

## Green Signals? Exploring price dynamics in Europe's green energy certificate market

*Working Paper*

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**Umwelt  
Bundesamt** 

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# Agenda

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## 1 Background and Motivation

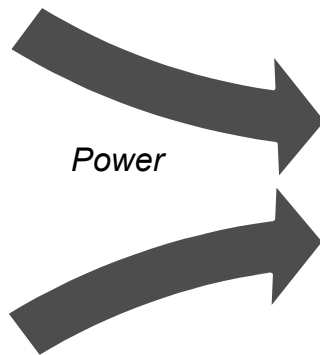
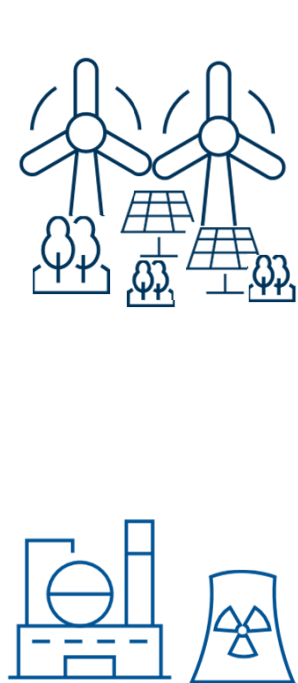
## 2 Research Question

## 3 Results

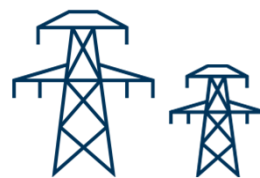


## Background: Current GO market design allows for decoupling of two markets ...

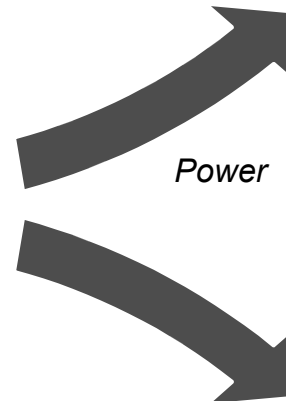
### Electricity producers



**Guarantees of Origin**  
Association of Issuing Bodies



**Electricity Market**  
Transmission System



### Electricity Consumers



With GO Purchase



Without GO Purchase

... and thus, academic literature claims that GO prices fail to reflect value of green electricity

## Dimension

## Market Design

## Criticism in literature



### Geographical decoupling

- GOs can be **freely traded** across AIB member states, independent of electricity flows
- Thus, GO “production” location, can be **geographically distant** from GO “consumption” location

- **Abundance of Nordic hydro GOs** is used in continental Europe to claim green electricity instead of local wind and solar GOs (Galzi, 2023; Hamburger, 2019; Mulder and Zoomer, 2016)
- **GOs from different technologies become perfect substitutes**, instead of being complements to regional electricity mixes (Hast et al., 2015)
- Thus, GO prices **fail to reflect locational value of green electricity**



### Temporal decoupling

- Current market design is based on “**annual volumetric matching**”
- Cumulative electricity volumes can be claimed as being “green” **within a yearly disclosure period**
- Thus, GO “production” time can be **temporally distant** from GO “consumption” time

- **Insufficient stimulation of flexible renewable investments** (Scholta and Blaschke, 2024; Xu et al., 2024) and effective grid decarbonization (Langer et al., 2024)
- Thus, GO prices **fail to reflect temporal value of green electricity**



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# Despite abundant criticism of current GO system, there is a lack of real-world price data

## Academic criticism

European GO price dynamics

GO prices fail to reflect value of green electricity due to decoupling from physical electricity flow

Dimension: Market Design, Criticism in literature, Response and Outlook

Geographical decoupling: GOs are not linked to physical electricity flow, leading to price distortions.

Temporal decoupling: GOs are not linked to time, leading to price distortions.

... also reflected in recent literature ...

Author	Journal	Focus	Main findings
Reisner et al. (2012)	Energy Policy	GOs as investment support	GOs might prevent effective investment incentives through carbon leakage, could highly depend on GO price
Müller & Ziemer (2016)	Energy Policy	Dutch GO market	Overcapacity of imported hydro GOs causes low premiums for green electricity in Netherlands
Jansen (2017)	CEPS Policy Insights	GO market characteristics	Low prices not sufficient to spur renewable investments
Hartberger (2018)	Society & Economy	GOs as policy tool	Present EU policy framework not suitable to achieve investment incentives, geographical limitations of trade
Hofstetler et al. (2019)	Energy Policy	GO market performance	GO markets characterized by low liquidity and volatile prices
Hofstetler et al. (2020)	Energy Policy	GOs as investment support	Green electricity products mainly rely on imported hydropower GOs that drive down prices
Berni (2022)	Nature Climate Change	GOs carbon accounting	GOs do not prevent additional emission reduction incentives, preventing a fair carbon accounting
Gaët (2023)	Energy Policy	French GO market	GOs used in France mainly from "old" French hydro plants, GO market mainly as cost-generating mechanism

Literature shows mainly critical assessment of current GO market mechanisms, yet mostly based on qualitative arguments and limited evidence based on price data.

## Associations and Industry initiatives criticism

AFRY

About time: How incorporating timestamped energy certificates into electricity markets could accelerate the energy transition

Member States Must Move Quickly to Enable Granular GOs

We urge EU Member States and housing Bodies to implement granular GOs in their national legislative frameworks and ensure issuance by housing Bodies in a timely fashion. A European system of granular GOs will help accelerate electricity system decarbonization by sending more accurate price signals and enable the robust verification of green hydrogen and green electricity claims. This will support and accelerate the transition to a sustainable and climate-neutral continent by 2050. By acting on global leadership in energy market reform, sustainable future. We stand ready to support transformation of energy origin trading in EU.

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- Time-based certificates
- Our vision
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- Areas of development
- Conclusion

EnergyTag

EnergyTag Whitepaper: Accelerating the transition to 24/7 clean power

“

It is “unclear to what extent certificate markets function properly” (Hulshof et al., 2019) due to lack of transparency of GO market



Do real-world price dynamics reflect criticisms of the current GO market design with regards to the geographical and temporal decoupling from electricity flows?



## Two research questions aim to assess whether criticism is reflected in GO price data

Detailed methodology available on request

Research question	Rationale	Methodology
<b>RQ1</b> <i>Does the GO market show a price premium for solar and wind GOs over hydro GOs?</i>	Testing whether <b>criticism of geographical decoupling</b> is reflected in prices: <ul style="list-style-type: none"> <li>Trade without geographical restrictions leads and <b>ability to substitute</b> (mostly Nordic) hydro with solar and wind Gos</li> <li>Thus, <b>prices across GO technologies converge</b></li> </ul>	Analysis of <b>GO price differences between technologies</b> $P_T$ (solar,wind) and hydro $P_H$ across time periods: <ul style="list-style-type: none"> <li>Absolute deviations: <math>D_a = P_T - P_H</math></li> <li>Relative deviations: <math>D_r = \frac{P_T - P_H}{P_H}</math></li> </ul>
<b>RQ2</b> <i>Does the GO market show price elasticity to energy market fluctuations?</i>	Testing whether <b>criticism of temporal decoupling</b> is reflected in prices: <ul style="list-style-type: none"> <li>Annual volumetric matching <b>reduces elasticity in response to supply and demand</b></li> <li>Thus, <b>price signals to not reflect time-value</b> of green electricity</li> </ul>	<b>VAR</b> (vector autoregressive model) to <b>analyze dynamic relationship</b> between GO prices and supply and demand proxies: <ul style="list-style-type: none"> <li><math>Y_t = \sum_{i=1}^m Z_i Y_{t-i} + e_t + c</math></li> <li>Supply and demand proxies: EU Electricity price and EU ETS prices (CO2 price) - (adapted to Schusser &amp; Jaraite, 2018, Energy Economics)</li> </ul>

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## Data deep dive: I obtained a proprietary GO price dataset from a leading market brokerage firm, allowing me to perform granular price analysis

### Raw GO price data

1	A	2	B	C	D	E	F	G	K
	transactionDateUtc		d_CY_v	hydro_CY_bio_CY_vw	solar_CY_v	ren-uns_C	ren_CY_vwap_weekly		
	03.01.2016						22,25		
	10.01.2016		26,25	14,25					
	17.01.2016						20,0459		
	24.01.2016			35,8721			35,8721		
	31.01.2016			37,5652			37,5652		

# veyt<sup>®</sup>

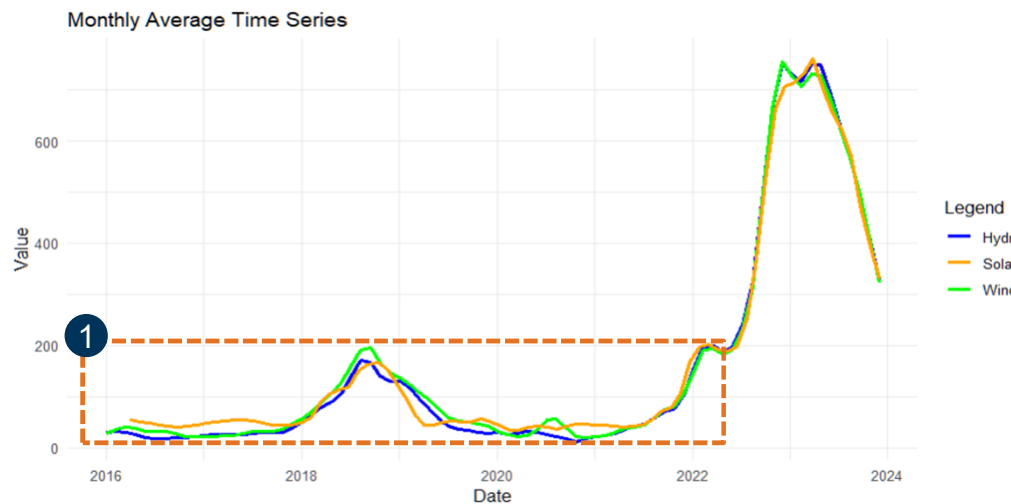
Provided by market intelligence  
firm "Veyt"

### Key Insights:

- 1 Data based on **weekly, volume-weighted average prices** in €cent/MWh base on real-world trades
- 2 Price available for **different "technologies"** (hydro, wind, solar)

*Data not intended for sharing or reuse  
without permission of the author and Veyt*

## Analysis of descriptive data shows higher average prices for solar and wind GoOs, with absolute differences decreasing over time



Plot of monthly average prices per technology in €cents/MWh

Table 5: Weekly average GoO prices per technology 2016-2023

Technology	N	Min	Max	Mean	Median	Unit
Wind	285	13.0	963.4	188.7	87.0	€cents/MWh
Solar	157	23.5	831.5	239.9	100.0	€cents/MWh
Hydro	369	10.0	970.8	164.7	55.8	€cents/MWh

Summary statistics of weekly prices per technology in €cent/MWh

SOURCE: Own results

### Key Insights

- 1 Visually, prices for solar and wind appear to be slightly higher until ~2022, converging afterwards
- 2 Average prices for wind and solar 2016-2023 higher for wind and solar compared to hydro



## RQ1: Solar and wind GOs show price premium over hydro GOs – yet not stable over time periods

### Key Insights

Solar and wind prices command a ~16-40% price premium over hydro GOs ...

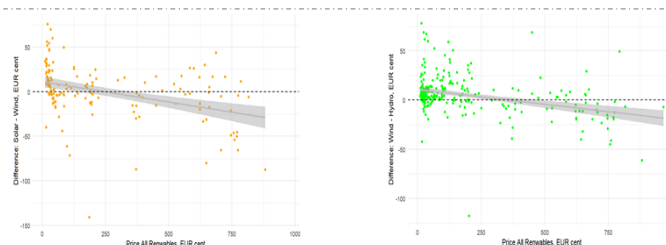
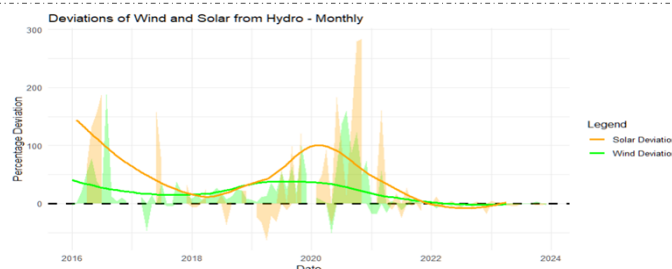
... with price **differences varying** over time ...

... tending to **converge** during times of higher prices

### Analysis

Table 6: **Relative price premia solar/wind over hydro 2016-2023**  
Table shows relative deviation of wind and solar GoO prices over hydro prices in %, for different aggregation periods

Technology	Monthly		Quarterly		Yearly	
	N	Mean	N	Mean	N	Mean
Wind	93	18.6	32	18.9	8	16.8
Solar	73	34.1	29	39.1	8	34.3



### Discussion

- Market tends to value **solar and wind GOs more than hydro GOs** based on **long-term average values**
- Yet, **premium is not constant** and tends to collapse during periods of general high prices
- GOs from different technologies function as **substitutes during times of higher prices**
- **Volatility and uncertainty around price premiums** for solar and wind could significantly dampen incentives for additional development of solar and wind assets

## RQ2: GO prices show significant lag in response to carbon price shocks

### Key Insights

To a positive shock in **electricity prices** (lower demand for GOs), GO prices react with a short negative response and lagged positive response...

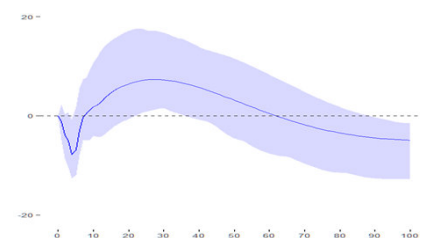
... indicating **limited price elasticity**

To a positive shock in **CO2 prices** (lower supply for GOs), GO prices react with a lagged positive response

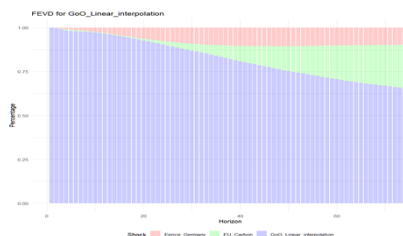
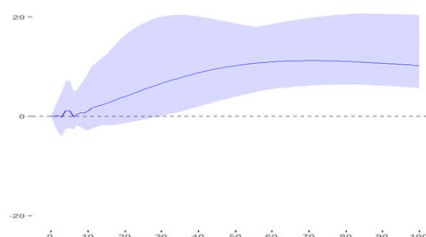
... indicating **price elasticity in the theorized direction** but with a **significantly long lag**

Both CO2 price variation and electricity price variations **influence GO price variations only marginally during first weeks**

### Analysis



*Impulse response functions for GO prices based on VAR model*



*Variance decomposition analysis*

### Discussion

- GO prices do react to movements in supply and demand proxies in **theorized direction**
- Yet, **significant lag in price reaction**, mainly to shocks in CO2 prices
- Demonstrates how **annual volumetric matching affects price signals**: Market participants do **not** need to match GO purchases with **real-time consumption**
- Thus, lagged GO prices **reduce incentives that could stimulate flexible** renewable capacities



# Forschungsüberblick: Unser Paper liefert neue empirische Evidenz für geografische und zeitliche Entkopplung von GO Preisen



## Hintergrund

- Kritik an geografischer und zeitlicher Entkopplung von HKN in Literatur
- Fehlende empirische Evidenz zur Frage, ob sich diese Kritik in realen Preisdaten widerspiegelt.
- **Ziel: Überprüfung, ob HKN-Preisdynamiken die Kritikpunkte stützen**



## Ergebnisse

- **RQ1 (geografische Entkopplung):** Solar- und Wind-HKNs zeigen im Schnitt höhere Preise als Wasser-HKNs – aber kein stabiler Preisaufschlag über die Zeit.
  - **In Hochpreisphasen fungieren Technologien als Substitute**
- **RQ2 (zeitliche Entkopplung):** HKN-Preise reagieren auf Preisschocks in Strom und CO2 Markt, aber mit signifikanter Verzögerung.
  - **Geringe kurzfristige Preiselastizität gegenüber Strom- und CO<sub>2</sub>-Märkten**
- Belegt empirisch die Schwächen des aktuellen Marktmechanismus.



## Mögliche Implikationen

- Neuer empirische Forschungsbeitrag
- **Granularere Zuordnung** (z. B. stündlich, regional) könnte Preissignale verbessern
- **Politische Entscheidungsträger sollten Reformbedarf** im HKN-Markt prüfen.
- **Marktteilnehmer könnten durch freiwillige Maßnahmen** (z. B. PPAs, lokale HKNs) Wirkung erhöhen.
- Grundlage für weitere Forschung:
  - Granularere HKN-Daten
  - Zahlungsbereitschaft für granularen Grünstrom (Stated-Choice-Studie mit >1.000 TN in Arbeit).

