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Large-Scale Agrivoltaics Visualisations for Assessing Landscape Impacts and Social Acceptance

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Abstract. Visual landscape impacts are of great importance when it comes to social acceptance measures of renewable energy. Although agrivoltaics seems to have higher acceptance values than other renewable energy infrastructures due to the dual land use approach, it is expected that they have a bigger visual impact on the landscape scenery than ground-mounted installations due to the increased land requirements and clearance heights. This article presents the development of a game-based visualisation approach using open-source software and open data (open government data) for visualising energy landscapes by creating large-scale interactive and immersive 3D visualisations. The results show that the use of open geodata and available open-source gaming technologies can be used to create comprehensive digital VR landscapes for assessing the visual impacts of agrivoltaics. Furthermore, the data-driven approach can provide additional indicators for evaluating planning scenarios and investigating the social acceptability due to renewable energy expansion.

Keywords: Landscape Impact, Social Acceptance, 3D Visualisations

1. Introduction

The upcoming years will need growth in the output of agricultural goods [1] and a significant increase in renewable energy generation for climate change mitigation purposes [2], especially wind energy and photovoltaics (PV). While common ground-mounted PV usually prevents agricultural production on the same site, agrivoltaics (AV) is a promising approach to combine agricultural practice with renewable energy generation with the goal to reduce land use conflicts [3] and increasing land use efficiency [4]. Furthermore, specific AV designs can act as adaptation strategies for climate change impacts such as reduced evapotranspiration and lower ground temperatures through shading [5], or protection from extreme weather events such as hail or heavy rain, especially for special cultures such as fruits or berries.

However, aside from those technical, agricultural and economic aspects, social acceptance as a positive attitude towards a technology [6] is crucial for archiving the climate targets. The first formal approach addressing the social acceptance of renewable energy was published by Wüstenhagen et al. in 2007 as the triangle of social acceptance [7]. In addition to socio-political and market acceptance, it is above all community acceptance within the framework of which resistance can form at the local implementation level as everyday landscapes are affected and aspects of procedural and distributive justice come into focus. Hübner et al. [8] indicated, that local economic impacts, attitude towards the energy transition, trust, impact on man and nature as well as social norms are the main factors that affect social acceptance of renewable energy development. Furthermore, the impact on landscape sceneries and disturbances of cultural landscapes or touristic settings is a very important factor that influences the level of acceptance [9]. While most of the previous acceptance studies emphasize the development of wind energy or ground-mounted PV, AV is a very novel expression of renewable energy generation in Europe and therefore, there is only a little knowledge about landscape impacts and social acceptance patterns. First studies indicate that AV has a higher acceptance rate compared to ground-mounted systems because it allows for dual land use and synergies, which can reduce siting conflicts [3]. However, in the case of AV, farmer acceptance also plays a crucial role, as it changes farming practices and economic factors [10]. Important aspects of local inhabitants towards social acceptance are often negative landscape impacts [11], place attachment [12] and negative effects on recreational values [13], suggesting that adequate communication of visual impacts can be an important tool to increase acceptance.

Visualising future landscape developments has evolved over the last decades as hardware and data become more and more powerful. Especially large-scale and interactive visualisations are important to address personal preferences (e.g. viewpoints) as well as the large-scale visibility of several structures such as wind turbines or large solar plants. A major problem is, that those large-scale visualisations are costly to realize for individual projects. Furthermore, they are hardly transferable to other regions. This article presents an approach for creating immersive and interactive 3D environments for participatory planning processes to mainly address the visual appearance of AV facilities in landscapes. Furthermore, since the system is created on the basis of spatial data, it is possible to calculate indicators estimating influences on economics and agricultural production. The system is based on freely available geodata in Austria and open-source technologies and can be applied for different planning regions and scales.

2. Material & Methods

2.1 GIS data gathering and processing

Within an initial web research between 01-2022 and 05-2022, data sources with the potential to contribute to the development of the 3D environments were identified. With the focus on Austria, national databases and repositories (data.gv.at and geometadatensuche.inspire.gv.at) were screened regarding relevant data for topography, land cover, water, transport and infrastructure. Additionally, European and global data portals and initiatives (Copernicus Landcover, JRC, OpenStreetmap) have been searched for supplementary data. The focus was solely on open and freely accessible data, especially open government data, a field that increased rapidly in the last decade [14].

The selected data were processed using QGIS including reprojection (to the EPSG:31287 – MGI / Austria Lambert), raster alignment, spatial and thematic resampling and selection as well as cropping to the case study area. The single datasets consisting mainly of relief, land cover and different infrastructural elements (buildings, roads, power poles, etc.). were then collected within a geodatabase (geopackage) as fundamental input for the game engine.

2.2 3D Visualisation using a game engine approach

For the creation of the 3D environments, the open-source game engine Godot is used. To access the geodatabase and prepare the data for visualisation, a plugin was developed. This allows not only access to the geometry for generic 3D modelling but also to attributes (e.g., relief parameters, yields, solar radiation, etc.), which means that in addition to the visual experience, indicators for different planning scenarios can be calculated and displayed in real-time.

Figure 1. Workflow of data (geodata, plants and 3D assets) for creating the 3D environment and applications such as collaborative planning and immersive visualisations using VR glasses.

Figure 1 shows the modelling workflow using different data for creating the 3D environment and potential applications for interaction with the game engine. The geodata are coupled with a plant library and 3D models for infrastructural elements to generate immersive landscapes in Godot for collaborative planning and visual assessment.

3. Results

3.1 Geodata availability and resolution

Our research has shown, that many nationwide data sets are available that have the potential to generate realistic 3D visualisations as they have a high spatial and thematic resolution. The basis for the 3D model is an elevation model that is available for the entire Austrian territory in a 1m-resolution. Additionally, the digital surface model with the same resolution can contribute to the calculation of building and forest heights. On top of the elevation model, detailed data for land use/land cover as well as water bodies are draped to provide a spatial model for the land cover distribution as well as landscape elements and structures. Infrastructural data such as transport infrastructure and built-up areas are selected in order to create visually accurate and reliable models to be able to evaluate visual relationships and the landscape scenery accordingly.

Table 1 gives an overview of the data that were selected for the generation of a 3D model in the game engine Godot.

Table 1. Selected geodata for visualising landscapes

Dataset	Extent	Type	Resolu-tion	Year	Category	Source
Digital elevation model	Austria	Raster	1 x 1m	2020	Topography	Federal Office of Me-trology and Survey-ing
Digital surface model	Austria	Raster	1 x 1m	2020	Topography	Federal Office of Me-trology and Survey-ing
Ortho images	Austria	Raster	0.3 x 0.3m	2018	Texture	Geoland.at
Sentinel 2-Landcover	Austria	Raster	10 x 10m	2016	Landcover	Umweltbundesamt GmbH
Agricultural fields	Austria	Vector	detailed	2021	Landcover	Agrarmarkt Austria
Forest areas	Austria	Raster	1 x 1m	2020	Landcover	Bundesforschungs-zentrum für Wald
EU-Hydro	Europe	Vector	generali-zed	2018	Streams and wa-terbodies	European Environ-ment Agency
OpenStreet-Map	World	Vector	detailed	2022	Buidlings, land-marks, streams and waterbodies	OpenStreetMap
GIP road data	Austria	Vector	detailed	2022	Roads and rail-ways	Austrian Institute for Transport Data Infra-structure

The research showed, that a broad range of geodata is available for Austria to create realistic and reliable 3D environments as a basis to assess the impact of AV infrastructure on a certain landscape.

3.2 Game Engine for 3D model creation

Although there is a range of different game engines for the creation of interactive 3D models, the import of geodata is hardly or only very rudimentary implemented in these systems. In addition, many systems are proprietary and can entail high licensing costs. Game engines are of particular importance for large-scale and interactive 3D visualisations in different fields, and there are several commercial products (e.g., Cry Engine, Unity) available [15][16]. We decided to use the open-source game engine Godot as initial tests with geodata processing have shown that this engine is very well suited for creating large-scale visualisations in terms of the degree of realism, performance and display options such as VR or AR.

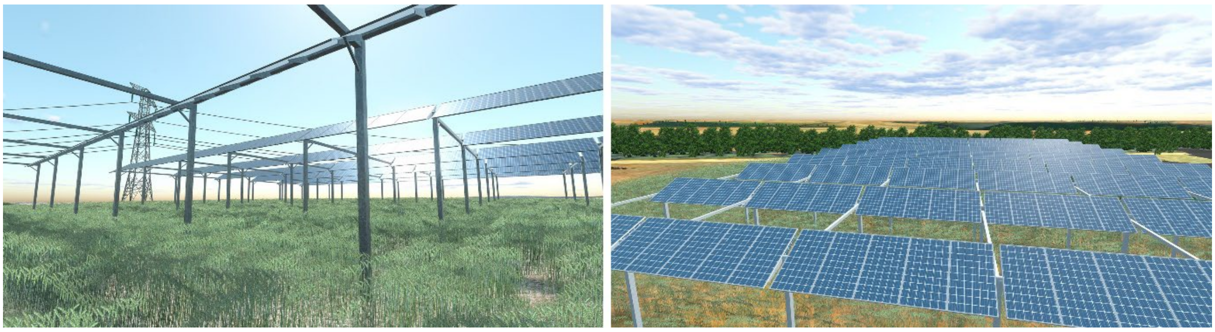

Figure 2. Visualisation of an overhead AV installation over a grain culture (left: first-person-view, right: overview).

Figure 2 shows the overall achievable quality of the visualisations in Godot. By using complex vegetation systems (attached to the land cover classes derived from geodata), high-quality textures that support reflections, roughness, and physical models for atmospheric effects, high quality can be achieved to evaluate the visual impact of AV installations using immersive VR technologies. In addition, real-time changes for date and time allow evaluation under different lighting conditions. This also enables dynamic shadow effects, reflections or tracker positions.

Figure 3. A tracker AV modell that follows the sun by changing date and time parameters (left: morning, middle: midday, right: evening)

Figure 3 gives an example of possible interactivity options. By changing date and time parameters, tracker systems can by animated and the effect of different light conditions can be explored.

For implementing 3D elements (plants, buildings, infrastructure) into the game engine environment, different techniques and approaches are used. Most of the buildings are built generically based on a footprint (derived from OpenStreetMap). The individual height value of each footprint is calculated as the difference between the digital surface model and the digital elevation model. The roof colours are taken from the ortho-image below to generate realistic and recognizable settlement areas. Special buildings such as historic ensembles or landmarks can be integrated as a realistic 3D model using a reference point (see Figure 1 with an example of an old castle that was created with laser scanning). Other assets such as power poles, wind turbines or AV plants are pre-modelled standard assets that can be scaled (e.g. in the case of wind turbines and power poles) or arrayed (in the case of AV). For the array, a base model is used (e.g. a 5x5m AV setup) that can be arrayed on a given field or for a given size. Plants are composed of ecosystems (Selection of different species, heights, densities and distribution) that will be linked to the land cover data (see also Figure 1).

As the 3D model is created from geo data containing different attribute information (e.g. slope, aspect, yields, etc.), further indicators can be calculated in real-time (e.g. within a collaborative planning process or for different planning scenarios). In the case of agrivoltaics, impacts on agricultural production as well as the amount of energy production can be calculated. Figure 4 show an example of indicators (numbers and bars below the 3D visualisation)

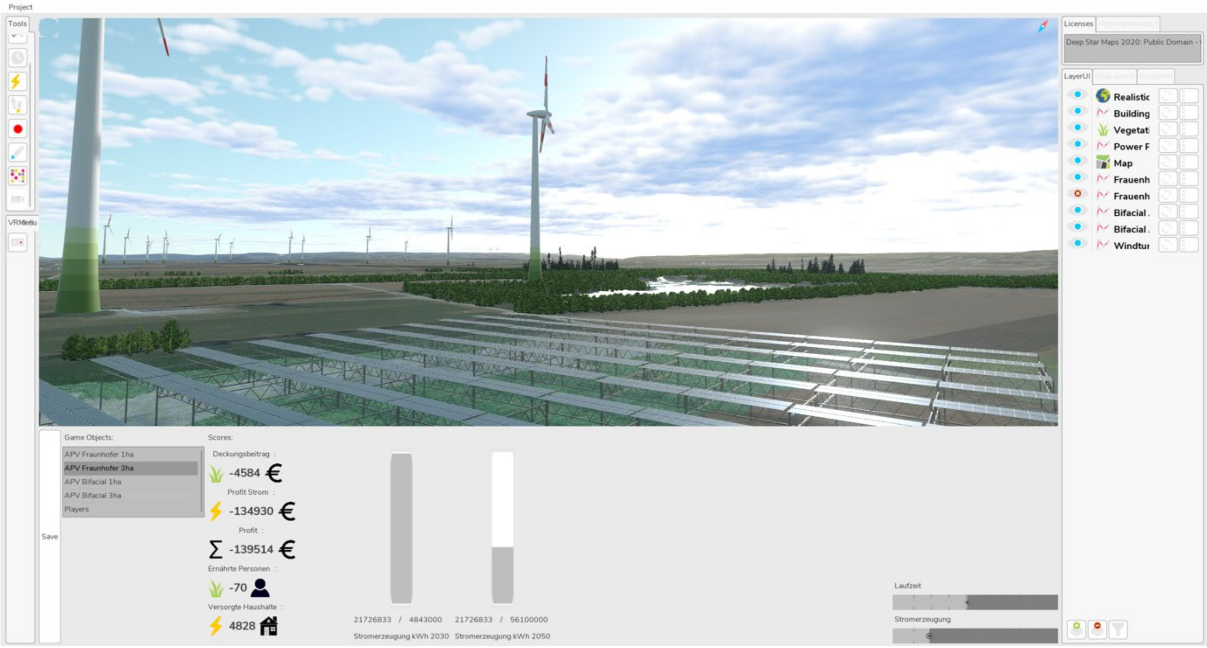

Figure 4. Examples for indicators such as marginal income or energy profit based on a specific AV planning layout.

To address different future expectations towards energy prices and plant runtime, slides can be used for different market and technology assumptions.

3.3 Geodot-Plugin for geodata-import

As mentioned above, the import of geodata into game engines is one of the crucial factors for an efficient application of game engines for visual landscape assessment using 3D environments. Therefore, we developed a Godot plugin written in GDNative with C++ and GDAL for loading geospatial data.

The input format used is Geopackage (GPKG) with which different types of raster and vector data can be combined in a compact container file. The georeferenced data contained in this file can be loaded into Godot with this plugin and used to build the 3D environment. Thanks to efficient filtering and cropping, the data can be loaded in real-time. Like Godot, the plugin is freely available with an open-source license and can be downloaded from GitHub.

4. Conclusions

AV is expected to have significant landscape impacts because the necessary infrastructure can be widely visible from a distance due to the land and height requirements. The traditional landscape is thus altered and mechanized. Therefore, similar to wind energy, conflicts with social acceptance addressing these landscape changes at local the level are to be expected. Large-scale interactive and reliable visualisations can contribute to depict these impacts in advance, supporting communication and social acceptance aspects associated with visual impacts. In addition, the geodata-based approach cannot merely serve a visual experience but also other indicators such as viewsheds or indicators for the impact on agricultural and solar yields. This offers a potential to contribute to the most often very emotional debates about the land competition between agricultural and energy production.

Since especially large-scale 3D visualisations are very time-consuming to create, we have demonstrated, that efficient, data-supported visualisation methods are possible to show the effects of the energy transition and to evaluate or optimize planning variants using an open-source game engine technology. It offers a method for the creation of very large 3D environments which means that it can be used for local planning projects, as well as a supporting tool for strategic planning at a regional, federal or national level. Using an open-source technology and open data as presented has furthermore a considerable potential for supporting democratization processes and bottom-up initiatives. Possible is this by applying comprehensive level of detail (LOD) algorithms and programmatical data access and data processing. Nevertheless, for very large regions, there is a high effort for data processing and data storage which should not be underestimated.

Our study has shown that the datasets, available in Austria are very well suited to create very realistic 3D scenes for any region very efficiently, as they have a very high spatial and thematic resolution and are updated regularly. Especially the nationally available elevation model and surface model with 1m resolution and the detailed agricultural areas allow very realistic visualisations. A comparison with pan-European data shows that the thematic areas relevant for visualisations (relief, land cover and infrastructure) are available in principle at the European level, but there are large differences in quality, especially in terms of spatial and thematic resolution.

As a tool for visualizing future AV developments, it can promote social acceptance at the local level by supporting decision-making and collaborative planning. The visual assessment can help to reduce the fear of significant visual impacts and enable discussions about socially acceptable scales or distributions. In addition, indicators of economical and/or agricultural impacts can help objectify the landscape competition debate.

5. Outlook

The development of renewable energy remains an urgent topic to reach the climate goals and contribute to the decarbonization of our energy system but will alter the landscape in different ways. There will be fundamental changes in the landscape scenery which impact everyday landscapes and recreation values as well as societal debates about land competition, nature conservation, procedural and distributional justice and, in the case of AV, also farmer acceptance as it changes the management system and impacts economical values. With the development of a spatially scalable open-data-driven approach for the creation of realistic immersive and interactive visualisations and the potential to calculate further indicators in real-time, it is possible to contribute to the establishment of new participatory planning approaches at various spatial and institutional levels as well as for research purposes. Therefore, we decided to use open-source software as it allows an open and transparent utilisation of current and future datasets as well as methods (e.g. machine learning) for the just development of renewable energy.

Data availability statement

The tools and scripts developed for importing data and generating the 3D environments using Godot are published under a GPL-3.0 license. A download of the geodot-plugin is possible via GitHub (search for boku-ilen and geodot).

Author contributions

Thomas Schauppenlehner: Lead author, Conceptualization, Methodology, Results, Conclusions and Outlook; Karl Bittner and Mathias Baumgartinger-Seiringer: Contributions to data curation, Methodology, Results, and Conclusions.

Competing interests

The authors declare no competing interests.

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