Quantifying Climate Change Measures Towards Mitigation and Adaption Optimisation

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Overview

Efforts to challenge climate change while maintaining a standard quality of life may be hindered by the lack of a clear action plan, as seen in the decarbonisation uncertainty of the UK's heating sector[1]. The motivation of this research is to assist stakeholders in creating suitable decarbonisation plans by reviewing climate change mitigation and adaptation measures and quantifying key model properties, such as technical costs and resource demands. A generalized approach is developed to apply indicators within optimisation methodologies and model the integrated impact of a mitigation and adaptation measure set. Demand and impact functions are defined from technical cost and resource consumption indicators and measure integration considered through a resource coupling approach. Results show that a method that defines the proposed indicators and functions while optimising for emission and damage impact responses is capable for use in a multi-objective framework to identify integrated measure responses for stakeholder usage.

Methods

Applying a similar method as van Vuuren et al.[2], the common properties of mitigation and adaptation actions allow for intersecting model approaches. Similarities between measure types can be described in terms of consumed resources, such as land area and construction materials, technical costs, such as installation expenses, and application tools, such as political and social programs. Condensing these terms to define the resource demands and effective costs of a measure, both mitigation and adaptation can be considered in equal contexts. A demand function (Eq. 1) is derived from these terms to value the relative opportunity cost of a measure set, considering the resources and social welfare of the target region. Measures differ in their impact responses and a similar approach is taken to formulate a combined impact function (Eq. 2). Interpreting energy accessibility and commodity demands as constraints to the problem, an analysis that aims to maximize the impact response while minimizing demands is developed (Eq. 3).

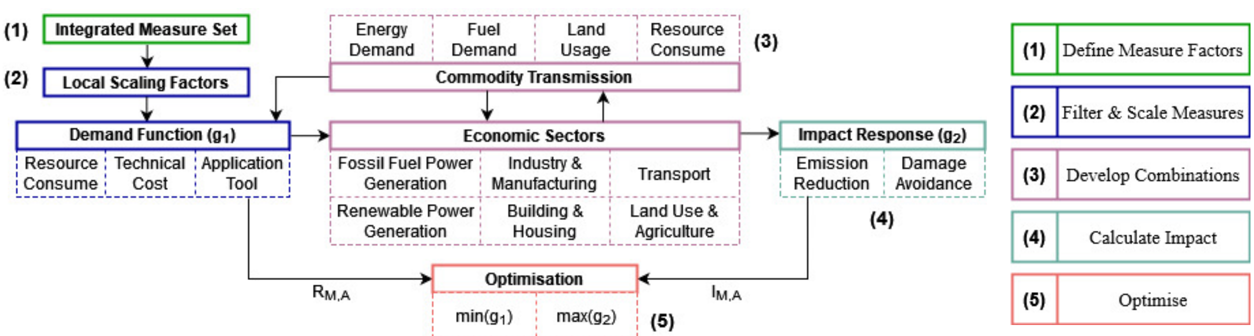


Figure 1: Measure mapping and analysis process

$$g_1 = \sum [W_M \cdot R_M + W_A \cdot R_A] \cdot S \quad (1)$$

$$g_2 = \sum [W_M \cdot I_M + W_A \cdot I_A] \cdot S \quad (2)$$

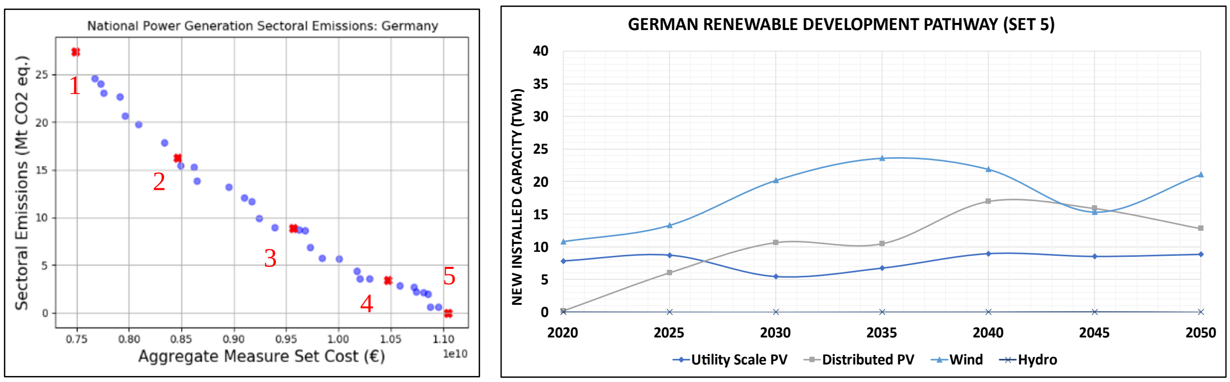
$$\min(g_1)\,, \max(g_2) \text{ s.t. } KI \in KI_{Region} \quad (3)$$

W = Measure weights, R = Resource factors, I = Impact factors, S = Scaling factors, and KI = Key indicators

Figure 1 maps the multi-stage process and highlights key model stages. First, implementation cost, resource consume, and feasibility criteria are defined for each measure. Measures are filtered and scaled for the analysed location and measure sets initialised. Commodity transmissions from measures may be considered independently or as a function of measure magnitudes and applied as a secondary or integrated component of the resource demand function. Resulting sets are optimised for emission reduction, damage avoidance, or as an integrated response. Using wind power as an example, technical costs are defined as the capital expenditure and operational costs, grid connection costs, and value depreciation. Consumed resources consist of required installation area and impacts are defined as the emission reduction due to the replacement of fossil fuels. Costs are scaled by regional wealth factors and the impact potential by available area and energy sector emissions. As an exemplary analysis, renewable energy integration in the German energy sector was assessed using the NSGA-2 genetic algorithm[3]. Measure constraints and energy supply boundaries were defined using national emission and energy production data[4], projected German renewable potentials[5], and technological cost data[6]. Referenced technologies were utility scale and distributed PV, onshore and offshore wind, and hydropower and were defined by their theoretical potentials, installation costs, and capacities.

Results

Ranked measure sets in Figure 2a depict the feasible boundary of the problem, sorted based on cost expenditure and impact. The impact function was defined as the emission reduction of eliminated fossil fuel production and the analysis looked to identify individual measure capacities and installation timing. Installed capacities in Figure 2b reflect the similar results in literature[5] (excl. biomass), indicating the proposed modelling method was capable for the general quantification of measures for analysis. The applied method constrained measures by limiting the capacity of each technology to their theoretical remaining potential within Germany. This offered a straightforward path to achieve a stable model response but created a dependence on the data used to define the potentials. Alternative methods may use available resources or measure installation rates as constraint criteria and extending the model to account for these aspects will bring results closer to realistic expectations. A key benefit of the generalized definition approach is the capability to extend and modularize an analysis as necessary, extending the model's usability and accuracy as supporting information is included. The final paper will contain similar impact analysis pathways and will further consider commodity transmission effects and alternative measure scopes.



Figures 2a (Left): Ranked renewable measure sets and 2b (Right): Representative installation pathway

Conclusions

This study proposed a method to quantify key model indicators of mitigation and adaptation measures for integration into an optimisation framework. Defining generalized key indicators facilitates the application of measures and their integrated responses within optimisation studies, without depending on specific input criteria and measure definition methods. It helps as well to build an understanding of how climate change measures may fundamentally interact when considered in combined contexts. In an exemplary analysis, an initial optimisation study was made to validate the proposed method to integrate measures. A consistent response was able to be achieved, describing measure interactions for a single impact response. Future research should further validate the approach with alternative measure scopes and define general commodity transmission criteria to properly capture realistic measure interactions.

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References

[1] Lowes, R. and Woodman, B. (2020). Disruptive and uncertain: Policy makers' perceptions on UK heat decarbonisation. Energy Policy, 142, p.111494.
[2] van Vuuren, D.P., Isaac, M., Kundzewicz, Z.W., Arnell, N., Barker, T., Criqui, P., Berkhout, F., Hilderink, H., Hinkel, J., Hof, A., Kitous, A., Kram, T., Mechler, R. and Scrieciu, S. (2011). The use of scenarios as the basis for combined assessment of climate change mitigation and adaptation. Global Environmental Change, 21(2), pp.575–591.
[3] Deb, K., Pratap, A., Agarwal, S. and Meyarivan, T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. IEEE Transactions on Evolutionary Computation, 6(2), pp.182–197.
[4] Statistical Office of the European Communities. (1990). EUROSTAT: Regional statistics: Reference guide. Luxembourg: Eurostat.
[5] Hansen, K., Mathiesen, B.V. and Skov, I.R. (2019). Full energy system transition towards 100% renewable energy in Germany in 2050. Renewable and Sustainable Energy Reviews, 102, pp.1–13.
[6] NREL (National Renewable Energy Laboratory) (2021). 2021 Annual Technology Baseline. Golden, CO: National Renewable Energy Laboratory. https://atb.nrel.gov/.