SEEDS project - Deliverable 1.3

An automated approach to integrate stakeholder preferences in the search for alternative carbon-neutral energy system configurations

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With this deliverable we design an approach that automatically uses stakeholder preferences to improve the generation of technically feasible and economically viable energy system design options. More precisely, we use the ranking of feasible options arising from the first iteration of modelling results with stakeholders as an input to the new process. Based on this input, we automatically generate new parameters for use in the SPORES algorithm for the generation of alternatives. The SPORES search is guided in such a way that stakeholders' desired features are maximised and undesired ones simultaneously minimised. At the same time, however, the SPORES search keeps generating many ways of deploying infrastructure spatially to meet these high-level preferences. The result is a set of feasible system design options that all meet stakeholder preferences but do so in different ways, leaving room for further decision flexibility.

1. Human-in-the-loop (HIL) methods: minimal background

The SEEDS project's modelling workflow revolves around the key idea of generating many equally feasible energy transition options for Portugal, as opposed to a single 'optimal solution'. This allows stakeholders to assess the trade-offs among the feasible options and discuss together what is most viable in practice. Yet, acknowledging that the feasible options that might matter for real-world discussion are virtually infinite (Lombardi et al. 2022), the project foresees the use of stakeholder feedback to update and improve the generated option space in the direction of stakeholder needs.

The scientific literature refers to approaches relying on user feedback to refine a computational workflow as 'human-in-the-loop' (HIL) or interactive methods (Meignan et al. 2015). The idea that man-machine interaction can provide better results than a purely machine-driven approach is consolidated in many fields, but not so much in optimisation, where it is still in an early adoption phase. The design of a human-in-the-loop optimisation process with application to energy system modelling is thus a first-of-its-kind scientific contribution airsing from the SEEDS project. Moreover, as mentioned above, the project's modelling workflow is grounded on the generation of many equally feasible alternatives via the SPORES optimisation method, an original development of techniques known as 'Modelling to Generate Alternatives' (MGA). Such a combination of HIL with MGA optimisation has never been attempted in any field of application and constitutes another original development.

2. HIL role in the SEEDS modelling workflow

Figure 1 summarises and simplifies the modelling workflow foreseen in the SEEDS project, highlighting the role of HIL in the overall process. Feasible energy transition options are generated from an energy system model via the SPORES optimisation algorithm and then enhanced with socio-environmental impact information quantified by an ad-hoc software developed by the consortium. A user interface lets stakeholders explore the options and select their preferences. For instance, some stakeholders might prefer the one option with the highest degree of hydrogen deployment; some others might value more the degree of decentralisation of the system and prefer the option that maximises such an aspect; et cetera. And yet, the availability of many more alternatives, including alternatives that might lie halfway between such likely conflicting priorities, will let stakeholders expand and refine the search and try and find solutions that compromise between their and other stakeholders' preferences.

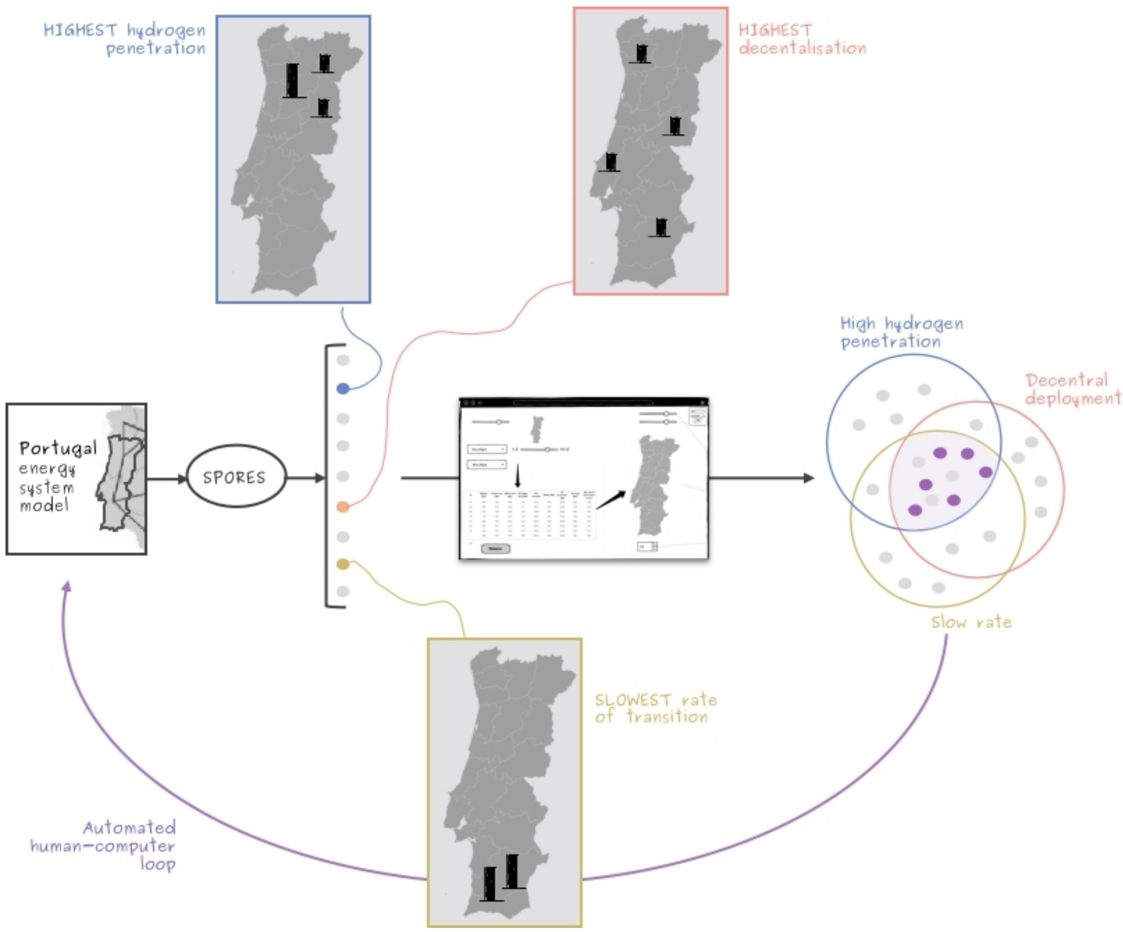

Figure 1. Simplified modelling workflow of the SEEDS project, with a focus on the human-in-the-loop approach.

However, it is possible that the initial sample of feasible options will not be enough to find a compromise solution that makes every stakeholder relatively satisfied. Therfore, we plan to collect the data about stakeholder preferences stored by the interface and feed them back to the SPORES algorithm. In particular, we will use the data to reparametrise and guide the search strategy of the algorithm, which will target specifically the generation of many alternatives around the most wanted and unwanted system features, as further detailed in the following section.

3. Method for HIL automation

The SPORES algorithm lends itself to customisation based on arbitrary preferences. It is possible to tweak the search in such a way to generate more energy transition options that have the same high-level features of the most highly ranked stakeholder choices or, viceversa, that avoid the undesired features (Lombardi et al. 2022). While maintaining such high-level features approximately stable, the SPORES algorithm generates diversity of system configurations in the way the infrastructure is located at the sub-national scale. This allows stakeholder having multiple ways to achieve a given high-level energy transition end-state, which may allow overcoming some unmodelled real-world complexities, such as the low social acceptance towards the deployment of infrastructure in a given area. The following sub-sections detail the procedure by which we realise such human-guided customisatin.

3.1 Stakeholder data conversion pipeline

The interface used by stakeholders to select preferences is equipped with a simple multi-criteria decison making system that allows aggregating individual preferences into an overall ranking of 'top-favorite' options. Such a ranking is produced in the form of a CSV file, each alternative in the list being identified by a unique 'SPORE_ID' associated to it when it is first generated in the modelling workflow. The SPORE_ID can be used to look for the complete list of features of each alternative in a summary table, which is also generated in the form of a CSV file as part of the modelling workflow.

Figure 2. Sketch of the automated process that converts data about stakeholder preferences into a YAML file that can be read by Calliope.

These two CSV files constitute the only input required for the automated conversion of stakeholder preference data into something that can be used to guide the search within the SPORES algorithm. The SPORES algorithm is, in fact, part of Calliope, the energy system modelling framework adopted in the SEEDS project for the generation of alternatives. As such, the SPORES search strategy can be reparametrised by building ad-hoc instructions in a YAML file that Calliope knows how to interpret (Figure 2).

3.2 Automated generation of instructions to guide SPORES

There are different ways in which the SPORES search strategy could be guided to look for feasible options with simillar high-level features to those preferred by stakeholders but different in the way they locate infrastructure at the sub-national scale.

One possibility is to define new constraints in the mathematical formulation of the problem that force the system design to remain in a certain range of high-level capacities. For instance, if the number one option in the overall stakeholder ranking has very high shares of offshore wind, one could force the model to have a capacity of offshore wind in a small range of that featured in the given system configuration. Within this newly defined constraints, the SPORES algorithm would still allow generating spatial and technology diversity. This can be referred to as 'brute-force' guided search.

A second possibility is, instead, to capitalise on the way in which SPORES normally explore the design option space from multiple anchoring points . Wanted and, respectively, unwanted high-level features of a given stakeholder-favourite option could be parametrised in the search in the same way in which certain technology features are maximised and minimised in parallel batches of SPORES (Lombardi et al. 2022). In other words, wanted and unwanted features can be parametrised as secondary objectives in a linearised multi-objective formulation of SPORES (Lombardi et al. 2022). The advantage of this possibility, compared to the brute-force option above, is that it does not entail arbitrary decisions about the range of allowed capacity values for different types of energy infrastructure, such as wind offshore. Instead, the search strategy automatically and autonomously maximises the deployment of wanted features while simultaneously minimising the deployment of unwanted ones. Accordingly, this is the strategy we adopt for the the automated human-computer loop of the SEEDS project.

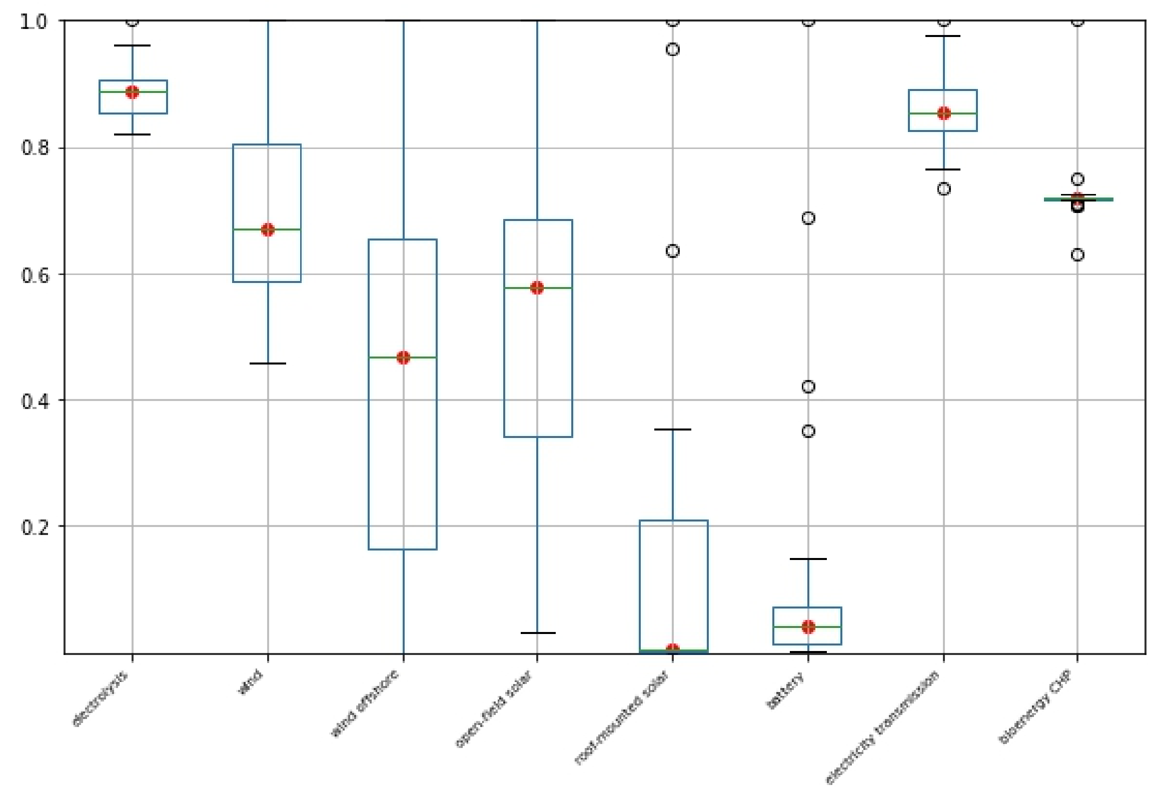

Figure 3. Example computation of distribution of normalised values across the whole SPORES design option space for representative high-level system features.

What remains to be automated is the identification of wanted and unwanted features in each of the most-favourite stakeholder options listed in the 'overall ranking' file. To do so, we look at the distribution of high-level feature values across the whole design option space, calculating the median after normalisation between minimum and maximum values (Figure 3).

For each stakeholder-favourite option in the ranking, we check the relative distance from the median of each of its high-level features. Anything with a relative distance from the median larger than 20% in absolute terms is considered significant. If the distance is positive (i.e., the given feature has a value much higher than its median), this is labelled as a critical wanted feature of that configuration. if the distance is positive, the opposite occurs.

Finally, we use this information to generate a YAML file (hli_spores.YAML) which translates the wanted and unwanted features into unitary values that can be interpreted through the Calliope modelling framework as weights for the SPORES search. We generate one formulation of the SPORES search forf each of the stakeholder-favourite system design options in the overall ranking. In addition, we generate one SPORES search formulation that tries to synthesise all wanted and unwanted features into a single search.

4. Results

Table 1 shows an example output provided by the abovementioned procedure.

SPORE_ID	Electrolysis (GW)	Wind (GW)	Offshore Wind (GW)	Open-field Solar (GW)	Roof-mounted Solar (GW)
0	5.5	5.4	0	84.6	0
1	5.2	10.7	0.5	79.3	3.9
2	3.8	30.8	0	16.7	0
3	3.9	28.3	0	24.8	0
4	4.5	5.4	9.9	58.5	0
5	4.3	5.4	9.1	63.2	0
6	4.3	5.4	9.2	62.0	0

Table 1. Example of summary table with the cost-optimal solution, three conventional SPORES (1-3, before HIL) and three SPORES generated via guided search based on stakeholder inputs (4-6). The assumption is that the wanted feature is offshore wind and the unwanted one is onshore wind.

In this example, the number one option in the overall stakeholder ranking (generated randomly) features substantially less onshore wind compared to the median of all SPORES, but substantially more offshore wind. These are accordingly translated into wanted and unwanted features and parametrised into Calliope as elements of the SPORES search strategy. Table 1 shows a subset of the original SPORES (options 1-3) alongside three new SPORES (4-6) resulting from the HIL approach. As desired, the new feasible options all feature relatively high shares of offshore wind and low shares of onshore wind. The overall high-level features are similar, but still slightly different. In fact, the spatial configuration of deployment differs for each of the three generated HIL-SPORES, leaving further room for stakeholder discussion about which configuration would lead to a viable implementation in practice.

Conclusions

We confirmed that SPORES lend themselves to cusomisation and particularly to the use of human-in-the-loop approaches. We have formalised a method to translate information collected from stakeholder through the user interface into meaningful quantitative parameters to guide the SPORES search in the desired direction. Finally, we have implemented such a method into Python scripts ready for use by the consortium as a piece fo the overall modelling workflow.

The results show that the designed method is effective at generating new alternatives that align more to stakeholder preferences in terms of wanted and unwanted high-level system features. While doing so, the method retains the capability of generating further spatial diversity in the technology neighbourhood where the search is guided, leaving further decision flexibility to stakeholders.

References

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