TECHNOLOGY-SPECIFIC RES PREMIUMS FOR A COST-EFFECTIVE RENEWABLES EXPANSION USING A TWO-STAGE RENEWABLE ELECTRICITY EXPANSION MODEL

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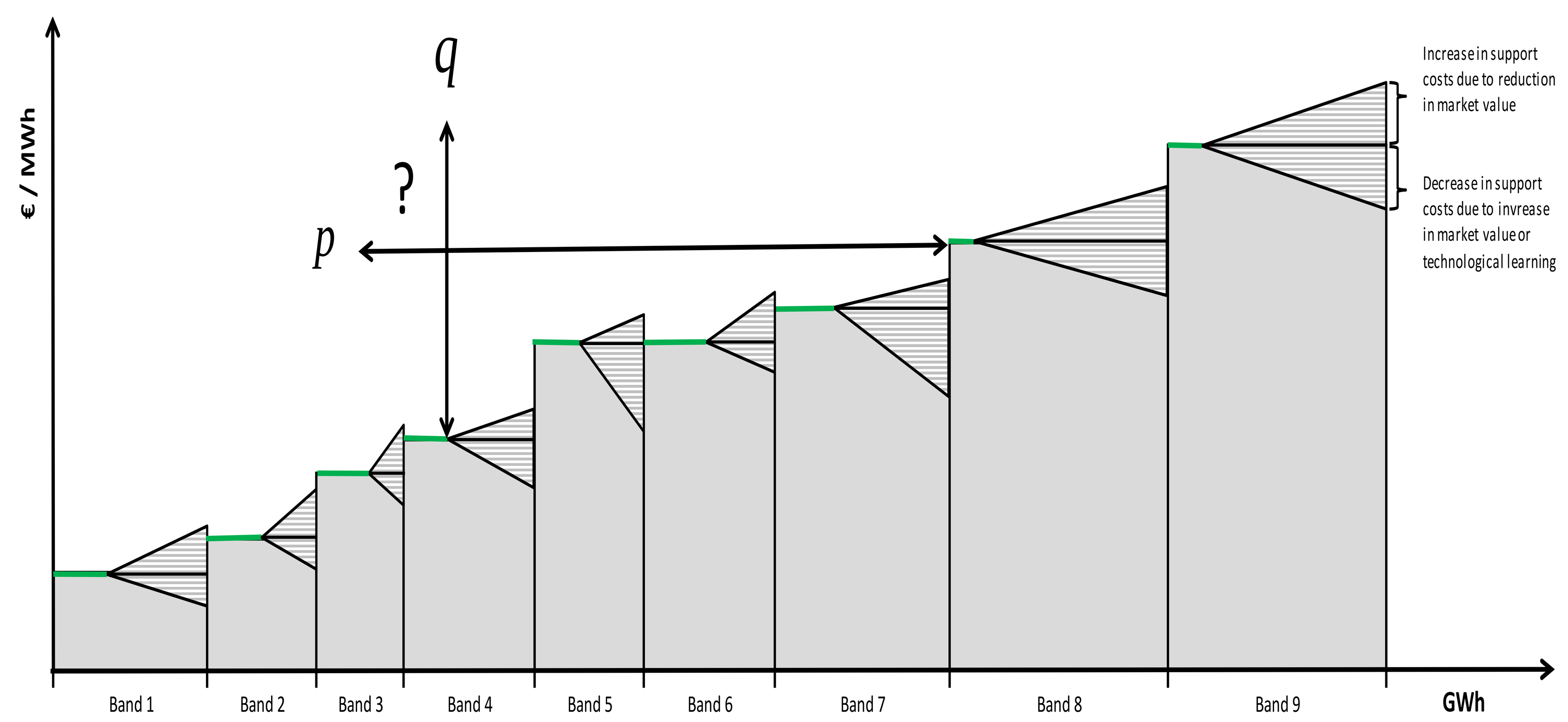
Problem formulation

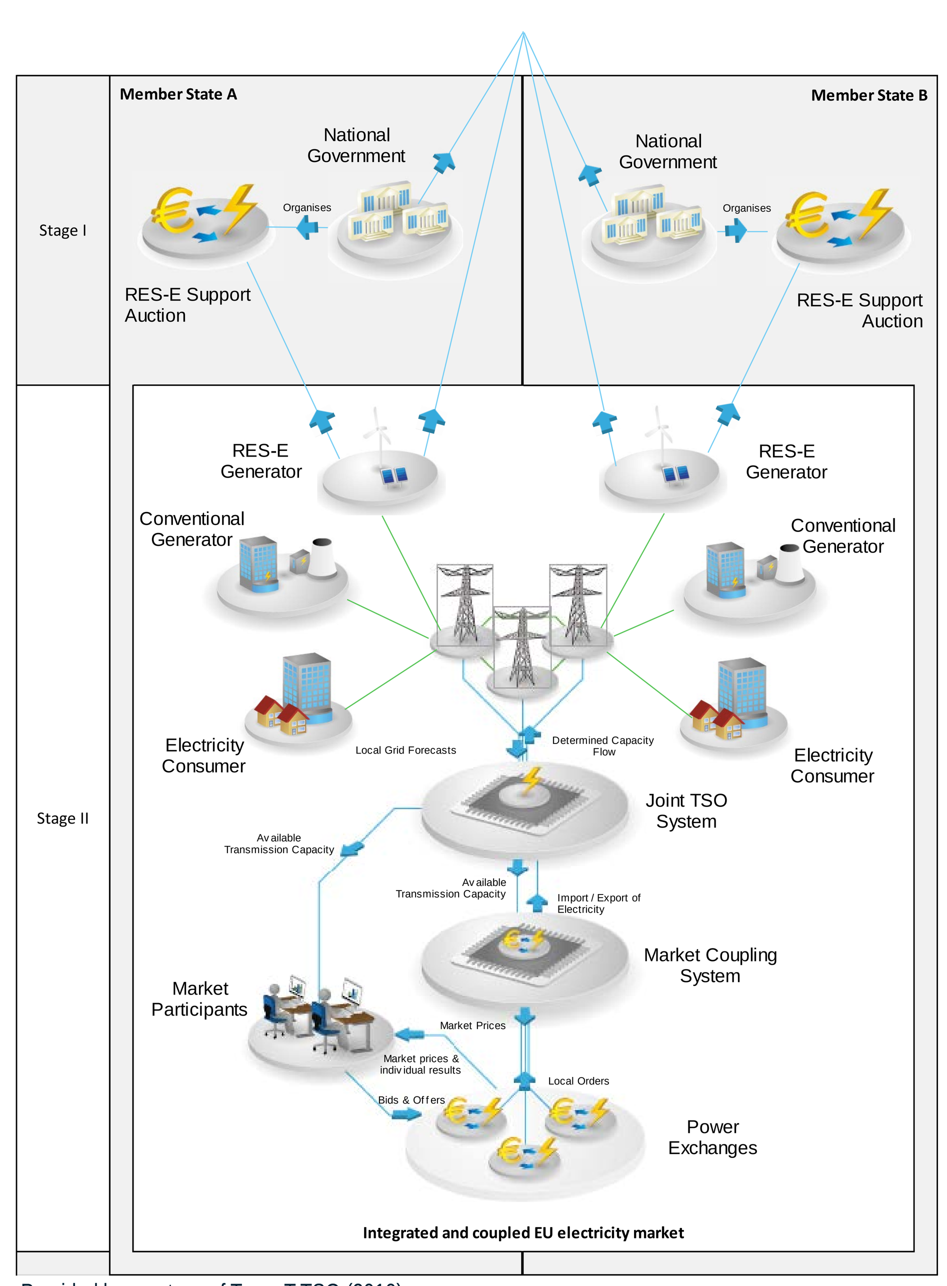


Modelling approaches

		Problem Classes			
		Optimisation			Simulation
		Social Planner		RES-E Investor	
System Boundaries	Single Agent		E.g.: Monopoly: Regulator / Regulated Entity (OPCoP)	Profit Maximization (LP, MILP)	Agent Based, System Dynamics and Econometric Models
	Electricity Market	Welfare maximization, Cost minimization (QP, LP, MILP)	MPEC	MCP	

In electricity-market RES-E expansion modelling, two types of models are typically/frequently used. Optimisation models minimize long-term costs of the energy system (or maximize welfare); they compute the optimal shares of different renewables generation technologies, but technology-specific premiums (prices) cannot be recuperated explicitly. The decision-maker in this model class can be interpreted as a social planner. In contrast, market equilibrium models can include endogenous determination of the premiums required to meet technology-specific expansion targets, but these targets have to be defined ex-ante. We seek to combine these two modelling types: we aim to determine the premiums required to warrant the investments necessary to meet RES targets in a market-equilibrium setting, while allowing the technology-specific targets to be set in such a way that the total budget necessary for RES support is as small as possible.

Our model is formulated as a two-stage Stackelberg game to determine cost-optimal technology-specific expansion targets and corresponding RES-E premiums paid on top of the electricity price consistent with an overall renewables expansion target. In the second stage of our model, electricity market participants (conventional and renewables players) invest into different technologies and produce electricity to meet the demand. Anticipating the reaction of market participants, in the first stage the strategic Stackelberg leader (i.e., the regulator) decides on the optimal RES-E premiums that will induce investors to make the cost-minimizing investments, reaching the expansion target. The table and figure on the right display the stages, players and decision variables in the two-stage game.



Provided by courtesy of TenneT TSO (2010).

We first solve for a Nash equilibrium between the different stakeholders of the electricity sector. In the first step, we investigate the investment and dispatch for exogenously given technology-specific targets. Mathematically, this can be formulated as a Mixed Complementarity Problem (MCP) ("One-stage equilibrium game"). As a second step, we introduce the government as an explicit player, who sets policy and regulations to incentivize investment and achieve a given renewable energy share. It anticipates the market equilibrium resulting from its policies in a Stackelberg-type leader-follower game.

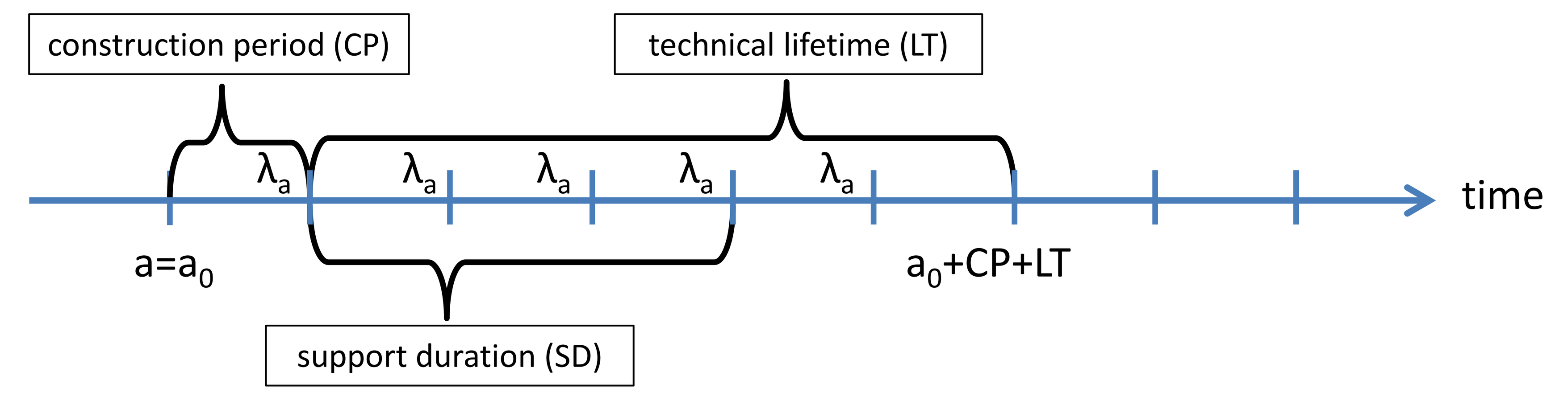
Following the methodology developed by Gabriel and Leuthold (2010) and extended by Huppmann et al. (2013), we then reformulate the equilibrium constraints of the one-stage model as disjunctive constraints, replacing them by binary constraints. Secondly, the bilinear objective function of the two-stage model (minimize RES-E premiums multiplied with generation, i.e. minimize RES-E support costs) is linearized using discretization, replacing the original MPEC by a mixed-integer linear programme (MILP). We determine the premiums resulting from an implementation of renewables targets up to 2030 for two fictive EU Member States, using a stylized dataset to obtain preliminary results.

Max problem of the renewables player in the lower level

$$\max_{x^R_{l,n,r,a},\, inv^R_{n,r,a}} \Pi^R = scale \cdot \sum_{a \in A} df_a \cdot$$
$$\left[\sum_{l\in L}\sum_{n\in N}\sum_{r\in R}\left(td \cdot \left(\left(eleprice_{l,n,a} - vc_{n,r,a}\right)\cdot x^R_{l,n,r,a} + \sum_{a-sd_r/scale \le aa < a}\left(avail_{l,n,r,a}\cdot inv^R_{n,r,aa} \cdot \sum_{aa<aaa\le aa+sd_r/scale} respremium_{n,r,aaa}\right)\right)\right) \right.$$
$$- \sum_{n\in N}\sum_{r\in R}\left(fc_{n,r,a}\cdot\left(inicap_{n,r,a} + \sum_{a-lt_r/scale \le aa<a} inv^R_{n,r,aa}\right)\right)$$
$$\left. - \sum_{n\in N}\sum_{r\in R}\left(\sum_{a-lt_r/scale\le aa<a} invc_{n,r,aa}\cdot inv^R_{n,r,aa}\right)\right]$$

$$\sum_{a\le a_0+CP}^{a\le a_0+CP+SD} \lambda_a$$

The Investment decision takes place in period a_0, resulting capacity can be used from a_0+CP until a_0+CP+LT (active time). The level of the feed-in-premium depends on the extend to which this capacity contributes to achieving the targets. In each period the renewable constraints have dual variables (shadow prices λ_a). In each period the premium is the sum of shadow prices over the duration of the active time that is eligible for support payments.



Max problem of the policy maker in the upper level

$$\min_{respremium_{n1,r,a}} \sum_a \left(df\_reg_a \sum_r \sum_l \sum_{a-sd_r/scale\le aa<a}\left(avail_{l,n1,r,aa}\cdot inv^R_{n1,r,aa}\cdot \sum_{aa<aaa\le aa+sd_r/scale} respremium_{n,r,aaa}\right)\right)$$

$$\sum_o b_{o,n1,r,a} \le 1 \qquad \forall o, n=n1, r, a$$

$$\min_{b_{o,n1,r,a}} \sum_o \sum_a \left(df\_reg_a \sum_r \sum_l td \cdot \sum_{a-sd_r/scale\le aa<a} avail_{l,n1,r,aa}\cdot inv^R_{n1,r,aa}\cdot b_{o,n1,r,aa}\cdot respremium^{level}_{o,n1,r,aa}\right)$$

$$respayment_{o,n1,r,a} = \begin{cases} respremium^{level}_{o,n1,r,a}\cdot \sum_l td\cdot avail_{l,n1,r,a}\cdot inv^R_{n1,r,a} & \text{if } b_o=1 \\ 0 & \text{if } b_o=0 \end{cases}$$

$$\min_{b_{o,n1,r,a}} \sum_a df\_reg_a \sum_r \sum_o \sum_{a-sd_r/scale\le aa<a} respayment_{o,n1,r,aa}$$

s.t.

$$respayment_{o,n1,r,a} \ge respremium^{level}_{o,n1,r,a}\cdot\left(\sum_l td\cdot avail_{l,n1,r,a}\cdot\left(inv^R_{n1,r,a} - \left(1-b_{o,n1,r,a}\right)\cdot cpot^R_{n1,r}\right)\right)$$

$$\sum_r\sum_{l\in L} x^R_{l,n1,r,2030} \ge \sum_{l\in L} d_{l,n,a}\cdot resgoal_{n1}$$

Preliminary results