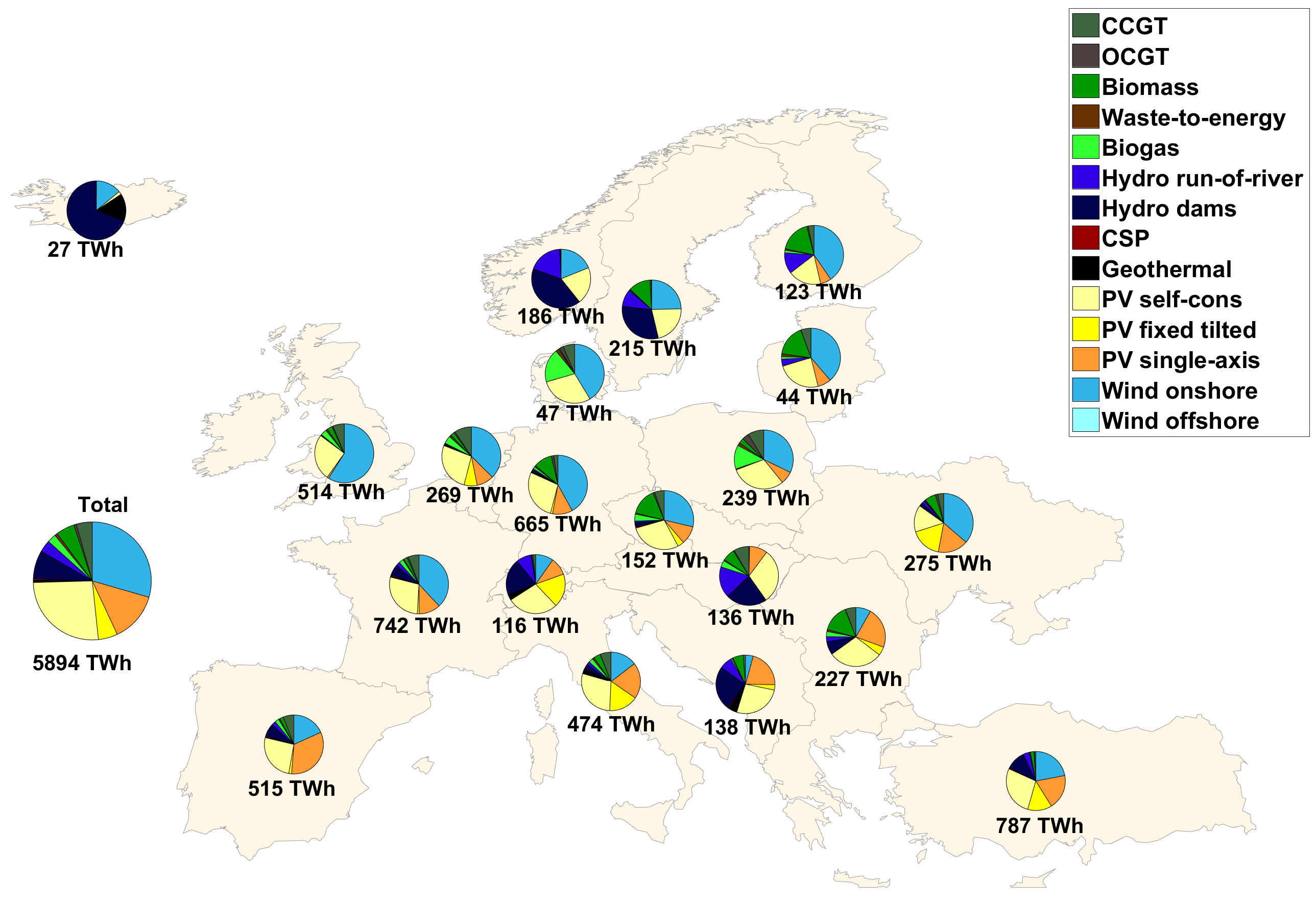
**Figure A.2:** Annual fixed (left) and variable (right) operations and maintenance costs from 2015 to 2050 for the Regions scenario.



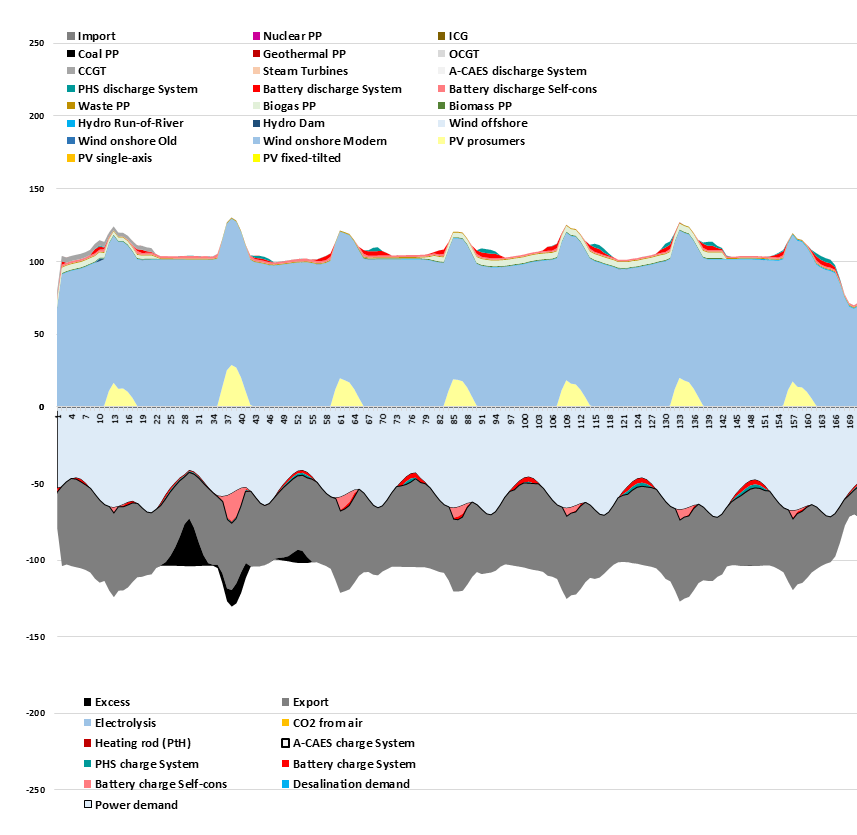
**Figure A.3:** Annual fixed (left) and variable (right) operations and maintenance costs from 2015 to 2050 for the Area scenario.

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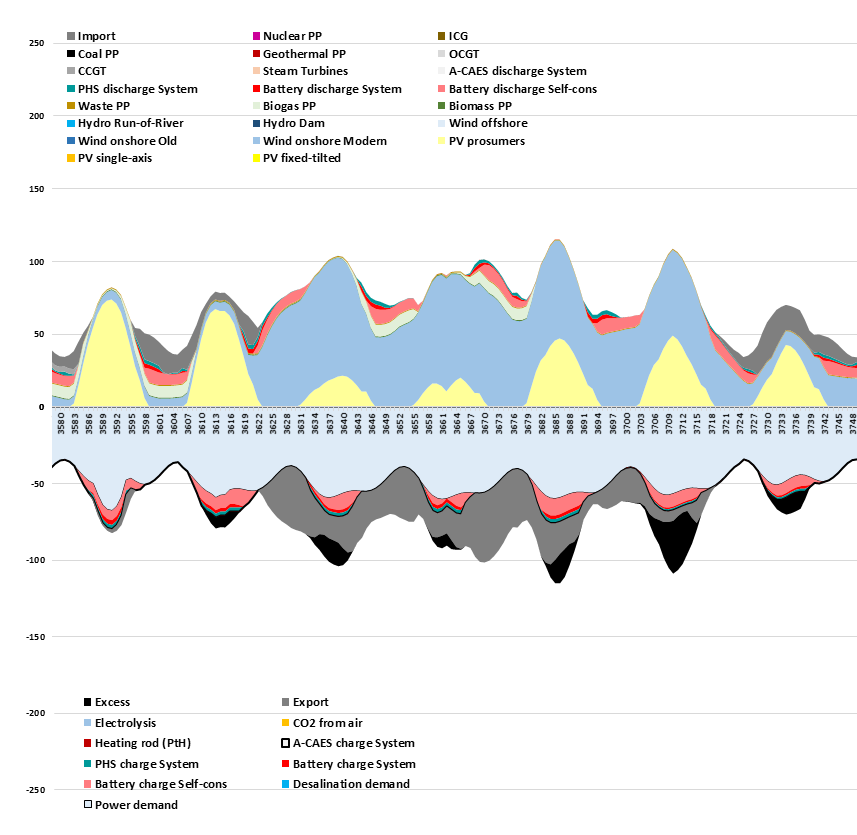




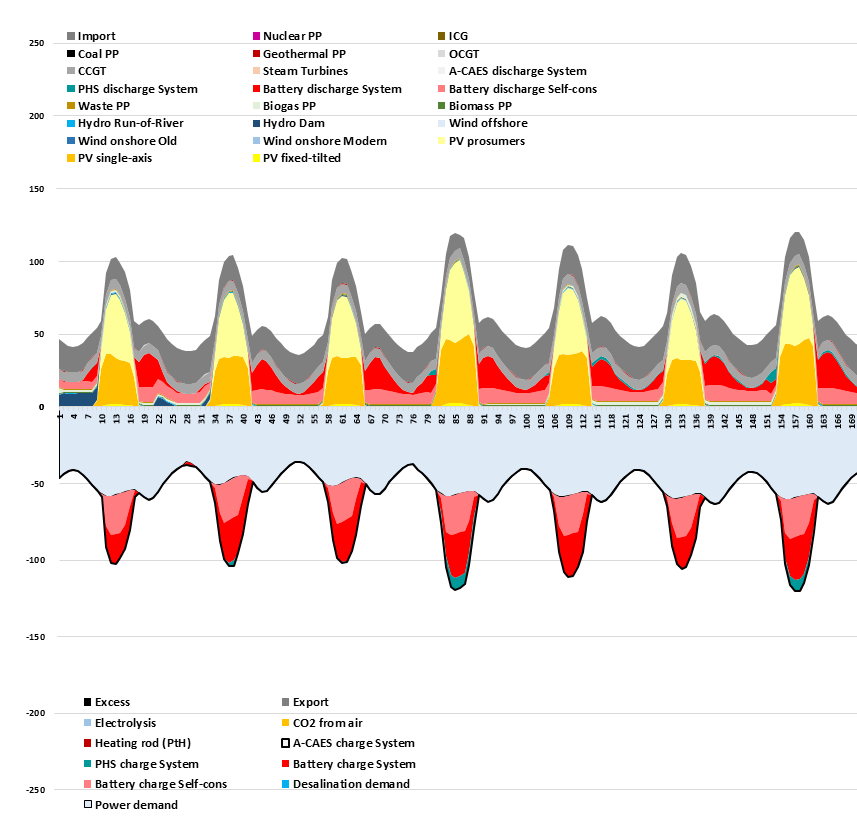
**Figure A.4:** Installed capacities (upper) and total generation (lower) for the Regions (left) and Area (right) scenarios for 2050.



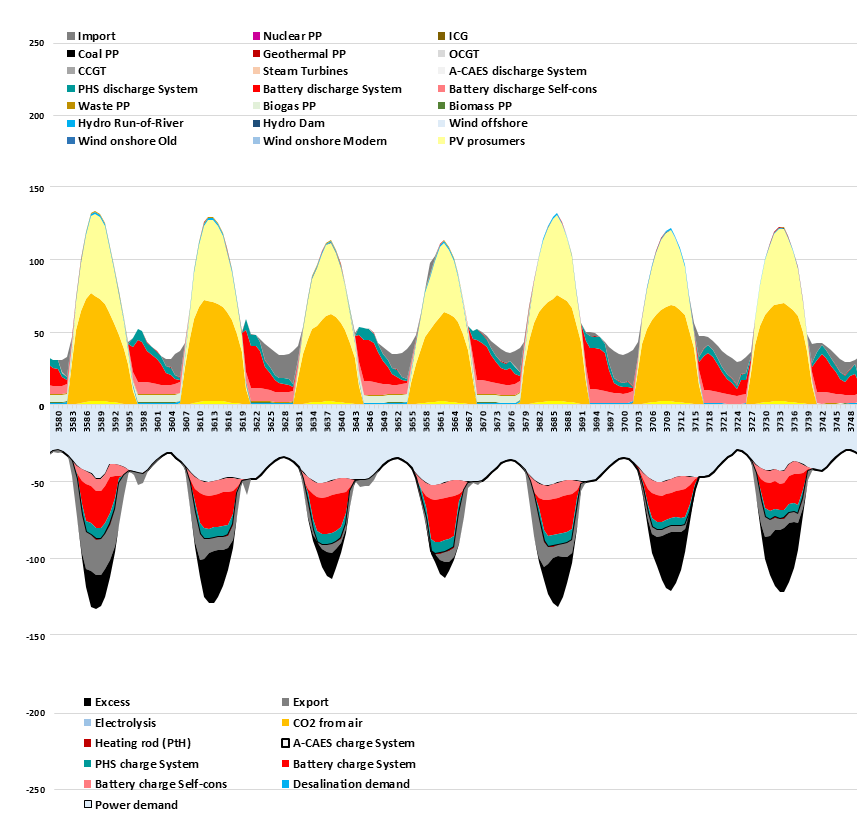
**Figure A.5:** Hourly profile of a representative winter period in the UK and Ireland in 2050. An example of a region with a high net export of wind power.



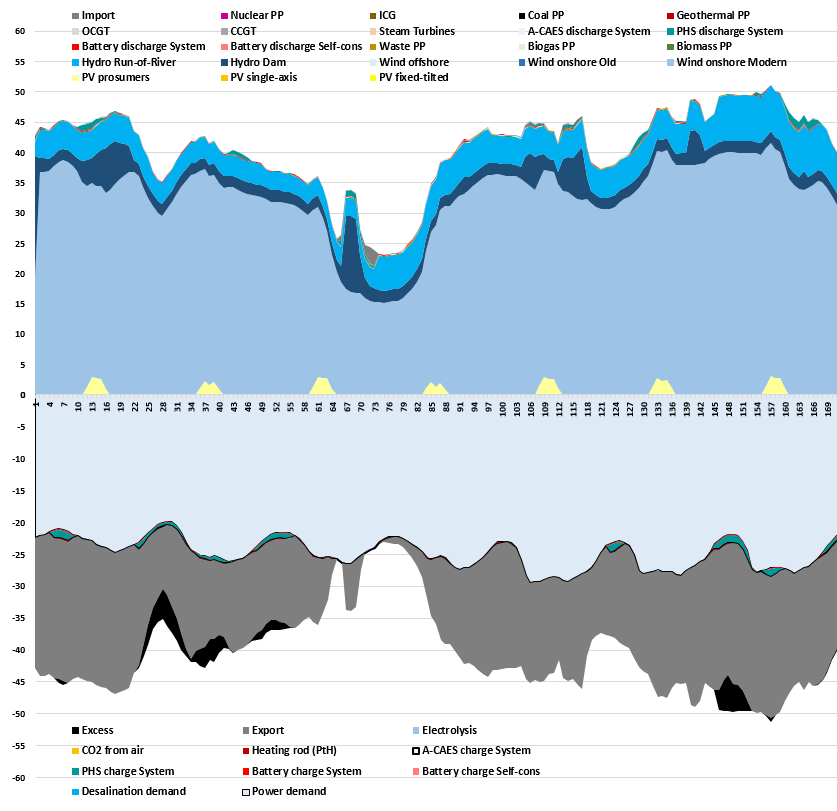
**Figure A.6:** Hourly profile of a representative summer period in Britain and Ireland in 2050. An example of a region with a high net export of wind power.

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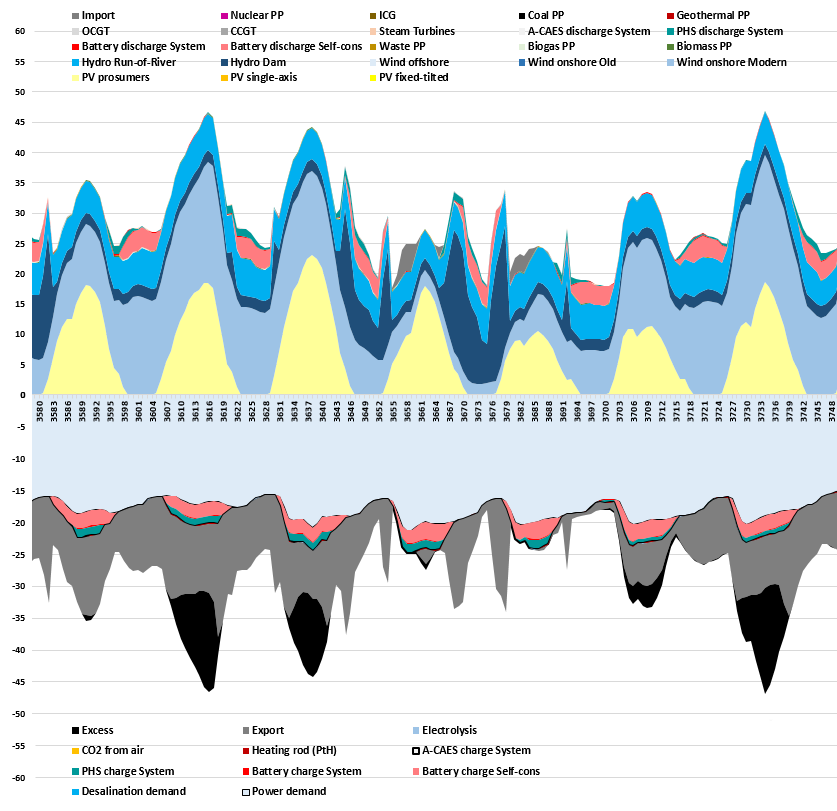
**Figure A.7:** Hourly profile of a representative winter period in Italy in 2050. An example of a region with a high net export of solar power.

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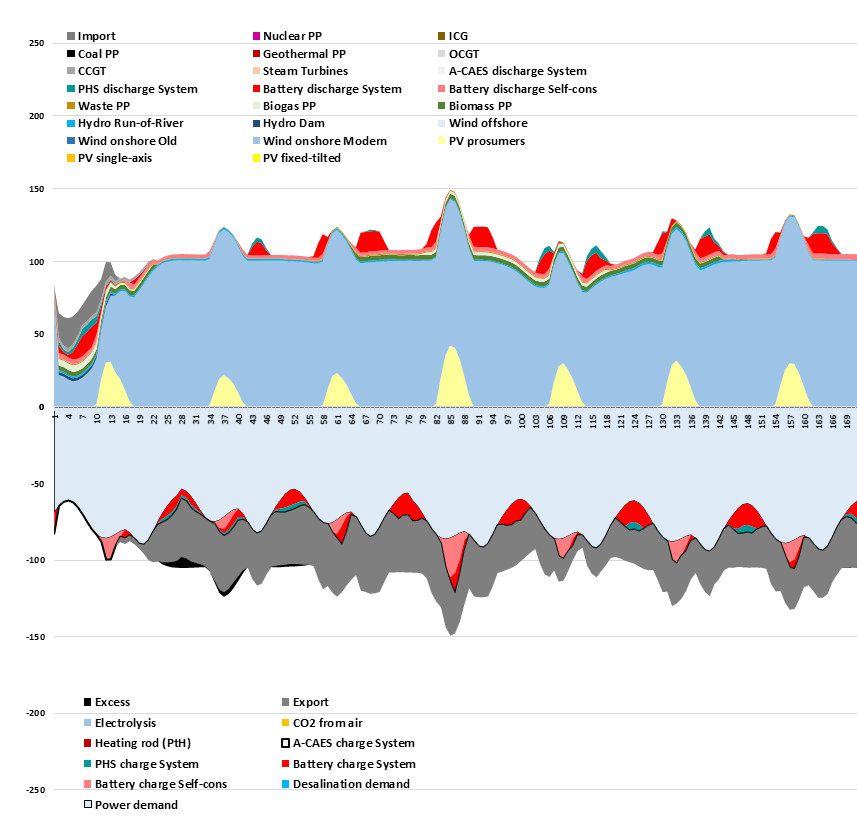
**Figure A.8:** Hourly profile of a representative summer period in the Italy in 2050. An example of a region with a high net export of solar power.

****

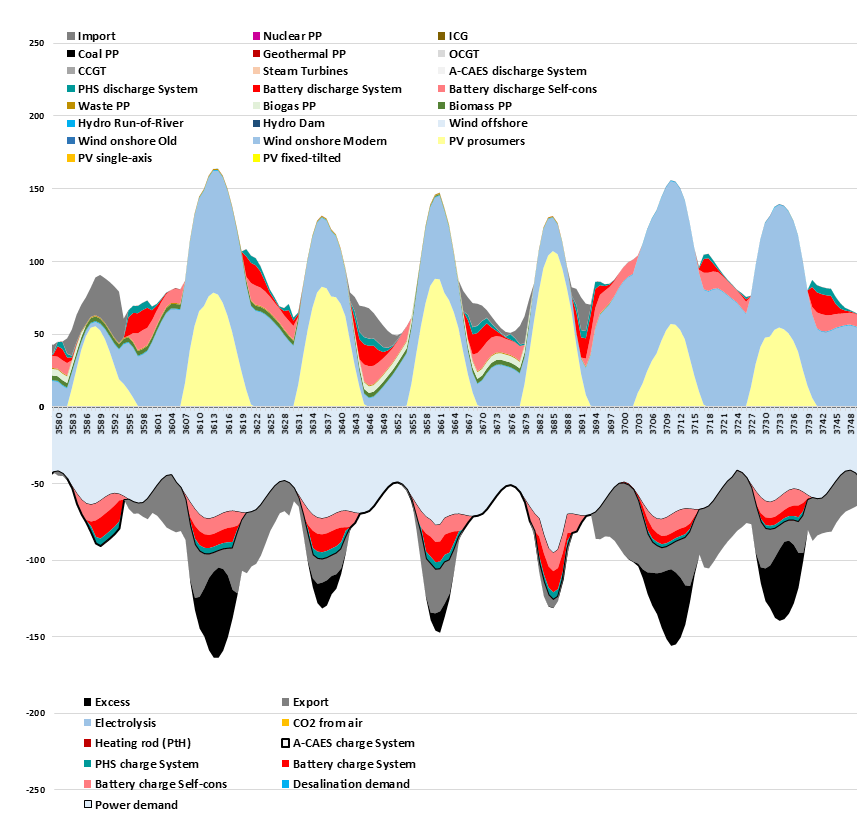
**Figure A.9:** Hourly profile of a representative winter period in Norway in 2050. An example of a region with a high net export of wind and hydropower.

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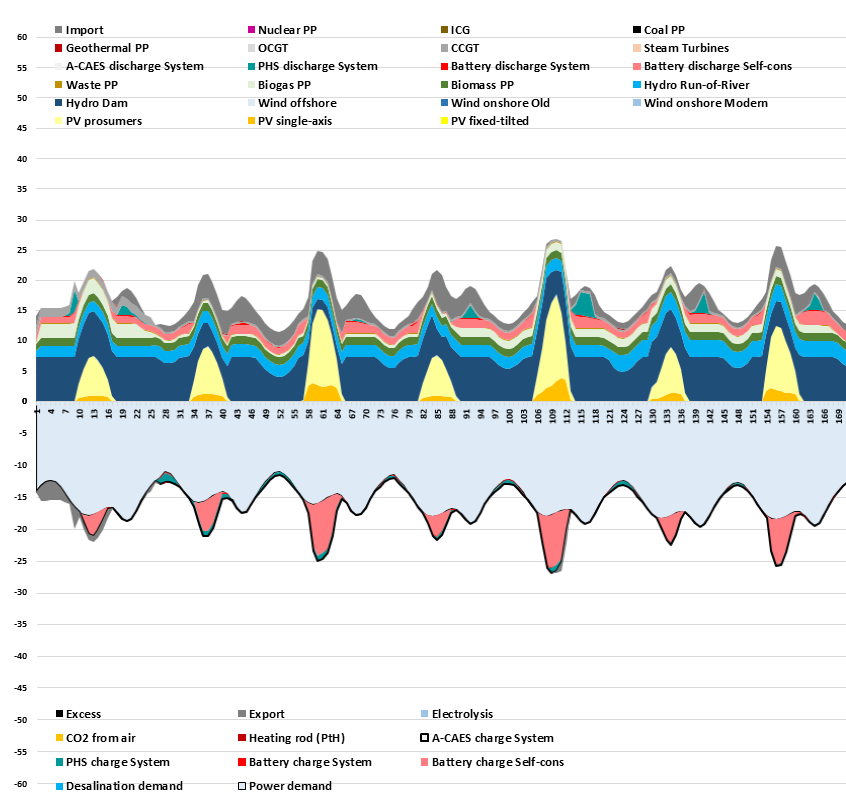
**Figure A.10:** Hourly profile of a representative summer period in Norway in 2050. An example of a region with a high net export of wind and hydropower.

****

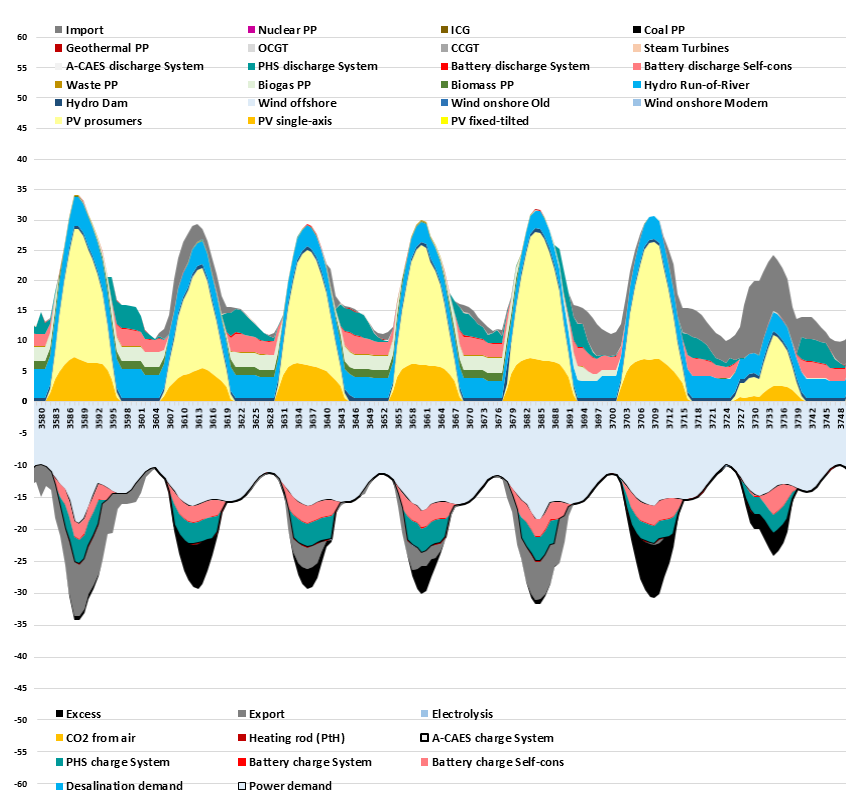
**Figure A.11:** Hourly profile of a representative winter period in Germany in 2050. An example of a large balancing region with a mix of several renewable resources.



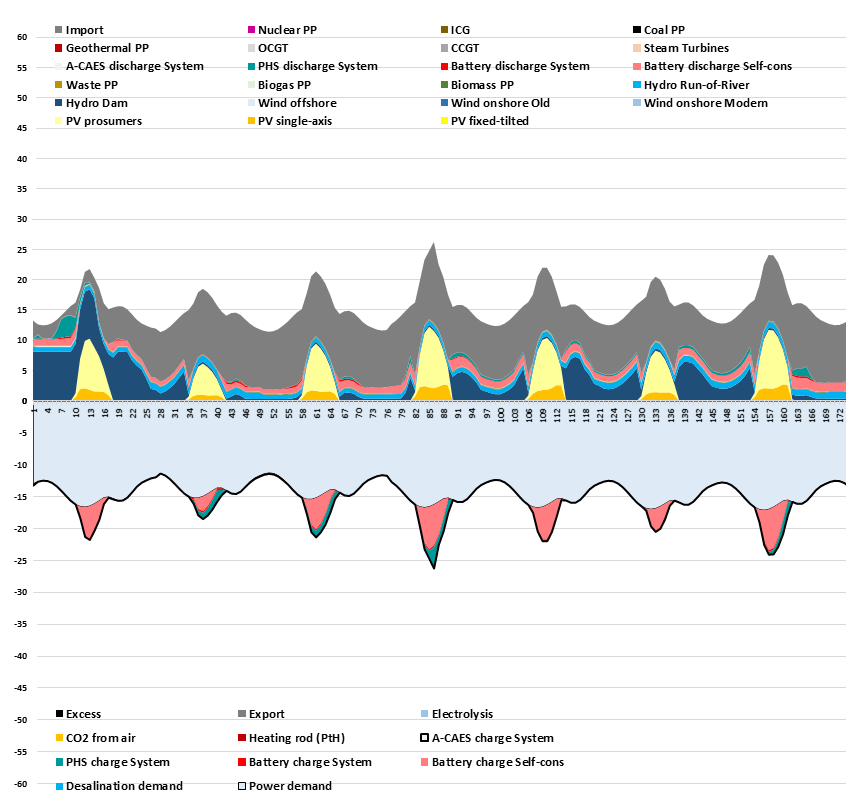
**Figure A.12:** Hourly profile of a representative summer period in Germany in 2050. An example of a large balancing region with a mix of several renewable resources.

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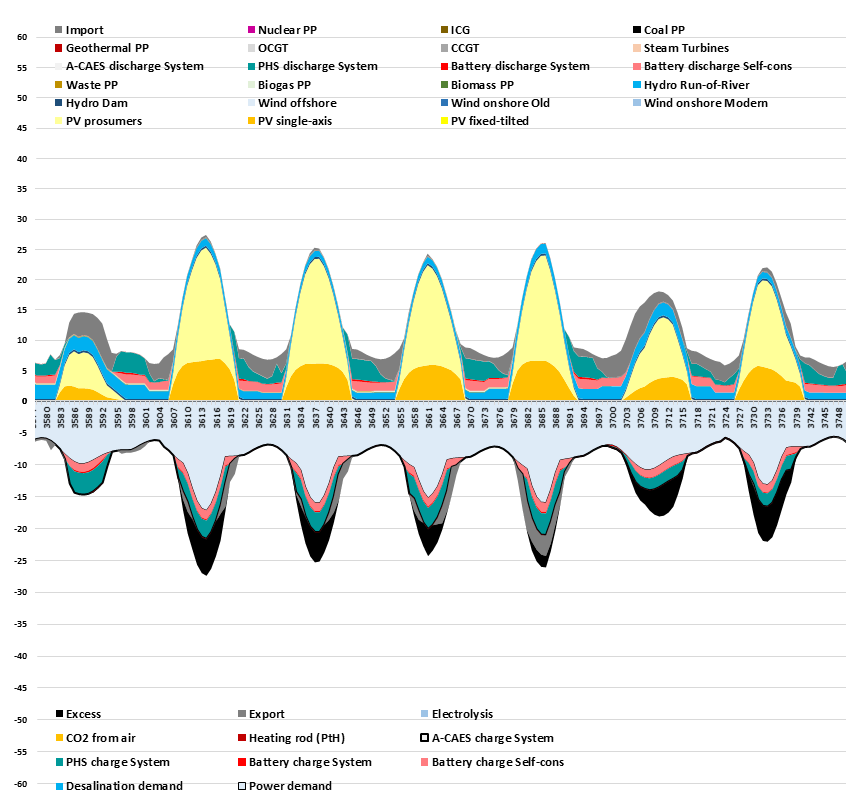
**Figure A.13:** Hourly profile of a representative winter period in Austria and Hungary in 2050. An example of a small balancing region.

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**Figure A.14:** Hourly profile of a representative summer period in Austria and Hungary in 2050. An example of a small balancing region.



**Figure A.15:** Hourly profile of a representative winter period in Switzerland in 2050. An example of a net importing country.

**Figure A.16:** Hourly profile of a representative summer period in Switzerland in 2050. An example of a net importing country.

**Table A22.** Transmission line distances (km) and interconnections (MW) between regional electricity demand centers. Future HVDC interconnection capacities have no restrictions, but are determined be the model.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Land distance (km) | Sea distance (km) | Total (km) | A  Current Connection (MW) | B\*  Future Potential (MW) | C\*\*  Current HVDC (MW) | A-C\*\*\*  Current HVAC (MW) |
| Oslo - Copenhagen | 546 | 5 | 550 | 950 | 1640 | 1700 | 0 |
| Oslo - London | 866 | 529 | 1395 | 0 | 1400 | 0 | 0 |
| Oslo -Amsterdam | 518 | 484 | 1002 | 0 | 700 | 700 | 0 |
| Oslo - Stockholm | 468 | 0 | 468 | 3895 | 3995 | 0 | 3895 |
| Stockholm - Helsinki | 234 | 184 | 419 | 2050 | 3200 | 1300 | 750 |
| Stockholm - Riga | 209 | 246 | 455 | 0 | 700 | 700 | 0 |
| Stockholm - Warsaw | 840 | 167 | 1008 | 600 | 600 | 600 | 0 |
| Stockholm - Copenhagen | 578 | 5 | 582 | 2450 | 2440 | 550 | 1900 |
| Helsinki - Riga | 330 | 66 | 396 | 350 | 1016 | 1000 | 0 |
| Riga - Warsaw | 622 | 0 | 622 | 0 | 1000 | 500 | 0 |
| Warsaw - Frankfurt | 981 | 0 | 981 | 1200 | 3000 | 0 | 1200 |
| Warsaw - Prague | 569 | 0 | 569 | 2400 | 2400 | 0 | 2400 |
| Warsaw - Kiev | 770 | 0 | 770 | 0 | 0 | 0 | 0 |
| Copenhagen - Frankfurt | 706 | 29 | 735 | 2085 | 4000 | 600 | 1485 |
| Frankfurt - Prague | 453 | 0 | 453 | 2300 | 2600 | 600 | 1700 |
| Frankfurt - Amsterdam | 399 | 0 | 399 | 4830 | 8300 | 0 | 4830 |
| Frankfurt - Zurich | 334 | 0 | 334 | 3500 | 4700 | 0 | 3500 |
| Frankfurt - Paris | 529 | 0 | 529 | 3200 | 4800 | 0 | 3200 |
| Amsterdam - London | 361 | 81 | 442 | 0 | 2000 | 1000 | 0 |
| Amsterdam - Paris | 473 | 0 | 473 | 3400 | 4680 | 0 | 3400 |
| London - Paris | 369 | 35 | 404 | 0 | 6100 | 2000 | 0 |
| London - Reykjavik | 1159 | 838 | 1997 | 0 | 0 | 0 | 0 |
| Paris - Madrid | 1161 | 0 | 1161 | 500 | 8000 | 2000 | 0 |
| Paris - Zurich | 538 | 0 | 538 | 3200 | 3700 | 0 | 3200 |
| Zurich - Rome | 752 | 0 | 752 | 1810 | 3860 | 0 | 1810 |
| Zurich - Vienna | 670 | 0 | 670 | 1200 | 1700 | 0 | 1200 |
| Prague - Vienna | 277 | 0 | 277 |  |  |  | 0 |
| Vienna - Belgrade | 541 | 0 | 541 | 2200 | 7500 | 0 | 2200 |
| Vienna - Kiev | 1164 | 0 | 1164 | 3400 | 5800 | 0 | 3400 |
| Rome - Sofia | 1114 | 139 | 1253 | 0 | 0 | 0 | 0 |
| Rome - Belgrade | 664 | 170 | 834 | 500 | 500 | 500 | 0 |
| Sofia - Belgrade | 360 | 0 | 360 | 580 | 2730 | 0 | 580 |
| Sofia - Kiev | 1123 | 0 | 1123 | 2100 | 3180 | 0 | 2100 |
| Sofia - Istanbul | 556 | 0 | 556 | 0 | 0 | 0 | 0 |
| Oslo-Frankfurt | 219 | 402 | 621 | 0 | 0 | 0 | 0 |
| Stockholm-Frankfurt | 341 | 348 | 689 | 0 | 1400 | 0 | 0 |
| Copenhagen-Amsterdam | 153 | 207 | 360 | 600 | 1315 | 600 | 0 |
| Copenhagen-London | 267 | 271 | 538 | 0 | 700 | 0 | 0 |
| Frankfurt-Vienna | 364 | 0 | 364 | 0 | 1400 | 0 | 0 |
| Paris-Rome | 660 | 0 | 660 | 2200 | 7500 | 0 | 2200 |
| Prague-Kiev | 733 | 0 | 733 | 2575 | 4350 | 0 | 2575 |
| Vienna-Rome | 535 | 0 | 535 | 0 | 0 | 0 | 0 |
| Vienna-Sofia | 519 | 0 | 519 | 285 | 1655 | 0 | 285 |

\* The future potential of the Warsaw-Prague interconnection was reported as 1590 MW, a value below the current interconnection. For this reason, the current level of 2400 MW is maintained.

\*\* Current HVDC interconnections are taken from the following sources: [22]–[24]

\*\*\* Values of 0 are assigned when calculated values are negative, or if the interconnection is known to be an undersea cable.

**Equations used for levelised cost of electricity calculations (Adapted from** [19]**):**

The total annualized cost of the system is calculated as the sum of all sectors costs Eq. (A1), which includes annualized capital cost and operational costs of all system elements Eq. (A2):

|  |  |
| --- | --- |
|  | (A1) |
|  | (A2) |
|  | (A3) |

Abbreviations: total annualized cost of the system (*𝑡otalCostsys*), annualized cost of the centralized Power sector (*elSysCost*), annualized cost of the electricity prosumers sector (*elProsCost*), annualized cost of the centralized heat sector (*heatSysCost*), annualized cost of the individual heat sector (*heatIndCost*), annualized cost of the transportation sector (*transpSysCost*), annualized cost of the industrial sector (*industrSysCost*), all technologies (*tech*), technology (*t*), capital expenditures (*CAPEX*), capital recovery factor for technology *t* (*crft*) Eq. (30), annual fixed operational expenditures (*OPEXfix*), variable operational expenditures (*OPEXvar*), installed capacity of the technology *t* (*Capt*), annual output for the technology *t* (*Egen,t*), weighted average cost of capital (*WACC*), lifetime for technology *t* (*Nt*).

Total levelized cost of electricity in the system (*LCOEtotal*) is calculated as the electricity demand weighted average of the centralized power system LCOE (*LCOEsys*) and prosumer sector LCOE (*LCOEpros*); the formula is presented in Eq. (A4). Centralized power system LCOE is comprised of levelized cost of consumed electricity (*LCOEprim*), levelized cost of storage (*LCOS*), levelized cost of curtailed electricity (*LCOC*), levelized cost of electricity transition (*LCOT*) and levelized cost of prosumer feed-in reimbursement (*LCOFS*), Eq. (A5). For the prosumer sector total LCOE is comprised of the levelized cost of consumed electricity (*LCOEprim*), levelized cost of storage (*LCOS*), and levelized cost of prosumer feed-in reimbursement (*LCOFS*), Eq. (A6). Levelized cost of generated electricity is calculated as the total annualized cost of the electricity generation system divided by total annual generation Eq. (A7). In this calculation, operational costs include costs of fuel and GHG emission cost per unit of generated electricity. The electricity generation systems also include part of the fuel production facilities, which are used for fuel production for power system generators. Levelized cost of consumed electricity is calculated based on the cost of the generated electricity (*LCOEgen*), excluding electricity lost due to curtailment, storage and transmission system losses Eq. (A8). Levelized cost of storage is calculated as the annualized cost of storage system equipment and annual cost of electricity losses divided by total electricity consumption Eq. (A9). Storage systems also include part of the fuel production facilities, which are used for fuel production for the storage system generators (e.g. for Power-to-Gas – Gas-to-Power). Levelized cost of curtailment is calculated as the annual cost of curtailed electricity divided by total electricity consumption Eq. (A10). Levelized cost of transmission is the calculated area total annualized cost of power grid equipment and annual cost of electricity losses divided by total electricity consumption, and multiplied by regional grid utilisation weights Eq. (A11), where regional grid utilisation weights are the average of regional shares of total export and import of energy Eq. (A12).

|  |  |
| --- | --- |
|  | (A4) |
|  | (A5) |
|  | (A6) |
|  | (A7) |
|  | (A8) |
|  | (A9) |
|  | (A10) |
|  | (A11) |
|  | (A12) |
|  | (A13) |

Abbreviations: region (*r*), total levelized cost of electricity in the system (*LCOEtotal*), centralized system levelized cost of electricity (*LCOEsys*), prosumer sector levelized cost of electricity (*LCOEpros*), centralized system electricity consumption (*ElconsSys*), prosumer sector electricity consumption (*ElconsPros*), consumed electricity LCOE (*LCOEprim*), levelized cost of stored electricity (*LCOS*), levelized cost of curtailed electricity (*LCOC*), levelized cost of prosumer feed-in reimbursement (*LCOFS*), generated electricity LCOE (*LCOEgen*), power generation technologies (*Gen*), storage technologies (*Stor*), power transmission technologies (*trans*), technology (*t*), capital expenditures (*CAPEX*), capital recovery factor for technology *t* (*crft*) , annual fixed operational expenditures (*OPEXfix*), variable operational expenditures (*OPEXvar*), installed capacity of the technology *t* (*Capt*), annual output for the technology *t* (*Elgen,t*), annual electricity generation (*Elgen*), annual electricity curtailment (*Elcurt*), annual storage loss (*ElstorLoss*), annual grid loss (*EltransLoss*), annual electricity consumption (*Elcons*), annual output of storage *t* (*Eout,t*), annual export of grid technology *t* (*Elout,t*), electricity exported by region r (*Export*), electricity imported by region *r* (*Import*), feed-in reimbursement (*feedInTarif*), electricity sold by prosumers to the grid (*ELprosTogrid*).

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