BS CS thesis project: Electricity production certificates

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1 Background

Electricity production certificates [BH06] are digital certificates issued by a trusted party such as Energinet that asserts that a certain amount of electricity was produced in a certain time period in a certain electricity production plant and fed into the public electricity grid it is connected to. It may furthermore contain or be associated, by the same or another authority, with information about environmental effects in connection with this production, specifically the generation and release of a certain amount of green house gases into the atmosphere.

Production certificates virtualize fine-grained (e.g. in 15- or 60-minute intervals) sourcing of energy by a customer from specific plants that it receives through an electricity grid that connects all producers and consumers even though, physically, all electricity retrieved at any time is a mix of all electricity plants producing electricity at that time.[1] This can be accomplished by a consumer buying usually pooled (over producers and time slots) production certificates corresponding in quantity to what they withdraw from the grid. For this to be correct the total amount of production certificates for a given period must be neither more nor less than the total amount of electricity consumed from the grid in the same time period, which in turn is whatever is fed into the grid in that period minus transmission losses in the grid.[2] The latter invariant is important to avoid greenwashing by production certificates from windmills and solar cell parks overstating or overcounting what these have actually produced, with transmission losses subtracted.

Fine-grained production certificates are the basis for production futures (promises to produce electricity in the future, equipped with the corresponding certificates). Thus production certificates facilitate purchasing and trading quasi-directly sourced energy and computing a consumer's climate impact by

[1] Electricity storage providers count as both electricity consumers and producers in this setting.

[2] Production certificates cover all production, not just "green" or otherwise desirable production.

operating as an independent complement alongside a spot and next-day market for nondifferentiated electricity such as Nordpool. Being fine-grained they furthermore facilitate *ex ante* operational planning and optimization aimed at Scope 2 (energy-based) GHG emissions minimization, not just *ex post* reporting of such emissions.

2 Goals

The overall goal of this project is to formalize and design automated issuance, accounting (who produced them, who used them, that is matching against energy consumption), pooling, transfer and trading of electricity production certificates.

Specific objectives are:

- Identifing, describing and specifying basic and advanced functional and nonfunctional requirements of an electric production certificate system, using REALISTIC modeling [BDH$^+$22] and algebraic ("total") resource accounting (TRA) [Hen19, TG20].
- Designing and implementing a prototype of an electricity production certificate system addressing basic requirements and illustrating its basic use (consumers purchasing unbundled certificates from producers) on real historic or on simulated electricity production and consumption data from the Danish electricity system.
- Designing and illustrating GHG emissions calculations based on fine-, medium- and coarse-grained GHG emissions data that get associated with energy production plants and time intervals.
- Optionally, designing, implementing and evaluating an extended prototype system that addresses identified advanced requirements such as bundling and trading production certificates.

The project's fundamental underlying research hypothesis is as follows.

1. REALISTIC modeling provides an effective analysis tool for modeling electricity production, transmission and consumption.
2. TRA and its guaranteed resource invariants are a productive high-level conceptual, mathematical and programming framework that guarantees prevention of digital greenwashing (here: guaranteed no-loss-no-duplication of energy).
3. The combination of REALISTIC and TRA can seamlessly be extended to include energy transformation (e.g. Power-to-X, sector coupling) to provide multistage origin tracing and greenwashing-proof energy certificate management and cumulative (Scope 3, upstream) GHG emissions reporting for fuels and other energy forms.

4. Energy production certificates and energy production futures can be used to design and trade both simple and complex financial (or rather commodity) products, based on a DLT- and smart contract platform such as Smart Financial Instruments.[3]

This project addresses parts 1 and 2.

3 Learning objectives

- Explain REALISTIC and TRA and analyze their applicability to electricity production certificate management.
- Design, implement (prototype), test and evaluate an electricity production certificate system using requirements-based, component-oriented design driven by the results of REALISTIC modeling. Report and discuss any problems discovered in this process.
- Discuss challenges for moving from the prototype to a pilot- or production-quality system, such as integration with desired or existing APIs, wire and data protocols for accessing systems with the requisite production and actor (producer, consumer) data; extending to multi-stage energy certificates in sector-coupled energy production; employing and implementing digital signatures or other commonly used authentication and authorization; securely (immutably and persistently) logging events (transactions); migrating the system to a decentralized platform (DLT or conventional blockchain system).

References

[BDH+22] Simon L. Bager, Boris Düdder, Fritz Henglein, Juan Manuel Hébert, and Haiqin Wu. Event-based supply chain network modeling: Blockchain for good coffee. *Frontiers in Blockchain*, 5, 2022.

[BH06] Paolo Bertoldi and Thomas Huld. Tradable certificates for renewable electricity and energy savings. *Energy policy*, 34(2):212–222, 2006.

[Hen19] Fritz Henglein. Smart digital contracts: Algebraic foundations for resource accounting. Oregon Programming Languages Summer School (OPLSS), Smart Digital Contracts, Lecture 2, June 2019.

[TG20] Juan-Manuel Torres Garcia. Algebraic resource accounting for transfers and transformations. Master's thesis in computer science, Department of Computer Science, University of Copenhagen (DIKU), September 2020.

[3] `https://www.deondigital.com/smart-financial-instrument/`