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Charting the Energy Transition: Rethinking Green Policy Strategy and Sustainable Technology Integration for Energy Efficiency Gains. Sectoral Evidence from Europe

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ΠΡΟΓΡΑΜΜΑ "ΜΕΔΙΚΟΣ"
Ενίσχυση Νεοδιοριζόμενων Μελών ΔΕΠ

Research project **GR.E.A.T.**: **GR**een **GR**owth and **E**nergy **E**fficiency for **A**ll **T**iers of Performance: Decision Making and Policy Implications to Chart Energy Transition.
This paper has been financed by the funding programme "MEDICUS", of the University of Patras.

Structure

Motivation

Concept & Research Questions

Data & Methodology

Estimation results

Robustness checks

Policy implications

Key messages

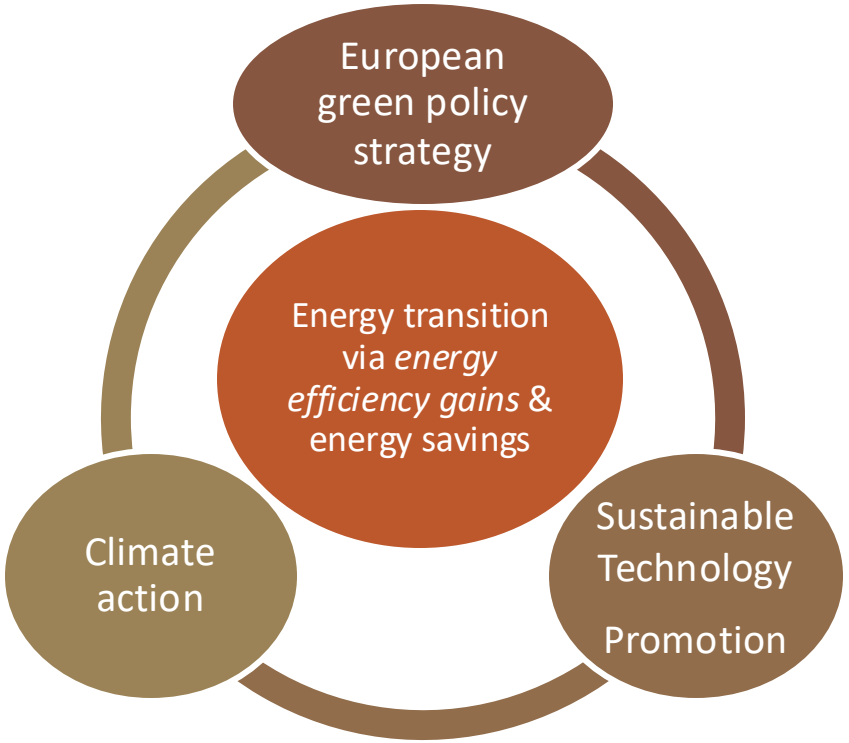
Motivation

- Achieving the climate neutrality status by 2050 is the goal of the European Union, as outlined in the European Green Deal.
- Energy, Environmental & Climate change policies are launched and updated, however the nation-wide effect of the assimilation of such policies remains largely unexplored.
- Recent policy specialized reports on the progress toward climate neutrality e.g., ECB (2021) Chancel et al., 2023):
  - Highlight that country asymmetries in policy implementation efforts & technology-related capacity affect green growth patterns &
  - Bring to the forefront the need to account for such inequalities in achieving progressing towards energy transition.

- We develop a conceptual framework that acts as the workhorse to investigate ***whether green policy and green technology affect progress toward energy transition in the EU, across tiers***.

Conceptual framework & Research Questions

Action towards energy transition in the EU:



- **We develop and test two main hypotheses:**

H_1: Green policy efforts influence progress towards energy transition across tiers.

H_{1a}: Energy taxes foster progress towards energy transition across tiers.

H_{1a}: Environmental R&D fosters progress towards energy transition across tiers.

H_{1c}: Environmental policy performance fosters progress towards energy transition across tiers.

H_2: Technology capacity fosters energy transition

H_2: Green Technology Development fosters progress towards energy transition, across tiers

Resources

- EU-28 over the period 2010-2019, 280 observations in the panel dimension.

Progress toward energy transition: *Energy Efficiency Gain (EEG) & Energy Efficiency Savings Rate (EESR).*

- **EU energy strategy governance: green policy tools:**
  - *Energy taxation, Environmental Public R&D, Environmental Policy Performance*.
- **Technology capacity for energy transition:**
  - *Green Technology Development level*.
- **Controls:**
  - *Renewable Energy Use.*
  - *Global Competitiveness Index.*
  - *Economy Structure.*

Sources: Enerdata Odyssee-MURE, Eurostat, OECD, World Bank, World Economic Forum, Quality of Governance.

Methodology

- We investigate whether ***green policy*** and ***green technology*** affect ***energy transition progress*** in the EU-28, across tiers of ***energy efficiency gains (EEG)*** & ***energy efficiency savings rate (EESR)***.

❖ However, **endogeneity arises** due to policy decisions and environmental conditions create a feedback loop where policies are both causes and effects of progress while at the same time influence progress, but this progress can also shape policy actions.

- To address these challenges, the analysis should be conducted within a framework that:
  i. Explores the effects on the progress toward energy transition via an instrumental variables' framework.
  ii. Accounts for unknown forms of heteroskedasticity - crucial for managing green policy and asymmetries across different quantiles of the dependent variables.

- Thus, we employ the instrumental variables panel quantile regression estimator using Markov Chain Monte Carlo optimization methods with non-additive fixed effects, to estimate the following model:

$$Quantile_{EEG\ \&\ EESR\ it}\left(\tau_{k|\ x_{it},\varepsilon_{it}^{*}}\right) = \boldsymbol{\beta' GreenPolicyTools}_{it} + \boldsymbol{\gamma' GreenTechnology}_{it} + \boldsymbol{\delta'_{\tau} Controls}_{it} + \varepsilon_{it}^{*}$$

Charting energy transition

The ***Energy Efficiency Index (EEI)***:

- *Tracks* energy efficiency progress over time.
- *Compares* ***actual energy consumption*** to ***a hypothetical reference-year scenario where no efficiency improvements occur***.
- Normalized to 100 in a reference year (2015), i.e., ***lower values improved energy efficiency***.

Example: EEI = 85 means a 15% efficiency improvement since the reference year.

➢ *We focus on two under-explored metrics* that could shed light on additional aspects of energy transition:

The *Energy Efficiency Gains (EEG)* offers:

- ***Clarity:*** It is a simple, cumulative metric of energy efficiency improvement, as EEG = 100−EEI.
- ***Convenience in interpretation & dissemination of results:*** Easier to understand and explain that is "The Energy Efficiency gain improved by 15%" is more straightforward than "The index is at 85."
- ***Transition Tracking:*** Energy efficiency gains reflect the real decoupling of energy use from activity (e.g., GDP, transport, housing) - critical for monitoring actual progress toward energy goals.

✓ Thus, ***EEG offer a clearer and more actionable signal for tracking the energy transition.***

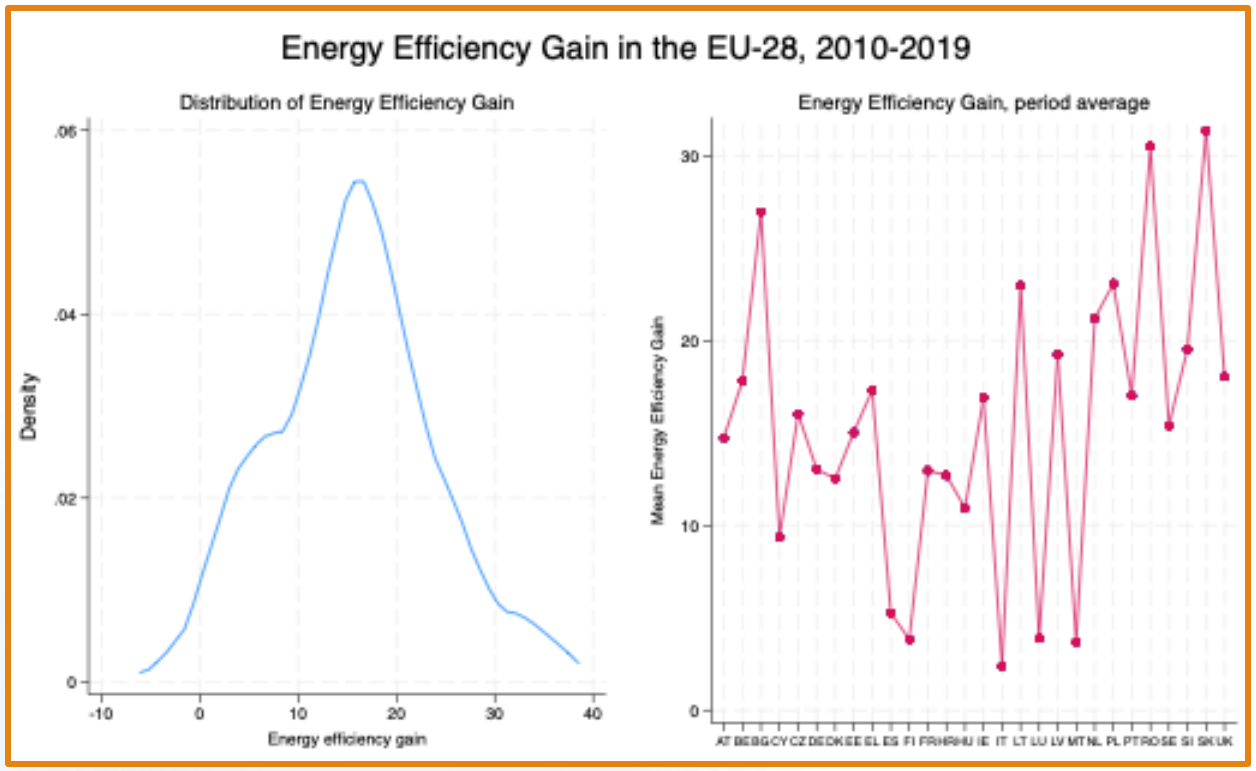
The *Energy Efficiency Savings Rate (EESR)*:

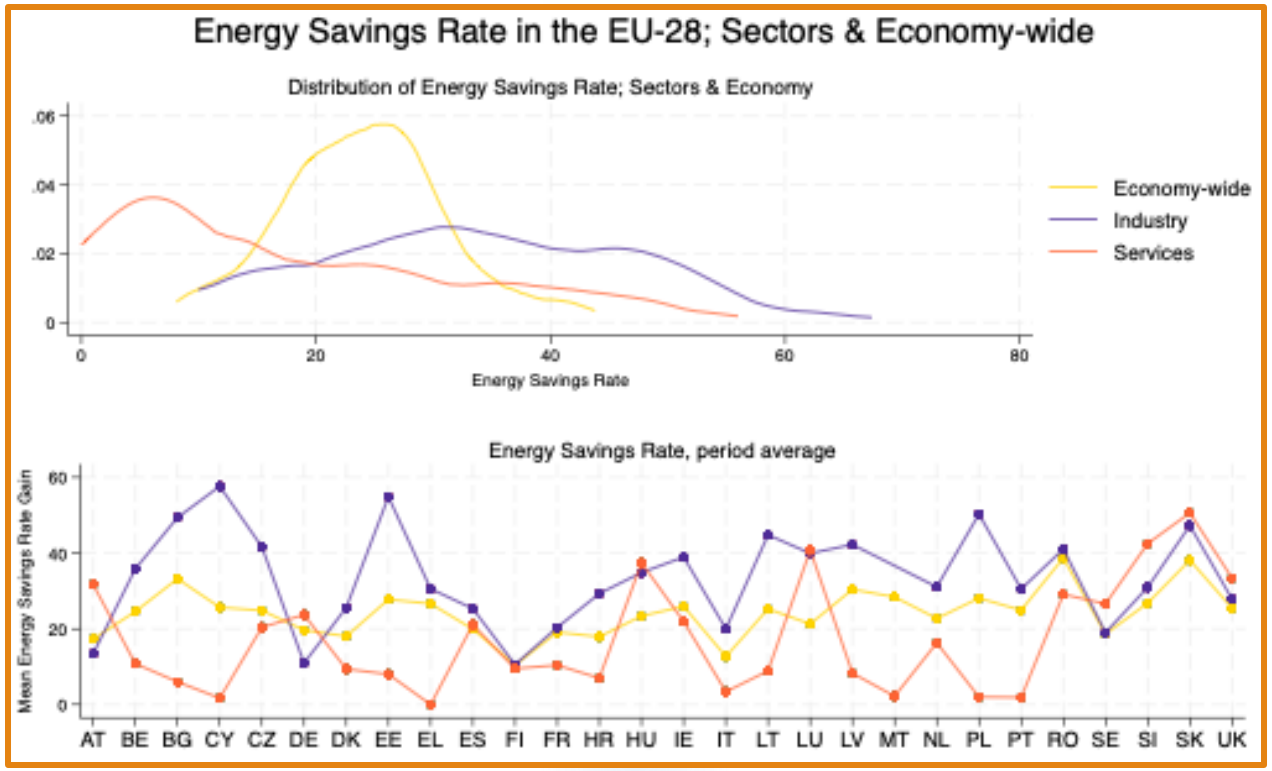
- ***Offers critical insights into sector-level progress***, essential for targeting policies and tracking real-world outcomes
- It's ***the only available indicator for sector-level energy efficiency savings progress***
- ***Includes structural shifts***, not just technical efficiency.
- Expressed as a % of energy saved, e.g., "Savings rate = 14.4%", 14.4% less energy used vs. the baseline.
- ***Highlights which sectors contribute most to avoided energy use***, helping direct policy attention and resources.

From a more technical perspective:

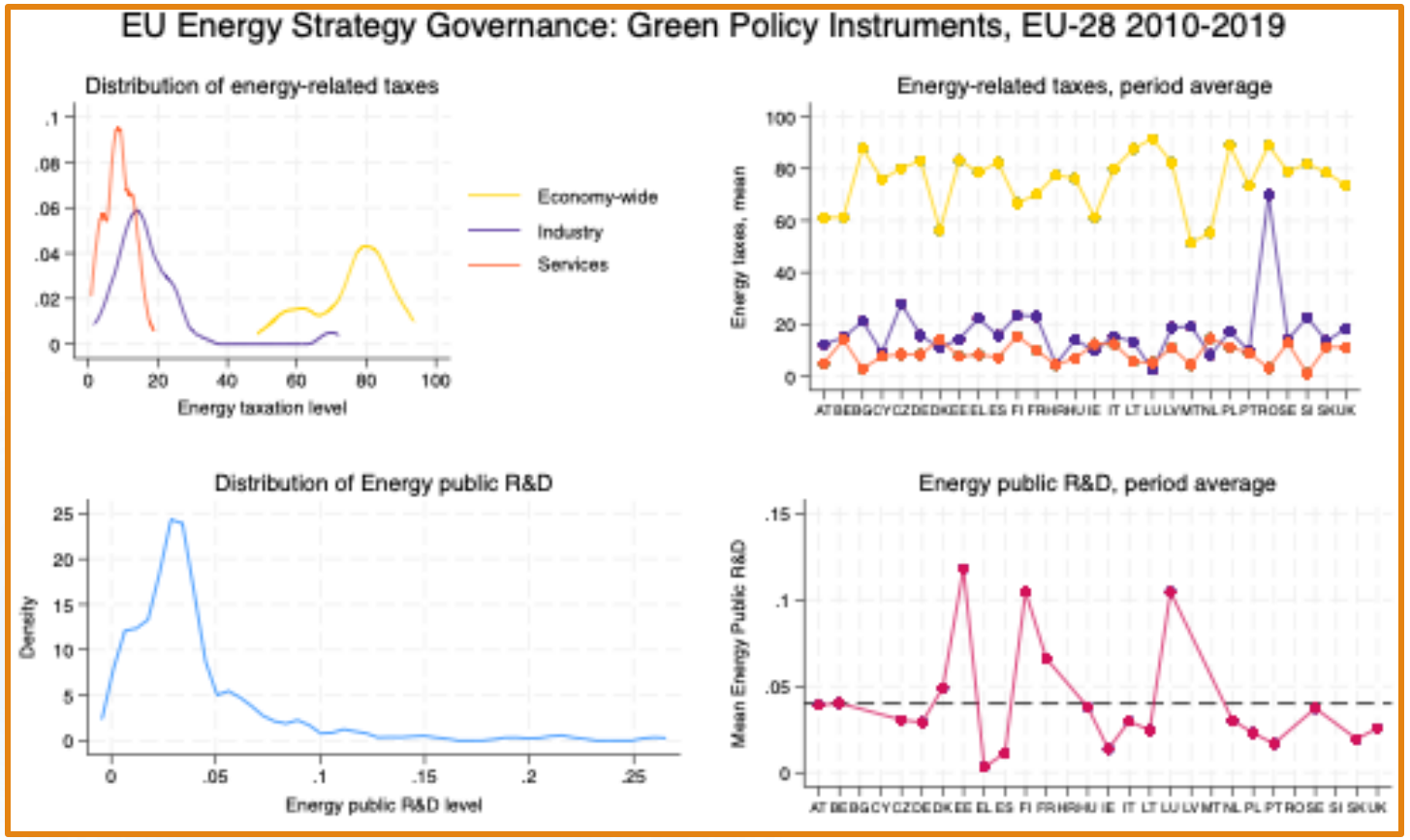
- EESR is a modeled indicator that estimates the percentage of energy avoided compared to a scenario with no efficiency improvements.
- Derived from the Energy Efficiency Index (EEI) but not linearly related.
- Based on modeled counterfactuals, not just observed consumption, includes both behavioral and structural effects.

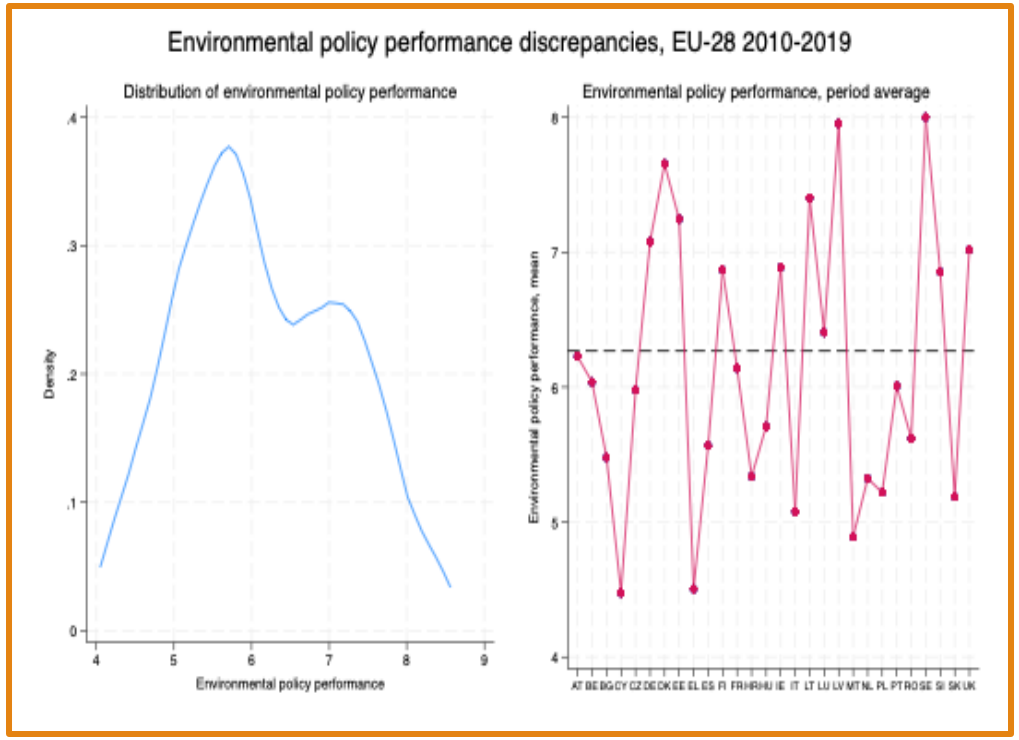
Charting energy transition graphically: EEG & EESR



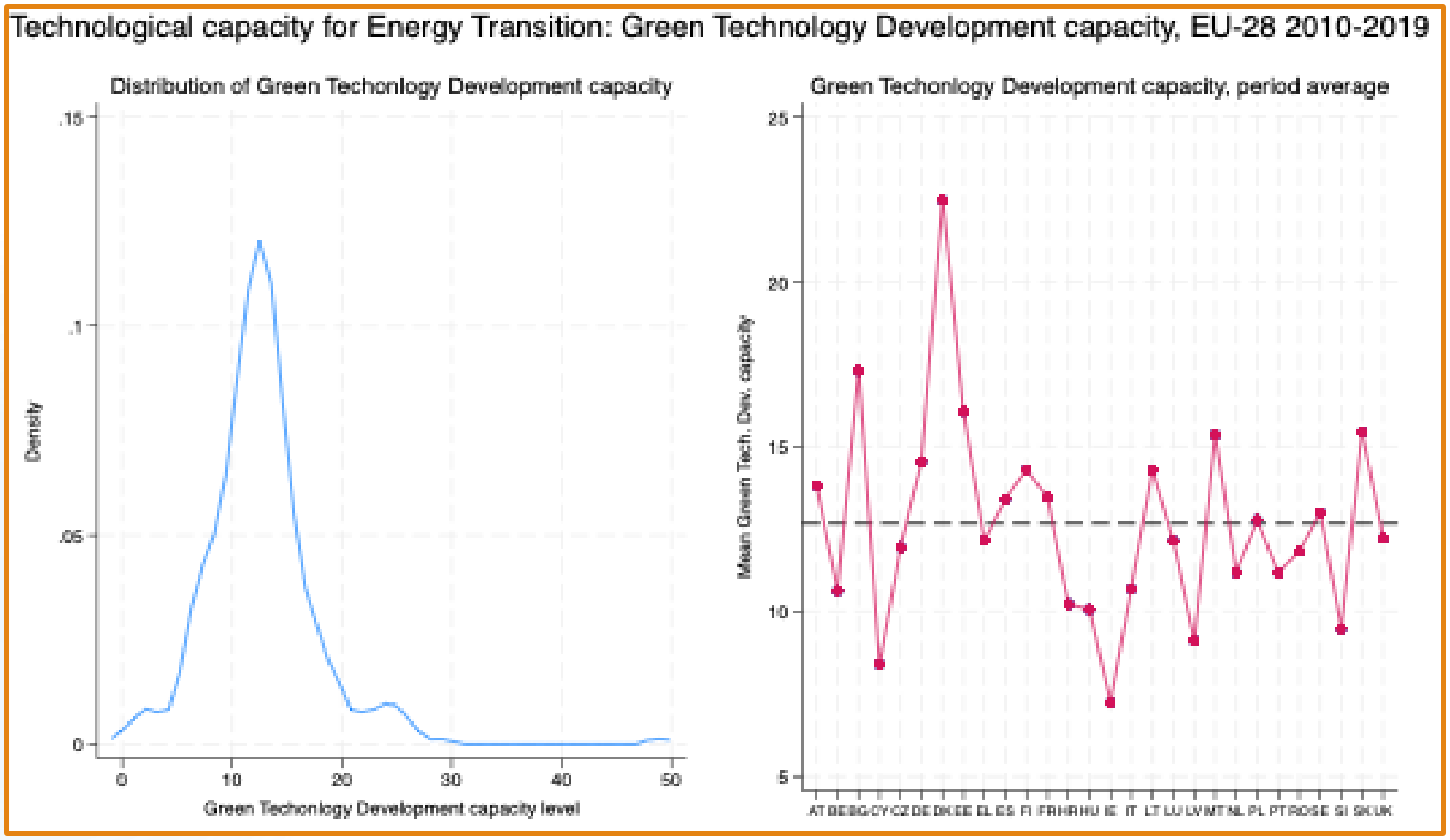


Green policy discrepancies





Green technology capacity asymmetries



Estimation results – Main model, *EEG*

Dependent variable: Energy Efficiency Gains, economy-wide – IV framework									
Contributors	**Main model**			Policy model			Lagged Policy & Technology model		
EU strategy governance: Green Policy Action	**Q25**	**Q50**	**Q75**	Q25	Q50	Q75	Q25	Q50	Q75
Energy related tax revenue	-0.191*** (0.011)	-0.003 (0.005)	0.160*** (0.003)	-0.351*** (0.041)	-0.055** (0.022)	0.159*** (0.004)	-0.361*** (0.022)	-0.169*** (0.019)	0.254*** (0.027)
Environmental public R&D	0.797*** (0.067)	0.747*** (0.034)	0.207*** (0.006)	0.915** (0.370)	1.128*** (0.045)	0.381*** (0.022)	1.253*** (0.178)	1.567*** (0.074)	-0.146 (0.101)
Environmental policy effectiveness	-	-	-	1.776 (0.315)	0.773*** (0.095)	-0.897*** (0.078)	2.034*** (0.272)	0.423*** (0.057)	-1.214*** (0.271)
Technology Capacity for energy transition									
Green Technology Development	-0.465*** (0.024)	-0.577*** (0.017)	-0.223*** (0.009)	-0.621*** (0.070)	-0.320*** (0.040)	-0.098*** (0.033)	-0.458*** (0.111)	-0.227*** (0.039)	-0.540*** (0.101)
Controls									
Renewable energy use	0.037*** (0.011)	-0.043*** (0.004)	-0.139*** (0.005)	-0.268*** (0.045)	-0.074*** (0.010)	0.064*** (0.020)	-0.087*** (0.024)	-0.084*** (0.008)	0.162*** (0.042)
Competitiveness	1.353*** (0.090)	1.163*** (0.115)	0.855*** (0.017)	0.337 (0.483)	0.744*** (0.071)	1.066*** (0.113)	-1.261*** (1.201)	0.379** (0.150)	-0.143 (0.408)
Economy structure	-0.437*** (0.107)	-0.478*** (0.047)	-1.708*** (0.025)	-1.811*** (0.219)	0.201 (0.262)	-1.698*** (0.072)	-0.339*** (0.408)	-0.395*** (0.067)	-1.557*** (0.175)
Observations		237			143			120	
Notes: (i) coefficients and robust standard errors in parentheses, (ii) stars indicate statistical significance at 1% "*", 5% "**", 10% "*".**									

Estimation results – Policy model, *EEG*

Dependent variable: Energy Efficiency Gains, economy-wide – IV framework									
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Robustness – Policy & Technology diffusion model

Dependent variable: Energy Efficiency Gains, economy-wide – IV framework									
Contributors	Main model			Policy model			Lagged Policy & Technology model		
EU strategy governance: Green Policy Action	Q25	Q50	Q75	Q25	Q50	Q75	**Q25**	**Q50**	**Q75**
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Environmental public R&D	0.797*** (0.067)	0.747*** (0.034)	0.207*** (0.006)	0.915** (0.370)	1.128*** (0.045)	0.381*** (0.022)	1.253*** (0.178)	1.567*** (0.074)	-0.146 (0.101)
Environmental policy effectiveness	-	-	-	1.776 (0.315)	0.773*** (0.095)	-0.897*** (0.078)	2.034*** (0.272)	0.423*** (0.057)	-1.214*** (0.271)
Technology Capacity for energy transition									
Green Technology Development	-0.465*** (0.024)	-0.577*** (0.017)	-0.223*** (0.009)	-0.621*** (0.070)	-0.320*** (0.040)	-0.098*** (0.033)	-0.458*** (0.111)	-0.227*** (0.039)	-0.540*** (0.101)
Controls									
Renewable energy use	0.037*** (0.011)	-0.043*** (0.004)	-0.139*** (0.005)	-0.268*** (0.045)	-0.074*** (0.010)	0.064*** (0.020)	-0.087*** (0.024)	-0.084*** (0.008)	0.162*** (0.042)
Competitiveness	1.353*** (0.090)	1.163*** (0.115)	0.855*** (0.017)	0.337 (0.483)	0.744*** (0.071)	1.066*** (0.113)	-1.261*** (1.201)	0.379** (0.150)	-0.143 (0.408)
Economy structure	-0.437*** (0.107)	-0.478*** (0.047)	-1.708*** (0.025)	-1.811*** (0.219)	0.201 (0.262)	-1.698*** (0.072)	-0.339*** (0.408)	-0.395*** (0.067)	-1.557*** (0.175)
Observations		237			143			120	
Notes: (i) coefficients and robust standard errors in parentheses, (ii) stars indicate statistical significance at 1% "*", 5% "**", 10% "*".**									

Estimation results – Sectoral insights, *EESR*

Dependent variable: Energy Savings Rate, Sectors & economy-wide – IV framework									
Aggegation level	**Industry**			**Services**			**Economy-wide**		
EU strategy governance: Green Policy Action	**Q25**	**Q50**	**Q75**	**Q25**	**Q50**	**Q75**	**Q25**	**Q50**	**Q75**
Energy related tax revenue	-0.209*** (0.006)	-0.086*** (0.003)	0.083*** (0.012)	-1.240*** (0.030)	-2.201*** (0.010)	-1.962*** (0.086)	-0.075*** (0.023)	0.044** (0.018)	0.123*** (0.002)
Environmental public R&D	2.540*** (0.053)	2.405*** (0.011)	2.605*** (0.148)	-1.309*** (0.090)	-1.378*** (0.008)	-1.864*** (0.070)	1.454*** (0.083)	1.548*** (0.041)	0.971*** (0.009)
Technology Capacity for energy transition									
Green Technology Development	-1.601*** (0.068)	-0.663*** (0.007)	0.295*** (0.046)	0.298*** (0.033)	-0.041*** (0.004)	-1.148*** (0.121)	-0.548*** (0.037)	-0.498*** (0.009)	-0.398*** (0.004)
Controls									
Renewable energy use	-0.345*** (0.015)	-0.369*** (0.002)	-0.480*** (0.024)	0.111*** (0.016)	-0.121*** (0.002)	0.168*** (0.037)	-0.050*** (0.011)	-0.102*** (0.038)	-0.027*** (0.002)
Competitiveness	-1.011*** (0.155)	0.051 (0.053)	-1.912*** (0.380)	2.292*** (0.353)	3.713*** (0.013)	3.640*** (0.222)	1.249*** (0.324)	0.461*** (0.180)	0.883*** (0.015)
Economy structure	0.313*** (0.118)	0.377*** (0.024)	2.025*** (0.076)	4.959*** (0.170)	2.479*** (0.014)	1.402*** (0.408)	-0.441*** (0.065)	-0.383** (0.108)	0.112*** (0.013)
Observations	237			143			120		
Notes: (i) coefficients and robust standard errors in parentheses, (ii) stars indicate statistical significance at 1% "*", 5% "**", 10% "*".**									

Robustness – Policy & Technology diffusion model Sectoral insights, *EESR*

Dependent variable: Energy Savings Rate, Sectors & economy-wide – IV framework									
Aggegation level	**Industry**			**Services**			**Economy-wide**		
EU strategy governance: Green Policy Action	**Q25**	**Q50**	**Q75**	**Q25**	**Q50**	**Q75**	**Q25**	**Q50**	**Q75**
Energy related tax revenue	-0.564*** (0.023)	0.282*** (0.018)	0.116*** (0.016)	-1.459*** (0.051)	-3.598*** (0.336)	-2.368*** (0.115)	-0.131*** (0.018)	-0.006 (0.005)	0.250*** (0.026)
Environmental public R&D	2.295*** (0.374)	2.525*** (0.149)	2.440*** (0.119)	-1.555*** (0.052)	3.016** (1.223)	-4.190*** (0.135)	1.442*** (0.067)	1.118*** (0.051)	-0.229 (0.171)
Environmental policy effectiveness	1.628*** (0.436)	3.650*** (0.217)	3.530*** (0.239)	0.690*** (0.128)	5.351*** (0.755)	4.227*** (0.250)	0.723*** (0.074)	0.606*** (0.031)	1.198*** (0.196)
Technology Capacity for energy transition									
Green Technology Development	-1.671*** (0.065)	-0.029 (0.142)	0.204*** (0.070)	0.034 (0.059)	1.098*** (0.255)	-0.419*** (0.088)	-0.665*** (0.011)	-0.598*** (0.010)	-0.922*** (0.082)
Controls									
Renewable energy use	-0.401*** (0.024)	-0.941*** (0.017)	-0.607*** (0.016)	-0.156*** (0.009)	0.054 (0.164)	-0.440*** (0.043)	-0.118*** (0.011)	-0.216*** (0.004)	-0.121*** (0.022)
Competitiveness	0.229 (1.402)	1.311*** (0.159)	-0.403 (0.319)	0.953*** (0.797)	0.779 (1.645)	1.427*** (0.223)	0.145 (0.099)	-0.210** (0.093)	-1.252*** (0.272)
Economy structure	0.562 (0.367)	1.855*** (0.250)	1.576*** (0.148)	3.686*** (0.151)	4.868*** (0.801)	-1.950*** (0.234)	0.309** (0.146)	-0.760*** (0.055)	-1.210*** (0.155)
Observations		237			143			120	
Notes: (i) coefficients and robust standard errors in parentheses, (ii) stars indicate statistical significance at 1% "*",5% "**", 10% "*".**									

Discussion of preliminary results

- ***Energy Taxation*** shows tier-specific effects on EEG:
  - Negative for low-performing countries (Q25),
  - No significant effect at the median (Q50),
  - Positive only for top-tier countries (Q75),

Reflecting differences in institutional capacity, energy dependency, and innovation readiness.

- ***Energy Public R&D*** *positively influences EEG across all tiers*, supporting the role of public innovation investment in promoting efficiency.

- ***Green Technology Independence*** has a *negative impact on EEG across tiers*:
  - Suggests lock-in effects and reduced access to superior foreign technologies.
  - Raises concerns over market fragmentation and techno-nationalism hindering innovation diffusion.

- ***Environmental Policy Effectiveness*** *has* ***mixed impacts***:
  - Positive effect at the median tier (Q50), but not at the top tier (Q75),
  - Flexible, well-integrated policies appear more effective, while rigid frameworks may stifle private-sector responsiveness.

Robustness checks using lagged policy and technology variables ***confirm results***, accounting for potential diffusion and endogeneity within the EU-28.

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Thank you!

ΠΡΟΓΡΑΜΜΑ "ΜΕΔΙΚΟΣ"
Ενίσχυση Νεοδιοριζόμενων Μελών ΔΕΠ

Research project **GR.E.A.T.**: **GR**een **GR**owth and **E**nergy **E**fficiency for **A**ll **T**iers of Performance: Decision Making and Policy Implications to Chart Energy Transition.
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