



*Supplement of*

## **GCAM-Europe v7.2.0: enhancing policy-relevant climate modelling through spatial and sectoral detail**

**Jon Sampedro et al.**

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## **Background**

| <b>Model</b>   | <b>Total Regions</b> | <b>European Regions</b>                                                                                  | <b>Economic Theory</b>                                                                                                        | <b>Open Source</b>            |
|----------------|----------------------|----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| <b>REMIND</b>  | 21*                  | 8 EU regions                                                                                             | Energy-economy general equilibrium (Ramsey-type growth model coupled with an energy system model); cost optimisation solution | Yes (with dependency on GAMS) |
| <b>MESSAGE</b> | 11                   | 2 european regions (including both EU and non-EU countries) +1 region for Former Soviet Union            | 5-module modelling framework with an energy system basis, and a general equilibrium approach; optimisation solution           | Yes (with dependency on GAMS) |
| <b>IMAGE</b>   | 26                   | 2 european regions (including both EU and non-EU countries) + 1 region for Ukraine + 1 region for Russia | Partial Equilibrium; Simulation solution                                                                                      | No                            |
| <b>WITCH</b>   | 13                   | 2 EU regions + 1 non-EU region                                                                           | Inter-temporal optimal growth model; general equilibrium; optimisation solution                                               | Yes (with dependency on GAMS) |
| <b>POLES</b>   | 66                   | 27 regions for all 27 EU countries + Individual regions for Norway,                                      | Global sectoral simulation model                                                                                              | No                            |

|               |    |                                                                                                                                                   |                                                        |                                                                                                                       |
|---------------|----|---------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
|               |    | Switzerland,<br>Iceland, Turkey,<br>Russia, Ukraine                                                                                               |                                                        |                                                                                                                       |
| <b>COFFEE</b> | 18 | 2 european regions<br>(including both EU<br>and non-EU<br>countries) + 1<br>region for Russia                                                     | Linear<br>programming<br>optimization model            | No                                                                                                                    |
| <b>AIM</b>    | 17 | 1 EU + 1 Rest of<br>Europe + 1 Turkey<br>+ 1 region for<br>Former Soviet<br>Union                                                                 | Computable<br>general equilibrium                      | No                                                                                                                    |
| <b>GCAM</b>   | 32 | 2 EU regions + 1<br>EFTA + 1 Ukraine<br>+ 1 non-EU Europe                                                                                         | Partial Equilibrium<br>recursive dynamic               | Yes**                                                                                                                 |
| <b>TIAM*</b>  | 36 | 2 european regions<br>(including both EU<br>and non-EU<br>countries) +1<br>Former Soviet<br>Union                                                 | Partial Equilibrium<br>welfare cost-<br>optimization   | The TIMES source<br>code is open;<br>dependencies on<br>GAMS and the<br>VEDA software for<br>input/output<br>handling |
| <b>GEM-E3</b> | 46 | 27 regions for all 27<br>EU countries + 1<br>region for Rest of<br>Europe, +<br>Individual regions<br>for the UK, Turkey,<br>Russia               | Recursive dynamic<br>computable general<br>equilibrium | No (ongoing efforts<br>to open the source<br>code); reliance on<br>GTAP                                               |
| <b>EPPA</b>   | 18 | 1 region for EU-27<br>including Croatia,<br>Norway,<br>Switzerland,<br>Iceland and<br>Liechtenstein<br>(capabilities for 13<br>regions in the EU) | Computable<br>general equilibrium                      | No                                                                                                                    |

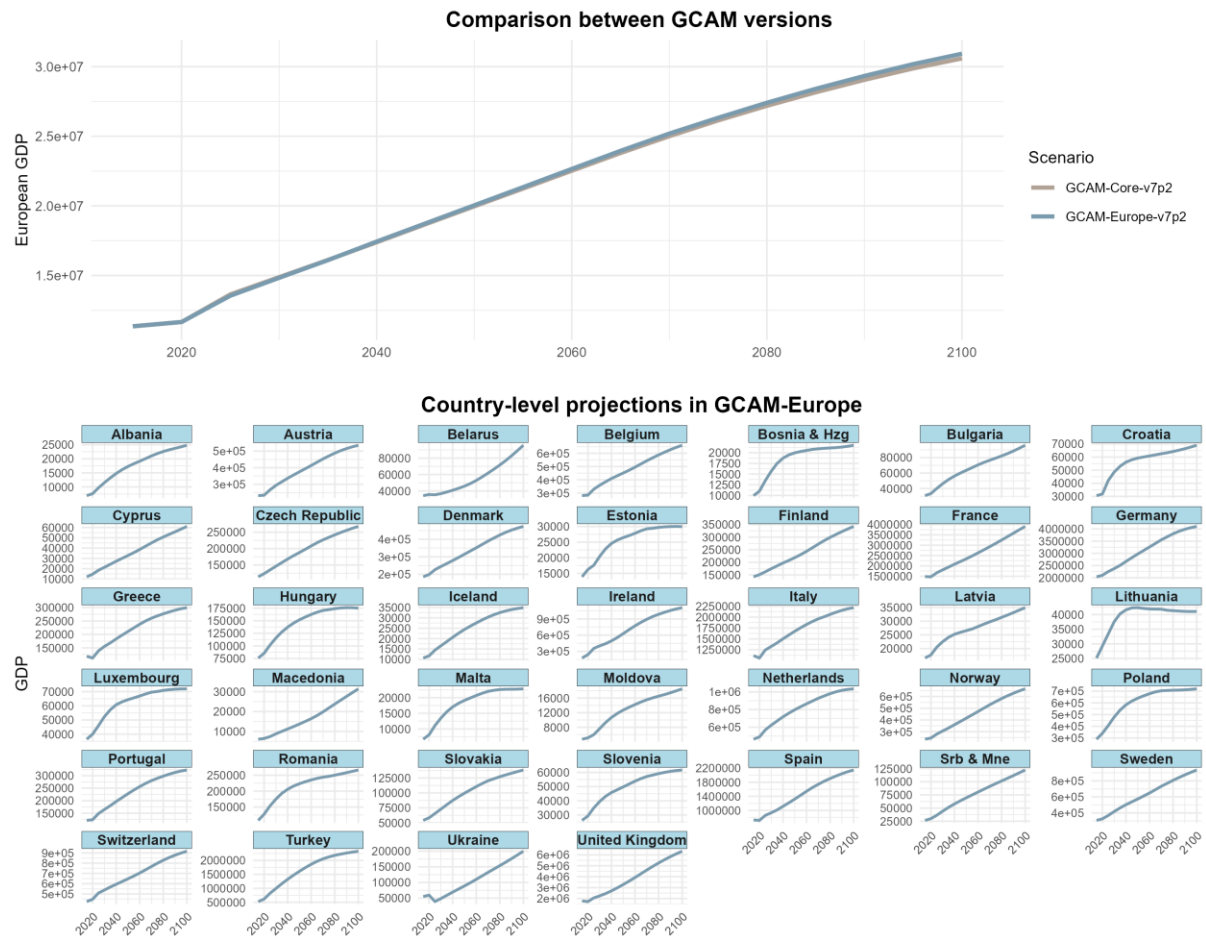
|                  |                                     |                                             |                                                    |                                            |
|------------------|-------------------------------------|---------------------------------------------|----------------------------------------------------|--------------------------------------------|
| <b>C-ROADS</b>   | Aggregations at 3, 6, and 7 regions | 1 region for the EU                         | System dynamics simulation                         | No (available only as an online simulator) |
| <b>MERGE-ETL</b> | 10                                  | 1 region for EU29+<br>+ 1 region for Russia | General Equilibrium;<br>Intertemporal optimisation | No                                         |

**Table S1: Overview of major IAM models**

\*REMIND features configurable spatial resolution; the 21-region setting (including 8 EU regions) corresponds to recent applications of version 3.3.1 (Schreyer et al. 2025).

Table S1 highlights a gap in terms of fully open-source models (including the execution environment) with a high regional disaggregation at the EU-level, including representing all EU member states separately. Although GCAM-Europe aims to fill this gap, it should be noted that country-level formulations are not necessarily always the preferred option. IAMs may deliberately adopt a sub-regional EU aggregation to balance regional detail with global model scope for policy assessment, especially in the light of potential computational limitations. In this context, GCAM-Europe should be seen not as a substitute for existing aggregated EU representations, but as an additional tool of the climate-economy modelling community that enables Member State-level analysis within a globally consistent framework, while remaining computationally tractable for policy applications.

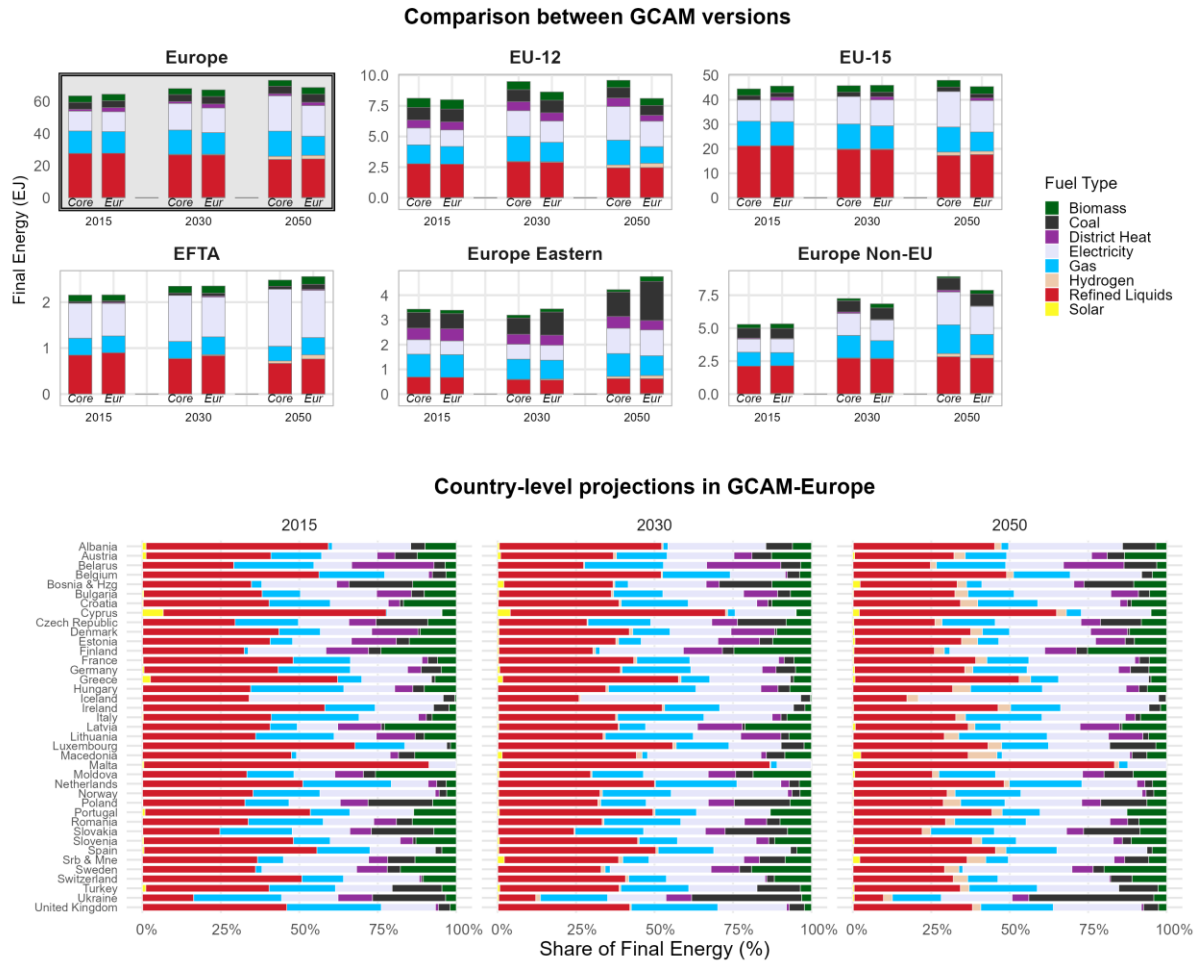
## Additional results



**Figure S1: GDP by period, region, and scenario (Million\$1990).** Panel A compares GDP projections between the GCAM-Europe and the core baseline scenarios. Panel B shows population projections by European country in the GCAM-Europe baseline.

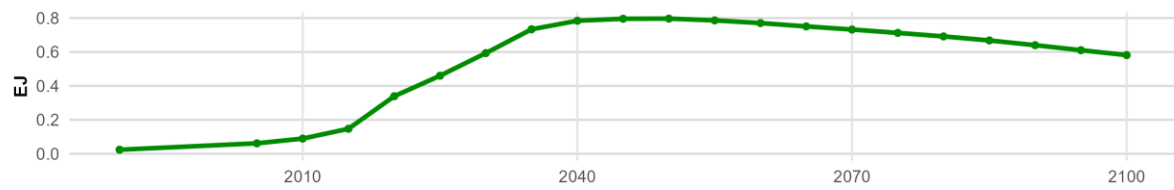


**Figure S2: Total primary energy by period, fuel and country (EJ) in the GCAM-Europe baseline scenario.**



**Figure S3: Total final energy in 2050 by fuel, region, period, and scenario.** The top panel shows total final energy for the European continent (EJ). The bottom panel shows the share of different fuels in each country's final energy mix in the GCAM-Europe baseline scenario (%).

a) European continent



b) Individual countries

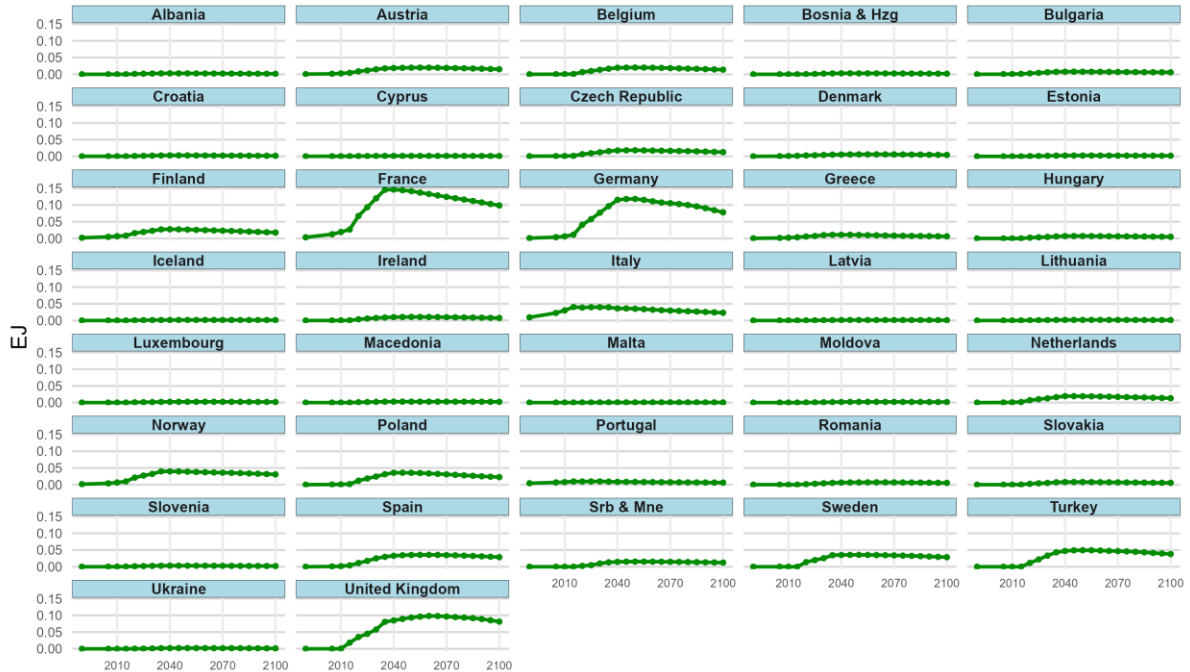
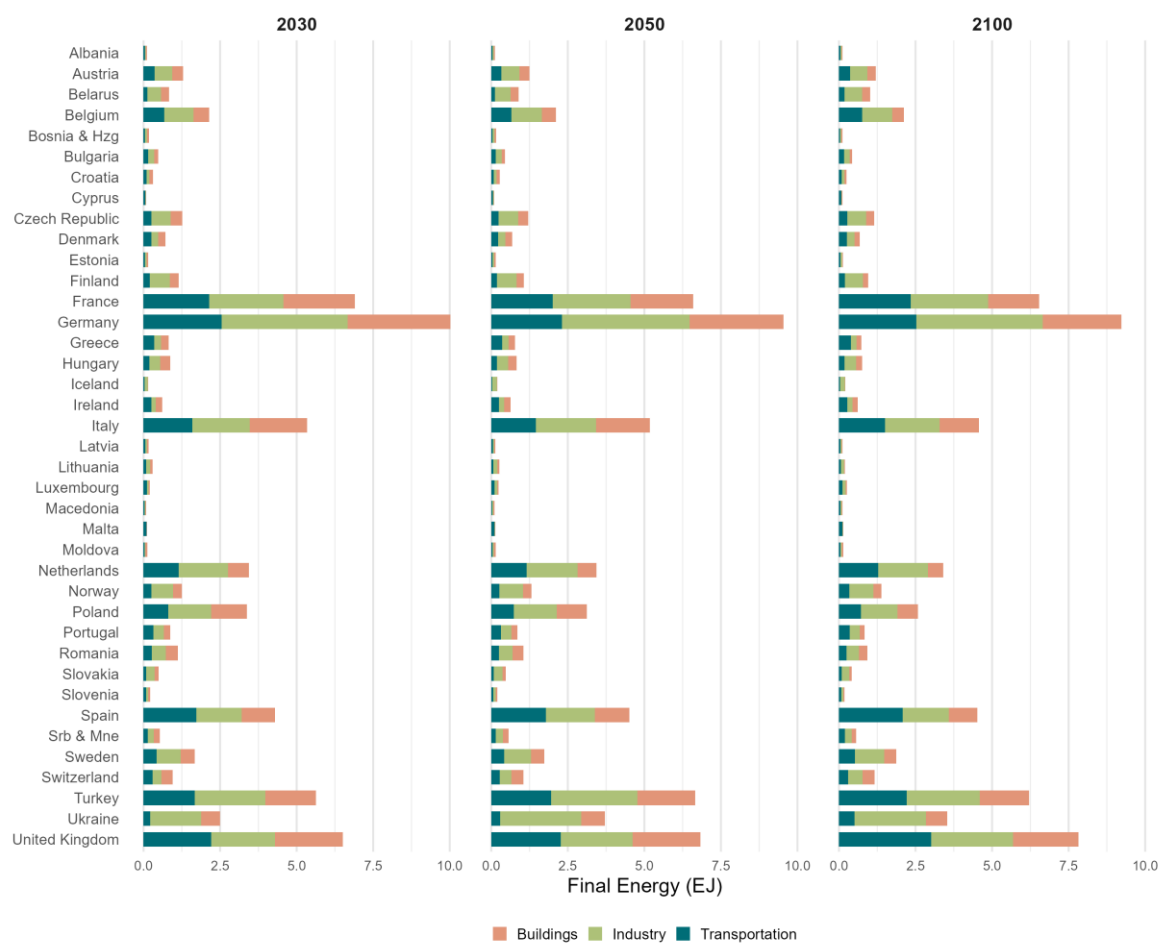
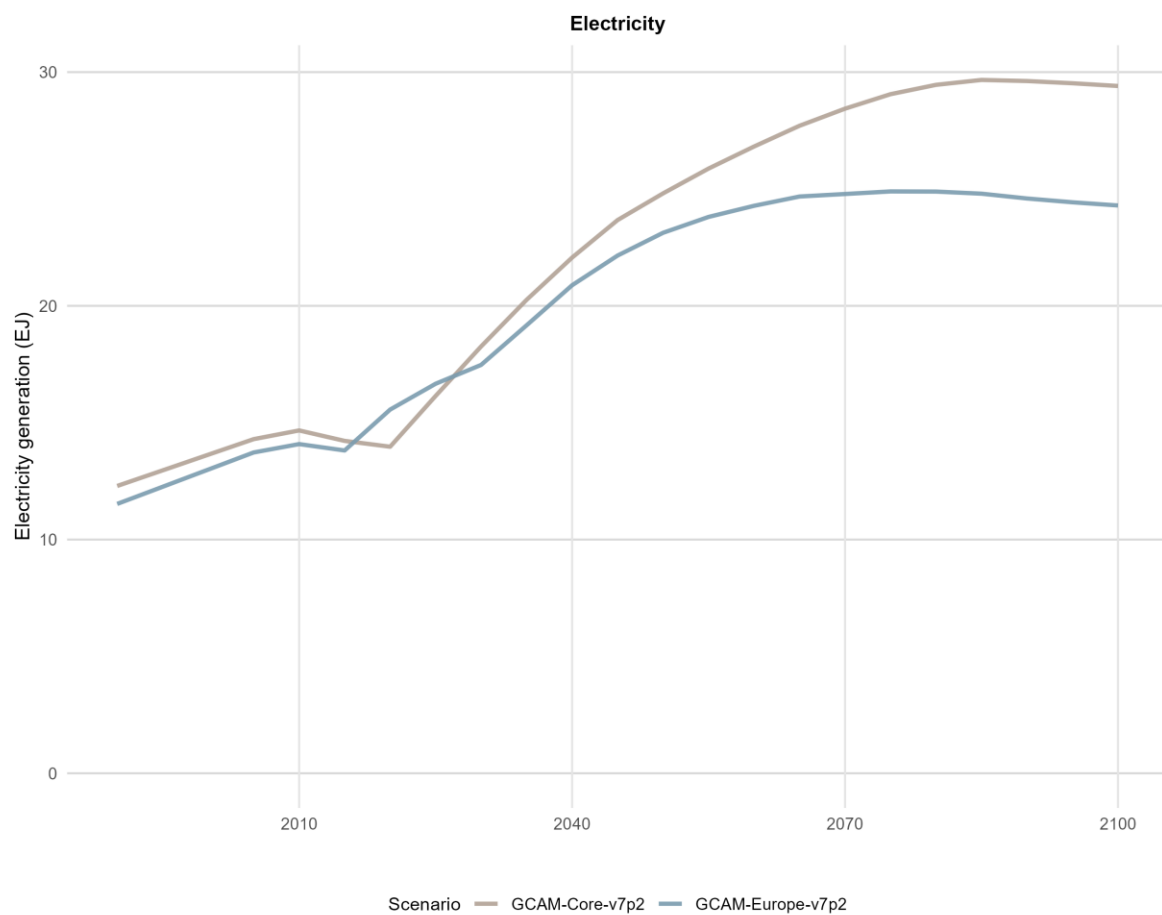


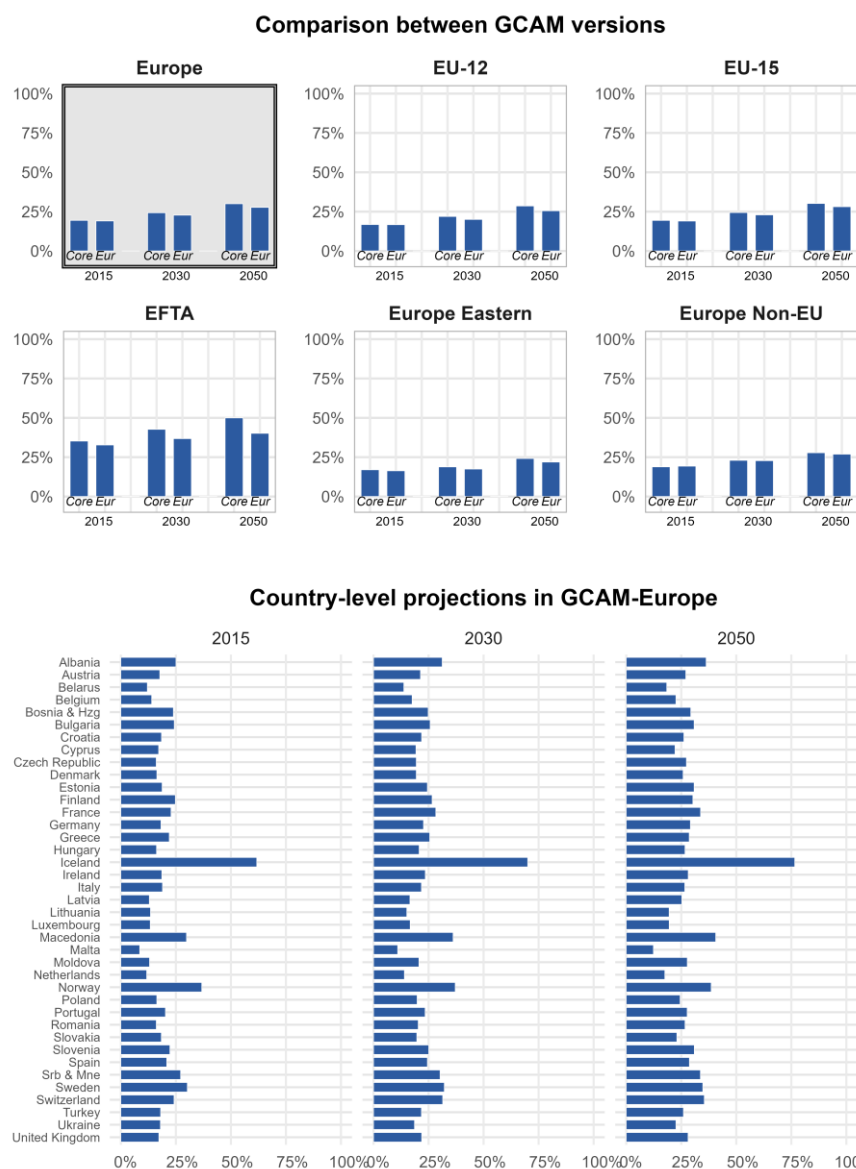
Figure S4: Adoption of heat pump technologies by region and period in the GCAM-Europe baseline scenario (EJ).



**Figure S5: Total final energy by period, fuel and country in the GCAM-Europe baseline scenario (EJ).**



**Figure S6: Electricity generation in Europe by period and scenario (EJ).**



**Figure S7: Share of electricity in total final energy by scenario, region, and period.** The top panel shows shares for the European continent and the five core European regions (%). The bottom panel shows the share of electricity in each country's final energy demand in the GCAM-Europe baseline scenario (%).

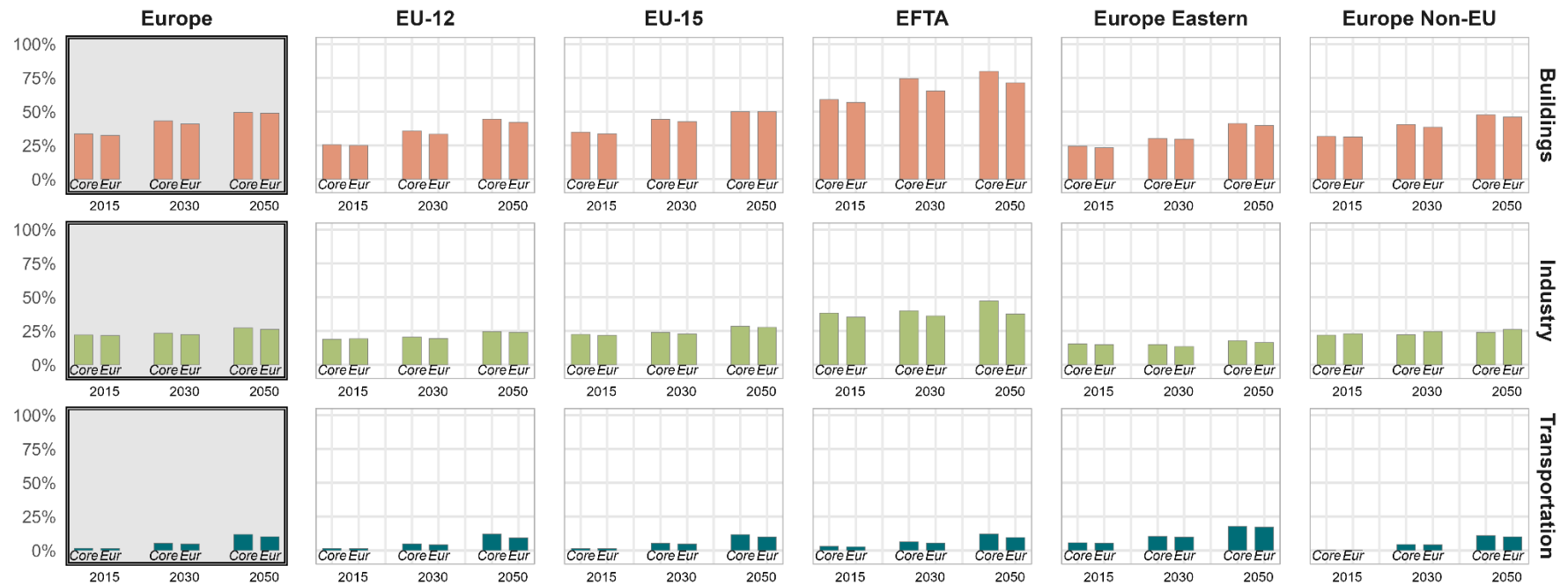
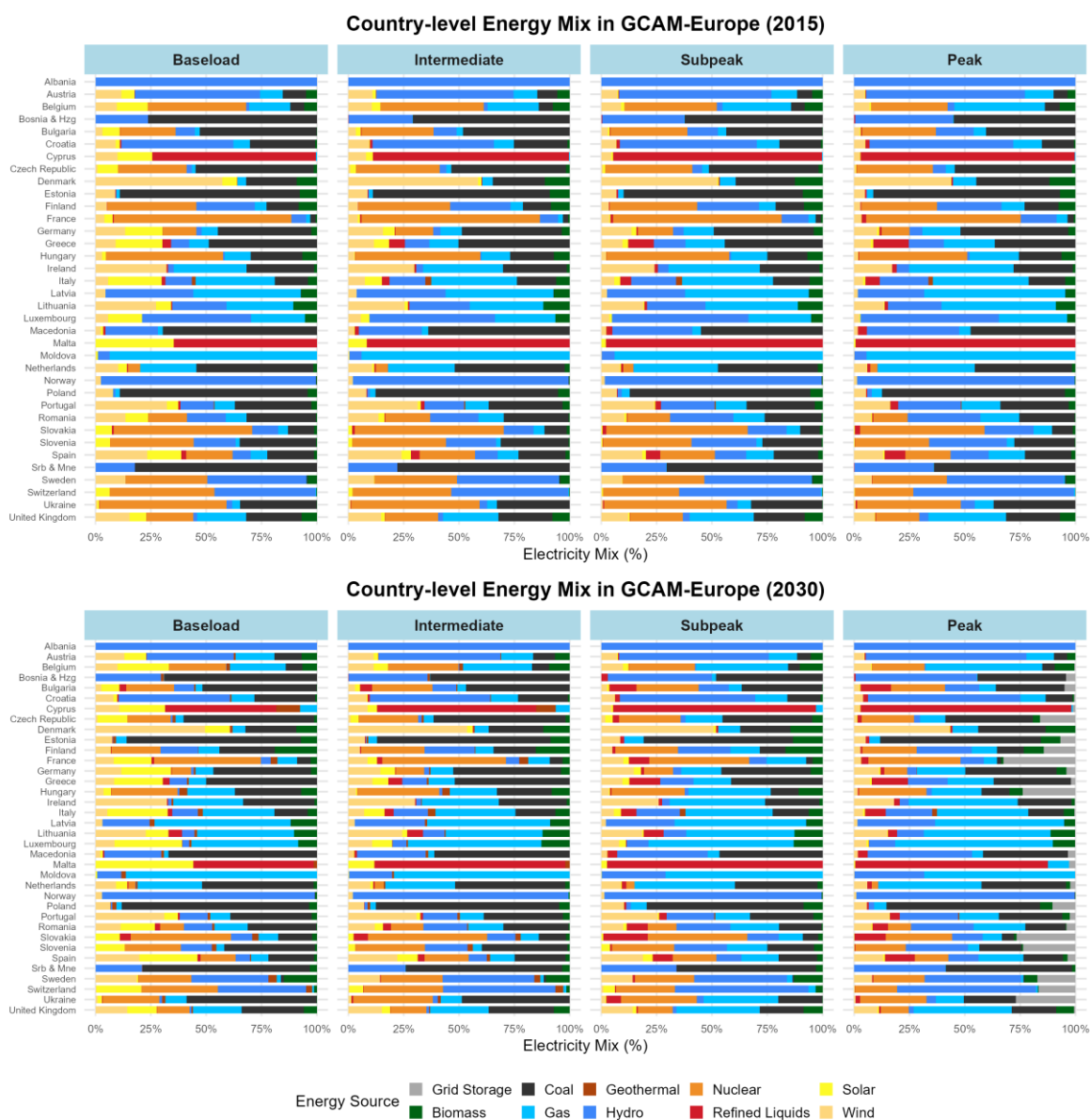
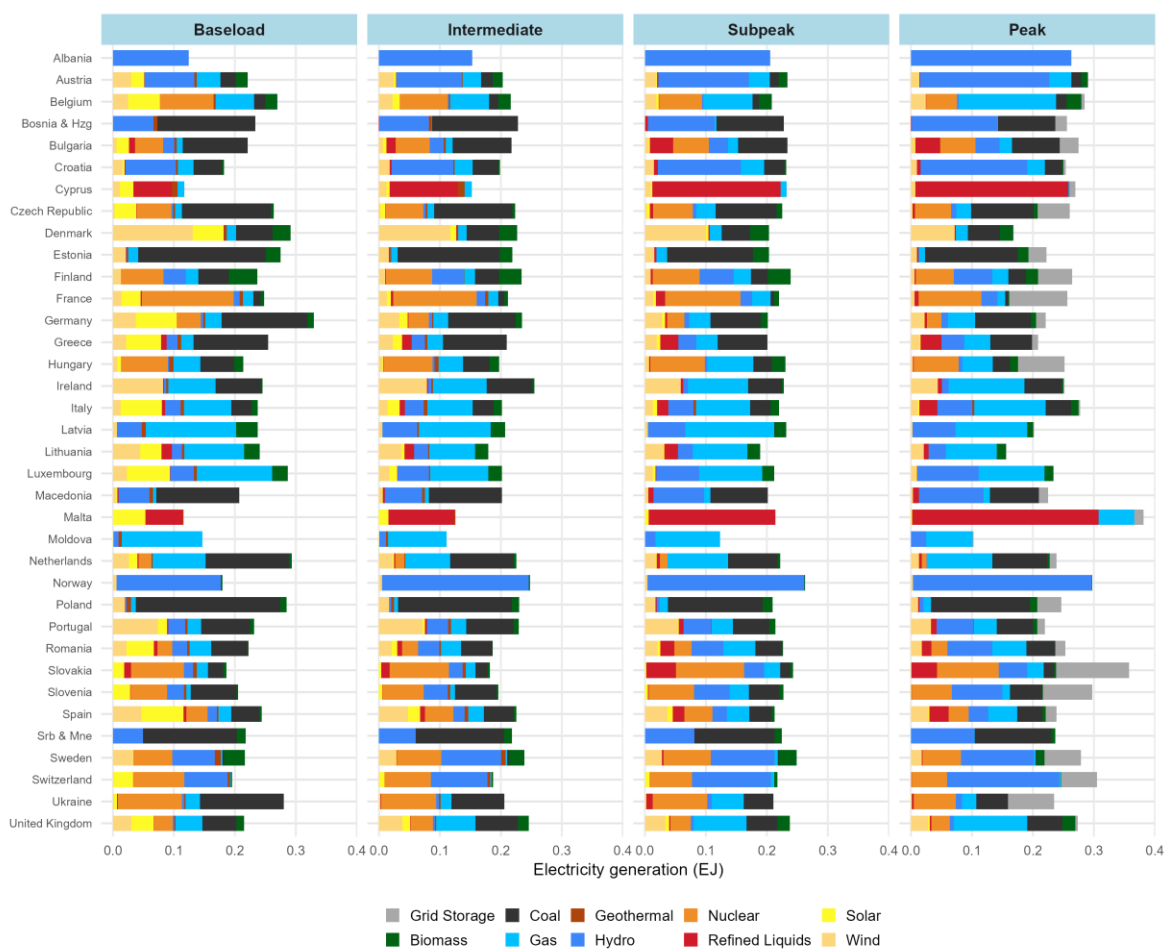


Figure S8: Share of electricity in total final energy by scenario, region, period and sector (%).



**Figure S9: weight of different sources in each country's final electricity mix (%) in the GCAM-Europe baseline in 2015 (top) and 2030 (bottom).**



**Figure S10: Electricity generation in 2050 by period, fuel, segment and country (EJ) in the GCAM-Europe baseline scenario.**

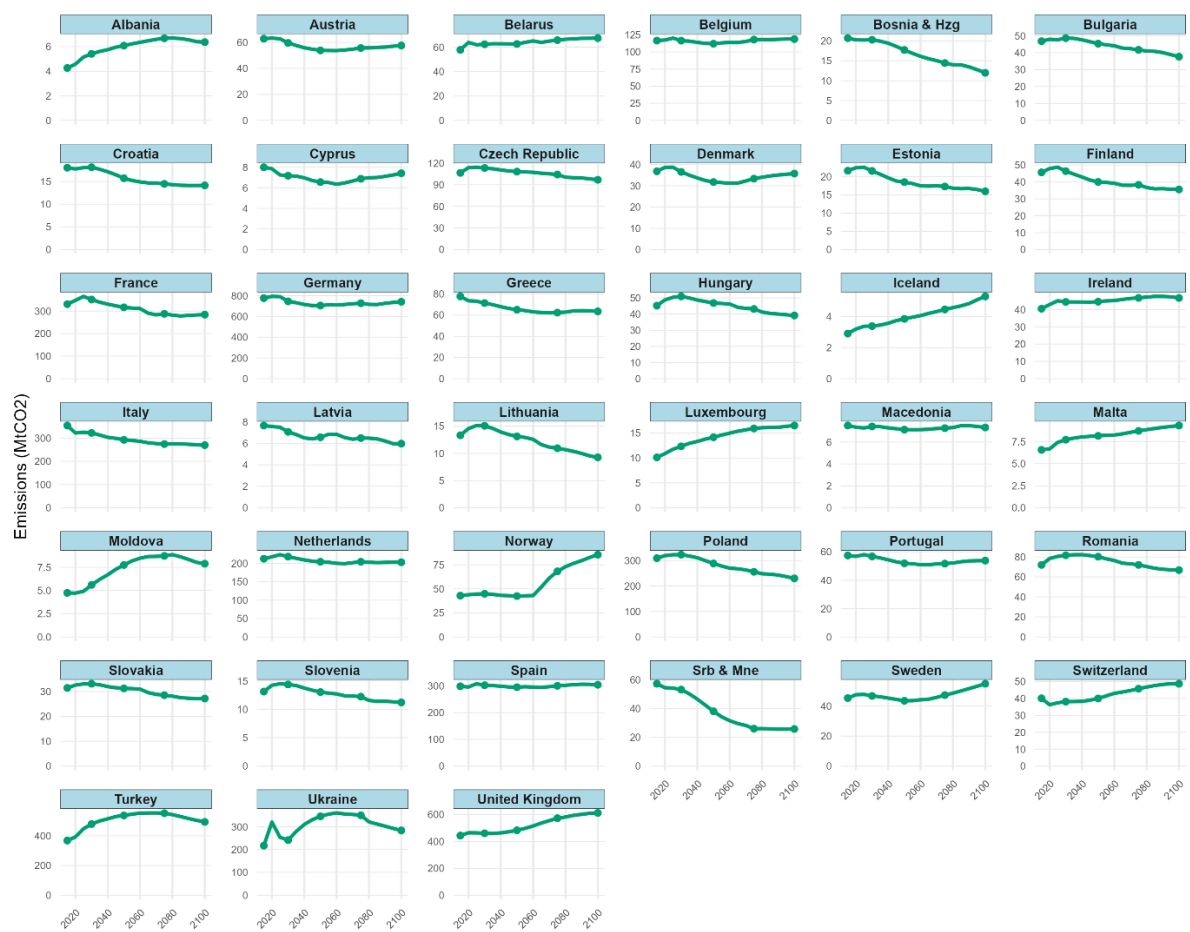
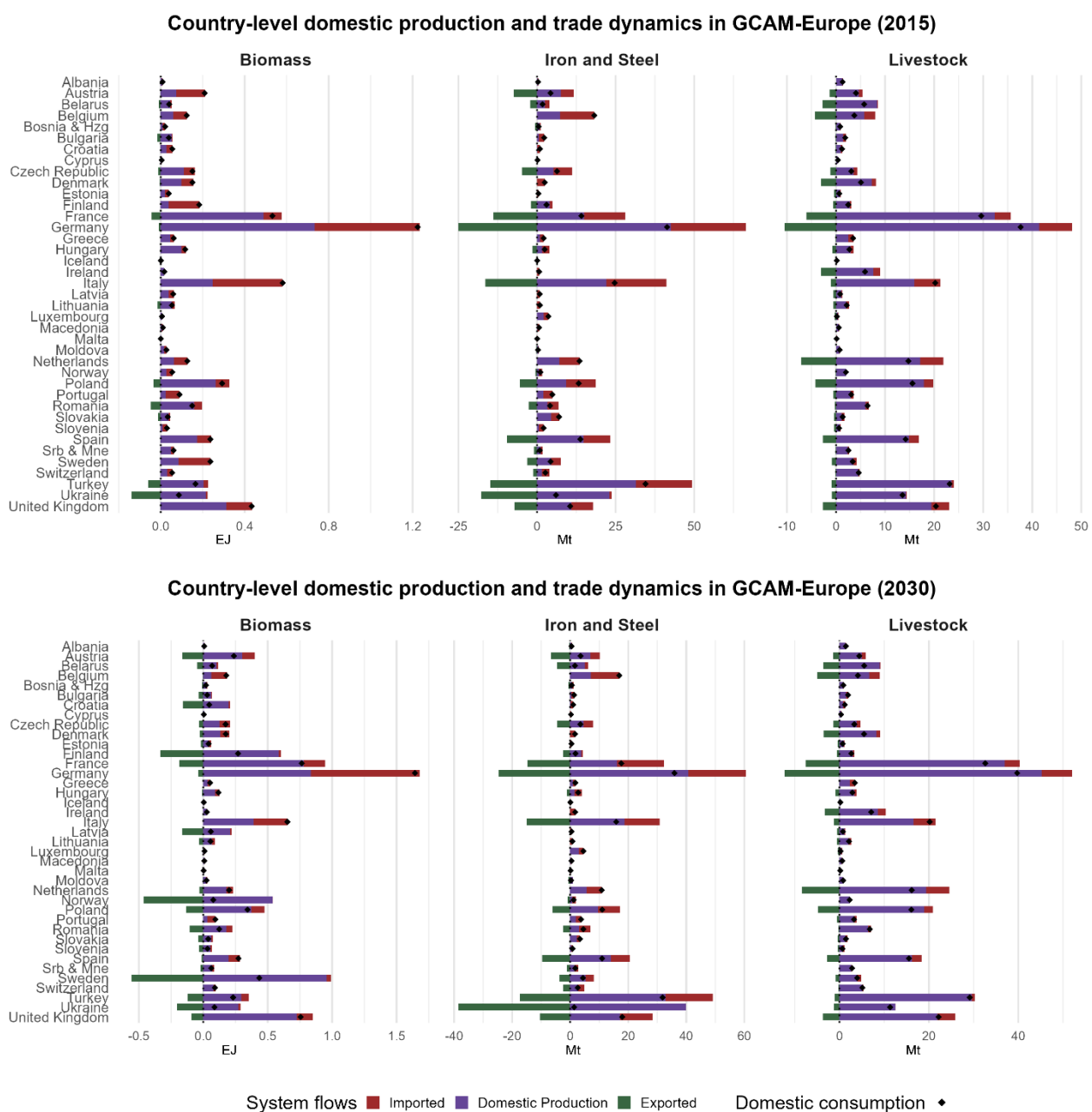
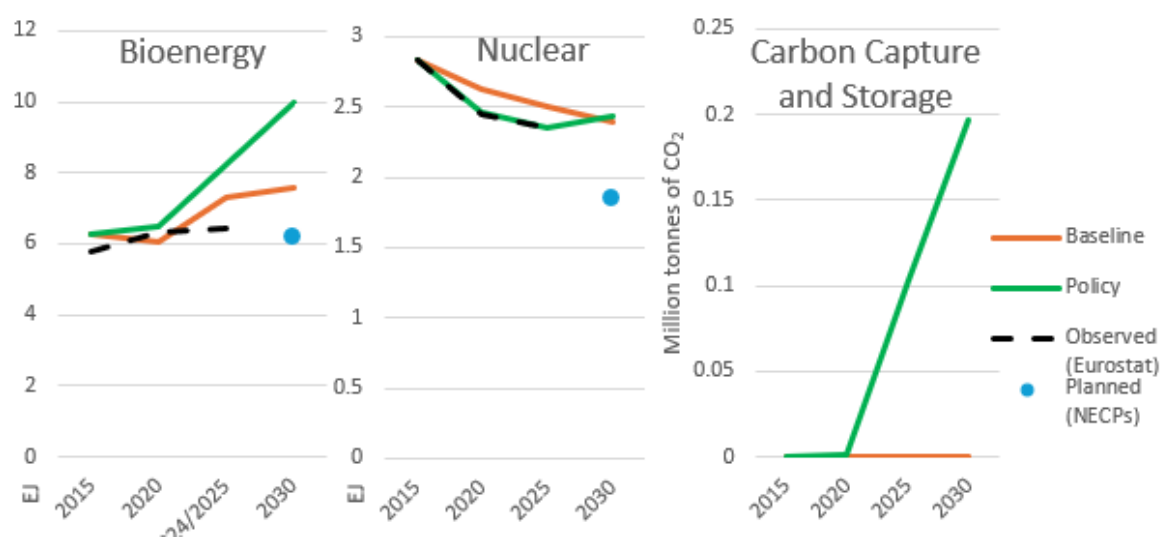


Figure S11: CO2 emissions by country and period in the GCAM-Europe baseline scenario (MTCO2)



**Figure S12: Trade dynamics by country and commodity for 2050 in the GCAM-Europe baseline in 2015 (top) and 2030 (bottom)**



**Figure S13: Comparison of model simulations with real-world and projected values for Bioenergy, CCS and Nuclear energy in the EU-27.** For Bioenergy, the observed value refers to 2024 due to lack of data for 2025. The blue dots represent the values projected by the EC for the FF55 scenario

| CO2 market     | GCAM region                                                                                          | 2020 | 2025 | 2030 | 2035 | 2040 | 2045  | 2050  |
|----------------|------------------------------------------------------------------------------------------------------|------|------|------|------|------|-------|-------|
| Austria        | Austria                                                                                              | -    | -    | -    | 525  | 630  | 639   | 664   |
| Belgium        | Belgium                                                                                              | -    | -    | -    | 557  | 662  | 756   | 879   |
| Bulgaria       | Bulgaria                                                                                             | -    | -    | -    | 407  | 492  | 586   | 667   |
| Croatia        | Croatia                                                                                              | -    | -    | -    | 465  | 571  | 669   | 768   |
| Cyprus         | Cyprus                                                                                               | -    | -    | -    | 583  | 824  | 929   | 1,411 |
| Czech Republic | Czech Republic                                                                                       | -    | -    | -    | 451  | 564  | 664   | 776   |
| Denmark        | Denmark                                                                                              | -    | -    | -    | 546  | 614  | 710   | 924   |
| Estonia        | Estonia                                                                                              | -    | -    | -    | 223  | 292  | 354   | 549   |
| Finland        | Finland                                                                                              | -    | -    | -    | 442  | 366  | 302   | 250   |
| France         | France                                                                                               | -    | -    | -    | 501  | 547  | 620   | 690   |
| Germany        | Germany                                                                                              | -    | -    | -    | 507  | 574  | 764   | 718   |
| Greece         | Greece                                                                                               | -    | -    | -    | 511  | 577  | 661   | 801   |
| Hungary        | Hungary                                                                                              | -    | -    | -    | 483  | 559  | 639   | 750   |
| Ireland        | Ireland                                                                                              | -    | -    | -    | 574  | 668  | 816   | 3,178 |
| Italy          | Italy                                                                                                | -    | -    | -    | 534  | 601  | 686   | 769   |
| Latvia         | Latvia                                                                                               | -    | -    | -    | 531  | 619  | 696   | 808   |
| Lithuania      | Lithuania                                                                                            | -    | -    | -    | 405  | 502  | 612   | 718   |
| Luxembourg     | Luxembourg                                                                                           | -    | -    | -    | 602  | 608  | 708   | 807   |
| Malta          | Malta                                                                                                | -    | -    | -    | 433  | 914  | 1,155 | 1,482 |
| Netherlands    | Netherlands                                                                                          | -    | -    | -    | 563  | 668  | 767   | 898   |
| Poland         | Poland                                                                                               | -    | -    | -    | 391  | 500  | 617   | 733   |
| Portugal       | Portugal                                                                                             | -    | -    | -    | 509  | 597  | 802   | 792   |
| Romania        | Romania                                                                                              | -    | -    | -    | 485  | 585  | 662   | 734   |
| Slovakia       | Slovakia                                                                                             | -    | -    | -    | 413  | 475  | 569   | 662   |
| Slovenia       | Slovenia                                                                                             | -    | -    | -    | 563  | 693  | 817   | 1,139 |
| Spain          | Spain                                                                                                | -    | -    | -    | 538  | 597  | 676   | 778   |
| Sweden         | Sweden                                                                                               | -    | -    | -    | 405  | 420  | 503   | 553   |
|                |                                                                                                      |      |      |      |      |      |       |       |
| ETS            | European Union                                                                                       | 9    | 158  | 310  | 0    | -    | -     | -     |
| ETS2           | European Union                                                                                       | -    | -    | 45   | -    | -    | -     | -     |
|                |                                                                                                      |      |      |      |      |      |       |       |
| EFTA           | Iceland; Norway; Switzerland; UK                                                                     | 25   | 133  | 151  | 223  | 255  | 313   | 398   |
| Other Europe   | Albania; Belarus; Bosnia and Herzegovina; Macedonia; Moldova; Serbia and Montenegro; Turkey; Ukraine | 24   | 19   | 24   | 42   | 100  | 139   | 164   |
| China          | China; Taiwan                                                                                        | 32   | 27   | 29   | 73   | 99   | 127   | 180   |
| India          | India; South Asia                                                                                    | 1    | 0    | 0    | 58   | 88   | 112   | 141   |
| Jap & Kor      | Japan; South Korea                                                                                   | 7    | 111  | 143  | 186  | 202  | 261   | 331   |

|                       |                                                                                                                  |    |     |     |     |     |     |     |
|-----------------------|------------------------------------------------------------------------------------------------------------------|----|-----|-----|-----|-----|-----|-----|
| Latin America         | Argentina; Brazil; Central America & Caribbean; Colombia; Mexico; South America Northern; South America Southern | 12 | 88  | 89  | 132 | 147 | 186 | 195 |
| MENA                  | Africa Northern; Middle East                                                                                     | 0  | 35  | 76  | 102 | 103 | 126 | 151 |
| Russia & Central Asia | Russia; Central Asia                                                                                             | 0  | 16  | 29  | 52  | 96  | 140 | 184 |
| South-East Asia       | Indonesia; Southeast Asia                                                                                        | 0  | 0   | 18  | 75  | 113 | 140 | 156 |
| SS Africa             | Africa Eastern; Africa Western; Africa Southern; South Africa                                                    | 0  | 11  | 40  | 71  | 100 | 149 | 195 |
| US & Canada & Aust    | Australia_NZ; Canada; USA                                                                                        | 62 | 120 | 146 | 188 | 210 | 208 | 206 |

**Table S2: Carbon prices in the NECP\_LTT scenario (2015\$/tCO2)**