When Digitalisation Becomes Green: Institutional Capacity and Energy Efficiency Gains in European Economies

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Abstract

Digitalisation is often associated with the promise of a greener and more efficient economy, yet the evidence developed here points to a more conditional mechanism. Internet use alone does not emerge as a stable driver of energy efficiency gains, while its interaction with government effectiveness remains positive across the main empirical specifications. The strongest pattern appears in countries with higher institutional capacity, where digital diffusion is more closely connected with faster reductions in energy intensity. This finding changes the interpretation of the digital-green transition: technology adoption becomes environmentally meaningful only when institutions can translate digital tools into coordinated economic, productive and policy adjustments. Investment, trade openness and environmental tax revenues also contribute to the explanation, confirming that energy efficiency gains depend on a wider structural environment rather than on digitalisation in isolation. The central contribution lies in showing that digitalisation is not automatically green; its relevance for energy efficiency increases when institutional capacity supports implementation, coordination and the practical conversion of technological diffusion into measurable efficiency gains.

Keywords: *Digitalisation; Energy efficiency; Institutional capacity; Government effectiveness; European economies*.

JEL classification: C23; O33; O43; Q43; Q48

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1. Introduction

Europe's shift to a low-carbon economy now turns on whether environmental targets and technological change can be pursued together. Because the European Green Deal places economic transformation at the centre of the decarbonization

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agenda, climate neutrality and structural modernization are no longer treated as separate policy priorities (European Commission, 2019). The twin transition framework extends this logic by tying the green and digital agendas together, while also making clear that their interaction rests on sectoral capacity, governance arrangements and how well institutions coordinate change over the long run (Muench et al., 2022).

Digitalisation is one of the clearest channels through which European economies reorganize production, consumption, communication and public administration. The EU digital strategy treats digital technologies as instruments for competitiveness and sustainable modernization, yet that ambition does not by itself settle the environmental consequences of digital expansion (European Commission, 2020; Georgescu et. al 2025). Digital transformation reshapes how value is created, working through data, connectivity and platform-based coordination, but the results depend on whether organizations adapt and manage the structural change that follows (Vial, 2019; Pricopoaia et al. 2024). The distinction between digitization, digitalization and digital transformation still matters, because adopting a technology does not on its own produce wider economic or environmental effects (Verhoef et al., 2021).

Whether digitalisation helps or harms the environment is not settled, because digital technologies can raise efficiency while also pushing energy demand upward through infrastructure, device use, data centres and rebound effects. The link between digitalisation and energy consumption therefore runs in more than one direction: efficiency gains can be cancelled out by the extra demand that digital services and faster growth generate (Lange et al., 2020). Estimates of the climate footprint of information and communication technologies confirm that the sector carries its own material and energy costs, so technological optimism is a weak analytical starting point (Freitag et al., 2021). Evidence from emerging economies points the same way, showing that ICT diffusion can raise electricity consumption depending on the structure of the economy and how intensively digital tools are adopted (Sadorsky, 2012).

Energy efficiency is a sharper empirical entry point than total emissions, because it measures how much energy is needed to produce a unit of output. Work in this field has long shown that technical potential does not automatically become realized efficiency, particularly where investment barriers, poor information and behavioural constraints persist (Gillingham et al., 2009). The energy efficiency gap literature makes a related point: economically worthwhile improvements often go unrealized when markets, firms or households fail to take up the solutions available to them (Allcott, Greenstone, 2012). Environmental regulation and competitiveness can also work through innovation, so policy design helps decide whether environmental constraints turn into a source of adaptation rather than a pure cost (Porter, van der Linde, 1995).

Research on the digital-green nexus in Europe has moved toward a conditional relationship rather than a uniform effect of digitalisation on sustainability. For European countries, digitalisation can be associated with energy productivity growth, but how strong that association is depends on the way digital capabilities meet institutional and policy conditions (Benedetti et al., 2023). Earlier scenario-based work reached a similar verdict: ICT may lower carbon intensity over time, though the aggregate effect stays small without broader structural and policy change (Moyer, Hughes, 2012). This is what makes the European setting useful, since its countries share a common policy frame yet differ widely in institutional capacity, economic structure and digital maturity.

Institutional capacity is the layer that helps explain why digitalisation yields stronger efficiency gains in some countries than in others. Institutions shape development through coordination, credibility, investment incentives and policy implementation, and these channels determine how far technological change turns into measurable economic outcomes (Rodrik et al., 2004). Government effectiveness matters here because it captures the quality of public services and of policy formulation and implementation, the very capacities that convert digital diffusion into practical efficiency gains, including through instruments such as green bonds (Hoinaru et al., 2020). Work on digital transformation at the EU level reinforces the point: digital capacity rests not only on infrastructure but on research activity, institutional support and the wider ecosystem that absorbs digital technologies (Cetulean, 2023).

The contribution here is to treat digitalisation as an institutionally conditioned mechanism rather than an independent driver of energy efficiency. Instead of asking whether digitalisation is green in general, the analysis asks under what conditions digital diffusion comes with faster reductions in energy intensity. Putting government effectiveness at the centre lets the digitalisation-efficiency relationship be read through the ability of public institutions to support coordination, implementation and adjustment. This adds to the twin transition literature by connecting digital adoption, institutional quality and energy efficiency within a single European panel.

The paper proceeds as follows. The Literature review sets out the main conceptual and empirical debates on digitalisation, institutional capacity and energy efficiency. The Methodology describes the data, the variables and the empirical strategy. The Results report the econometric estimates and the robustness checks. The Discussion reads those results against the wider digital-green transition, and the Conclusions draw together the implications, the limitations and the directions for further work.

2. Literature review

Digitalisation has long been studied as a source of productivity and organizational change, but the literature now treats its effects as dependent on complementary capabilities rather than as a direct technological outcome. Information technology delivers stronger performance when it comes with organizational change, intangible investment and new managerial practices (Brynjolfsson, Hitt, 2000). Evidence from multinational firms tells a similar story:

digital technologies become more productive inside stronger management systems, which helps explain why the same infrastructure produces different results across countries (Bloom et al., 2012). At the macroeconomic level, ICT diffusion has been linked to growth through innovation and better information flows, yet those channels still depend on whether firms, households and institutions can use the technology well (Vu, 2011).

Cross-country studies of ICT and economic performance offer a useful backdrop, because they show that technological diffusion does not behave the same way in every development context. ICT capital contributes to growth in developed, emerging and developing economies alike, but the size of that contribution depends on absorptive capacity and structural conditions (Niebel, 2018). Work on the European and regional dimensions of digital transformation adds that digital dynamics follow territorial differences, research capacity and institutional ecosystems rather than infrastructure alone (Cetulean, 2025). Taken together, this evidence treats digitalisation as a mediated process, not as a uniform input with the same effect everywhere.

The energy implications of ICT are contested, because digital technologies can cut some forms of energy demand while adding to others. For OECD countries, ICT capital is associated with lower total energy demand, though the effect differs by energy type and is stronger for non-electric energy than for electricity (Schulte et al., 2016). A separate OECD panel reaches a different result, finding that ICT use and growth raise electricity consumption in both the short and the long run, which unsettles any assumption that digitalisation automatically eases energy pressure (Salahuddin, Alam, 2016). Country evidence from Japan is more moderate, suggesting that ICT investment can reduce energy consumption without producing strong growth effects (Ishida, 2015). These conflicting findings are precisely why energy efficiency, rather than energy consumption alone, is the cleaner outcome for judging the environmental relevance of digitalisation.

ICT has a double effect that the environmental literature keeps returning to: digital technologies can make systems more efficient, yet they carry their own material and energy footprint. Global evidence describes a nonlinear link between ICT and carbon emissions, in which the early stages of ICT expansion add environmental pressure before efficiency-enhancing applications become visible (Higón et al., 2017). Estimates of the sector's global emissions footprint show that devices, data centres and communication networks impose substantial costs across both production and use (Belkhir, Elmeligi, 2018). Footprint assessments of the ICT and entertainment-media sectors confirm that digital expansion cannot be separated from electricity demand, embodied energy and infrastructure (Malmodin, Lundén, 2018). The digital-green relationship therefore calls for empirical designs that pin down when efficiency effects outweigh the added energy burden.

Research on energy digitalisation takes a more operational view, asking how digital tools change monitoring, optimization and system responsiveness. Regional data from China show positive effects of digitalisation on energy efficiency, working through infrastructure, participation, information channels and technological pathways (Niu et al., 2022). Broader work treats artificial intelligence, digital twins, smart platforms and connected systems as instruments that can improve efficiency and reliability, while flagging barriers tied to cost, interoperability, governance and implementation capacity (Olabi et al., 2023). Both fit the expectation tested here: digitalisation can support efficiency gains, but only where complementary institutional and organizational conditions let digital tools change how energy is actually used.

The energy efficiency literature explains why a technology being available does not guarantee measurable improvement. The energy-efficiency gap is the distance between the gains that are technically or economically available and those that firms, households or economies actually realize (Jaffe, Stavins, 1994). Innovation responds to energy prices and to accumulated knowledge, so incentives and technological learning steer the direction of energy-saving change over time (Popp, 2002). Cross-country evidence shows that energy efficiency varies with productivity, structural characteristics and convergence dynamics, which makes energy intensity a workable indicator for studying that variation (Stern, 2012). Decomposition work across OECD economies adds that movements in energy intensity owe more to structural change and within-sector convergence than to any single technological factor (Mulder, de Groot, 2012).

Institutional explanations add a further layer, centred on the ability to coordinate, implement and sustain structural adjustment. Long-run development research shows that institutional quality shapes investment incentives, economic organization and the credibility of rules, with lasting effects on performance (Acemoglu et al., 2001). The concept of social infrastructure ties output differences across countries to the institutions and policies that govern accumulation, productivity and resource allocation (Hall, Jones, 1999). Governance quality has likewise been linked to whether economic growth translates into broader social and developmental outcomes, which speaks to why similar technological resources yield different efficiency effects (Vargas et al., 2022; Marin, et. al, 2013). State capability research goes further, warning that implementation capacity cannot be inferred from formal policy adoption, since governments differ markedly in their ability to solve practical coordination problems (Andrews et al., 2017).

One gap remains: digitalisation, institutional capacity and energy efficiency have rarely been brought into the same European empirical framework. Existing work has looked at ICT and energy demand, ICT and emissions, digital transformation and productivity, or institutions and development, but few studies ask whether digitalisation becomes more closely tied to lower energy intensity when government effectiveness is higher. The gap addressed here is not the general link between digitalisation and sustainability, but the conditional mechanism through which institutional capacity may strengthen the conversion of digital diffusion into measurable efficiency gains across European economies.

3. Methodology

The empirical design asks under what conditions digitalisation comes with faster gains in energy efficiency across European economies. Digital diffusion is not treated as an automatic environmental mechanism, since turning technological adoption into lower energy intensity depends on institutional quality, investment patterns, economic openness and policy conditions. A panel structure was chosen because repeated observations on the same countries let the estimation absorb persistent national characteristics while controlling for shocks shared by all countries in a given year, an approach widely used in applied panel econometrics when unobserved heterogeneity may affect the relationship between the explanatory variables and the dependent variable (Baltagi, 2021; Wooldridge, 2010).

The dataset was assembled from Eurostat and World Bank sources and covers 27 European countries from 2002 to 2023. Processing and estimation were carried out in RStudio Version 2024.12.1+563. The final data include energy intensity, individuals using the internet, GDP per capita, gross fixed capital formation, trade openness, government effectiveness, unemployment and environmental tax revenues. Country-year observations were harmonized, variables were converted to numeric form where needed, duplicated country-year values were averaged, and the estimation sample retained the complete observations for the variables entering each specification.

Energy efficiency was measured as the annual change in the logarithm of energy intensity. Since a lower energy intensity means energy is used more efficiently relative to output, the dependent variable was built so that positive values stand for faster reductions in energy intensity. This makes the estimates easier to read: the coefficients describe changes in the annual pace of efficiency improvement, not changes in the level of energy intensity.

$$\Delta\ln(\mathrm{EI}_{it}) = 100 \times \left[\ln(\mathrm{EI}_{it}) - \ln(\mathrm{EI}_{i,t-1})\right]$$
$$\mathrm{EEG}_{it} = -\Delta\ln(\mathrm{EI}_{it})$$

where EI_{it} denotes energy intensity in country i and year t, while EEG_{it} denotes the annual energy efficiency gain. A higher value of EEG_{it} corresponds to a stronger reduction in energy intensity. Logarithmic transformations are commonly used in empirical panel models when the analytical interest concerns proportional changes rather than absolute differences (Wooldridge, 2010).

Digitalisation was measured by the share of individuals using the internet, and institutional capacity by government effectiveness. The explanatory variables were standardized so that indicators on different scales could be compared and so that the interaction effects could be read clearly. Standardization lets the marginal effect of digitalisation be evaluated at low, average and high levels of institutional capacity without depending on the original units of each indicator.

$$Z_{it} = \frac{X_{it} - \bar{X}}{s_X}$$

where Z_{it} represents the standardized value of variable X, $\bar{X}$ is the sample mean, and s_X is the sample standard deviation. The same procedure was applied to internet use, GDP per capita, gross fixed capital formation, trade, government effectiveness, unemployment and environmental tax revenues.

The main research question is this: under what institutional conditions does digitalisation become associated with faster reductions in energy intensity across European countries? The question allows for the possibility that digital diffusion yields efficiency gains only when institutions help convert technological use into organizational, productive and policy adjustments. Three hypotheses guide the empirical design:

H1: Digitalisation is associated with stronger energy efficiency gains in countries with higher institutional capacity.
H2: The relationship between digitalisation and energy efficiency is not uniform across European countries, because governance conditions shape the conversion of technological diffusion into measurable efficiency gains.
H3: The conditional relationship between digitalisation and energy efficiency remains relevant after accounting for investment, economic openness, labour market conditions and environmental taxation.

The preferred specification is a two-way fixed-effects panel model with country and year effects entered together. Country fixed effects absorb time-invariant national characteristics such as geography, long-term industrial structure, historical energy systems and persistent institutional traits. Year fixed effects absorb shocks common to all countries in a period, including energy market disruptions, European policy changes and macroeconomic cycles. Fixed-effects estimation suits this setting because unobserved country characteristics may correlate with the explanatory variables, and leaving that heterogeneity in would weaken the credibility of the estimates.

$$\begin{aligned} EEG_{it} = \alpha_i + \lambda_t + \beta_1 DIG_{i,t-1} + \beta_2 GOV_{i,t-1} + \beta_3\left(DIG_{i,t-1} \times GOV_{i,t-1}\right) \\ + \gamma' X_{i,t-1} + \varepsilon_{it} \end{aligned}$$

where $DIG_{i,t-1}$ denotes lagged standardized internet use, $GOV_{i,t-1}$ denotes lagged standardized government effectiveness, $DIG_{i,t-1} \times GOV_{i,t-1}$ captures the institutional conditioning of digitalisation, $X_{i,t-1}$ is the vector of control variables, α_i represents country fixed effects, λ_t represents year fixed effects, and ε_{it} is the error term. Lagged explanatory variables were used to reduce simultaneity concerns and to impose a clearer temporal ordering between digitalisation, institutional conditions and subsequent changes in energy intensity.

The coefficient of primary interest sits on the interaction between lagged internet use and lagged government effectiveness. A positive interaction means the link between digitalisation and energy efficiency strengthens as institutional capacity rises. Because an interaction coefficient needs interpretation beyond its sign and significance, marginal effects were computed at three levels of institutional capacity: one standard deviation below the mean, the sample mean and one standard deviation above the mean.

$$\frac{\partial \mathrm{EEG_{it}}}{\partial \mathrm{DIG_{i,t-1}}} = \beta_1 + \beta_3 \mathrm{GOV_{i,t-1}}$$

Computing marginal effects this way separates the estimated association between digitalisation and energy efficiency across weaker, average and stronger institutional environments. The distinction matters because the argument is about conditionality, not about a single average effect of digitalisation that holds for every country.

Several robustness checks test whether the central result is sensitive to specification and error structure. The dependent variable was winsorized to see whether the preferred estimate is driven by extreme annual changes in energy intensity. An alternative interaction between digitalisation and environmental tax revenues was estimated to check whether policy conditions open a further channel from digitalisation to efficiency gains. The institutional model was also re-estimated without GDP per capita, since government effectiveness and economic development are often closely correlated, which can blur the institutional coefficients. Driscoll-Kraay standard errors were applied to guard against cross-sectional dependence and serial correlation in the panel (Driscoll, Kraay, 1998; Stock, Watson, 2008). Finally, a leave-one-country-out procedure re-estimated the preferred model dropping each country in turn, so the stability of the interaction coefficient could be judged across the sample.

4. Results

The results place the digitalisation-efficiency relationship inside a conditional institutional frame rather than a simple diffusion mechanism. Internet use on its own shows no statistically stable direct association with energy efficiency gains, whereas the interaction between digitalisation and government effectiveness stays positive across the main specifications. That pattern supports the central argument: digitalisation matters more for energy efficiency where institutional capacity helps turn technological adoption into measurable reductions in energy intensity.

Institutional conditioning of digitalisation and energy efficiency gains

Table 1

Variable	Institutional model	Winsorized specification	Specification excluding GDP per capita
Lagged Internet use	0.7485	0.7155	0.2424
Lagged government effectiveness	0.1990	0.0871	-0.2200
Internet use × Government effectiveness	0.4320.	0.4092.	0.6899***
Lagged ln(GDP per capita)	-4.8245*	-4.6984*	n/a
Lagged gross fixed capital formation	0.7688*	0.7403*	0.6938*
Lagged trade	3.0852*	2.9382*	2.5757*
Lagged unemployment	-0.1337	-0.1331	0.3824
Lagged environmental tax revenues	1.0644*	1.0403*	1.2985**

Note: . $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$.

Source: Authors' own processing.

In Table 1, the institutional model returns a positive interaction between lagged Internet use and lagged government effectiveness, with a coefficient of 0.4320 and weak support at the 10% threshold. The interaction stays positive in the winsorized specification, at 0.4092, which makes it less likely that extreme annual changes in energy intensity are driving the estimate. Dropping GDP per capita makes the interaction larger and statistically stronger, at 0.6899*. This case is telling, because government effectiveness and income move together in many European economies, and the interaction surviving the removal of GDP per capita suggests the institutional mechanism is not fully absorbed by the level of economic development.

Investment, trade openness and environmental taxation give the models additional structure. Lagged gross fixed capital formation stays positive and statistically supported across all three specifications, with coefficients between 0.6938* and 0.7688*, and trade openness is positive as well, ranging from 2.5757* to 3.0852*. Environmental tax revenues are positively associated with efficiency gains throughout, rising from 1.0403* in the winsorized model to 1.2985** once GDP per capita is excluded. So efficiency gains are not the work of digitalisation alone: investment dynamics, economic openness and environmental fiscal instruments all bear on how fast energy intensity falls.

Marginal effects of digitalisation across institutional capacity levels

Table 2

Institutional capacity level	Marginal effect	Standard error	t-value	p-value	95% CI lower bound	95% CI upper bound
Low institutional capacity	0.3165	0.4743	0.6673	0.5104	-0.6132	1.2462

Institutional capacity level	Marginal effect	Standard error	t-value	p-value	95% CI lower bound	95% CI upper bound
Average institutional capacity	0.7485	0.5044	1.4841	0.1498	-0.2400	1.7371
High institutional capacity	1.1805.	0.6143	1.9218	0.0657	-0.0235	2.3845

Note: . p < .10; * p < .05; ** p < .01; *** p < .001.

Source: Authors' own processing.

The marginal effects in Table 2 expose the institutional threshold built into the interaction. At low institutional capacity, the marginal effect of Internet use is 0.3165 with a p-value of 0.5104, giving no statistical support for a meaningful relationship. At average institutional capacity, it rises to 0.7485 but stays unsupported, with a p-value of 0.1498. At high institutional capacity, it reaches 1.1805, with weak support at the 10% threshold and a p-value of 0.0657. The effect grows steadily across the three levels, which shows the digitalisation-efficiency link tightening as government effectiveness improves.

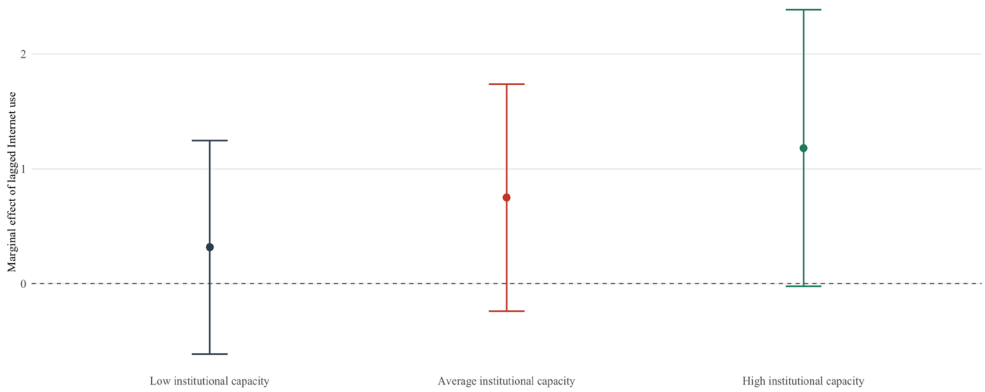

Figure 1. Marginal effect of digitalisation across institutional capacity levels

Source: Authors' own processing.

Figure 1 makes the same conditional point visually: the marginal effect of digitalisation climbs from low to high institutional capacity. The confidence intervals stay fairly wide, especially at the higher levels, so the result calls for caution. What the figure rules out is a uniform digitalisation effect across countries; the estimated effect becomes pronounced only where institutional capacity is stronger.

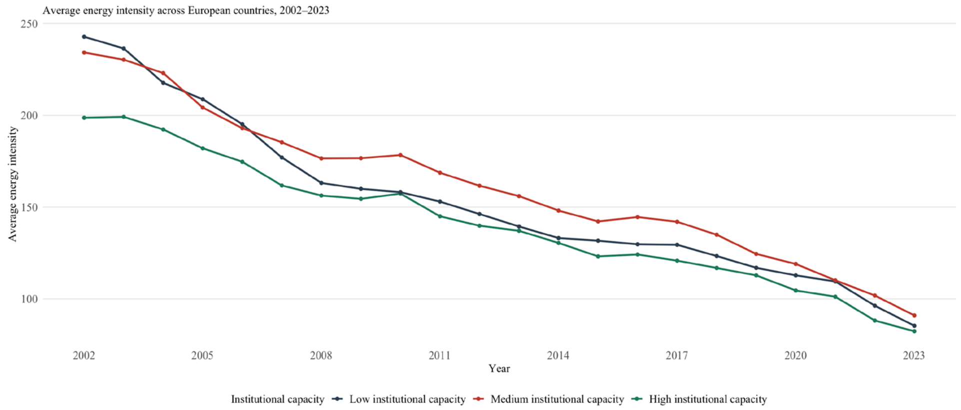

Figure 2. Energy intensity trajectories by institutional capacity group, 2002-2023
Source: Authors' own processing.

Figure 2 sets the regressions against a longer backdrop by tracing energy intensity for each institutional capacity group. All three groups show falling average energy intensity between 2002 and 2023, a general move toward more efficient energy use across European economies. The high-capacity group sits below the others for most of the period, while the medium and low groups start higher and converge only gradually. The decline is shared, but the level gaps mark out distinct long-term efficiency profiles tied to institutional environment.

Robustness checks for the digitalisation-institutional capacity interaction

Table 3

Specification	Interaction coefficient	Standard error	t-value	p-value
Institutional model	0.4320.	0.2163	1.9972	0.0564
Winsorized specification	0.4092.	0.2258	1.8122	0.0815
Specification excluding GDP per capita	0.6899***	0.1853	3.7226	0.0010
Driscoll-Kraay standard errors	0.4320	0.2559	1.6879	0.1070
Driscoll-Kraay excluding GDP per capita	0.6899**	0.2069	3.3341	0.0033
Leave-one-country-out procedure	0.3504-0.6055	n/a	n/a	n/a

Note: . p < .10; * p < .05; ** p < .01; *** p < .001.
Source: Authors' own processing.

The robustness checks in Table 3 hold the institutional interaction steady, even as the strength of the statistical signal moves around. The interaction stays positive in the institutional model (0.4320.), in the winsorized specification (0.4092.) and with GDP per capita excluded (0.6899*). Under Driscoll-Kraay standard errors the coefficient keeps its magnitude in the full model, but the p-value climbs to 0.1070, just outside the 10% threshold. With GDP per capita excluded, the Driscoll-Kraay correction still leaves the interaction supported, at 0.6899** with a p-value of

0.0033. The leave-one-country-out procedure returns only positive interaction coefficients, between 0.3504 and 0.6055, so no single country is driving the result.

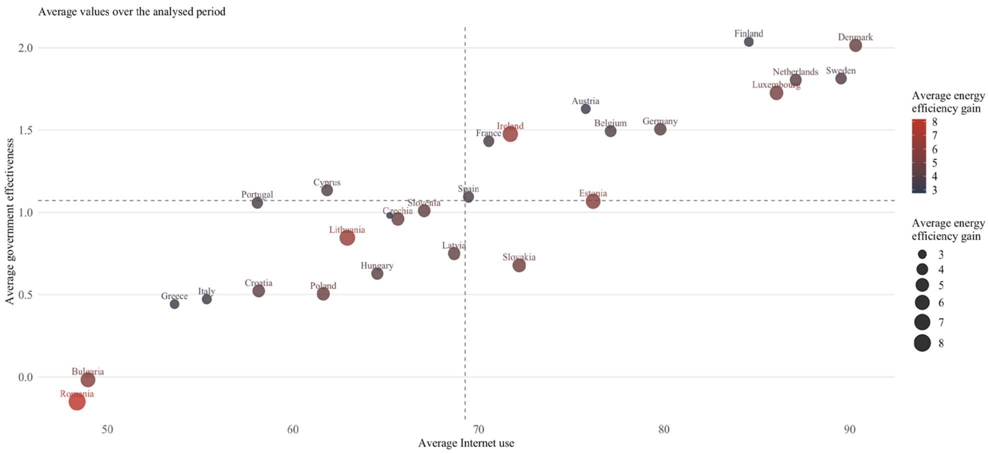

Figure 3. Digitalisation-institutional capacity positioning of European countries
Source: Authors' own processing.

Figure 3 adds a cross-country view, plotting average Internet use against average government effectiveness, with energy efficiency gains shown through point size and shading. Countries in the upper-right combine stronger digital diffusion with higher government effectiveness, while those in the lower-left tend to pair weaker institutional capacity with lower digitalisation. The spread does not mean every highly digitalised country achieves the same efficiency performance, but it does show that digital and institutional conditions matter jointly for the cross-country differences.

Taken as a whole, the evidence calls for a restrained reading of the digitalisation-efficiency relationship. Digitalisation is not an independent, uniform driver of lower energy intensity; the institutional interaction, by contrast, stays positive, holds its direction and grows stronger under higher government effectiveness. The result is at its clearest when the institutional mechanism is isolated from GDP per capita and when country influence is tested through repeated exclusions. The central message is that digitalisation connects more closely with efficiency gains where institutional capacity lets technological diffusion translate into economic and policy adjustment.

5. Discussions

The findings support the first hypothesis: digitalisation comes with stronger energy efficiency gains in countries with higher institutional capacity. The interaction between Internet use and government effectiveness shows that digital diffusion matters more where public institutions have the capacity to implement and coordinate. This fits the view that digital transformation produces economic effects only when adoption is paired with organizational and institutional adjustment, not through infrastructure expansion alone (Vial, 2019). It also matches the argument that institutional quality governs how economies turn resources, technologies and policy incentives into measurable outcomes (Rodrik et al., 2004). On this reading, digitalisation is less a direct environmental driver than a mechanism whose efficiency outcomes hinge on the governance environment around it.

The second hypothesis holds as well, since the relationship is not uniform across European countries. The marginal effects rise clearly from low to high institutional capacity, confirming that digital technologies do not deliver the same efficiency gains in every institutional setting. This aligns with evidence that ICT-energy relationships vary across countries, sectors and stages of development, with digital tools easing some energy pressures while adding to others (Salahuddin, Alam, 2016; Schulte et al., 2016). The European case sharpens the point, because its countries share a policy frame yet differ in digital maturity, institutional capacity and long-term energy profiles. That conditionality refines the twin transition narrative: the green value of digitalisation depends on the institutional capacity to turn diffusion into practical efficiency gains (Muench et al., 2022).

The third hypothesis receives partial but meaningful support, as the institutional interaction stays positive after accounting for investment, economic openness, labour market conditions and environmental taxation. The positive role of gross fixed capital formation ties efficiency gains to wider investment dynamics, while the contribution of trade openness and environmental tax revenues points to the weight of structural exposure and policy incentives. These patterns echo the energy efficiency gap literature, where technological potential goes unrealized when complementary investment, incentives or institutions are weak (Allcott, Greenstone, 2012; Jaffe, Stavins, 1994). The stronger interaction once GDP per capita is excluded also shows that government effectiveness is not just a stand-in for income, even though development and institutional quality move together. That matters, because efficiency improvements depend not only on the resources available but on the capacity to coordinate their use across firms, households and public institutions.

Several limitations qualify these findings. The estimates identify robust associations rather than strict causal effects, since the design rests on observational country-level panel data and cannot fully rule out endogeneity tied to technological adoption, institutional development or energy policy priorities. Internet use captures digital diffusion broadly, but it does not separate advanced applications, industrial digitalisation, smart energy systems or public-sector digital capacity. Government effectiveness is a useful proxy for institutional capacity, yet it cannot capture every aspect of regulatory quality, administrative learning, policy enforcement or sector-specific governance. The statistical support is also firmer in some specifications than in others, particularly once stricter error corrections are applied, which again argues for a restrained reading. Even so, the core contribution holds: digitalisation connects more closely with energy efficiency gains where institutional capacity supports the conversion of diffusion into coordinated economic and policy adjustment, a result that joins the literatures on digital transformation, energy efficiency and institutional development without treating technology as an automatic green solution (Benedetti et al., 2023; Hoinaru et al., 2020).

6. Conclusions

The evidence places digitalisation within a conditional mechanism of energy efficiency improvement rather than a linear technological story. Internet use on its own does not explain faster reductions in energy intensity, while its interaction with government effectiveness stays positive across the main specifications. That distinction is central to reading the digital-green transition, because technological diffusion seems to acquire environmental relevance only where institutions support coordination, implementation and economic adjustment.

The relationship found across European countries confirms that institutional capacity changes what digitalisation means for energy efficiency. Where government effectiveness is weaker, digital diffusion stays only loosely tied to improvements in energy intensity; where it is stronger, the association firms up. The evidence thus supports the idea that governance quality governs the capacity to turn digital technologies into practical efficiency gains, above all when public institutions can hold policy coherence, investment orientation and administrative implementation together.

Investment, trade openness and environmental tax revenues also help account for energy efficiency gains. Their positive coefficients show that digitalisation does not act alone: reductions in energy intensity depend on how technological diffusion interacts with capital formation, external exposure and environmental policy. The institutional mechanism is at its strongest once GDP per capita is excluded, which again indicates that government effectiveness is a distinct condition shaping the conversion of digitalisation into efficiency outcomes, not merely a proxy for income.

The robustness checks reinforce the central pattern without inviting an overstated causal claim. The interaction between digitalisation and institutional capacity stays positive after winsorizing the dependent variable, after applying stricter standard-error corrections and after dropping each country in turn. The statistical strength shifts across specifications, but the direction holds, which supports a cautious yet coherent reading: digitalisation is more likely to come with energy efficiency gains where institutional capacity is stronger.

The main implication is that the European twin transition cannot rest on digital expansion, infrastructure deployment or higher adoption rates alone. Energy efficiency gains require institutions able to translate digital diffusion into operational, productive and policy change. Further research could refine the picture by separating types of digital technology, sectoral energy use, public-sector digital capacity and firm-level adoption, since a country-level approach cannot fully capture the mechanisms through which digitalisation reaches energy intensity.

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