Background and aim

Research gap
Increasing energy efficiency is known to be a significant driver for decarbonizing the energy system. To analyze the impact of energy efficiency ex ante usually technology-based models are applied. However, because of limited knowledge about long-term technological progress, the applicability of this approach is restricted for long modeling horizons. The objective of this study is to develop a concept that considers technological myopia in long-term energy demand modeling in the residential sector. To emphasize the added value of this study the concept will be applied to the German residential sector in terms of explorative scenarios up to 2050 focusing on electricity.

Methodological approach

Energy Appliance Model (EAM)
EAM is based on the simulation method and designed as a vintage stock model. To calculate energy demand the EAM comprises socio-economic (macro-economic drivers) and techno-economic (detailed stock representation) parameters. EAM is structured by three hierarchical levels: energy appliances (e.g. televisions, technologies (e.g. LCD) and efficiency classes (e.g. A++). Overall, the model captures 32 appliance alternatives. The diffusion process is modeled based on sigmoid growth curves in combination with a multinomial logit approach and different types of distribution functions (e.g. Weibull). In a subsequent step EAM results are decomposed by effect (activity, structural and intensity effect), using additive logarithmic mean Divisia Index (LMDI) to analyze the influencing factors on energy demand change.

Energy Service Model (ESM)
As techno-economic parameters are not known for long-term modeling horizons, ESM energy demand calculation is abstracted from certain appliances and represented by energy services capturing individual’s needs. ESM captures 12 energy services. To do so the energy-using appliances of EAM are assigned to these energy services. Although, there is just myopic technological knowledge about certain appliances. To define the transition between the two energy models, the obsolescence of technological knowledge about certain energy appliances needs to be captured. To do so, a patent-based model is applied that quantifies technological progress by appliances using an innovation indicator (KSM).

Knowledge Stock Model (KSM)
The knowledge stock per energy-consuming appliance is the key driver to derive a time span in which calculation of energy demand shifts from EAM to ESM. This time span depends on the appliance specific pace of technological progress. As technological progress cannot directly be measured, backward citations of patent documents to existing patents are used as correlative indicator (technological cycle time indicator; TCT indicator) to draw conclusions about the magnitude of technological myopia. To capture the continuous drop in ability to explain the future state of technology development (obsolescence of technological knowledge) the TCT indicator is transformed into exponential depreciation rates. When coupling EAM and ESM the depreciation rate serves as a weighting factor of the energy demand calculated.

Results & Conclusions

Scenario results
The high-energy-efficiency scenario (HEE) leads to a decrease of the German residential electricity demand from 139.5 TWh in 2008 to 101.2 TWh by 2050. Result representation in Fig. 5 illustrates the share of electricity demand based on EAM and ESM calculation by effect for the years 2030 and 2050. Beyond 2030 more than 50% of the electricity demand is described by energy services. Fig. 6 emphasizes the heterogeneity in technological myopia between the alternative appliances categories. Besides the technological cycle time the following parameters influence technology myopia: ownership rate, reinvestment cycles, market entrance or elimination and adoption behaviour.

Main findings
Overall, the analysis highlights that technological myopia is a key limitation of bottom-up methodology when developing long-term energy scenarios. The integrative concept enables a more transparent analysis of energy scenarios and essentially provides three advantages:
(1) all strengths of bottom-up modelling are retained for the short- to medium term projection horizon,
(2) by including an innovation indicator an appliance specific time horizon can be defined, that determines the point in time as of energy demand cannot any longer be calculated via techno-economic parameters and
(3) for the medium- to long-term projection horizon energy demand is abstracted from certain appliances and represented by energy services.

Limitations: The developed concept is restricted to existing energy services and furthermore only models incremental changes of technological progress.

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Acknowledgement
I would like to thank my colleagues Tobias Bollmann, Wolfgang Eichhammer and Martin Wietschel for their helpful suggestions on the theoretical and conceptual issues.

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