Playful Complexity: Using a Serious Game with Immersive 3D Visualization to Balance Economy, Ecology, and Landscape Impact of Photovoltaic Plants

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Abstract: The transition to renewable energy is a balancing act: solutions should address both the climate crisis and the biodiversity crisis. At the same time, considering economical aspects, potential landscape impacts, and social acceptance patterns is crucial for success. This article presents an inter- and transdisciplinary approach for collaborative solar energy planning using a serious game combined with data-driven immersive 3D landscape visualizations. The process and results of connecting various interdisciplinary research outcomes and iteratively transforming them into a comprehensive game logic with corresponding visualization parameters are described. In the resulting game, players are challenged to achieve regional renewable energy targets by placing and configuring photovoltaic plants. Immediate feedback is provided for every action in the game regarding potential energy production, costs, and impacts on biodiversity, allowing an evaluation of potential impacts or synergies. 3D Visualizations also make it possible to assess the visual impact from any desired viewpoint. A total of five stakeholder workshops serves as the evaluation for this serious game. The workshop outcomes suggest that the presented strategy of developing a serious game as part of an interdisciplinary research project can aid in the communication and integration of scientific results. The resulting game impacted the decisions made by the stakeholders within the workshops, with most groups making a conscious effort to keep the biodiversity impact positive while also reaching the energy production target. Serious games such as this one could also be developed for similarly controversial landscape development processes to integrate stakeholders and find holistic and balanced solutions.

Keywords: Serious game, biodiversity communication, scientific communication, interdisciplinary research, virtual reality, renewable energy, stakeholder engagement

1 Introduction

When developing future scenarios for the transition to renewable energy, three aspects need to be balanced: economic feasibility, ecologic sustainability, and landscape impact. However, these aspects often conflict with each other – an economically efficient power plant may impair the local ecology and undesirably alter the visual identity of the landscape, leading to citizen resistance. On the other hand, the transition to renewables provides unique opportunities for synergies. Ground-mounted photovoltaic (PV) in particular can satisfy energy demands while also being beneficial towards the local ecology compared to the previous land use, provided a holistic planning and implementation (CUI et al. 2025).

To find such holistic solutions, inter- and transdisciplinary approaches are needed: different disciplines must be able to include their respective data and expertise, linking them to real-world needs and concerns (LAWRENCE 2010). The involvement of stakeholders has proven valuable (BIDWELL 2016), but raises the question of how to integrate and communicate the

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variety of scientific data, and how to include the subjective opinions of the affected people. How can a transdisciplinary consensus be reached based on interdisciplinary data and specific regional knowledge?

Serious games offer a promising solution: they have been shown to be effective in communicating data in understandable ways, fostering engagement, and promoting productive discussions (BOYLE et al. 2016, SCHAUPPENLEHNER et al. 2024). As opposed to traditional games, serious games have a purpose beyond entertainment, such as education or communication; however, they share the common characteristics of games, particularly the use of game mechanics and targets which the players need to reach (ZYDA 2005). To develop such a game logic, a simplified model of the systems linking economic, environmental, and social data in the context of PV planning is needed. In order to also depict the visual landscape effects, the game can be combined with immersive landscape visualization (LOVETT et al. 2015).

In this article, we present a process for integrating various scientific datasets into a serious game definition. This process is conducted as part of an inter- and transdisciplinary research project examining potential conflicts and synergies of ground-mounted PV development on plots currently used for agriculture. The serious game approach aims to involve various interest groups in the development and consolidation of PV scenarios at a regional level. To make their decisions more tangible, an interactive landscape visualization is integrated to include the visual impacts in the discussion. The resulting serious planning game is used in three case study regions in a total of five stakeholder workshops. Actions and statements made at these workshops are recorded anonymously; these outcomes serve to validate the presented approach.

2 Materials and Methods

2.1 Serious Game and Visualization Technology

A serious game and virtual reality landscape visualization toolkit developed in the game engine Godot is used as the basis. The toolkit utilizes GIS data to create 3D landscapes and to define a set of rules, constraints, and opportunities for the game logic. The individual components of the immersive 3D landscape are defined by combining multiple GIS layers into 3D *layer compositions*: for example, a layer composition which renders buildings accesses a vector layer of building polygons and a digital terrain model for placing each building at the correct height. Open governmental data and volunteered geographic information (VGI) are used as a basis for both the visualization and the game logic. The data and rendering components required for depicting a landscape as-is serve as the starting point for this study; the visualization is then extended with components for the specific use-case of PV planning.

In order to discuss ecological impacts or synergies of ground-mounted PV, it is important for different management regimes and layouts to be represented accurately in the visualization. This is realized by making the ground cover and vegetation rendering components react to newly placed PV rows: virtual PV panels can alter the land cover data, replacing the previous vegetation (usually agriculture) with varying soil and plant growth underneath, behind, in front of, and around modules. The effect of this is shown in Figure 1.

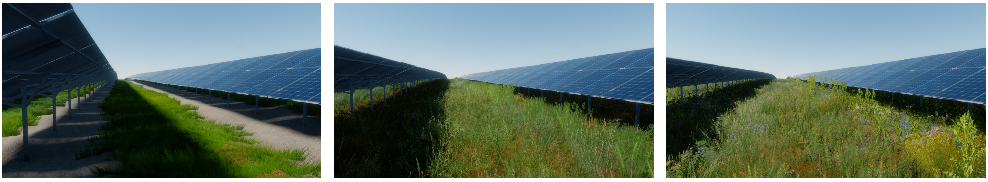

Fig. 1: Visualization of different management methods of PV fields: intensive (left, graveled and regularly mowed, distance of 2m between modules), medium (center, mowed and mulched, 4m between modules), and extensive (right, measures taken to promote flowering plants, 6m between modules)

For the game logic, layers are wrapped as *game object collections*, with each GIS feature (point, line, or polygon) in such a layer becoming a *game object*. These game objects can have attributes of different types: they may come directly from a GIS attribute, or they may correspond to the value of a raster layer at their position, or they may even be an aggregate of other attributes based on a given formula. Attributes can be visualized per game object or summed into scores, which may also have a target which the players are suggested to reach.

Rather than using traditional computer inputs, we use the input method described by Schauppenlehner et al. (2024) to allow stakeholders to intuitively and spontaneously interact with the serious game. A map is projected onto a table and toy bricks can interact with this projection. For example, a red brick may depict a PV plant to be placed at that location. The bricks also serve as the input to the user interface, allowing players to make changes to individual PV plants such as changing the distance between rows or the surrounding fencing. Indicators and scores are displayed on this interface as well. As the input method is directly connected to the serious game and landscape visualization, the effects of the participants' actions are visible in real-time.

2.2 Interdisciplinary Game Development

This serious game is developed as part of an inter- and transdisciplinary research project. Specifically, experts in energy economy, biology, and social sciences are part of the interdisciplinary group. In an iterative process, we incorporate and interconnect different thematic data outputs and validate the result based on their expertise and scientific studies. In practice, this iterative process unfolds as follows: experts provide a dataset along with a description of outcomes from their field. Together, we discuss how to best simplify and integrate this data into the serious game. Based on this discussion, a first implementation is built, which is then tested together with the experts. The process is repeated as needed based on their feedback.

Care must be taken to strike a balance between playability and visual fidelity on the one hand, and objectivity and accuracy on the other. For example, a game may elicit a stronger emotional response if biodiversity is visualized in an exaggerated way, while this causes accuracy (and potentially credibility) to suffer (SKULMOWSKI et al. 2022).

2.3 Stakeholder Workshops

The serious game developed as part of this case study is intended to be used to collaboratively plan potential future PV scenarios in stakeholder workshops. To test the efficacy of the tool in such a workshop, it is applied in a total of five different stakeholder workshops throughout three different regions in Austria. Local stakeholders such as politicians, people involved in energy cooperatives, and interested citizens are invited, with an average of 8 participants per workshop. 3 hours are scheduled for each workshop, about half of which is set aside for the serious PV planning game.

It should be noted that the concrete results of the case study, as well as the specific methodology of stakeholder involvement applied here, are not the primary focus of this article. Rather, the stakeholder workshops serve to assess the impact which the tool has on the workshop, and how it influences discussions and decisions made by the participants.

Verbatim statements made by the participants while playing and discussing the serious game are recorded in a pseudonymized written protocol. In order to ascertain the role which the serious game plays in the discussions and whether it communicates the conflicts and synergies effectively, a thematic analysis is then applied to these protocols. Specifically, the *codebook thematic analysis* according to Braun et al. (2019) is used to iteratively generate and assign themes from the protocols.

3 Results

Two distinct results will be described: the serious game, which combines data from different disciplines into a simplified game logic and visualization, and the evaluation of the stakeholder workshops, which serves to assess whether the serious game was effective.

3.1 Serious Game Definition

In an iterative process described in section 2.2, a serious game logic is defined based on data compiled and processed by experts throughout the project. A flow chart diagram of this game logic is shown in Figure 2.

In the game, participants can place photovoltaic plants and configure the following design parameters for each of them:

1) **Land management**: intensive, moderate, or extensive
2) **Size of PV plant**: 0.5 hectares, 2 hectares, or 8 hectares
3) **Spacing between rows**: 2 meters, 4 meters, or 6 meters
4) **Fencing**: none, hedge, or chain-link fence

In combination with pre-calculated spatial datasets and fixed constants, these parameters serve as the basis for estimating biodiversity impacts and calculating economic outputs.

To calculate the **energy production** of a PV installation in kWh/a, a pre-calculated energy potential dataset (in kWh/kWp) is accessed and multiplied by the number of modules (derived from the size and row spacing of the PV plant) and their power rating. The total cost of a PV installation is a sum of the system costs (depending on the number of PV modules), grid costs (depending on the location), and maintenance costs (depending on the size and management regime); the underlying data for this was provided by partners in the interdisciplinary project team. Dividing this cost by the energy production yields the **cost per kWh**. This cost is not judged by the game, but presented to participants as-is; it serves as another factor to consider for their subjective, overall evaluation. It should be noted that indirect costs, e. g. lost profits due to reduced agricultural use, are not considered; the cost factor does not provide a holistic economical evaluation, but an estimate of the electricity price.

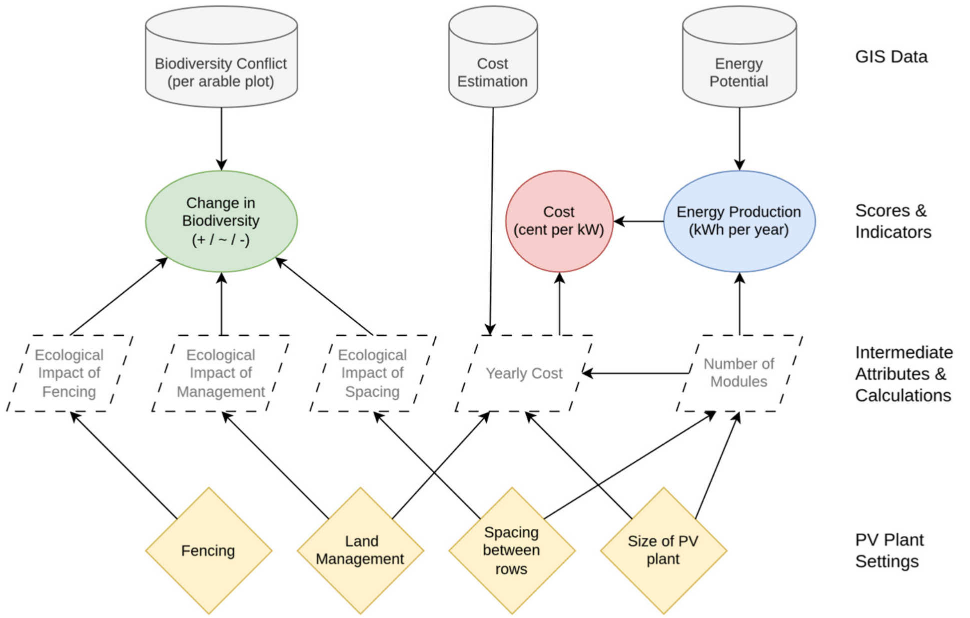

Fig. 2: Flow chart diagram of the serious game logic showing how GIS datasets are connected to attributes and user inputs

Integrating the ecological data to calculate a **change in biodiversity** required multiple iterations. Using the national IACS (INVEKOS) dataset (AMA 2025), each agricultural plot within the case study area is rated with an ecological potential for conflict (EPFC) based on its current condition and cultivation (low, medium or high EPFC). A low EPFC means that biodiversity is currently scarce (e. g. intensively cultivated crops), while a high EPFC value indicates that the existing land use creates high ecological value (e. g. extensive meadows) and changes in land use are likely to adversely affect biodiversity. For further detail on the methodology behind this classification which was devised as part of this project and utilized for the serious game, we refer to Hainz-Renetzeder et al. (2025).

Each decision made by the participants regarding the design and management of a PV system is assigned an environmental impact based on the EPFC of the plot in which it was placed. These impacts are defined together with biologists based on field surveys in which they compared photovoltaic sites with reference plots. The sum of the ecological impacts of one PV system is an integer value. Because of the difficulty of quantifying ecologic impact, only the sign of this value is communicated in the game as a general trend: Negative values indicate a decline in biodiversity, positive values correspond to a potential increase in biodiversity, and zero implies that biodiversity will remain largely unchanged. Generally, installing PV in locations with a high EPFC will always lead to negative biodiversity impacts, while areas with a low EPFC generally see an increase in biodiversity unless the PV installation is configured to be highly dense and intensively managed. The rating scheme is shown in Table 1. Of course, these are estimations which serve primarily to initiate discussions among participants on the trade-offs to be made, not to provide definitive assessments of individual plots.

Table 1: Impact of different ground-mounted PV configurations on the biodiversity score in the serious game based on the ecological potential for conflict (EPFC) of the previous land use

EPFC		Low	Medium	High
Row Distance	6m	+2	+2	-1
	4m	+1	0	-2
	2m	0	-2	-3
Fencing	Chain-link	-1	-1	-1
	Hedge	+1	+1	+1
	None	0	0	0
Management	Extensive	+2	+2	-1
	Moderate	+1	0	-2
	Intensive	-1	-2	-3

In addition to displaying these indicators within each PV installation, two global game targets are added to the game. One is energy production: players can see how much their currently planned PV installations contribute to the national energy targets (scaled to each workshop region). The second target is the assessment of the effects on biodiversity. Because this cannot meaningfully be communicated as a numeric value, it is displayed as a deviation from the status quo: participants can see if, in total, their activities have a potential to improve or worsen the biodiversity within the workshop region. These two scores are displayed individually and not summed into a total score, since the weighting should be up to the participants.

3.2 Visualization

Like the biodiversity indicator, the definitions and visual representations of different management regimes are developed iteratively together with experts in the field. Based on field surveys within existing PV plants, typical distinct management regimes are identified, and corresponding ground and plant textures are assigned based on the reference PV installations to match their visual appearance as closely as possible.

Players can choose between three management regimes: *intensive*, characterized by short, frequently mowed grass; *medium*, dominated by species-poor grassland due to mulching; and *extensive*, where specific measures are taken to promote a diversity of different (flowering) plants. Four ground cover types are defined for each management regime: vegetation directly underneath each module, in front of a row of modules, behind a row of modules, and in the remaining area. The strips before and behind modules have a width of 1 meter. Figure 3 illustrates the visualization of these areas for each management regime and features some of the textures used in the visualization.

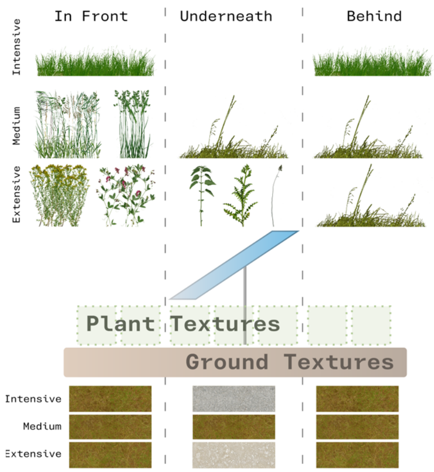

Fig. 3:
Schematic depiction showing how vegetation is configured and visualized around PV modules. The textures shown are examples of textures used in the 3D visualization; they are selected based on location and management regime.

3.3 Stakeholder Workshop Evaluation

Two tags are assigned to each entry in the written workshop protocols. The first signifies the **scope** in which the discussion was taking place:

- *Within:* Discussion in direct reference to the serious game or visualization
- *Beyond:* Discussion of siting-related topics beyond the direct scope of the game
- *About:* Discussion of the methods (the serious game, the visualization, or the underlying data) at a meta-level

The second tag specifies the **content** of the discussion. Some directly correlate to themes brought up by the game, specifically *Energy*, *Ecology*, *Visual*, and *Economy*. Others refer to new themes brought up by participants; these include *Legal*, *Other Renewable Energy*, and *Method* (statements or questions about the game, visualization, or data).

The *Within* and *Beyond* tags were approximately equally common (41% and 39% respectively), suggesting that the tool facilitated discussion of the content being shown while also encouraging the discussion of new themes. The *About* tag was half as common (20%), indicating that meta-level discussions did not dominate over other topics.

Among discussions *within* the game, the *visual* theme, i.e. participants expressing their opinion on the visualized PV installations, was most common (43%). *Ecology* and *Energy* were discussed at 24% and 20% respectively, suggesting a relatively balanced discussion of ecological sustainability and energy-efficiency. The remaining 13% are tagged with *Method*. Notably, the *Economy* tag never occurred at the *Within* scope.

In discussions *beyond* the game, visual aspects account for just 9%, indicating that participants were able to sufficiently discuss this aspect *within* the visualization. *Ecology* and *Energy* account for 20% and 15% respectively; these statements usually added specific local knowledge which was not present in the game data. *Economy* also accounted for 15% of statements *beyond* the game. Similarly, discussions about *legal* aspects, which were not covered by the game at all (except implicitly by the inclusion of legal boundaries between agricultural plots), account for 15% in this scope. Other types of renewable energy were also brought up in most workshops.

Discussions *about* the game largely centered around the *method* with 46%. This includes e. g. questions about the usage of the tool and remarks about the feasibility of the plans as simulated in the game. The remaining topics in the *About* scope are spread relatively equal, usually questions about the underlying data or statements about potential inaccuracies. This scope was usually most prevalent in the first halves of workshops, while the *within* scope was more frequent in the second halves.

Comparing the protocols between individual workshops reveals that the focus varied significantly. In some workshops, the *visual* impact played a central role, making participants rely primarily on the landscape visualization. In others, the discussion centered more on the practical aspects of *economy* and *energy*, although as noted above, while the discussions of *energy* did often center around the data provided by the game, discussions of *economical* aspects did not take the game into account, often occurring at the intersection with political topics (funding) rather than the purely techno-economical calculation.

Although there were significant differences between the workshops, *energy* and *ecology* as presented *within* the game were a topic in all of them, and in each workshop, participants actively attempted to reach the national energy target while paying attention to causing no negative total impact on biodiversity. This suggests that the global scores effectively influenced the discussion, while being open enough to facilitate sufficient discussion of other aspects *beyond* the serious game.

4 Discussion

In the context of an inter- and transdisciplinary research project, a comprehensive serious game for PV siting at the regional level was developed, taking economy, ecology, and landscape into account. Complex data and interrelations were translated into a comprehensible game logic. The accompanying immersive landscape visualization shows the specific parameters of the PV installations and how they fit into the surrounding landscape.

The iterative integration of the interdisciplinary data into the serious game also provided a unique opportunity for the other experts to reflect on their data output and simplify and generalize it, while still being comfortable with the accuracy. This process of gamifying data outputs may aid not only the external presentation of the results, but also the internal cooperation and communication in interdisciplinary projects. A future article will analyze the interdisciplinary cooperation within this scientific project in its entirety.

The workshops showed that the game provided a useful basis for discussion and collaboration. In particular, the national energy targets and the total biodiversity score influenced the participants' choices in all workshops. In some cases, the visualization was a crucial aspect and allowed participants to effectively factor the subjective visual landscape impact into their plan. On the other hand, participants paid no attention to the economic score expressed in cent per kWh, instead discussing other economic aspects such as funding. It is possible that this difference was partly caused by the lack of a total target for this aspect. However, it should be noted that participants did still discuss this point and factor the discussion into their plan, suggesting that it was important for the serious game not to be overly restrictive, providing a basis for discussion but not insisting on it.

Our method, from technical implementation to practical usage, could be applied in a variety of other landscape planning and development processes, particularly those involving similar conflicts of interest. Alongside other forms of renewable energy, the joint and holistic planning of nature-based solutions using a similar method could be a promising area for future studies. It may also be interesting to transfer these results to other fields and even back to traditional video games: we would encourage game developers, particularly of strategy games, to consider incorporating a realistic ecological component similar to the game logic developed in this study.

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References

AMA (2025), INVEKOS Schläge Österreich 2024-1. https://www.data.gv.at/katalog/datasets/bbd8ee1b-76a1-451f-88ef-84e9c7a1faaf.

BIDWELL, D. (2016), Thinking Through Participation in Renewable Energy Decisions, Nature Energy, 1 (5), 16051. https://doi.org/10.1038/nenergy.2016.51.

BOYLE, E. A., HAINEY, T., CONNOLLY, T. M., GRAY, G., EARP, J., OTT, M., LIM, T., NINAUS, M., RIBEIRO, C. & PEREIRA, J. (2016), An Update to the Systematic Literature Review of Empirical Evidence of the Impacts and Outcomes of Computer Games and Serious Games. Comput. Educ. https://doi.org/10.1016/j.compedu.2015.11.003.

BRAUN, V., CLARKE, V., HAYFIELD, N. & TERRY, G. (2019), Thematic Analysis. Handbook of Research Methods in Health Social Sciences, edited by Pranee Liamputtong, 843-60. Singapore: Springer. https://doi.org/10.1007/978-981-10-5251-4_103.

CUI, H., YANG, J., LV, B. & DING, N. (2025), Ecological Impacts of Photovoltaic Power Plants: From Perspective of Atmosphere, Soil, Hydrology, and Biodiversity. Reviews in Environmental Science and Bio/Technology, October. https://doi.org/10.1007/s11157-025-09750-6.

HAINZ-RENETZEDER, C., SCHAUPPENLEHNER, T. SCHERHAUFER, P. & PACHINGER, B. (2025), Navigating the Nexus Between Renewable Energy and Biodiversity: Impacts and Mitigation Strategies for Ground-Mounted Photovoltaic Systems. Landscape Online, November, 1141-41. https://doi.org/10.3097/LO.2025.1141.

LAWRENCE, R. J. (2010), Deciphering Interdisciplinary and Transdisciplinary Contributions. Transdisciplinary Journal of Engineering & Science, 1 (1). https://doi.org/10.22545/2010/0003.

LOVETT, A., APPLETON, K., WARREN-KRETZSCHMAR, B. & VON HAAREN, C. (2015), Using 3D Visualization Methods in Landscape Planning: An Evaluation of Options and Practical Issues. Landscape and Urban Planning, 142 (October), 85-94. https://doi.org/10.1016/j.landurbplan.2015.02.021.

SCHAUPPENLEHNER, T., BAUMGARTINGER-SEIRINGER, M. & BITTNER, K. (2024), Where Should We Place It? The Potential of a Serious Planning Game Approach for Participatory Planning Processes in the Context of Renewable Energy Development. Journal of Digital Landscape Architecture, 9-2024. https://doi.org/10.14627/537752035.

SKULMOWSKI, A., NEBEL, S., REMMELE, M. & REY, G. D. (2022), Is a Preference for Realism Really Naive After All? A Cognitive Model of Learning with Realistic Visualizations. Educational Psychology Review, 34 (2), 649-75. https://doi.org/10.1007/s10648-021-09638-1.

ZYDA, M. (2005), "From Visual Simulation to Virtual Reality to Games." Computer, 38 (9), 25-32. https://doi.org/10.1109/MC.2005.297.