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Defining a day-ahead spot market for unbundled time-specific renewable energy certificates

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***Abstract*—One option to counteract anthropogenic climate change is to increase the share of renewable electricity supply. Current market structures provide only a limited framework for the creation of "green" electricity tariffs, which are often criticised as "greenwashing", lacking transparency, and ineffective invest-ment signalling. This paper defines and discusses a day-ahead spot market for tradable (short-term) time-specific renewable energy certificates (REC). Implementing an unbundled spot market for REC promises a more credible provision of renewable electricity, along with a mechanism rewarding flexibility in renewable production and storage as well as tangible investment signals.**

Keywords—Time-specific Renewable Energy Certificates, Green Power Tariffs, Market Design, Plug-in Electric Vehicles

I. Introduction

Growing climate concerns lead to more restrictive carbon standards for passenger vehicles all around the globe, the current discussion about a zero-emission quota in China is only the most recent of these developments. The industry shifts towards alter-native fuels, most notably plug-in electric vehicles (PEV). How-ever, this approach can only guarantee a more sustainable mobility if the electricity used for charging comes from renew-able sources. Some progress has been made in the last decades, but most major vehicle markets are struggling to achieve significant carbon reductions in electricity production [1].

In addition to increasing the cumulative availability of green electricity, vehicle charging should be synchronised with renewable feed-in time: the surplus demand from PEV charging requires additional power generation at that time, often from fossil fuels. In consequence, consumers' real-time electricity mix varies greatly from the mix communicated in their green power tariffs [2]. These increased marginal emissions are allocated to all consumers via the current energy-only market (EoM). Long vehicle idling times of typically up to 23 h per day [3] allow PEV to react to volatile renewable supply. By shifting charging periods to times of renewable production, power demand would increase in times of renewable oversupply instead of in often carbon-intensive peak demand periods [4].

Today, green power marketing either relies on over-the-counter contracts with generators, or on renewable energy certi-ficates (REC). REC can often be banked (e.g. for three years in California [5]) and borrowed, and therefore do not promote time-specific consumption. In fact, time-specific information on green power availability is currently not accessible to the demand side. Retailers that aim to provide green power from predominantly fluctuating wind and solar power – not only to PEV – require time-specific signals to incentivise shifting of demand, in order to promote consumption at times of abundant renewable supply [6,7].

In a macro-economic context, European REC (or Guarantees of Origin) were introduced to capture consumers' additional valuation for sustainable electricity [8]. They are registered and monitored at national databases and traded once a week within the international European Energy Certificate System (EECS) [6]. The traditional (or old) REC-market (oRM) is generally criticised for lacking transparency ("greenwashing") but also for its economic ineffectiveness [9]. REC mostly come from large hydropower plants in Scandinavia or the Alps. These have competitive costs of electricity production and can therefore command very low REC-prices (below 1 EUR/MWh in Germany [10]). Thus, production from more expensive but sustainable sources remains unprofitable and there is no incentive to install new capacity – contrary to the effect consumers aim to achieve [11]. Due to the low prices of REC, governmental subsidies, e.g. the German EEG, were introduced to foster renewable capacity expansion [12]. While being successful in increasing capacity, these subsidies hamper the competitive marketing of green electricity [13,14]. To improve transparency, certification agencies have constructed eco-labels that take additional sustainability criteria of green power into account, such as plant age or transparent business practices, but tracking their subtle differences is tedious for consumers [15].

A suitable market mechanism could replace inefficient subsidies with long-term, market-based incentives for renewable generation and offer opportunities for smart charging. This work aims to facilitate the time-specific provision of renewable energy through proposing a day-ahead voluntary spot market for time-specific REC (tsRM), from the point of view of (but not exclusive to) Germany. After reviewing related literature, we define the market by applying the framework of Market Engineering, discuss its merits and drawbacks, and conclude.

II. Related work

A considerable amount of research discusses demand side management in the context of increasing renewable power production [e.g. 16,17], the significance of PEV [e.g. 18], and the necessary tools for its implementation [e.g. 19]. However, very little attention is payed to the market structure facilitating such services – especially in the transition phase until current subsidy mechanisms have run out or need to be replaced, and truly disrupting shares of renewable production need to be included in the power system: While Jensen & Skytte (2002) [20] and Ciarreta et al. (2014) [13] generally promote REC markets over subsidy schemes, Morthorst (2000) [21] suggests to allow banking of REC beyond a one year period to moderate volatility. Oppositely, Schaeffer & Sonnemans (2000) [22] add that unlimited banking could lead suppliers to coordinate on higher prices. More recently, Leprich et al. (2015) [6] collect ideas for remodelling existing market structures to improve green power marketing and time-specific trade in ¼-hour granularity. Lemming (2003) [23] scrutinises the traditional REC-quota system for wind power and sheds light on resulting risk exposure and risk-premiums. Bertoldi & Huld (2006) [24] describe a joint market for REC and energy efficiency certificates (incl. quota) with shorter validity periods but still allow banking and borrowing of REC. Paulun (2011) [25] discusses capacity investment decisions in general and concludes that tradeable REC can contribute as investment incentives for renewable capacity. He also suggests moving towards more time-specific REC. Decentralised solutions, with direct and live sale of green power, e.g. from local photovoltaics, have recently been receiving more and more attention [e.g. 26]

In 2012 the Austrian market platform EXAA introduced an hourly day-ahead market for green power (certified energy from renewable sources, beyond unbundled REC), the Green-Power@EXAA. For market entry, suppliers need to certify individual or a pool of plants with the "Erzeugung EE+" label and their final product with the "EE02" label, both issued by TÜVSüd. Prices were on average 2.2 % (0.7 EUR/MWh) above the price level on the corresponding grey power market in 2015. This small premium for time-specific renewable electricity can be attributed to the predominance of supply by Scandinavian hydropower. Likely in order to reduce suppliers' risk exposure, the GreenPower auction takes place shortly before the regular day-ahead auction, so that unsold energy can still be sold without its "renewable" attribute. In consequence, the two markets are highly correlated in their price variations ($\rho_{green,grey} > 0.879$ for 2015). The market reached its peak liquidity in 2015 with an annual sales volume of 31.6 GWh (compared to 8.2 TWh on the Austrian grey power day-ahead market). However, trade has ceased since July of 2016 [27]. The likely cause is a lack of demand due to customers' differing valuation of green power characteristics (origin, technology, plant age, etc.) beyond "EE02"[1].

Countries with a diverse renewable portfolio could introduce a similar mechanism to pool liquidity of unbundled REC-sales but with a stronger orientation towards volatile sources and away from large hydropower. By unbundling REC from power offers, market entry barriers could be lowered for new players, e.g. aggregators of flexible demand from PEV, electric heating or cooling or even power-to-gas [17]. Additionally, an unbundled market gives specific information on the valuation for sustain ability, without dilution by power valuation.

[1] Source: Direct correspondence with the VERBUND AG, a major actor on GreenPower@EXAA.

III. METHOD: THE FRAMEWORK OF MARKET ENGINEERING

In order for a market to allocate resources efficiently, it needs to be consciously designed with respect to rules on information disclosure, signalling and allocation. Market Engineering after Weinhardt et al. (2003) [28] uses legal frameworks, economic and management science models and information and telecommunication technologies to design markets for the exchange of goods and services. It is often – but not exclusively – used for the design of electronic markets [e.g. 29].

Fig. 1 shows the framework of Market Engineering in its generalised form. A market is always embedded in its socio-economic and legal environment. The market engineer has no direct influence on the environment but can design transaction objects, the market structure and auxiliary services in order to incentivise participants' (i.e. agents') behaviour towards achieving a certain measurable market outcome or performance. The transaction objects are the goods or services traded on the market. The market structure consists of the microstructure (allocation and pricing rules), the infrastructure (enabling transactions), and the business structure (e.g. trading fees as a business model for the market operator). Auxiliary services can provide decision support for market participants [30].

IV. DEFINING A NEW SPOT MARKET FOR UNBUNDLED REC

In the following, we apply the framework of Market Engineering to design a time-specific day-ahead REC market (tsRM) [28,30]. Fig. 2 displays an overview of the intended market structure. The grey dot represents the virtual flow of electricity, the green circle a time-specific REC. Information exchange with the REC-registry is shown in dashed lines.

A. Desired market outcome

REC generally are a useful tool for marketing green electricity: Since a full-time supply of renewable power directly from a specified source is costly for individual customers, REC allow for trading the characteristic "renewable" independent of physical power, while preventing double-marketing. The goal of a day-ahead market for time-specific REC is to provide an efficient price for renewable electricity at the specific time of

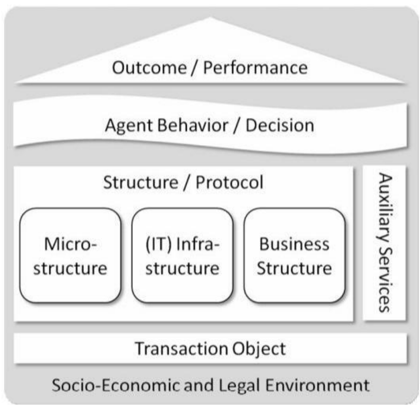

Fig. 1 The framework of Market Engineering [30]

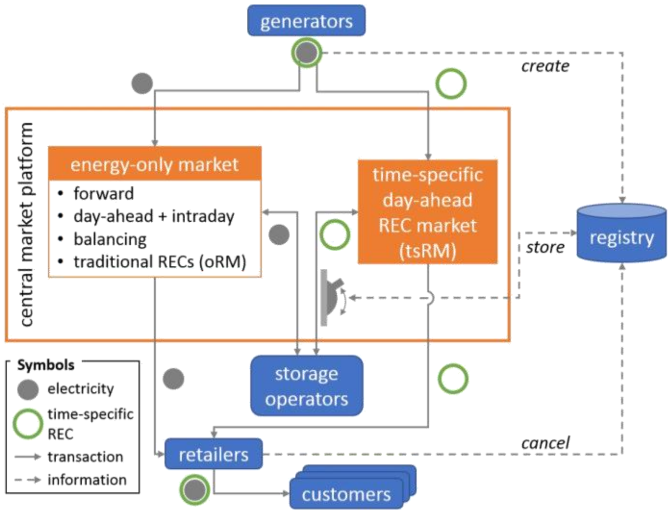

Fig. 2 Structure of the time-specific day-ahead REC market (tsRM).

production. Suppliers would be able to capture customers' additional valuation for sustainable power supply and contribute to covering their investment cost for renewable capacity [31].

B. Socio-economic and legal environment

A fundamental prerequisite for a tsRM is a positive willing-ness-to-pay (WTP) for green power with a high temporal resolution. A positive WTP, albeit small, has been found [e.g. 11,32], often accredited to green consumer values [e.g. 33]. This demand will only increase with growing PEV numbers.

The supply of renewable power has increased dramatically, especially in Europe and China. The example of Germany shows how important REC trading is today: Almost 20 % of German households receive green power – together with business cus-tomers this represents an energy demand of around 50 TWh [34]. However, it is estimated that for 2012 only 19 % of the green power consumption via REC actually came from German power plants. The REC are rather imported from Scandinavian and alpine hydropower plants [35,36]. Most of Germany's re-newable capacity growth, especially wind and solar power, was directly subsidised and is therefore not eligible for REC. The abundant, cheap hydropower imports severely reduce REC-prices and push less plannable production out of the market [10].

The legislative basis for REC trading in Europe is the EU-directive 2009/28/EG [37], which defines the EECS and is translated into national legislations with national issuing bodies and registration mechanisms. Key information recorded for REC are the date of creation, source technology, plant location and size, date of plant construction and financial support. So far, REC can be banked for up to one year [38].

A tsRM should be based largely on existing REC and liberal-ised EoM such as in central Europe as the potential stakeholders of a day-ahead REC market would already have extensive experience with the regulatory framework conditions. Neverthe-less, liquidity might be threatened due to oversupply and low demand for time-specific REC [cf. 39]. The design process aims to address this problem.

C. Transaction object

A REC (or Guarantee of Origin) is the transaction object of the market, calculated in 1 MWh, and largely unchanged to its current definition as given above. The specific *time* of creation and a "stored"-identifier are the only additions. The latter indicates if a REC is being stored (e.g. in a pumped -storage hydro power plant, PEV or stationary battery). A more detailed discussion on storage is given in subsections D and F.

D. Market structure

The proposed *microstructure* is largely derived from the existing day-ahead EoM: utilities sell their renewable electricity output on the EoM while receiving REC with a time-stamp of generation. Time-specific REC are issued and monitored by national registration institutions and can be exchanged via a unified protocol. Suppliers place them on the market for the expected feed-in time (e.g. based on wind prognosis) for the following day. Only REC from plants outside of governmental incentive programs can be sold, in order to reward investments according to actual demand for green electricity.

Retailers buy REC to cover their projected customer demand, immediately cancelling the REC upon purchase. All market participants must maintain a balancing group to ensure balanced supply and demand of REC at all times. At time of de-livery, groups with too few REC for time-specific demand must compensate their customers for breach of contract. Surplus time-specific REC are not eligible for the oRM and expire unused.

In addition, storage plays a pivotal role for the system inte-gration of volatile renewables. Since the tsRM is designed to un-bundle REC from electricity, storages must be able to store both, the physical energy and the time-specific REC. Storage opera-tors must only be able to sell REC to the tsRM if they prove to have previously bought REC for storing. This requires a kind of tag only available to certified storage operators, in order to pre-vent the automatic cancellation (i.e. use) of REC upon purchase by a storage operator. A time-specific REC therefore has three states: *created*, *stored*, and *cancelled* (cf. Fig. 2). When a REC is being discharged the specific time is recorded. This discharge time stamp is used for validating the REC upon cancellation.

The bids (e.g. in EUR/MWh) are aggregated into a merit-order for every trading interval (Fig. 3). The market is cleared for e.g. every hour with the uniform price of the marginal bid. The interval should be shortened after a defined adaptation period to provide more flexibility for storage and volatile wind and solar production. The tsRM-auction should be scheduled shortly before the day-ahead EoM in order to allow flexible suppliers to adapt their EoM-bids in case of unexpected tsRM outcomes. Otherwise, the risk of mismatching allocations for power and REC might deter market participation.

The tsRM microstructure has no influence on the current *infrastructure* requirements for power market operation. For tariff construction, however, retailers need time-specific, granu-lar information on expected consumption. This becomes particu-larly relevant for large demand from PEV. Thus, Smart Meters and charge planners are likely to be a necessity for time-specific green power contracts [cf. 40]. The infrastructure must also allow for the transmission of time-specific price-signals to the consumer [cf. 19].

Fees for market participation, i.e. the *business structure*, can follow current business models for market operators, but in the beginning should aim to lower market entry barriers to increase market liquidity.

E. Auxiliary services

Since the tsRM should be added to existing trading platforms of the EoM, auxiliary services specific to trading should be available soon, e.g. by adapting or expanding such existing technologies as price-forward curve calculators. Since the REC are time-specific, some form of very short-term balancing mechanism might be made available to unbalanced retailers who want to avoid breach-of-contract payments. However, as excess REC simply expire, only a positive balancing scheme is neces-sary. Alternatively, retailers must buy excess REC to avoid im-balance, which would increase prices. Given adequate liquidity, a later introduction of an intraday-market could be considered.

F. Agent-behaviour

Due to the similarities between the proposed tsRM and current liberalised EoM, most of the mechanics of trading should be well established. However, it is important to note, that flexible green suppliers must always sell electricity correspond-ing to the sold REC, but not the other way around. The decision to act on the tsRM therefore strongly depends on the achievable green power premium. Since REC have no obligation to be sold and the oRM offers a fall-back opportunity, suppliers' strategies are expected to differ: Usually, short-term marginal costs of production are the basis for the bid-prices on the EoM. Here, the single-price auction regularly leads to prices that also allow covering the fixed costs of conventional power plants. In the future, when subsidies for renewable production are phased out, the REC-revenues from the tsRM could contribute to covering the high fixed costs, which is likely to incentivise further investments in volatile sources such as wind and solar.

Whether a supplier should be active on the tsRM at all de-pends on the expected prices on the EoM and the oRM: If a flexible supplier expects higher REC-prices on the tsRM, he bids equal capacity to the tsRM and the EoM, but likely at different prices: E.g., he might allocate the marginal costs to the tsRM-bid and submit a very low bid for power in order to guarantee allocation, or vice-versa. Equation (1) shows the idea behind a fleible supplier's (e.g. a biomass plant's) sell-bid $p^*_{tsRM,h}$ in the case of higher expected prices on the tsRM compared to the oRM ($E(p_{tsRM,h}) > E(p_{oRM,w})$). Correspondingly, Table I summarieses all sell-bids $p^*_{tsRM,h}$ and $p^*_{EoM,h}$ (considering expectated price relations) on the tsRM and EoM (based on [41]). The variable costs of production c_{var} and the start-up (or cold-start) costs s are taken into account. In the case of negative expected prices on the EoM , i.e. a power over-supply, suffi-ciently positive tsRM-prices are unlikely, as over-supply situ-ations are usually caused by strong renewable feed-in at times of low demand. For example, high output from subsidised (and thus not tsRM-eligible) wind power could cause EoM-prices to plummet, while strong green power demand cannot be met.

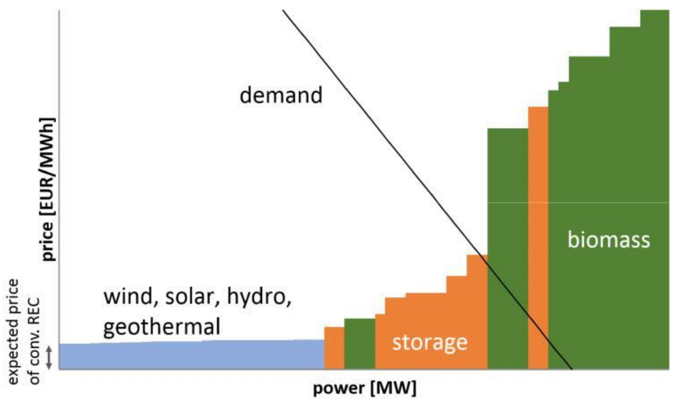

Fig. 3 Exemplary merit-order of the time-specific REC market.

The demand side buys power plus REC and pays the sum of the market prices, or buys only the power and accepts a breach-of-contract penalty for insufficient REC-coverage of customer demand. A high penalty on the tsRM could motivate storage expansion due to a high WTP by the demand side to avoid it. The penalty also represents a natural price cap and therefore requires a careful design. Equation (2) describes the optimal buy-bid $p^*_{tsRM,h}$ on the time-specific day-ahead REC market for every hour h, under consideration of the expected prices on the tsRM $E(p_{tsRM,h})$ and the EoM $E(p_{EoM,h})$

$$p^*_{tsRM,h} = \min\left(\begin{array}{c} E(p_{EoM,h}) + E(p_{tsRM,h}) \\ E(p_{EoM,h}) + penalty \end{array}\right) \quad (2)$$

Furthermore, the role of storages shall be considered in more detail: Theoretically, storages are charged when the market price is below their costs for storing (depending on purchase price, storage efficiency, and grid usage fees) and discharged if these costs are compensated. However, such an operation neglects the value of future discharge at times of potentially even higher prices. This is particularly important for long-term storages (e.g. hydro pump-storages) and trading activities across multiple markets. A shadow price can be calculated that depends on the optional value of future discharge [42]. The storage is charged if the sum of the expected prices on tsRM and EoM is projected to be below the shadow price of charging, and discharged if the sum is above the shadow price of discharging. Bids are placed accordingly, although the differing consumption obligations for tsRM and EoM have again to be taken into account. Since the oRM is not open to storages, there is no fall-back option.

Due to the supposed premium and higher price volatility on the tsRM, storage operators have an immediate incentive to store green power instead of grey power and exploit periods of abundant volatile feed -in. This could provide the means for positive business cases for battery storages and flexibility aggre-gators of an active demand side.

$$p^*_{tsRM,h} = \begin{cases} c_{var} + \frac{s}{n} - E(p_{EoM,h}), & if\ \left(E(p_{tsRM,h}) + E(p_{EoM,h})\right) > c_{var} \land (cold\ start\ necessary) \\ max\left(c_{var} - \frac{s}{24-n} - E(p_{EoM,h}), 0\right), & if\ \left(E(p_{tsRM,h}) + E(p_{EoM,h})\right) < c_{var} \land (is\ running) \\ c_{var} - E(p_{EoM,h}), & else \end{cases} \quad (1)$$

G. Expected market outcome

Low prices are expected for REC from wind, solar, geothermal, and hydropower in correspondence with their low marginal costs. However, since REC can simply expire unused without threatening system stability, unlike electricity, prices below the level of conventional, lower-quality REC on the oRM are unlikely (cf. Fig. 3). Bids above the tsRM-market-price are only sold at the regular spot market; bids below generate a surplus for the provider. The demand curve should be significantly less steep than on the EoM, as retailers might only want to guarantee partial renewable supply or strive to induce demand response.

A considerable price ramp is expected for storage and flexible generation due to costs of storage or time -dependent biofuel costs. Biomass plant operation has to take harvesting periods into account, which could lower tsRM prices in autumn. Nevertheless, possible price drops on the regular power markets (due to favourable wind and sun conditions) might cause flexible bidders to lower their tsRM-bids to stay in the market. In general, the correlation between tsRM and EoM is expected to be high. On the other hand, if a power price drop has other causes, flexible bidders might consider increasing REC-bids in order to compensate. This commands further research.

V. Discussion

The proposed unbundled day-ahead market for time-specific REC enables retailers to supply higher-quality renewable electricity at the true time of production to customers with a valuation for improved sustainability. Demand response aggregators, e.g. for PEV charging, could benefit from a trading platform for REC independent of customers' private power tariff. However, in the case of diverging trends on EoM and tsRM, the aggregator must carefully decide which steering signal to relay to customers, depending on the agreed service level (i.e. partial or total guarantee of green power) . Suppliers have the opportunity to create additional revenue from their high-quality product. The tsRM rewards predictable or flexible renewable production and could support the viability of storage business cases. Given liquidity and sustained demand, this market could play a role in replacing governmental incentive programs in an efficient manner as well as provide the tools to incentivise load adjustments according to volatile renewable output.

However, the exclusion of subsidised plants or already profitable technologies (e.g. large hydropower) might threaten liquidity. While beneficial to market functionality and transparency, reducing the supplier pool to exclusively national production might be too restrictive, considering that most REC used in Germany are sourced internationally [35]. It is similarly unclear if the demand for real-time green power is high enough for cost-covering prices, despite falling levelised costs of electricity for wind and solar. This depends on customers' WTP for the added value of real-time feed-in. Additionally, an unbundled REC spot market further complicates the dispatch for renewable suppliers, especially with respect to the supposed interdepend-encies with the EoM.

The proposed market structure leaves the question of price risk exposure mostly unanswered for both supply and demand. While the supply side can draw from increasingly reliable fore-casts for wind and solar power in a day-ahead-setting, retailers might need granular Smart Meter data or sophisticated demand response measures to be able to predict demand precisely – especially under consideration of PEV. Eventually, a framework for long-term risk hedging for time-specific REC might be required, i.e. a future market analogous to the EoM [cf. 23].

VI. Conclusion

Marketing of green electricity has so far not reached its full potential, since existing valuations by the customers have yet to lead to premiums serving as investment incentives to power generators. To allow for an efficient provision of green power with a reduced propensity for "greenwashing"-critique, we

TABLE I. Strategy of a flexible supplier.

Case 1: $E(p_{tsRM,h}) > E(p_{oRM,w})$		
$p^*_{tsRM,h} = \{$	$p^*_{EoM,h} = \{$	
$c_{var} + \frac{s}{n} - E(p_{EoM,h}),$	$0,$	$if\ \left(E(p_{tsRM,h}) + E(p_{EoM,h})\right) > c_{var} \wedge (cold\ start\ necessary)$
$max\left(c_{var} - \frac{s}{24-n} - E(p_{EoM,h}), 0\right),$	$0,$	$if\ \left(E(p_{tsRM,h}) + E(p_{EoM,h})\right) < c_{var} \wedge (is\ running)$
$c_{var} - E(p_{EoM,h}),$	$0,$	$else$
Case 2: $E(p_{tsRM,h}) \leq E(p_{oRM,w})$		
$p^*_{tsRM,h} = \{$	$p^*_{EoM,h} = \{$	
$none\ [\Rightarrow p^*_{oRM,w} \geq 0]$	$c_{var} + \frac{s}{n},$	$if\ E(p_{EoM,h}) > c_{var} \wedge (cold\ start\ necessary)$
$none\ [\Rightarrow p^*_{oRM,w} \geq 0]$	$max\left(c_{var} - \frac{s}{24-n}, 0\right),$	$if\ E(p_{EoM,h}) < c_{var} \wedge (is\ running)$
$none\ [\Rightarrow p^*_{oRM,w} \geq 0]$	$c_{var},$	$else$

with

Variables / parameters			Unit	Indices		
p_{tsRM}	=	price on time-specific day-ahead REC market	[EUR/MWh]	h	=	hour
p_{EoM}	=	price (day-ahead) energy-only market	[EUR/MWh]	w	=	week
p_{oRM}	=	price on long-term (old) REC market	[EUR/MWh]	*	=	bid-price
c_{car}	=	variable costs (fuel considering efficiency, maintenance)	[EUR/MWh]			
s	=	start-up costs	[EUR]			
n	=	number of scheduled hours per day	[hour]			

applied the framework of Market Engineering to propose a day-ahead market for time-specific renewable energy certificates. The market was defined and placed in the context of current legislation and a first approach towards analysing possible bidding strategies was made.

To better understand the implications of the proposed REC market and assess its functionality, future research will focus on assessing customer understanding and acceptance of the different qualities of renewable electricity. Based on this, agent-based simulations of power markets will shed light on liquidity and performance. Interdependencies between tsRM, EoM and heat markets are of particular interest. Due to the significance of price expectations, further research could benefit from agent learning approaches. The model could be expanded with more short-term trading options such as an intraday market or balancing mechanisms, or long-term options for risk hedging. A further differentiation of power markets with respect to renewable source technology could also be considered.

REFERENCES

[1] Axsen J, Kurani KS. Connecting plug-in vehicles with green electricity through consumer demand. Environ. Res. Let. 2013; 8(1).

[2] Jochem P, Babrowski S, Fichtner W. Assessing CO2 emissions of electric vehicles in Germany in 2030. Transport. Res. A-Pol. 2015; 78: 68–83.

[3] infas, DLR. Mobilität in Deutschland (MiD) 2008: Ergebnisbericht Struktur - Aufkommen - Emissionen - Trends. Bonn/Berlin, Germany; 2010.

[4] Gohla-Neudecker B, Kuhn P, Hamacher T, Wagner U. Sustainable mobility — Modelling a cost-efficient supply of renewables for EVs. In: 2011 Internat. Conf. on Clean Elect. Power (ICCEP); 2011. p. 189–95.

[5] CEC. Renewable Energy - Tracking Progress. California Energy Commission (CEC), 2016. www.energy.ca.gov/renewables/ tracking_progress/documents/renewable.pdf, accessed 24.04.2017.

[6] Leprich U, Hoffmann P, Luxenburger M. Zertifikate im Markt der Erneuerbaren Energien in Deutschland. In: Herbes C, Friege C, Eds. Marketing Erneuerbarer Energien. Wiesbaden, Germany: Springer Fachmedien; 2015. p. 203–39.

[7] Dallinger D, Wietschel M. Grid integration of intermittent renewable energy sources using price-responsive plug-in electric vehicles. Renew. Sust. Energ. Rev. 2012; 16(5): 3370–82.

[8] Schaeffer GJ, Boots MG, Martens JW, Voogt MH. Tradable green certificates: A new market-based incentive scheme for renewable energy: introduction and analysis. Energy Research Centre of the Netherlands 1999; ECN-I-99–004.

[9] Herbes C. Wie grün ist Grünstrom? Sonne Wind & Wärme 2014; 11.

[10] Reichmuth M. Marktanalyse Ökostrom: Endbericht. Dessau-Roßlau, Germany; 2014.

[11] Roe B, Teisl MF, Levy A, Russell M. US consumers' willingness to pay for green electricity. Energ. Policy 2001; 29(11): 917–25.

[12] Haas R, Panzer C, Resch G, Ragwitz M, Reece G, Held A. A historical review of promotion strategies for electricity from renewable energy sources in EU countries. Renew. Sust. Energ. Rev. 2011; 15(2): 1003–34.

[13] Ciarreta A, Espinosa MP, Pizarro-Irizar C. Switching from Feed-in Tariffs to a Tradable Green Certificate Market. In: Ramos S, Veiga H, Eds. The interrelationship between financial and energy markets. Lect. Notes in Energ. Berlin/Heidelberg, Germany: Springer; 2014. p. 261–80.

[14] Herbes C, Ramme I. Online marketing of green electricity in Germany— A content analysis of providers' websites. Energ. Policy 2014; 66: 257– 66.

[15] Schwidden M. §7 Der Markt für Grünstrom. In: Zenke I, Schäfer R, Eds. Energiehandel in Europa: Öl, Gas, Strom, Derivate, Zertifikate. 3rd ed., Energierecht. München, Germany: Beck; 2012. p. 111–31.

[16] Vardakas JS, Zorba N, Verikoukis CV. A Survey on Demand Response Programs in Smart Grids: Pricing Methods and Optimization Algorithms. IEEE Commun. Surveys & Tutorials 2014; 17(1).

[17] Siano P. Demand response and smart grids—A survey. Renew. Sust. Energ. Rev. 2014; 30: 461–78.

[18] Kempton W, Letendre SE. Electric vehicles as a new power source for electric utilities. Transport. Res. D-Tr. E. 1997; 2(3): 157–75.

[19] Albadi MH, El-Saadany EF. Demand Response in Electricity Markets: An Overview. In: Power Engineering Society General Meeting; 2007. p. 1–5.

[20] Jensen SG, Skytte K. Interactions between the power and green certificate markets. Energ. Policy 2002; 30(5): 425–35.

[21] Morthorst PE. The development of a green certificate market. Energ. Policy 2000; 28(15): 1085–94.

[22] Schaeffer, Sonnemans J. The Influence of Banking and Borrowing under Different Penalty Regimes in Tradable Green Certificate Markets: Results from an Experimental Economics Laboratory Experiment. Energ. & Env. 2000; 11(4): 407–22.

[23] Lemming J. Financial risks for green electricity investors and producers in a tradable green certificate market. Energ. Policy 2003; 31(1): 21–32.

[24] Bertoldi P, Huld T. Tradable certificates for renewable electricity and energy savings. Energ. Policy 2006; 34(2): 212–22.

[25] Paulun T. Aktuelle und zukünftige Marktmechanismen des Stromhandels. In: Vorträge des internationalen ETG-Kongresses 2011. ETG-Fachbericht vol. 130. Berlin, Germany: VDE-Verl.; 2011.

[26] Mihaylov ME, Jurado S, Moffaert K van, Avellana N, Nowe A. NRG-X-Change: A Novel Mechanism for Trading of Renewable Energy in Smart Grids. In: Helfert M, Krempels K-H, Donnellan B, Eds. P. of the 3rd International Conference on Smart Grids and Green IT Systems, Barcelona, Spain, 3-4 April, 2014: SCITEPRESS; 2014. p. 101–06.

[27] EXAA. Spotmarkt GreenPower [Internet], Energy Exchange Austria (EXAA). http://www.exaa.at/de/spotmarkt-strom/greenpower, accessed 15.11.2016.

[28] Weinhardt C, Holtmann C, Neumann D. Market-Engineering. Wirtschaftsinf. 2003; 45(6): 635–40.

[29] Dauer D, Scheidt F vom, Weinhardt C. Towards smart distribution grids: a structured market engineering review. In: P. of the 6th Karlsruhe Service Summit; 2016.

[30] Gimpel H, Jennings NR, Kersten GE, Ockenfels A, Weinhardt C. Market Engineering: A Research Agenda. In: Gimpel H, Jennings NR, Kersten GE, Ockenfels A, Weinhardt C, Eds. Negotiation, Auctions, and Market Engineering: International Seminar, Dagstuhl Castle, Germany, Nov 12-17 2006. Lect. Notes in Bus. Inf. P., vol 2. Berlin/Heidelberg, Germany: Springer-Verlag; 2008. p. 1–15.

[31] Hansla A, Gamble A, Juliusson A, Gärling T. Psychological determinants of attitude towards and willingness to pay for green electricity. Energ. Policy 2008; 36(2): 768–74.

[32] Kaenzig J, Heinzle SL, Wüstenhagen R. Whatever the customer wants, the customer gets?: Exploring the gap between consumer preferences and default electricity products in Germany. Energ. Policy 2013; 53: 311–22.

[33] Clark CF, Kotchen MJ, Moore MR. Internal and external influences on pro-environmental behavior: Participation in a green electricity program. J. of Environ. Psych. 2003; 23(3): 237–46.

[34] BNetzA. Monitoringbericht 2016. Bonn, Germany; 2016.

[35] Kübler K. Leistet man durch den Kauf von „Ökostrom" einen Beitrag zur Energiewende in Deutschland? Energiewirt. Tagesfrag. 2014; 64(3): 43–46.

[36] AIB. Facts | Market information | Activity statistics. Association of Issuing Bodies. https://www.aib-net.org/facts/market_information/aib_statistics, accessed 08.02.2017.

[37] DIRECTIVE 2009/28/EG on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC: 2009/28/EG, L 140; 2009.

[38] EEX. Herkunftsnachweise für Grünstrom - Überblick. European Energy Exchange (EEX). https://www.eex.com/de/produkte/umweltprodukte/ herkunftsnachweise/%C3%BCberblick, accessed 19.09.2016.

[39] Gillenwater M. Redefining RECs—Part 1: Untangling attributes and offsets. Energ. Policy 2008; 36(6): 2109–19.

[40] Salah F, Flath CM, Schuller A, Will C, Weinhardt C. Morphological analysis of energy services: Paving the way to quality differentiation in the power sector. Energy Policy 2017; in press, doi: 10.1016/j.enpol.2017.03.024.

[41] Sensfuß F. Assessment of the impact of renewable electricity generation on the German electricity sector: An agent-based simulation approach. Dissertation, Universität Karlsruhe (TH), Karlsruhe, Germany; 2007.

[42] Braun S. Hydropower Storage Optimization Considering Spot and Intraday Auction Market. Energ. Procedia 2016; 87: 36–44.