

Evaluating Renewable Energy Guarantees of Origin for Achieving European Clean Energy Targets

Haruto Nakamura ¹, Yui Tanaka ²

¹ Department of Sustainable Energy Engineering, University of Tokyo, Tokyo, Japan

² Department of Energy and Environmental Engineering, Kyoto University, Kyoto, Japan

ABSTRACT: The expansion of renewable electricity in Europe requires not only physical deployment of renewable generation but also reliable mechanisms for identifying, tracking, and communicating the renewable attributes associated with electricity. Guarantees of Origin (GOs) represent an important instrument in this context because they provide an accounting mechanism through which renewable electricity attributes can be certified and transferred. This research evaluates the relevance of GOs for achieving European clean energy targets by examining their relationship with renewable electricity accounting, consumer disclosure, additionality, market coordination, and emerging applications such as green hydrogen. The study adopts a structured analytical methodology based exclusively on the provided literature, integrating perspectives on energy attribute certificates, renewable energy certificate markets, electricity markets, greenhouse-gas accounting, renewable transport fuels, and European energy-system development. The analysis indicates that GOs can improve transparency and market-based allocation of renewable attributes, but their contribution to physical renewable deployment depends strongly on additionality, temporal and spatial matching, market design, and regulatory integration. The findings further indicate that increasing temporal resolution and coordinating certification with interconnected electricity systems can improve the credibility of renewable electricity claims. Consequently, GOs should be viewed not merely as documentation instruments but as components of a broader renewable-energy governance architecture.

KEYWORDS: Guarantees of Origin, Renewable Energy, Energy Attribute Certificates, European Energy Policy, Renewable Electricity, Additionality, Green Hydrogen, Energy Markets, Renewable Energy Targets

1. Introduction

Europe's transition toward a low-carbon energy system requires substantial growth in renewable electricity and increasingly sophisticated mechanisms for verifying the environmental attributes of energy consumption. Physical electricity flows alone cannot reveal whether a particular unit of electricity consumed by an organization or household originated from renewable generation. Certification systems therefore provide an important informational layer through which renewable attributes can be identified, transferred, and retired. Energy attribute certificates represent one such mechanism, with Guarantees of Origin being particularly relevant to European electricity markets (Bricaud, 2022).

The policy relevance of certification becomes stronger as renewable energy targets increasingly interact with corporate procurement, electricity disclosure, transport-fuel requirements, and emerging renewable hydrogen markets. European electricity

systems are also highly interconnected, meaning that renewable attributes can potentially be traded across geographical boundaries even when the physical electricity follows different network paths. The ENTSO-E transmission-system map illustrates the structural interconnectedness of European electricity networks and therefore the importance of considering network geography when evaluating certificate-based claims (Entsoe, 2023).

The central problem is that certification of renewable attributes does not automatically imply additional renewable generation. A certificate may provide evidence concerning the renewable origin of electricity, while the underlying investment decision depends on market conditions, policy incentives, and the additionality of renewable procurement. Evidence from renewable-energy certificate markets outside Europe demonstrates the importance of distinguishing attribute accounting from investment effects (Gillenwater et al., 2014; Shrimali and Tirumalachetty, 2013).

This research therefore evaluates the role of renewable-energy Guarantees of Origin in supporting European clean-energy objectives. The objectives are to examine the functional contribution of GOs, assess their relationship with renewable-energy targets, identify important limitations concerning additionality and accounting resolution, and develop an analytical framework for improving their effectiveness. Particular attention is given to the interaction between certificate systems and renewable electricity innovation, since digital economic development can influence renewable-energy innovation and consequently alter the wider market environment in which certification mechanisms operate (Yi et al., 2024).

2. Literature Review

The conceptual foundation of Guarantees of Origin can be understood through the broader category of energy attribute certificates. Bricaud describes an energy attribute certificate as a mechanism for representing specified attributes of energy production, consumption, or environmental characteristics (Bricaud, 2022). The Center for Resource Solutions similarly emphasizes the legal and accounting foundations underlying renewable energy certificates, demonstrating that certificate systems require clearly defined ownership, issuance, tracking, and retirement mechanisms (Center for Resource Solutions, 2023). These perspectives establish GOs as instruments of attribute accounting rather than substitutes for physical electricity production.

The literature also demonstrates that certificate markets operate within wider electricity-market structures. Faia et al. identify local electricity markets as an evolving component of energy-system transformation, characterized by opportunities for decentralized participation, market integration, and new forms of electricity exchange (Faia et al., 2024). Within such systems, certification can strengthen the informational dimension of renewable-energy transactions by enabling consumers to distinguish renewable attributes from undifferentiated electricity consumption.

A major theoretical issue is additionality. Gillenwater et al. examine whether voluntary renewable-energy purchases generate additional wind-energy investment, highlighting the distinction between purchasing renewable attributes and directly causing new renewable generation (Gillenwater et al., 2014). The same conceptual challenge appears in renewable-energy certificate markets in India, where Shrimali and Tirumalachetty examine market structures, implementation challenges, and the effectiveness of certificates as policy instruments (Shrimali and Tirumalachetty, 2013). These studies indicate that the

environmental value of certificate markets cannot be assessed solely by transaction volume.

The literature further demonstrates the increasing importance of temporal resolution. Blizniukova et al. show that greenhouse-gas accounting for electricity consumption can change substantially when electricity consumption is evaluated at higher temporal resolution rather than through less differentiated accounting approaches (Blizniukova et al., 2023). This insight is particularly important for GOs because annual matching may allow renewable claims that do not correspond closely to the temporal availability of renewable generation.

The European policy environment also connects renewable electricity certification with transport fuels and hydrogen. European Commission material on renewable transport fuels demonstrates the regulatory importance of renewable electricity in determining compliance with renewable-fuel requirements (European Commission, 2023). Similarly, Schmidt-Achert and Mohr discuss how renewable electricity is connected to the definition of green hydrogen under the EU delegated-act framework (Schmidt-Achert and Mohr, 2023). The International Energy Agency's net-zero roadmap reinforces the broader importance of rapidly expanding clean-energy systems to achieve long-term decarbonization objectives (International Energy Agency, 2023).

The literature therefore reveals a research gap concerning the integrated evaluation of GOs as a European clean-energy governance mechanism. Existing sources address certificates, additionality, electricity markets, accounting resolution, hydrogen, and renewable-energy innovation from different perspectives. A unified analytical framework is required to explain how these dimensions interact.

3. Methodology

3.1 Research Design

This study employs a qualitative analytical research design based exclusively on the supplied literature. The methodology combines conceptual synthesis, comparative literature analysis, and framework development. Rather than estimating a statistical causal effect, the study evaluates the functional contribution of GOs through five dimensions: attribute transparency, additionality, temporal matching, spatial integration, and policy-sector coordination.

The analytical framework can be represented as:

GO effectiveness = f (transparency, additionality, temporal matching, spatial integration, policy integration).

This formulation treats GO effectiveness as multidimensional. A certification mechanism can perform strongly in one dimension while remaining weak in another. For example, a certificate may provide clear evidence of renewable origin but have limited influence on new renewable investment if additionality is not adequately established.

3.2 Attribute Transparency

The first dimension concerns the ability of a GO system to communicate the renewable characteristics associated with electricity. Attribute certificates create a standardized informational representation that can be separated from the physical electricity commodity. This distinction is essential because electricity is continuously mixed within interconnected networks. Certification consequently addresses an information problem rather than changing the physical path of electricity.

A hypothetical European manufacturer purchasing renewable electricity illustrates this function. The electricity physically delivered to its facility may originate from a mixture of generators, while retired GOs provide an accounting basis for claiming renewable consumption. The value of the certificate therefore depends on the integrity of issuance, transfer, and retirement procedures.

3.3 Additionality

The second dimension evaluates whether certificate demand contributes to new renewable generation. Additionality is theoretically important because the purchase of an existing renewable attribute does not necessarily cause new capacity to be installed. Gillenwater et al. demonstrate why voluntary renewable-energy purchasing must be examined in relation to investment effects rather than simply procurement volumes (Gillenwater et al., 2014).

An effective European framework should therefore distinguish between certificates representing existing renewable generation and procurement arrangements explicitly designed to stimulate additional capacity. Additionality can be strengthened through long-term procurement arrangements, project-specific contracting, or market mechanisms that create stronger investment signals. However, the degree to which a certificate independently causes investment may remain difficult to isolate because renewable projects commonly receive multiple forms of market or policy support.

3.4 Temporal and Spatial Matching

Temporal matching represents a further methodological dimension. Annual renewable-energy accounting can mask differences between renewable

production and electricity consumption. Blizniukova et al. demonstrate the analytical importance of increasing temporal resolution in electricity-related greenhouse-gas accounting (Blizniukova et al., 2023). Applied to GOs, this implies that hourly or otherwise finer-grained matching could provide a more precise representation of renewable electricity consumption.

Spatial matching is similarly relevant. European electricity markets are interconnected, and the ENTSO-E transmission network demonstrates the geographical complexity of the electricity system (Entsoe, 2023). A GO system must therefore establish credible rules for determining the geographic validity of renewable attributes. Excessively broad geographical accounting may improve market liquidity but weaken the intuitive relationship between consumption and renewable generation.

3.5 Cross-Sector Policy Integration

The final methodological dimension considers the interaction of GOs with emerging renewable-energy applications. Renewable electricity increasingly contributes to hydrogen production and renewable transport fuels. European Commission requirements concerning renewable electricity in transport-fuel production demonstrate the importance of certification and verification in sectoral decarbonization (European Commission, 2023). Similarly, the treatment of renewable electricity in green-hydrogen definitions indicates that certificate-based evidence may influence whether energy inputs satisfy regulatory sustainability conditions (Schmidt-Achert and Mohr, 2023).

Digitalization may further improve the functioning of such systems. Yi et al. associate digital-economy development with renewable-energy innovation, suggesting that improved digital infrastructure can support more sophisticated information and market mechanisms (Yi et al., 2024). Digital certificate registries, automated verification, and higher-frequency energy data could therefore strengthen the operational architecture of GOs.

4. Results / Findings

The analysis identifies five principal findings concerning the contribution of GOs to European clean-energy targets. First, GOs provide substantial value as transparency and accounting instruments. Their fundamental contribution is to separate renewable attributes from the physical electricity commodity and create a traceable mechanism through which renewable consumption claims can be documented. This function becomes increasingly important as electricity markets become more interconnected and consumers demand evidence of renewable procurement.

Second, the effectiveness of GOs in promoting additional renewable capacity is conditional rather than automatic. Certificate purchases can demonstrate demand for renewable attributes, but demand does not necessarily equal additional investment. The evidence concerning voluntary renewable-energy markets shows why the relationship between certificate procurement and new generation must be evaluated separately (Gillenwater et al., 2014). Consequently, European GO policy should avoid treating certificate retirement alone as an unambiguous measure of additional renewable deployment.

Third, temporal resolution emerges as a critical factor. Traditional annual accounting can obscure the relationship between consumption and renewable generation. Higher-resolution approaches provide a more differentiated representation of when renewable electricity is produced and consumed, consistent with the accounting concerns identified by Blizniukova et al. (2023). This suggests that future GO systems could become more credible if temporal information is increasingly incorporated into procurement and reporting.

Fourth, spatial coordination is essential because Europe's electricity system crosses national and market boundaries. A certificate framework must balance geographical flexibility with the credibility of renewable claims. Excessively restrictive geographic rules may reduce liquidity and increase procurement costs, while excessively broad rules may weaken the connection between renewable generation and consumption.

Finally, the role of GOs is expanding beyond conventional electricity disclosure. Their relevance to renewable transport fuels and green hydrogen indicates that certification systems may become part of a broader cross-sector energy-accounting architecture (European Commission, 2023; Schmidt-Achert and Mohr, 2023). Digitalization and renewable-energy innovation may further increase this relevance, as technological development enables more sophisticated monitoring and verification systems (Yi et al., 2024). Overall, the findings indicate that GOs are most effective when integrated with investment incentives, accurate accounting, interconnected electricity-market governance, and sector-specific sustainability requirements.

5. Discussion

The findings position GOs as an important but inherently limited component of European renewable-energy policy. The theoretical contribution of the study is the distinction between attribute credibility and deployment additionality. Attribute credibility concerns whether a renewable claim can be accurately documented, while deployment additionality concerns

whether that claim contributes to new renewable capacity. These concepts are related but should not be treated as equivalent.

This distinction has practical consequences for European clean-energy targets. If policymakers use certificate retirement as a direct proxy for renewable deployment, they risk overstating the investment impact of the certificate market. The additionality concerns identified by Gillenwater et al. (2014) and the broader certificate-market evidence from Shrimali and Tirumalachetty (2013) support a more cautious interpretation. GOs can create demand for renewable attributes, but their contribution to physical capacity expansion depends on the surrounding policy and investment environment.

A second implication concerns accounting precision. Blizniukova et al. (2023) demonstrate that temporal resolution can materially affect electricity-related environmental accounting. Applying this principle to GOs suggests that future certification systems could increasingly emphasize temporal matching. Such an approach would make renewable consumption claims more closely aligned with actual renewable generation profiles. However, greater temporal granularity also increases data requirements, transaction complexity, and potentially procurement costs. The policy challenge is therefore to identify an appropriate balance between accounting accuracy and market accessibility.

Spatial integration creates a comparable trade-off. European electricity networks are highly interconnected, making cross-border renewable electricity markets economically rational. However, renewable claims become less intuitive if certificates can circulate without adequate consideration of system boundaries. The solution is not necessarily to eliminate geographic trading, but to establish transparent rules governing geographic eligibility and attribute transfer.

The findings also reinforce the importance of cross-sector coordination. Green hydrogen and renewable transport fuels increasingly connect electricity certification with broader decarbonization strategies (European Commission, 2023; Schmidt-Achert and Mohr, 2023). If different sectors adopt incompatible definitions or accounting mechanisms, the resulting fragmentation may reduce the credibility of renewable claims. Conversely, harmonized certification can support consistent renewable-energy accounting across electricity and emerging energy carriers.

Digital transformation provides an opportunity to address several of these limitations. The relationship between digital economic development and renewable-energy innovation identified by Yi et al. (2024) suggests that improved digital infrastructure can support more responsive energy markets. For GO systems, this could

mean automated certificate tracking, higher-frequency matching, improved data verification, and more transparent market information. Nevertheless, technological sophistication should not replace regulatory clarity; digital systems can improve measurement but cannot independently resolve questions concerning additionality or policy eligibility.

The principal limitation of this study is its qualitative and literature-based design. It does not estimate GO prices, investment elasticities, cross-border certificate flows, or the causal relationship between certificate demand and renewable capacity. In addition, the analysis is constrained to the supplied references. Future empirical research should therefore test the proposed framework using European GO transaction data, renewable-capacity additions, temporal electricity-generation data, and cross-border market indicators.

6. Conclusion

Guarantees of Origin constitute an important institutional mechanism for Europe's renewable-energy transition because they provide a standardized means of identifying, transferring, and retiring renewable electricity attributes. This study demonstrates that their contribution to European clean-energy targets extends beyond simple renewable-energy disclosure. GOs can enhance transparency, support consumer and corporate procurement, facilitate cross-border renewable-energy accounting, and increasingly interact with renewable transport fuels and green hydrogen.

However, the analysis also demonstrates that certificate ownership should not automatically be interpreted as evidence of additional renewable generation. The effectiveness of GOs depends on the surrounding market and policy architecture, particularly mechanisms addressing additionality, temporal matching, spatial credibility, and cross-sector consistency.

A more advanced GO framework should therefore combine reliable attribute tracking with increasingly precise temporal and spatial accounting. Digital infrastructure can strengthen verification and market coordination, while policy mechanisms can ensure that certificate demand is more effectively connected to new renewable investment. Such integration would transform GOs from relatively passive accounting instruments into more effective components of renewable-energy governance.

The principal research contribution is the development of a multidimensional perspective in which GO effectiveness is evaluated through transparency, additionality, temporal matching, spatial integration, and policy-sector coordination. Future

research should empirically test these dimensions across European markets and determine how alternative GO designs affect renewable investment, consumer behavior, emissions accounting, and the development of emerging renewable-energy sectors.

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