COMPARISON OF SOLAR PLANNING TOOLS

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Abstract

The energy master planning process for districts requires an analysis of different scenarios, which often includes the determination of the solar potential of a district. In the past, several solar planning tools were developed. These are reviewed in the first part of this paper and classified in the main part of the paper according to a list of restriction and functionality classification. Three classifications of tools were found and specified in tables. The first level comprises of stand-alone tools (e.g. PVSys, Polysun) with certain functionality restrictions. The second level comprises tools based on GIS data (e.g. PVGIS, Solroof) with restrictions by introducing reduction factor. The third level is embedded solar potential analysis in Energy Master Planning (EMP) tools (e.g. City Energy Analyst (CEA), Sympheny). By integrating comprehensive spatial and temporal analyses, along with multiple renewable energy sources, urban areas can optimize their energy utilization, minimize energy waste, and advance towards a sustainable and low-carbon future.

Keywords: Solar radiation, planning tool, simulation

1. Introduction

Climate change challenges the ambitious goals that policy makers have put in place by setting more and more ambitious energy-related building and community requirements and standards based on the Sustainable Development Goals of the United Nations (UN) [1]. The concept of Energy Master Planning (EMP) – a roadmap of planning for energy efficiency and grid optimization - can help to initiate a better planning and implementation process to fulfil these goals. Reaching for the greenhouse gas reduction goals of the Paris Agreement, stakeholders on all geographical and organisational levels from nations, regions, cities and communities are challenged. Following bottom-up approaches for energy planning on the neighbourhood level is a promising attempt to reduce energy demand, increase efficiency and lower the carbon footprint in a multi-stakeholder approach (JPI UE, 2020). Reaching for the Global Sustainability Goals, cities and communities play a prominent role as they are geographically the main cause for emissions and on the other hand play a prominent role in putting global goals into local policies and means and at the same time embedding them in the local context with site specific demands and settings

With the 2015 Paris commitment in mind it is even more important to make sure that energy generation is renewable. Since solar energy systems can replace other building materials such as cladding or shading devices, they have additional advantages compared to other heat and power production solutions (Schiefelbein 2018). Solar power as a source of low carbon energy is an essential component for the sustainability of cities and its implementation and management, through urban planning practices, can play a strategic role in improving the energy efficiency of cities. Solar urban planning is a complex process which needs to consider the interplay between multiple factors and variables, depending on urban form and solar energy inputs. In order to enhance solar considerations within the planning process, there is a great need for knowledge from different disciplines to reach the planning practice and the public (Eicker 2012, Kaiser 1996).

1.1. Urban planning process

The urban planning process is a political and technical process that balances different needs of society within a physical and spatial environment (Haase and Lohse 2019; Haase 2020). Decisions need to be taken during the process in regard to spatial, social, environmental, economical, technical and political aspirations and goals. Strategies and tools are needed to support and facilitate these decisions and to enhance solar energy considerations

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within the existing urban planning processes (Sharp et al. 2020; Schiefelbein 2018). The concept of Energy Master Planning (EMP) in Urban planning can help to initiate a better planning and implementation process to fulfil these goals through providing a roadmap for energy planning. The application of principles of a holistic approach to neighbourhood and districts, often coined community energy planning in the literature and discussed in Haase and Baer (2020). The concept of Energy Master Planning (EMP) can help to initiate a better planning and implementation process to fulfil these goals through providing a roadmap for energy efficiency in the district as a basis for energy planning that points into the future. Haase and Lohse (2019) tried to define EMP and explained the different steps involved in the process; energy efficiency (1) and comprehensive energy planning (2) (Haase and Lohse 2019). In addition, to provide the necessary methods and instruments to stakeholders involved, it is essential to identify and frame the constraints that bound the options towards an optimized energy master planning solution (Sharp et al. 2020).

1.2. Constraints and goals in Energy Master Planning

Far less common in EMP guidance and related literature is information on the identification of constraints that limit energy technology options and how stakeholders influence the decision-making process. Although the work of Sharp et al. (2020) contributes by widening the definition of constraints into EMP, it is limited in its scope while focusing on single-ownership neighbourhoods like campuses or military garrisons (Sharp et al. 2020). Not much work is available on the role constraints, stakeholders, and boundary conditions in EMP for multi-owner, multi-stakeholder neighbourhoods many cities and regions are characterized of more complex ownerships and therefore a more complex stakeholder group with more complex framing goals that can lead to further constraints in EMP. An important part is the constraints analysis as part of the assessment when energy options are developed which can be divided into the following five categories:

- Natural Locational Constraints – Resources and threats
- Distribution System & Storage Constraints
- Building and Facility Constraints
- Indoor Environment Constraints
- Building Equipment and District System Constraints

1.3 Aim of the study

As argued above there is an intrinsic need to know the natural locational constraints of a site early in the Energy Master Planning process. Especially the resources need to be evaluated to form the basis for goal setting and further steps in the EMP. The aim of this study was to collect and assess different approaches to quantify solar energy potential from photovoltaic systems in the urban context. Within this framework, the amount of energy provided by the integration of photovoltaic systems into existing buildings and their energy consumption, are two key indicators to identify the neighborhoods of the city that behave as urban units with positive, negative or balanced energy performances.

2. Methodology

We collected methods and tools from various sources. An extensive literature review was conducted, followed by a review of past and present solar neighbourhood research activities:

- *ScienceDirect and Scopus database*
- *International research activities (IEA SHC Task 51, IEA SHC Task 63, IEA EBC Annex 73, IEA EBC* Annex 83, IEA EBC Annex 75, EU projects)
- *Software databases (e.g. https://www.buildingenergysoftwaretools.com/)*
- Other research projects (e.g. national initiatives, local planning tools)

Then we adopted factors which were divided between exclusion factors and reduction factors in order to consider spatial aspects for PV arrays installation, shading effects, roof typologies and other roof uses and PV module efficiency. Other factors are related to other urban parameters and the energy demand of the buildings within the district. Table 1 provides an overview of the factors that were included in the analysis.

Tab. 1: Factors included in the analysis

Exclusion factors	Reduction factors	Urban factors
surfaces	obstructions	Morphology
technologies	Surfaces	Energy demand
Performance factors	Physical parameters	Demand profiles
Period		

It can be seen that there were factors identified that exclude certain features of solar radiation potential calculations. These refer to surfaces, technologies, performance factors and simulation periods. The second set of factors were found that reduce the amount of solar radiation, such as obstructions, surfaces and other physical parameters. Then, there are urban factors like morphology, energy demand and demand profiles of districts. Based on these functionality factors, it was possible to classify the mapped tools into three levels (level1 – 3).

3. Results

An increasing number of cities and even regions are producing online solar maps which can give building owners an indication of the solar energy potential of their roofs, and some cities are additionally including solar potential of facades. These solar maps are both urban planning and assessment tools. When reviewing the assessment tools it became clear that the tools were developed and are explored in different ways. There are three main levels of functionality. Tools which produce solar radiation on surfaces and estimate electricity production by using exclusion factors were classified as Level 1. Figure 1 shows the calculation procedure. Tools which use a digital model and combine neighboring buildings and the terrain relief were classified as Level 2. Figure 2 shows the simulation procedure. Tools which are capable of coupling solar radiation analysis with the local specificity were classified as Level 3.

3.1. Level 1

Solar maps are used to identify suitable building surfaces for the installation of solar energy systems. These maps quantify the solar potential on building roofs or facades and predict the amount of solar energy that can be generated. While most solar maps focus on displaying the existing urban landscape, some cities are exploring the possibility of incorporating these features into urban planning maps. The production of solar maps involves the use of advanced technologies such as photogrammetry and drones.

To obtain solar radiation data, various National Solar Radiation Databases (e.g., NSRDB in the US) have been established. These databases contain solar radiation and meteorological data for national and regional areas, including neighboring countries. They provide publicly available datasets that have been collected and distributed over a certain period of time. The databases typically consist of surface observations, models, satellite data, as well as measurement and modeling technologies. For example, the current NSRDB includes solar irradiance data at a 4-km horizontal resolution for every 30-minute interval from 1998 to 2016. This data is computed using the National Renewable Energy Laboratory's (NREL's) Physical Solar Model (PSM), along with products from other research labs in the US (Sengupta 2018). It is important to validate the irradiance data with surface observations, which can be done by assessing mean percentage biases for global horizontal irradiance (GHI) and direct normal irradiance (DNI).

Efforts to develop solar maps can also be observed in other countries, as indicated in Table 2. However, existing solar maps have limitations, particularly in estimating solar potential for integrated solar facade systems, as the majority of maps are designed for small-scale roofing installations (Lobaccaro et al. 2012). Furthermore, some solar energy potential assessment categories are not clearly defined (Lobaccaro et al. 2019).

Tab. 2: Solar maps

name	features	country
Aurora	AI engine, sales support, contract manager	Global
BlueSol	• BlueSol is a software for the design of photovoltaic systems in every country in the world. • It allows to perform the entire process of designing a PV system, from the preliminary assessment of producibility to the realization of the project documentation. • made with a standard Microsoft interface, easy to use and manages every detail of the PV system.	Global
Helioscope	• web-based sales and design tool for solar professionals • robust 3D design engine and bankable energy yield simulator • detailed financial calculator and drag-and-drop proposal editor	Global
Global Solar Atlas	• Regional and local geographical characteristics may represent technical and environmental prerequisites, but also constraints for solar energy development. • Ground imagery from satellite and city maps helps identify potential areas of interest. Main roads, railways, and transmission line networks help define the accessibility and feasibility of sites for the location of power plants. • Different map layers can be selected: photovoltaic electricity output (PVOUT), global horizontal irradiation (GHI), direct normal irradiation (DNI), diffuse horizontal irradiation (DIF), global tilted irradiation for fixed systems at optimum angle (GTI), optimum angle of PV modules (OPTA), temperature (TEMP), elevation (TERRAIN), satellite view (SATELLITE) and information on roads and streets (NORMAL).	Global
NREL	The maps illustrate select multiyear annual and monthly average maps and geospatial data from the National Solar Radiation Database (NSRDB) Physical Solar Model (PSM). The PSM covers most of the Americas.	US
NY Solar map	The website provides a step-by-Step approach 1. Evaluate the building's solar potential (see solar map solar potential calculator) 2. Learn about solar technologies (see solar basics) 3. Learn about available PV incentives 4. Gather energy bills and roof schematic drawings (if available), and contact solar installers using the 'solar connect' feature on the map 5. Receive remote and on-site evaluations from contractors to get at least 3 quotes 6. Evaluate if your roof needs to be reinforced or replaced 7. Contact references from solar contractors 8. Evaluate costs and financing options to decide on direct ownership or third-party ownership 9. Sign contract with selected solar installer 10. The solar contractor files applications for incentives and permits; the installation moves forward	NY, US
PV Sol Free & Premium	• PV*SOL is a software used by planners, architects, installers and skilled technicians around the world to plan and design efficient PV systems. • PV*SOL offers the most detailed configuration and shade analysis for PV systems. It calculates solar output, panel sizing and economic forecasting for a PV system.	Global
PV F-chart	PV F-CHART is a comprehensive photovoltaic system analysis and design program. The program provides monthly-average performance estimates for each hour of the day. The calculations are based upon methods developed at the University of Wisconsin which use solar radiation utilizability to account for statistical variation of radiation and the load.	Global

Polysun	Polysun software from Vela Solaris allows a multi-practice simulation of various energy system with reliable results in terms of functionality, energy efficiency and profitability – from single-family homes to districts, worldwide and for all market-standard technologies.	Global
Pylon	Web-based PV design software	US
PVsyst	• PVsyst is designed to be used by architects, engineers, and researchers. It is also a very useful educative tool. • It includes a detailed contextual Help menu that explains the procedures and models that are used, and offers a user-friendly approach with a guide to develop a project. • PVsyst is able to import meteo data, as well as personal data from many different sources.	Global
PVGIS	Free and open access to: • Electricity generation potential for different PV technologies and configurations • Solar radiation and temperature, as monthly averages or daily profiles • Full time series of hourly values of both solar radiation and PV performance • TMY data for nine climatic variables, formatted for building energy calculation tools • Application Programming Interface for fast, automated access needs • Maps of solar resource and PV potential, by country or region, in ready to print files • PVMAPS, a software suite for users to make customised maps • PVGIS uses high-quality and high-spatial and temporal resolution data of solar radiation obtained from satellite images, as well as ambient temperature and wind speed from climate reanalysis models. The PVGIS energy yield model is validated from measurements performed on commercial modules at the JRC's European Solar Test Installation (ESTI). ESTI is an ISO 17025 accredited photovoltaic calibration laboratory for all photovoltaic materials.	Europe
Solar PV map	Understand the Australian solar PV market with live generation data, historical maps and animations, and tools to explore rooftop PV potential and per-postcode market penetration.	Australia
Solar Reference map	This interactive solar reference map is intended to provide quick and intuitive access to weather data needed to install code-compliant PV systems.	Florida, US
Solcast	• Solcast takes on the many challenges of producing live and forecast solar data, • making the data as easy to access, validate and integrate as possible, which is made possible through an API Toolkit. • It provides instant access to live and forecast data products via this web interface. • These include direct estimates of global, direct and diffuse solar radiation, as well as PV power output.	Global
Solar calculator	• The residential solar calculator is a tool intended to help determine the viability of adding solar photovoltaic (PV) panels as an alternative energy source to residential buildings (single-family homes) in Calgary. • Homeowners can use this tool as a starting point to help assess their home's solar potential, and to get an idea of the estimated costs and payment options. • The residential solar calculator is intended for informational purposes only.	Calgary, Canada
SolarEdge site designer	• SolarEdge Designer is a free web-based solar design tool that helps solar professionals lower PV design costs and generate winning customer proposals. • plan, build and validate with SolarEdge residential and commercial systems from inception to installation with this powerful selling tool	Global
Solarius	Solarius PV is a professional software for technical design and economic analysis for any type of photovoltaic system connected to national electricity grids (grid-connected).	Global

	Sizing, financial analysis and single-line diagrams in a single solution, which can be used in every situation and for all kinds of needs: • for PV systems installed on new or existing buildings or even for large systems (photovoltaic farms) • in every location (geolocation with reference climate data) • in any boundary condition (near and far obstacles) • all types of Panels and Inverters (extensive library with thousands of different models)	
Solargis	• Multiple independent studies have found Solargis to be the most reliable solar database • Spatial resolution of 250 m and sub-hourly temporal resolution better represent typical and extreme weather and improve accuracy • Solutions available for all solar energy assessment needs: from prospecting to effective operation • Solargis data and services are available for any location between latitudes 60N and 50S	Global
Suncalc	SunCalc shows the movement of the sun and sunlight-phase for a certain day at a certain place. The results can be printed or given by API.	Global
Sunroof	Solar savings are calculated using roof size and shape, shaded roof areas, local weather, local electricity prices, solar costs, and estimated incentives over time. Using a sample address, the detailed estimate Project Sunroof can give output for any address.	US

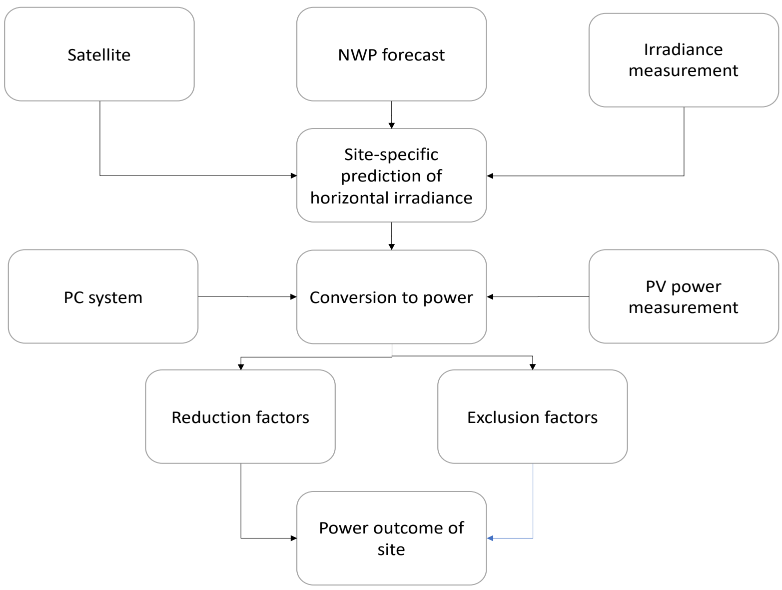

Fig. 1: Calculation illustration

3.2. Level 2

Alternatively, the solar potential of every roof and facade may be precisely calculated using a digital model which combines neighboring buildings and the terrain relief (Digital Surface Models or 3D City Models) with an adapted solar simulation software. The identified tools in this category are listed in Table 3. Such digital models are available in an increasing number of places. Solar simulation tools integrate radiation models considering urban shading effect and the possibility of reflections. Solar energy can be utilized in buildings to a much higher degree than is the case today, but the first obstacle is at the urban level. Local authorities currently lack the approaches, methods and tools to assess the potential for active solar energy. In order to perform an analysis of the solar potential of a study area, a 3D model built at a certain Level of Detail needs to be employed. According to (Biljecki, 2015), buildings are represented as footprint extrusions and with flat roofs at LOD 1 (at this level of detail). The complexity of the built agglomerations (such as building volumes, urban or building typological factors, density, vegetation, etc.) affects the incidence of solar irradiation on the buildings' surfaces (e.g., partial shading or localized hot spots causing overheating), which may lead to power losses, non-optimal operating conditions caused by potential malfunctions, or safety and reliability reduction effects. Moreover, the determination of the solar potential of construction surfaces in a more realistic way becomes more prominent. In the analysis of constraints at the urban scale it becomes important to analyze typological factors. By introducing weighting indicators to translate the different constructive, geometric, and typological constraints that affect the solar system's integration, shading from surrounding buildings and solar inter-building reflections are becoming common solution to the deployment of solar systems on façades and roofs in such highly densified urban environments. Nonetheless, it is possible to use more detailed three-dimensional representations for analysis concerning a limited number of buildings since computation time exponentially increases with the number of modelled surfaces. Once the physical model is available, two main approaches for estimating solar irradiance values on building envelopes can be employed according to the literature review of Freitas et al. (2015): empirical based or computational based.

The empirical based models transpose the global and diffuse horizontal radiation values measured from weather stations located in open fields into the direct beam and diffuse components for any tilted surface by also considering the reflections due to the ground's albedo.

In general, there is a big consensus around the use of the Perez anisotropic sky model (Perez et al., 1987) that considers one direct beam component from the sun, three diffuse sky components e deriving from the circumsolar disc close to the sun's position, the horizon band close to the ground and the isotropic contribution from the remaining of the sky dome respectively e and the ground reflected component. However, these models fail when complex urban layouts need to be taken into account, especially when obstructions to sunlight can strongly affect solar harvesting like within dense urban environments. Consequently, the development of computational based models that mainly differ each other for the resolution (both spatial and temporal) of the analysis and the radiation components taken into account.

Tab. 3: Solar simulation

name	Description	System level
Design-Builder	DesignBuilder Software Ltd specialises in developing high-quality, easy-to-use simulation software that helps you to quickly assess the environmental performance of new and existing buildings. DesignBuilder's advanced building performance simulation tools minimise modelling time and maximise productivity. Models either imported from BIM, or built quickly within DesignBuilder, provide fully-integrated performance analysis including energy and comfort, HVAC, daylighting, cost, design optimisation, CFD, BREEAM/LEED credits, and reports complying with several national building regulations and certification standards. DesignBuilder software is distributed globally and via a network of international partners.	Building, components
District Energy Concept Adviser	This software was developed in collaboration with international partners from IEA ECBCS Annex 51 "Energy Efficient Communities“ and comprises a set of individual supporting tools. The very heart of the software is a tool for the energy assessment of districts, which uses archetypes and other pre-set configurations to allow for a simple and quick data input mapping all the buildings in the district. Thus it takes the user just a few steps to identify the energy saving potential of various strategies in the areas of building construction, technical building systems, and centralized supply systems. Other included tools are a case study viewer with 19 exemplary energy efficient city quarters, information on energy efficient technologies and strategies and a benchmarking tool for measured energy use.	Building
Homer	HOMER software is built on the trusted, market-leading HOMER platform, used by more than 250,000 system designers and developers in over 190 countries. I	Building

	Whether designing hybrid microgrids or distributed generation systems, the software solution consider geographic-specific criteria and risks, such as fuel price changes, load growth, accelerated battery degradation and changing weather patterns.	
IDA ICE	IDA ICE is an innovative and trusted whole-year detailed and dynamic multi-zone simulation application for study of thermal indoor climate as well as the energy consumption of the entire building. The physical models of IDA ICE reflect the latest research and best models available, and the computed results compare well with measured data. While serving a global market, IDA ICE is adapted to local languages and requirements (climate data, standards, special systems, special reports, product and material data).	Building, components, systems
OnGrid Tool	OnGrid offers data, software, and education to solar companies — so those companies can offer effective financial presentations to their prospects. OnGrid started in 2005, in Northern California	system
Polysun	Polysun software from Vela Solaris allows a multi-practice simulation of various energy system with reliable results in terms of functionality, energy efficiency and profitability – from single-family homes to districts, worldwide and for all market-standard technologies.	Building, components, system
RETscreen	CanmetENERGY's engineering experts have developed innovative clean energy project analysis, modelling, and simulation software tools to help users: • assess various types of renewable energy and energy efficient technologies • reduce greenhouse gas emissions • optimize integrated energy efficient design in domestic and international markets • reduce operating costs & comply with code requirements • qualify for funding and incentive programs	District, systems
Sonnendach (CH), Solroof	The map shows the degree of suitability of roofs for the use of solar energy, together with the potential yield. For this purpose the course of the sun throughout the year is simulated and the level of solar radiation reaching the roof is calculated.	Building, system
Sympheny	Sympheny aims to empowers the planners and managers of buildings & local areas to drive the global energy transition. Their unique combination of digital twin technology and intelligent algorithms allows to provide for the new knowledge needs of energy planners, facility managers and site owners in the emerging energy landscape. Sympheny aims to support energy planners and energy managers in different countries and contexts around this world by providing software that is globally scalable and locally adaptable.	Building, components, systems
System Advisor Model (SAM)	The System Advisor Model (SAM) is a free techno-economic software model that can model many types of renewable energy systems. SAM simulates the performance of photovoltaic, concentrating solar power, solar water heating, wind, geothermal, and biomass power systems, and includes a basic generic model for comparisons with conventional or other types of systems. The financial models are for projects that either buy and sell electricity at retail rates (residential and commercial) or sell electricity at a price determined in a power purchase agreement (PPA). SAM's simulation tools facilitate parametric and sensitivity analyses, Monte Carlo simulation and weather variability studies. It includes a built-in scripting language called LK that automates simulations for batch processing and allows for more complex analyses and reading and writing data from files. Several macros written in LK come with SAM to help with tasks such as checking weather files, sizing photovoltaic systems, and other tasks.	Building, components, systems
TRNSYS - Solar	• TRNSYS is made up of two parts. The first is an engine (called the kernel) that reads and processes the input file, iteratively solves the system, determines convergence and plots system variables. The kernel	Building, components, systems

Thermal Energy	also provides utilities that, among other things, determine thermophysical properties, invert matrices, perform linear regressions and interpolate external data files. • The second part of TRNSYS is an extensive library of components, each of which models the performance of one part of the system. The standard library includes approximately 150 models ranging from pumps to multi-zone buildings, wind turbines to electrolyzers, weather data processors to economics routines, and basic HVAC equipment to cutting edge emerging technologies. Models are constructed in such a way that users can modify existing components or write their own, extending the capabilities of the environment.	
UrbaSun	• Meteodyn have been studying micro-meteorology since 2003. • They develop wind flow and solar radiation simulation software that is suitable for all types of terrain. • Their software and services allow the renewable energy, construction and transportation industries to accurately calculate and model wind or solar radiation.	Building

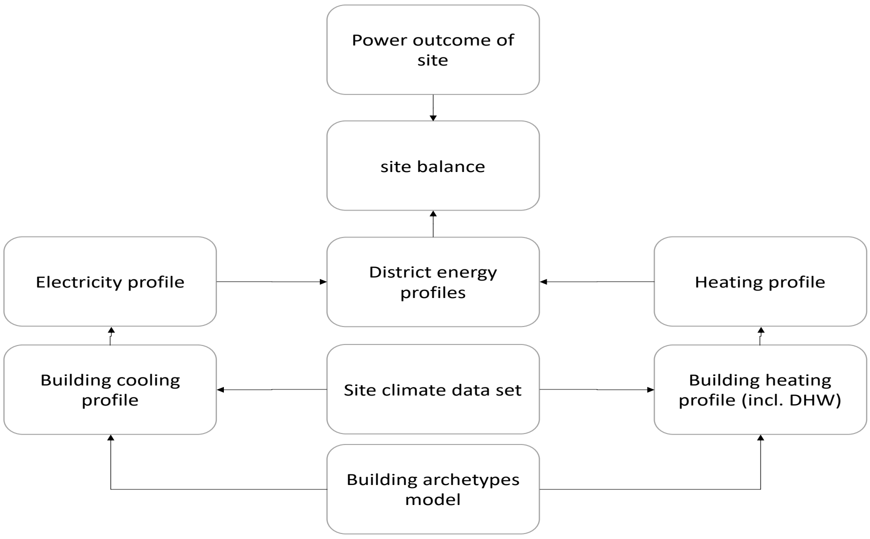

Fig. 2: Simulation illustration

3.3 Level 3

On the strategic planning level, buildings and neighborhoods can be recognized in districts. Regarding sensitivity, particularly sensitive (or non-sensitive) districts can be identified in an area that otherwise is assessed as a uniform medium-sensitive territory. In GIS zones with different heritage categories in accordance with the method of context sensitivity presented in the previous chapter can be marked in maps. As such protected zones in land use plans can be marked as highly sensitive areas, commercial and industrial zones as low sensitive areas. These considerations need to be coupled with a deep understanding of the local specificity and a constructive discussion with the local site protection authorities (Amado and Poggi 2014). Table 4 lists the tools that were identified in this category.

Tab. 4: Solar urban design tools

name	url	Urban planning level
City Energy Analyst (CEA)	https://cityenergyanalyst.com/	advanced

DIVA-For-Rhino	http://www.solemma.com	advanced
RETscreen	http://www.retscreen.net	high
Sonnendach (CH), Solroof	https://www.uvek-gis.admin.ch/BFE/sonnendach/index.html	medium
Sympheny	https://www.sympheny.com/#1	advanced

3.4 Features of Solar PV planning tools

All solar PV design software need some kind of features to match technical accuracy and urban planning criteria (e.g. gross roof area of building (m²) Calculating the shadow free area on the site, available for solar PV installation, Estimation of the annual yield for PV systems on available roof area (kWh), etc.). These are elaborated and provide useful information for further EMP.

All solar PV design software need some kind of input data, which include:

- Gross roof area of building (m²)
- Available flat roof area for PV installation considering exclusion factors (m²)
- Estimating the solar energy available at a given location – for example, rooftop of a building
- Calculating the shadow free area on the site, available for solar PV installation
- Sum of all global solar irradiation values over a year (kWh/m²)
- Mean annual global radiation on available roof area (kWh)
- Designing a solar PV installation to produce the required solar power
- Calculating the projected solar energy production
- Creating the engineering drawings and reports for the planned installation
- Available pitched roof area for PV installation considering exclusion and reduction factors (m²)
- Estimation of the annual yield for PV systems on available roof area (kWh)

The characteristics and parameters of the urban system which are required to estimate photovoltaic solar electricity have been gathered by mean of quantitative spatial analysis. According to related approaches to available roof surface area for photovoltaic energy potential evaluations, some specific criteria have to be assumed for taking into account those factors that can reduce the gross roof surface.

Table 5 shows the analysis results of the functionality levels of different solar planning tools.

Tab. 5: Analysis results of functionality levels of different solar planning tools

Planning tool	**url**	**Functionality**		
		Level 1	Level 2	Level 3
Aurora	http://www.aurorasolar.com/	X		
BlueSol	http://www.bluesolpv.com/	X		
City Energy Analyst (CEA)	https://cityenergyanalyst.com/			X
DesignBuilder	https://designbuilder.co.uk/	X	X	
District Energy Concept Adviser	https://www.district-eca.com/		X	
DIVA-For-Rhino	http://www.solemma.com			X

Helioscope	https://www.helioscope.com/	X		
Homer	https://www.homerenergy.com/		X	
IDA ICE	https://www.equa.se/de/ida-ice		X	
OnGrid Tool	http://www.ongrid.net/		X	
PV Sol Free & Premium	https://pvsol.software/en/	X		
PV F-chart	http://fchartsoftware.com/pvfchart/	X		
Polysun	https://www.velasolaris.com/	X	X	
Pylon	https://getpylon.com	X		
PVGIS tool	https://re.jrc.ec.europa.eu/pvg_tools/en/	X		
PVsyst	https://www.pvsyst.com/	X		
RETscreen	http://www.retscreen.net		X	X
SolarEdge site designer	https://www.solaredge.com/us/products/installer-tools/designer#/	X		
Solarius	https://www.accasoftware.com/en/solar-design-software	X		
Sonnendach (CH), Solroof	https://www.uvek-gis.admin.ch/BFE/sonnendach/index.html		X	X
Sympheny	https://www.sympheny.com/#1		X	X
System Advisor Model (SAM)	https://sam.nrel.gov/download		X	
TRANSYS - Solar Thermal Energy	http://www.aiguasol.coop		X	
UrbaSun	http://meteodyn.com/en/		X	

4. Conclusions

Typical-alone tools were classified as Level 1 (e.g. PVSys, Polysun). The Level 2 tools are based on GIS data (e.g. PVGIS, Solroof) and provide urban planning relevant features. Level 3 tools embedded solar potential analysis in Energy Master Planning (EMP) tools (e.g. City Energy Analyst (CEA), Sympheny).

Solar potential calculations for different buildings are incorporated into a Geographic Information System (GIS) platform, which provides a comprehensive map for clear identification of urban areas, their energy consumption, and their potential for energy production. This step allows for achieving an energy balance in urban areas and enables the identification of areas with higher energy needs. Urban parameters can then be developed to transform and adapt the energy demand and production patterns accordingly. Conversely, by analyzing areas with energy surplus, it is possible to assess buildings and make necessary adjustments or improvements to urban parameters.

However, energy balances are not the sole focus of interest. In the future, there will be a greater emphasis on spatial and temporal distributions. It will be important to consider not only diurnal variations but also seasonal differences. Solar planning tools should incorporate these developments into their analysis. Additionally, other renewable energy sources at the district scale, such as wind energy, biomass-based solutions, and geothermal energy, need to be integrated into these types of analyses. The full potential of renewable energy can only be harnessed when buildings are considered not only in terms of their surfaces (roofs and facades) but also in terms of their overall structure and fabric. Heating, cooling, and electricity demands are significant components of the equation for achieving a decarbonized future energy system.

By integrating comprehensive spatial and temporal analyses, along with multiple renewable energy sources, urban areas can optimize their energy utilization, minimize energy waste, and advance towards a sustainable and low-carbon future.

The next step will be to choose a typical district and to perform for each solar potential tool class an analysis. The results can then be compared and used for benchmarking purposes.

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