Modelling renewable transformation paths considering hyperbolic discounting

Michael Bucksteeg, University of Hagen, michael.bucksteeg@fernuni-hagen.de

Overview

The transformation of energy systems involves multiple decisions by utilities, consumers, and regulators. Reaching the climate targets will require a massive expansion of renewable energy sources, putting intertemporal investment decisions and their understanding at the centre of long-term transformation strategies. The analysis of investments in infrastructure and facilities represents the main application field of energy market models. However, the modelling of investment decisions is usually simplified by assuming rational decision-making and identical preferences of investors. With the increasing decentralization of energy systems, the heterogeneity of actors, particularly private households, and corresponding differentiated discount rates become increasingly important for describing investment decisions and transformation paths.

Several studies have addressed private households' discount rates, emphasizing energy-saving investments and mature technologies like air conditioning, heating, or cars. However, private discount rates for innovative technologies, such as combined solar photovoltaic (PV) and battery storage systems, are considered in very few studies (e.g. [1]). With a focus on dynamic inconsistency, hyperbolic discount functions have been proposed as more accurate representations of how individuals value costs and benefits over time. So far, in energy system analyses, one applied study focuses on gas markets, not electricity markets [2]. Thus, there has been no study of hyperbolic discount rates in adopting renewable energy technologies.

The reference case of this study will be based on the cost minimum using a uniform discount rate with exponential discounting, implying a normative perspective focusing on the optimal design of policy instruments. However, anomalies in time preferences may reduce or amplify the effects of policy instruments asking for a change in the perspective from normative to descriptive. Considering the exponential and hyperbolic case, the lead question is: What are the impacts on transformation paths and target systems if exponential discounting is used in models when decision-makers apply hyperbolic discounting? This question will provide insights into the effects of policy instruments (e.g. investment support to reduce upfront costs versus feed-in tariff to guarantee a certain income).

Methods

An energy market model is developed to gain insights into the effects of hyperbolic discounting. The model is formulated as a linear problem with recursive optimization of yearly stages. The objective function minimizes total system costs (including variable production and investment costs):

$$\min TC; TC = \sum_r \sum_i \sum_t \left(\frac{c_{r,t}^{fuel} + f_i^{CO2} C_{r,t}^{CO2}}{eff_i} + c_{r,i}^{O\&M} \right) \cdot PROD_{r,i,t}$$
$$+ \sum_r \sum_i \boldsymbol{c_i^{ann}} \cdot INV_{r,i} + c_i^{fix} \cdot \left(cap0_{r,i} + INV_{r,i} - DEC_{r,i} \right)$$
$$+ \sum_r \sum_i \sum_t \left(CURT_{r,i,t} \cdot penalty \right)$$

The objective function is subject to side constraints, such as generation, storage and capacity restrictions. Decision variables are the dispatch of generation and storage facilities ($PROD_{r,i,t}$) and investments ($INV_{r,i}$) and decommissioning ($DEC_{r,i}$). The model assumes exponential discounting for the reference case (normative perspective) so that the annual investment costs c_i^{ann} are given by:

$$\boldsymbol{c_i^{ann,exp}} = c_i^{inv} \cdot \frac{(1+r)^N \cdot r}{(1+r)^N - 1}$$

Moreover, the model includes hyperbolic discount functions with a time variable discount rate impacting investment costs and decisions:

$$\boldsymbol{c_i^{ann,hyp}} = c_i^{inv} \cdot ANN_N$$

$$ANN_N = \frac{(1+r_1) \cdot r_1}{(1+r_1) - 1}$$

$$+\frac{(1+r_2)\cdot r_2}{(1+r_2)-1}\cdot\frac{1}{(1+r_2)^2}$$

$$+\cdots+\frac{(1+r_N)\cdot r_N}{(1+r_N)-1}\cdot\frac{1}{(1+r_N)^N}$$

$$\text{with } r_n=\frac{1+r_h\cdot n}{1+r_h\cdot(n-1)}-1 \text{ and } r_h=0.21 \qquad \text{(cf. [3])}$$

Discount rates and functions may also differ between technologies and regions. Furthermore, the model includes restrictions for modelling policy instruments, such as CO_2 pricing or renewables support schemes.

Results

A case study is performed using the example of Germany and covering the time horizon until 2045. The results show that considering a hyperbolic discount function (taken from [3]) for decentral renewable energies, such as solar PV and wind onshore, leads to significant differences in the transformation path and future generation mix. Figure 1 compares the development of the resulting energy mix until 2045 for both discounting approaches. Accordingly, hyperbolic discounting leads to earlier and higher solar PV and onshore wind adoptions. This effect can be explained by the assumed time-inconsistent preferences associated with a higher discounting of the near future and a lower discounting of the far future compared to exponential discounting.

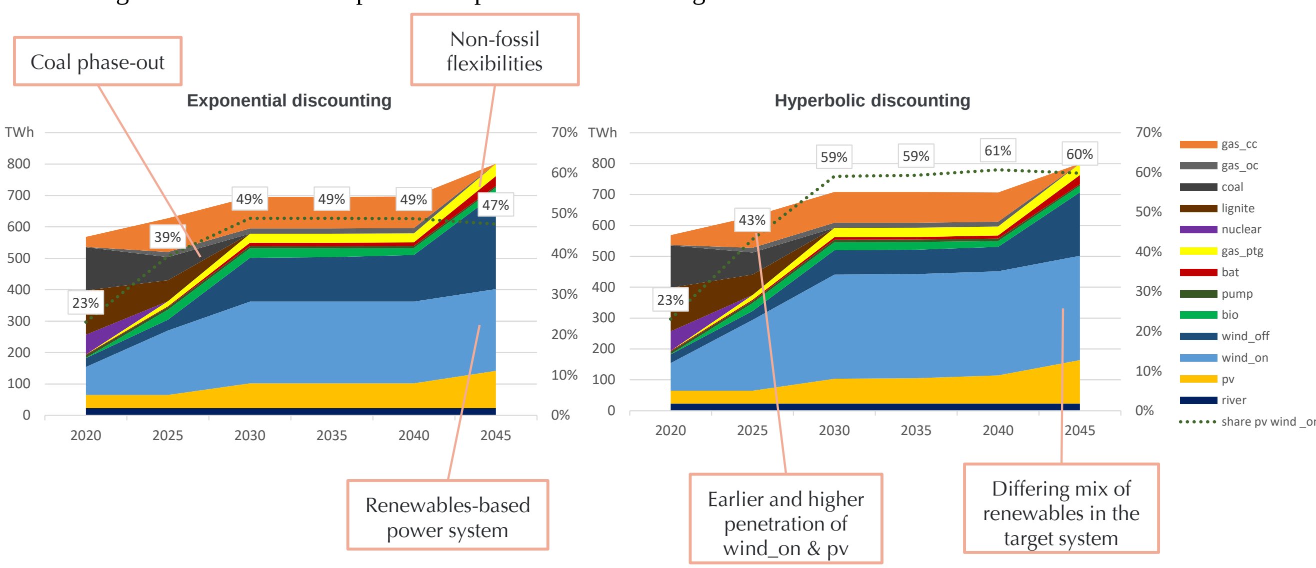

Figure 1: Comparison of the generation mix for exponential and hyperbolic discounting (cc: combined cycle, oc: open cycle, ptg: power-to-gas, bat: battery storage, pump: pumped storage, bio: biomass, wind_off: wind offshore, wind_on: wind onshore, pv: photovoltaics, river: run of river)

The differing generation mix comes with a different capacity mix, which has further implications regarding the residual peak load and the need for flexible capacities, such as pumped storage, battery storage and power-to-gas. Regarding transition costs until 2045, compensational effects between renewable technologies can be observed. Moreover, the differing mix of renewables reduces overall flexibility costs in the case of hyperbolic discounting. These findings conclude that if exponential discounting is used when decision-makers apply hyperbolic discounting, overall transition costs to a CO_2-neutral power system are higher (+4.1 %).

Conclusions

This contribution analyses the impact of hyperbolic discounting on renewable transformation paths using the case study of Germany. Results reveal that hyperbolic discounting leads to a differing generation mix and implications for transition costs. Further analyses will focus on an improved empirical foundation of the considered discount functions and extend on the effects of potential policy instruments.

References

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