The arising Role of PV and Wind Energy in the Power Sector and beyond: changing the Northeast Asian power landscape

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Supplementary data
This document contains additional data to support the manuscript: Table S1 to Table S11. The financial and technical assumptions used for the simulation are presented in Tables S1 – S6. The main results of the simulation – installed capacities and output for the generation and storage technologies for each studied country are presented in Tables S7 – S11.

Table S1: Technical and financial assumptions of energy system components used in the energy transition from 2015 to 2050. Assumptions are taken from Pleßmann et al.¹¹ and European Commission¹², and further references are individually mentioned. All technical and financial assumptions are given in currency values of the year 2015.

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<tr>
<td>Methanation</td>
<td>Capex $$/kW$_{el}$</td>
<td>Opex fix $$/kW$_{el}$ a</td>
<td>Opex var $$/kWh$_{el}$</td>
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<tr>
<td>CO$_2$ direct air capture</td>
<td>Capex $$/kW$_{el}$</td>
<td>Opex fix $$/kW$_{el}$ a</td>
<td>Opex var $$/kWh$_{el}$</td>
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<td>Coal PP</td>
<td>Capex $$/kW$_{el}$</td>
<td>Opex fix $$/kW$_{el}$ a</td>
<td>Opex var $$/kWh$_{el}$</td>
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<td>Opex var $$/kWh$_{el}$</td>
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<td>CCGT</td>
<td>Capex $$/kW$_{el}$</td>
<td>Opex fix $$/kW$_{el}$ a</td>
<td>Opex var $$/kWh$_{el}$</td>
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<td>Opex var $$/kWh$_{el}$</td>
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<tr>
<td>Steam turbine (CSP)</td>
<td>Capex $$/kW$_{el}$</td>
<td>Opex fix $$/kW$_{el}$ a</td>
<td>Opex var $$/kWh$_{el}$</td>
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[10,11] [12,13]
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<tr>
<th>System</th>
<th>Capex (£/kW$_{el}$)</th>
<th>Opex fix (£/(kW$_{el}$ a))</th>
<th>Opex var (£/(kWh$_{el}$))</th>
<th>Efficiency (%)</th>
<th>Lifetime years</th>
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<td>2755 2620 2475 2330 2195 2060 1945 1830</td>
<td>55.4 47.2 44.6 41.9 39.5 37.1 35 32.9</td>
<td>0.004 0.004 0.004 0.004 0.004 0.004 0.004 0.004</td>
<td>35 36 36.5 37 37.5 38 38.5 39</td>
<td>25 25 25 25 25 25 25 25</td>
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<tr>
<td>Biogas CHP</td>
<td>503 429 400 370 340 326 311 296</td>
<td>20.1 17.2 16.0 14.8 13.6 13.0 12.4 11.8</td>
<td>0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001</td>
<td>33.5 34.4 37.2 40.0 41.9 43.7 44.2 44.7</td>
<td>30 30 30 30 30 30 30 30</td>
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<td>Waste incinerator</td>
<td>5940 5630 5440 5240 5030 4870 4690 4540</td>
<td>267.3 253.35 244.8 235.8 226.35 219.15 211.05 204.3</td>
<td>0.0069 0.0069 0.0069 0.0069 0.0069 0.0069 0.0069 0.0069</td>
<td>27 31 32.5 34 35.5 37 37 42</td>
<td>30 30 30 30 30 30 30 30</td>
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<tr>
<td>Biogas digester</td>
<td>771 731 706 680 653 632 609 589</td>
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<td>100 100 100 100 100 100 100 100</td>
<td>20 20 20 20 25 25 25 25</td>
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<tr>
<td>Biogas upgrade</td>
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<td>98 98 98 98 98 98 98 98</td>
<td>20 20 20 20 25 25 25 25</td>
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<tr>
<td>Battery, Li-ion</td>
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<td>90 91 92 93 94 95 95 95</td>
<td>20 20 20 20 20 20 20 20</td>
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<tr>
<td>Adiabatic compressed air energy storage (A-CAES)</td>
<td>35.0 35.0 33.0 31.1 30.4 29.8 28.0 26.3</td>
<td>0.46 0.46 0.43 0.40 0.40 0.39 0.36 0.34</td>
<td>0.0012 0.0012 0.0012 0.0012 0.0012 0.0012 0.0012 0.0012</td>
<td>54 59 65 70 70 70 70 70</td>
<td>40 55 55 55 55 55 55 55</td>
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<td>Gas storage</td>
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<td>0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001</td>
<td>0 0 0 0 0 0 0 0</td>
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**Table S2:** Energy to power ratio and self-discharge rates of storage technologies.

<table>
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<th>Technology</th>
<th>Efficiency [%]</th>
<th>Energy/Power Ratio [h]</th>
<th>Self-Discharge [%/h]</th>
<th>References</th>
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<td>A-CAES</td>
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<td>0.1</td>
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**Table S3:** Financial assumptions for the fossil-nuclear fuel prices and GHG emission cost.

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<tr>
<th>Name of component</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
<th>Ref.</th>
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<tr>
<td>Gas coal</td>
<td>€/MWth</td>
<td>7.7</td>
<td>7.7</td>
<td>8.4</td>
<td>9.2</td>
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<td>11.1</td>
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<td>Fossil petrol</td>
<td>€/kWth</td>
<td>52.5</td>
<td>35.2</td>
<td>39.8</td>
<td>44.4</td>
<td>43.9</td>
<td>43.5</td>
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<td>21.8</td>
<td>22.2</td>
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<td>40.2</td>
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<td>€/MWth</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Carbon dioxide</td>
<td>€/tonne</td>
<td>9</td>
<td>28</td>
<td>52</td>
<td>61</td>
<td>68</td>
<td>75</td>
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**Table S4:** Efficiency assumptions for HVDC transmission for the 2030 reference year\(^{19}\).

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<td>HVDC line</td>
<td>1.6 % / 1000 km</td>
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<tr>
<td>HVDC converter pair</td>
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Table S5: Electricity price and demand

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<th>Country</th>
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<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
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<tr>
<td>Residential</td>
<td>€/MWh</td>
<td>69</td>
<td>88</td>
<td>76</td>
<td>97</td>
<td>84</td>
<td>107</td>
<td>92</td>
<td>118</td>
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<tr>
<td>Commercial</td>
<td>€/MWh</td>
<td>69</td>
<td>88</td>
<td>84</td>
<td>97</td>
<td>93</td>
<td>107</td>
<td>102</td>
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<tr>
<td>Industrial</td>
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<td>5981</td>
<td>6757</td>
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Table S6: Full Load Hours and energy potentials for RE technologies

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<th>Hydro</th>
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<td>TWh</td>
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Table S7: China - Installed cumulative capacities and net electricity generation by various power sources; installed capacities and net output of various storage sources during the energy transition from 2015 to 2050 at 5-year intervals.

<table>
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<tr>
<th>Power Generation</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capacity [GW]</td>
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<td></td>
<td></td>
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<td></td>
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<td>49</td>
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|Storage                    |      |      |      |      |      |      |      |      |
|Installed Capacity [GWh]   |      |      |      |      |      |      |      |      |
|Battery total              | 0    | 0    | 13   | 2028 | 4214 | 6508 | 9463 | 13348|
|PHS storage                | 23   | 23   | 28   | 65   | 65   | 65   | 65   | 65   |
|A-CAES storage             | 0    | 4    | 11   | 64   | 65   | 67   | 68   | 68   |
|TES storage                | 1104 | 1105 | 1110 | 1142 | 1145 | 1147 | 50   | 49   |
|Gas storage                | 0    | 2542 | 3201 | 7642 | 22537| 30798| 70326| 139721|

|Output [TWh]               |      |      |      |      |      |      |      |      |
|Battery total              | 0    | 0    | 5    | 631  | 1295 | 1996 | 2896 | 4069 |
|PHS storage                | 12   | 5    | 7    | 19   | 16   | 17   | 15   | 14   |
|A-CAES storage             | 0    | 0    | 0    | 1    | 1    | 2    | 2    | 2    |
|TES storage                | 0    | 0    | 59   | 103  | 110  | 115  | 8    | 7    |
|Gas storage                | 0    | 82   | 82   | 85   | 92   | 93   | 125  | 193  |
Table S8: Japan - Installed cumulative capacities and net electricity generation by various power sources; installed capacities and net output of various storage sources during the energy transition from 2015 to 2050 at 5-year intervals.

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<th>2020</th>
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<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
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<td>11</td>
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<td>166</td>
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<td>203</td>
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<td>1</td>
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<td>0</td>
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<td>1</td>
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<td>49</td>
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<td>32</td>
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| PV utility-scale | 14    | 14    | 14    | 150   | 265   | 425   | 512   | 665   |
| Wind total       | 7     | 122   | 338   | 343   | 345   | 351   | 350   | 247   |
| Hydro total      | 69    | 87    | 87    | 87    | 87    | 87    | 87    | 87    |
| Biomass PP       | 0     | 7     | 5     | 3     | 2     | 0     | 0     | 0     |
| Waste PP         | 6     | 6     | 6     | 6     | 6     | 6     | 8     | 7     |
| Biogas PP        | 0     | 2     | 2     | 2     | 2     | 2     | 2     | 2     |
| Geothermal       | 4     | 4     | 4     | 4     | 4     | 4     | 4     | 4     |
| GT               | 421   | 12    | 6     | 6     | 6     | 18    | 26    | 25    |
| Hard coal PP     | 352   | 427   | 168   | 109   | 76    | 32    | 4     | 0     |
| ICE              | 116   | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| Nuclear PP       | 0     | 284   | 254   | 186   | 136   | 66    | 38    | 15    |
| Steam turbines   | 0     | 0     | 0     | 5     | 6     | 5     | 5     | 4     |

| Battery total    | 0     | 60    | 239   | 354   | 531   | 813   | 1017  | 1262  |
| PHS storage      | 27    | 27    | 27    | 27    | 27    | 27    | 27    | 27    |
| A-CAES storage   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| TES storage      | 0     | 0     | 0     | 0     | 96    | 96    | 96    | 96    |
| Gas storage      | 0     | 495   | 496   | 497   | 519   | 7919  | 18602 | 19314 |

| Battery total    | 0     | 17    | 68    | 101   | 150   | 226   | 280   | 363   |
| PHS storage      | 1     | 4     | 6     | 6     | 5     | 6     | 5     | 5     |
| A-CAES storage   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| TES storage      | 0     | 0     | 0     | 0     | 12    | 13    | 11    | 9     |
| Gas storage      | 0     | 10    | 10    | 10    | 31    | 50    | 50    | 46    |
Table S9: South Korea - Installed cumulative capacities and net electricity generation by various power sources; installed capacities and net output of various storage sources during the energy transition from 2015 to 2050 at 5-year intervals.

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<th>2030</th>
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<td>73</td>
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<td>2</td>
<td>1</td>
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| Generation [TWh] | | | | | | | |
| PV utility-scale | 4 | 4 | 26 | 126 | 270 | 311 | 414 | 464 |
| PV prosumers | 0 | 6 | 18 | 43 | 81 | 118 | 127 | 139 |
| Wind total | 1 | 42 | 97 | 97 | 97 | 96 | 95 | 95 |
| Hydro total | 6 | 7 | 8 | 9 | 9 | 9 | 9 | 9 |
| Biomass PP | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| Waste PP | 1 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Biogas PP | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Geothermal | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| GT | 170 | 100 | 40 | 32 | 4 | 6 | 21 | 24 |
| Hard coal PP | 182 | 214 | 208 | 131 | 65 | 39 | 9 | 0 |
| ICE | 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nuclear PP | 156 | 154 | 150 | 133 | 97 | 89 | 52 | 22 |
| ST | 0 | 0 | 0 | 0 | 7 | 6 | 4 | 2 |

| Installed Capacity [GWh] | | | | | | | |
| Battery total | 0 | 0 | 0 | 75 | 398 | 546 | 801 | 1024 |
| PHS storage | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| A-CAES storage | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| TES storage | 0 | 1 | 1 | 1 | 114 | 114 | 114 | 113 |
| Gas storage | 0 | 38 | 38 | 38 | 52 | 2256 | 17004 | 23091 |

| Output [TWh] | | | | | | | |
| Battery total | 0 | 0 | 0 | 26 | 117 | 157 | 225 | 268 |
| PHS storage | 0 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| A-CAES storage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| TES storage | 0 | 0 | 0 | 0 | 16 | 13 | 9 | 4 |
| Gas storage | 0 | 1 | 2 | 2 | 2 | 10 | 37 | 44 |
Table S10: North Korea - Installed cumulative capacities and net electricity generation by various power sources; installed capacities and net output of various storage sources during the energy transition from 2015 to 2050 at 5-year intervals.

<table>
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<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
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Table S11: Mongolia - Installed cumulative capacities and net electricity generation by various power sources; installed capacities and net output of various storage sources during the energy transition from 2015 to 2050 at 5-year intervals.

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<th>Power Generation</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
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<tr>
<td>TES storage</td>
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<tr>
<td>Gas storage</td>
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<table>
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<tr>
<td>TES storage</td>
</tr>
<tr>
<td>Gas storage</td>
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References
15) W. Hoffmann, 29th EU PVSEC (2014).