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| --- | --- | --- | --- | --- | --- | --- |
| Source | Sector | Region | Nodes | Intertemporal | GHG reduction (relative to 1990 level) | Cost Deviation |
| Price et al. | Coupled | Global | 16 | Yes | 50 % | < 10 % |
| DeCarolis et. al. | Electricity | US | 1 | Yes | 80 % | < 15 % |
| Li et. al. | Electricity | UK | 1 | Yes | 80 % | < 15 % |
| Sasse et al. | Electricity | CH | 2,258 | No | None | < 20 % |
| Trutnevyte et al. | Electricity | UK | 1 | No | None | < 23 % |
| Nacken et al. | Coupled | DE | 1 | No | None | < 10 % |
| Neumann et al. | Electricity | Europe | 100 | No | 100 % | < 10 % |
| My study | Electricity | DE | 1 | Yes | 95% | User Defined |

* First I want to start with motivation of my study
* Why it worths studying this topic, what is the point
* Classical cost optimization of an energy system returnas a single cost optimal solution.
* However long term investment decisions of an energy systems can not be made purely cost driven
* There are many other criterias that remain uncaptured by the model
* For example, social acceptance, scale of infrastructure projects, complexity and scale of the system itself,
* Those criterias can be counted as structural uncertainties of the model
* In addition to that, input parameters to the model are highly uncertain by nature
* Long term prediction of Cost of technologies, fuel prices, load profile
* As an end effect ,Real world transitions are usually more costly than modelled cost optimal solutions
* For this reasons it is important to analyse near cost optimal alternatives of an energy system.
* But what exactly near cost optimal alternatives

Near Cost Optimal alternatives are similar costly but sub cost optimal alternative solutions to cost optimal solution.

- In my study I utilize Modelling to Generate Alternatives methodology to study near optimal space of German power system.

* In this methodology cost optimal solution is used as an anchor point to explore the surrounding decision space
* In this graph this point is PV capacity given by the cost optimal solution as we diverge from cost optimum we see investment flexibility increases. 2% cost increase gives almost 50 GW flexibility in PV capacity investment
* So why modeling tio generate alternatives
* MGA helps to
* Observe technologically diverse but similar costly solutions
* Offers alternative transition pathways to meet unmodelled criteria like social exceptance for example
* Evaluate the stability of cost optimal solution , here we seeoffered PV capacity by cost optimum solution is not stable at all
* Show persisterent long term investment decisions ,again here we can say that even with 15% cost increase it is not possible to retrackt from PV technology completely
* Now as we discussed about the methodology applied lets talk about the novel point. W
* What is the novel point of this study?
* Here you see a list of studies that apply Studies that apply modeling to generate alternatives (MAG) to energy system models.
* To my knowledge, my study is the first to utilize MGA for an intertemporal model of German power system.
* I am going to analyze the period from 2020 to 2050 with total of 4 different modelled years.
* The model will also consider progressive GHG mitigation goal defined by the German authorities.
* To put it in one sentence
* Goal of my thesis is to explore near-optimal, intertemporal investment alternatives to German power system model while sticking to long term emmission goals of Energiewende.
* Hmm! now probably you are asking yourselves what is the deal with intertemporal?
* Well, Intertemporal models analyse the development of the power system through a modeling horizon.
* They give the solution as snapshots of the transition across multiple years
* And plus they consider the investment dependencies between modelled years
* On the left side you see a single year solution, which gives cost optimum for 2034
* On the right side you see the same solution with 4 different moddelled years from 2019 to 2034.
* In the latter it is possible to observe how the transition will look like.
* As we are finished with terminology lets take a look at the application procedure
* I applied MAG on „URBS“ , which is a linear energy system modelling framework
* URBS already has working intertemporal modules, however it is originally capable of doing only classical optimization.
* In order to apply MAG with urbs I created an independent module that analyses near cost optimal alternatives
* Which first runs the model with a classical cost optimization.
* Minimum cost found is applied to the model as a new constraint with a small percentage increase
* A set of generation capacities are choosen to be objected to optimization , here only PV capacity is choosen but program is designed to accept also more than one
* A new objective function is formulated to first maximize then minimize objected generation capacities
* As outcome a range of capacity is obtained for the same cost
* Some other capabilites of the new feature:
* It takes a list of slack values and applies them in succession automatically
* For multi node models it is possible to choose optimization regions independently for each optimized generation technology.
* Region selection made available also for the original objectives
* Now it is time to see the first results ☺
* I have the input file for 2050 German power system from a former student‘s master Thesis
* I analyzed this input file my new module
* In the first graph PV capacity is subjected to optimization
* and in the second graph onshore wind capacity is subjected
* As we see ,
* for current ghg mitigation goals it is not possible to imagine a power system for germay either without onshore wind or PV technologies
* However as we diverge from the minimum cost, investment flexibility of technologies improves drastically.
* PV capacity has a greater range of flexibility as also pointed out by other similar studies
* Here is an intertemporal solution.
* Example input files from urbs git hub repository is used for this analysis
* On left side only solution of the last year is shown and
* on the right side you see development of the solution through years
* These graphs are only for pv capacities, which is the objected technology
* Here is another view of the same solution this time only for 10 percent cost increse
* On the left side you see how system will evolve when pv capacity is subjected to minimization
* On the right side PV capacity is subjected to maximization
* Here we can interpret that wind energy and PV are substitutes of each other
* Minimization of one will cause increase of the other due to ambitious GHG reduction goals.
* Lastly I want to talk about the next steps I plan to achieve during course of my thesis