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

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Overview

Feed-in tariffs have emerged as the most common support instrument. More recently, as renewable electricity generation is maturing and accounts for higher market shares, a transition to more market-oriented approaches can be observed. The single most important evaluation criterion, is cost-effectiveness. Limiting RES support costs to a reasonable amount decides about the social acceptance of support for renewable electricity generation. Policy makers are interested in the optimal allocation of renewable electricity generation expansion across technologies and time, when a certain expansion target has to be met in the future. The challenge is to find the prices and corresponding quantities to reach this target at minimal support costs, which means either a premium or an expansion target needs to be decided and fixed by a policy maker.

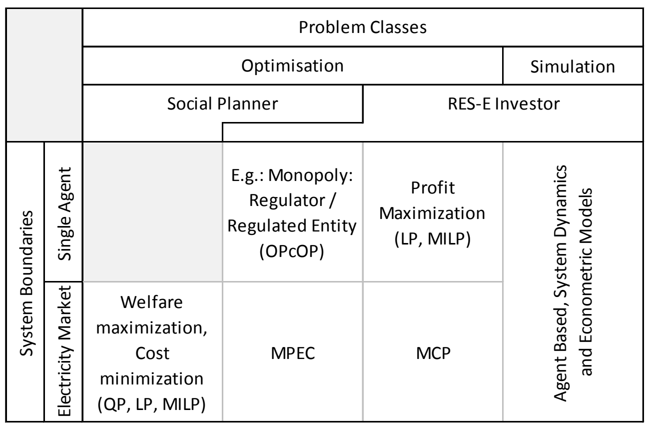

Figure 1: Types of models used for modelling RES-E expansion

In electricity market modelling, different types of models are used to simulate investments into renewable electricity generation technologies. Figure 1 provides a comprehensive, though non-exhaustive overview of different types of investment models.

Methods

Our model is formulated as a two-stage Stackelberg game to determine cost-optimal technology-specific expansion targets and corresponding RES 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 premiums that will induce investors to make the cost-minimizing investments, reaching the expansion target. Table 1 display the stages, players and deciosn variables in the two-stage game.

Table 1: Stages, Players and Decision Variables in the MPEC

Stage	Player(s)	Decision Variable(s)
I	Policy Maker min. support costs	Respremium
II	Ele. Market Actors max. revenues	Generation, Investments

In stage one of the model, the regulator ("Stackelberg leader") determines the optimal RES premium for each technology and year, which minimizes support costs (see equation (1.1)). The regulator uses a discount rate (and corresponding discount factor df_reg_a), which can be different from "private" discount rates used in the second stage. In the second stage, the electricity market participants ("Stackelberg follower") maximize their. The level of the premium set by the regulator determines which technologies the renewables player finds most profitable to invest in, and will therefore influence his investment decision inv^R. In minimizing support costs, the regulator takes this reaction of the renewables player in the second stage into account.

$$\min_{respremium_{n,r,a}} \sum_a \left(df\_reg_a \sum_r \sum_l \sum_{a-sd_r/scale \le aa < a} \left(avail_{l,n,r,aa} \cdot inv^R_{n,r,aa} \cdot respremium_{n,r,aa} \right) \right) \qquad (1.1)$$

There are two challenges in transforming the one-stage equilibrium game into a two-stage model: Equation(1.1) is bilinear because two variables are multiplied with each other, $inv^R_{\mathrm{DE},r,aa} \cdot respremium_{\mathrm{DE},r,aa}$. To work around the bi-linearity we need to reformulate the objective function in a way that will allow the model to solve as a mixed-integer linear programme (MILP).

To solve the two-stage model in GAMS, the equations of the second stage have to be included in some way in the support cost minimization on the first stage. The methodology adopted here is based on Gabriel and Leuthold (Gabriel und Leuthold 2010). Following the methodology developed by Gabriel and Leuthold (Gabriel und Leuthold 2010)and extended by Huppmann et al. (Huppmann, Gabriel, und Leuthold 2013) we then reformulate the equilibrium constraints of the one-stage model as disjunctive constraints, replacing them by binary constraints.

Results

To illustrate the intuition for our 2-stage approach we run the model in two different set-ups. First we run only the second stage as mixed complementarity problem with exageneous, technology specific targets for renewable electricity generation, implies certain values for the level of the premiums. Next we let the regulator choose the "optimal" levels for the premium only subject o a constraint that a certain overall share of rnewabel electricity generation is met in the last model period. We find that the premium levels differ from the exogeneusly chosen ones leading to overall lower support cost at for equal amounts of renewable electricity generation.

Conclusions

The 2-stage formulation combines the strength of both optimisation and mixed complemenarity types of problems. In the upper stage the support costs can be minimized, whereby the reaction of the renewables investor in the lower level can be taken into account.

References

Gabriel, Steven A., und Florian U. Leuthold. 2010. „Solving Discretely-Constrained MPEC Problems with Applications in Electric Power Markets". *Energy Economics* 32 (1): 3–14. doi:10.1016/j.eneco.2009.03.008.

Huppmann, Daniel, Steven A. Gabriel, und Florian U. Leuthold. 2013. „A Note on Allowing Negative Energy Prices in a Discretely Constrained MPEC (Corrigendum)". *Energy Economics* 40: 1023–25. doi:10.1016/j.eneco.2013.07.001.