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SOFTWARE TOOL ARTICLE

REVISED APOLLO-Live: A multi-criteria-based webtool for synchronous group decision making and consensus support in energy and climate policy deliberations

[version 3; peer review: 2 approved, 2 approved with reservations]

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Abstract

Pursuing a just, equitable, and desirable sustainable transition requires stakeholders from a diverse set of backgrounds and varying viewpoints to actively engage in deliberations to co-design their future. Facilitating stakeholder engagement activities has so far relied on either qualitative frameworks and processes or simplified quantitative approaches such as surveys, which render eliciting tangible and actionable outcomes challenging. Although group decision making and consensus reaching can leverage the capacity of multi-criteria decision aid to address this gap, tools implementing such processes remain scarce.

Here, we present APOLLO-Live, a stakeholder engagement webtool that can be used live in workshops to facilitate deliberations in energy and climate policy. The tool relies on linguistic variables, which are easily comprehensible by the participants, and employs the 2-tuple TOPSIS group decision making method to prioritise needs faced by different communities, as well as solutions that can be implemented to advance the energy transition. It also fleshes out differences in the voting patterns of different groups of voters and calculates a consensus metric to shed light on conflicts arising. Through tips and

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suggestions provided within the tool and based on multiple rounds of voting, supplemented by live discussions during the workshop, the tool can improve consensus and synthesise multiple perspectives in the produced outcomes, assisting towards bridging the conflicts and producing solutions that are widely accepted.

We highlight the functionalities of the webtool, including how it can be used to advance stakeholder dialogues, in two pilot use cases targeting the preferences of the youth in terms of (a) actions to advance climate action and (b) investments to be prioritised. Finally, although the development and use principles followed focused on the energy and climate policy domain, the tool can be used in any application where multi-criteria decision aid and group decision making can potentially be employed.

Plain Language Summary

Climate change is a serious threat to humanity. However, not all people agree on the best way to address it, since neither the impacts of climate change nor the potential benefits of the green transition are evenly and fairly distributed. As such, it is important that all people become an active part of the discussions and debates. Here, we present APOLLO-Live, an online tool that can be used live in workshops to assist such discussions. For example, it can be used to assist voters in highlighting the most important challenges they face in their communities, as well as indicate solutions, such as investments, that should be urgently implemented. The tool aims to improve the agreement between participants, based on multiple rounds of voting, discussions, and displayed suggestions. A core component of the tool lies in understanding how the opinions of different groups of people differ (e.g., citizens compared to academics or policymakers). The methodologies employed offer a seamless use of the tool by both the participants and potential organisers of workshops. We also present two use case examples focusing on understanding the preferences of young people in questions related to climate action, explaining how the tool can be used, and discussing what types of results can be produced. Despite our focus on themes related to climate change, the tool can be used in various domains and decision-making in the context of conflicting viewpoints.

Keywords

Group decision making, consensus reaching, multi-criteria decision aid, stakeholder engagement, deliberation, climate action, just transition

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REVISED **Amendments from Version 2**

This version includes changes in the text description drawing on the valuable feedback received by the reviewers. These include:

1) The addition of discussions on foundational and methodological novelties of APOLLO-Live compared to existing methodologies and other MCDA-based webtools, to enhance the presentation of the added value of the tool.

2) The addition of the term "pilot" with regards to the use cases throughout the text, to further ensure that they are perceived primarily as numerical examples, serving to showcase functionalities of the tool, and ways to flesh out results, rather than generalisable findings.

3) Further discussions on strategic voting and consensus dynamics regarding the preservation of disagreement, the indirect tracking of erratic voting patterns, and limitations of consensus metrics.

4) Minor proofreading corrections, including defining missing abbreviations and improving clarity (i.e., on the research objective).

Any further responses from the reviewers can be found at the end of the article

Introduction

Involving and interacting with stakeholders within the scientific process has been gaining traction[1], not to mention the increasingly acknowledged need to better communicate scientific findings to broader audiences as well as enable implementation of these findings in real-life applications[2]. Although stakeholder theory has its roots in the business world[3], as a means for businesses and entities to engage with those affected by their decisions[4] and in the essence of corporate social responsibility[5,6], stakeholder engagement has found applications across many fields that are relevant to sustainability[7] including environmental conservation[8,9] and decarbonisation[10], and provided support to both scientific and policymaking processes[11,12].

Especially with regard to climate change mitigation, and particularly upon raising aspects of justice and fairness, stakeholder engagement is of utmost importance: the envisaged energy transitions, albeit vital to ensure environmental conservation and addressing climate change, are expected to also have negative impacts on national and regional scales—for example, on communities that have hitherto thrived on fossil fuel development (extraction, use, export, etc.). Similarly, inequalities between and within countries may be exacerbated as a result of climate change impacts or distributional implications of climate policies[13]. As such, all stakeholders—citizens included—affected the most must be part of the process that gives shape to their future; their inclusion can help towards societal acceptance and legitimise the required transformations[14].

More often than not, however, stakeholders are not a homogeneous group of people that share a common vision for their future, nor for the right pathway to that. This conflict of viewpoints, strategies, motives, and concerns can spark vivid debates over the desired course of action across multiple geographical scales (e.g., climate negotiations among countries, national policy consultations, municipal planning deliberations, etc.)—e.g., on the timeline of the transition, policies and required investments, eligible technologies, or the allocation of funds[15,16]. When deliberating such topics, and in particular when engaging with affected communities, it is therefore important to flesh out and highlight these different priorities and preferences, as well as attempt to bridge conflicting viewpoints and converge to widely acceptable paths through compromises.

Despite this increasingly acknowledged importance to include stakeholders in energy and climate policymaking as well as in scientific processes underpinning it, deliberation and co-creation activities with the aim to accommodate and synthesise different perspectives, and make progress towards bridging said conflicts remain scarce[17]. Most existing efforts focus on producing stakeholder-informed outputs through deliberation exercises[18,19] or asynchronous elicitation activities—for instance, with the use of multi-criteria decision aid (MCDA) approaches[20–22]. MCDA techniques, especially within the context of group decision making (GDM) and consensus measuring/reaching, are considered very useful in engaging with stakeholders due to their ability to incorporate multiple dimensions of any studied aspect, while maintaining comprehensibility in terms of their interaction with participants providing their feedback[23]. Yet, despite numerous tools existing in the MCDA literature[24–30], only a handful have been used synchronously in workshops[31–33], in a way that resolves conflicts and approaches consensus live, and only in context-specific and thus non-generalisable applications.

To address this gap, the research objective of this paper is to introduce APOLLO-Live, a GDM- and MCDA-based interactive webtool designed for stakeholder engagement during live workshops. The tool enables stakeholders to voice their opinions, assists in reconciling diverse and potentially conflicting perspectives and viewpoints, and facilitates prioritisation of needs and evaluation of solutions. Developed within the principles of deliberative democracy, the processes followed in the tool aim to enable equitable, fair, and inclusive transitions in collaboration with stakeholders.

Methods

Overview and theoretical concepts of the APOLLO-Live stakeholder engagement webtool

Drawing from an existing asynchronous MCDA tool[20,34], APOLLO-Live constitutes a significant expansion in the field of MCDA tools for stakeholder engagement, primarily in that it can be used live in workshops to allow stakeholders to express their opinions, as well as to bridge conflicts in participatory workshops through consensus-based decision aid. As such, although the methodological foundations rely on existing methods with targeted expansions, the tool itself, including the interface and its functionalities, constitute a novel contribution to the field of participatory decision support. Other commonly known MCDA webtools include DEXi[35], which uses hierarchical trees and qualitative rule tables, and Hiview3[36] and Web-HIPRE[37] which employ value trees and functions grounded in the multi-attribute value theory. In these tools, a stakeholder can define the rule tables (in the case of DEXi) or provide quantitative weights (for Web-HIPRE this can be achieved through the Analytic Hierarchy Process). However,

none of these tools offer built-in functionalities for real-time or formal preference aggregation internally. Consequently, to be useful in the context of GDM, the individual models of the stakeholders should be post-processed externally, or they should jointly build one representative model. The built-in voting, aggregation, consensus metrics and multi-round process of APOLLO-Live aim to address this gap.

The following concepts are core in the development and use of the tool:

- Alternatives: A set of options that the stakeholders vote on and evaluate.
- Criteria: The dimensions against which each alternative is evaluated by the stakeholders. The selection of criteria should ensure that the principle of a "consistent family of criteria"[38] is respected, to ensure comprehensibility and that all necessary dimensions are accounted.
- Vote: Each stakeholder provides their evaluations using non-negative Likert-type linguistic scales—e.g., {Very Low, Low, Medium, High, Very High}—which can be used to perform semi-quantitative calculations.
- Ranking: Different MCDA techniques offer different outputs (i.e., selection, ranking, classification). Those typically employed in GDM, and as such in the APOLLO-Live webtool, comprise mostly of aggregation and/or distance-based approaches that offer a ranking of the alternatives, the translation of which depends on the selection of criteria.
- Consensus: A metric expressing the agreement and proximity—in line with the distance-based focus of the MCDA framework—in the votes between the group of stakeholders. In this context, consensus refers to 'soft consensus'[39,40], defined as the level of agreement, rather than a 'hard consensus'—which is instead defined as a unanimous agreement that is almost impossible to achieve[41].

In particular, stakeholders participate by casting their votes on different options through a fit-for-purpose and completely customisable survey-style questionnaire. To increase the comprehensibility of the aforementioned concepts, we can consider the following working example: Stakeholder S_k might consider (and vote accordingly) that the construction of a factory for producing components for renewable energy plants [Alternative S_i] could potentially have a 'High' impact [Stakeholder's vote following a linguistic scale] on regional development [Criterion C_j]. The tool then aggregates all individual votes—namely the evaluation of the impact of all alternatives to all established criteria independently and from all stakeholders—and then generates a collective solution that reflects the group's overall perspective. This outcome is essentially a ranking of alternatives, ordered from the most to the least significant/impactful, based on how they are evaluated by the participants across the criteria. Returning to the previous working example, if most stakeholders believe that the factory could indeed have an equally high impact not only on regional development but on other dimensions as well (e.g., job creation), this alternative is expected to rank among the top positions with a qualitative evaluation of high importance. The tool also identifies the level of (dis-) agreement between the participants and offers tailored tips to improve the consensus among the stakeholders in multiple rounds of voting.

The methodological foundations of the tool are rooted in the operations research domain, drawing in particular on the MCDA, GDM, and consensus making and reaching fields. Relying on MCDA, the tool aligns with the complexity of climate and energy trade-offs, since decisions are often based on environmental, economic, social, and technical criteria. It employs the 2-tuple group TOPSIS method, which combines TOPSIS[42], a well-established MCDA methodology for ranking alternatives, with 2-tuples[43] that essentially constitute an expansion of linguistic terms that are easy for stakeholders to comprehend, as well as with a GDM setup[44] in that it is based on multiple stakeholders voting simultaneously. Through these methodological choices, the tool enables comparisons and ranking under value-based judgments, which are essential for navigating energy policy objectives (e.g., which investments should be implemented or prioritised according to stakeholders and what is their potential impact). In particular, the typical MCDA problem consists of two-dimensions with alternatives being evaluated against certain criteria. When employed in a GDM context and the stakeholders offer the evaluation, this problem is converted into a three-dimensional problem; in that case, the additional dimension consists of the multiple stakeholders participating in the process (Figure 1). The aim is to calculate a 'group solution' combining all votes of the stakeholders, expressing the belief of the group as a whole.

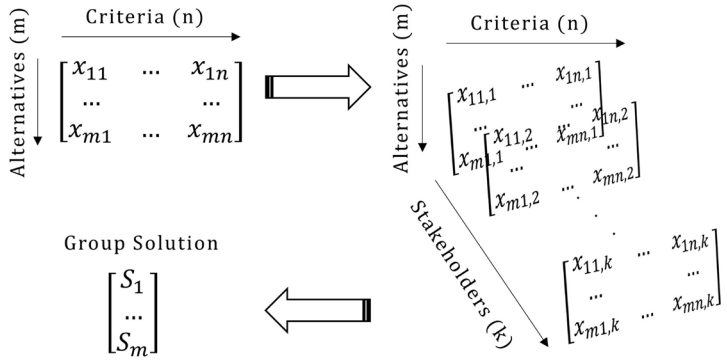


Figure 1. The group decision making process followed in APOLLO-Live.

To reach the group solution, the most common approach is to aggregate the *k* matrices presented in Figure 1 using weighted averages to configure a new decision matrix that represents the entire group. Then, after another set of weighted averages, the vector representing the final group solution can be calculated[45]. Alternatively, and instead of calculating a group decision matrix, Krohling and Campanharo[44] calculated a vector representing the solution of each independent stakeholder using the fuzzy-TOPSIS method. Then, they combined these vectors in a new matrix, where this time the stakeholders essentially comprised a new set of evaluation criteria of the MCDA process, before eventually using another round of fuzzy-TOPSIS to calculate the final group solution. APOLLO-Live uses the latter approach, since in energy and climate policy it is important not only to reach a group solution but also to understand the conflicts existing in the individual solution of each stakeholder[20]. It also employs the 2-tuple TOPSIS instead of the fuzzy TOPSIS[34], since the use of 2-tuples is usually closer to the way stakeholders operate—compared to fuzzy sets[20]. This semi-quantitative approach allows the integration of both qualitative and quantitative criteria, reflecting the reality of energy and climate policy decisions where not all criteria are strictly numerical.

Additionally, by selecting only the stakeholders that belong to a certain category (e.g., based on socio-demographics, occupation, etc.), we can follow the same approach to calculate the solution of each category and compare them (e.g., identify how the results differ based on the viewpoint of academics compared to industry experts or policymakers). The rationale for performing these types of category-based analyses lies in the fact that the tool is envisaged to be used in workshops with participants from diverse backgrounds. However, in such cases, it is possible that markedly divergent preferences may be exhibited based on the background of each participant[20,21,46]. Comparisons between the collective solution and the solutions preferred by members on a specific category may reveal patterns that advance the debates. This design enables integrating uncertainty and stakeholder diversity considerations in decision and policy support, which is common in climate-related topics.

The methodological choice followed comes at a disadvantage with regards to consensus reaching processes (CRP). Such processes refer to feedback mechanisms that provide stakeholders with suggestions on how to willingly change their votes towards increasing the consensus levels of the group[40]. In the original APOLLO version, no such processes were implemented, since the tool only focused on consensus measuring. Usually, in the first approach, which uses aggregations based on weighted averages, the group decision matrix and the matrices of the stakeholders are of equal dimensions and format, making them easy to compare and provide the required tips. This is not the case when first calculating the individual solution for each stakeholder and then the global group solution, due to the difference in the dimensions of the initial matrix that the stakeholders vote on and the matrices emerging along the way. For this reason, most applications of CRP opt for the former approach[45]. Given our methodological reliance on the latter process though, as explained above, and to address this gap, in APOLLO-Live we apply a consensus support process based on tips using the following protocol, which constitutes an expansion on the existing methods used in the original APOLLO tool. We first use the consensus measurement metric introduced in 34, which compares the individual solution vector of each stakeholder with the group solution vector, and calculates how close each stakeholder is to the group solution, thereby offering a universal consensus of the group (expressed as a percentage). Then we identify the stakeholders that feature a proximity to the group consensus below the average of the group and find the alternatives with the highest distance between their solution and the group solution. Finally, in the subsequent voting rounds, stakeholders are asked if they want to change their votes on the identified alternative, offering changes to their evaluations against all potential criteria.

Usually, in computer-simulated GDM and consensus reaching, a core aspect is the speed of convergence[47]. However, in our case, convergence lies entirely in the participants' behaviour, which is not always cooperative as implied in all simulated cases, where some form of compromise is always assumed[45]. To facilitate this process, a target featuring a predefined desired level of consensus and a total number of voting rounds that can realistically be performed (e.g., to account for participants' fatigue) should be agreed with the participants beforehand. In this case, the deliberations end once the first of the two conditions are met (i.e., the desired level of consensus is achieved, or the total number of voting rounds is reached without the desired consensus). We note, however, that consensus reaching is not necessarily the ultimate objective. As such, even in the cases that the process ends without consensus, the results can still be of added value to inform decision- or policy-making on different viewpoints in the group that are difficult to bridge. Following the solution process introduced by Krohling and Campanharo[44] ensures that the individual and grouped solutions are also calculated to accompany the results produced by the tool.

These theoretical underpinnings bring forward group dynamics that should be considered. A core issue lies in understanding why the opinions of participants could change by participating in activities supported by APOLLO-Live. The tool offers group-focused suggestions that can be used to feed discussions between rounds, which can help stakeholders improve their understanding of their own and the others' preferences and beliefs, as well as be exposed to different viewpoints not previously thought of or largely considered. These mechanisms could influence participants towards changing their opinions and consequently their votes. Crucially, the ability of deliberations to change opinions has long been established in the literature (see for example Fishkin's work on "Deliberative polling"[48], or Chong & Druckman's work on framing and deliberation[49]). Our first pilot use case presents an example of how such behaviours could manifest in the tool and alter the results, changing the order of the alternatives, rather than force the first-round opinion of the majority. However, as previously discussed, convergence to a consensual result is neither guaranteed nor the only end goal. During the discussions, the emergence of disagreements is also possible, especially in cases of small or ideologically diverse groups. In this case, it is the responsibility of the organiser and moderator of the exercise to ensure that the discussions avoid escalation and

conflict, but rather remain fruitful, and that the results can meaningfully inform decision makers, especially on aspects that were found difficult to bridge, or were not bridged in the end. As such consensus metrics may still be useful to reflect such differences but are limited in terms of reaching a widely accepted solution. The tool opts not to penalise dissenting voices at the individual level, hence preserving all viewpoints expressed.

Finally, the potential for some form of strategic behaviour from participants, who may try to take advantage of the system to promote self-interests, is always part of any system that tries to aggregate individual preferences into a collective result. Drawing a conceptual parallel to Arrow's impossibility theorem[50], we argue that rarely can any mathematical tool be foolproof against all types of potential manipulation. The tradeoff between truthful expression and strategic influence is not only a weakness of the APOLLO-Live tool, but of collective decision-making in general. The methods employed within the tool encourage truthful expression and discourage strategic voting. Crucially, it would be rather difficult to influence the results through strategic behaviour within the employed MCDA approach, as the input required is more complex than simple selection, and hence strategic distortion is diluted (i.e., participants evaluate all alternatives against a set of criteria rather than selecting a preferred option). The tool also presents a figure on the individual anonymised consensus level of stakeholders (see the Operation section), which provides a simple qualitative security over truly erratic voting patterns. The anonymised identifier of each stakeholder remains the same in each voting round within this figure, to ensure an indirect tracking of continuous distortions in the form of soft social enforcement. In these cases, the awareness of the participants and the moderator can arguably be more important than any mathematical algorithm to protect the process.

Implementation

The APOLLO-Live webtool is a sophisticated platform designed to facilitate anonymous online voting workshops, while ensuring data security and integrity so that stakeholders and interested parties feel confident and safe to participate. This application leverages Hexagonal Architecture, allowing the application core to define abstract interfaces (ports) and leaving the implementation details (adapters) to be provided by external components. This architecture promotes the Dependency Inversion Principle (DIP) which enhances flexibility and testability, as the core remains decoupled from specific technologies or frameworks.

The clear separation of concerns and the use of interfaces make it easier to write unit tests for the application core. Test doubles can be easily created for ports, allowing for isolated testing without the need for external resources. In addition, the modular structure of Hexagonal Architecture facilitates the maintenance and future extension of the software. Changes to the external interfaces do not affect the core logic, reducing the risk of introducing bugs and enabling easier transitions between technologies and frameworks. Replacing or updating external dependencies is simplified, as long as the new adapters conform to the existing ports.

The first step when designing with the Hexagonal Architecture is to define the primary and secondary actors. In our case, we have three primary actors: the administrator of the system, the moderator of the workshops, and the voter(s). Our secondary actors are the algorithm used to support our decisions, the caching mechanism of the requests, the database, the emailing system, the encryption system, and the import methods (Figure 2). The second step is to identify our ports by envisioning different interactions among the actors. These interactions are then implemented through ports, using a technology-agnostic

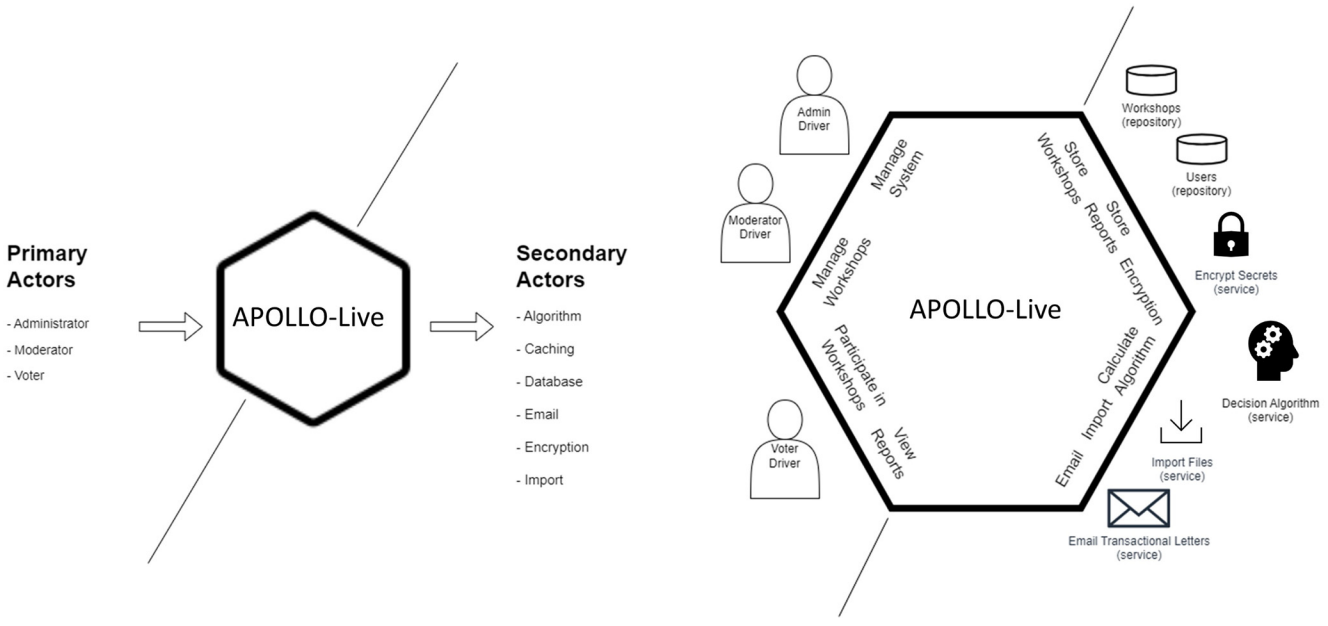


Figure 2. Primary and secondary actors including their respective ports in the Hexagonal Architecture of APOLLO-Live.

programming interface. The primary and secondary ports are presented in Figure 2.

Finally, we define the adapters, following the principle that for every adapter we typically have two implementations: the "real" adapter doing the work in the production-level system, and the tester that tests the port's functionality. In our case, we have the following adapters:

- Algorithm Adapter, which implements the 2-tuple TOPSIS calculations
- Database Adapter
- The Entity Framework, which supports all known databases like SQL Server, MySQL, MariaDB, PostgreSQL, SQLite—the current implementation works with a PostgreSQL database
- Cache Adapter, using .net core process in-memory caching
- Email Adapter, that sends e-mail messages using the SMTP protocol
- Encryption Adapter, using Entity Framework Core and Microsoft Data Protection stack to store secret keys
- Import Adapter, using Excel files to import manually-ran workshops
- UI Adapter
- .net core web app
- .net xunit acceptance tester.

In essence, by using Hexagonal Architecture and integrated with the 2-tuple Group TOPSIS algorithm, the APOLLO-Live webtool offers a secure, scalable, and decision-enhancing platform for anonymous online voting workshops. It seamlessly integrates cryptographic techniques, real-time communication, and multi-criteria decision-making to ensure a trusted and engaging voting experience.

Operation

Considering that APOLLO-Live is intended to be used live in workshops, the operation of the tool can be viewed from two perspectives: (i) the participants of the workshops; and (ii) the organisers and by extension the moderator(s) of the workshop.

In both cases, the webtool is considered a lightweight application without intensive background processes. For potential organisers that intend to host the tool in their own servers (see Software Availability statement) the following minimum hardware requirements may apply (depending on the expected traffic):

General Requirements:

- CPU: 1 vCPU (1 GHz or higher)
- RAM: 512 MB – 1 GB
- Storage: 1 GB of available disk space (actual usage is typically lower but depends on data retention and usage patterns)

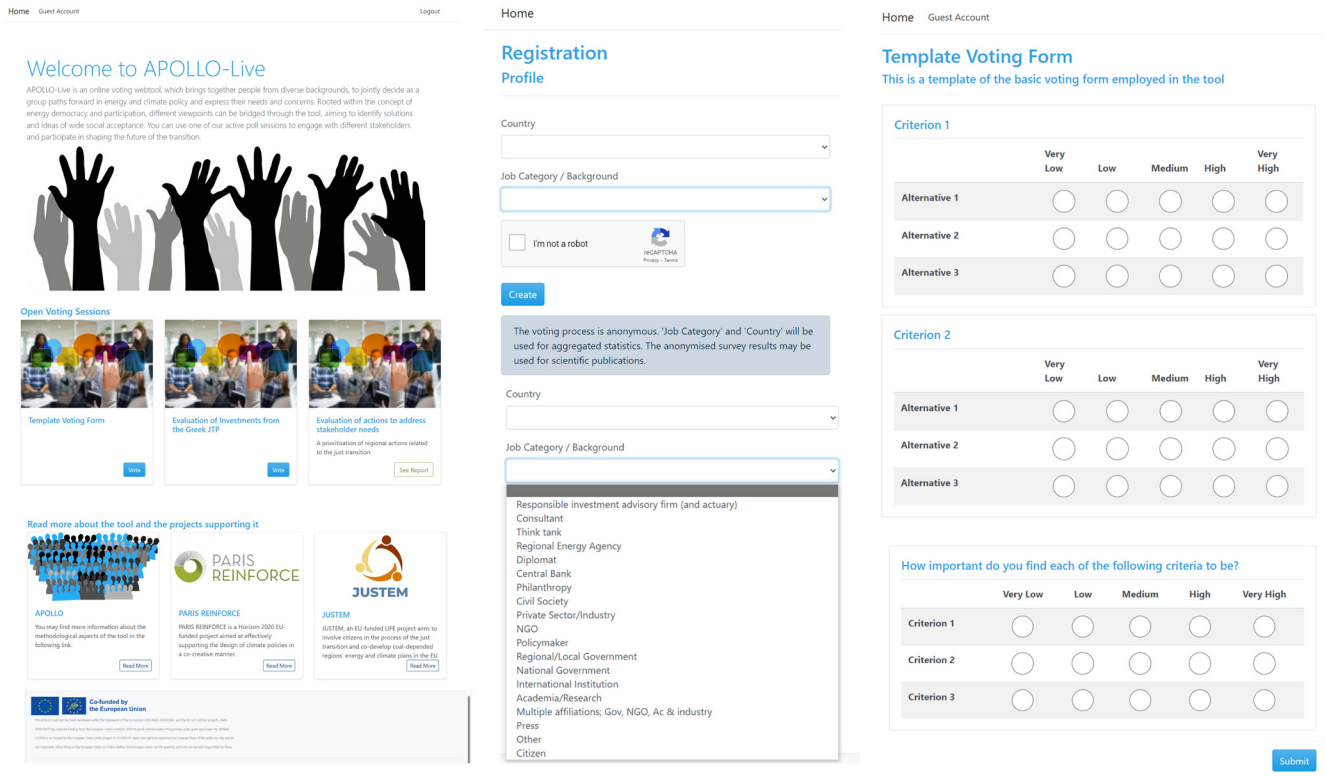
Containerised Deployment:

- Alpine-based Image: 512 MB – 1 GB RAM
- Ubuntu-based Image: 1 GB – 2 GB RAM

The tool from the perspective of the participants. Starting from the viewpoint of workshop participants (Figure 3), users arriving on the landing page (Figure 3a) can view information on the tool and choose one of the active poll sessions to participate in an engagement exercise with different stakeholders. It is also possible for users to land directly on the registration page if, for example, the organisers use QR codes to facilitate the process. After joining a poll, the user is initially asked to provide some basic information on the country and background of the users (Figure 3b). This information is collected to facilitate the category-based analyses described in the methods section. The tool collects no names, e-mail addresses, or other information that can be used to identify the users. A disclaimer explicitly explains how the data collected (in reference to the user's background and country) will be used to provide aggregated results. Through drop-down menus, the tool can facilitate a wide range of backgrounds, enabling engagement that is as inclusive as possible. Hence, the tool Additional background options and extra profile variables can be added in future iterations of the tool.

After providing the required information, the user is directed to the voting page of the selected session. In Figure 3c, a generic template of such a survey is presented. In real-life applications, both the alternatives and the criteria will be filled out by the organiser, while detailed information (e.g., questions) will be displayed to ease the voting process. Finally, the user can also provide values for the criteria weights—i.e., importance of each dimension—against which alternatives are evaluated. The uniqueness of these weights reflects the independent valuation and preference system of each participant.

During workshops, when all participants cast their votes, these are analysed in the background. While a user waits for either the results to be calculated or other participants to vote, they are presented with a loading page. Once the calculation process is over, the participants are automatically redirected to the results page (Figure 4; the results presented in the figure are based on random responses). This marks the beginning of the feedback process, where results are discussed among participants and a moderator, across three dimensions: (i) prioritisation (Figure 4a); (ii) consensus (Figure 4a–b); and (iii) results based on the background of the participants (Figure 4c). Essentially, the participants can see a rank of the alternatives that reflects the importance given to each option by the whole group, the consensus level, indicating how close the votes of the participants were and how each participant is positioned within the group. All participants are anonymised, meaning that a user can see the consensus level of the other anonymised users, but not any identifying attributes.



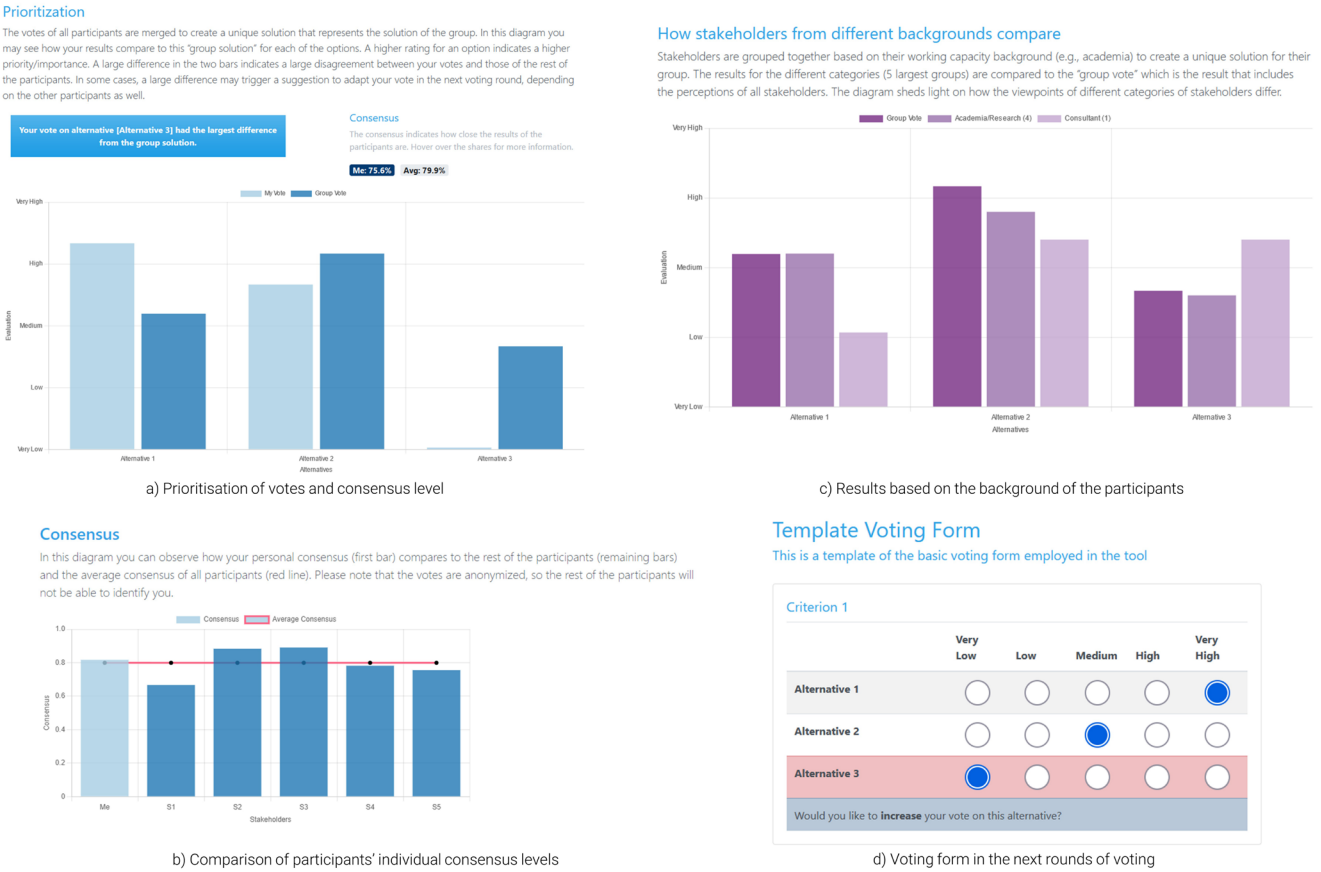
a) Landing Page b) Registration Page c) Voting Page

Figure 3. Initial pages of the APOLLO-Live webtool from the perspective of workshop participants.

Finally, the tool presents results based on the background of each user, to flesh out different dynamics between users of different working capacity. This attribute can be expanded to incorporate different groups (e.g., analysis based on gender, age, etc.). Each plot within this page is coupled with explanatory text to help the participants understand and interpret the results presented in the figures. As indicated in the overview of the theoretical concepts, participants with lower levels of consensus receive tips for adapting their preferences in the next voting rounds to improve consensus. These tips are provided during the presentation of the results (Figure 4a) and the re-opening of the voting form with their previous votes pre-filled (Figure 4d); the users are automatically redirected there by the moderator once discussions are over.

The tool from the perspective of the organisers. To allow organisers and moderators to facilitate the operation of the workshop, the tool includes a slightly differentiated interface (Figure 5), but with additional functionalities to enable setting up the workshop's structure and moderating the process (i.e., calculating results and managing the direction of users between the presentation of results and voting). Any interested party intending to host a workshop using the tool must register for an 'admin' account, which is an open and free process, but is subject to confirmation from the development team. Alternatively, the tool can be downloaded from GitHub (see software availability statement) and launched in the users' server of choice. When logging in as an admin, an organiser has the chance to define the setup of a new workspace, which represents the activities they wish to perform during the workshop. When setting up the structure, the organiser adds basic information regarding the questionnaire of the exercise, such as the name of the workshop and the number of alternatives and criteria, which can also be adapted later (Figure 5a).

In the main interface for defining the details of the structure of the questionnaire, there are two types of information that should be filled in (Figure 5b–c). The first type refers to the presentation of information to the participants so that they have a proper understanding of what is required from them; these include details on the name and description of the questionnaire, which are presented both in the landing and the voting page and could help users choose the poll they are interested in (e.g., in the case of parallel polls), as well as understand how to fill in the survey. The second type is related to technical information, including the set of parameters necessary for the framework of the tool to be operational based on the defined theoretical principles; such information includes the choice of linguistic terms used for evaluating the alternatives and the criteria (e.g., number of scales, qualitative terms, and their interpretation to semi-quantitative values; Figure 5d), which can be similar for the two cases depending on the



a) Prioritisation of votes and consensus level

c) Results based on the background of the participants

b) Comparison of participants' individual consensus levels

d) Voting form in the next rounds of voting

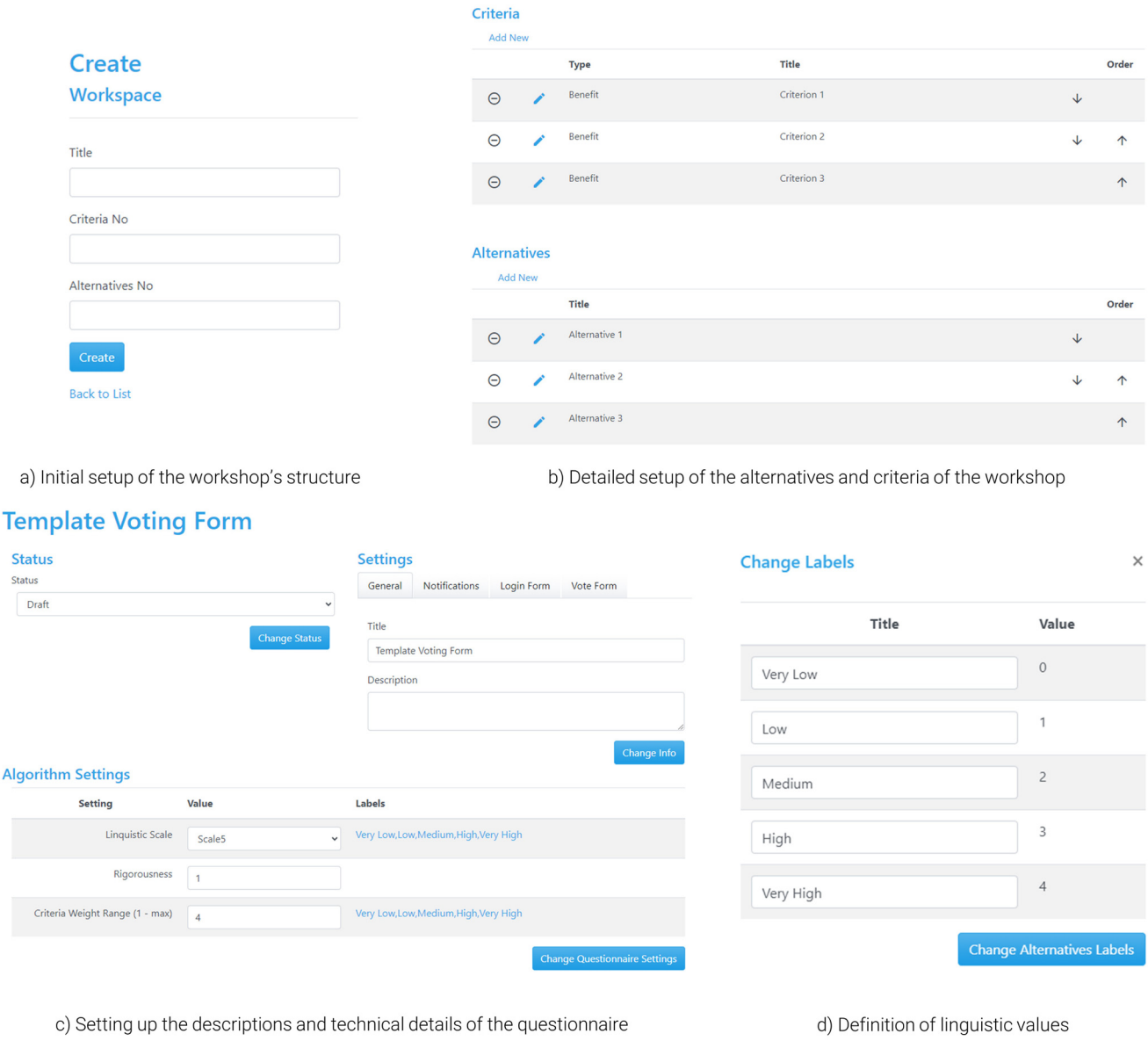
Figure 4. Results page and voting form for the follow-up round of voting.

overarching structure of the questionnaire. Finally, the 2-tuple Group TOPSIS method requires setting up a rigorousness parameter, which depends on the level of 'penalty' that should be imposed to disagreements in the calculation of the consensus (i.e., same level of disagreement leads to larger reduction in consensus under a strict parameter). This value is suggested to be set between 0.6 (strict value) and 1 (usually employed when there is only one round of voting), with the middle value (0.8) usually being employed when multiple rounds of voting are expected[51].

Once the structure is set, a workshop moderator —who is not necessarily the organiser, although the two should be in close collaboration—can make the poll public so that participants can join and start voting.

During the preparation of the workshop (Figure 6), the admin should set the status (Figure 6a) to 'Draft' in order to be able to configure the questionnaire, such as defining the alternatives and criteria in detail. During the 'Draft' stage, the poll is hidden from non-admin users. Once the setup of the questionnaire is finalised, the admin can change the status to 'Accepting Votes', which creates a public poll in the land page that users can access and start voting (as in Figure 3). During voting, the tool offers the organiser/moderator some functionalities to facilitate the voting process and have a better overview of the flow of the workshop, notably including a 'pre-calculate' button that monitors the number of participants that have already submitted their responses, the current level of consensus, or options for the moderator to send in-tool messages to participants (e.g., in case there are time limits for voting). Once all participants have voted, the admin can proceed with the next steps through the 'Finalised with Feedback' status, which closes the poll (no further voting is accepted onwards). This allows the admin to calculate the solution (Figure 6b) and automatically redirects users to the visualisation of the calculated results, including the tips highlighted in the previous sections.

During the 'Finalised with Feedback' status the users have access to the voting results (including their own results and the entire group's), and hence this is the primary stage where deliberations among participants take place. By sharing their screen and the group's results, the moderator can help all participants follow these discussions closely. No personalised results are presented as the moderator is not voting; these can be viewed by each user on their own screens as well. Once discussions are concluded or reach a stage at which there are indications that a follow-up vote can lead to improvements in terms of resolving conflicts within the group, the moderator



a) Initial setup of the workshop's structure

b) Detailed setup of the alternatives and criteria of the workshop

c) Setting up the descriptions and technical details of the questionnaire

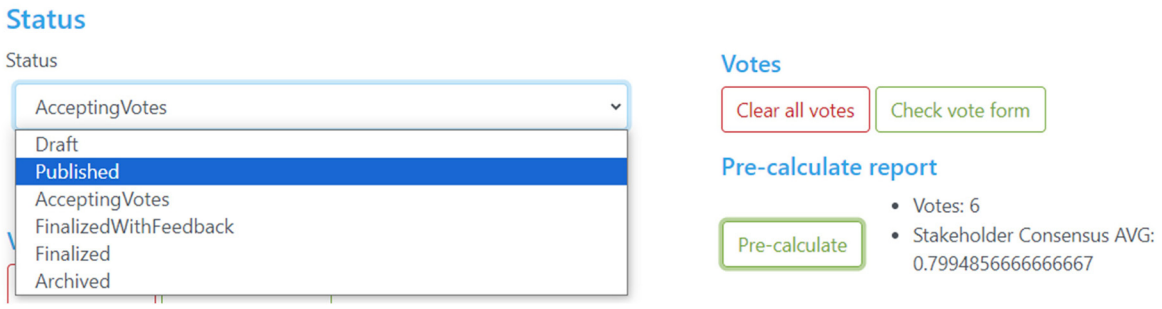
d) Definition of linguistic values

Figure 5. Main interface for setting up a questionnaire in APOLLO-Live from the perspective of the organiser.

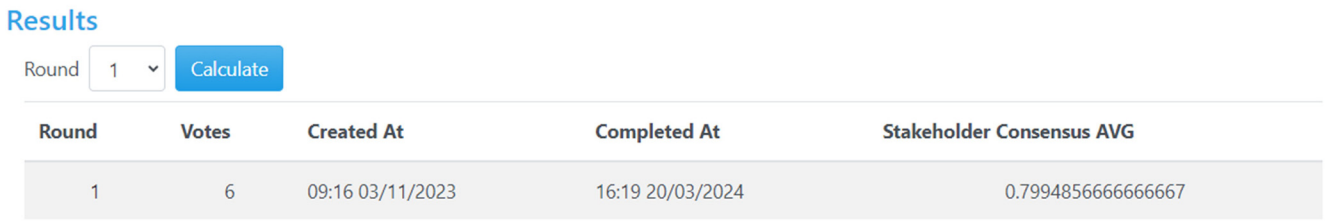
can change the status to 'Accepting votes' again, which provides the participants with the opportunity to change their votes.

Once the workshop is over, the admin can view and download the results either for further processing or archiving offline in a concise JSON format (Figure 7), which is easy to handle by most common data processing software and ensures anonymity as it maintains the encrypted user-ID used within the tool.

The final functionality offered to admins and workshop organisers is that of an asynchronous analysis, which is essentially a solver of the 2-tuple Group TOPSIS without the feedback mechanism for consensus support, since in this setup no follow-up voting can occur. Although the tool is primarily developed for synchronous use in workshops, occasionally polls are rolled out in advance of a workshop or are used as a completely standalone engagement process. In this case, the "Import" functionality in the workspace section of the tool enables an admin to upload an excel with the format of the workshop and the responses of the stakeholders, with the tool then creating a workspace, compiling the votes and immediately offering the opportunity to calculate the results based on the 2-tuple Group TOPSIS previously described. The template to do so can be found in the supplementary material and the tool's GitHub page (see Data and software availability



a) Moderation of stages



b) Calculation of results

Figure 6. Stages of the voting process and calculation of results.



User: 5511E427-3B54-491B-B3B4-2CC248A1C3DF

Alternative	[4] Criterion 1	[5] Criterion 2	[6] Criterion 3	Topsis
[11] Alternative 1	3	2	2	3.2
[12] Alternative 2	2	2	1	1.2
[13] Alternative 3	1	3	1	0.8

User: C6464E5F-7A34-48B1-8E45-E12C7AA336DF

Alternative	[4] Criterion 1	[5] Criterion 2	[6] Criterion 3	Topsis
[11] Alternative 1	1	2	4	2.666667
[12] Alternative 2	1	1	2	0.666667
[13] Alternative 3	2	3	1	2

{"stakeholders":[{"uid":"5511E427-3B54-491B-B3B4-2CC248A1C3DF","w":1.0,"topsis":3.2,"aid":11},{"uid":"5511E427-3B54-491B-B3B4-2CC248A1C3DF","w":1.0,"topsis":1.2,"aid":12},{"uid":"5511E427-3B54-491B-B3B4-2CC248A1C3DF","w":1.0,"topsis":0.8,"aid":13},{"uid":"C6464E5F-7A34-48B1-8E45-E12C7AA336DF","w":1.0,"topsis":2.666667,"aid":11},{"uid":"C6464E5F-7A34-48B1-8E45-E12C7AA336DF","w":1.0,"topsis":0.666667,"aid":12},{"uid":"C6464E5F-7A34-48B1-8E45-E12C7AA336DF","w":1.0,"topsis":2.0,"aid":13}],"groups":{"Global":[{"topsis":4.0,"aid":11},{"topsis":0.363636,"aid":12},{"topsis":1.212121,"aid":13}],"Academia/Research (2)":[{"topsis":4.0,"aid":11},{"topsis":0.363636,"aid":12},{"topsis":1.212121,"aid":13}]},"consensus_stakeholders":{"5511E427-3B54-491B-B3B4-2CC248A1C3DF":0.820487,"C6464E5F-7A34-48B1-8E45-E12C7AA336DF":0.713109},"consensus_degree":{"11":0.733333,"12":0.857576,"13":0.85}}

Figure 7. Data format for the results of each workspace.

section), and it closely resembles the format produced by common online forms (e.g., Google forms) to increase interoperability.

Pilot use cases

In this section, we will present two pilot use cases of the tool to elicit stakeholder opinions on aspects of climate action and just transition with emphasis on the role and perspectives of the youth. The two pilot use cases represent the two main functionalities of the tool presented in the methods section: the synchronous (live) use of the tool in workshops, and the asynchronous analysis on previously conducted polls. Although intended to constitute concrete examples of how the tool can be used, the two use cases should be primarily treated as pilot appraisals with numerical examples showcasing the capabilities of APOLLO-Live, rather than concluded research with policy-relevant outputs; the group of participants do not necessarily represent representative samples of any particular stakeholder group, neither the selection of alternatives and criteria can be viewed as potentially exhaustive or complete. As such, any commentary on the results is primarily intended to showcase how results of the tool from future exercises can be interpreted and translated into relevant findings—if representativeness is achieved—rather than generalisable findings on their own.

Pilot use case I (synchronous use): Live evaluation of actions the youth can undertake to support climate action

In this first pilot use case, we attempted to collect the perceptions of undergraduate students among those enrolled in the climate change mitigation modelling course of the School of Electrical and Computer Engineering, at the National Technical University of Athens, with regard to a diversity of actions young scholars can undertake to support climate efforts. Participation was voluntary—with no academic incentives provided—and anonymous (for the voting stage) as clearly communicated to the participants in advance and through disclaimers within the tool itself. Although anonymity within the tool is de facto ensured by software design (i.e., neither the participants nor the organiser can identify the origin of any particular vote), expectedly as with any live workshop the discussions can provide hints on the viewpoints of specific participants, which is however expected during such deliberations. Five students showed interest and participated in this exercise.

The selection of alternatives, criteria, and linguistic scales used to elicit the participants perceptions are presented in Table 1. The overarching theme of the questionnaire focused on what young academics should do to advance climate action and the role of science in society. Hence, a good alternative out of the five possible ones within this configuration would be one that has a large impact on climate action, increases the trust of the public in climate science, and improves the quality of science itself.

Two rounds of voting took place, while no predefined target for the level of consensus was established due to time restrictions. Initially, the organisers (authoring team) provided a brief context on the questionnaire and what is expected from the participants regarding the voting process, avoiding detailed explanations to ensure that the participants will not be biased. Then, the participants accessed the tool and started voting. After the first round, the results were calculated and presented, including the consensus metrics and the sources of deviation from the group's aggregate results. At this stage, a discussion took place between the participants with the facilitation of a moderator; when this process was over, the participants started voting again, this time receiving the feedback from the tool and the discussion itself. Eventually, the final results were presented and discussed.

The results from the two rounds of voting are presented in Figure 8. We observe that two alternatives were the most dominant: 'improvements on communication skills' ranking

Table 1. Configuration of alternatives, criteria, and linguistic scales for the first use case.

		Criteria		
		Impact on climate action	Legitimacy of climate science as perceived by the general public	Quality of climate science
Alternatives	Pursue positions in the government	Linguistic Scale: {Very Low, Low, Medium, High, Very High} *Example: "What it the impact on climate action of pursuing positions in the government?*		
	Participate in climate activism			
	Improve communication skills			
	Seek collaborative projects with the private sector			
	Adopt climate-conscious behaviours			
	Criteria Weights	Linguistic Scale: {Very Little, Little, Moderate, Much, Very Much} *Example: "How important do you consider the impact on climate action when evaluating a potential action?*		

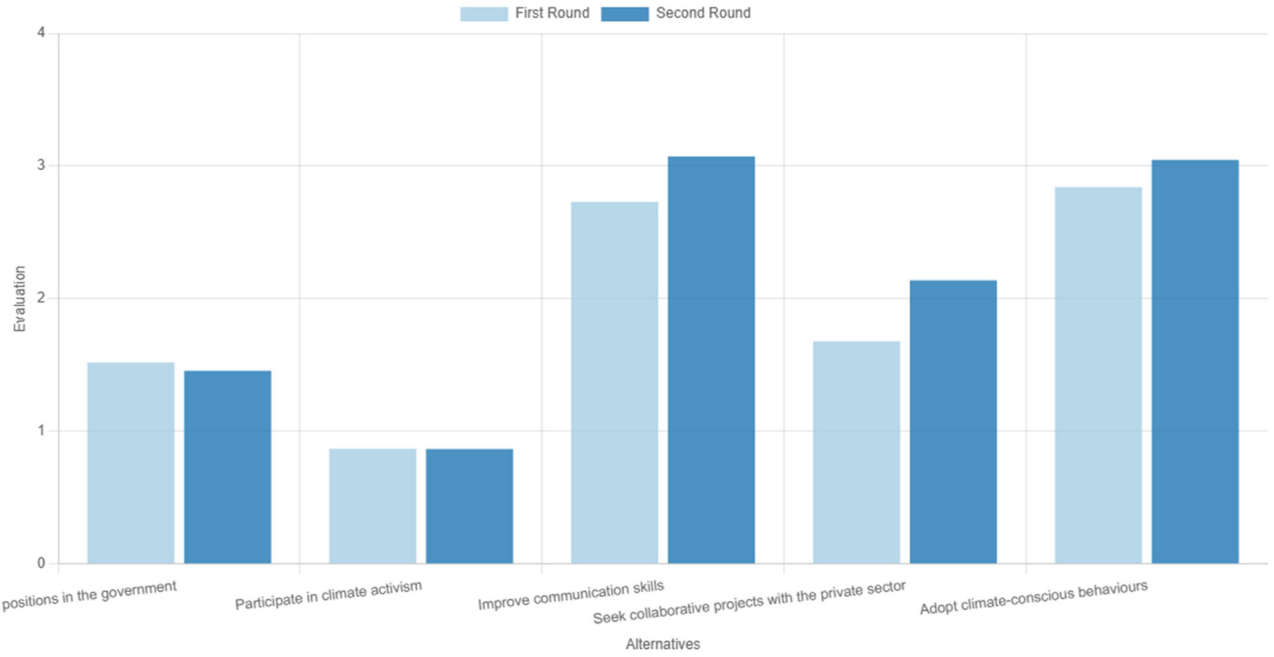


Figure 8. Ranking of the alternatives in the two rounds of voting during the first use case.

marginally first, and 'adoption of climate-conscious behaviours'. Then came 'collaboration with the private sector', with the other two alternatives following at a distance. Consensus was measured at 78.5%, an overall average result, but adequate considering that only two rounds of voting were performed.

These results generally reflect two interesting discussions among the participants during the deliberation stage in between the voting rounds.

The first discussion focused on the proximity of the two alternatives that were featured in the first places of the ranking order. Already during the first round, these two options were considered as top actions compared to the rest, but in a reverse order—i.e., adopting climate-conscious behaviours was the preferred alternative against the selected criteria. However, some participants stressed that, although leading by example is good practice, improving communication skills has the potential to impact a larger audience and for a longer time. A discussion followed on the impact of these two, which evidently caused a shift in the group's sentiment regarding the two alternatives; hence, in the second round, the order between the two was reversed. Despite the marginal differences, this example underpins the added value of deliberation as a process that may gradually shift opinions, but also of the tool itself, as in ranking methods the order can be deduced by small margins[45]: even marginal changes in ranking scores could have important implications for a real-world problem, where a winner-takes-it-all solution is sought or where a ranking of alternatives can influence the synthesis of an investment portfolio.

The second discussion also featured a debate on two alternatives. This time, the discussion focussed on the 'pursuing government jobs' on the one hand and 'collaborating with the private sector' on the other. The participants discussed the pros and cons of each option, with the outcome of this discussion not leading to any change in the order of the alternatives, like before, but instead strengthening the gap (score difference between the two) emerging after the first voting round.

The following reflections are not generalisable due to the limited sample but can illustrate how APOLLO-Live can be used analytically in future exercises. In our case, they also highlight that there may be value in discussing alternatives ranked in the last places, since such results are usually left with limited commentary in ranking-based exercises. In particular, participation in climate activism actions ranked in the bottom, despite youth movements gaining traction as a means of protest[52], with evidence showing such initiatives are overall viewed positively by the youth[53]. Using results from the APOLLO-Live engagement process and cross-validating them with literature can open up several interpretive avenues—further supported by participant discussions—that demonstrate the kind of reflective engagement the tool can support. In this indicative case, even among the young generation, there may be largely different opinions on the effectiveness of a certain action; this may reflect the opinion of only a small sample, but it may also underscore the need to significantly expand deliberation and co-creation activities to include the youth and capture broader viewpoints of the engaged groups. Also, the actions provided to the participants as options are not mutually exclusive, meaning that results merely reflect prioritisation rather than selection.

This is usually the case for most MCDA questionnaires based on ranking; hence analysts should be careful in their interpretations. Considering the small sample caveat, these elaborations act as an example of how outcomes of the tool should be dynamically interpreted through active discussions with the participants, instead of strictly based on the quantitative results.

Pilot use case II (asynchronous use): Ex-post analysis of the youth's elicited perspective on actions for a just transition

Within the second pilot use case, we shift the focus to the just transition of coal-dependent regions—similarly to the first case, however, through the lens of the youth again. This case featured an asynchronous analysis of polling results, outside the scope of a workshop, and serves to highlight the complete range of functionalities of the tool and its interoperability with other voting platforms. Notably, a Google Form was set up to approach young people (<25 years old) in Western Macedonia, Greece, the country's primary coal-producing and -dependent region, and thus the most vulnerable to energy transition policies and to the impacts of Greece's coal phaseout[54]. The voting form was also completely anonymous (only gender information was collected for aggregate analyses that cannot be traced back to the voter), with the form providing relevant disclaimers. 13 participants filled out the survey.

The alternatives, criteria, and employed linguistic scales are presented in Table 2. The alternatives constitute mixes of potential actions that the national and regional governments could pursue to mitigate the impacts of coal phaseout in the region. The selection was based on the actions outlined in the territorial just transition plan of Greece[55], thematically grouped to simplify the exercise given that the organising team could not provide elaborations. Therefore, further information such as which actions these policy mixes could entail were provided to the participants in the voting form. Given the age focus of the target group, relevant criteria were selected, relating to potential impacts of the actions on the region, today's youth future in it, the participants' peers, and the entire regional community. Contrary to the first pilot use case, we could not ask the participants to share their views on the contribution of each criterion to their personal preference model, considering the asynchronous nature of the questionnaire.

Figure 9 presents the results of the second pilot use case. Evidently, supporting development actions was deemed as potentially the most effective route to mitigate regional socioeconomic impacts of the transition. Considering that coal phaseout can be viewed as a drop in regional competitive advantage[56], coal-dependent regions typically require a wide set of supporting actions to ensure their economic development is secured, which can explain this result. Following that, participants emphasised energy and industrial infrastructure as their second preferred action, potentially motivated by the already established energy-oriented identity of the region, with all other options following at a distance.

The consensus in this exercise was measured at 70.6%, which is relatively low and underpins the need for deliberation and consensus-based decision aid processes through multiple rounds of voting, such as in the first pilot use case. The low consensus level can be partially attributed to significant deviations of responders based on their gender, which is an interesting output on its own, given the underrepresentation of women in scientific processes and deliberations on climate change[57]. Notably, female participants ranked 'supporting actions' first, while male participants prioritised the 'research and innovation' action instead, providing indications of the different needs the two groups face along the ongoing transition. Given the small sample that was relatively skewed towards female responders, not much should be read in these results, which should rather

Table 2. Configuration of alternatives, criteria, and linguistic scales for the second asynchronous use case.

		Criteria		
		How strong is the ability of the following actions to improve conditions for you and your future in the region?	How strong is the ability of the following actions to improve conditions for your peers and their future in the region?	How strong is the ability of the following actions to improve conditions for other members of your community in the region?
Alternatives	Reskilling programs	Linguistic Scale: {Very Weak, Weak, Moderate, Strong, Very Strong}		
	Research Infrastructure and Innovation Valleys			
	Energy or Industrial Infrastructure			
	Supporting Development Actions			
	Criteria Weights	Fixed equal weights		

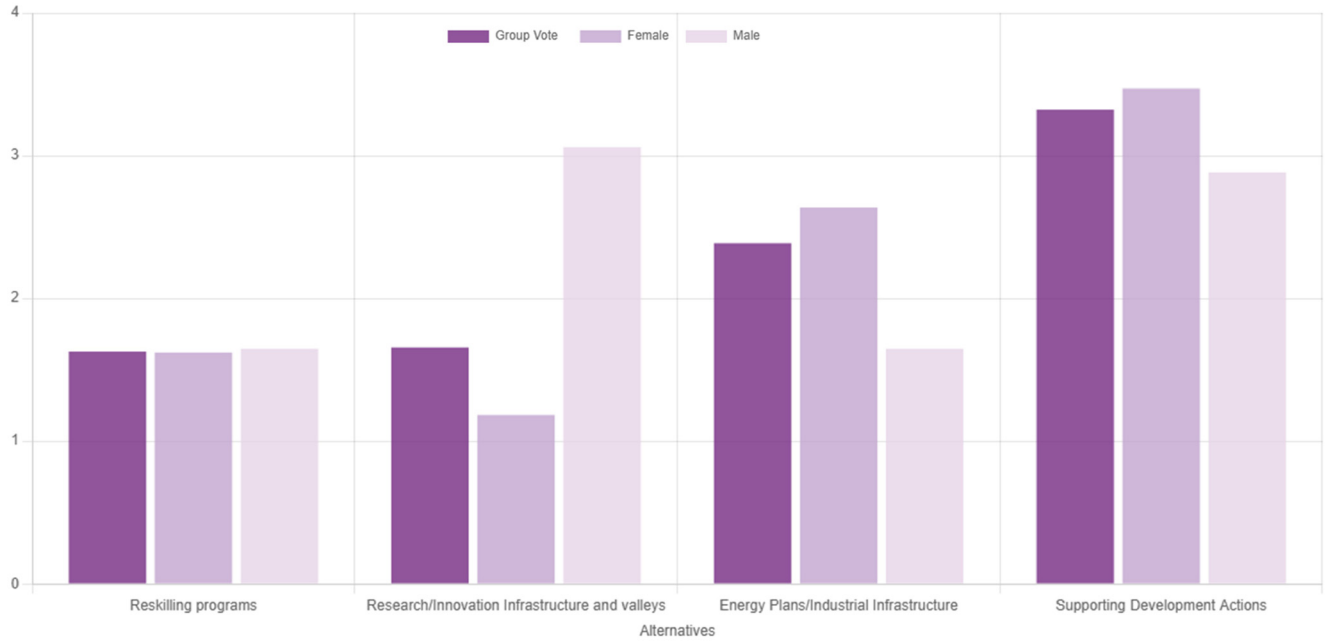


Figure 9. Ranking of the alternatives with gender-based disaggregated results during the second use case.

be used to reflect that the category-based analysis offered in the tool (i.e., results by group) can flesh out and potentially bridge areas of conflict between different viewpoints, while at the same time enhancing inclusivity.

Conclusions

In this paper, we presented APOLLO-Live, a webtool to synchronously facilitate stakeholder engagement activities in workshops focusing on issues and debates arising in the energy and climate policy domain. With its methodological foundations rooted in group decision making and consensus-based decision aid processes, the tool is capable of identifying common solutions within a group of participants, shedding light on conflicts among the different viewpoints expressed within the group, as well as providing relevant feedback to bridge said conflicts and calculating consensual solutions in public debates.

We also demonstrated its functionalities in two indicative pilot use cases focusing on the young generation, one identifying preferred actions of young scholars to boost the impact of climate action and science, and the second evaluating actions related to the just transition of coal-dependent regions. Within these cases, we presented tangible examples of how the tool can be used to moderate discussions that shift the opinion of participants towards consensual solutions that might differ to their pre-existing beliefs, as well as flesh out different opinions based on the background of the voters.

A key strength of the tool lies in its flexibility, as it can be used to provide answers to a diverse range of questions. Essentially the tool is able to contribute, through a live stakeholder engagement process, to general topics that have so far been addressed by the use of asynchronous decision support tools and multi-criteria decision aid in energy and climate policy[23,58], with the selection of alternatives, criteria, and linguistic terms being completely unrestricted. However, this also acts as a limitation of the tool, since the potential questionnaires that can be developed need to follow the common structure of MCDA problems, compared to online survey tools that incorporate multiple options for eliciting feedback, but lacking the functionalities of APOLLO-Live. Additionally, when designing and developing the tool, our guiding principles focused on how it could be applied to problems related to energy and climate policy. Consequently, structural choices of the model aimed to capture relevant requirements and attributes such as criteria trade-offs, comparisons and ranking under value-based judgments, qualitative and quantitative dimensions, uncertainty and stakeholder diversity. Although these requirements are not unique in energy and climate policy decisions independently, collectively integrating such aspects is necessary to be able to capture problems in the energy and climate policy space. However, this does not exclude potential uses of the tool across completely different domains, again with the caveat that following the standard MCDA format in designing future use cases is necessary.

Other limitations of the tool lie in the difficulty to use symmetrical scales with negative values, or handle responses such as ‘not able to respond’. On the former caveat, the method itself does not restrict the use of negative scales.

However, it is possible for negative results to appear even in cases that the responder provided non-negative results (and vice versa), since TOPSIS is a distance-based method that can stretch results within the whole spectrum of the scale. This issue is significantly mitigated in scales of the same sign, and their use is advised. On the latter caveat, although efforts in the MCDA community have been made to introduce 'not able to respond' responses in MCDA exercises[16], the ability to actually implement such options depends on multiple conditions (i.e., notably the number of responders and in particular the requirement for a large sample in order to be able to replace the "not able to respond" responses with the average of the remaining participants), while in a tool used live in workshops there is no guarantee that these conditions are met. At the same time, the use of 'do not know' or 'not able to respond' has been contested in stakeholder engagement, as it may discourage people from responding in case of inter alia ambivalence[59]. As such, to mitigate this caveat, it is suggested that the questionnaires are structured with clarity to avoid ambiguities and select a sample that is suitable to respond to the questions posed.

Based on these, future work on the tool includes its use in full-scale experiments with a large number of participants, including post-workshop feedback surveys to validate user experience, tests across different domains and questionnaires, as well as incorporation of different solving techniques (e.g., MCDA methods other than the 2-tuple Group TOPSIS used in GDM[60]), and consensus reaching mechanisms, as well as explicit methods for incorporating manipulative behaviours[61]. Finally, although efforts have been made to provide users of the tool with elaborations on the results, these are mostly static and focus on the definitions of the metrics used and the figures presented. In future versions, the dynamic explainability of the model's results can be considered, also leveraging breakthroughs in explainable artificial intelligence[62,63].

Ethics and consent statement

Our study involved anonymous online surveys focused on perceptions on the energy transition—an area where ethical considerations per national standards and practices orient towards transparency, confidentiality, voluntary participation, and the right to withdraw, rather than a formalized institutional review board process as required in cases involving medical studies, clinical trials, or sensitive personal data. Researchers continuously ensured compliance with these considerations.

Notably, survey respondents provided the research team with their implied informed consent by completion of the survey for their participation and the use of the information shared in this study. The polls used included dedicated and transparent disclaimers informing respondents that their anonymous aggregated responses would be used for research purposes and published in a scientific article. Consent to using and publishing this data was inferred by completion of the survey. The data was collected under the assurance of anonymity, while respondents also retained the right to withdraw their participation and information at any point. All participants were over the age of 18. The entire engagement and elicitation process was conducted in compliance with ethical approval from the HOLISTIC Management Board.

Data and software availability

Underlying data

Repository: The APOLLO-Live synchronous GDM-CRP webtool: Datasets and Template https://doi.org/10.5281/zenodo.14510524[64].

This project contains the following underlying data:

- First use case data. Includes the data produced by the tool related to the first use case.
- Second use case data. Includes the data produced by the tool related to the second use case.
- Template. A file that can be used as input for an asynchronous analysis with APOLLO-Live based on the import function.

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Software availability

APOLLO-live is publicly available at https://apollo-live.epu.ntua.gr. Visitors that intend to try the deployed tool as workshop organisers should first register a new account which will be then approved by the tool developers. Users can also deploy the tool to a server of their own choice and run it independently.

- Source code available from: https://github.com/i2amparis/APOLLO-Live
- Archived software available from: https://zenodo.org/records/14851912
- License: The software is provided under the Apache-2.0 license (OSI approved open license).

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Open Peer Review

Current Peer Review Status: ✔ ✔ ? ?

Version 3

Reviewer Report 19 August 2025

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✔ **Phoebe Koundouri**
Technical University of Denmark, Lyngby, Denmark

I am happy with the revised version of the paper. The authors have successfully answered to my comments, clarifying the aspects that I raised.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Environmental & Natural Resource Economics Sustainable Development Water & Marine Resources Energy & Green Transition. Climate Economics – Climate risk, carbon pricing, policy impact. Behavioral & Experimental Economics Interdisciplinary Systems Research

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 18 August 2025

https://doi.org/10.21956/openreseurope.22907.r58332

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✔ **George Tsihrintzis**
University of Piraeus, Piraeus, Greece

My previous suggestions have been sufficiently addressed and responded to. I recommend acceptance.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Artificial Intelligence, Decision Support Systems, Machine Learning, Generative Artificial Intelligence, Explainable Artificial Intelligence

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 2

Reviewer Report 04 August 2025

https://doi.org/10.21956/openreseurope.22598.r56688

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Nebiyu Girgibo
[1] University of Vaasa, Vaasa, Finland
[2] University of Vaasa, Vaasa, Finland

Article title: "APOLLO-Live: A multi-criteria-based webtool for synchronous group decision making and consensus support in energy and climate policy deliberations"

Journal: Open Research Europe
Author: Koasidis et al.

General comments

- It is a good article, and it is written well. A lot of pages for an article, but it is well if it is accepted by the Journal.
- If the minor comments are addressed for this article, I recommended it will be accepted based on editor's decision.

The article language check-ups and its editing

- The language is ok, well written and not seen that much language mistakes.

Title

- The title is great and it's on the number of counts is ok, which is 15-word count. The maximum number of words shall be less than 12 and more than 6.
- Otherwise, the title represents the article text well even if it is a bit long one.
- It reflects the content of the article and its strength.

Abstract

- The abstract is good and it looks good, well organized and written with intellect.

- The abstract on well written and well reflecting the chance they have to show their passion in research of this kind.
- Please highlight the aims, novelties, contributions and significance of the study.
- Avoid using references in the abstract section.

Keywords

- The 7 keywords, which are the number of counts of key words that are in the requirement limit.

The introduction

- The introduction is short, it ok, well written and good level compressive that will help reader understand the concept.
- It has a very good acceptability by the readers and help to understand the context of the article well.
- It is very ok, but the method used and the compressive paper is good.
- Research question should be included.
- A good level of references was used. The number of references can help understand well the climate change issue along with energy security.

Methods

- The methods written in was long and good one, well done.
- The method used was good, well-organised and impressive well to highlight the necessity of this method to work on this paper.
- In addition, the number of references and method, which is efficient are able to give a soon compressive review paper.

Conclusions

- The paper is good and it summarizes all the necessary section the article.
- The conclusion is very good, it is well written text, and good conclusions mentioned.
- It is matured and well written text that helps the reader understand the whole text is perfect.
- It has constructive conclusion that very goodly highlighted and showed the paper.
- Future direction section is quite well written.

Abbreviations and Acknowledgments

- Please include acknowledgment and abbreviation full list on your paper. If it is included, helps significantly while reading this article.
- Please acknowledge kindly your work mates, funding organizations and all helpers as well.

References

- Very good referencing and good number of references.

Is the rationale for developing the new software tool clearly explained?

Yes

Is the description of the software tool technically sound?

Yes

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?
Yes

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Energy technology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 09 Aug 2025

Konstantinos Koasidis

R4.1: General comments It is a good article, and it is written well. A lot of pages for an article, but it is well if it is accepted by the Journal. If the minor comments are addressed for this article, I recommended it will be accepted based on editor's decision. **Response:** The authors would like to thank the reviewer for their positive general assessment of the manuscript.

R4.2: The article language check-ups and its editing
The language is ok, well written and not seen that much language mistakes. **Response:** We thank the reviewer for the positive comment and thorough check on the language and clarity of the manuscript.

R4.3: Title The title is great and it's on the number of counts is ok, which is 15-word count. The maximum number of words shall be less than 12 and more than 6. Otherwise, the title represents the article text well even if it is a bit long one. It reflects the content of the article and its strength. **Response:** Indeed, the title is towards the higher-end of the word-count, but we deemed it necessary to clearly reflect the content of the article. Based on the journal's "authors' guidelines", we confirm that the length of the title does not violate explicit guidelines.

R4.4: Abstract The abstract is good and it looks good, well organized and written with intellect. The abstract on well written and well reflecting the chance they have to show their passion in research of this kind. Please highlight the aims, novelties, contributions and significance of the study. Avoid using references in the abstract section. **Response:** We confirm that the abstract does not include any references. On the structure, given that this is a "software tool article", we adapted the standard

"Background, Methods, Results and Conclusions" format used in research articles and used the following logical flow: "Context, Gap, Added Value and novelty of the software, Methodological underpinnings, Pilot use cases to validate the tool, Concluding remarks". Through this equivalent structure, we deem we highlight the aspects indicated in the reviewer's comment.

R4.5: Keywords The 7 keywords, which are the number of counts of key words that are in the requirement limit. **Response:** We confirm that the number of keywords used (7) adheres to journal standards (8).

R4.6: The introduction The introduction is short, it ok, well written and good level compressive that will help reader understand the concept. It has a very good acceptability by the readers and help to understand the context of the article well. It is very ok, but the method used and the compressive paper is good. Research question should be included. A good level of references was used. The number of references can help understand well the climate change issue along with energy security. **Response:** We thank the reviewer for the feedback. A formal research question that is common in research articles might not be as relevant in a software tool article. We confirm that the research motivation (i.e., the gaps in MCDA and GDM tools) and objectives (i.e., developing a tool with added value) are clearly presented in the introduction. We revised the following sentence to explicitly make the research objective clear to the reader: *"To address this gap, the research objective of this paper is to introduce APOLLO-Live"*

R4.7: Methods The methods written in was long and good one, well done. The method used was good, well-organised and impressive well to highlight the necessity of this method to work on this paper. In addition, the number of references and method, which is efficient are able to give a soon compressive review paper. **Response:** We thank the reviewer for the positive evaluation of the methodological section. In principle, we agree that it is on the higher end of word count, but we believe this is justified to ensure that the methodological, technical and functional elements are adequately described.

R4.8: Conclusions The paper is good and it summarizes all the necessary section the article. The conclusion is very good, it is well written text, and good conclusions mentioned. It is matured and well written text that helps the reader understand the whole text is perfect. It has constructive conclusion that very goodly highlighted and showed the paper. Future direction section is quite well written. **Response:** We thank the reviewer for the positive assessment of the conclusion and future directions sections.

R4.9: Abbreviations and Acknowledgments Please include acknowledgment and abbreviation full list on your paper. If it is included, helps significantly while reading this article. Please acknowledge kindly your work mates, funding organizations and all helpers as well. **Response:** We confirm that the article features an acknowledgment section with explicit mentions on support received in our research, a section on funding, while a CRediT author statement is also included to ensure that the co-authors' contributions are clearly defined. Finally, it is our understanding that the journal does not have a dedicated section in the manuscript for an abbreviation table. Nonetheless, we thoroughly checked the manuscript to ensure that all abbreviations are defined upon first use, which is a common

practice, remedying instances of an abbreviation not defined.

R4.10: References Very good referencing and good number of references. **Response:** Thank you for the positive remark on references. They have been slightly expanded to include further webtools in the literature to better position our tool in the field. **Final Remark:** Once again, the authors would like to thank the reviewer for the thorough checks and suggestions, which helped us improve our manuscript.

Competing Interests: No competing interests were disclosed.

Reviewer Report 21 July 2025

https://doi.org/10.21956/openreseurope.22598.r56695

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Tuhibur Rahman
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The manuscript presents **APOLLO-Live**, a web-based stakeholder engagement tool for real-time, group-based decision-making in climate and energy policy deliberations. Built upon the 2-tuple TOPSIS methodology within an MCDA framework, the tool aims to support consensus-building in workshops and participatory settings. The paper is well-written, addresses a timely need, and contributes to the field of participatory decision support.

However, several key areas require strengthening before the work is suitable for indexing.

1.While the paper describes a useful implementation of MCDA in a web environment, its **methodological contribution is unclear**. The reliance on existing techniques (e.g., 2-tuple TOPSIS, linguistic scales) is valid, but the paper should explicitly articulate **what is new**—in either process, interface design, or application strategy. How is APOLLO-Live meaningfully different from other tools in the MCDA landscape?

2. Both use cases (a classroom workshop and an online form with youth) offer illustrative value but are **too limited in scope and sample size** to substantiate broader claims. Please Consider adding **larger, more diverse samples** in future iterations, reporting **user experience metrics**, usability feedback, or post-workshop surveys and clearly stating that these are **pilot examples**, not generalizable findings.

3. The authors briefly discuss strategic voting and consensus dynamics but should provide **stronger evidence or safeguards** against manipulation. Explain how the tool tracks erratic voting patterns? Discuss the **limitations of consensus metrics** when used in small or ideologically

diverse groups. Clarify how the tool supports disagreement or preserves dissenting voices, especially when consensus is not the goal?

4. The manuscript would benefit from a **comparative review** of existing GDM and MCDA tools used in similar domains (e.g., DEMO, DEXi, Web-HIPRE). A table or short section comparing APOLLO-Live's capabilities, features, and domain applicability with similar tools would help readers understand its **relative advantages and trade-offs**.

Is the rationale for developing the new software tool clearly explained?
Partly

Is the description of the software tool technically sound?
Partly

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?
Partly

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Information Technology, AI, Reinforcement Learning, Energy Transition and Climate Change, Electric Vehicles

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 09 Aug 2025

Konstantinos Koasidis

R3.1: The manuscript presents APOLLO-Live, a web-based stakeholder engagement tool for real-time, group-based decision-making in climate and energy policy deliberations. Built upon the 2-tuple TOPSIS methodology within an MCDA framework, the tool aims to support consensus-building in workshops and participatory settings. The paper is well-written, addresses a timely need, and contributes to the field of participatory decision support. However, several key areas require strengthening before the work is suitable for indexing.
Response: The authors would like to sincerely thank the reviewer for their positive remarks and thorough suggestions for improvement. We believe that the revisions performed based on the reviewer's report have significantly improved the quality of the manuscript.

R3.2: While the paper describes a useful implementation of MCDA in a web environment, its methodological contribution is unclear. The reliance on existing techniques (e.g., 2-tuple

TOPSIS, linguistic scales) is valid, but the paper should explicitly articulate what is new—in either process, interface design, or application strategy. How is APOLLO-Live meaningfully different from other tools in the MCDA landscape? **Response:** The reviewer is correct that aspects of the methodological foundations of the APOLLO-Live tool are based on existing methodologies (including as correctly pointed out the 2-tuple TOPSIS, the linguistic scales, and the basis for the consensus metric used), which were implemented in the original APOLLO tool. The added value (and different elements) of this tool is twofold. First, given that the original APOLLO was asynchronous, the whole APOLLO-Live tool, including the interface and the functionalities, is markedly different in structure, usefulness and openness. Additionally, based on the reviewer's suggestion in comment R3.5 we also provide elaborations of how the tool is different compared to other MCDA tools, notably on its built-in capabilities to facilitate synchronous GDM. Both these elements are reflected in the following addition in the manuscript: *"As such, although the methodological foundations rely on existing methods with targeted expansions, the tool itself, including the interface and its functionalities, constitute a novel contribution to the field of participatory decision support. Other commonly known MCDA webtools include DEXi, which uses hierarchical trees and qualitative rule tables, and Hiview3 and Web-HIPRE which employ value trees and functions grounded in the multi-attribute value theory. In these tools, a stakeholder can define the rule tables (in the case of DEXi) or provide quantitative weights (for Web-HIPRE this can be achieved through the Analytic Hierarchy Process). However, none of these tools offer built-in functionalities for real-time or formal preference aggregation internally. Consequently, to be useful in the context of GDM, the individual models of the stakeholders should be post-processed externally, or they should jointly build one representative model. The built-in voting, aggregation, consensus metrics and multi-round process of APOLLO-Live aim to address this gap."* Second, a core novelty of the tool lies in a newly established process for providing feedback and tips to support consensus improvement, not part of the original which focused only on consensus measuring. We discuss how literature has implemented CRP processes so far, the bottlenecks stemming from necessary methodological choices, and the newly implemented solution. This is reflected in the following passage: *"In the original APOLLO version, no such processes were implemented, since the tool only focused on consensus measuring. Usually, in the first approach, which uses aggregations based on weighted averages, the group decision matrix and the matrices of the stakeholders are of equal dimensions and format, making them easy to compare and provide the required tips. This is not the case when first calculating the individual solution for each stakeholder and then the global group solution, due to the difference in the dimensions of the initial matrix that the stakeholders vote on and the matrices emerging along the way. For this reason, most applications of CRP opt for the former approach. Given our methodological reliance on the latter process though, as explained above, and to address this gap, in APOLLO-Live we apply a consensus support process based on tips using the following protocol, which constitutes an expansion on the existing methods used in the original APOLLO tool."*

R3.3: Both use cases (a classroom workshop and an online form with youth) offer illustrative value but are too limited in scope and sample size to substantiate broader claims. Please Consider adding larger, more diverse samples in future iterations, reporting user experience metrics, usability feedback, or post-workshop surveys and clearly stating that these are pilot examples, not generalizable findings. **Response:** We agree with the reviewer that the use cases presented serve primarily to highlight the functionalities of the tool, the provision of results, and ways to interpret them. In the main text we include numerous

disclaimers explicitly mentioning that the results should be treated as numerical examples and not be interpreted as generalisable findings. To further enhance this, as the reviewer indicated, we added the term *"pilot"* to accompany the previous term "use cases" in numerous instances throughout the text, crucially including in the abstract and the respective subsections, which are now termed as *"Pilot use cases"*. The remark to include post-workshop surveys and feedback on the tool, notably based on larger samples, is a valuable suggestion. So far, the non-structured feedback we received on the tool focused on beta-tests to incorporate comments and reach a stable version. However, having reached that stage, in the future research section, we added the prospect of rigorously gathering feedback from a large sample through post-workshop surveys: *"...future work on the tool includes its use in full-scale experiments with a large number of participants, including post-workshop feedback surveys to validate user experience..."*

R3.4: The authors briefly discuss strategic voting and consensus dynamics but should provide stronger evidence or safeguards against manipulation. Explain how the tool tracks erratic voting patterns? Discuss the limitations of consensus metrics when used in small or ideologically diverse groups. Clarify how the tool supports disagreement or preserves dissenting voices, especially when consensus is not the goal? **Response:** Thank you for these remarks and suggestions. As elaborated in the main text, we argue that the potential for some form of strategic behaviour is always part of any system that tries to aggregate individual preferences into a collective result (i.e., also drawing a conceptual parallel to Arrow's impossibility theorem). In this case, penalties may be incorporated to discourage strategic voting. But such approaches might not yield the expected results, since such patterns are usually hard to detect and they run the risk of penalising truthful votes. As the reviewer correctly points out, this is a limitation of consensus metrics in general and especially in ideologically diverse groups, and penalties could potentially crowd out honest disagreements. For this reason, we opted not to implement penalties, which implies that the tool preserves all votes (even when disagreements exist). We elaborate on this in the revised paragraph on group behaviours. *"However, as previously discussed, convergence to a consensual result is neither guaranteed nor the only end goal. During the discussions, the emergence of disagreements is also possible, especially in cases of small or ideologically diverse groups. In this case, it is the responsibility of the organiser and moderator of the exercise to ensure that the discussions avoid escalation and conflict, but rather remain fruitful, and that the results can meaningfully inform decision makers, especially on aspects that were found difficult to bridge, or were not bridged in the end. As such consensus metrics may still be useful to reflect such differences but are limited in terms of reaching a widely accepted solution. The tool opts not to penalise dissenting voices at the individual level, hence preserving all viewpoints expressed."* With this in mind, we opted for an indirect approach towards discouraging strategic voting and encouraging truthful expression via methodological choices made. We argue that it would be rather difficult to influence the results through such a strategy within the employed MCDA approach, as the input required is more complex than simple selection, and hence strategic distortion is diluted. As a safeguard, the tool includes a figure on the individual consensus of stakeholders (still anonymously), which provides a simple qualitative security over truly erratic voting patterns. Although not an explicit mathematical tracking, the number of each stakeholder presented in the figure remains the same throughout voting rounds, ensuring that continuous erratic behaviours are easier to be identified. In these cases, the awareness of the participants and the moderator can

arguably be more important than any mathematical algorithm. We enhanced the following section to reflect on these: *"The methods employed within the tool encourage truthful expression and discourage strategic voting. Crucially, it would be rather difficult to influence the results through strategic behaviour within the employed MCDA approach, as the input required is more complex than simple selection, and hence strategic distortion is diluted (i.e., participants evaluate all alternatives against a set of criteria rather than selecting a preferred option). The tool also presents a figure on the individual anonymised consensus level of stakeholders (see the Operation section), which provides a simple qualitative security over truly erratic voting patterns. The anonymised identifier of each stakeholder remains the same in each voting round within this figure, to ensure an indirect tracking of continuous distortions in the form of soft social enforcement. In these cases, the awareness of the participants and the moderator can arguably be more important than any mathematical algorithm to protect the process."*

R3.5: The manuscript would benefit from a comparative review of existing GDM and MCDA tools used in similar domains (e.g., DEMO, DEXi, Web-HIPRE). A table or short section comparing APOLLO-Live's capabilities, features, and domain applicability with similar tools would help readers understand its relative advantages and trade-offs. **Response:** As hinted in our response to comment R2.2, we added a short paragraph comparing APOLLO-Live to existing MCDA webtools in the literature, namely, DEXi, Hiview3, Web-HIPRE. Given the different scopes of these tools (i.e., not designed for synchronous GDM), we opted for a paragraph instead of a table as it was deemed more appropriate to highlight the differences. The following section has been added: *"Other commonly known MCDA webtools include DEXi 62, which uses hierarchical trees and qualitative rule tables, and Hiview3 63 and Web-HIPRE 64 which employ value trees and functions grounded in the multi-attribute value theory. In these tools, a stakeholder can define the rule tables (in the case of DEXi) or provide quantitative weights (for Web-HIPRE this can be achieved through the Analytic Hierarchy Process). However, none of these tools offer built-in functionalities for real-time or formal preference aggregation internally. Consequently, to be useful in the context of GDM, the individual models of the stakeholders should be post-processed externally, or they should jointly build one representative model. The built-in voting, aggregation, consensus metrics and multi-round process of APOLLO-Live aim to address this gap."*

Final Remark: The authors would once more like to genuinely thank the reviewer for their helpful and constructive comments.

Competing Interests: No competing interests were disclosed.

Version 1

Reviewer Report 11 April 2025

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Phoebe Koundouri
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revise and resubmit

The authors present a model that can aid real time and asynchronous decision making, presenting two case studies. The tool presents an interesting interface that can be both useful for the organizers and the participants. However, my main concern has to do with the group dynamics that can be triggered by the model.
1) The authors have created a model for "consensus reaching" (among others). However, it is not clear how the methodology presented promotes consensus. The following bullets illustrate the same major issue, presented in three different ways.

- The authors claim that: "...in our case, convergence lies entirely in the participants' behaviour, which is not always cooperative as implied in all simulated cases, where some form of compromise is always assumed". Indeed, convergence cannot be guaranteed, but it needs to be promoted through the model structure. The model indeed offers useful group-focused results and can be used to feed an interesting discussion between rounds, but how does this lead to consensus? A fruitful discussion helps the stakeholders improve their understanding of their own and the others' preferences, but this can also lead to a disagreement.
- Specifically, there are two main questions: why would a voter change their vote and why would that change be towards the most popular opinion in the group (mainstream group opinion)?
- Suppose a voter A, a vector of 5 options *{x1,x2,...,x5}* $\{x_1, x_2, \dots, x_5\}$ and a vector of preferences *{uAx1w,uAx2w,..., uAx5w}* $\{u_A(x_1^w), u_A(x_2^w), \dots, u_A(x_5^w)\}$, representing the utilities that voter A obtains from each of the options, when this option wins (noted as "w") after a number of rounds. Finally suppose that a voter A presents the following preferences: *uAx1<uAx2<uAx3<uAx4* $u_A(x_1) < u_A(x_2) < u_A(x_3) < u_A(x_4)$ and *uAx4>uAx5* $u_A(x_4) > u_A(x_5)$. Namely, if there was one round and A was honest, A would vote *x4* x_4, targeting on *uAx4* $u_A(x_4)$. However, as there is no penalty

inserted in the model presented, nor any other mechanism that could lead to consensus, the model can lead to anti-coordinating behavior, which is interestingly the opposite of the goal of the paper. Actually, in the first rounds voter A has strong motivation to vote *x5* x_5 (even though they would prefer *x4* x_4). This way the results of the "model" will present biased results, making the players with other preferences (such as *x1,x2,x3)* $x_1, x_2, x_3)$ move towards *x4,x5* x_4, x_5 in order to reach consensus. This process, known as strategic voting, is actually encouraged by the model. Anonymity also makes it easier for such players to determine the outcome of the discussions.

2) In page 17, trying to obtain generalizable outcomes about youth opinions in climate change from 5 participants should be strongly avoided. At the same time, we should have in mind that these 5 students are not randomly chosen. They are the students that "with no academic incentives provided" have been agreed to participate. Does environmental awareness make them participate? Is it their good relationships with the model developers that makes them participate? There are so many parameters that affect youth behavior.

3) The structural characteristics of the model that make it particularly useful for energy and climate policy discussions are not clear through the manuscript.

Is the rationale for developing the new software tool clearly explained?

No

Is the description of the software tool technically sound?

Yes

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?

Yes

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Environmental & Natural Resource EconomicsSustainable Development Water & Marine Resources Energy & Green Transition .Climate Economics – Climate risk, carbon pricing, policy impact.Behavioral & Experimental Economics Interdisciplinary Systems Research

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 04 Jul 2025

Konstantinos Koasidis

Comment R2.1. The authors present a model that can aid real time and asynchronous decision making, presenting two case studies. The tool presents an interesting interface that can be both useful for the organizers and the participants. However, my main concern has to do with the group dynamics that can be triggered by the model.

Response: The authors would like to sincerely thank the reviewer for their constructive and thorough remarks. We are confident that the revisions performed in line with these comments significantly improved the quality of the manuscript, notably regarding elaborations on consensus and potential group dynamics arising. In this response, we annotate with italics exact sections from the manuscript that have been added or updated.

Comment R2.2. 1) The authors have created a model for "consensus reaching" (among others). However, it is not clear how the methodology presented promotes consensus. The following bullets illustrate the same major issue, presented in three different ways.

Response: The reviewer raises some very interesting remarks in this set of comments. In the principle that comments R2.2-R2.5 are positioned within a broader argument, but also constitute dedicated comments, we will respond to them individually but also following a consistent narrative as well (i.e., two dedicated paragraphs on group dynamics have been inserted in the theoretical underpinnings section of the manuscript to discuss these elements; see more details in the responses below). On a high-level note, as the reviewer acknowledges, consensus is not the single goal of the tool—with a central goal being the prioritisation of alternatives. However, even within the notion of consensus, reaching one is always preferable/ideal but not a goal in itself. The tool provides tips and suggestions to potentially help improve consensus, but whether these are taken on board lie entirely in the participants' hands. Even in the cases though that consensus is not reached, we deem these results interesting to understand why consensus was not reached, how the opinions of groups of participants differ, and consequently inform decision making. This is why we opted for the Krohling and Campanharo solution process for group decision making, which calculates individual solutions on top of the aggregated solution. Based on this discussion, we added the following disclaimer: *"We note, however, that consensus reaching is not necessarily the ultimate objective. As such, even in the cases that the process ends without consensus, the results can still be of added value to inform decision- or policy-making on different viewpoints in the group that are difficult to bridge. Following the solution process introduced by Krohling and Campanharo, the aim was to ensure that the individual and grouped solutions are also calculated to accompany the results produced by the tool."* Additionally, to better reflect on this, we have kept the term "consensus reaching" in broader discussions as it is the standard term used in this field, but we replaced it with terms such as "*consensus-based decision aid*" and "*Consensus support*" (in text and in the title of manuscript as well) when referring to the purpose of the tool itself.

Comment R2.3: The authors claim that: "...in our case, convergence lies entirely in the participants' behaviour, which is not always cooperative as implied in all simulated cases, where some form of compromise is always assumed". Indeed, convergence cannot be

guaranteed, but it needs to be promoted through the model structure. The model indeed offers useful group-focused results and can be used to feed an interesting discussion between rounds, but how does this lead to consensus? A fruitful discussion helps the stakeholders improve their understanding of their own and the others' preferences, but this can also lead to a disagreement.

Response: We agree with the reviewer that the deliberations and discussions taking place between rounds of voting could indeed help stakeholders improve their understanding of their own and the others' preferences, adding that they could also discover lines of thinking not initially considered, which could lead them to change their voting. We made the following addition to the theoritical underpinnings section (see also response to R2.4): *"These theoretical underpinnings bring forward group dynamics that should be considered. A core issue lies in understanding why the opinions of participants could change by participating in such activities. The tool offers group-focused suggestions that can be used to feed discussions between rounds, which can help stakeholders improve their understanding of their own and the others' preferences and beliefs, as well as be exposed to different viewpoints not previously thought of or largely considered. These mechanisms could influence participants towards changing their opinions and consequently their votes. Crucially, the ability of deliberations to change opinions has long been established in the literature (see for example Fishkin's work on "Deliberative polling", or Chong & Druckman's work on framing and deliberation). Our first use case presents an example of how such behaviours could manifest in the tool and alter the results, changing the order of the alternatives, rather that force the first-round opinion of the majority."* However, it is also true that deliberations could lead to disagreements, which is an inherent part of any deliberation. For this reason, we explicitly mentioned in the previous response (R2.2) that reaching consensus is not the only goal. It is the responsibility of the organiser and moderator of the exercise to ensure that the discussion remains fruitful even within disagreements, and that the results can meaningfully inform decision makers. Based on this, we added the following: *"However, as previously discussed, convergence to a consensual result is neither guaranteed nor the only end goal. During the discussions, the emergence of disagreements is also possible. In this case, it is the responsibility of the organiser and moderator of the exercise to ensure that the discussions avoid escalation and conflict, but rather remain fruitful, and that the results can meaningfully inform decision makers, especially on aspects that were found difficult to bridge, or were not bridged in the end."*

Comment R2.4: Specifically, there are two main questions: why would a voter change their vote and why would that change be towards the most popular opinion in the group (mainstream group opinion)?

Response: Following on our response to comment R2.3, we believe that deliberations and discussions in between voting, help participants reflect on their beliefs, the ones of others, as well as potentially be made aware of ideas and considerations not previously thought of. Through these mechanisms, it is quite possible that participants could alter or change their votes. Many foundational papers discuss the possibility of participants' opinions changing, from Fishkin's work on "Deliberative Polling" showing that in structured deliberations opinions often change (see for example Fishkin and Luskin, 2005), to Chong and Druckman (2007) arguing that, through a properly developed framing, it was possible to move public opinion. In our first numerical example, we also present a case that this happened with

participants getting introduced to ideas not previously considered, hence altering the ranking. On the latter point, it is not necessary that opinions need to change towards the most popular opinions. It is also possible that the result (i.e., ranking) in the second round of voting is different to that in the first one. The first numerical example serves as a case for that, with the first two options altering places in the ranking. Based on these, and your helpful remark, we made the following additions: *"These theoretical underpinnings bring forward group dynamics that should be considered. A core issue lies in understanding why the opinions of participants could change by participating in such activities. The tool offers group-focused suggestions that can be used to feed discussions between rounds, which can help stakeholders improve their understanding of their own and the others' preferences and beliefs, as well as be exposed to different viewpoints not previously thought of or largely considered. These mechanisms could influence participants towards changing their opinions and consequently their votes. Crucially, the ability of deliberations to change opinions has long been established in the literature (see for example Fishkin's work on "Deliberative polling", or Chong & Druckman's work on framing and deliberation). Our first use case presents an example of how such behaviours could manifest in the tool and alter the results, changing the order of the alternatives, rather that force the first-round opinion of the majority."*

- Fishkin, J. S., & Luskin, R. C. (2005). Experimenting with a democratic ideal: Deliberative polling and public opinion. Acta politica, 40, 284-298.
- Chong, D., & Druckman, J. N. (2007). Framing public opinion in competitive democracies. American political science review, 101(4), 637-655.

Comment R2.5: Suppose a voter A, a vector of 5 options $\{x_1, x_2, \dots, x_5\}$ and a vector of preferences $\{U_A(x_1^W), U_A(x_2^W), \dots, U_A(x_5^W)\}$, representing the utilities that voter A obtains from each of the options, when this option wins (noted as "w") after a number of rounds. Finally suppose that a voter A presents the following preferences: $\{U_A(x_1) < U_A(x_2) < U_A(x_3) < U_A(x_4)\}$ and $\{U_A(x_4) > U_A(x_5)\}$. Namely, if there was one round and A was honest, A would vote x_4, targeting on $U_A(x_4)$. However, as there is no penalty inserted in the model presented, nor any other mechanism that could lead to consensus, the model can lead to anti-coordinating behavior, which is interestingly the opposite of the goal of the paper. Actually, in the first rounds voter A has strong motivation to vote x_5 (even though they would prefer x_4). This way the results of the "model" will present biased results, making the players with other preferences (such as x_1, x_2, x_3) move towards x_4, x_5 in order to reach consensus. This process, known as strategic voting, is actually encouraged by the model. Anonymity also makes it easier for such players to determine the outcome of the discussions.

Response: This is an interesting thought experiment that helps us clarify aspects of the methodological underpinnings of the tool, as well as advance the discussion on strategic or even manipulative voting. First, the approach followed is based on the TOPSIS method, which provides an order of preference, meaning that the end result is a ranking of alternatives, rather than a "winner-takes-all" approach. Although, it is observed that in a ranking-based result people tend to focus on the first place, this is inherently wrong, as useful information is deduced also from the distance between alternatives, as well as from those alternatives placed in the bottom rank. Second, TOPSIS is a multi-criteria decision aid

method, meaning that the participants evaluate the impact of all alternatives on a series of criteria, rather than select one preferred alternative. This makes "rigging the system" more difficult. Following the nomenclature of the reviewer's comment, this strategic participant would have to provide alternative 5 with very high evaluations across all criteria and alternative 4 with very low. But this would cause their individual consensus to be very low and, if this erratic voting behaviour was expressed in the deliberations, it would be fairly easy for the group to isolate said participant (the individual consensus is shown to participants in Figure 4b; the figure is anonymous but there is space to identify persistent erratic voting behaviours. On the other hand, the participant could also evaluate alternative 4 relatively high, but then this would have a much smaller impact on the result diluting the distortion. Also, this voting pattern is an admittedly distorted but rather realistic expression of their preference. Third, the thought experiment assumes that voters have a fixed utility for a given result (e.g., dominance of a solution, which given the MCDA setup, is not usually the case). However, as discussed in points R2.3 and R2.4, opinions and hence preferences and utilities could change as part of the process. Overall, the potential for some form of strategic behaviour is always part of any system that tries to aggregate individual preferences into a collective result. Hence, we view this remark over the tradeoff between truthful expression and strategic influence as not a weakness of the APOLLO-Live tool, but a general criticism of collective decision-making. However, drawing a conceptual parallel with Arrow's impossibility theorem, we argue that rarely can any mathematical tool be foolproof against all types of potential manipulation. We also argue that our tool encourages truthful expression and discourages strategic voting. As previously explained, it would be rather difficult to influence the results through such a strategy within the employed MCDA approach, as the input required is more complex than simple selection, and hence strategic distortion is diluted. What is more, the tool includes a figure on the individual consensus of stakeholders (still anonymously), which provides a simple qualitative security over truly erratic voting patterns. In these cases, the awareness of the participants and the moderator can arguably be more important than any mathematical algorithm. We elaborate on this very interesting discussion in the final paragraph of the theoretical underpinnings section in Methods: *"Finally, the potential for some form of strategic behaviour from participants, who may try to take advantage of the system to promote self-interests, is always part of any system that tries to aggregate individual preferences into a collective result. Drawing a conceptual parallel to Arrow's impossibility theorem, we argue that rarely can any mathematical tool be foolproof against all types of potential manipulation. The tradeoff between truthful expression and strategic influence is not only a weakness of the APOLLO-Live tool, but of collective decision-making in general. The methods employed within the tool encourage truthful expression and discourage strategic voting. Crucially, it would be rather difficult to influence the results through strategic behaviour within the employed MCDA approach, as the input required is more complex than simple selection, and hence strategic distortion is diluted (i.e., participants evaluate all alternatives against a set of criteria rather than selecting a preferred option). The tool also presents a figure on the individual anonymised consensus level of stakeholders (see the Operation section), which provides a simple qualitative security over truly erratic voting patterns. In these cases, the awareness of the participants and the moderator can arguably be more important than any mathematical algorithm to protect the process."* Finally, a potential suggestion to include penalties for uncoordinated behaviours as an explicit method to discourage strategic voting might not yield the expected results. Such patterns are usually hard to detect (e.g., even in the thought experiment how do we differentiate a participant

that prefers alternative 5 over someone who promotes alternative 5 only to converge to alternative 4). As such penalties come at a disadvantage of their own, as they run the risk of penalising truthful votes. There is a very recent paper that aimed to address manipulative and manipulated behaviours in GDM (Zhong et al., 2025), but the authors acknowledge that simple weight penalties are insufficient and require more complex methods to address, while such complex methods still rely on participants' willingness to make subjective adjustments, and the potential of a cluster of manipulators influencing results remains as a gap. Based on upcoming advancements in this field, future versions of the tool could attempt to incorporate such mechanisms for addressing manipulative behaviour. We added this in the future research part of the conclusions: *"...as well as incorporation of different solving techniques (e.g., MCDA methods other than the 2-tuple Group TOPSIS used in GDM), and consensus reaching mechanisms, as well as explicit methods for incorporating manipulative behaviours"*

- Zhong, X., Liu, F., Du, Z., & Wan, Q. (2025). A Two-Stage Consensus Model Incorporating Manipulative and Manipulated Behaviors for Large Group Decision-Making under Social Network Environment. Applied Soft Computing, 113240.

Comment R2.6: 2) In page 17, trying to obtain generalizable outcomes about youth opinions in climate change from 5 participants should be strongly avoided. At the same time, we should have in mind that these 5 students are not randomly chosen. They are the students that "with no academic incentives provided" have been agreed to participate. Does environmental awareness make them participate? Is it their good relationships with the model developers that makes them participate? There are so many parameters that affect youth behavior.

Response: The reviewer is correct that the discussions presented on the use cases should not be misinterpreted as generalisable findings. The use cases serve primarily as numerical examples, highlighting the functionalities of the tool. In the first version, we had already provided some disclaimers on this. Acknowledging that these required strengthening, in this version we further expanded on these to ensure transparent reflections on the commentary provided. In particular, we first expanded on the existing disclaimer in the intro of the "Use Cases" section, right before the start of the two use cases, further stating that the commentary provided serves as an example of how results of the tool from potential representative exercises can be translated to concrete decision-aid findings: *"As such, any commentary on the results is primarily intended to showcase how results of the tool from future exercises can be interpreted and translated into relevant findings—if representativeness is achieved—rather than generalisable findings on their own"* Crucially, the whole paragraph serving as an example of the interpretation of results from APOLLO-Live in the first use case mentioned by the Reviewer was heavily edited. Notably, we added a disclaimer to ensure that the caveat of a small sample is clear, we ensured clarity that the commentary serves as an example of how one could potentially engage with the tools' results by toning down statements, and we also offered examples to analysts of how to interpret results in general, rather than focus on the results themselves: *"The following reflections are not generalisable due to the limited sample but can illustrate how APOLLO-Live can be used analytically in future exercises. In our case, they also highlight that there may be value in discussing alternatives ranked in the last places, since such results are usually left with limited commentary in ranking-based exercises. In particular, participation in climate activism actions ranked in the bottom, despite youth movements gaining traction as a means of protest* [46]

, with evidence showing such initiatives are overall viewed positively by the youth [47]. Using results from the APOLLO-Live engagement process and cross-validating them with literature can open up several interpretive avenues—further supported by participant discussions—that demonstrate the kind of reflective engagement the tool can support. In this indicative case, even among the young generation, there may be largely different opinions on the effectiveness of a certain action; this may reflect the opinion of only a small sample, but it may also underscore the need to significantly expand deliberation and co-creation activities to include the youth and capture broader viewpoints of the engaged groups. Also, the actions provided to the participants as options are not mutually exclusive, meaning that results merely reflect prioritisation rather than selection. This is usually the case for most MCDA questionnaires based on ranking; hence analysts should be careful in their interpretations. Considering the small sample caveat, these elaborations act as an example of how outcomes of the tool should be dynamically interpreted through active discussions with the participants, instead of strictly based on the quantitative results."

Comment R2.7: 3) The structural characteristics of the model that make it particularly useful for energy and climate policy discussions are not clear through the manuscript

Response: As we acknowledge in the conclusions, when developing the tool, our guiding principles focused on how it could be applied to problems related to energy and climate policy. However, the tool can be meaningfully applied in other fields. Still, as the Reviewer correctly points out, the structural choices making the tool explicitly tailored to energy and climate policy decisions could be improved. As such, throughout the theoretical underpinnings section of the manuscript, we added specific requirements/attributes incorporated that we enhance the tool's link to energy and climate policy. Notably on the choice of MCDA as the core part of the solution algorithm we added: *"Relying on MCDA, the tool aligns with the complexity of climate and energy trade-offs, since decisions are often based on environmental, economic, social, and technical criteria."* On the selection of TOPSIS and linguistic values, we now mention: *"Through these methodological choices, the tool enables comparisons and ranking under value-based judgments, which are essential for navigating energy policy objectives (e.g., which investments should be implemented or prioritised according to stakeholders and what is their potential impact)."* On the use of 2-tuples, we explain that: *"This semi-quantitative approach allows the integration of both qualitative and quantitative criteria, reflecting the reality of energy and climate policy decisions where not all criteria are strictly numerical."* And on the choice of approach to enable the calculation and comparison of individual, grouped and collective solutions, we mention that: *"This design enables integrating uncertainty and stakeholder diversity considerations in decision and policy support, which is common in climate-related topics."* We acknowledge that these four requirements/attributes and the associated structural choices (i.e., criteria trade-offs, comparisons and ranking under value-based judgments, qualitative and quantitative criteria, uncertainty and stakeholder diversity) are not unique in energy and climate policy decisions independently. but collectively, they are requiring characteristics to be able to capture the energy and climate policy space. We now explicitly make this argument in the conclusions: *"Additionally, when designing and developing the tool, our guiding principles focused on how it could be applied to problems related to energy and climate policy. Consequently, structural choices of the model aimed to capture relevant requirements and attributes such as criteria trade-offs, comparisons and ranking under value-based judgments,*

qualitative and quantitative dimensions, uncertainty and stakeholder diversity. Although these requirements are not unique in energy and climate policy decisions independently, collectively integrating such aspects is necessary to be able to capture problems in the energy and climate policy space. However, this does not exclude potential uses of the tool across completely different domains, again with the caveat that following the standard MCDA format in designing future use cases is necessary."

Final remark: Once again, the authors would like to thank the reviewer for deeply engaging with our research, and we hope the changes made, especially on methodological clarifications related to consensus and group dynamics, address their concerns.

Competing Interests: No competing interests were disclosed.

Reviewer Report 04 April 2025

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George Tsihrintzis
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The authors present APOLLO-Live, a webtool for engaging stakeholders in online discussions. The authors initially focus their efforts on the use of the tool on climate change and energy policy-related group decision making; however, the same tool can be used in more general settings and for engaging stakeholders in other disciplines too. Two use cases are also included in the authors' paper.

Overall, the development of APOLLO-Live is expected to fill in a gap in the group decision making tools, as current tools are oriented more towards asynchronous rather than synchronous (live) interactions.

The authors also identify some limitations of the current version of APOLLO-Live, which they can improve in future versions of it. In addition to the limitations identified by the authors, it is a good idea for them to also look at issues of explainability of the suggestions made by the tool, as explained suggestions may be easier to adopt by interested parties.

Is the rationale for developing the new software tool clearly explained?
Yes

Is the description of the software tool technically sound?

Yes

Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?
Yes

Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Artificial intelligence, machine learning, decision support systems, recommender systems, artificial intelligence-empowered software, artificial intelligence-empowered information systems

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 04 Jul 2025

Konstantinos Koasidis

Comment R1.1. The authors present APOLLO-Live, a webtool for engaging stakeholders in online discussions. The authors initially focus their efforts on the use of the tool on climate change and energy policy-related group decision making; however, the same tool can be used in more general settings and for engaging stakeholders in other disciplines too. Two use cases are also included in the authors' paper. Overall, the development of APOLLO-Live is expected to fill in a gap in the group decision making tools, as current tools are oriented more towards asynchronous rather than synchronous (live) interactions.

Response: The authors would like to thank the reviewer for their positive recommendation and remarks.

Comment R1.2. The authors also identify some limitations of the current version of APOLLO-Live, which they can improve in future versions of it. In addition to the limitations identified by the authors, it is a good idea for them to also look at issues of explainability of the suggestions made by the tool, as explained suggestions may be easier to adopt by interested parties.

Response: This is a very interesting suggestion. The current version of the tool already includes some explanations, but these mostly orient towards elaborating on the metrics used, as well as providing simple descriptions of the figures. Dynamic explanations and additional suggestions, potentially leveraging artificial intelligence and acknowledging caveats associated with such solutions, could indeed provide added value for future versions. As suggested, we reflect on these in the final sections of the conclusions, with the following addition: *"Finally, although efforts have been made to provide users of the tool with*

elaborations on the results, these are mostly static and focus on the definitions of the metrics used and the figures presented. In future versions, the dynamic explainability of the model's results can be considered, also leveraging breakthroughs in explainable artificial intelligence"

Competing Interests: No competing interests were disclosed.