Role of immersive visualization tools in renewable energy system development☆,☆☆

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Abstract

Hybrid renewable energy systems (RESs) are being widely utilized as an alternate source of energy for mitigating the rapidly increasing energy demand. Explicit representation of the results obtained from the impact analysis made on a newly proposed or an existing hybrid RES is complex, and it requires powerful visualization tools. Over the years, various visualization techniques were developed towards addressing this problem. Therefore, the use of visualization techniques are continuously growing and have been the focus of many researchers across the world. This review article presents a comprehensive analysis of the advancements in the use of different immersive visualization (IV) tools in state-of-the-art RES development. A total of 41 software packages and a collection of recently published research articles in the field of RES development incorporated with advanced IV tools was identified and critically reviewed based on its use-case, accessibility, complexity, robustness, immersivity, and adaptability. Finally, a list of fit-for-purpose software packages that could be used at different stages of the RES development is recommended. A summary of the current advancements in the use of the IV tools in RES development is presented to highlight the broader potential of multidisciplinary applications of the advanced IV tools in RES development.

Keywords: Augmented reality (AR), immersive visualization tool, renewable energy system (RES), two-/three- dimensional visualization (2D/3D viz), virtual reality (VR)

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1. Introduction

Energy demand and consumption rates are significantly influenced by the expeditious urbanization, population growth, and technological advancements [1, 2]. Energy demand caused by daily human activities, including maintenance and development of urban infrastructure, industrial manufacturing, and transportation is primarily addressed by conventional energy resources (fossil fuels). However, using conventional energy resources causes adverse environmental impact leading to global warming and climate change. Therefore, entirely relying on conventional energy resources to produce electricity is considered an ineffective solution. Renewable energy resources such as solar, wind, tidal, biomass, hydro, geothermal, etc., reduce adverse environmental, economic, and social impact, thereby making it a sustainable choice to address this issue [3]. Recent advancements in the field of battery storage and highly efficient power electronic converters prove that the vision of replacing conventional fossil fuels by 100% renewable energy is feasible. However, renewable energy systems (RESs) have a drawback in relation to the dependency of stochastic weather conditions, which has to be considered when modeling the system.

Clear visualization of the energy demand distribution pattern and impact analysis of a newly proposed or an existing hybrid RES is complex, and it requires a powerful visualization tool. Usage of advanced simulation packages integrated with computer-aided designing (CAD)/ immersive visualization (IV) tools addresses this continuously growing requirement and has been the focus of many researchers across the world till date. Figure 1 illustrates the geographical distribution of research articles published in the field relevant to the use of IV tools in RES development obtained from the web of science (WoS).

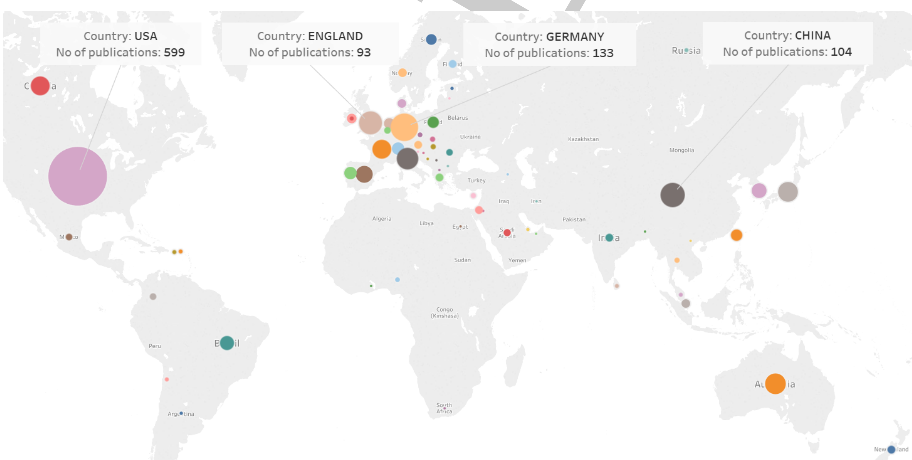

Figure 1: Distribution of research focused on immersive visualization

IV tools like augmented reality (AR), virtual reality (VR), augmented virtuality (or) mixed reality, basic interactive two-/three-dimensional visualization

(2D/3D viz) and few more are mainly considered to be used in RES development. Inclusion of visualization tools into the existing RES development packages facilitates in better understanding of complex, multi-aspect, multidimensional data and blurs the line between physical and digital world to provide a sense of immersion to evaluate the newly proposed RES. In addition to the basic photomontages and 3D models used in standard RES development packages, advanced IV tools bring the paradigm of mixed reality, which assists in many ways with respect to the development of interactive simulations. With the increasing demand for RES development and the limitless potential of IV tools, creating a collaboration between these two domains is highly encouraged. Numerous studies and software packages have been explored in the use of IV tools in RES development, which is collectively reviewed in this article.

Drigas et al. [4] highlight the rapid development in information communication technologies revealing its potential in the RES development. Alongside technological advancements, presenting reality and establishing the communication between researchers and end-users is facilitated by the use of IV tools [5]. A summary of the existing review articles highlighting the critical observations on different software packages used in RES development is presented in Table 1. In spite of the significant numbers review articles published focusing on the software packages used in RES development, the importance of visualization techniques incorporated into these software packages is not explored. To address this gap, a critical review of the influence of IV tools in software packages and research articles used in different stages of RES development is presented in this manuscript.

A collection of 41 software packages and state-of-the-art research articles in the field of RES development incorporated with advanced IV tools was identified and critically reviewed based on its use-case, accessibility, complexity, robustness, immersivity, and adaptability in this review. The review article is organized as follows: Firstly, the different stages of RES development and the advantages of identified software packages where deliberately discussed in section 2.1 and 2.2. Section 2.3 presented a critical review on the use of IV tools in research articles based on the use of IV in RES development. Later, in section 3, the importance and advantages of the collaboration of IV tools with RES development were discussed. Finally, in section 4, the tables listed in the review are presented, and in section 5, we conclude the article.

2. Renewable energy system development

The conventional RES consists of energy generation sources (solar and wind) along with appropriate AC/DC or DC/AC converters, power conditioning units, battery storage system, and fluctuating load. RESs can operate either as a standalone or grid-connected, as shown in Figures 2 and 3. Solar energy is a form of the renewable energy resource which is widely utilized in different industries as an alternate source of power considering its abundant availability and carbon-free characteristics. Solar energy can be efficiently trapped by using the PV panel, solar thermal or concentrated solar systems; it provides excellent environmental benefits in comparison to non-renewable sources. Among which, solar PV is the most frequently used system which converts the abundant solar energy into electricity. In the Australian context, the utilization of solar energy in different sectors has increased drastically, mainly because of the influence on the reduction of GHG emission [6]. Figure 4 illustrates the decline of the GHG emission due to the use of solar PV systems, and Figure 5 highlights the relationship between the total generation capacity and peak demand of Australia.

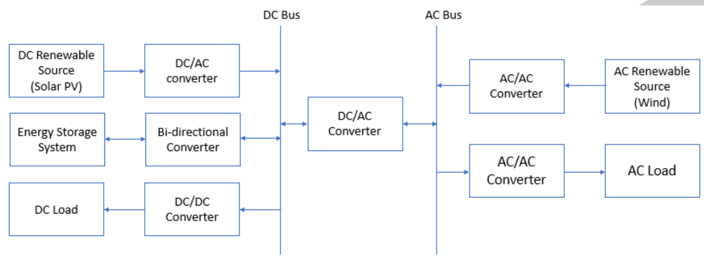

Figure 2: Standalone RES [7]

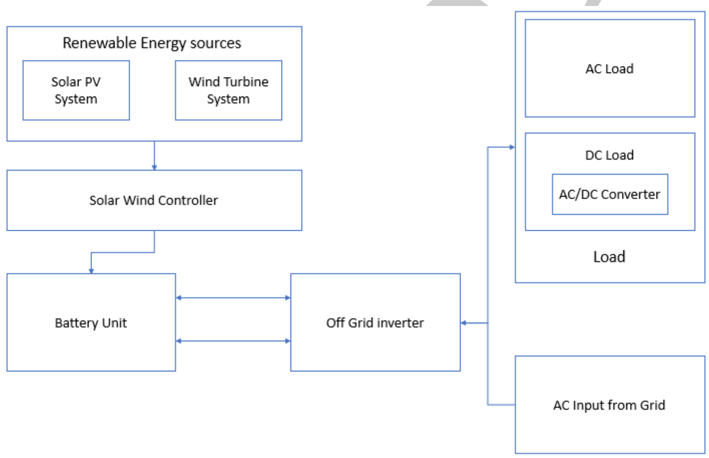

Figure 3: Grid-connected RES [7]

Wind energy is widely used in countries with excessive coastal areas or high wind velocity rates [3]. Wind turbines convert the lateral wind motion into rotational kinetic energy that drives electricity generators. Highly competent, well-developed systems and virtually pollution-free characteristic of wind turbines encourage the extensive application worldwide [8]. For developing countries with high energy demand, wind energy is considered a useful alternative source considering its low maintenance characteristics and remote accessibility [3]. For example, countries like India have excellent potential for wind energy development, considering the geographical location [9]. Installing wind energy systems involves several challenges, such as extensive landscaping, noise pollution and adverse impact on wildlife biodiversity. Poor decision making while planning the wind energy system will have a significant effect on the time, effort, and public concern [5, 10]. The rotation of the blades of wind turbines induces a visual and aural impact. Incorporation of IV tools can help in simulating such situations and carrying out an impact analysis of such adverse disturbances in a remote environment [10]. Research areas like acoustic impact analysis of a new blade design of wind turbine [5], the effect of partial shading in solar PV installation in smart city design, etc., can be benefited by the use of IV tools. The different stages in RES development are classified into three types, which is explained in detail in the following section.

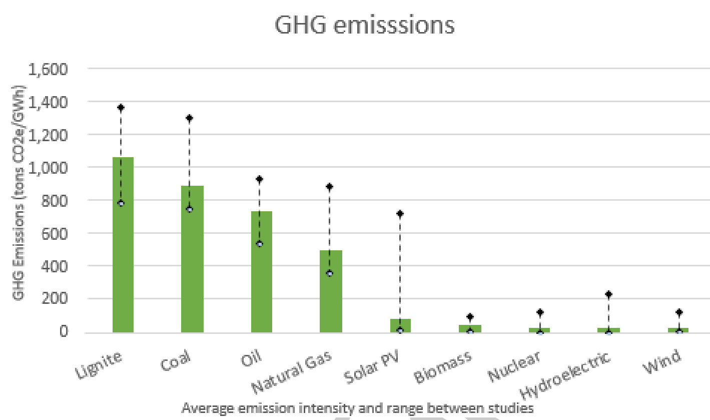

Figure 4: Solar PV emits less GHGs than conventional energy resources [11]

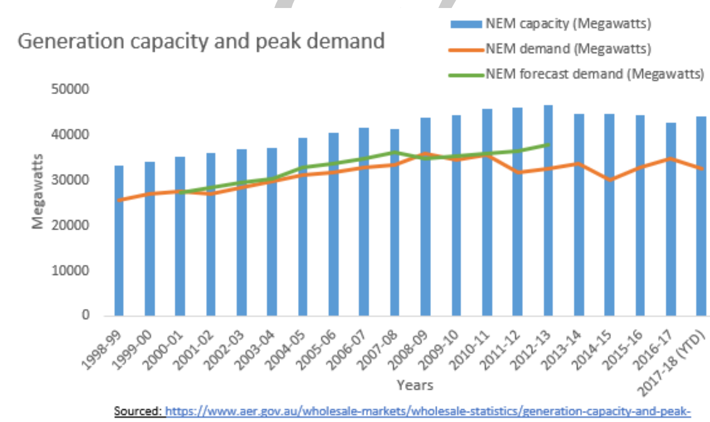

Figure 5: Generation capacity and peak demand relationship of Australia

2.1. Stages of RES installation

2.1.1. Planning stage

Planning stage (PS) is the initial stage of RES development projects, and it has a significant impact on the overall success. PV systems, wind turbines, and other renewable setups have a high installation cost, which makes the PS an essential phase in RES development. Therefore, proper planning is necessary to construct a cost-effective solution that enables on-time project delivery. Complete and accurate data collection is a crucial thing to note in order to reduce the inaccuracies of the planned RES. For example, proper site inspection must be conducted before any installations to ensure that the system produces the highest level of power output. The geographic location is a vital parameter to be observed in this stage, considering its influence on the power output and noise level. Decisions related to the use of the proposed setup as an off-grid (also known as standalone) or grid-connected configuration largely depends on information obtained from the site visit. This process is critical because the location of the site dictates the performance of the RES. Several parameters are influenced by site location (e.g., amount of sunlight received at a certain point, wind speed at the selected area). Therefore, the installation location (e.g., geographical location, weather data, and user requirements) must be appropriately inspected before setting up a solar PV system [12] and a wind turbine installation [13]. In addition to site assessment, the PS involves critical components, including identification of the most suitable optimization techniques and appropriate sizing of the system. Conventional software packages, such as HOMER come in handy for such applications. In this review, the classification of software packages with additional design components is considered to be categorized as the design and integration stage (DIS) for the ease of understanding.

2.1.2. Design and integration stage

The design stage of RES consists of two parts, namely, hardware and software design. Software design includes mathematical modeling of system to analyze the performance, estimation of total power consumption, accurate forecasting of power generated based on the stochastic weather parameters like radiation, temperature, etc., Whereas, hardware design includes selection of an ideal system configurations, design specifications (wind turbines, solar cells, and batteries), a perfect inverter design, and suitable control systems. Considerations to be made in PV system design is explained in detail in [14–16]. Visualization of the site topography, layout, and other features is the primary step in designing and installing RES. One of the barriers that hinder the large-scale deployment of RES is obtaining permission from city councils [17]. All deployment decisions are made based on the recommendation of city councils [17], after extensive planning, coordination, and design work [18]. Trust and approval for system deployment cannot be obtained without proper interaction between the project managers and stakeholders. Therefore, there exists a need for an appropriate medium of interactive communication between project managers and end-users, for which we require of a proper and powerful visualization tool. During this decision-making process, advanced IV tools can be handy in communicating the impact of the proposed system through a simulated environment using IV tools such as VR and AR. Figure 6 illustrates the use of advanced IV tools in Skelion for designing a PV-based RES. Inclusion of CAD tools like SketchUp in such software packages along with the other system design gives the RES designer the feasibility of using the advanced system for designing and analyzing the newly planned RES in DIS stage.

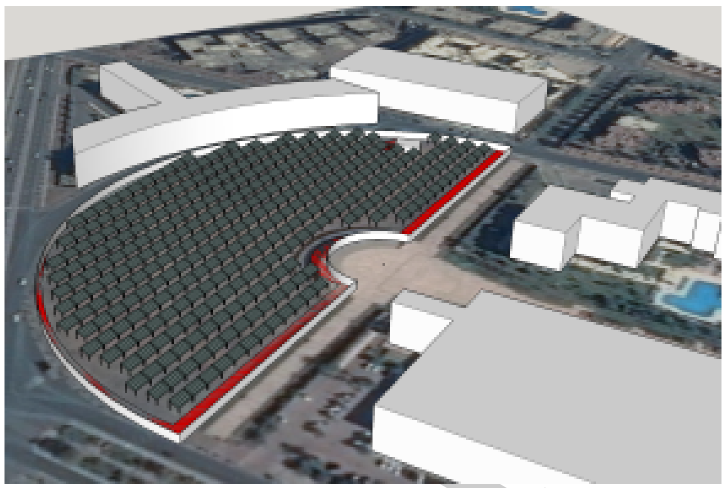

Figure 6: Screenshot of skelion used for PV system development [19]

2.1.3. Maintenance stage

The Maintenance stage (MS) is the final stage after DIS, where the system undergoes a scheduled condition monitoring and maintenance cycle to prevent damage and to improve the overall system performance. The purpose of maintenance is to avoid expensive failures and increase the lifespan of the system. After identifying the defect, a proper decision-making process is required to fix the system. The most critical parameters to be considered during the MS are cost and time. Hence, strategic maintenance plays a significant role in lengthening the system lifespan. For a wind turbine system, regular inspection and evaluation of health are required for proper maintenance. Maintenance activities include checking the lubrication oil, seals, and worn-out components [18]. Any defective component identified from wind turbines must be taken out of service and subjected to repair. The performance of a wind turbine is measured indirectly in a primitive manner. For protective reasons, the relationship among power, wind velocity, rotor speed, and blade angle may be used, and in case of significant deviations, an alarm is generated; detection margins help prevent false alarms in the report of Verbruggen et al. [20]. AR could be used to provide step-by-step illustration and visual guidance during the MS. Figure 7 shows a technician using a similar application called Upskill, which is an AR-based tool that guides the assembly and maintenance of wind turbines. Along with the increase in the productivity of technicians to a great extent [21], the use of such advanced IV tools increases the accuracy of the maintenance cycle. VR could be an effective medium used for training technicians with complex systems which have accessibility issues.

Figure 7: Use of upskill for wind turbine maintenance [21]

2.2. Overview of software packages used for RES development

In this section, a set of 41 software packages used in RES development was identified based on the influence of IV tools, and it is critically reviewed based on the stages of application, type of visualization tools used, type of software package, application and availability. Few conventional tools like CECPV calculator [22], CREST [23], ESVT [24], SMA SunnyDesign3, iHOGA, HOMER, HYBRID2, SAM, TRANSYS, RETScreen, and PVsyst considered in this review are not critically analyzed because of the lack of influence on IV tools and available knowledge in previous reviews. A summary of the benefits and drawbacks of these conventional simulation packages used in RES development is presented in Table 2. Software packages critically analyzed in this review are selected based on two factors: 1) lack of clear explanation in existing reviews and 2) influence of the use of IV tools.

Few of the applications of these conventional tools are discussed briefly in this section. Blair et al. [25] used the tool for modeling PV and concentrating solar power using CECPV calculator. Corbus et al. [26] and Gifford et al. [27] applied CREST [23] to examine the economic impact on transmitting wind power to customers in California. Zakeri et al. [28] used ESVT [24] to analyze the different energy storage systems over the life cycle analysis. An ideal application of the SMA SunnyDesign3 tool is exhibited in the feasibility study conducted by Seeman et al. evaluating PV systems [29]. iHOGA [30] was used to design a hybrid RES setup in Malaysia [31] and Portland [32]. Bahramara et al. [33] presented a collective review on different applications of the HOMER[34]. HYBRID2 [35] based versatile mathematical model is a prime feature of the system [36]as illustrated by Mills et al. in 2004 [37].

A review on applications of SAM was highlighted in [38]. Rudie et al. illustrated a case study of 100 sites using SAM [39]. Furthermore, Guzman et al. [40] and Gilman et al. [41] and Blair et al.[42] highlighted the application scope of energy management using SAM. Like SAM, the CREST cannot perform a cost estimate of multiple/hybrid systems together [43]. TRNSYS is an extremely flexible graphics-based design software environment that is used to simulate transient system behaviors [44]. TRNSYS was used to model and simulate a hybrid PV-thermal solar system in Cyprus [45] and Magnier et al. [46] illustrated the use of performing different optimization techniques. Lee et al. [47] presented the results of a case study, indicating the use of RETScreen [48] to determine the optimum size of renewable energy in a building. Alireza et al. illustrated the influence of RETScreen on financial analysis [49]. Sauer et al. [50] demonstrated the dependence of the PV modules output to irradiance and temperature using PVsyst [51]. Many profound publications show the widespread use case of PVsyst [52–56].

In addition, software packages, like CitySim [57–59], EnergyPlus [60, 61], ESP-r [62, 63], Envi-met [64, 65], EnergyPRO [66, 67], Neplan [68, 69] and Radiance [70], used for estimating parameters like light radiance within a building, GHG estimation, etc., are considered in this review. Despite the more advanced IV tools incorporated into these software packages mentioned above, the detailed description of these packages mentioned above is not included in this review as its focuses mainly rely on RES development. Finally, Table 3 presents the analysis of the software packages based on the use-case, accessibility, and type of visualization tool incorporated. The following section deliberately discusses the advantages and disadvantages of the use of IV tools in the set of identified software packages listed below alphabetically aiming to create a knowledge base for studying the influence of IV tools in RES development.

2.2.1. *Archelios*

Archelios is a powerful, easy-to-use PV installation simulation software package that allows the user to design and perform a feasibility study for developing a PV system. The software allows the user to create a geolocalized 3D mock-up of the planned setup with the help of the 3D design plugin (SketchUp) and calculates the accurate financial and technical results, which illustrate the application in DIS. The Archelios O&M version allows real-time monitoring of PV installations for its application in the MS. Axaopoulos et al. [71] emphasized the transition of preference with PV designers and engineers to use high-end visualization tools, such as Archelios. Apart from the visual add-ons, the software also delivers accurate energy generation results for a forecasted period of the year, which makes Archelios one of the advanced PV installation simulation tool incorporating IV tools. It is a commercialized desktop-based 2D/3D visualization tool used in both DIS and MS of RES development.

2.2.2. *EnergyPLAN*

EnergyPLAN [72] is a freeware energy management tool developed by the sustainable energy planning research group at Aalborg University. This tool has been established to simulate the operation of national energy systems accurately on an hourly basis. The primary purpose of the tool is to evaluate various energy strategies and determine the optimum solution with high-cost returns. Furthermore, the tool is used in the PS of the RES development. A list of case studies on the usage of EnergyPLAN along with a detailed inference of the software tools is listed on their website [73]. Connolly et al. [74] applied the tool to conduct a case study on the effect of 100% renewable energy systems in the European Union. Basic 2D graphs and charts are types of IV tools used in this software package.

2.2.3. GridLAB-D

GridLAB-D is a multi-agent-based power distribution simulation software tool developed by the pacific northwest national laboratory (PNNL) of the US department of energy. GridLAB-D is an open-source package that is like PVWatts; this tool consists of a cutting-edge modeling mechanism and highly efficient optimization algorithms that form a competent and reliable modeling tool [75]. The tool helps users create and validate distributed energy resource models effectively [76]. GridLAB-D is also available as a MATLAB toolbox, which enables easy access to an energy model and application of simulating RES development [77]. Schneider et al. [78] demonstrated the use of GridLAB-D tool for evaluating the conservation of voltage reduction in a distributed energy system. An interactive web-based 2D/3D visualization is available in this tool with a third-party plugin. Solar panel penetration levels are simulated for different climate patterns over a period; additional applications are listed in [79].

2.2.4. Helios 3D

Helios3D is a universal solution for solar power plant layout design because this tool is equipped with advanced planning/design tools that allow energy management analysis by placing PV racks on a digitally generated 3D model of any geographical position [80]. Also, this all-round simulation package has evolved from a basic calculation model highlighted in Seong et al. work[81]. The current version of Helios3D includes a web-based VR application that allows system designers to design in a virtual environment. Visualization of simulated weather data in a virtual environment gives a better understanding. As previously mentioned, Helios3D includes a design tool (Autodesk's Civil 3D) that will allow a user to place and design a 3D rack of PV panels that correspond to the location of a generated 3D mesh [82]. This tool will enable us to conduct simulations by considering the shading effect and visualize the results obtained from the cost analysis intuitively [83]. Besides, financial analysis can also be performed using this software. The VR component of this application enhances the immersivity when conveying the plan to decision-makers.

2.2.5. Helioscope

Helioscope is a commercialized energy management software tool, which focuses on pre-screening of risk and advanced site assessment process for PV systems. Helioscope consists of PVsyst and AutoCAD packages automating the process of designing RE systems and performing a site assessment and energy analysis simultaneously with increased accuracy [84]. In addition, the helioscope has a simple, powerful, and user-friendly interface, thereby enhancing the 3D designing of the RES development. The helioscope also aims to output financial and energy simulation results with a maximum capacity of 5 MW [85]. TMY3 weather data is used for energy assessment analysis, thus enhancing the accuracy of the system. In an educational case study conducted by Ciriminna et al. [86], the performance of a helioscope is compared with HOMER by making students perform various energy management analysis, which indicated the helioscope provides students with an intuitive and more detailed inference of the results.

2.2.6. INSEL

INSEL is a MATLAB toolkit which works on the concept of block diagram-based simulation used for programming applications of distributed RES. INSEL is mainly designed to work on complex energy projects. The underlying block diagram architecture of the tool provides the designers with a fundamental understanding of the system. Besides, adding advanced AI-based optimization techniques to increase the accuracy of the forecasting results is feasible. The visualization front of this tool is moderate because it is integrated with MATLAB, thereby providing us with the scope of working with advanced 2D and 3D tools based on the requirement for the type of result [87].

2.2.7. Nearmap

Nearmap solar uses $PhotoMaps^{TM}$ high-resolution aerial imagery of any selected location to provide users with an option of adding virtual roof-top solar panels and obtain a detailed solar report for calculating the average energy output based on the geographical conditions [88]. Nearmap solar package uses weather data with respect to the location to calculate accurate forecasted output in the form of an auto-generated solar report consisting of 2D visualization of data. Nearmap is planning to integrate the new feature called Nearmap Oblique into Nearmap solar, thereby presenting a 3D view of the panoramic, oblique aerial imagery to visualize the 3D planning during installation. This feature has capabilities of integrating IV tools like VR, which can benefit the end-user to understand the advantages of the newly set up RES. Kyle et al. [89] applied machine learning algorithms to identify the distributed solar PV location from the aerial imagery and estimated the total energy consumption influencing the fellow researchers to explore the extended use case of advanced IV tools with AI and ML algorithms in RES development.

2.2.8. OpenPV

OpenPV aims to create a collaborative database of PV installation data of the United States of America. The data is obtained by the combined efforts of the government, industry, and public through an open-source web portal [90]. This project allows users to download data sets for conducting their research for estimating the total cost and energy production within the United States. OpenPV consists of web-based visualizations of graphs, charts, and geo-localized maps that illustrate the distribution of PVs in the country. A few quantitative analyses for deriving policies and interactions using OpenPV are conducted by Doris and Krasko et al. [91, 92] in 2012. Many other researchers worldwide use data from OpenPV to perform the study on the distribution of market share [93] and the influence on local policy development of the distributed PV market [92].

2.2.9. Polysun

Polysun is a simulation software package used for designing, dimensioning, and optimizing PV and solar thermal systems, heat pumps, cogeneration units, and combined systems [94]. Polysun consists of an intuitive, user-friendly UI, which allows the user to understand a clear representation of results through interactive tables and graphs. Bornatico et al. [95] applied Polysun to perform a multi-objective optimization for sizing of a solar thermal installation using particle swarm optimization. DDS CAD-PV is an extended tool of Polysun that integrates 3D designing functionalities, which allows the user to design the RES and perform feasibility analysis similar Solarius PV and skelion. Abanda et al. [96] and Gupta et al. [97] illustrated the application of the DDS CAD-PV tool used in solar PV simulations for modeling and designing advanced BIM systems.

2.2.10. PV designer

The PV designer software is a PV simulation tool that is ideally suited for residential and small-scale energy systems. The PV designer package is recently incorporated into the SunEye tool, which uses a shadow-based energy prediction allowing us to perform partial shading analysis [98] more accurately. The PV designer consists of worldwide inverter module databases and historical weather data, which is used to simulate different scenarios with improved accuracy. The incorporation of tools, such as SunEye, makes PV designer stand out from the other software packages used in RES development.

2.2.11. PV-Designpro

PV-Designpro is a PV system design suite for simulating PV systems on the basis of the configured weather and system information provided by the user as an input to the simulation [99]. PV-Designpro consists of a conventional 2D/3D UI embedded with capabilities of replicating the results in the form of intuitive but non-interactive graphs and charts. Deshmukh et al. [100] used the PV-DesignPro tool for designing a 14 kW grid-tied PV system to power a hydrogen refueling system situated at Las Vegas valley water district, thereby illustrating the application scope of the PV-Designpro software suite clearly.

2.2.12. PVscout

PVscout is a web-based PV-sizing simulation software used for planning and calculating grid-connected PV systems output, regardless of the manufacturer specifications. PVscout consists of a cloud-based architecture which allows easy access to different databases for obtaining specifications about electrical components, such as inverters, batteries, and PV modules for accurate simulation results. Mohd Khairy, in his PhD thesis, highlighted the key advantages of using PVscout, by exploring the key opportunities that exist in PV generation simulation [101].

*2.2.13. PV*sol*

PV*sol is an advanced PV simulation tool that considers the effect of shading from the surrounding environment to forecast the power output of the proposed PV system with increased precision and accuracy. This tool is integrated with a user-friendly 3D design tools consisting of menus that allow a designer to place the PV system in the roof-integrated systems, thereby enabling the features of simulating energy yields under different climatic patterns [102]. Advancements in IV tools aid in the integration of an energy model simulation into 3D modeling platform. This feature enables the possibilities of exploring the effect of partial shading in PV panels located on the roof-top [103].

2.2.14. PVWatts

PVWatts is a freeware software tool used for estimating the financial returns of a newly proposed PV system over the grid-connected system [104]. PVWatts is a simple, robust, and easy-to-use software, which can be used by users worldwide to estimate the potential benefit of the proposed PV system. PVWatts is a hybrid software package incorporating popular tools like SAM and REopt [105]. PVWatts is used in the PS of RES development. Historical weather data, estimations on the cost returns are calculated using PVWatts with moderate accuracy. The main advantage of PVWatts is its use of an environmental dataset of over 30 years to estimate the solar insolation, which is used for predicting the total power of the PV system. Liu et al. highlighted the impact of climate on the economic influence of the PV system, which showcases the application of PVWatts, and this package uses essential IV tools [106].

2.2.15. ReEDS

ReEDS is a long-term regional-level capacity-expansion energy model simulator used by policymakers [107]. The ReEDS is a US-based nationwide simulator used for detailed representations of energy systems, addressing various issues. 2D visualizations, such as graphs and charts, are used to illustrate the annual generation capacity, expansion analysis, and mitigation cost of the system. Ibanez et al. [108] modeled the Canadian and US power models using the ReEDS to analyze the integrated expansions that illustrate the application of the ReEDS tool. The recent version of ReEDS includes IV tools like interactive maps and graphs, which help in providing high spatial resolution and high-fidelity modeling to understand the pattern of demand and supply of energy.

2.2.16. REopt

REopt is an energy modeling tool developed to evaluate the integration and optimization of cost-saving schemes [109], the effect of GHG emission, and influence of the energy performance of the designed energy system (renewable sources, conventional distributed energy sources, utility grid, energy storage elements, and dispatchable loads) [110]. REopt provides information about the options for simulating different RES type and size that is suitable for the selected location [111]. REopt is a useful visualization tool used in the initial screening process of the RES development, which incorporates basic 2D visualizations to exhibit the results of the impact analysis on the energy market addressing the energy and financial demand. Simpkins et al. [112] conducted a remote study of energy systems in Alaskan villages and showed 75% of fuel reduction when using REopt to schedule the energy dispatch of the grid-connected system. LEAP system is a cost analysis tool that is similar to REopt, which performs long-range simulations and optimizations of energy consumption and production [113], along with the influence on carbon emissions. Heaps et al. [114] used LEAP software tool for conducting a feasibility study of the impact of RE on Co_2 reduction by 2050.

2.2.17. Skelion

Skelion is a SketchUp plugin that allows designing of solar PV installations with the help of a synchronized 3D models to the geographic location to estimate the output power generated in a year. Moreover, this plugin provides options for comparing the results of different models and configurations of the PV that can be installed in the designed building. The Pro version of skelion is licensed and has added features of shading loss estimation and curved roof PV panel installations [115]. Besides, skelion uses third-party plugins, such as the PVsyst and PVWatts, to estimate power output accurately based on the weather information. Soucase et al. [19] applied the SKELION software tool used in designing a solar power system installation in Marrakesch.

2.2.18. Solar pro

Solar Pro is a PV system simulation software that can simulate electricity generation under different conditions with high precision [116]. Recent releases of Solar Pro consists of 3D CAD design features used for simulating the influence of partial shading from the surrounding environment. Illustrative I–V curves are calculated internally using the data obtained from the manufacturers of each electrical component and weather data of the installation site. Solar Pro visualizes results obtained from the financial and power analyses using 2D/3D tools used in DIS stage of RES development.

2.2.19. Solarius PV

Solarius PV is a complete, reliable tool used for calculating the output of a solar PV system [117]. Solarius PV helps in DIS stage of PV system development and performing precise financial and technical feasibility analyses to determine the advantages and disadvantages of the system. Solarius PV consists of an intuitive user interface which allows users to understand the effect of shading and perform user-assisted PV sizing in a 2D/3D environment. Kask et al. [118] conducted a feasibility study for installing PV systems in Sri Lanka, thus illustrating a broad scope of application of Solarius PV.

2.2.20. Upskill

Upskill's skylight on $GLASS^{TM}$ is one of the state-of-the-art augmented reality application used by technicians at GE during the DIS and MS of wind turbine production line. The app overlays an augmented view with instruction for wiring up the wind turbines. The tool helps in quickly identifying the appropriate wire and correct location for connection. The time required to refer to paper-based manuals is saved by the augmented instructions overlaid in the augmented interface. According to a business review conducted by Harvard, the use of Upskill in GE's renewables and other divisions increased the performance of employees by 32% [119]. The integration of such advanced IV tools helps companies to solve the skill gap by improving worker efficiency, workflow, and increases the productivity of system development rapidly agility in manufacturing, warehousing, and fieldwork services.

2.2.21. Windographer

Windographer is a commercialized software tool widely used in the wind industry to perform feasibility analysis and quality control of all commonly used wind flow models [120]. Windographer is a data analyzer that imports data in any format and automatically detects the data structure so that the user can rapidly visualize the data in a highly efficient manner during the PS [121]. Windographer helps in the detection and flagging of issues, such as overshading, the icing on blades, sensor malfunctions, low signal-to-noise ratio, and in the investigation of the problems involving wind shear, turbulence intensity, tower distortion, vertical temperature profile, and long-term trends. Aldeman et al. and Aksas et al. explored the use of Windographer to determine the potential of wind power integration in Illinios, USA [122] and Batna, Algeria [123].

2.2.22. WindPro

WindPro is another commercialized software used in the wind power industry. Compared with Windographer, Windpro allows users to simulate a group of wind generators on a farm altogether, which is not feasible with Windographer. Windpro is a module-based software used for designing and planning of energy outputs, financial outcomes, air density, turbulence intensity, wind speed shear, and wind direction shear of an individual wind turbine or a group of turbines in a wind farm [124]. Geographical information, along with wind data, is given as inputs, allowing the statistical solver to estimate the output of the system[125]. Ozerdem et al. [126] highlighted the use of Windpro to determine the total power generated within a campus area of Izmir Institute of Technology.

The use of highly advanced IV tools and integration of game engine-based simulation into software packages used in RES development provide the benefits of adding adverse climatic pattern simulations and visualizing the advantages and drawbacks of a newly planned RES. From the software packages that are critically reviewed in this review article software packages like Helios3D, Skelion, SolariusPV, and Upskill standout with relevance to the influence of IV tools used in RES development. Also, it is significantly vital to integrate the financial and mathematical models into the highly advanced software packages like Skelion, which will come in handy as a complete software suite for end-to-end RES development simulation. Authors would like to highlight the gap and would recommend the readers to focus on undertaking further studies which extensively use IV tools to build an end-to-end software suite which will help in simulating the complete cycle of RES development.

2.3. IV tools in RES development

The installation cost of RES is very high, and this demotivates users from extending or modifying the existing setup. Integration of IV tools into RES software packages will help in simulating and visualizing the impact of a newly proposed system. One of the reasons for integrating IV tools is its high level of accuracy in monitoring and controlling systems along with increased immersivity of the virtual environment [127, 128]. AR and VR technologies enable users to visualize and understand complex data-sets, along with the advantage of foreseeing the visual aesthetics of the proposed system. Accurate prediction of system outputs can be simulated in a virtual environment replicating the stochastic weather patterns using soft computing techniques [128]. IV tools are the new means of interfacing and controlling a built environment in real-time [127–129]. Integration of IoT-based condition monitoring systems can also be implemented to obtain real-time feedback of a system, and this information can be interfaced with advanced IV tools like AR/VR to facilitate the understanding of the system health. In this section, an overview of the role of IV tools used in the RES in context of state-of-the-art research articles is critically reviewed.

2.3.1. Dimensional (2D/3D/4D) Visualization

Researchers have already discovered the potential of integrating existing IV tools with solar energy applications. Wong et al. [130] investigated the use of 3D geographic information (GI) to improve the positioning of rooftop PV panels. 3D GI is partially driven by the data obtained from Google Earth [131]. Wong et al. also identified several advantages of using 3D GI, which include increment in realism and immersive capabilities [130]. Figure 8 illustrates an example of using 3D GI for simulating a house covered with roof-top solar panels.

Sheppard et al. investigated the use of 3D modeling tools in visualizing the role of RES in climate change mitigation. The use of simple 2D realistic tools integrated into a 4D visualization medium increases the level of accurate data acquisition [132]. The process of building an interactive medium which can bridge the gap between scientific and social realities in the community is

Figure 8: 3D GI for simulating a house covered with roof-top solar panels [132]

essential. Integration if IV tools into RES development aids in addressing this gap and brings in the potential of increasing educational awareness. Figure 9 highlights the use case of a 4D visualization medium.

Figure 9: 4D visualization of housing and solar panels [132]

The integration of IV tools into RES development increases the reliability, efficiency of RES simulations, and it is considered as a cost-effective approach that increases the accuracy of the simulations [128]. These IV tools can ensure effective communication between researchers and respondents regarding their perception of the acceptability by evaluating social and ecological conditions in a virtual or simulated environment [5, 133]. Moreover, the use of 3D tools for the validation of performance before the integration stage can considerably reduce expenses. Use of animated models solve two possible problematic aspects, namely, movement of turbines and movement of individuals within the landscape. These aspects help in evaluating the impact of a newly proposed system in a virtual environment [134]. The conventional method requires considerable time and effort to analyze the landscape and select the most efficient approach. Higgs et al. conducted a study which aimed at investigating the use of IV tools that let users experience the visual impact of wind farms in a virtual environment illustrating the use of IV tools in RES development [135]. Map-based software, such as Google Earth, enables users to obtain a satellite view of a landscape and produces a real image of the location on top of which the planned system can be integrated for proper visualization of the proposed system. The user can also zoom in or out on a site and have different views of the site. Therefore, it is evident from the available resources that the use of simple 2D/3D visualization plays a vital role in PS and DIS of RES development.

Figure 10: Use of Google Earth and SketchUp for wind turbine installation [133]

2.3.2. Augmented reality

Augmented reality (AR) is one of the IV tools that combines a virtual 3D object into an existing real environment. Camba et al. [129] conducted a study on the integration of AR into a solar radiation-harnessing system to support an effective and efficient decision-making process. Mobile devices with high processing power, advanced cameras, and sensors (e.g., accelerometers and gyroscopes), geolocation capability, and web connectivity along with dedicated AR kits like Microsoft hololens can support AR applications [136]. AR applications allows the user to increase the awareness on the use of renewable energy systems. AR can be used as a useful tool in training and providing visual assistance when installing or performing maintenance tasks in RES development. Camba et al. [129] concluded that AR is a practical approach for presenting data and mimicking PV module installation on walls in a real-world scenario. Figures 11 and 12 show examples of AR applications in buildings, illustrating the scope of using AR as a tool to perform a site evaluation and impact study with the help of AI and ML techniques.

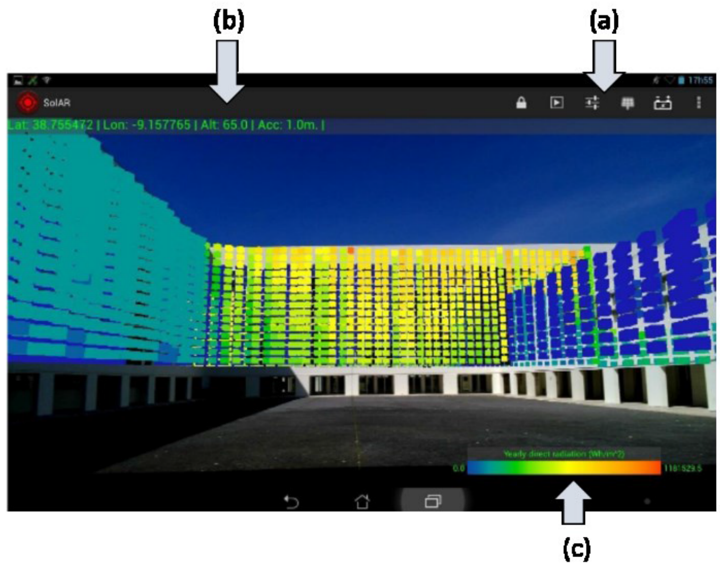

Figure 11: Graphical user interface of the proposed AR solution [129]

According to Bishop et al., a virtual environment that is used to simulate and visualize wind farm installation provides good visual and aural experiences for users. The researchers employed the spatial information exploration and visualization environment (SIEVE) platform with AR functionality. They concluded that using AR technology in real-world environments provides users with realistic views of the proposed changes and assists them in understanding the economic, environmental, and social consequences of the changes [5]. Simulating the visual effect of the wind turbine during DIS would not be an ideal visualization with AR considering the size of wind turbines, in which case VR comes in handy. However, when it comes to evaluating the impact of solar PV system AR could play a significant role in illustrating the widespread application of AR-based systems in the MS and DIS of RES development.

2.3.3. *Virtual reality*

The use of virtual reality (VR) comes in handy when addressing the challenges in development and adaptability of RES. VR gives a virtual experience by the use of stereoscopic projections in a head-mounted displays (HMDs) (e.g.,

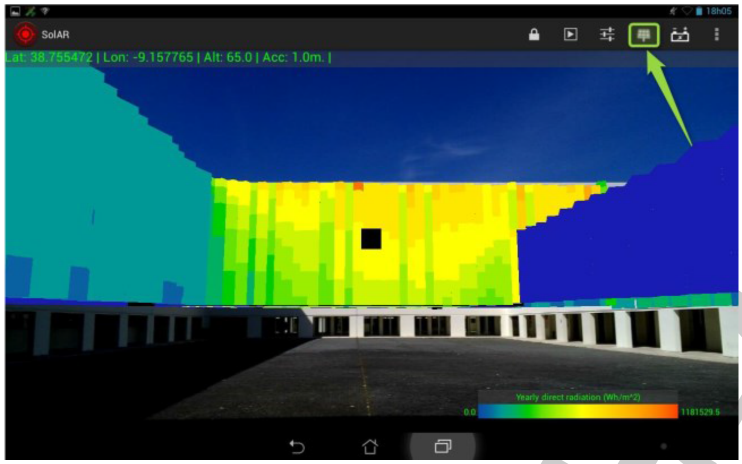

Figure 12: Illustration of the positioning of the solar panel in a building using AR [129]

HTC Vive or Oculus). For example, detailed system information, site assessment, and the effect of shadows on the output of PV systems can be evaluated with higher precision using a VR based simulation. VR enables users to walk through or into objects, which could be highly beneficial in terms of maintenance support for electrical wires in wind turbine design [127]. The conventional method of installing solar PV systems requires experienced experts who understand the system design; however, employing a professional is costly and time-consuming [15], which could be avoided by the use of VR. A.J. Veldhius conducted a study on how to overcome the slow computation of conventional ray-tracing methods and found that rasterization can address this issue by obtaining real-time data. This research focused on simulating irradiance for PV products and building-integrated PV in a VR environment. The study concluded that performing annual simulations is a practical approach for accurately calculating the annual solar irradiation received by building surfaces [137]. The study also showed that VR for PV (VR4PV) system development considers the shadowing effect of the surrounding buildings, trees, and birds on the solar system [137, 138].

Figures 13 and 14 illustrate the simulation of VR4PV to compute the irradiance received by each panel in the simulation environment. This software is also used to determine the location of shadows and PV output in the built environment.

One of the challenges in installing a solar PV system is the partial shading effect, which can be adequately addressed by high-accuracy simulation with tools like VR. Mainly because the simulation of different weather patterns and shadowing effects can be easily simulated in the gaming environment used for VR development. Moreover, VR can be used as a rich knowledge sharing toolkit for educating and training people about the effect of partial shading, risk evalu-

Figure 13: Virtual environment created by VR4PV [138]

ating and impact analysis. Partial shading is inevitable and exerts a significant influence on PV output performance. With a visualization method, such as VR, designers can select the ideal system location for installation and evaluate the performance with the weather data set. It can also be handy, during the design phase of a newly proposed suburb where the designer will have the flexibility of planning high rise buildings considering the effect of partial shading of the PV systems planned in the neighbourhood. This approach reduces cost and requires minimal effort. VR simulations help in identifying the shadowing effects on PV module surfaces and in computing the efficiency of a PV system with high precision [139]. In a previous study, VR simulation was tested in three cities in Turkey. The study concluded that using VR enables users to include all the factors that create shadows, contributes to improved understanding of PV system behaviour, and leads to high accuracy in power output estimation [139].

Anggoro et al. developed a tool called SunTool by integrating VR into solar energy system development. This application is designed to animate how the sun works, including producing shadows from animated sunlight inside an immersive virtual environment. Producing high-quality designs under real conditions in nature is required and possible by visualizing the scene in the immersive virtual environment. Furthermore, development of VR applications use game engines, such as Unity and Unreal, which opens the possibility of performing multiple adverse simulations and robustly testing the performance of the proposed system, thus making VR an excellent platform to observe the influence in real-time. An example of such case is the study conducted by Anggoro which calculated the desired output of the system in relation to the sun position by using the Meeus algorithm [140].

Figure 15 shows where the researchers inserted SunTool's prototype into

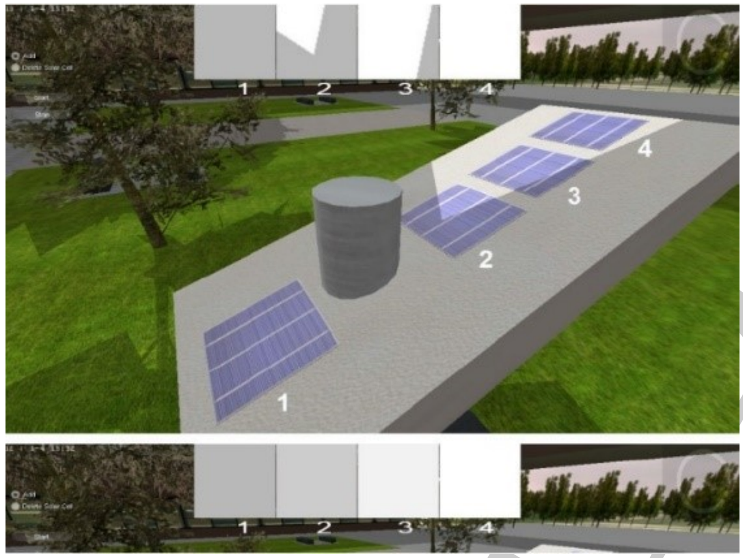

Figure 14: Illustration of shadows on the PV system using VR4PV [138]

an immersive virtual environment that was created by Tan and Hii (2007) for testing purposes. After inserting SunTool's prototype for observing real-time sunlight, a comparison between Mahaweli IVE with baked texture and SunTool was performed. The results obtained and screen shots of the SunTool's GUI are shown in Figure 16 [140].

Jallouli et al. [10] compared participants' understanding of immersed and normal environments by using VR. The virtual simulation revealed that motion provides rich information on the perception of users. The immenseness of the environment originates from the visual space, acoustics, shapes, and motion. Jallouli et al. [10] also concluded that two main features, namely, sunlight and wind, influence the immenseness of a virtual environment in RES development. They recommended applying possible VR techniques in the PS/DIS to increase the level of public acceptance of wind turbine installation [10].

Furthermore, VR provides users with full control of the surrounding environment, such that users can manipulate the environment visually and examine different sound scenarios after wind turbine installation. The location of wind turbines is selected based on tests conducted on the consequent noise pollution simulation. Research that used SIEVE viewer discovered that VR also allows for the exploration of visual and noise pollution at different distances [5]. SIEVE Builder enables the automatic building of a complete 3D environment, including wind turbines, from data obtained from a 2D map. Once the virtual environment has been created, users can add, remove, or move the objects inside the virtual environment [5]. The virtual environment provides realistic sounds simulating the actual environment, which significantly helps in evaluating the acceptance level for wind turbine installation. VR also assists designers in ob-

Figure 15: Scene of Mahaweli in the SunTool virtual environment [140]

taining real-time feedback from users, which in turn helps them in selecting the ideal location for wind turbine installation. Figure 17 shows the creation of a virtual environment to obtain feedback from users and select the ideal location for wind turbine installation. SIEVE Viewer increases the flexibility of the community and planners in creating an environment that mimics the natural environment [5].

In conclusion, VR is beneficial in the DIS of wind farm/ solar PV installation because it plays a vital role in simulating the impact of noise, visual pollution, simulating partial shading and weather patterns [141]. Moreover, VR provides a high level of realism, reduces uncertainties, and allows users to have a wide range of choices [140]. VR is computationally expensive, but the flexibility it provides for simulating different environmental behaviours in a gaming engine makes it stand out for the application of RES development in PS/DIS. The use of VR in MS is not yet thoroughly explored, and authors would like to highlight this gap to recommend future researchers to work in this area. Table 3 highlights the collection of research articles reviewed in this section based on the type of visualization tool, application and the stage of RES in which it is used.

3. Discussion

Different visualization tools bring different perceptions and immersive feelings to users and contribute to improving the conventional method of RES development. Integrating IV tools, such as 2D/3D dimensional models, AR, and VR, into RES development, provides numerous benefits to users and developers. The PS/DIS includes site assessment, which requires an extensive site inspection before system installation. 2D/3D visualization and VR are considered

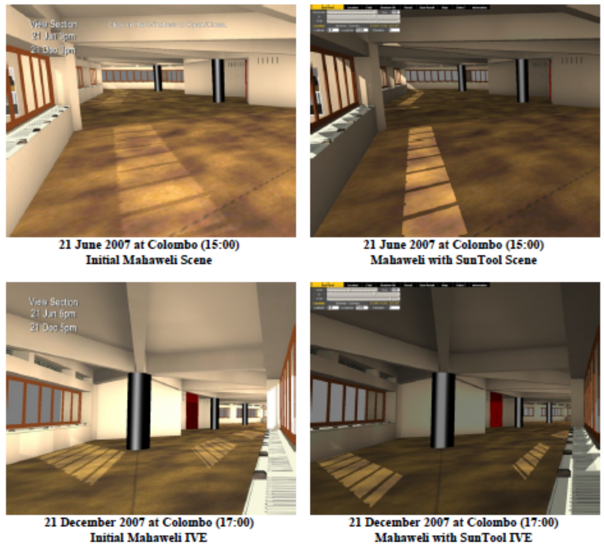

Figure 16: Comparison of Mahaweli IVE with baked texture and SunTool [140]

to be useful IV tool that simulates the overall environment and provides the best feedback for designers in PS/DIS stage. VR also enables users to interact further with their surrounding environment, which is a critical capability during the early stages of RES development. One of the indicators of a successful visualization tool is the level of acceptance by the people, and VR stands as an effective communication medium in this case. For example, noise pollution from the wind turbine, the effect of partial shading from the surrounding building can be visualized before system installation using VR. The need to simulate the environment and provide instant feedback can be addressed by utilizing VR. VR is the most effective visualization tool in the PS and DIS because it provides a high level of understanding of the diverse consequences of RES development, which can be social, economic, or environmental. The DIS often requires accurate calculations to produce the most efficient RES. The most important part of this stage is to understand how the components of a system can be adjusted and how to evaluate the overall performance of the system using the existing simulation. Different design software (e.g., AutoCAD and MATLAB Simulink) can be utilized to design a good control system and help system designers understand and visualize the system components.

2D/3D visualization tools provide the highest level of accuracy in modeling, which is a prerequisite of the successful design of RES development. With advancements in VR, design tools such as SketchUp, use VR-based plug-ins to ensure that architects can design a 3D space instead of a 2D environment. Which would be highly beneficial. The DIS/MS involves system deployment. Limited studies have examined the possibility of incorporating IV tools. Nevertheless, AR may be an appropriate tool in this stage because of its capability to

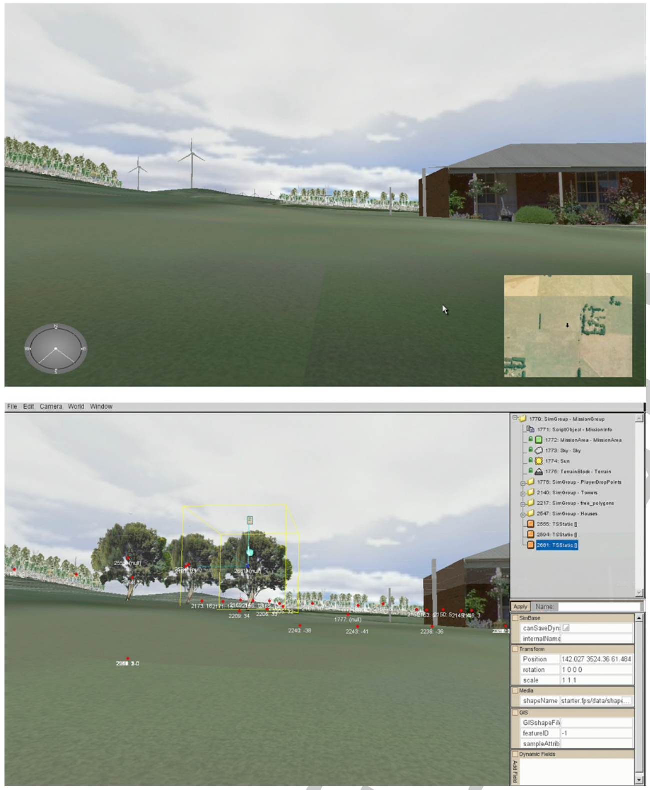

Figure 17: View of wind turbines in SIEVE Viewer [5]

integrate virtual objects with the real environment, which is helpful for system installers in implementing the system in the manner that the system designers visualized it. In literature, AR has been used on-site to help system designers in planning and understanding system integration strategies. This technology can also help people on-site in understanding and visualizing an appropriate method of installation.

The maintenance phase includes performance monitoring. The visualization tools used in this stage should have the capability to record and simulate the performance of the system for a specified period. This stage does not require any real environment, but it requires the user to understand the factors that influence system performance. With the advancement in the field of IoT and could computing, applications for monitoring real-time data using an AR application would be an ideal innovation to look forward in the future. Tools like VR and AR also enables users to experience a different environment and simulate real-world conditions that may affect system performance. However, the use of standalone VR applications is insufficient, considering the performance evaluation and complex simulations that run in the background. Therefore, the integration of other platforms, such as MATLAB, is required. With recent advancements in ML-based game engines, such as Unity, the use of IV tools can be scaled up in the coming years to build a complete end-to-end software package using advanced visualization tools for simulating the complete development cycle of RES development. Authors aim at contributing towards the development of applications of combining robotics, IoT, and immersive visualization techniques, like remote teleoperation of robots for performing maintenance tasks in regions with difficult accessibility in future [142].

In a nutshell, based on the inferences obtained from the critical analysis made on the research articles and existing software packages which use IV tools in RES development, the integration IV tools into RES has several advantages over conventional recursive planning, design evaluation, system integration and maintenance stages. In addition to this, the list of identified software packages that were critically reviewed in the previous section was categorized based on the stage of RES development in which it is used and type of IV tools incorporated in Table 4. Finally, the software packages which were critically analyzed based on the metrics of complexity, robustness, immersivity, and adaptability was presented in Table 5. An index for each metric is assigned, ranging from very low to very high based on the assumptions below. In terms of, complexity, the factors like ease of use, simplicity and computational requirement are considered. Following which, the immersivity metric is assigned based on the type of visualization tool used. Software packages with 2D visualization tools are given the index of very low, low or moderate based on the advanced tool incorporated with the package. Packages with VR/AR are given an index of high and very high. The robustness index is assigned based on the scope of application of the software package, which mainly includes the range of systems simulated in the package and accuracy of the simulation. Finally, the adaptability of the software package was accessed based on the total number of research articles published using this software package. Finally, three software packages (Skelion, Upskill and PVWatts) was selected representing identical IV tool and stage of RES development for critical analysis aiming at identifying which IV tool is more useful for which stage of RES development. Results of this critical analysis were presented using a radial plot illustrating the use case of the IV tool along with software package corresponding to the stage of RES development.

Some of the key benefits of using IV tools in RES development obtained from the critical analysis presented in the review are listed as follows:

- Instant visual and audio feedback by the use of moving objects (e.g., blades of wind turbines, shading visualization of solar PV panels) and moving actors help in an accurate simulation of the impact of the proposed system.
- High degrees of freedom to explore multiple points of interest from multiple angles without any restrictions.
- Freedom and flexibility in editing the environment by placing objects in 3D and receiving instant feedback.
- Collaborative scenario planning, where multiple stakeholders can make changes and identify the best possible solution.

- Animation can be used for analyzing a given timeline.

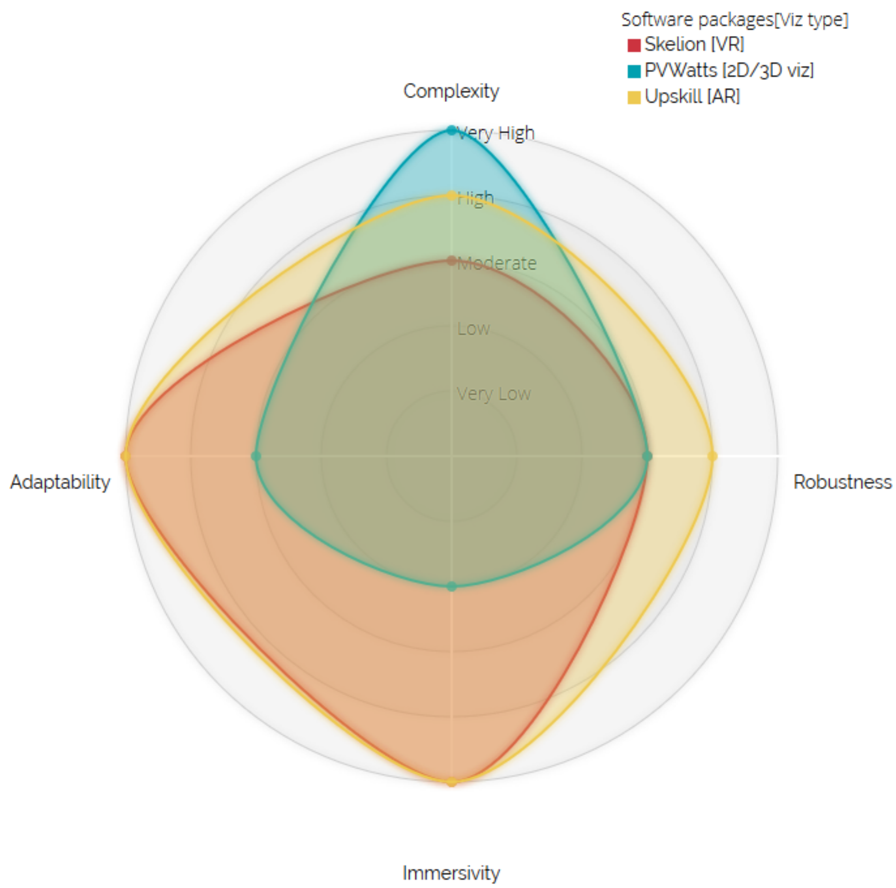

Figure 18: Results of the critical analysis of identified software packages used in RES development

4. Tables

Table 1.
Table 2.
Table 3.
Table 4.
Table 5.

Table 1: List of review articles on software packages used in RES development

Reference	Highlights of the study	Year
Connolly et al.[143]	• This review article was one among the first of its type, reviewing software packages or computer tools. • A detailed review of the use of different computer tools that were used in the analysis of the integration of renewable energy is presented. • A total of 68 tools are considered for this review, and finally, an analysis of 37 software tools used in RES development is presented. • The review article has been proven to be a go-to reference for decision-makers for selecting the appropriate energy tool for the required analysis, thereby encouraging this type of review articles.	2010
Zhou et al.[144]	• Optimization and simulation of a hybrid RES with PV, wind turbines, and battery storage systems are presented. • The focus of the paper is centered toward standalone hybrid RESs. • AI techniques are identified to be promising and require further exploration to determine how optimization can aid in simulation effectively. • Software tools, including HOMER, iHOGA, and Hybrid2, are reviewed in detail.	2010
Erdinc et al.[145]	• Optimization and simulation of a hybrid RES with PV, wind turbines, and battery storage systems are presented, focusing mainly on the standalone hybrid RESs. • A more in-depth focus is given to explaining the influence of AI techniques used in the optimization of simulation results. • Software tools, including HOMER, Hybrid2, GAMS, Orient, OptQuest, LINDO, WDILOG2, DIRECT, DORIS, Sinfosys, GRHYSO, and H2RES, are covered in this review.	2010
Upadhyay et al.[146]	• This review article mainly focuses on the different configurations, control, selection criteria, and sizing techniques implemented in hybrid RESs. • This review article aims to help designers and researchers in selecting and using suitable or appropriate tools for designing and implementing grid-connected and offline-grid-mode hybrid RESs. • This article highlights the advantages of the six most used tools, namely HOMER, Hybrid2, HYBRIDS, RETScreen, iHOGA, and TRNSYS, in addition to the optimization algorithms used to address the sizing problem.	2014

Table 1: List of review articles on software packages used in RES development[Cont.]

Reference	Highlights of the study	Year
Chauhan et al.[7]	• This article focuses on integrated RESs based on standalone power generation systems and discusses further detail the factors of configurations, storage, options, sizing, and control techniques. • Similar to the review of Upadhyay et al. [146], this article also highlights the use of conventional tools, including HOMER, Hybrid2, HYBRIDS, RETScreen, iHOGA, and TRNSYS. In addition, the article presents a deep insight into the different research articles presented covering the concepts of optimizing the issues associated with sizing and control techniques.	2014
Sinha et al.[147]	• This review article focuses on software tools used for hybrid RESs. • Software packages, including HOMER, Hybrid2, RETScreen, iHOGA, INSEL, TRNSYS, iGRHYSO, HYBRIDS, RAPSIM, SOMES, SOLSTOR, HySim, HybSim, IPSYS, HySys, Dymola/Modelica, ARES, SOLSIM, and HYBRID DESIGNER, are reviewed in this article. • The comprehensive capabilities of different software packages are highlighted in this review.	2014
Freitas et al.[148]	• This review presents state-of-the-art computer tools used for modeling solar potential in urban development. • This article is considered as a useeful reference for sophisticated visualization tools; however, it does not focus on RES development.	2015
Huang et al.[149]	• Tools used for community energy planning is reviewed in this manuscript. • Community energy planning method for the community master plan (CMP), community regulatory plan (CRP), community site plan (CSP), and architectural design (AD) stages are considered as the main focus in classifying the diversified methods used to perform energy planning. • The characteristics of different computer tools are deliberately explained, and the challenge of predicting community energy demand and associated software tools to perform demand estimation in a community-scale are highlighted. • Use of software packages, including EnergyPLAN, H2RES, DER-CAM, RETScreen, E-GIS, SUNtool, HOMER, and EAM, are highlighted in this review.	2015
Allegrini et al.[38]	• The general modeling approaches and tools for simulating district-scale energy systems are presented in this paper. • The review includes heat networks, multi-energy systems, and low-temperature networks, with respect to district energy systems. It also provides a gist on the different renewable energy generation techniques, and urban micro-climate-related energy demand is discussed in detail. • It discusses 20 software packages in detail, directing the readers to the future directions and challenges associated with built environment software packages and simulations.	2015

Accepted for publication in Renewable and sustainable energy reviews

Table 1: List of review articles on software packages used in RES development[Cont.]

Reference	Highlights of the study	Year
Tozzi et al.[150]	• This recent review article is focusing on the area of simulation tools used in renewable energy analysis. • In this article, software packages are categorized based on the stages of the project level, namely, multiscale RESs, district-level system, or region-level system. • The review article mainly highlights 14 tools used for the analysis of renewable energy. The categorization of the tools based on the scale of the project is highly beneficial for selecting the most suited tool for analyzing energy systems.	2017
Jakica et al.[137]	• This article is a detailed and comprehensive review of state-of-the-art solar designing tools used for assessing daylight simulation in building design. • Several advanced tools are highlighted in this research, which includes a list of highly advanced visualization tools incorporated into the software package. • The review is conducted under the framework of IEA-PVPS Task 15, focusing mainly on BIPV. • It has allowed many new perspectives on a potentially more extensive multidisciplinary usage of more advanced tools used for solar design, which is one of the prime highlights of the research.	2017
Sanhudo et al.[151]	• This article presents a detailed review of the different tools used in the context of information modeling for energy retrofitting in energy systems. • A detailed analysis of different software packages used in building information modeling (BIM) is highlighted in this research. • Finally, the paper concludes an argument of the future innovations that can be useful. Considering the scope of prediction of future highlights makes this article standout.	2018
Anoune et al.[152]	• This article critically reviews the use of software packages, including HOMER, HOGA, Hybrid2, HYBRIDS, TRNSYS, HYDROGEMS, INSEL, ARES, SOLSIM, SOMES, and H2RES, addressing the sizing and optimization techniques used for PV–wind hybrid RES. • It is a recent review article that focuses on the latest trend in sizing and optimization of PV–wind-based hybrid system for an isolated area to reach the best compromise between power reliability and hybrid system costs. • Finally, the article emphasizes the importance of incorporating simulation tools with advance optimization techniques to improve power reliability and system cost.	2018

Table 2: Summary of conventional simulation tools used in RES development

Software packages	Benefits	Drawbacks
CECPV calculator	• The CECPV Calculator incorporates detailed inverter performance modeling. • The Excel-based user interface is used to calculate energy consumption based on the Energy Commission norms. • The user has functionalities to select PV modules and inverters from a library of eligible equipment.	• It is an excel based software, and the visualization of the results are not very advanced. • The use of this application is limited, based on the 16 climatic zones of California.
CREST	• Easy to use and understand. • A toolkit for evaluation and development of cost-based incentive planning to support renewable energy technologies. • Accurate financial analysis is done using CREST.	• It is a spreadsheet-based software package, so it consists of the only basic visualization of results. • It covers only the financial analysis and does not have any influence over the performance factors.
ESVT	• It is User-friendly because of the features like intuitive flow, preloaded data, and short-run times enable usability. • Site-specific information can be easily incorporated for custom use case analysis making the tool more robust. • A "white-box" approach makes model inputs and logic accessible to users for ease in customization based on the use case.	• It is more focused on the cost-effectiveness simulation of the energy storage units, and not all other renewable energy resources are integrated into the simulation. • Simple and basic visual representation of the outputs is considered as a significant drawback.
energyPRO	• energyPRO allows you to calculate the optimal operation of an energy plant. • It has functionalities like modeling industrial co-generation and tri-generation with detailed investment analyses. • It allows the user to simulate energy plants participating in different electricity markets and analyze the interaction between separate energy plants with high accuracy.	• It is more focused on industrial co-generation and tri-generations models and does not include conventional RES. • Visualization of the state-of-the-art tool used in RES development uses only basic tools.
HOMER	• It is user-friendly and easy to use software package. • It consists of efficient graphical representations of the results. • It has the capacity to handling hourly data with high accuracy. • The software tool gives you options to compare thousands of possibilities in a single simulation.	• The Black box coding approach of the software tool makes it very hard to use for customized applications. • It has capabilities to handle only first-degree linear equations. • It does not have the features to import time series data. • The graphical representations are pretty standard, and they are not interactive.

Table 2: Summary of conventional simulation tools used in RES development[Cont.]

Software packages	**Benefits**	**Drawbacks**
HYBRID	• It is user-friendly and has capabilities to perform detailed long-term performance and economic analysis on a wide range of hybrid devices. • HYBRID2 works based on a probabilistic/time series computer model for prediction of performance of the hybrid power system.	• The software package is obsolete on windows platform later than XP. • Possibilities of random simulations errors are high. • The code does not consider short term system fluctuations caused by system dynamics or component transients. • The visualization of the results is moderate.
iHOGA	• iHOGA requires low computational time, highly sensitive, and easy to use. • It is easy to perform mono or multi-objective optimizations using the genetic algorithm-based analysis tool. • The net metering option is available, and it is easy to simulate the purchase and selling schemes of the energy within peers.	• The free version has many limitations in terms of the analysis capabilities. • The visualization of the results is moderate. • It does not have the functionality of working offline and it requires an internet connection to be used.
LEAP	• LEAP is easy to use, freeware modeling tool used to analyze national energy systems. • It has the capabilities to run simulations for an extended period. • LEAP also supports multiple modeling methodologies and gives the capabilities to manage scenarios that could be used for defining a policy scheme.	• The results are displayed in the form of basic charts, tables and maps with the capabilities to be downloaded. • Accuracy of the system is low as it performs calculations for a long time horizon.
Pvsyst	• PVSyst is a user-friendly contextual tool for designing renewable projects. • It is capable of performing a detailed economic evaluation using real component prices, any additional costs, and investment conditions.	• Maximization of the application is not feasible, and this becomes a significant drawback when using a small screen. • Visualization of the output results could be ranked moderate. • It cannot handle detailed shadow analysis. • No capabilities to perform single line diagram simulations.
RETScreen	• RETScreen has support from the NASA databases providing access to highly accurate meteorological and product information. • It is capable of producing more accurate financial analysis. • It is easy to use software package as it Excel based.	• It has moderate visualization of the results. • It does not contain the option to import time series data, which is considered as a significant drawback. • Limited input data options make this software package fit limited applications.

Table 2: Summary of conventional simulation tools used in RES development[Cont.]

Software packages	Benefits	Drawbacks
SMA SunnyDesign3	• It is a web-based cross-sector energy system planning software package. • It has the capabilities of an integrated energy management system for PV, battery storage, and thermal systems. • The inclusion of electric vehicles and charging stations encourages the use of the tool for planning and simulating energy systems.	• The accuracy of the system is highly moderate and has capabilities of future development. • Visualization tools used to represent the output of the system is better than conventional tools, but the integration of more advanced tools would enhance the use case of the tool.
SAM	• SAM is a highly efficient financial model designed to facilitate rapid decision making of RES development planning. • It is a simulation-based software package, so it allows the user to simulate different inputs to model an accurate system.	• The accuracy of the system model highly depends on the input parameters. • Inaccuracies in input values may lead to a significant impact on the performance of the model. • The outputs of the performance and financial model are represented using basic customizable graphs.
TRNSYS	• TRNSYS software package is highly flexible based on the use case. • The modularity and the open-source availability of the code base of the tool make it more feasible for diversified applications. • It has a complex and large component library allowing the user model the system rapidly.	• It is highly complex and complicated for new users. • Lack of proper documentation and support makes it more challenging for new users. • It does not use SI system units, which creates more confusion. • Unclear error messages in the software package making the requirement of having a FORTRAN compiler. • Lack of advanced visualization tools is also considered as a significant drawback.

Table 3: List of research articles reviewed based on IV tools used in different stages of RES development

S. No	Stage of RES development	Visualization type used	Application type	Year of publication	Reference
1	MS	VR	PV	2004	[127]
2	PS	VR	WT	2005	[153]
3	PS	2D/3DViz	WT	2008	[133]
4	DIS	VR	PV	2008	[140]
5	PS	VR	WT	2009	[10]
6	PS	AR	WT	2010	[5]
7	MS	AR	PV	2010	[154]
8	PS	2D/3DViz	PV	2011	[132]
9	PS	2D/3DViz	WT	2011	[155]
10	PS	VR	WT	2012	[141]
11	DIS	VR	PV	2012	[156]
12	PS/MS	VR	PV	2013	[139]
13	DIS	2D/3DViz	PV	2013	[157]
14	PS	VR	PV	2013	[158]
15	MS	AR	PV	2013	[154]
16	PS	2D/3DViz	WT	2014	[159]
17	MS	VR	PV	2014	[160]
18	PS	2D/3DViz	PV	2015	[130]
19	PS/MS	VR	PV	2015	[138]
20	DIS	VR	PV	2015	[161]
21	DIS/MS	VR	PV	2016	[15]
22	PS	VR	PV	2016	[128]
23	DIS	AR	PV	2016	[136]
24	PS	VR	PV	2017	[137]
25	MS	VR	PV	2017	[162]
26	MS	2D/3DViz	PV	2018	[163]

Table 4: List of software packages reviewed based on IV tools used in different stages of RES development

Software packages	**Visualization type**	**Stage of RES development**	**Software type**	**Application type**	**Free-ware**	**Web Link**
Archelious	2D/3DViz	DIS/MS	Desktop	PV	No	http://www.trace-software.com/archelios/photovoltaic-pv-software/
CECPV calculator	2D/3DViz	PS	Desktop	PV	Yes	http://www.gosolarcalifornia.org/tools/nshpcalculator/index.php
CitySim	2D/3DViz	DIS	Desktop	others	Yes	https://citysim.epfl.ch/
CREST	2D/3DViz	PS	Desktop	DRES	Yes	https://financere.nrel.gov/finance/content/CREST-model
ESVT	2D/3DViz	PS	Desktop	DRES	No	https://www.epri.com/#/pages/product/1024280/?lang=en
EnergyPLAN	2D/3DViz	PS	Desktop/Web	PV	Yes	https://www.energyplan.eu/
EnergyPlus	2D/3DViz	NA	Desktop	others	Yes	https://energyplus.net/
EnergyPRO	2D/3DViz	NA	Desktop	others	Yes	https://www.emd.dk/energypro/
Envi-met	2D/3DViz	NA	Desktop	others	Yes	https://www.envi-met.com/
ESP-r	2D/3DViz	NA	Desktop	others	Yes	https://www.envi-met.com/
GridLAB-D	2D/3DViz	DIS	Desktop	DRES	Yes	https://www.gridlabd.org/
Helios3D	VR	DIS	Web	PV	Yes	https://www.helios3d.com/index.php/en/
Helioscope	2D/3DViz	DIS	Desktop	DRES	No	https://www.helioscope.com/
HOMER	2D/3DViz	DIS	Desktop	DRES	No	https://www.homerenergy.com
HYBRID2	2D/3DViz	PS	Desktop	DRES	Yes	http://www.umass.edu/windenergy/research/topics/tools/software/hybrid2
iHOGA	2D/3DViz	DIS	Desktop	DRES	Yes	https://ihoga.unizar.es/en/
INSEL	2D/3DViz	DIS	Desktop	PV	No	http://www.insel.eu
LEAP	2D/3DViz	PS	Desktop	DRES	Yes	https://www.energycommunity.org
Nearmap	2D/3DViz/VR	DIS	Web	PV	No	https://www.nearmap.com.au/industries/solar
Neplan	2D/3DViz	NA	Desktop/Web	others	No	https://www.neplan.ch/

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Table 4: List of software packages reviewed based on IV tools used in different stages of RES development [Cont.]

Software packages	Visualization type	Stage of RES development	Software type	Application type	Free-ware	Web Link
OpenPV	2D/3DViz	MS	Web	PV	Yes	https://openpv.nrel.gov/
Polysun	2D/3DViz	DIS	Desktop	PV	Yes	http://www.velasolaris.com/english/home.html
PV designer	2D/3DViz	DIS	Desktop	PV	Yes	http://www.solmetric.com/pvdesigner.html
PV-Designpro	2D/3DViz	DIS	Desktop	PV	No	http://www.mauisolarsoftware.com/
PVscout	2D/3DViz	DIS	Web	PV	No	https://www.solarschmiede.de
PV*sol	2D/3DViz	DIS	Web	PV	No	https://www.valentin-software.com/en/products/photovoltaics/57/pvsol-premium
PVSyst	2D/3DViz	DIS	Desktop	PV	No	http://www.pvsyst.com/en/
PVWatts	2D/3DViz	PS	Web	PV	Yes	https://pvwatts.nrel.gov/
Radiance	2D/3DViz	NA	Desktop	others	No	http://www.radianceenergy.com/
ReEDS	2D/3DViz	PS	Desktop	DRES	No	https://www.nrel.gov/analysis/reeds/
REopt	2D/3DViz	DIS	Desktop/web	DRES	Yes	https://reopt.nrel.gov/
RETScreen	2D/3DViz	PS	Desktop	DRES	Yes	http://www.nrcan.gc.ca/energy/software-tools/7465
Skelion	VR	DIS	Desktop	PV	No	http://skelion.com/#
SunnyDesign3	2D/3DViz	DIS	Desktop/web	PV	Yes	http://www.sunnydesignweb.com
Solar pro	2D/3DViz	DIS	Desktop	PV	No	https://www.lapsys.co.jp/english/products/pro.html
SolariusPV	2D/3DViz	DIS	Desktop	PV	No	https://www.accasoftware.com/en/solar-design-software
SAM	2D/3DViz	PS	Desktop	DRES	Yes	https://sam.nrel.gov/
TRNSYS	2D/3DViz	DIS	Desktop	DRES	No	http://www.trnsys.com/
Upskill	AR	DIS/MS	Mobile	DRES	No	https://upskill.io/
Windographer	2D/3DViz	PS	Desktop	WT	No	https://www.windographer.com/
WindPro	2D/3DViz	DIS	Desktop	WT	No	https://www.emd.dk/windpro/

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Table 5: Critical analysis of different software packages used in RES development

Software packages	**Complexity**	**Robustness**	**Immersivity**	**Adaptability**
Archelious	High	Moderate	High	Moderate
EnergyPLAN	Moderate	High	Low	High
GridLAB-D	High	High	Moderate	High
Helios3D	Moderate	Moderate	Very High	Very High
Helioscope	Low	Low	High	Very High
INSEL	High	High	Low	High
Nearmap	Moderate	High	Very High	High
OpenPV	Low	Low	Moderate	Low
Polysun	High	Moderate	High	Low
PV designer	Low	Low	Moderate	Moderate
PV-Designpro	High	Low	Moderate	Moderate
PVscout	Very High	Low	Low	Very Low
PV*sol	Moderate	Low	High	High
PVWatts	Very High	Moderate	Low	Moderate
ReEDS	High	High	Low	Low
REopt	Moderate	High	Moderate	Low
Skelion	High	High	Very High	Very High
Solar pro	Moderate	Low	High	Moderate
SolariusPV	High	Low	High	Moderate
Upskill	High	High	Very High	Very High
Windographer	Moderate	Low	High	High
WindPro	Moderate	Low	High	High

5. Conclusion

This paper explains the need for incorporating IV tools in RES development by presenting a critical review of the state-of-the-art research articles and software packages used in different stages of RES development. The review also highlights the benefits and drawbacks of collaboration between IV tools in existing software packages used in RES development with an interdisciplinary perspective. Based on the different stages of RES development and the type of IV tools incorporated the identified articles and software packages where categorized initially and then critically reviewed based on its use-case, accessibility, complexity, robustness, immersivity, and adaptability. Observations obtained from the study indicated that, 1. Conventional visualization tools (2D/3D visualization) possess several drawbacks, such as unreliability, high cost, and lack of immenseness. 2. AR is one of the best-suited visualization tools that could be used in the maintenance phase of RES development. However, applications focused on the use of AR in RES development from literature are very less. 3. VR is a tool which is ideal for scenarios that require instant feedback on the proposed system; it simulates possibilities and acts as a medium for communicating the idea of a newly planned RES system to the community. 4. Techniques involving advanced machine learning algorithms, procedural generation of 3D environments simulating the RES developments are considered to be the revolutionary change, which is yet to be explored. Inferences obtained from this review is aimed at providing researchers and engineers with a knowledge base to identify the best-suited IV tool or the software package available for RES development based on the stage of development. Accordingly, these advantages should be considered for highlighting the importance of future research leading towards the development of a comprehensive end-to-end RES development simulation package incorporating advanced IV tools.

Reference

[1] S. R. Madeti, S. Singh, Monitoring system for photovoltaic plants: A review, Renewable and Sustainable Energy Reviews 67 (2017) 1180–1207.

[2] H. Rezk, I. Tyukhov, M. Al-Dhaifallah, A. Tikhonov, Performance of data acquisition system for monitoring pv system parameters, Measurement 104 (2017) 204–211.

[3] N. Panwar, S. Kaushik, S. Kothari, Role of renewable energy sources in environmental protection: a review, Renewable and Sustainable Energy Reviews 15 (2011) 1513–1524.

[4] A. Drigas, J. Vrettaros, L. Koukianakis, J. Glentzes, A virtual lab and e-learning system for renewable energy sources, architecture 6 (2006) 12–16.

[5] I. D. Bishop, C. Stock, Using collaborative virtual environments to plan wind energy installations, Renewable energy 35 (2010) 2348–2355.

[6] A. Coram, J. Moss, G. Blashki, Harms unknown: health uncertainties cast doubt on the role of unconventional gas in australia's energy future, The Medical Journal of Australia 200 (2014) 210–213.

[7] A. Chauhan, R. Saini, A review on integrated renewable energy system based power generation for stand-alone applications: configurations, storage options, sizing methodologies and control, Renewable and Sustainable Energy Reviews 38 (2014) 99–120.

[8] M. Balat, A review of modern wind turbine technology, Energy Sources, Part A 31 (2009) 1561–1572.

[9] M. C. Mabel, E. Fernandez, Growth and future trends of wind energy in india, Renewable and Sustainable Energy Reviews 12 (2008) 1745–1757.

[10] J. Jallouli, G. Moreau, An immersive path-based study of wind turbines' landscape: A french case in plouguin, Renewable Energy 34 (2009) 597–607.

[11] W. N. Association, et al., Comparison of lifecycle greenhouse gas emissions of various electricity generation sources, WNA Report, London (2011).

[12] L. Tianze, L. Hengwei, J. Chuan, H. Luan, Z. Xia, Application and design of solar photovoltaic system, in: Journal of Physics: Conference Series, volume 276, IOP Publishing, p. 012175.

[13] J. K. Kaldellis, Social attitude towards wind energy applications in greece, Energy Policy 33 (2005) 595–602.

[14] E. D. Dunlop, D. Halton, The performance of crystalline silicon photovoltaic solar modules after 22 years of continuous outdoor exposure, Progress in photovoltaics: Research and Applications 14 (2006) 53–64.

[15] A. K. Shukla, K. Sudhakar, P. Baredar, Design, simulation and economic analysis of standalone roof top solar pv system in india, Solar Energy 136 (2016) 437–449.

[16] T. Alamsyah, S. Kamaruzzaman, A. Shahrir, Technoeconomics analysis of a photovoltaic system to provide electricity for a household in malaysia (2006).

[17] D. C. Eltham, G. P. Harrison, S. J. Allen, Change in public attitudes towards a cornish wind farm: Implications for planning, Energy Policy 36 (2008) 23–33.

[18] J. Manwell, J. McGowan, A. Rogers, Introduction: Modern wind energy and its origins, Wind Energy Explained: John Wiley & Sons, Ltd (2009) 1–22.

[19] B. M. Soucase, J. P. Aleman, I. Guaita-Pradas, Design of a solar system installation in marrakesch using the skelion software tool, in: Renewable and Sustainable Energy Conference (IRSEC), 2016 International, IEEE, pp. 717–721.

[20] T. Verbruggen, Wind turbine operation & maintenance based on condition monitoring wt-ω, Final Report, April (2003).

[21] Case study on ge renewables speeds wind turbine production using ar, https://upskill.io/landing/ge-renewables-case-study/, 2017. Retrieved 12th July 2018.

[22] B. Wilcox, W. Beckman, California energy commission cecpv calculator 2.3, 2008.

[23] Crest cost of energy models | renewable energy project finance, https://financere.nrel.gov/finance/content/crest-cost-energy-models, 2016. Retrieved 12th July 2018.

[24] Esvt | product abstract; 2016. epri.com., http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003839, 2016. Retrieved 12th July 2018.

[25] N. Blair, M. Mehos, C. Christensen, C. Cameron, Modeling photovoltaic and concentrating solar power trough performance, cost, and financing with the solar advisor model, Solar 2008, American Solar Energy Society (2008).

[26] D. Corbus, D. Hurlbut, P. Schwabe, E. Ibanez, M. Milligan, G. Brinkman, A. Paduru, V. Diakov, M. Hand, California-Wyoming Grid Integration Study: Phase 1–economic Analysis, National Renewable Energy Laboratory, 2014.

[27] J. S. Gifford, R. C. Grace, CREST Cost of Renewable Energy Spreadsheet Tool: A Model for Developing Cost-Based Incentives in the United States; User Manual Version 4, August 2009-March 2011 (Updated July 2013), Technical Report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2013.

[28] B. Zakeri, S. Syri, Electrical energy storage systems: A comparative life cycle cost analysis, Renewable and Sustainable Energy Reviews 42 (2015) 569–596.

[29] B. Šerman, H. Glavaš, M. Vukobratović, Z. Kraus, Telos feasibility analysis of photovoltaic power plant, Applied Engineering Letters 2 (2017) 91–97.

[30] J. B. Fulzele, M. B. Daigavane, Simulation and optimization of hybrid pv-wind renewable energy system (2016).

[31] M. Fadaeenejad, M. Radzi, M. AbKadir, H. Hizam, Assessment of hybrid renewable power sources for rural electrification in malaysia, Renewable and Sustainable Energy Reviews 30 (2014) 299–305.

[32] P. Ganguly, A. Kalam, A. Zayegh, Design an optimum standalone hybrid renewable energy system for a small town at portland, victoria using ihoga, in: Universities Power Engineering Conference (AUPEC), 2017 Australasian, IEEE, pp. 1–6.

[33] S. Bahramara, M. P. Moghaddam, M. Haghifam, Optimal planning of hybrid renewable energy systems using homer: A review, Renewable and Sustainable Energy Reviews 62 (2016) 609–620.

[34] Homer pro-hybrid renewable microgrid system design software;, https://www.homerenergy.com/, 2015. Retrieved 12th July 2018.

[35] E. I. Baring-Gould, Hybrid2: The hybrid system simulation model, Version 1.0, user manual, Technical Report, National Renewable Energy Lab., Golden, CO (United States), 1996.

[36] J. Manwell, A. Rogers, G. Hayman, C. Avelar, J. McGowan, U. Abdulwahid, K. Wu, Hybrid2–a hybrid system simulation model–theory manual, Renewable Energy Research Laboratory, University of Massachusetts (2006).

[37] A. Mills, S. Al-Hallaj, Simulation of hydrogen-based hybrid systems using hybrid2, International Journal of Hydrogen Energy 29 (2004) 991–999.

[38] J. Allegrini, K. Orehounig, G. Mavromatidis, F. Ruesch, V. Dorer, R. Evins, A review of modelling approaches and tools for the simulation of district-scale energy systems, Renewable and Sustainable Energy Reviews 52 (2015) 1391–1404.

[39] E. Rudie, A. Thornton, N. Rajendra, S. Kerrigan, System advisor model performance modelling validation report: analysis of 100 sites, SAM Integration and Validation 3 (2014) 1–31.

[40] L. Guzman, A. Henao, R. Vasquez, Simulation and optimization of a parabolic trough solar power plant in the city of barranquilla by using system advisor model (sam), Energy Procedia 57 (2014) 497–506.

[41] P. Gilman, SAM Photovoltaic Model Technical Reference. National Renewable Energy Laboratory, 59: NREL, Technical Report, TP-6A20-64102, 2015.

[42] N. Blair, A. P. Dobos, J. Freeman, T. Neises, M. Wagner, T. Ferguson, P. Gilman, S. Janzou, System advisor model, sam 2014.1. 14: General description (2014).

[43] M. J. Wagner, P. Gilman, System advisor model documentation, Technical manual for the physical trough model. National Renewable Energy Laboratory. Golden, CO, USA (2011) 13–7.

[44] A. Trnsys, Transient system simulation program, University of Wisconsin (2000).

[45] S. A. Kalogirou, Use of trnsys for modelling and simulation of a hybrid pv–thermal solar system for cyprus, Renewable energy 23 (2001) 247–260.

[46] L. Magnier, F. Haghighat, Multiobjective optimization of building design using trnsys simulations, genetic algorithm, and artificial neural network, Building and Environment 45 (2010) 739–746.

[47] K.-H. Lee, D.-W. Lee, N.-C. Baek, H.-M. Kwon, C.-J. Lee, Preliminary determination of optimal size for renewable energy resources in buildings using retscreen, Energy 47 (2012) 83–96.

[48] D. Thevenard, G. Leng, S. Martel, The retscreen model for assessing potential pv projects, in: Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE, IEEE, pp. 1626–1629.

[49] A. H. Mirzahosseini, T. Taheri, Environmental, technical and financial feasibility study of solar power plants by retscreen, according to the targeting of energy subsidies in iran, Renewable and Sustainable Energy Reviews 16 (2012) 2806–2811.

[50] K. J. Sauer, T. Roessler, C. W. Hansen, Modeling the irradiance and temperature dependence of photovoltaic modules in pvsyst, IEEE Journal of Photovoltaics 5 (2015) 152–158.

[51] A. Mermoud, Pvsyst: Software for the study and simulation of photovoltaic systems, ISE, University of Geneva, www. pvsyst. com (2012).

[52] C. Kandasamy, P. Prabu, K. Niruba, Solar potential assessment using pvsyst software, in: Green Computing, Communication and Conservation of Energy (ICGCE), 2013 International Conference on, IEEE, pp. 667–672.

[53] P. Karki, B. Adhikary, K. Sherpa, Comparative study of grid-tied photovoltaic (pv) system in kathmandu and berlin using pvsyst, in: Sustainable Energy Technologies (ICSET), 2012 IEEE Third International Conference on, IEEE, pp. 196–199.

[54] J. V. Ramoliya, Performance evaluation of grid-connected solar photovoltaic plant using pvsyst software, Journal of Emerging Technologies and Innovative Research (JETIR) 2 (2015) 7.

[55] Y. Irwan, A. Amelia, M. Irwanto, W. Leow, N. Gomesh, I. Safwati, et al., Stand-alone photovoltaic (sapv) system assessment using pvsyst software, Energy Procedia 79 (2015) 596–603.

[56] D. Okello, E. Van Dyk, F. Vorster, Analysis of measured and simulated performance data of a 3.2 kwp grid-connected pv system in port elizabeth, south africa, Energy conversion and management 100 (2015) 10–15.

[57] D. Robinson, F. Haldi, J. Kämpf, P. Leroux, D. Perez, A. Rasheed, U. Wilke, Citysim: Comprehensive micro-simulation of resource flows for sustainable urban planning, in: Proc. Building Simulation, pp. 1614–1627.

[58] D. Thomas, C. Miller, J. Kämpf, A. Schlueter, Multiscale co-simulation of energyplus and citysim models derived from a building information model, in: Bausim 2014: Fifth German-Austrian IBPSA Conference.

[59] E. Walter, J. H. Kämpf, A verification of citysim results using the bestest and monitored consumption values, in: Proceedings of the 2nd Building Simulation Applications conference, EPFL-CONF-214754, Bozen-Bolzano University Press, pp. 215–222.

[60] D. B. Crawley, L. K. Lawrie, F. C. Winkelmann, W. F. Buhl, Y. J. Huang, C. O. Pedersen, R. K. Strand, R. J. Liesen, D. E. Fisher, M. J. Witte, et al., Energyplus: creating a new-generation building energy simulation program, Energy and buildings 33 (2001) 319–331.

[61] N. Fumo, P. Mago, R. Luck, Methodology to estimate building energy consumption using energyplus benchmark models, Energy and Buildings 42 (2010) 2331–2337.

[62] D. Heim, J. A. Clarke, Numerical modelling and thermal simulation of pcm–gypsum composites with esp-r, Energy and buildings 36 (2004) 795–805.

[63] J. Clarke, W. Dempster, C. Negrao, The implementation of a computational fluid dynamics algorithm within the esp-r system, Proc. Building Simulation'95 (1995) 166–75.

[64] S. Huttner, M. Bruse, Numerical modeling of the urban climate–a preview on envi-met 4.0, in: 7th International Conference on Urban Climate ICUC-7, Yokohama, Japan, volume 29.

[65] M. Bruse, et al., Envi-met, Available online: www. envi-met. com/(accessed on 1 June 2017) (2009).

[66] A. Fragaki, A. N. Andersen, Conditions for aggregation of chp plants in the uk electricity market and exploration of plant size, Applied Energy 88 (2011) 3930–3940.

[67] T. Fang, R. Lahdelma, Optimization of combined heat and power production with heat storage based on sliding time window method, Applied energy 162 (2016) 723–732.

[68] R. Uhunmwangho, E. Omorogiuwa, Reliability prediction of port harcourt electricity distribution network using neplan, The International Journal Of Engineering And Science (IJES) 3 (2014) 68–79.

[69] D. Bica, C. Moldovan, M. Muji, Power engineering education using neplan software, in: Universities Power Engineering Conference, 2008. UPEC 2008. 43rd International, IEEE, pp. 1–3.

[70] P. Gautron, J. Křivánek, K. Bouatouch, S. Pattanaik, Radiance cache splatting: A gpu-friendly global illumination algorithm, in: ACM SIGGRAPH 2005 Sketches, ACM, p. 36.

[71] P. J. Axaopoulos, E. D. Fylladitakis, K. Gkarakis, Accuracy analysis of software for the estimation and planning of photovoltaic installations, International Journal of Energy and Environmental Engineering 5 (2014) 1.

[72] Energyplan | advanced energy systems analysis computer model; 2014.energyplan.eu.;, http://www.energyplan.eu/, 2014. Retrieved 12th July 2018.

[73] Case studies | energyplan;, http://www.energyplan.eu/useful_resources/casestudies/, 2014. Retrieved 12th July 2018.

[74] D. Connolly, H. Lund, B. Mathiesen, Smart energy europe: The technical and economic impact of one potential 100% renewable energy scenario for the european union, Renewable and Sustainable Energy Reviews 60 (2016) 1634–1653.

[75] Gridlab-d, https://www.gridlabd.org/, 2017. Retrieved 12th July 2018.

[76] D. P. Chassin, J. C. Fuller, N. Djilali, Gridlab-d: An agent-based simulation framework for smart grids, Journal of Applied Mathematics 2014 (2014).

[77] M. A. Al Faruque, F. Ahourai, Gridmat: Matlab toolbox for gridlab-d to analyze grid impact and validate residential microgrid level energy management algorithms, in: Innovative Smart Grid Technologies Conference (ISGT), 2014 IEEE PES, IEEE, pp. 1–5.

[78] K. P. Schneider, J. C. Fuller, D. Chassin, Evaluating conservation voltage reduction: An application of gridlab-d: An open source software package, in: Power and Energy Society General Meeting, 2011 IEEE, IEEE, pp. 1–6.

[79] Gridlab-d demos, https://www.gridlabd.org/demonstrations.stm, 2017. Retrieved 12th July 2018.

[80] Helios 3d the universal system solution for solar plant layout;, https://www.helios3d.com/index.php/en/, 2017. Retrieved 12th July 2018.

[81] Y.-B. Seong, J.-H. Lim, M.-S. Yeo, I.-D. Goh, K.-W. Kim, Helios: Solar rights analysis system for apartment buildings, Solar energy 80 (2006) 723–741.

[82] Helios 3d is one of the most powerful layout tools for utility scale solar plants available on the market.;, https://www.helios3d.com/index.php/en/helios-3d, 2017. Retrieved 12th July 2018.

[83] S. Deambi, Photovoltaic System Design: Procedures, Tools and Applications, Crc Press, 2016.

[84] Helioscope: advanced solar design; 2016. helioscope.folsomlabs.com.;, https://www.helioscope.com/, 2016. Retrieved 12th July 2018.

[85] D. M. Riley, J. E. Fleming, G. R. Gallegos, A Photovoltaic System Payback Calculator, Technical Report, Sandia National Laboratories (SNL-NM), Albuquerque, NM (United States), 2016.

[86] R. Ciriminna, F. Meneguzzo, M. Pecoraino, M. Pagliaro, Rethinking solar energy education on the dawn of the solar economy, Renewable and Sustainable Energy Reviews 63 (2016) 13–18.

[87] J. Luther, J. Schumacher-Gröhn, Insel—a simulation system for renewable electrical energy supply systems, in: Tenth EC Photovoltaic Solar Energy Conference, Springer, pp. 457–460.

[88] D. Kyriakou, et al., A bird's eye view of solar installations, Electrical Connection (2014) 73.

[89] K. Bradbury, R. Saboo, T. L. Johnson, J. M. Malof, A. Devarajan, W. Zhang, L. M. Collins, R. G. Newell, Distributed solar photovoltaic array location and extent dataset for remote sensing object identification, Scientific data 3 (2016) 160106.

[90] E. Doris, V. Krasko, Strategic sequencing for state distributed PV policies: A quantitative analysis of policy impacts and interactions, Technical Report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2012.

[91] V. Krasko, E. Doris, Strategic sequencing for state distributed pv policies: a quantitative analysis of policy impacts and interactions, Contract 303 (2012) 275–3000.

[92] E. Doris, S. Booth, J. Chavez, V. Krasko, S. Stout, Understanding the impacts of local policies on distributed photovoltaic market development, in: ASME 2014 8th International Conference on Energy Sustainability collocated with the ASME 2014 12th International Conference on Fuel Cell Science, Engineering and Technology, American Society of Mechanical Engineers, pp. V002T11A001–V002T11A001.

[93] E. Miller, E. Nobler, C. Wolf, E. Doris, Market barriers to solar in michigan, Contract 303 (2012) 275–3000.

[94] A. Vela Solaris, Polysun simulation software, Institut für Solartechnik SPF, Rapperswil (2012).

[95] S. H. Rezaei, A. Witzig, M. Pfeiffer, B. Lacoste, A. Wolf, Modeling and analyzing solar cooling systems in polysun, in: Proc. 3rd International Conference for Solar Air-Conditioning, OTTI, Palermo, Italy.

[96] F. H. Abanda, C. Vidalakis, A. H. Oti, J. H. Tah, A critical analysis of building information modelling systems used in construction projects, Advances in Engineering Software 90 (2015) 183–201.

[97] A. Gupta, A. Cemesova, C. J. Hopfe, Y. Rezgui, T. Sweet, A conceptual framework to support solar pv simulation using an open-bim data exchange standard, Automation in Construction 37 (2014) 166–181.

[98] S. Pisklak, J. McKeen, P. Del Mar, Combining solmetric suneye data with simple 3d modeling to improve residential photovoltaic shade impact predictions, in: Photovoltaic Specialists Conference (PVSC), 2013 IEEE 39th, IEEE, pp. 0802–0808.

[99] M. Pelosi, Pv-designpro-g solar design studio ver. 5.0, 2001.

[100] S. Deshmukh, Y. Baghzouz, R. F. Boehm, Design of grid connected-pv system for a hydrogen refueling station, in: ASME 2006 International Solar Energy Conference, American Society of Mechanical Engineers, pp. 171–175.

[101] A. Mohd Khairy, Photovoltaic generation opportunity analysis at Murdoch University, Ph.D. thesis, Murdoch University, 2016.

[102] Pvsol| overview, https://www.valentin-software.com/en/products/photovoltaics/57/pvsol-premium, 2015. Retrieved 12th July 2018.

[103] T. Patarau, D. Petreus, R. Etz, Analysis and optimization of a geothermal, biomass, solar hybrid system: An application of pv* sol software, in: Electronics Technology (ISSE), 2015 38th International Spring Seminar on, IEEE, pp. 370–375.

[104] Pvwatts calculator;, https://pvwatts.nrel.gov/, 2016. Retrieved 12th July 2018.

[105] A. P. Dobos, PVWatts version 1 technical reference, Technical Report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2013.

[106] X. Liu, S. K. Hoekman, C. Robbins, P. Ross, Lifecycle climate impacts and economic performance of commercial-scale solar pv systems: A study of pv systems at nevada's desert research institute (dri), Solar Energy 119 (2015) 561–572.

[107] Regional energy deployment system (reeds) is a capacity planning and dispatch model for the north american electricity system.;, https://www.nrel.gov/analysis/reeds/, 2016. Retrieved 12th July 2018.

[108] E. Ibanez, O. Zinaman, Modeling the integrated expansion of the canadian and us power sectors, The Electricity Journal 29 (2016) 71–80.

[109] D. Cutler, D. Olis, E. Elgqvist, X. Li, N. Laws, N. DiOrio, A. Walker, K. Anderson, Reopt: A platform for energy system integration and optimization, National Renewable Energy Laboratory, Golden, CO (2017).

[110] T. Simpkins, D. Cutler, K. Anderson, D. Olis, E. Elgqvist, M. Callahan, A. Walker, Reopt: a platform for energy system integration and optimization, in: ASME 2014 8th international conference on energy sustainability collocated with the ASME 2014 12th international conference on fuel cell science, engineering and technology, American Society of Mechanical Engineers, pp. V002T03A006–V002T03A006.

[111] K. Funk, J. Milford, T. Simpkins, Waste Not, Want Not: Analyzing the Economic and Environmental Viability of Waste-to-Energy (WTE) Technology for Site-Specific Optimization of Renewable Energy Options, Technical Report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2013.

[112] T. Simpkins, D. Cutler, B. Hirsch, D. Olis, K. Anderson, Cost-optimal pathways to 75% fuel reduction in remote alaskan villages, in: Proc. Conf. on Technologies for Sustainability.

[113] Leap, the long-range energy alternatives planning system, https://www.energycommunity.org/default.asp?action=introduction, 2016. Retrieved 12th July 2018.

[114] C. Heaps, A deep carbon reduction scenario for china (2009).

[115] Skelionl| solar system design plugin for sketchup, https://www.valentin-software.com/en/products/photovoltaics/57/pvsol-premium, 2015. Retrieved 12th July 2018.

[116] M. Lalwani, D. Kothari, M. Singh, Investigation of solar photovoltaic simulation softwares, International journal of applied engineering research 1 (2010) 585–601.

[117] Solariuspv| solar pv system design software, https://www.accasoftware.com/en/solar-design-software, 2015. Retrieved 12th July 2018.

[118] H. KASK, P. LDRD, Feasibility study of installing solar panels in sri lanka ports authority; mahapola training institute, Faculty of Applied Sciences Wayamba University of Sri Lanka (2012) 16.

[119] M. Abraham, M. Annunziata, Augmented reality is already improving worker performance, Harvard Business Review (2017).

[120] W. 1.1:, Wind data analysis software, 2008.

[121] F. Dunne, E. Simley, L. Y. Pao, LIDAR Wind Speed Measurement Analysis and Feed-Forward Blade Pitch Control for Load Mitigation in Wind Turbines: January 2010–January 2011, Technical Report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2011.

[122] M. Aldeman, J. Jo, D. Loomis, The technical potential for wind energy in illinois, Energy 90 (2015) 1082–1090.

[123] M. Aksas, A. Gama, Assessment of wind and solar energy resources in batna, algeria, Energy Procedia 6 (2011) 459–466.

[124] M. Thørgersen, T. Sørensen, P. Nielsen, A. Grötzner, S. Chun, Windpro/park: introduction to wind turbine wake modelling and wake generated turbulence, EMD International A/S, Aalborg, Denmark (2005).

[125] T. Acker, A. H. Chime, Wind modeling using windpro and wasp software, Norther Arizon University, USA 1560000 (2011).

[126] B. Ozerdem, H. Turkeli, Wind energy potential estimation and micrositting on izmir institute of technology campus, turkey, Renewable Energy 30 (2005) 1623–1633.

[127] A. M. Malkawi, Developments in environmental performance simulation, Automation in Construction 13 (2004) 437–445.

[128] D. R. Riley, K. Wright, A. Mohammadpour, P. Delgoshaei, Challenges and opportunities in microgrid and solar photovoltaic system construction, in: Construction Research Congress 2016, pp. 1092–1101.

[129] J. D. Camba, J. L. Soler, M. Contero, Immersive visualization technologies to facilitate multidisciplinary design education, in: International Conference on Learning and Collaboration Technologies, Springer, pp. 3–11.

[130] K. Wong, C. Ellul, Enhancing positioning of photovoltaic panels using 3d geographic information, in: Proceedings of the 21st GIS Research UK (GISRUK) Conference, Liverpool, UK, pp. 3–5.

[131] A. Hudson-Smith, R. Milton, J. Dearden, M. Batty, Virtual cities: Digital mirrors into a recursive world (2007).

[132] S. R. Sheppard, A. Shaw, D. Flanders, S. Burch, A. Wiek, J. Carmichael, J. Robinson, S. Cohen, Future visioning of local climate change: a framework for community engagement and planning with scenarios and visualisation, Futures 43 (2011) 400–412.

[133] R. M. Wolk, Utilizing google earth and google sketchup to visualize wind farms, in: Technology and Society, 2008. ISTAS 2008. IEEE International Symposium on, IEEE, pp. 1–8.

[134] K. J. Williams, R. M. Ford, I. D. Bishop, D. Loiterton, J. Hickey, Realism and selectivity in data-driven visualisations: A process for developing viewer-oriented landscape surrogates, Landscape and Urban Planning 81 (2007) 213–224.

[135] G. Higgs, R. Berry, D. Kidner, M. Langford, Using it approaches to promote public participation in renewable energy planning: Prospects and challenges, Land use policy 25 (2008) 596–607.

[136] M. B. Carmo, A. P. Cláudio, A. Ferreira, A. P. Afonso, P. Redweik, C. Catita, M. C. Brito, S. Silva, C. Meireles, Augmented reality for support decision on solar radiation harnessing, in: Computação Gráfica e Interação (EPCGI), 2016 23 Encontro Português de, IEEE, pp. 1–8.

[137] N. Jakica, State-of-the-art review of solar design tools and methods for assessing daylighting and solar potential for building-integrated photovoltaics, Renewable and Sustainable Energy Reviews (2017).

[138] A. Veldhuis, A. H. Reinders, Shadow analysis for bipv and pipv systems in a virtual environment, in: Photovoltaic Specialist Conference (PVSC), 2015 IEEE 42nd, IEEE, pp. 1–5.

[139] B. Celik, E. Karatepe, N. Gokmen, S. Silvestre, A virtual reality study of surrounding obstacles on bipv systems for estimation of long-term performance of partially shaded pv arrays, Renewable energy 60 (2013) 402–414.

[140] R. ANGGORO, Development of Suntool prototype for sunlight/shadow study in architecture immersive visualization, Ph.D. thesis, 2008.

[141] F. Ruotolo, V. P. Senese, G. Ruggiero, L. Maffei, M. Masullo, T. Iachini, Individual reactions to a multisensory immersive virtual environment: the impact of a wind farm on individuals, Cognitive processing 13 (2012) 319–323.

[142] M. A. Mortimer, B. Horan, Dynamic virtual workspace for teleoperation of heterogeneous robots in non-deterministic environments, in: DHSS 2015: Proceedings of the Defence Human Sciences 2015 Symposium, [The Conference], pp. 1–14.

[143] D. Connolly, H. Lund, B. V. Mathiesen, M. Leahy, A review of computer tools for analysing the integration of renewable energy into various energy systems, Applied energy 87 (2010) 1059–1082.

[144] W. Zhou, C. Lou, Z. Li, L. Lu, H. Yang, Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems, Applied Energy 87 (2010) 380–389.

[145] O. Erdinc, M. Uzunoglu, Optimum design of hybrid renewable energy systems: Overview of different approaches, Renewable and Sustainable Energy Reviews 16 (2012) 1412–1425.

[146] S. Upadhyay, M. Sharma, A review on configurations, control and sizing methodologies of hybrid energy systems, Renewable and Sustainable Energy Reviews 38 (2014) 47–63.

[147] S. Sinha, S. Chandel, Review of software tools for hybrid renewable energy systems, Renewable and Sustainable Energy Reviews 32 (2014) 192–205.

[148] S. Freitas, C. Catita, P. Redweik, M. C. Brito, Modelling solar potential in the urban environment: State-of-the-art review, Renewable and Sustainable Energy Reviews 41 (2015) 915–931.

[149] Z. Huang, H. Yu, Z. Peng, M. Zhao, Methods and tools for community energy planning: A review, Renewable and sustainable energy reviews 42 (2015) 1335–1348.

[150] P. Tozzi Jr, J. H. Jo, A comparative analysis of renewable energy simulation tools: Performance simulation model vs. system optimization, Renewable and Sustainable Energy Reviews 80 (2017) 390–398.

[151] L. Sanhudo, N. M. Ramos, J. P. Martins, R. M. Almeida, E. Barreira, M. L. Simões, V. Cardoso, Building information modeling for energy retrofitting–a review, Renewable and Sustainable Energy Reviews 89 (2018) 249–260.

[152] K. Anoune, M. Bouya, A. Astito, A. B. Abdellah, Sizing methods and optimization techniques for pv-wind based hybrid renewable energy system: A review, Renewable and Sustainable Energy Reviews 93 (2018) 652–673.

[153] E. Lange, S. Hehl-Lange, Combining a participatory planning approach with a virtual landscape model for the siting of wind turbines, Journal of Environmental Planning and Management 48 (2005) 833–852.

[154] S. Benbelkacem, M. Belhocine, A. Bellarbi, N. Zenati-Henda, M. Tadjine, Augmented reality for photovoltaic pumping systems maintenance tasks, Renewable energy 55 (2013) 428–437.

[155] R. Berry, G. Higgs, R. Fry, M. Langford, Web-based gis approaches to enhance public participation in wind farm planning, Transactions in GIS 15 (2011) 147–172.

[156] A. J. Veldhuis, A. H. Reinders, Real-time irradiance simulation for pv products and building integrated pv in a virtual reality environment, IEEE Journal of Photovoltaics 2 (2012) 352–358.

[157] M. M. E. Ali, S. K. Salih, A visual basic-based tool for design of stand-alone solar power systems, Energy Procedia 36 (2013) 1255–1264.

[158] J. B. Kodysh, O. A. Omitaomu, B. L. Bhaduri, B. S. Neish, Methodology for estimating solar potential on multiple building rooftops for photovoltaic systems, Sustainable Cities and Society 8 (2013) 31–41.

[159] M. E. Portman, Visualization for planning and management of oceans and coasts, Ocean & coastal management 98 (2014) 176–185.

[160] C. Donalek, S. G. Djorgovski, A. Cioc, A. Wang, J. Zhang, E. Lawler, S. Yeh, A. Mahabal, M. Graham, A. Drake, et al., Immersive and collaborative data visualization using virtual reality platforms, in: Big Data (Big Data), 2014 IEEE International Conference on, IEEE, pp. 609–614.

[161] B. Celik, E. Karatepe, S. Silvestre, N. Gokmen, A. Chouder, Analysis of spatial fixed pv arrays configurations to maximize energy harvesting in bipv applications, Renewable Energy 75 (2015) 534–540.

[162] A. K. Rohit, A. Tomar, A. Kumar, S. Rangnekar, Virtual lab based real-time data acquisition, measurement and monitoring platform for solar photovoltaic module, Resource-Efficient Technologies 3 (2017) 446–451.

[163] Y. Wei, X. Zhang, Y. Shi, L. Xia, S. Pan, J. Wu, M. Han, X. Zhao, A review of data-driven approaches for prediction and classification of building energy consumption, Renewable and Sustainable Energy Reviews 82 (2018) 1027–1047.