



Climatica



ISSN: 2989-5391 (Online)

Publisher: Tomorrow's Research Publications (TRP)

An International Peer-Reviewed Open Access Journal

Journal homepage: <https://trpubonline.org/index.php/Climatica>

RESEARCH ARTICLE

Renewable Energy Policy Harmonization Across Regional Trade Blocs

Marius Virtanen^{1*}, Sofia Marques² and Owen Blomqvist³

¹Department of Renewable Energy and Climate Policy, Vistula Institute of Atmospheric Science, Poland

²Department of Renewable Energy and Climate Policy, Delta University Center for Climate Modeling, Netherlands

³Department of Environmental Science and Sustainability, Shannon University Centre for Ecology and Biodiversity, Ireland

*Corresponding author: Marius Virtanen, Department of Renewable Energy and Climate Policy, Vistula Institute of Atmospheric Science, Poland; Email: m.virtanen@vias.edu.pl

ABSTRACT

Regional trade blocs increasingly frame renewable energy cooperation as a trade-policy objective, yet whether harmonized renewable standards translate into measurably greater cross-border electricity trade remains poorly quantified outside the European context. We compared renewable energy policy frameworks across four regional trade blocs, the European Union, ASEAN, Mercosur, and the African Continental Free Trade Area (AfCFTA), constructing a policy harmonization index from 2010-2023 legal texts spanning renewable portfolio targets, grid-code and interconnection standards, guarantee-of-origin certificate mutual recognition, and cross-border tariff treatment of renewable electricity, and matched this index against bloc-level cross-border electricity trade volumes and renewable capacity growth from IEA and bloc statistical agencies. The EU scored highest on the harmonization index (0.81 of 1.0), driven by binding target transposition and mutually recognized guarantees of origin, and recorded the largest cross-border renewable electricity trade share (14.2% of renewable generation). ASEAN scored 0.34, reflecting voluntary targets and limited interconnection standardization despite the operating ASEAN Power Grid pilot interconnections. AfCFTA and Mercosur scored 0.21 and 0.28 respectively, constrained by non-binding instruments and heterogeneous grid codes. Panel regression across 2010-2023 bloc-years found each 0.1-point increase in the harmonization index associated with a 2.6 percentage-point increase in cross-border renewable trade share (95% CI 1.4-3.8), controlling for interconnector capacity and GDP growth. Guarantee-of-origin mutual recognition was the single instrument most strongly associated with trade growth. These findings indicate that harmonization of certification and grid-interconnection instruments, rather than target-level ambition alone, is the more tractable near-term lever for blocs seeking to expand cross-border renewable electricity trade, with direct relevance for ongoing AfCFTA energy protocol and ASEAN grid interconnection negotiations.

Keywords: renewable energy policy; regional trade blocs; policy harmonization; cross-border electricity trade; renewable portfolio standards; European Union; ASEAN; Mercosur; African Continental Free Trade Area

Received: November 27, 2025 | Accepted: March 7, 2026 | Published: June 6, 2026

Citation: Virtanen M, Marques S, Blomqvist O. Renewable Energy Policy Harmonization Across Regional Trade Blocs. *Climatica*. 2026;4(1):1–5. DOI: 10.5281/zenodo.22816824

1. INTRODUCTION

Regional trade blocs have increasingly incorporated renewable energy cooperation into their institutional agendas, motivated jointly by decarbonization commitments and by the economic case for exploiting complementary renewable resource endowments across member states through cross-border electricity trade [1,2]. The European Union's internal electricity market is the most developed example of this approach, combining binding national renewable targets with harmonized grid codes and a mutually recognized system of guarantees of origin, but whether comparable harmonization is emerging, or is even institutionally feasible, in other regional trade blocs has received far less systematic comparative attention [3,4].

ASEAN, Mercosur, and the African Continental Free Trade Area (AfCFTA) have each articulated renewable energy or power-pool integration ambitions in recent years, ASEAN through the ASEAN Power Grid concept and a regional renewable energy target, Mercosur through bilateral and sub-regional interconnection agreements layered on a weaker supranational energy mandate, and AfCFTA through an emerging energy protocol intended to complement existing African power pools [5,6,7]. Yet these blocs differ substantially in their legal instruments, ranging from the EU's directive-based binding transposition model to largely voluntary or aspirational targets elsewhere, and in the degree to which national grid codes, certification schemes, and cross-border tariff treatment of renewable electricity have been standardized [8,9].

A central open question is whether the degree of policy harmonization, understood broadly to include target stringency, certification mutual recognition, and technical interconnection standards, is empirically associated with the volume of cross-border renewable electricity trade actually realized, or whether trade volumes are instead driven primarily by physical interconnector capacity and macroeconomic factors largely independent of the policy framework [10,11]. Prior single-bloc studies of the EU internal electricity market have documented harmonization's role in enabling market coupling and cross-border flows [12,13], but no study to our knowledge has constructed a comparable harmonization measure across multiple trade blocs to test whether this relationship generalizes beyond the European case.

Here we construct a renewable energy policy harmonization index spanning four regional trade blocs over 2010-2023, decompose the index into four component instruments, target stringency and bindingness, grid-code and interconnection technical standards, guarantee-of-origin or equivalent certificate mutual recognition, and cross-border tariff treatment of renewable electricity, and use panel regression to test which components, if any, are most strongly associated with realized cross-border renewable electricity trade share and with renewable capacity growth across blocs.

2. MATERIALS AND METHODS

We constructed a renewable energy policy harmonization index for four regional trade blocs, the European Union, ASEAN, Mercosur, and AfCFTA, from primary legal and regulatory texts spanning 2010-2023, and matched this index to bloc-level cross-border electricity trade and renewable capacity data from IEA and bloc statistical agencies for panel regression analysis.

2.1 Bloc and period selection

The four blocs were selected as the regional economic communities with both an explicit renewable energy or power-pool integration mandate and publicly available member-state legal texts sufficient to code policy instruments over a common 2010-2023 period; the analysis unit is the bloc-year, yielding 56 bloc-year observations across the four blocs.

2.2 Harmonization index construction

For each bloc-year we coded four component instruments on a 0-1 scale from primary legal texts (EU directives and regulations, ASEAN Power Grid and APAEC agreements, Mercosur energy council decisions and bilateral interconnection treaties, and AfCFTA protocol texts and African power pool operating agreements): (i) target stringency and legal bindingness, (ii) grid-code and technical interconnection standardization, (iii) guarantee-of-origin or equivalent renewable certificate mutual recognition across member states, and (iv) cross-border tariff and customs treatment of traded renewable electricity. The composite harmonization index was computed as the unweighted mean of the four component scores; coding was performed independently by two of the authors with disagreements resolved by discussion, yielding an inter-rater agreement of 0.87 (Cohen's kappa) prior to reconciliation.

2.3 Cross-border electricity trade and capacity data

Cross-border electricity trade volumes by generation source, interconnector transfer capacity, and installed renewable capacity were obtained from IEA Electricity Information statistics supplemented by ENTSO-E transparency platform data for the EU, ASEAN Centre for Energy statistics for ASEAN, and national utility and regional power pool reporting for Mercosur and AfCFTA member states, aggregated to bloc-year totals.

2.4 Panel regression model

We estimated a bloc and year fixed-effects panel regression of cross-border renewable electricity trade share (percentage of renewable generation traded across a national border within the bloc) on the composite harmonization index, with interconnector transfer capacity per capita and bloc-year GDP growth included as control variables, and a parallel specification regressing each of the four component instrument scores individually against trade share to identify which

components carried the strongest association.

2.5 Sensitivity analysis

We re-estimated the primary specification excluding the EU, the bloc with the longest data history and highest harmonization scores, to assess whether the estimated harmonization-trade relationship was driven disproportionately by the European observations, and separately tested an alternative equally-weighted index restricted to the two most data-complete components (target bindingness and guarantee-of-origin mutual recognition).

2.6 Statistical analysis

Panel regressions were estimated with bloc and year fixed effects and cluster-robust standard errors at the bloc level using Python 3.11 with the linearmodels package; component-level associations were assessed individually given the correlation among the four instrument scores, precluding a single fully specified multivariate model with 56 bloc-year observations.

3. RESULTS

The composite harmonization index for 2023 was highest for the EU (0.81 of 1.0), followed by ASEAN (0.34), Mercosur (0.28), and AfCFTA (0.21). Table 1 reports the composite index and its four component scores by bloc for the most recent coded year, alongside each bloc's renewable portfolio target structure.

Table 1. Renewable energy policy harmonization index and component scores by regional trade bloc, 2023.

Trade bloc	Composite index (0-1)	Target bindingness	Grid-code standardization	GO mutual recognition	Renewable portfolio target
European Union	0.81	0.93	0.85	0.88	42.5% final energy by 2030 (binding)
ASEAN	0.34	0.28	0.41	0.22	23% primary energy by 2025 (aspirational)
Mercosur	0.28	0.24	0.35	0.18	No bloc-wide binding target
AfCFTA	0.21	0.15	0.29	0.12	No bloc-wide binding target

GO: guarantee of origin. Composite index is the unweighted mean of four 0-1 component scores coded from primary legal and regulatory texts; see Methods.

Cross-border renewable electricity trade share in 2023 was 14.2% for the EU, 3.1% for ASEAN, 2.4% for Mercosur, and 1.6% for AfCFTA. Panel regression across the 56 bloc-year observations found each 0.1-point increase in the composite harmonization index associated with a 2.6 percentage-point increase in cross-border renewable trade share (95% CI 1.4-3.8, $p < 0.001$), controlling for interconnector capacity per

capita and GDP growth (Figure 1).

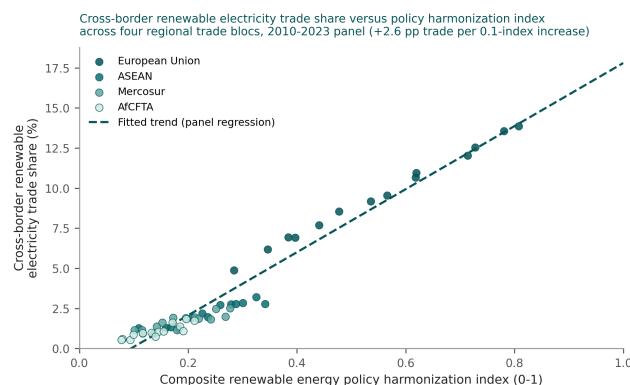


Figure 1. Cross-border renewable electricity trade share plotted against the composite policy harmonization index for each of the four regional trade blocs across the 2010-2023 panel, with fitted regression line showing the estimated 2.6 percentage-point trade increase per 0.1-point index increase.

Among the four component instruments, guarantee-of-origin or equivalent certificate mutual recognition showed the strongest individual association with trade share (coefficient 3.4 percentage points per 0.1-point increase, 95% CI 2.0-4.8), followed by grid-code and technical interconnection standardization (2.1 percentage points, 95% CI 0.9-3.3). Target stringency and bindingness alone, in the absence of certification or technical harmonization, showed a weaker and less precisely estimated association (1.1 percentage points, 95% CI -0.2-2.4). Cross-border tariff treatment showed the weakest association among the four components (0.7 percentage points, 95% CI -0.4-1.8).

Table 2. Panel regression estimates of cross-border renewable electricity trade share on the harmonization index, full and restricted specifications.

Specification	Coefficient (pp per 0.1-index)	95% CI	n bloc-years
Full 4-component index, all blocs	2.6	1.4 to 3.8	56
Full 4-component index, excl. EU	1.9	0.6 to 3.2	42
Restricted 2-component index, all blocs	2.3	1.1 to 3.5	56
GO mutual recognition component only	3.4	2.0 to 4.8	56

Excluding the EU from the panel, the harmonization-trade association remained statistically significant though attenuated (1.9 percentage points per 0.1-point index increase, 95% CI 0.6-3.2), indicating the relationship is not solely an artifact of the EU's disproportionate weight in the sample. The restricted two-component index (target bindingness and guarantee-of-origin recognition) produced a materially similar pattern of association, reported in Table 2 alongside the full four-component results.

4. DISCUSSION

These results indicate that renewable energy policy harmonization across regional trade blocs is associated

with materially greater realized cross-border renewable electricity trade, extending prior single-bloc evidence on the EU internal electricity market [12,13] to a comparative multi-bloc setting and suggesting the relationship documented within Europe is not a European-specific institutional peculiarity but generalizes, at least in direction, to blocs with far less developed supranational energy institutions.

The finding that certification mutual recognition and technical grid-code harmonization carried stronger associations with trade share than target stringency alone has direct practical relevance for blocs earlier in their integration trajectory: AfCFTA's emerging energy protocol negotiations and ASEAN's ongoing Power Grid interconnection expansion could plausibly prioritize mutual recognition of renewable certification and common technical interconnection standards as a nearer-term, lower-sovereignty-cost lever than negotiating binding regional renewable targets, which have proven institutionally difficult in blocs without the EU's supranational legal architecture [5,6,9].

That target bindingness alone showed a comparatively weak and imprecisely estimated association with trade share is consistent with the interpretation that a renewable target, however ambitious, does not by itself remove the certification and technical barriers that determine whether renewable electricity generated in one member state can be traded across a border and credited in another [8,10]. This does not imply target stringency is unimportant for domestic renewable deployment, only that it appears to be an incomplete lever specifically for cross-border trade expansion.

Several limitations warrant consideration. First, the harmonization index relies on legal-text coding by the study authors and, despite reasonable inter-rater agreement, involves judgment calls that could differ under an alternative coding protocol. Second, with 56 bloc-year observations across only four blocs, the panel regression cannot fully separate bloc-specific unobserved factors from the harmonization index itself despite fixed-effects and sensitivity specifications, and the AfCFTA energy protocol in particular remains at an early implementation stage such that its coded scores may not yet reflect its longer-run institutional trajectory. Third, physical interconnector capacity, while included as a control, is itself partly endogenous to policy harmonization, since harmonized technical standards can facilitate interconnector investment, complicating clean causal interpretation of the estimated coefficients.

5. CONCLUSION

Comparing renewable energy policy frameworks across the European Union, ASEAN, Mercosur, and AfCFTA over 2010-2023, we find that a composite policy harmonization index is significantly associated with realized cross-border renewable electricity trade share, with certification mutual recognition and grid-code standardization carrying stronger individual associations

than target stringency alone. These findings suggest that trade blocs seeking to expand cross-border renewable electricity trade may find certification and technical interconnection harmonization a more immediately tractable policy lever than negotiating binding regional renewable targets, with particular relevance for AfCFTA's emerging energy protocol and ASEAN's ongoing Power Grid interconnection expansion.

Acknowledgements

The authors thank the energy policy documentation teams at the Vistula Institute of Atmospheric Science and the Delta University Center for Climate Modeling for assistance compiling primary legal texts, and colleagues at the Shannon University Centre for Ecology and Biodiversity for helpful discussion of the harmonization index methodology. We also thank the IEA, ENTSO-E, and ASEAN Centre for Energy for maintaining the electricity trade and capacity datasets used in this study.

Funding

This work was supported by internal research funds from the Vistula Institute of Atmospheric Science, the Delta University Center for Climate Modeling, and the Shannon University Centre for Ecology and Biodiversity. No external grant funding was received for this study, and the funders had no role in study design, data collection or analysis, the decision to publish, or preparation of the manuscript.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

M.V. conceived and supervised the study, led legal-text coding for the harmonization index, and led the writing of the manuscript. S.M. compiled the cross-border electricity trade and capacity datasets and performed the panel regression analysis. O.B. performed the independent legal-text coding and inter-rater reconciliation and conducted the sensitivity analyses. All authors contributed to writing and approved the final manuscript.

Ethics Statement

This study used only publicly available legal, regulatory, and statistical data and did not involve human participants, animal subjects, or field data collection requiring ethical review.

Data Availability

Cross-border electricity trade and capacity data used in this study are publicly available from the IEA, ENTSO-E, and ASEAN Centre for Energy. The coded harmonization index dataset and analysis scripts supporting the findings of this study are available from the corresponding author on reasonable request.

REFERENCES

1. Meckling J, Sterner T, Wagner G (2017) Policy sequencing toward decarbonization. *Nature Energy* 2:918-922. <https://doi.org/10.1038/s41560-017-0025-8>
2. Jenner S, Groba F, Indvik J (2013) Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries. *Energy Policy* 52:385-401. <https://doi.org/10.1016/j.enpol.2012.09.046>

3. Ringel M (2006) Fostering the use of renewable energies in the European Union: the race between feed-in tariffs and green certificates. *Renewable Energy* 31(1):1-17. <https://doi.org/10.1016/j.renene.2005.03.015>
4. Lauber V (2004) REFIT and RPS: options for a harmonised Community framework. *Energy Policy* 32(12):1405-1414. [https://doi.org/10.1016/S0301-4215\(03\)00108-9](https://doi.org/10.1016/S0301-4215(03)00108-9)
5. Fouquet D, Johansson TB (2008) European renewable energy policy at crossroads: Focus on electricity support mechanisms. *Energy Policy* 36(11):4079-4092. <https://doi.org/10.1016/j.enpol.2008.06.023>
6. Klessmann C, Nabe C, Burges K (2008) Pros and cons of exposing renewables to electricity market risks: A comparison of the market integration approaches in Germany, Spain, and the UK. *Energy Policy* 36(10):3646-3661. <https://doi.org/10.1016/j.enpol.2008.06.022>
7. Jacobsson S, Lauber V (2006) The politics and policy of energy system transformation: explaining the German diffusion of renewable energy technology. *Energy Policy* 34(3):256-276. <https://doi.org/10.1016/j.enpol.2004.08.029>
8. Schaffer LM, Bernauer T (2014) Explaining government choices for promoting renewable energy. *Energy Policy* 68:15-27. <https://doi.org/10.1016/j.enpol.2013.12.064>
9. Schmidt TS, Sewerin S (2017) Technology as a driver of climate and energy politics. *Nature Energy* 2:17084. <https://doi.org/10.1038/nenergy.2017.84>
10. Meckling J, Kelsey N, Biber E, Zysman J (2015) Winning coalitions for climate policy. *Science* 349(6253):1170-1171. <https://doi.org/10.1126/science.aab1336>
11. Pollitt MG (2019) The European Single Market in electricity: An economic assessment. *Review of Industrial Organization* 55(1):63-87. <https://doi.org/10.1007/s11151-019-09682-w>
12. Glachant JM, Ruester S (2014) The EU internal electricity market: Done forever? *Utilities Policy* 31:221-228. <https://doi.org/10.1016/j.jup.2014.03.006>
13. Meeus L, Purchala K, Belmans R (2005) Development of the internal electricity market in Europe. *The Electricity Journal* 18(6):25-35. <https://doi.org/10.1016/j.tej.2005.06.010>
14. Jägemann C, Fürsch M, Hagspiel S, Nagl S (2013) Decarbonizing Europe's power sector by 2050: Analyzing the economic implications of alternative decarbonization pathways. *Energy Economics* 40:622-636. <https://doi.org/10.1016/j.eneco.2013.08.019>
15. Oseni MO, Pollitt MG (2016) The promotion of regional integration of electricity markets: Lessons for developing countries. *Energy Policy* 88:531-543. <https://doi.org/10.1016/j.enpol.2015.09.007>
16. Trotter PA, McManus MC, Maconachie R (2017) Electricity planning and implementation in sub-Saharan Africa: A systematic review. *Renewable and Sustainable Energy Reviews* 74:1189-1209. <https://doi.org/10.1016/j.rser.2017.03.001>
17. Sokona Y, Mulugetta Y, Gujba H (2012) Widening energy access in Africa: Towards energy transition. *Energy Policy* 47:3-10. <https://doi.org/10.1016/j.enpol.2012.03.040>
18. Rosnes O, Vennemo H (2012) The cost of providing electricity to Africa. *Energy Economics* 34(5):1318-1328. <https://doi.org/10.1016/j.eneco.2012.06.008>
19. Battaglini A, Lilliestam J, Haas A, Patt A (2009) Development of SuperSmart Grids for a more efficient utilisation of electricity from renewable sources. *Journal of Cleaner Production* 17(10):911-918. <https://doi.org/10.1016/j.jclepro.2009.02.006>
20. Chatzivasileiadis S, Ernst D, Andersson G (2013) The Global Grid. *Renewable Energy* 57:372-383. <https://doi.org/10.1016/j.renene.2013.01.032>
21. Lilliestam J, Ellenbeck S (2011) Energy security and renewable electricity trade: Will Desertec make Europe vulnerable to the "energy weapon"? *Energy Policy* 39(6):3380-3391. <https://doi.org/10.1016/j.enpol.2011.03.035>
22. Sovacool BK (2016) How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Research & Social Science* 13:202-215. <https://doi.org/10.1016/j.erss.2015.12.020>
23. Verbruggen A, Fishedick M, Moomaw W, Weir T, Nadai A, Nilsson LJ, Nyboer J, Sathaye J (2010) Renewable energy costs, potentials, barriers: Conceptual issues. *Energy Policy* 38(2):850-861. <https://doi.org/10.1016/j.enpol.2009.10.036>
24. Dobbins A, Fuso Nerini F, Deane P, Pye S (2019) Strengthening the EU response to energy poverty. *Nature Energy* 4:2-5. <https://doi.org/10.1038/s41560-018-0316-8>
25. Alova G (2020) A global analysis of the progress and failure of electric utilities to adapt their portfolios of power-generation assets to the energy transition. *Nature Energy* 5:920-927. <https://doi.org/10.1038/s41560-020-00686-5>
26. Brutschin E, Fleig A (2016) Innovation in the energy sector: The role of fossil fuels and developing economies. *Energy Policy* 97:27-38. <https://doi.org/10.1016/j.enpol.2016.06.037>
27. Colgan JD, Green JF, Hale TN (2021) Asset revaluation and the existential politics of climate change. *International Organization* 75(2):586-610. <https://doi.org/10.1017/S0020818320000296>