Renewable and Sustainable Energy Reviews 108 (2019) 209–237

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A cross-country perspective on solar energy in urban planning: Lessons learned from international case studies

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ARTICLE INFO

Keywords:
Solar energy
Photovoltaics
Urban planning
Case studies
Planning process
Solar landscapes

ABSTRACT

This work, framed in the IEA SHC Task 51 “Solar Energy in Urban Planning”, presents an illustrative perspective of solar energy in urban planning through the analysis of 34 international case studies conducted in 10 countries. The aim here is to examine challenges, barriers and opportunities for active solar systems and passive solar strategies by taking into consideration interrelated technical and non-technical aspects in ongoing and completed projects. It focuses on exposing potential pitfalls and illustrating lessons learned in case studies divided into three categories: (i) existing urban areas, (ii) new urban areas, and (iii) solar landscapes. The analysis has yielded insights into the solar energy strategy adoption, the evaluation of solar energy production, solar irradiation and daylighting, and the architectural quality, sensitivity and visibility of the solar systems for urban planning. The outcomes have implications to stimulate successful practices in implementing solar strategies in urban planning and facilitating their replicability worldwide by avoiding common mistakes.

1. Introduction

By 2050, a share of 49–67% of primary energy will be supplied by renewable energy sources (RES) [1], by lowering energy use and decarbonizing energy supply in the built-up environment, where solar energy will play a fundamental role.

Since 1990, solar energy was widely implemented into building and its significance was illustrated largely amongst other RES. From 2000 to 2010, in Europe, the average annual growth rate was 40% for photovoltaics (PV), and 12% for solar thermal (ST), while, over the last decade, 2017 being a mark for both PV and ST globally. PV capacity worldwide reached 98 GW installed (both on- and off-grid), for a 402 GW cumulative in total, which overtook the capacity of any other type of power generating technology in several major markets, including China, India, Japan, and the United States. ST on the other hand, reaching 35 GW of capacity of glazed (flat plate and vacuum tube technology) and unglazed collectors being newly commissioned in 2017, brings the total global capacity to 472 GW. The causes of the success of solar systems are multiple: (i) more affordable technologies thanks to increased efficiency and competitiveness, (ii) the dropping of systems' cost, (iii) the increasing awareness of solar systems' potential to reduce CO_2 emissions [2,3] and providing energy access [4], and (iv) more favorable political conditions driven by governments' incentives and regulations [5,6].

In this scenario, the implementation of solar energy becomes fundamental to make buildings, neighborhoods and cities to progressively move towards low carbon energy transition [7].

Abbreviations: BIPV, building integrated photovoltaic; BIST, building integrated solar thermal; DH, district heating; GHG, green-house gas; PV, photovoltaic; RES, renewable energy sources; ST, solar thermal

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https://doi.org/10.1016/j.rser.2019.03.041
Received 29 November 2018; Received in revised form 26 February 2019; Accepted 19 March 2019

2. Background

2.1. State of knowledge and gaps in solar energy in urban planning

Solar energy solutions are becoming more diffused in built-up areas; however, their implementation in urban planning is not straightforward. In fact, it faces several technical and non-technical challenges in what regards to the planning process, architectural integration, technology and energy related issues, as well as social, environmental and economic barriers [8]. The implementation of solar energy in urban planning considers the interactions between solar energy and urban morphology [9–11], together with land use and spatial configuration of cities [12–14] and it influences the economic and energy performance of solar systems [8]. Solar energy is only one of many parameters to be considered during the planning process, many of them are neither under the control of urban planners. For example, the urban density is often set without awareness of its consequences in terms of solar accessibility and solar energy potential [15]. As a consequence, the number of factors to be considered during the planning process is broad and includes the stakeholders involved; the technical solutions adopted; and the development plan for the area [5,16,17], therefore, interdisciplinary thinking is required [18]. For this reason, energy planning moves away from common urban planning approaches, which first include the areas' spatial characteristics and later consider energy related issues [19]. This complex process requires the integration of diverse technical and non-technical perspectives [20,21], especially in relation with the long timeline associated with planning process [16,22].

A considerable amount of literature has analyzed energy and financial performance of solar energy systems [13,23–27]; while a limited number of studies have focused on the actual implementation of solar energy in urban planning [11,28–31]. In that regard, the role of planning instruments, such as urban and regional energy plans, demonstrated the influence of the legislative framework on the feasibility of PV installation in urban areas [28]. Analyses have also been conducted to estimate the potential increase of solar systems competitiveness through incentive policies [25,26], and feed-in-tariffs [24].

Economic and energy policies are only some of the determinants for solar energy implementation in urban planning [13]. Other influential factors are related to energy-generation, technological and aesthetic aspects such as the understanding of the buildings' solar potential, and the architectural quality of Building Integrated Photovoltaic (BIPV) and Solar Thermal (BIST) systems [32,33]. In fact, considering active solar technologies in the early design phases may lead to more effective and attractive solutions [5]. Furthermore, the assessment of solar potential may help architects to identify the most suitable locations for solar systems installation, and urban developers to evaluate the potential of solar energy-generation. In that regard, several municipalities and public authorities have supported the creation of solar cadasters [34], which are often used as support instruments for the design process. In this direction, several studies focused on the development of solar design guidelines [29,32] through the capability of approaches, methods and tools [34–39], which allow ranging from solar accessibility and solar potential evaluation at neighborhood scale, to the assessment of daylighting levels and solar irradiation on surfaces at building scale. Such analyses can influence significantly the decisions at different design stages, especially in complex and dense urban environments. Consequently, the choice of suitable and reliable methods, approaches and tools is crucial to achieve energy efficient and high performative urban solar designs [35]. Tools are today used in a broad interdisciplinary context to optimize both passive (e.g. daylighting) and active (e.g. BIPV/BIST, PV, ST) solar strategies in urban planning and building design processes [40,41].

Previous researches investigated the spatial and temporal characteristics of solar systems' adoption to assess the influence of external factors on the planning process [42,43]. Among others, technical aspects as installed capacity and power generation, together with the environmental and economic impacts of the project, resulted to be the most influential factors [43,44]. In this domain of research, several studies have focused on identifying the main challenges for the implementation of solar strategies in relation to: (i) selection of technological components, (ii) potential conflicts arising between different stakeholders involved into the process, and (iii) social acceptance [45–47]. One of the major components of social acceptance in urban areas is the "visual impact". A scale-dependent method, based on multicriteria decision framework considering annual solar radiation, visibility, and socio-cultural sensitivity of the built environment, has been developed to assess the building envelope surfaces that can host solar systems [33,48].

Finally, in recent years, the concept of "energy landscapes" has been developed in literature. The use of those concepts aimed at the production of solar energy [49,50]. Studies have focused on: (i) the aesthetic impact of solar energy systems [51], (ii) the inter-relationship between renewable energy and ecosystem services in landscape planning and design landscape design [49], and (iii) the harmonization of energy production and agriculture, together with the enhancement of ecosystem services in the area [52,53]. Furthermore, Scognamiglio proposed an inclusive design of PV systems as elements of landscape they belong to, focusing not only on energy efficiency, but also on further ecological and landscape objectives [54].

The contribution of the hereby-presented study opens up scenarios on the diverse perspectives and understandings of solar energy in urban planning on an international basis.

2.2. Framework, aims and structure of the work

This work presents an illustrative perspective of solar energy in urban planning through a collection of 34 international case studies, which were analyzed within the *Subtask C – Case Studies and Action Research*, framed in the International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC) Task 51 "*Solar Energy in Urban Planning*". The cases focus on the integration of solar energy in urban planning, with the aim to implement the use of solar technologies from the early design phases. The aim was to encourage successful practices and facilitate their replicability, by documenting ongoing experiences, exposing potential pitfalls, and creating arenas for mutual interaction between researchers and city representatives. The analysis of the cases was structured as follows: (i) planning process development and stakeholders involvement (Section 3.2.1); (ii) approaches, methods and tools applied to develop energy concepts and to define energy technology (Section 3.2.2); (iii) architectural visibility, sensitivity and quality (Section 3.2.3); (iv) solar potential and solar landscapes (Section 3.2.4); and (v) environmental economic and social impact (Section 3.2.5).

3. Methodology

The work within the IEA SHC Task 51 was mainly conducted as action research, a reflective process of progressive problem solving led by individuals working in teams or as part of a "community of practice" to improve the way they address issues and solve problems [55]. This approach was evident in the collaboration of the participants, such as urban planners and other key actors within local urban planning developments in each participating country. In this way, information about important issues were collected to investigate and learn from real planning experiences, to develop useful knowledge both for practicing urban planners, and to educate architects and developers [56].

3.1. Case studies and definition of environments

In the first step, case studies from all the participating countries were collected (Table 1 and Fig. 1). The extent and scale of cases varied from single groups of buildings to smaller communities, and large urban

Table 1
List of the analyzed case studies.

Country[a]	n°	Case study	Location	Type of environment	Authors (Institute[b])
AT	1	*aspern + Die Seestadt Wiens*	Vienna	New urban areas	D. Jakutyte Walangitang (AIT)
	2	*Stadtwerk Lehen*	Salzburg	New urban areas	M. Gratzl, T. Weiss (fhs), I. Straβl, H. Strasser (SIR)
	3	*Graz Reininghaus*	Graz	New urban areas	M. Malderle, E. Rainer and T. Mach (TUGraz)
CA	4	*Drake Landing Solar Community*	Okotoks	New urban areas	C. Hachem-Vermette and N. Robertson (UCalgary)
	5	*Sarnia Photovoltaic Power Plant*	Sarnia	Solar landscapes	K. Saunders, N. Sephery–Rad, M. Horvat (Ryerson University)
	6	*London Solar Community Ontario*	London	New urban areas	C. Hachem-Vermette and N. Robertson (UCalgary)
	7	*Solar in Halifax Regional Municipality*	Halifax Regional Municipality	Existing urban fabric	A. Pavlovski and M. Moore (Green Power Labs Inc.)
CN	8	*Residential Plot B45*	Fengtai District, Beijing	New urban areas	J. He (Zhang Xiaoxuan)
DK	9	*Solar District Heating Brædstrup*	Brædstrup	Solar landscapes	S. Stendorf Sørensen, (PlanEnergi)
	10	*Fredericiac*	Fredericia	New urban areas	O. Bruun Jørgensen (Dansk Energi Management & Esbensen)
	11	*Gehry City Harbor*	Sønderborg	New urban areas	O. Bruun Jørgensen (Dansk Energi Management & Esbensen)
FR	12	*Lyon Confluence*	Lyon	New urban areas	C. Ménézo (USMB) and M. Musy (ENSA)
	13	*The Sustainable City of Beausèjour*	Sainte-Marie, Reunion Island	New urban areas	F. Garde and A. Delmas (University of Réunion Island)
	14	*Flores Malacca Buildings*	Le Port, Réunion Island	Infills and densification	F. Garde and A. Delmas (University of Reunion Island)
	15	*The Eco-Neighborhood of Ravine Blanche*	Saint-Pierre, Reunion Island	Infills and densification	V. Grosdemouge (University of Reunion Island, City of Saint-Pierre) and F. Garde (University of Reunion Island)
	16	*Agrienergie 5*	Saint Joseph, Reunion Island	Solar landscapes	F. Garde (University of Reunion Island), A. Monnier (Akuo Energy), A.Scognamiglio (ENEA)
	17	*Les Cedres*	Etang-Salé les Bains, Réunion Island	Solar landscapes	A. Monnier (Akuo Energy), A.Scognamiglio (ENEA)
DE	18	*Science and Technology Park Adlershof*	Berlin	Infills and densification	M. Korolkow (IBUS GmbH)
	19	*Freiham Nord Munich*	Munich	New urban areas	R. Nouvel (HFT Stuttgart)
IT	20	*Photovoltaic Village*	Alessandria	Infills and densification	R. Paparella, E. Saretta and M. Caini (UNIPD)
	21	*Sinfonia*	Bolzano	Existing urban fabric	S. Croce, D. Vettorato, A. Zubaryeva and M. Castagna (Eurac Research)
	22	*Le Albere*	Trento	New urban areas	S. Croce and D. Vettorato (Eurac Research)
	23	*Violino District*	Brescia	New urban areas	R. Paparella, E. Saretta and M. Caini (UNIPD)
	24	*Agrovoltaico*	Monticelli d'Ongina	Solar landscapes	A. Scognamiglio (ENEA)
NO	25	*Zero Emission Office Building*	Trondheim	Infills and densification	G. Lobaccaro, C. Lindkvist and A. Wyckmans (NTNU)
	26	*Øvre Rotvoll Sustainable Masterplan*	Trondheim	New urban areas	(a) T. Siems and K. Simon (BUW)/(b) S. Croce (UNIPD)
	27	*Dale community*	Sandnes	Infills and densification	G. Lobaccaro, C. Lindkvist and A. Wyckmans (NTNU)
SE	28	*Uppsala Frodeparken*	Uppsala	Infills and densification	J. Dahlberg, M. Åberg and M. Lundgren (White arkitekter)
	29	*Lund Brunnshög*	Lund	New urban areas	J. Kanters (Lund University)
	30	*Malmö Hyllie*	Malmo	New urban areas	J. Kanters (Lund University)
CH	31	*PDLi Nord-Lausannois*	Romanel-sur-Lausanne	New urban areas	E. Nault, M. Andersen and E. Rey (EPFL)
	32	*PDL Gare-Lac*	Yverdon-Les-Bains	Existing urban fabric	G. Peronato, E. Nault, M. Andersen and E. Rey (EPFL)
	33	*VerGe Project*	Lugano Paradiso	Infills and densification	C. S. Polo López and F. Frontini (SUPSI)
	34	*Energy Innovation Solar Purchase Group*	Castel San Pietro	Existing urban fabric	I. Zanetti and C. S. Polo López (SUPSI)

[a] Austria (AT); Canada (CA); China (CN); Denmark (DK); France (FR); Germany (DE); Italy (IT); Norway (NO); Sweden (SE); Switzerland (CH).

[b] The Institutes are: Austrian Institute of Technology (AIT); Fachhochschule Salzburg (fhs); Salzburger Institut für Raumordnung und Wohnen (SIR); Graz University of Technology (TU Graz); University of Calgary (UCalgary) Zhang Xiaoxuan, China National Engineering Research Center For Human Settlements (Zhang Xiaoxuan), University Savoie Mont-Blanc (USMB); École Nationale Supérieure d'Architecture de Nantes (ENSA); Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA); Institut für Bau- Umwelt-und Solarforschung GmbH (IBUS GmbH); Hochschule für Technik Stuttgart (HFT); University of Padova (UNIPD); Norwegian University of Science and Technology (NTNU); Bergishe Universität Wuppertal (BUW); École Polytechnique Fédérale de Lausanne (EPFL); University of Applied Sciences and Arts of Southern Switzerland (SUPSI).

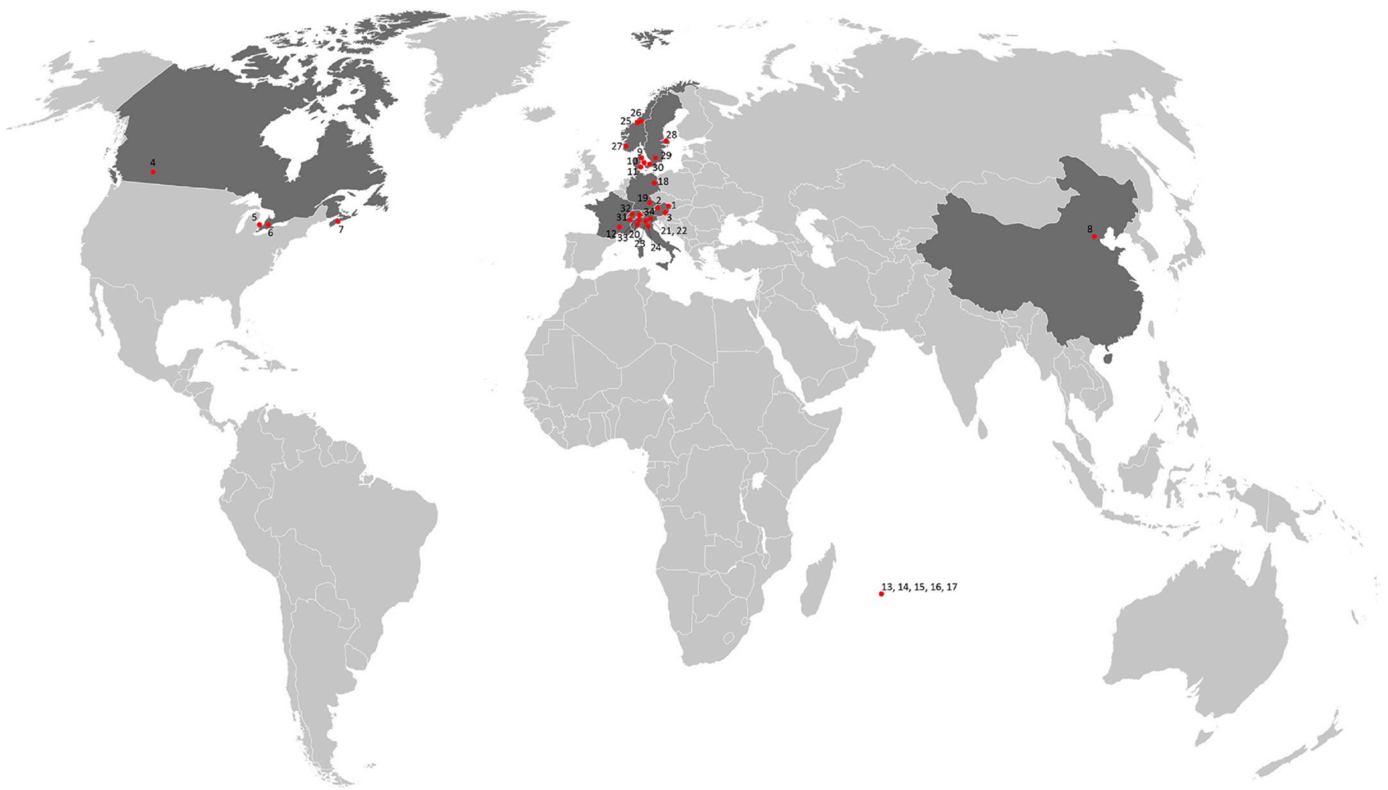
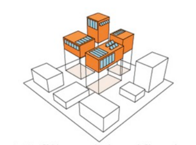


Fig. 1. World map with the location of the case studies in red points and the participating countries in dark grey [57].

districts. They were organized as follows:

- 17 case studies in *existing urban areas*, which illustrate how urban planning decisions require an evaluation of the impact on the urban area, rather than focusing only on the planned single building. Two main groups define this environment:


a) Infills and densification

Infills and densification of urban areas, characterized by new buildings connected to surrounding fabrics.


b) Existing urban fabric

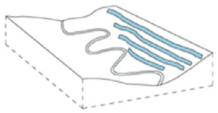
Existing urban fabric: alterations, refurbishment interventions, or new buildings constructed within existing urban environments.

- 12 case studies in *new urban areas*, where urban planners were involved from the beginning of the planning process, which usually requires in-depth urban design.


New urban areas

New urban areas: new buildings demanded for new infrastructures and detailed development plans.

- 5 case studies in *solar landscapes* aimed to explore the potential impacts, both positive and negative, of solar energy in landscapes.


Solar landscapes

Solar landscapes include solar arrays – large systems, which are important elements in the context of urban development, since the majority of built areas rely on energy supply provided from outside their immediate spatial boundaries.

3.2. Categories of analysis of the case studies

The second step of the methodology implied the definition of the categories, according to which the case studies were analyzed (Fig. 2). The third step was related to the definition of criteria for the case studies' analysis. The cases in existing and new urban areas were examined under the categories of: (i) planning process, (ii) energy concept and simulation tools - approaches and methods, (iii) architectural visibility, sensitivity and quality, and (iv) environmental and social impact. The solar landscapes cases were analyzed in terms of: (i) planning process, (ii) solar landscapes (iii) site potential, and (iv) environmental, visual, economic and social impact.

3.2.1. Planning process

The planning process describes how each case study is related to different spatial scales and stages of urban and landscape planning. It also provides a brief description of the stakeholders involved, and the influential decisions taken throughout the process. As the context and process of each case are very specific, the content of this section varies greatly between cases and environments.

3.2.2. Energy strategies, and approaches, methods and tools

The category presents the solar strategies (active, passive or both) and the energy concept and technology adopted in each case study as well as information related to the use of approaches, methods and tools. Approaches are means of incorporating solar methods into regular planning processes (e.g. policies, community engagement). Methods are

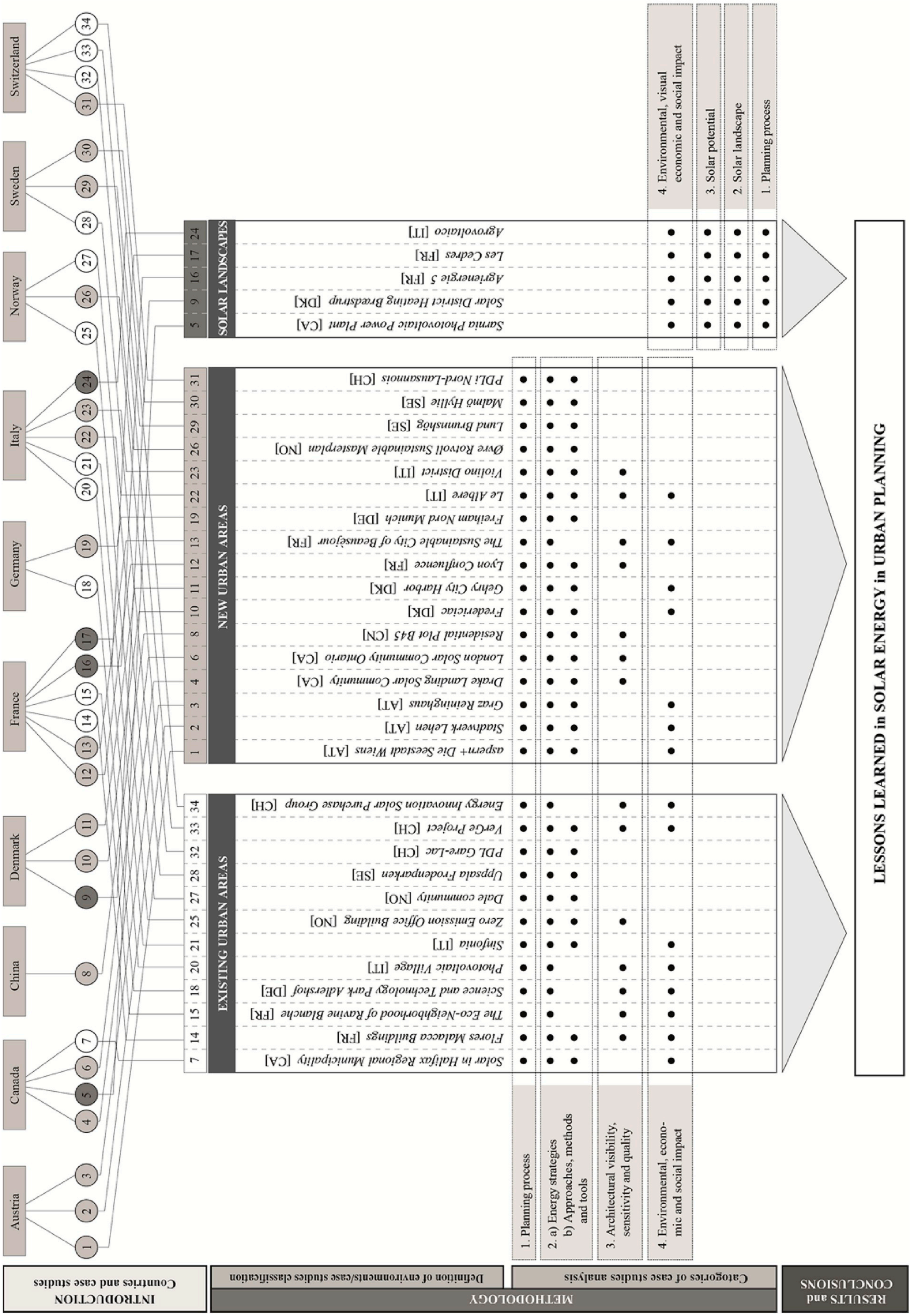


Fig. 2. Scheme of the workflow of the study.

planned procedures to assess and evaluate solar aspects in relation to other aspects in urban planning. Tools include simulation software to produce geometrical or numerical results (e.g. solar maps, solar potential software, GIS software) [8].

3.2.3. Architectural visibility, sensitivity and quality

The evaluation of architectural visibility, sensitivity and quality is based on the approach developed in the IEA SHC Task 41 “Solar Energy and Architecture” by EPFL-LESO [58] and now integrated in the LESO-QSV tool at urban scale [33,48]. It is composed by two parts:

a) *Architectural integration quality*: assessment of the quality of integration of solar systems. According to this evaluation, in order to perceive the system as integrated, it has to be designed as an integral part of the building architecture, i.e. all the formal characteristics of the solar system (e.g. field size/position, visible materials, surface textures, colors, module shape/size, and joints) should be coherent with the global design logic.

The qualitative assessment is articulated into three simplified steps, grouping the mentioned integration criteria. The coherency of *system geometry*, *system materiality*, and *system modular pattern* is evaluated using a three level scale (fully - partly - not coherent). The global system quality is then expressed by a circle made of three separated colored sectors (green, yellow or red) according to the level of coherency of each step (Fig. 3).

b) *Urban context criticity*. The quality requirements for architectural integration should be adapted to the local situation, specifically to the *sensitivity* of the urban area and the *visibility* of the building surface; the concept of architectural “criticity” embodies these notions (Fig. 4).

Context *sensitivity* is the socio-cultural value of the urban zone where the analyzed buildings are or will be located. As an example, an historical center is generally considered high sensitive, a low quality industrial district as low sensitive, and a post-war residential development in most cases as medium sensitive. A new urban development should be evaluated according to the urban aptitude that it will assume after the realization (e.g. new high-standards residential neighborhood on previously industrial exploited land). Some indicators of sensitivity can be found in traditional urban planning tools, such as land use plans.

The system *visibility* assesses the perception of solar systems from the public spaces. It can be defined as close visibility from an urban perspective, or remote visibility from a far observation point (Fig. 5).

3.2.4. Solar landscapes and site potential

The *solar landscapes* section includes the analysis of the formal functional features of the solar system used (as the type of pattern or the presence of edges), and the specifications about energy production in the overall area [54]. The ST/PV landscape mosaic pattern (patch, corridor, matrix model) proposes an understanding of a ST/PV landscape based on landscape ecology approach and methods. Three scales of reading (linked to different planning and design scales) have been defined, together with related design parameters and choices. In the applied approach, the landscape is seen as a pattern, and the ST/PV landscape as a pattern within a pattern. It is a spatial system made out of a space (the “pore” space), and its partition (the ST/PV modules), to which energy features, and landscape ecological performances are associated. The scheme (Fig. 6) addresses design parameters and needs

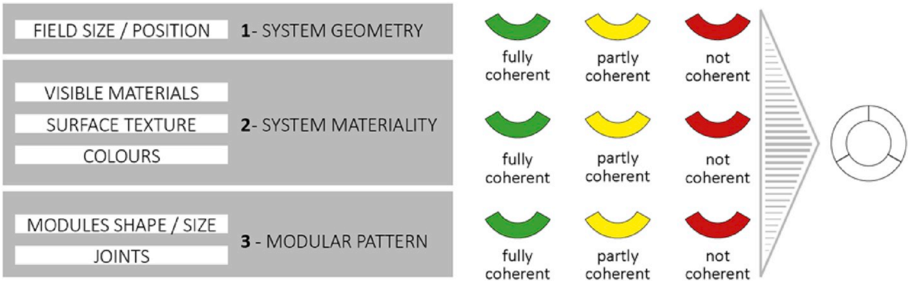


Fig. 3. Definition of level of *criticity* of the installed active system [48].

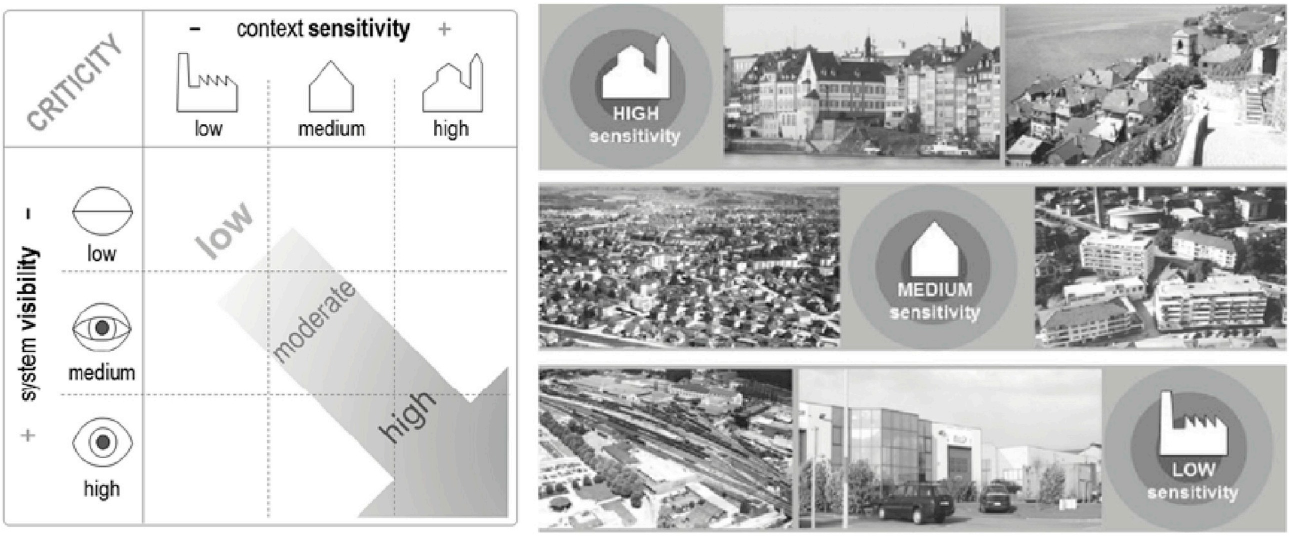


Fig. 4. *Criticity* of city surfaces in relation to architectural integration quality (on the left); Different levels of urban context *sensitivity* (on the right) [33,48].

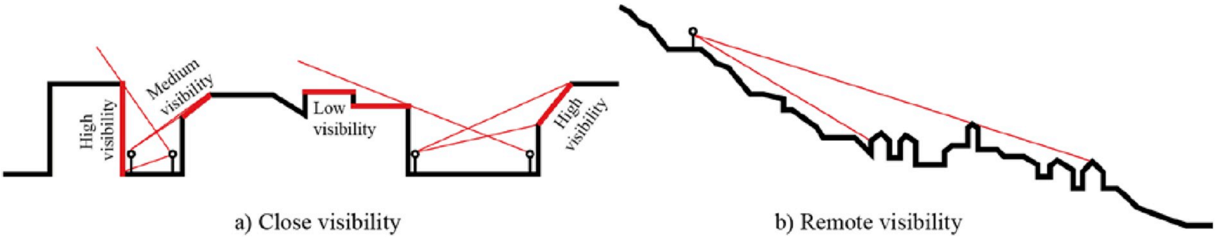


Fig. 5. Different levels of *visibility* of city surfaces from public domain [48].

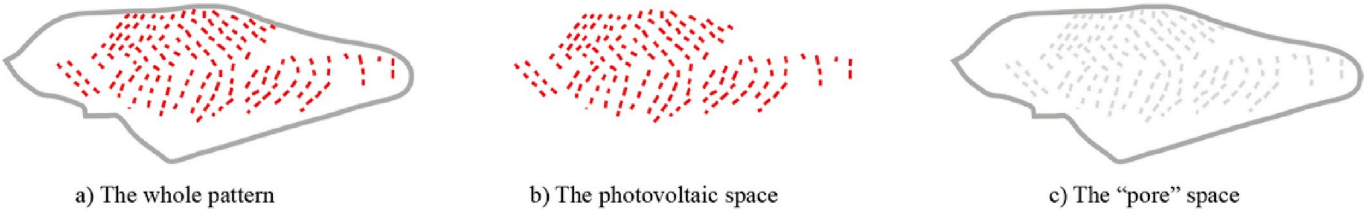


Fig. 6. The different spatial systems of solar landscapes [54].

for ST/PV landscapes to be controlled at the scale of planning, landscape, and architecture design.

Regarding the site potential aspect (*sensitivity*), landscape factors are analyzed. The features of a certain landscape that strongly influence the site selection in order to optimize the solar potential and the ST/PV installation are described. Furthermore, landscape factors that influence the suitability of a site for the installation of ST/PV are identified and qualitatively assessed [54].

3.2.5. Environmental, economic and social impacts

The environmental, social and economic impacts focus on the integration between the energy/solar systems and the surrounding environment to evaluate the case studies' impact. The economic impacts are assessed through the creation of new business opportunities, and the construction of new housing units. The analysis of social impacts considers the interaction with the community and users as part of the planning process.

4. Results and discussion

4.1. Existing urban areas: planning process

The analysis of the existing urban areas (Table 2) highlights that the duration of the planning process varies on average from five to twelve years, with two exceptions: the *Science and Technology Park Adlershof* (DE), characterized by longest process (more than 35 years), and the *Energy Innovation Solar Purchase Group* (CH), which has the shortest duration (2 years). Regarding *Science and Technology Park Adlershof* (DE), the major challenge was to combine the densification and the development of the large area with mixed functionalities and maintaining the historical value of the existing buildings. Therefore, the project foreseen a long-term development with different phases [59]. In contrast, the *Energy Innovation Solar Purchase Group,* did not require the development of multiple planning activities. It implied the set-up of a solar purchase group first for ST and then for PV systems, each phase lasting one year.

The case studies of solar integration in existing buildings, such as *Solar in the Halifax Municipal Region* (CA) and the *Photovoltaic Village* (IT), demonstrate the limitations in using PV systems in existing urban areas.

In particular, in the *Photovoltaic Village* (IT), interventions did not include any deep renovation; therefore, the design options were limited by the integration of the systems in the existing building envelope [63]. The area offered several opportunities in terms of PV installations in outdoor public spaces; however, only a limited use of them was made (Fig. 7a). To overcome implementation barriers in the case of *Solar in the Halifax Municipal Region* (CA), a solar cadaster, together with innovative financing options, were developed to provide support and guidance to property owners interested in installing solar systems (Fig. 7 b) [71]. Furthermore, most of the cases demonstrate that several specific competences and interests of different stakeholders involved in a project can strongly influence the duration, and success or failure of the planning process. The *Photovoltaic Village* (IT) represents a successful example: a Building Council was created to better coordinate the cooperation among the public and private stakeholders during the whole process. This approach is now replicated in other Italian cities [64].

Another positive example is the case study of *Eco Neighborhood of Ravine Blanche* in *Saint-Pierre* (*Réunion Island*), where a multi-stakeholders governance approach was tested. A Steering Committee with representatives from all stakeholders and decision makers worked on common objectives, such as the reconnection of the district to the city center and the incorporation of bioclimatic principles into the design. A participatory approach was carried out to involve citizens in the project's process through public consultation and information campaigns. Similarly, the cooperation between local authorities and citizens was one of the main reasons of the success in the Swiss case of *Energy Innovation Solar Purchase Group* (CH). The initiative allowed involving citizens to acquire a solar system with the buying power of a group of purchasers, and with the accompaniment of the public authorities, technical partners and specialist in the subject [61]. In contrast, the case *Dale community* (NO) highlights the complexities in planning an energy ambitious development in an area with cultural significance, and the challenges of integrating a wide variety of stakeholder influences coming from both local, regional and EU perspectives.

Finally, the case of *VerGe project Lugano Paradiso* (CH) illustrates the benefits of the collaboration between local contributors, researchers, professionals, and decision makers. Researchers analyzed the different urban densification scenarios in order to investigate the impacts of the new urban pattern and building shapes in terms of energy behavior and solar accessibility of existing buildings [72]. The cooperation with urban planners and municipalities was facilitated by showing the effect of these scenarios in visual three-dimensional representations (Fig. 8); it also increased the public acceptance to the implementation of urban changes.

Table 2
Planning process and stakeholders of case studies in existing urban districts. Stakeholders: Citizens [C]; Education actors [EA]; Professional and stakeholders [PS]; Politicians and decision makers [PD].

Case study [Country]	Planning Process		Stakeholders				Ref
	Duration	Highlights	C	EA	PS	PD	
Solar in Halifax Regional Municipality [CA]	2009–2016	- Masterplan: urban solar planning, and deployment of solar energy systems on municipal properties and on residential houses. - Roadmap for solar energy generation based on solar suitability assessment.	✓	✓	✓	✓	[60]
Flores Malacca Buildings [FR]	2005–2011	- Preoperational participatory approach with private and public stakeholders. - Integration of an environmental approach to urban planning at all the stages of the project.	✓		✓	✓	[61]
The Eco-Neighborhood of Ravine Blanche [FR]	2007–2019	- Implementation of multi-stakeholders governance. - Reconnection of the neighborhood to the city center and the sea.	✓		✓	✓	
Science and Technology Park Adlershof [DE]	1992–2030	- Defined as an urban development area since 1994. - Original master plan adapted to the functional diverse needs and mixed functions.			✓	✓	[59,62]
Photovoltaic Village [IT]	1996–2005	- Integrated innovative process between public and private stakeholders to define an urban plan by setting energy goals. - Requalification of a residential urban area with adequate solar exposition integrating PV on buildings and urban furniture.			✓	✓	[63,64]
Sinfonia [IT]	2014–2019	- Phase 1: design phase guided by an interdisciplinary team. - Phase 2: construction phase with lived-in apartments. - Phase 3: monitoring phase lasting for one year.	✓	✓	✓	✓	[65]
Zero Emission Office Building [NO]	2010–2013	- Buildings, partially planned in parallel but constructed afterward, impacted the solar potential of the case study. - Evaluation of the impact of surrounding buildings on solar energy performance of the case study.			✓	✓	[9]
Dale community [NO]	2009–2014	- Funding from EU project, which prioritized a planning solution based on solar energy. - Development focused on maintaining cultural heritage. - Project halted due to elevate costs.		✓	✓	✓	[66,67]
Uppsala Frodeparken [SE]	2004–2016	- The case study integrates the largest solar facade on a residential building in Scandinavia. - Competition on a plot south of Frodeparken aroused questions about solar rights and how the design of a new building should consider nearby active solar energy installations.		✓	✓	✓	[61]
PDL Gare-Lac [CH]	2006–2014	- Master plan defining the main strategies for the renewal of a central sector of the city. - Focus on potential energy improvements that can be obtained by varying the sizes of the building typology set by the master plan.		✓	✓		[68,69]
VerGe Project [CH]	2011–2015	- Urban densification process focused on changing the open urban sprawl towards infill with closed and compact urban fabrics. - Masterplan does not take into consideration solar active or passive strategies.		✓	✓	✓	[70]
Energy Innovation Solar Purchase Group [CH]	2012–2014	- Creation of a solar purchase group for ST and PV systems to promote their installations locally. - Federal Council's strategy focused on the exploitation of the existing energy efficiency potentials and on the balanced use of hydropower and other RES.	✓	✓	✓	✓	[61]

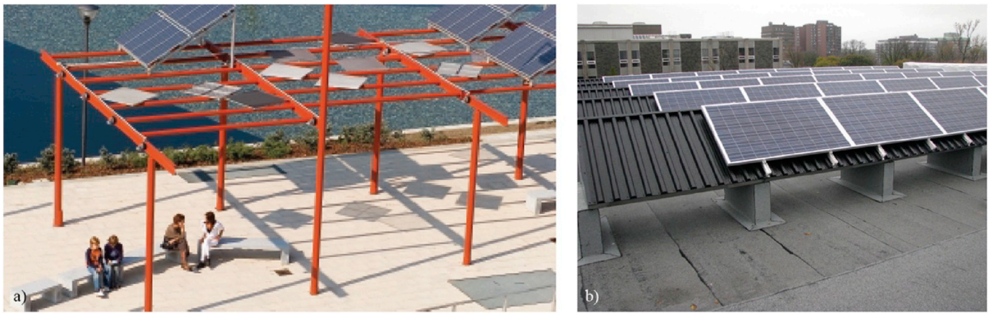


Fig. 7. a) *Photovoltaic Village* (IT) - PV systems on urban furniture (Source: © Municipality of Alessandria); b) *Halifax Regional Municipality* (CA) - Solar PV on the roof of the room of the *Goldberg Computer Science Building* (Source: © Dalhousie University).

4.2. Existing urban areas: energy strategies, and approaches, methods and tools

The energy strategies and simulation tools applied in each case study are presented in Table 3.

PV systems were applied in all the case studies of existing urban areas, while ST were integrated in five of them. In *Science and Technology Park Adlershof* (DE), buildings are also connected to the district heating (DH): the grid is planned to support more ST systems where solar thermal energy can be fed into it, while in *Sinfonia* (IT), ST systems are used for DHW production, and geothermal heat-pumps plant supply heating for buildings.

In terms of passive design strategies, solar shading and natural ventilation were applied in *Flores Malacca Buildings* (FR) and *The Eco-Neighborhood of Ravine Blanche* (FR), both located in a tropical climate, to ensure comfort without the use of air conditioning. In *Flores Malacca* (FR), the study of the solar shading devices (Fig. 9) allowed using facades with a high porosity (25%) that favors the cross-natural ventilation while avoiding overheating or glare issues. Furthermore, dynamic thermal simulations were performed to ensure comfortable human thermal conditions in every housing unit and in the outdoor area [72,75].

In *Sinfonia* (IT), daylight and micro-climate analyses [76] were used in the early design phases to test different configurations. Daylight

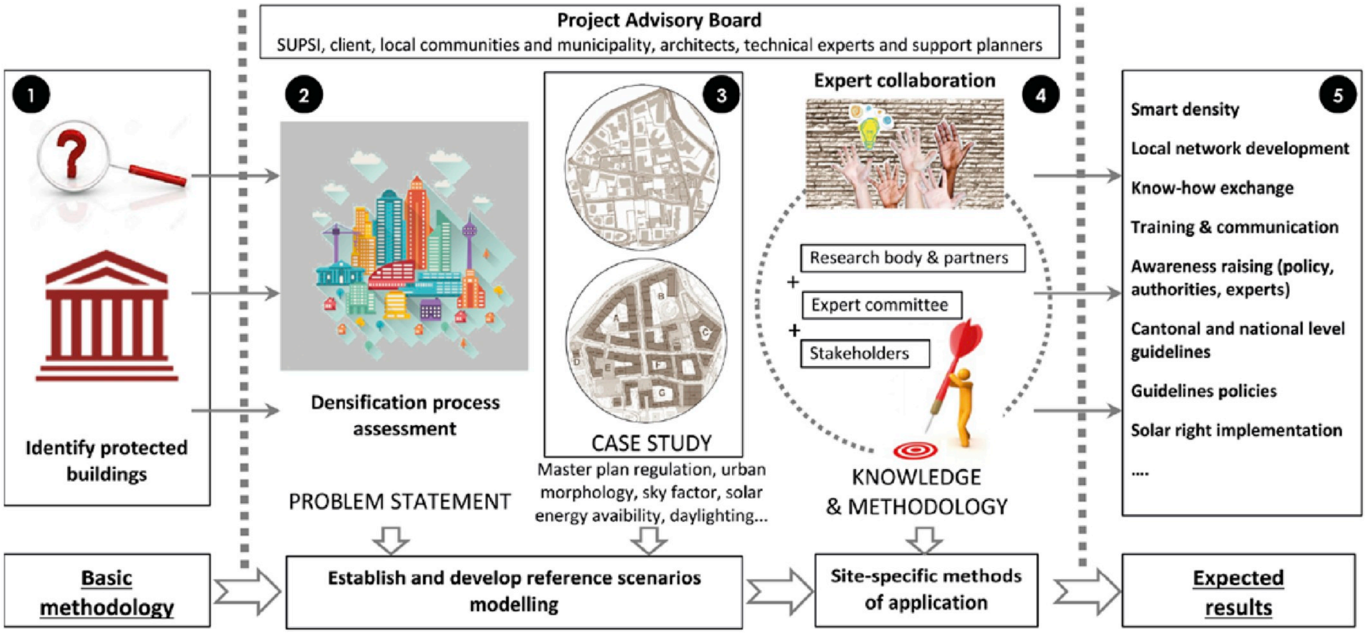


Fig. 8. *VerGe Lugano Paradiso* (CH) - Structure of the research project (Source: © SUPSI).

Table 3
Energy strategies and simulation tools of case studies in existing urban districts. Energy strategies - Active: Photovoltaic [PV]; Solar-thermal [ST]; District heating [DH]; Thermal storage [TS]; Waste heat recovery [WR]; geothermal [G]. Passive: Solar gains [SG]; Solar shading [SS]; Daylight [DL]; Natural Ventilation [NV].

Case study [Country]	Energy Strategies										Simulation Tools		Ref
	Active						Passive				Tools	Type of analysis	
	PV	ST	DH	TS	WR	G	SG	SS	DL	NV			
Solar in Halifax Regional Municipality [CA]	✓	✓									Green Power Labs' Solar- Rating Online	- Solar irradiation - Overshadowing - High-resolution solar resource mapping	[60]
Flores Malacca Buildings [FR]	✓	✓						✓		✓	SketchUp	- Solar shading optimization - Thermal analyses	[61]
The Eco-Neighborhood of Ravine Blanche [FR]	✓	✓						✓		✓	–		
Science and Technology Park Adlershof [DE]	✓	✓	✓								–		
Photovoltaic Village [IT]	✓										–		[64,73]
Sinfonia [IT]	✓	✓	✓			✓			✓		Radiance, Diva-for-Rhino	- Solar irradiation - Daylight analysis	[61]
Zero Emission Office Building [NO]	✓										Diva-for-Rhino, Polysun, PVsyst	- Solar potential - Overshadowing - Energy analysis	[9]
Dale community [NO]	✓										DIVE Analysis, T-sol, PVsyst	- Energy analysis - Solar irradiation - Thermal simulation	[67]
Uppsala Frodeparken [SE]	✓										Ladybug for grasshopper	- Solar irradiation - Overshadowing	[61]
PDL Gare-Lac [CH]	✓	✓							✓		Radiance/Daysim, EnergyPlus, Diva-for-Grasshopper	- Energy analysis - Solar potential - Daylight autonomy	[68,74]
VerGe Project [CH]	✓	✓							✓		Ecotect, Daysim/Radiance, BESTenergy, ImageJ	- Solar irradiation - Daylight availability - Humen comfort evaluation - Sky-factor assessment	[72,75]
Energy Innovation Solar Purchase Group [CH]	✓	✓									–		[61]

studies provided indications on minimum visible light transmission of windows and solar reflectance of finishing materials to guarantee minimum indoor daylight levels (i.e. mean daylight factor MDF ≥2%) (Fig. 10 a). In the *VerGe project Lugano Paradiso* (CH) case study, the method used a combination of numerical tools and 3D simulations, together with photo processing images and sun-path diagrams. Solar irradiation, overshadowing effect, and daylight levels were evaluated in different scenarios by using *3D Ecotect*, *Radiance/Daysim* and *BESTenergy* software. Furthermore, obstructions to sunlight and sky view factors (SVF) were assessed by processing fish-eye images with a

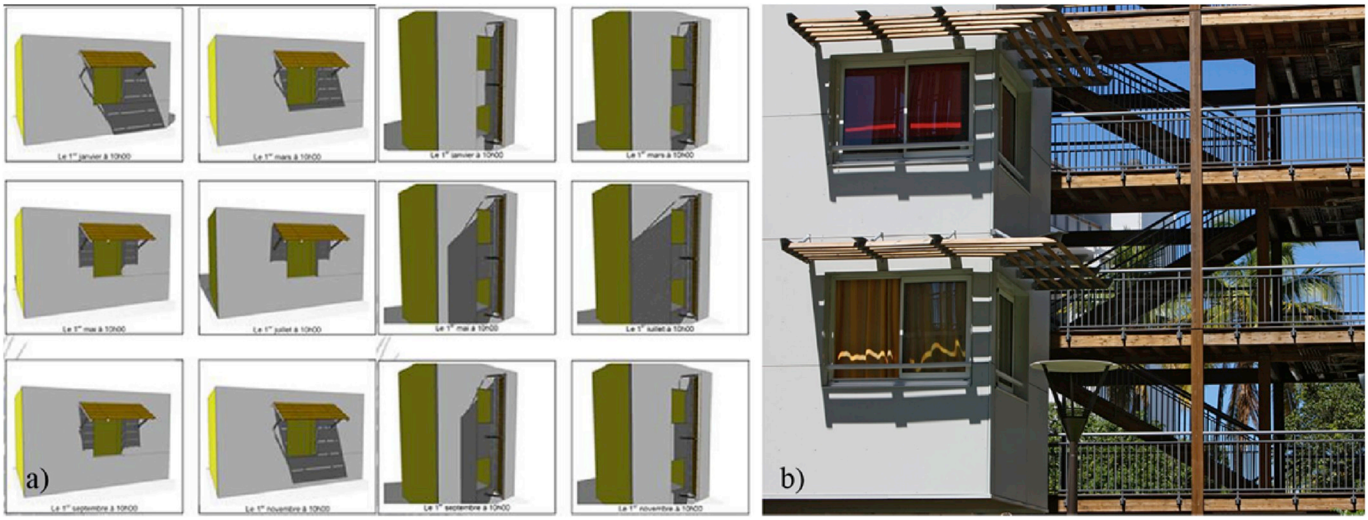


Fig. 9. *Flores Malacca* (FR) – (a) Study of the solar shading devices on the facades of the buildings (Source: © LEU Reunion); (b) Presence of wooden elements in the project: passageways and solar shading blades (Source: © H. Douris).

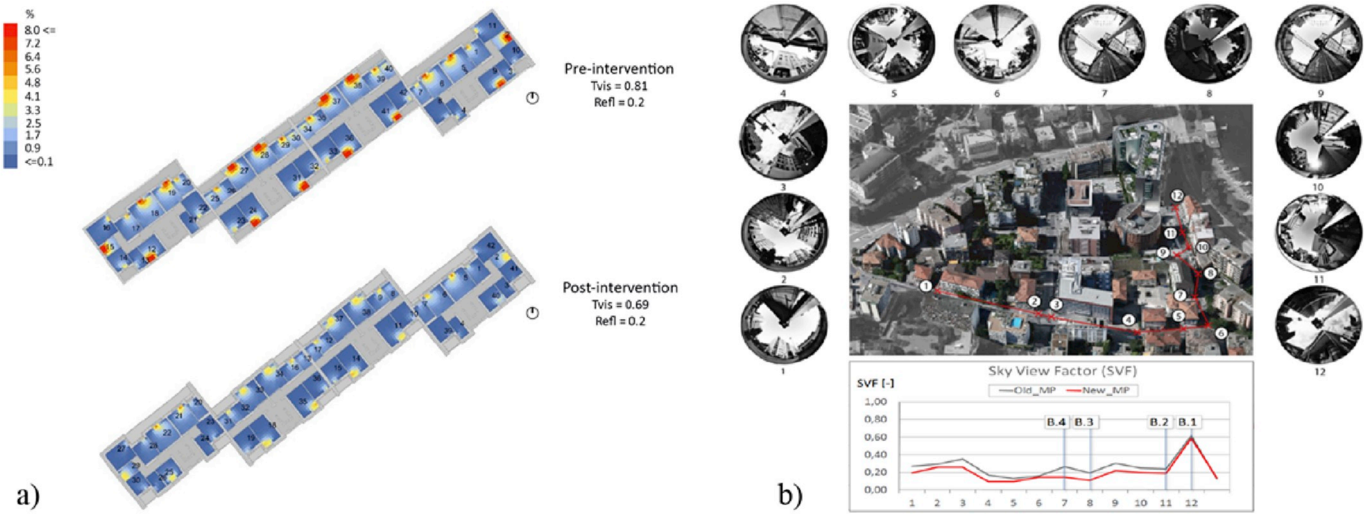


Fig. 10. a) *Sinfonia (IT)* - Daylight analysis for the first floor of *Sinfonia* case study. Tvis: visible light transmission of the windows - Refl: reflectance value of the finishing materials of the loggia's floor and windowsills (Source: © Eurac Research); b) V*erGe project Lugano Paradiso* (CH) - Pictures taken on a site inspection for data collection (Source: © SUPSI).

specific software (*ImageJ*) (Fig. 10 b) [8].

In *PDL Gare-Lac* and *VerGe Project* (CH), the comparison between the current situation with proposed planning alternatives, allowed to study the effects of planning strategies on internal and external daylight [68,74]. The implementation of urban planning strategies for energy use was also evaluated in relation to solar accessibility and solar potential through studying the impacts of different densification scenarios as well as their effects on the energy behavior of existing cultural protected buildings located in the area (Fig. 11). A detailed calculation of energy flows, energy requirements for thermal conditioning, and energy demand was made by using dynamic energy simulation tools [72,75].

Other examples related to solar accessibility issues are *Uppsala Frodeparken* (SE) and *Zero Emission Office Building* (NO), where solar potential analyses were conducted in unobstructed and urban scenarios to assess the impact of the complex overshadowing effect created by the new urban surroundings on the BIPV systems installed on the facade of the existing fabrics (Fig. 12).

In the Swedish case, the comparison of unobstructed and urban scenario was conducted with solar radiation mapping analysis in *Ladybug*, a Grasshopper plug-in. In the Norwegian case, a combination of different tools has been used. Solar analyses were run using *DIVA-for-Rhino*; the estimation of energy production from PV and ST systems was done in *PVsyst* and *Polysun* respectively [9].

In the case study of *Solar in Halifax Regional Municipality* (CA), tools were used to determine the suitability of urban surfaces for solar energy generation and for developing recommendations to use solar technologies in the energy mix (Fig. 13). Fisheye imagery processing technology was used for assessing obstructions to sunlight on building surfaces and open spaces. For the areas not covered by LiDAR survey, a combination of tools (e.g. high-resolution aerial oblique imagery, and *Green Power Labs*' Solar- Rating Online tool) was used. The results were collected in the *Solar City Program*, a toolset being used to assess solar suitability of candidate buildings and to select the applications with best economic outcome [60].

4.3. Existing urban areas: architectural visibility, sensitivity and quality

The architectural visibility, sensitivity and quality of the case studies in existing urban areas is summarized in Table 4; this section,

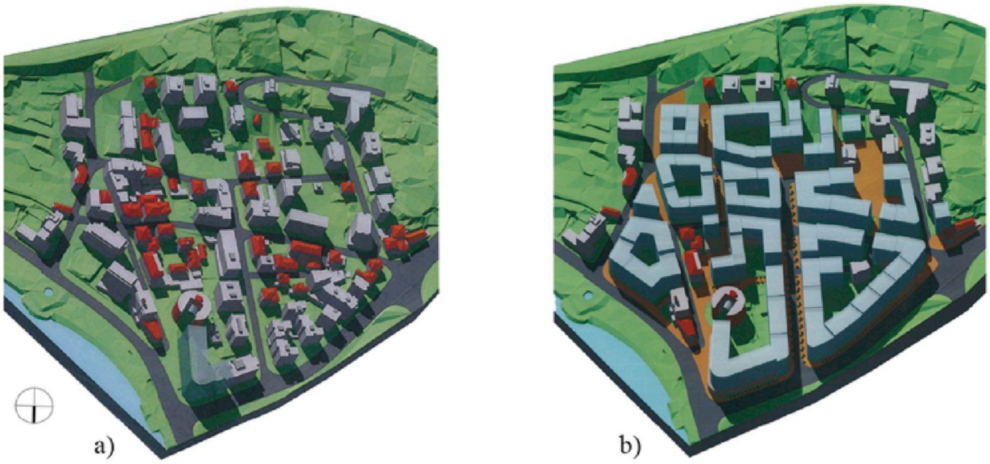


Fig. 11. *VerGe Lugano Paradiso* (CH) - Three-dimensional visual representation to compare the impact of different densification scenarios: a) Current status; b) Final status after the new masterplan will be implemented (Source: © Planidea SA).

Fig. 12. *Zero Emission Office Building* (NO) – a) Current situation of the building; b) Solar mapping analysis of the South facade in the unobstructed scenario; c) Shadow analysis with visualization of the current PV area (in dashed white line) [9] (Source: © Gabriele Lobaccaro). *Uppsala Frodeparken (SE) - d)* Current situation of the building; e) Shading study of *Frodeparken* with a generic volume on the site of *Juvelen; f)* Comparison of solar radiation map, conducting with *Ladybug*, between the unobstructed scenario (on top) and the urban context scenario (on the bottom) (Source: © White Arkitekter).

focuses on the deep discussion of three representative projects, characterized by different levels of coherency in the integration of solar systems. The *Science and Technology Park Adlershof* [DE], assessed as the best example among the cases, the *Photovoltaic Village* [IT], representing a case study with medium coherency, and *Ravine Blanche* [FR]), one of the worse cases (Table 4).

In terms of architectural integration quality, the solar system applied on a research center's building in *Science and Technology Park Adlershof* (DE) is fully coherent: the slight curve facade of one of the buildings is entirely covered by PV panels (Figure c in Table 4). The dark thin film modules contrast with the white bricks of the building, both for their color and for their patterns. The modules are one directly above the other, while the bricks are arranged as a header bond where the offset of each successive course is half a header. Furthermore, a building added PV system is located on the roof.

The buildings in the *Photovoltaic Village* (IT) present a partly coherent integration of solar systems on their envelope (figure d in Table 4). The systems applied on the roof are not integrated but overlaid; those applied on the facades cover some rectangular portions without a clear architectural logic composition and integration with the rest of the building envelope. Furthermore, the blue color of solar cells contrast with the color of the underlying facade results in a clear contrast.

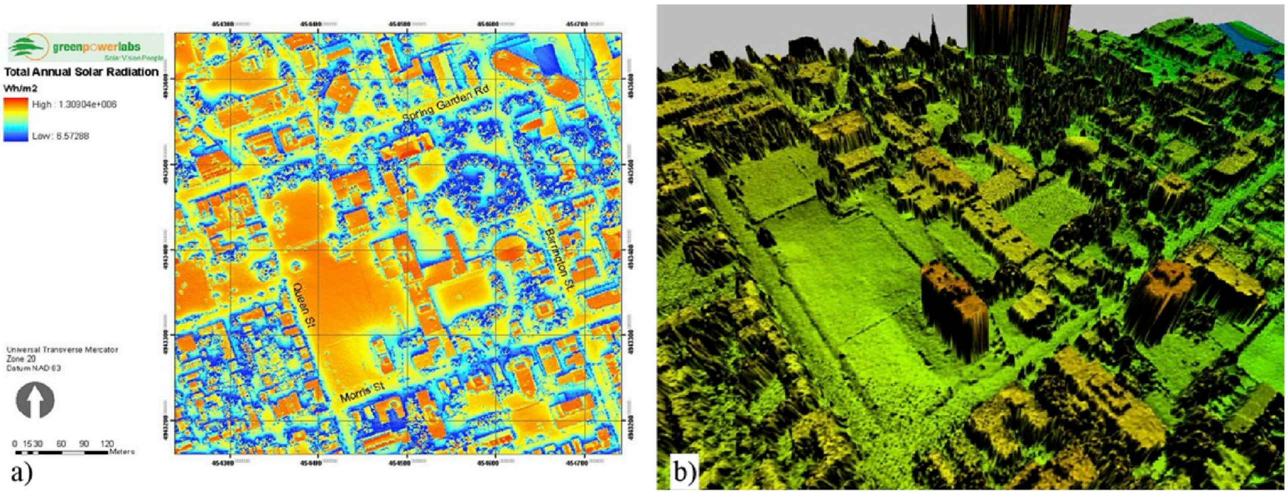
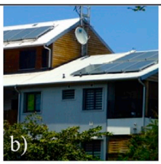
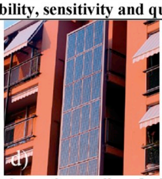
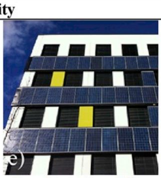
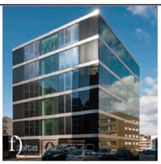


Fig. 13. *Solar in Halifax Regional Municipality* (CA) – a) High Resolution Urban Solar Resource Mapping; b) LiDAR-based Urban Digital Elevation Model (Source of both pictures: © Green Power Labs Inc.).

Table 4
Architectural integration quality, context sensitivity and system visibility of case studies in existing urban areas.

Architectural visibility, sensitivity and quality																					
	 a)			 b)			 c)			 d)			 e)			 f)			 g)		
	Flores Malacca [FR]			*Ravine Blanche* [FR]			*Science and Technology Park Adlershof* [DE]			*Photovoltaic Village* [IT]			*Zero Emission Office Building* [NO]			*VerGe Lugano Paradiso* [CH]			*Energy Innovation Solar Purchase Group* [CH]		
System geometry	fully coherent	[✓ partly coherent]	not coherent	fully coherent	partly coherent	[✓ not coherent]	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent	fully coherent	[✓ partly coherent]	not coherent	[✓ fully coherent]	partly coherent	not coherent	fully coherent	partly coherent	[✓ not coherent]
System materiality	fully coherent	partly coherent	[✓ not coherent]	fully coherent	partly coherent	[✓ not coherent]	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent	fully coherent	[✓ partly coherent]	not coherent	fully coherent	[✓ partly coherent]	not coherent	fully coherent	partly coherent	[✓ not coherent]
Modular pattern	fully coherent	partly coherent	[✓ not coherent]	fully coherent	partly coherent	[✓ not coherent]	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent	fully coherent	[✓ partly coherent]	not coherent	[✓ fully coherent]	partly coherent	not coherent	fully coherent	partly coherent	[✓ not coherent]
		🟨🟥🟥			🟥🟥🟥			🟩🟩🟩			🟨🟨🟨			🟨🟨🟨			🟩🟨🟩			🟥🟥🟥	
Context Sensitivity	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high
Urban area socio-cultural value		✓			✓			✓			✓			✓		✓				✓	
System Visibility	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high
Close visibility			✓		✓		✓			✓			✓			✓				✓	
Remote visibility		✓			✓				✓		✓			✓				✓		✓	

Finally, in *Ravine Blanche* (FR), the field size and position of the solar systems is not coherent (figure b in Table 4). The solar panels have different orientations with gaps between the modules, and the overall system results asymmetric. Both ST and PV systems are installed on the same over-roof pans. However, due to their different sizes and materials, they result as not coherently integrated.

The context sensitivity is medium for all the three cases. *Science and Technology Park Adlershof* (DE) is a mixed urban area with a heterogeneous appearance. In the *Photovoltaic Village* (IT), the district is integrated withing the industrial surroundings that does not present historical or meaningful elements. *Ravine Blanche* (FR) is located in an old neighborhood composed by mass housing blocks, without significant architectural quality.

Regarding the system's visibility, the PV facade in *Science and Technology Park Adlershof* is highly visible, while the solar system on the roof is not visible; since the area is mainly flat, remote visibility is not an issue. In the *Photovoltaic Village*, the close visibility for an observer at ground level is medium for the solar collectors installed on the roofs, while it is high for the portions of PV facade. In contrast, in *Ravine Blanche* the installed solar systems are seldom visible since they are installed on high over-roofs.

4.4. Existing urban areas: environmental, economic and social impact

The main environmental impacts in the existing urban areas are related to the reduction of energy consumption and GHG emissions. In

Fig. 14. a) *Eco Neighborhood of Ravine Blanche* (FR) - The inhabitants have played a pivotal role in the project with the implementation of a consultative approach, different workshops and surveys (Source: © City of Saint-Pierre). b) *Energy Innovation Solar Purchase Group* (CH) – First informative meeting of the photovoltaic purchase group (Source: © SUPSI).

the *Solar in Halifax Regional Municipality* (CA), the community installed 380 ST systems in two years, with and estimated CO_2 reduction of more than 16 million kg over the expected lifespan of the systems. In *Flores Malacca* (FR), wood was widely used and integrated in the project to reduce the GHG emissions related to construction materials. Another significant environmental impact is the enhancement of outdoor areas through the application of bioclimatic strategies, and the increase of vegetation. In a tropical climate, *Flores Malacca* (FR) and *The Eco-neighborhood of Ravine Blanche* (FR) implemented key strategies to preserve water through rainwater and grey waters management systems connected to the vegetated spaces (Fig. 14). *The Eco-neighborhood of Ravine Blanche* (FR) implemented soft mobility and reduction of the car parking area. Finally, some other cases adopted measures concerning air quality improvement and smart mobility, such as in *Sinfonia* (IT), and in *Science and Technology Park Adlershof* (DE).

The economic impact of the integration of solar strategies in existing urban districts lays in revitalization of the areas, with new housing and economic activities, and in strengthening business opportunities with new employment alternatives. This is best exemplified by the cases of *VerGe Project* (CH) and *Science and Technology Park Adlershof* (DE), where today circa 1000 companies are located, 16 scientific organizations and 370 single-family houses [59].

In term of social impacts, the case studies mainly highlighted: (i) the importance of the engagement of citizens and users, and (ii) the use of architectural and urban features for favoring social integration. One of the reasons for the success of *Solar in Halifax Regional Municipality* (CA) project was the active engagement of citizens across all districts of the city and diverse socio-economic background of the Community Energy Planning and their subsequent involvement in the *Solar City Program*. In *The Eco-neighborhood of Ravine Blanche* (FR), consultation with the residents played a key role, especially for the planning of the new urban park and the choice of its facilities (Fig. 14). In *Sinfonia* (IT), the tenants of the apartments being refurbished were involved through informative meetings and questionnaire-based surveys [77]. After the renovation, they will be further engaged in the analysis of their behaviors through information points installed in the apartments showing their electricity consumption. Finally, the *Energy Innovation Solar Purchase Group* (CH) demonstrates the importance of reaching and motivate property owners, which are key players in the local energy policies. Over 300 owners attended the informative meetings, and many of them were motivated to conduct their own installation (Fig. 14). The initiative resulted in the installation of 35 ST systems, and 50 PV systems.

4.5. New urban areas: planning process

The process for integrating solar strategies in the planning of new urban areas can have very different durations depending on the characteristics and scale of the project: it spans from five up to 35 years (Table 5).

The project with the shortest duration are the *Residential Plot B45* (CN) (five years) and *Violino District* (IT) (six years), which are characterized by a limited scale, both involving residential districts (Fig. 15). The Chinese case study, a nine building towers complex, is part of a national pilot project for the development of the eco-community *Changxiandian Eco-city*. Its planning process was short because it was regulated by the criteria for zoning set for the entire city. It took two years to obtain final zoning and land use approval, and three years to complete the construction. Also in *Violino District* (IT), the duration of the planning process was quite short due to the presence of a municipal plan for social housing and a successive design competition set by the council with clear goals.

In contrast, the case studies characterized by a longer duration of the planning process, from 25 up to 35 years, are characterized by having a greater scale and number of buildings involved, together with mixed used functions and involvement of several public and private stakeholders. As an example, in the case of *Freiham Nord Munich* (DE), after more than five years of workshops with local stakeholders for defining the boundary conditions of the new urban development, the council organized a planning competition for the entire area. The selected site plan fixed a set of criteria for each parcel of the lot, including buildings height, alignment, and occupancy ratio, while the architectural and energy design decisions were left to the single developers (Fig. 16 a). Similarly, the planning and implementation process of *aspern + Die Seestadt Wiens* (AT) was divided in three time phases (Fig. 16 b). In both cases, the council is owner of the land and the initiator of the projects. One of the main challenges in the *aspern +* development is the timely integration of energy and urban planning concepts and implementation in the context of existing regulatory and legal frameworks.

Regarding the implementation of solar strategies, the Danish case studies of *FredericiaC* and *Gehry City Harbor*, together with the Swedish ones, *Lund Brunnshög* and *Malmö Hyllie*, are examples that illustrates the importance of solar energy evaluation an initial phase of the planning process. This step allows the transfer of solar potential into the system's physical installation, requiring the involvement of design solar experts. The studies also show that routines built into the planning process ease the development of solar energy in an urban environment. However, due to the involvement of many different city administration's departments and professionals, the overall planning process may be slowed down. The aim of *FredericiaC* (DK) project was to plan an area providing a cost effective heating supply solution, and at the same time maximizing the daylight access, and ensuring solar incidence in urban spaces. Hence, studies on solar energy, solar accessibility, and daylight were carried out in parallel with the architectural development of the plan and in close dialogue with the architects [8].

In other case studies, the competences and the interests of stakeholders had a relevant impact on the development of the planning process. Open-mindedness is relevant for both researchers and those responsible for the urban planning process and its implementation. In that regard, *aspern + Die Seestadt* (AT) highlights the importance of the involvement of all the stakeholders from the beginning in order to embed innovative concepts and technologies from research into reality. Integration and competition among diverse stakeholders is a common theme also in *Stadtwerk Lehen* (AT), where all parties involved signed a

Table 5
Planning process and stakeholders of case studies in new urban districts. Stakeholders: Citizens [C]; Education actors [EA]; Professional and stakeholders [PS]; Politicians and Decision makers [PD].

Case study [Country]	Planning Process		Stakeholders				Ref
	Duration	Highlights	C	EA	PS	PD	
aspern + Die Seestadt Wiens [AT]	2003–2029	- High demand for quality housing - Creation of new workplaces and accommodations	✓	✓	✓	✓	[78]
Stadtwerk Lehen [AT]	2004–2013	- District renewal, and creation of sustainable and attracting environment - Numerous developers and teams of architects working together at the project, which consists of several phases and areas		✓	✓	✓	[79,80]
Graz Reininghaus [AT]	2008–2035	- Compact urban building structures, integrated sustainable energy systems, and green infrastructures - Multi-year process involving numerous groups of stakeholders		✓	✓	✓	[61]
Drake Landing Solar Community [CA]	2003–2012	- Technological feasibility study - Financial support by several organizations and initiatives - Involvement of several researchers and institutions		✓	✓	✓	
London Solar Community Ontario [CA]	2011–2020	- Private developer - Solar optimization and passive strategies implemented only partially, two years after the initial plan		✓	✓	✓	[81]
Residential Plot B45 [CN]	2011–2016	- National Pilot Project for ecological development by benchmarking eco-city criteria - Two years to obtain zoning and land use approval		✓	✓	✓	[82]
Fredericiac [DK]	2010–2040	- Aim to become CO_2-neutral urban area - Development plan to be followed when detailing the individual lots - Local legislation includes maximum building heights to optimize daylight conditions			✓	✓	[61]
Gehry City Harbor [DK]	2007–2029	- Development of CO_2-neutral urban area - Simulation studies carried out in parallel with architectural development			✓	✓	
Lyon Confluence [FR]	2005–2016	- Long-term project of district renewal at the city center of Lyon - Stage 1: focus on energy issues in early stage of design - Stage 2: other ecologic principles (i.e. waste, water, green, etc.)	✓		✓	✓	
The Sustainable City of Beausèjour [FR]	2008–2020	- Regional stakes of building urban housing density compatible with a rational land use - Integration of "Green Urbanism" principles in pre-operational studies - Iterative and transversal planning process			✓	✓	
Freiham Nord Munich [DE]	2005–2040	- The site plan fixes the building line, height and occupancy ratio of each parcel - Architectural and energy design decisions are left to the developers			✓	✓	[83]
Le Albere [IT]	1998–2013	- Reconnection of a former industrial site with the city - The process involved private stakeholders, the municipality, and the architect Renzo Piano			✓	✓	[84]
Violino District [IT]	2000–2006	- Competition initiated by the Municipality for realizing a social housing project characterized by holistic sustainable approach - Request for quantifiable requirements to "measure" the quality and sustainability of the project	✓		✓	✓	[85]
Øvre Rotvoll Sustainable Masterplan [NO]	N/A	- Students' research for creating a masterplan based on the analysis of infrastructural, energetic and social impacts, and urban structure - Definition of building typologies and orientation in relation to solar access		✓			[61]
		- Implementation of the renewable energy production with solar systems from the early phases of masterplan design - Nordic climate urban design guidelines with regard to solar exposure and solar potential			✓	✓	[29]
Lund Brunnshög [SE]	2011–2030	- New district embedding research plants into a mixed urban district with different functions - Whole planning process divided in several phases to keep the process manageable			✓	✓	[61]
Malmö Hyllie [SE]	2000-N/A	- Constant change of legislation during the course of the planning process - Effort on convincing real estate developers interested in solar energy on creating good conditions for solar energy production		✓	✓	✓	
PDLi Nord-Lausannois [CH]	2003–2030	- Collaborative study during the elaboration of the strategic plan - Willingness to incorporate solar-related targets in the plan for promoting good daylight autonomy and passive solar gains as well as installation of active energy solar systems	✓	✓	✓	✓	[86]

Fig. 15. a) *Residential Plot B45* (CN) – Top view of the ST collectors on the roofs of the high-rise buildings' blocks (Source: © www.zhulong.com). b) *Violino District* (IT) - Aerial view of the BIPV system on the roof of the 112 terraced houses (Source: © BAMSphoto - Basilio).

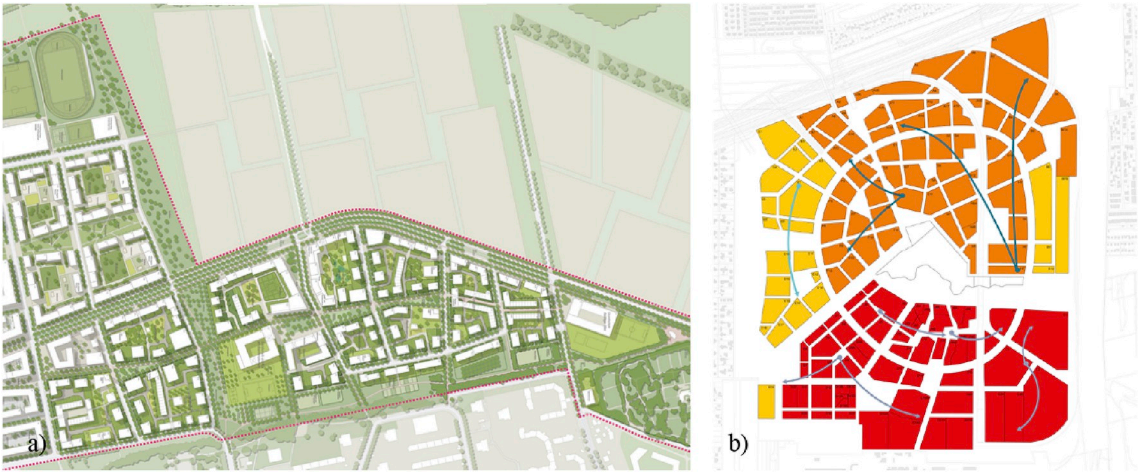


Fig. 16. a) *Freiham Nord Munich* (DE) - Masterplan of the entire intervention (Source: © West 8) b) *aspern + Die Seestadt* (AT) - Development stages (Source: www-aspern-seestadt.at).

quality assurance agreement, which sets goals concerning energy efficiency, renewable energy, ecology, mobility and social factors (Fig. 17 a). The agreement was designed to guarantee the successful implementation of the project, which is divided into several phases and area; and to coordinate the several developers and teams of architects [79]. Similarly, the case study of *Graz Reininghaus* (AT), illustrates the relevance of collaboration and interaction with a complex network of investors, planners, energy suppliers, interested representatives, and locally-based companies (Fig. 17 b). The interdisciplinary collaboration was framed within the research project *ECR Energy City Graz Reininghaus*, which was focused on establishing urban strategies for the new development, building construction, operation and restructuring of the district. The whole process benefitted directly from the scientific research activities carried out simultaneously; of which the results were communicated directly to the stakeholders.

The clear understanding of solar energy strategies amongst stakeholders at an early planning phase is also important for the development of the entire project, as illustrated in *FredericiaC* (DK) and *Gehry City Harbor* (DK). These strategies should be interdisciplinary and discussed together with other topics, such as area density, minimization of construction costs, etc.

4.6. New urban areas: energy strategies, and approaches, methods and tools

Almost all the case studies in new urban areas implemented the use of PV systems in their development. The only exceptions are *Residential Plot B45* (CN), and *Drake Landing Solar Community* (CA), which focused on solar heating strategies (Table 6).

In the first case, ST systems were installed on the roof of the building towers to provide DHW; the systems were integrated with geothermal heat pumps for heating purposes. In *Drake Landing Solar Community* (CA), the first large-scale seasonal energy storage solar heating project in North America has been implemented.

The system consists of almost 800 flat plate ST collectors installed on roofs, a borehole seasonal long-term thermal storage, and an energy center with short-term thermal storage tanks. The heated water is distributed to each dwelling using the DH network (Fig. 18 a). The integration of solar systems, thermal storage, and DH characterizes also the energy concept in *Stadtwerk Lehen* (AT), where the existing DH system, loaded mainly with industrial waste heat, is used as base system implemented with ST. To avoid the installation of cost-intensive long-term storages, a medium-sized buffer storage was combined with a heat pump to increase solar ratio; additionally, a PV system provides energy for the heat pump [80,87]. The presence of DH characterizes several case studies (Table 6), among those *Lund Brunnshög* (SE) and *Malmö Hyllie* (SE). In these two Swedish urban areas, only the generation of electricity by PV is considered as solar active strategy, because the presence of the DH network reduces the feasibility of ST. Geothermal energy strategies are integrated with PV and ST systems in *aspern + Die Seestadt* (AT), and in *Freiham Nord Munich* (DE). In the first case, maximum possible and feasible PV and ST installations are being encouraged and subsidized in the entire area. In *Freiham Nord Munich* (DE), the energy supply company decided to invest in a new DH system based on geothermal energy. For this reason, ST panels are contractually banned in the parcels connected to the DH network, whereas PV panels are encouraged without being mandatory.

Finally, three case studies present a single energy strategy based on the installation of PV systems: *London Solar Community Ontario* (CA),

Fig. 17. a) *Stadtwerk Lehen* (AT) - Cooperative neighborhood management as a hub for district marketing and public information (Source: ©Verein Stadtwerk). b) *Graz Reininghaus* (AT) - Workshop with stakeholders, planners and experts (Source: TU Graz. Institute of Urbanism).

Table 6
Energy strategies and simulation tools of case studies in new urban districts. Energy strategies - Active: Photovoltaic [PV]; Solar-thermal [ST]; District heating [DH]; Thermal storage [TS]; Waste heat recovery [WR]; geothermal [G]. Passive: Solar gains [SG]; Solar shading [SS]; Daylight [DL]; Natural Ventilation [NV].

Case study [Country]	Energy Strategies										Simulation Tools		Ref
	Active						Passive				Tools	Type of analysis	
	PV	ST	DH	TS	WR	G	SG	SS	DL	NV			
aspern + Die Seestadt Wiens [AT]	✓	✓				✓					N/A	- Solar potential - Overshadowing	[61]
Stadtwerk Lehen [AT]	✓	✓	✓	✓							N/A	- Energy analyses aimed at whole system optimization	[79,80,87]
Graz Reininghaus [AT]	✓		✓		✓						TRNSYS, Matlab, genetic algorithms	- Dynamic energy simulations - Structure optimization of energy supply systems	[88–90]
Drake Landing Solar Community [CA]		✓	✓	✓							TRNSYS, ESP-r	- Energy analyses - Building performance simulations	[91–93]
London Solar Community Ontario [CA]	✓										EnergyPlus, HOT2000, RETScreen International, HOT2XP, HOT2EC	- Solar potential - Overshadowing - Energy analyses	[81]
Residential Plot B45 [CN]		✓				✓					Phoenics2009, SCREEN3, PKPM - PBECA, SUNSHINE-V 3.0	- Microclimate - Air pollution - Daylight - Energy analyses	[61]
Fredericiac [DK]	✓		✓				✓		✓		DIVA-for-Rhino PV-SYST	- Solar potential - Overshadowing - Daylight	[94,95]
Gehry City Harbor [DK]	✓						✓		✓		N/A, PV-SYST	- Solar potential - Overshadowing - Daylight - Electricity production	[96]
Lyon Confluence [FR]	✓	✓					✓		✓	✓	SOLENE	- Solar potential - Summer overheating risk - Daylight - Microclimate	[97,98]
The Sustainable City of Beausèjour [FR]	✓	✓						✓		✓	–	–	[61]
Freiham Nord Munich [DE]	✓	✓	✓			✓					SimStadt	- Solar irradiation - Energy analyses	[99]
Le Albere [IT]	✓										Solergo	- Energy analyses - PV system design	[61]
Violino District [IT]	✓		✓				✓		✓		N/A	- Color strategy assessment - Solar irradiation - Daylight	[85]
Øvre Rotvoll Sustainable Masterplan [NO]	✓	✓					✓		✓		Diva-for-Rhino, DECA, EnOB-Lernnetz	- Solar irradiation - Energy analyses	
	✓	✓									Diva-for-Rhino, Grasshopper	- Solar potential - Overshadowing	[29]
Lund Brunnshög [SE]	✓		✓		✓						Radiance	- Energy analyses - Solar irradiation	[61]
Malmö Hyllie [SE]	✓		✓								Radiance	- Energy analyses - Solar irradiation	
PDLi Nord-Lausannois [CH]	✓	✓							✓		Archsim, Diva-for-Grasshopper, Matlab and Grasshopper scripts	- Thermal simulation - Solar irradiation - Daylight	[36]

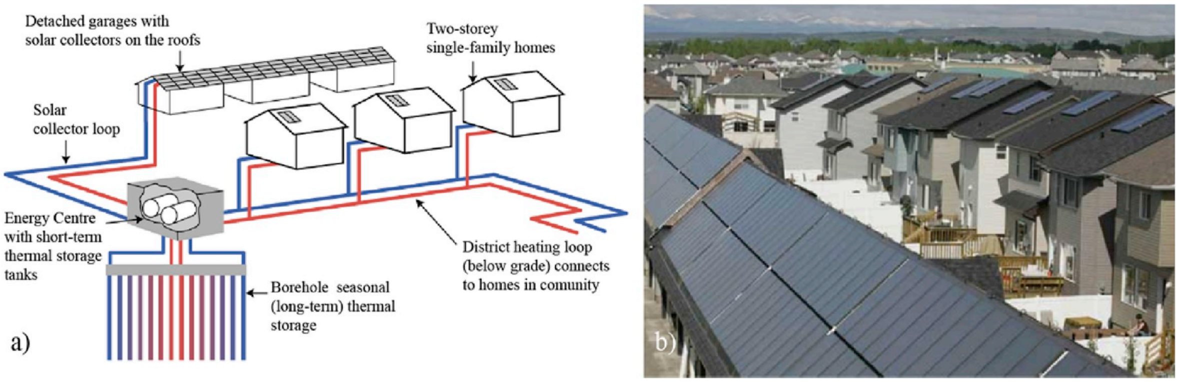


Fig. 18. *Drake Landing Solar Community* (CA) - a) Storage and solar heating system (Source: © www.dlsc.ca); b) View of ST collectors installed on the roofs. (Source: © CanmetENERGY, Natural Resources Canada).

Fig. 19. a) *London Solar Community Ontario* (CA) - View of the PV panels installed on the roofs of the buildings (Source: © west 5). b) *Le Albere* (IT) – View of the polycrystalline PV modules integrated on the roof of the museum (Source: © S. Croce).

Gehry City Harbor (DK), and *Le Albere* (IT).

The overall goal of *London Solar Community Ontario* is to create a solar-powered micro-grid by adding PV panels to 95% of local rooftops, and BIPV on the south facade of the main commercial buildings (Fig. 19 a). In *Le Albere* (IT), polycrystalline PV modules were integrated in the buildings' roofs and facades by following precise architectural choices (Fig. 19 b). Instead, in *Gehry City Harbor* (DK) the use of PV is combined with passive strategies focusing on solar gains through windows and daylight to ensure good visual indoor conditions and to reduce the energy demand for artificial lighting. In terms of passive strategies, four other case studies considered solar gains and daylight. Among these, *Violino District* (IT) presents an interesting approach for the architectural choices connected. A color study was carried out to choose several alternative colors; each unit of the district is identified by one color used in three degrading shades (Fig. 20). In this way, the perception of the composition varies during the day, and minimum daylight levels are guaranteed.

Passive strategies in a tropical climate were applied in *The Sustainable City of Beausèjour* (FR), where the building envelopes are highly porous to promote both natural ventilation and daylighting, while the openings are protected from direct sunlight with various types of solar shadings to limit any heating or glare issue.

The case of *FredericiaC* (DK) demonstrates that the analysis conducted throughout all the development phases of a project leads to a high implementation of solar active strategies. From the early design stage, the solar irradiance on roofs and facades was calculated to ensure a high integration of PV systems and to prevent future constructions from shading existing PV systems. The simulations were used as a design and verification tool to maximize building's heights and minimize building's distances while guaranteeing high solar exposure. The final layout shows its effectiveness as it was assessed that more than 95% of the roof area could be used for PV corresponding to an effective area of 65 000 m^2 of PV-panels [94]. Similarly, daylight analyses were carried out to evaluate if the proposals allow for sufficient outdoor natural light access, and indoor daylight conditions meeting the minimum requirements for each building type [95]. Verification of solar gains in public areas and analysis of indoor daylight levels characterized also the methods applied in *Gehry City Harbor* (DK) and *PDLi Nord-Lausannois* (CH). In the Danish case, direct solar gains to key urbans spaces were analyzed for various versions of the masterplan together with studies on daylight access, leading to a final masterplan with a building disposition adjusted to improve solar accessibility (Fig. 21). In *PDLi Nord-Lausannois* (CH), a study was conducted through parametric modelling and simulation workflow based in *Rhinoceros* and *Grasshopper*, combined with other tools. Two types of simulations were carried out: (i) thermal simulations via *Archsim*, and (ii) lighting simulations via *DIVA-for-Grasshopper*. Results in terms of overall annual heating demand and spatial daylight autonomy were used to compare the effects of buildings shape and position on their passive solar potential. Furthermore, custom *Matlab* and *Grasshopper* scripts were developed to consider the solar inter-buildings effects at the meso-scale, such as the impact of shading from the surroundings on each building's performance [100].

The effectiveness of the analysis to exploit daylight and external environmental conditions in the early design stages is demonstrated by the two cases of *Residential Plot B45* (CN), and *Lyon Confluence* (FR). The Chinese method was based on several different simulations aimed at ensuring living quality, energy efficiency and limited environmental impact. Wind conditions in the area have been evaluated with

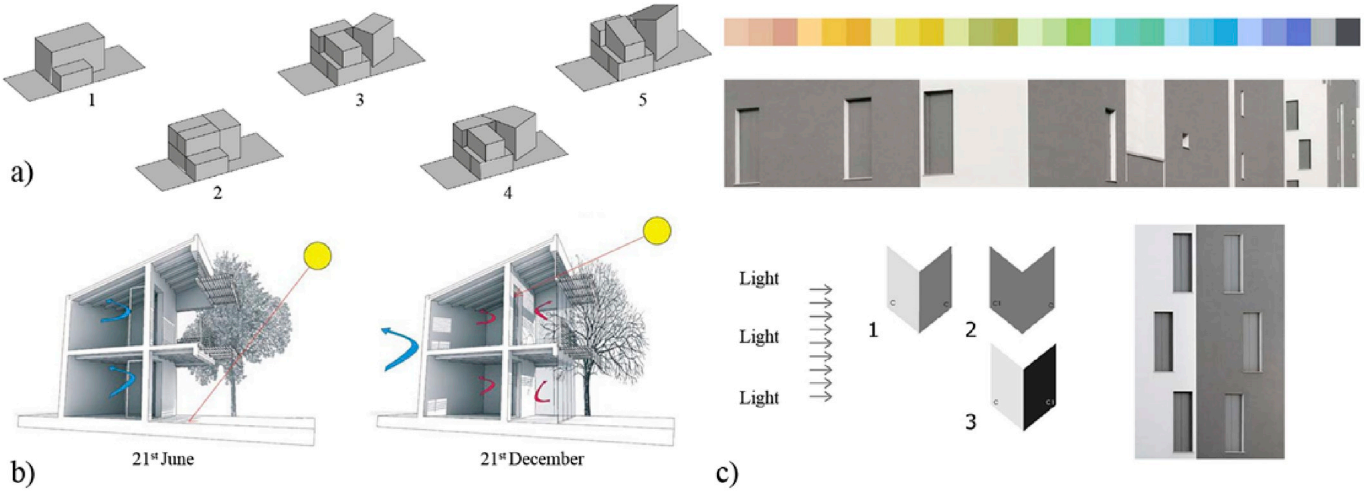


Fig. 20. *Violino district* (IT) - a) Volume composition and evolution; b) Section with identification of the passive strategies applied; c) Color study (Source: © Boschi + Serboli Architetti Associati).

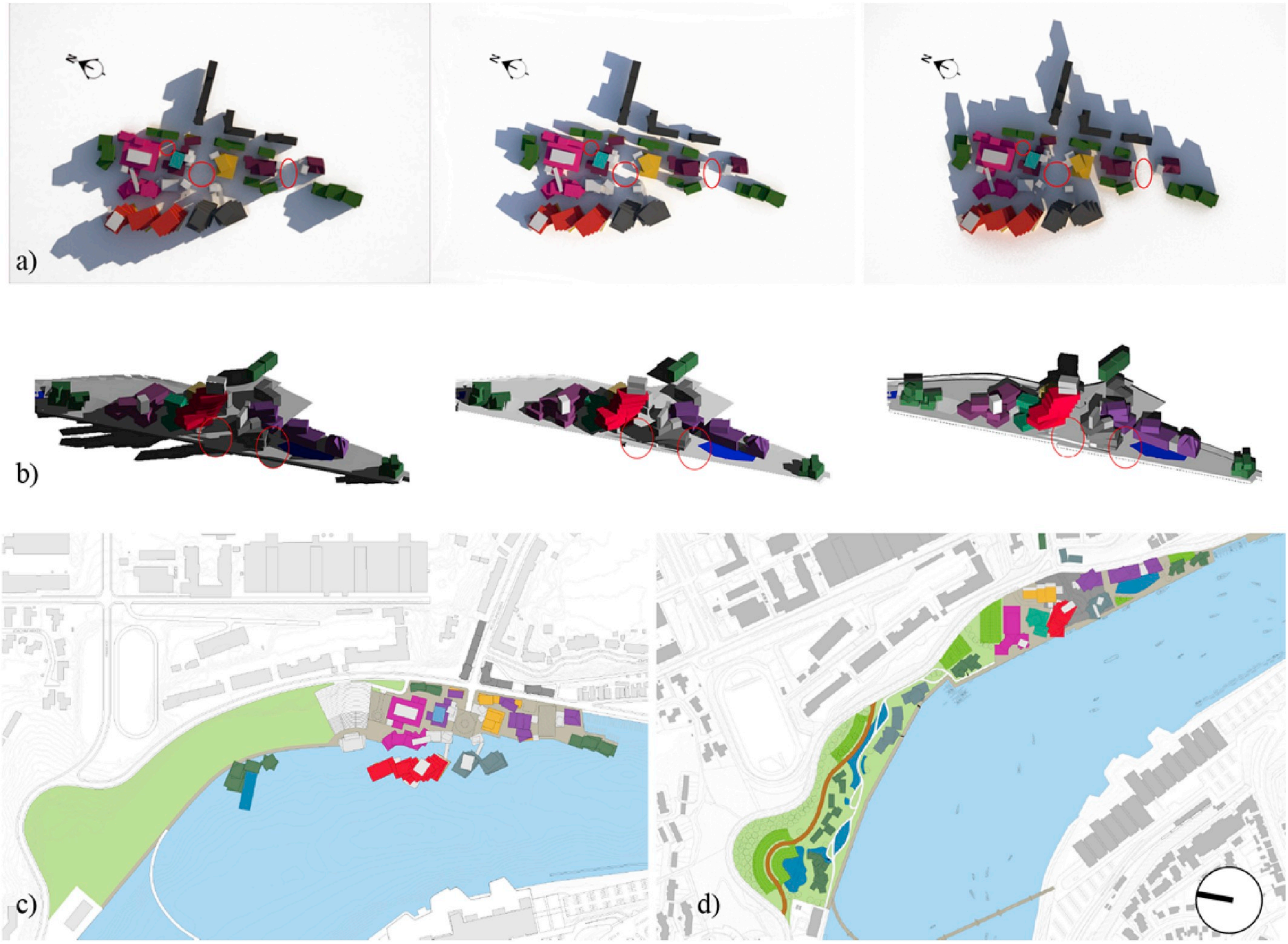


Fig. 21. *Gehry City Harbor* (DK) - Shadows at 9:00, 12:00, and 15:00 of 21st September in a) first version of the masterplan and b) after adjusting the masterplan; c) First version of the masterplan; d) Final masterplan after adjustment for solar accessibility (Source: © Dansk Energi Management & Esbensen A/S).

Phoenics2009 (Fig. 22), air pollution and noise levels have been assessed by using *SCREEN3* and *Cadna/A* respectively. The layout of the site was modelled in 3D, simulated and optimized in *SketchUp*; while solar irradiation and daylight conditions were evaluated with *SUNSHINE-V 3.0*. In the final layout, the building energy efficiency and the overall performance of the district have been also assessed.

In *Lyon Confluence* (FR), the analysis method was characterized by two phases. Firstly, solar irradiation levels and sky view factors have been calculated. In what regards buildings, the study focused on free solar gains, summer overheating risks and natural lighting; while in what regards public spaces, daylight and solar accessibility have been evaluated. In the second phase, the urban planners' proposals were studied in detail using *SOLENE*, both for solar potential and natural lighting (Fig. 23). In this phase, *SOLENE* was also used to calculate the equivalent albedo of the district, which is a main factor influencing the Urban Heat Island Effect [97].

Finally, the use of energy analyses proved to be crucial as support to the development of sustainable energy solutions and systems. The tools applied in the case study of *Graz Reininghaus* (AT) were focused on defining the urban energy systems. First, the expected thermal and electric energy demand was modelled using dynamic energy simulation tools like *TRNSYS* and *MATLAB*. Secondly, thermal and system simulations were performed for the whole building structure to estimate the overall energy demand; in addition, the potential energy production

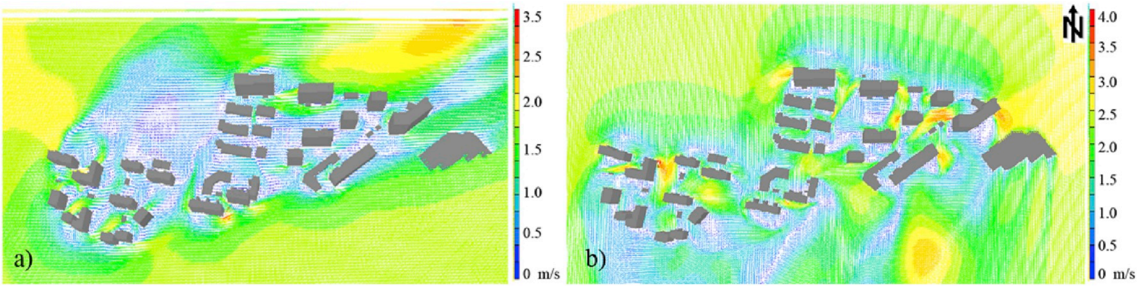


Fig. 22. *Residential Plot B45* (CN) - Summer (a) and winter (b) wind environment simulation at 1.5 m a.g.l. (Source: © Beijing Zhongchengshenke Ecological Science Co., Ltd.).

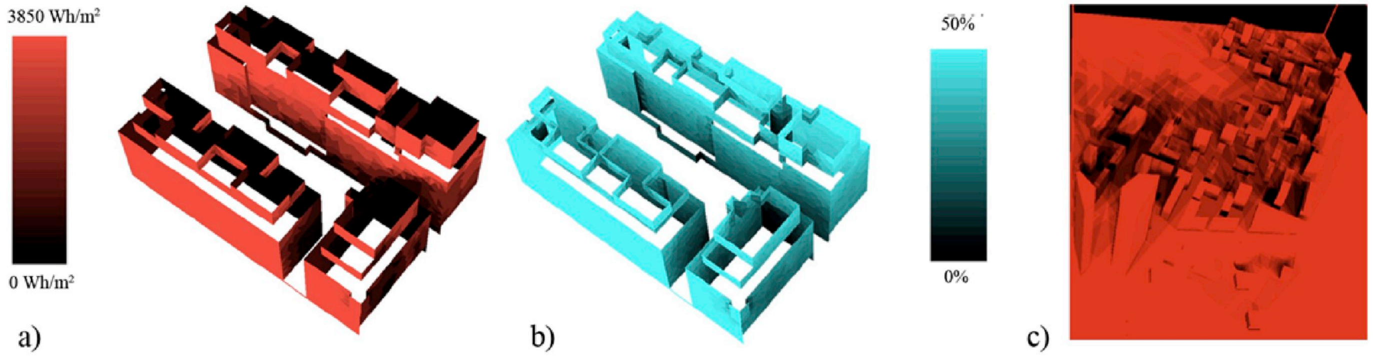


Fig. 23. *Lyon Confluence* (FR) – First phase: a) Calculation of the cumulated solar energy received by a block the 31st March using *SOLENE*; b) Calculation of the facades' sky view factor; c) Second phase: south towers and their masking impact (Source: © M. Musy).

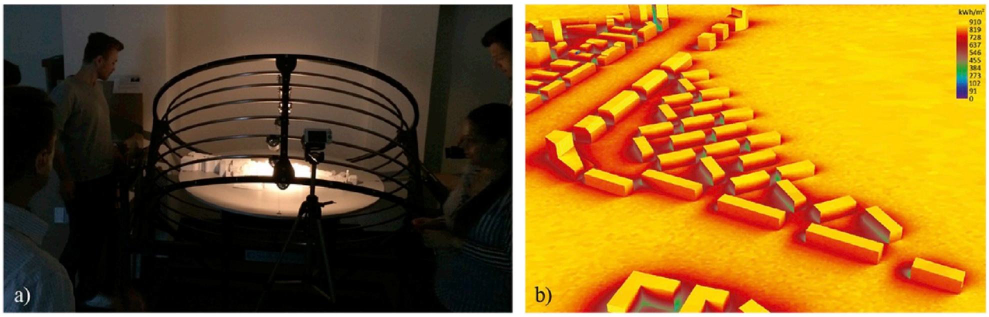


Fig. 24. *Øvre Rotvoll* (NO) – a) Planning with artificial sun with heliodon. (Source: © Katharina Simon). b) Solar map of an area of the masterplan used for individuating the surfaces suitable for installing solar systems [29] (Source: © Silvia Croce).

from PV systems was assessed. Finally, based on the evaluated energy demand and production, a design-based approach was implemented. The application of genetic optimization algorithms, enabled to identify the most cost-efficient and sustainable supply system structure [88,89]. A similar method was applied in the design of the thermal system in *Drake Landing Solar Community* (CA). A *TRNSYS* model was built to simulate each part of the collection, storage energy distribution systems, and to predict temperatures and energy flow, through *ESP-r* simulations in each component of the system [92].

The approaches and methods adopted for the design of new urban areas and the implementation of solar energy strategies demonstrate the relevance of solar accessibility and solar potential analyses through the planning process. In *Øvre Rotvoll* (NO) case study, solar simulations were used to generate the urban structure of the masterplan with the focus on the optimization of the solar energy potential, and the implementation of the renewable energy production. Two different methods were adopted. In the first one, exemplary building shapes with different roof types and orientations were investigated both with software and experiments with heliodon (Fig. 24 a). To develop a sustainable energy concept, the software *District Energy Concept Adviser* (*DECA*) was used to calculate the energy demand and to evaluate the energy potentials. The tool *EnOB-Lernnetz* was adopted to analyze the solar irradiation potential of the urban surfaces and to evaluate the overshadowing effect by nearby buildings. The second method was based on coupling parametric modelling software, such as *Rhinoceros* and *Grasshopper*, with solar dynamic simulation tools, as *DIVA-for-Rhino* (Fig. 24 b). Simulations and parametric analyses were conducted on two typical building typologies (i.e. row houses, and high-rise building blocks) in different scenarios characterized by various facade painting colors and finishing materials in order to outline urban planning recommendations, which have been then applied in the design of the masterplan. The results demonstrate the importance of taking into consideration the integration of solar systems since the early design phases to reach energy efficient districts [29].

In the *London Solar Community* (CA) case study, methods and tools were used to by support stakeholders to understand the effects of specific layouts in relation with solar access, and potential for passive and active designs. Several tools, such as *EnergyPlus*, *HOT2000*, *RETScreen International*, *HOT2XP*, and *HOT2EC* were used to evaluate the performance of various layouts.

In *Freiham North Munich* (DE), the city of Munich asked researchers of the *Stuttgart Technology University of Applied Sciences* to evaluate the solar design of different urban forms in two different phases of the planning process. In the first phase: the design variants were evaluated qualitatively, by visually determining the main orientations of the facades, the impact of the building height on solar accessibility, and the coherency between building usage and passive solar gains. In the second phase, different alternatives of a single buildings cluster were quantitatively analyzed (Fig. 25). The yearly average irradiance on each surface, the potential electricity production for different solar installation alternatives, and the building heating demands were calculated using the simulation platform *SimStadt* [99]. Similarly, in the Swedish case studies *Lund Brunnshög* and *Malmö Hyllie* the proposed masterplans were evaluated to estimate the solar potential energy production, and to individuate the surfaces suitable for solar systems installation. The analysis provided a foundation for the discussion between researchers and stakeholders, on how solar energy systems can be installed, especially on flat roofs.

4.7. New urban areas: architectural visibility, sensitivity and quality

In new urban areas, the integration of solar systems is part of the

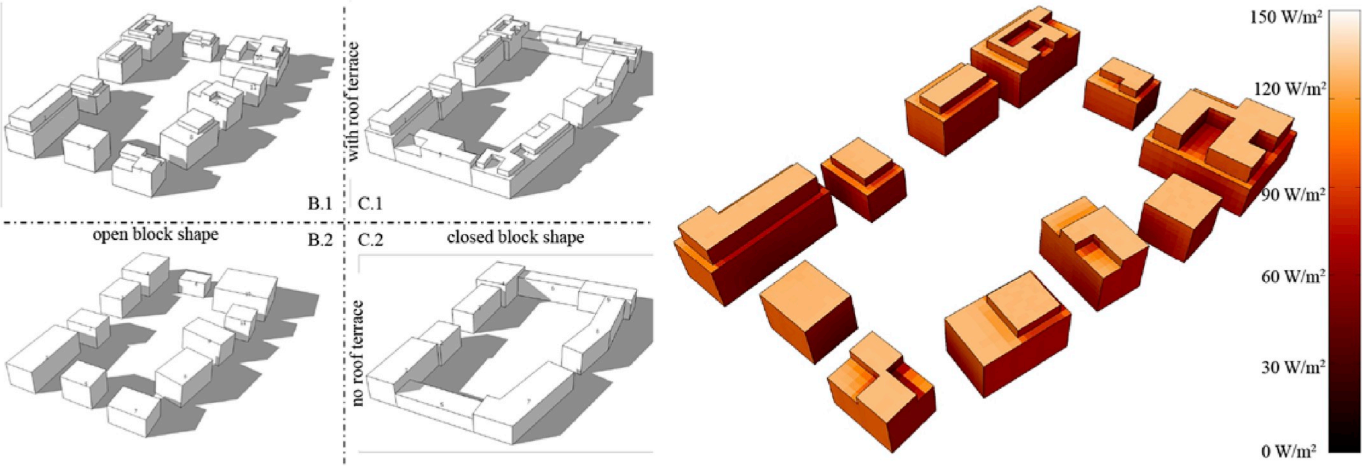


Fig. 25. *Freiham North Munich* (DE) – a) Four studied variants for a cluster; b) Yearly average irradiance on facade and on roof for the first variant (Source: © HFT Stuttgart).

Table 7
Architectural integration quality, context sensitivity and system visibility of case studies in new urban areas.

	Architectural visibility, sensitivity and quality																				
																					
	Drake Landing Solar Community [CA]			*London Solar Community Ontario* [CA]			*Residential Plot B45*[CN]			*Lyon Confluence* [FR]			*The Sustainable City of Beausèjour* [FR]			*Le Albere* [IT]			*Violino district in Brescia* [IT]		
System geometry	[✓ fully coherent]	partly coherent	not coherent	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent	[✓ fully coherent]	partly coherent	not coherent	[✓ fully coherent]	partly coherent	not coherent	[✓ fully coherent]	partly coherent	not coherent	[✓ fully coherent]	partly coherent	not coherent
System materiality	fully coherent	[✓ partly coherent]	not coherent	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent	[✓ fully coherent]	partly coherent	not coherent	[✓ fully coherent]	partly coherent	not coherent
Modular pattern	[✓ fully coherent]	partly coherent	not coherent	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent	[✓ fully coherent]	partly coherent	not coherent	fully coherent	[✓ partly coherent]	not coherent
		🟩🟩🟨			🟩🟩🟩			🟨🟨🟨			🟩🟩🟩			🟩🟨🟨			🟩🟩🟩			🟩🟩🟨	
Context Sensitivity	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high
Urban area socio-cultural value		✓			✓			✓			✓			✓			✓			✓	
System Visibility	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high	low	medium	high
Close visibility	✓			✓					✓	✓				✓			✓			✓	
Remote visibility			✓			✓			✓		✓			✓				✓		✓	

planning process and the detailed architectural design of the buildings. As a result, the architectural integration quality of the solutions proposed by the analyzed case studies varies from fully to partly coherent; there are no projects in which one or more characteristics are evaluated as not coherent (Table 7).

Three projects are discussed in detail as representative of the architectural sensitivity, visibility, and quality of solar installations in new urban areas: *Lyon Confluence* (FR) and *The Sustainable City of Beausèjour* (FR), and *Residential Plot B45* (CN). In terms of architectural integration quality, the BIPV solution through a semi-transparent facade adopted in *Lyon Confluence* (FR) is fully coherent (figure d in Table 7). PV cells form a kind of "pixelisation" on the facade, compliant with the overall glazed-metallic surface. They are integrated in a glass panel, acting as a filter between the balconies and the outdoor environment, and concentrated at the fencing level. In *The Sustainable City of Beausèjour* (FR), the size and position of the PV panels are fully coherent as they follow the roof pans slopes (figure e in Table 7). However, the material and color of the panels do not merge with those of roof, making them materially ineffectively integrated. Furthermore, the joints of the modules are considerably thick and apparent due to their contrasting color. The architectural quality of the solar thermal systems installed on the roof of the tower buildings in *Residential Plot B45* (CN) is partly coherent (figure c in Table 7). The ST collectors have the same orientation as the buildings. However, their geometry and modular pattern do not appear to be integrated in the overall architectural design, and the blue color of the systems contrast with the bright colors characterizing the buildings' facades.

The context sensitivity is medium for all the three cases. In *Lyon*

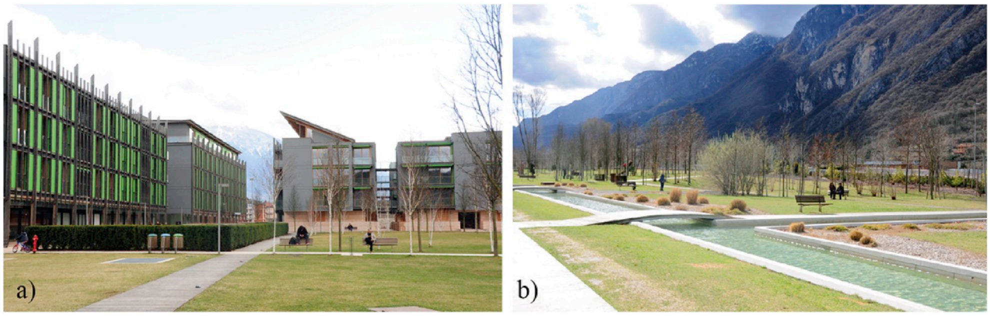


Fig. 26. *Le Albere* (IT) - a) buildings, and b) outdoor public green areas (Source: © S. Croce).

Confluence (FR), the district is part of the new urban texture of the Metropolis, but the surrounding buildings do not have historical value, neither there is the presence of monuments or meaningful elements. While both *The Sustainable City of Beausèjour* (FR) and *Residential Plot B45* (CN) are located in new areas.

The system visibility varies between the projects; in *Lyon Confluence* (FR) the installation of solar systems on the facades ensures high visibility from the pedestrian level. The remote visibility results possible despite being low as it is only visible from the hills around the site area. *The Sustainable City of Beausèjour* (FR) is built on a mid-slope area, with various view angles onto the roofs of the district from upper locations. However, PV panels have low visual impact since they are integrated to the large over-roofs of the buildings, with a consequent medium visibility. In *Residential Plot B45* (CN) the height of the buildings, which varies from 11 to 15 storeys, and the location of the ST panels on the flat roof, result in low visibility both from close and remote points of view.

4.8. New urban areas: environmental, economic and social impact

Among the presented case studies, those already partially or totally completed offer insights on the environmental, economic, and social impact of new urban areas integrating solar strategies. The consequences on the environment are studied in several projects, focusing mainly on the reduction of CO_2 emissions. In *Stadtwerk Lehen* (AT), one of the main goals was the integration of a superior energy concept based on ST collectors and renewable DH system; the planning approach resulted in a reduction of primary energy demand and CO_2 emissions compared to oil-heated systems of 68% and 76% respectively. Also in *FredericiaC* (DK), the positive environmental impact is significant aiming at ensuring CO_2-neutrality on annual basis with respect to building operation. Several measures, such as energy conscious building design, the integration of PV systems, and the implementation of energy efficient lighting and waste disposal, are applied also in *Gehry City Harbor* (DK) to reduce the GHG emission. In *Lyon Confluence* (FR) best practice in terms of design and construction of energy efficient buildings are implemented to maintain the CO_2 emissions in 2020 to their level in 2000. In *The Sustainable City of Beausèjour* (FR) and *Le Albere* (IT) the environmental impact of the construction of new districts was reduced combining measures for the preservation of natural features, soft mobility, and ecological restoration through the creation of new biotopes. In *The Sustainable City of Beausèjour* (FR), an environmental approach to urban planning led to the definition of a density ten times greater than the average on the island to preserve the land, green corridors, and natural water flows. In *Le Albere* (IT), local materials, such as wood and stone (Fig. 26), have been chosen to guarantee a low environmental impact.

Positive economic impacts were achieved by the projects in terms of job creation and attraction of new residents and businesses to the areas. In *aspern + Die Seestadt* (AT), the collective urban gardening, the co-

Table 8
Planning process and stakeholders of case studies of solar landscapes. Stakeholders: Citizens [C]; Education actors [EA]; Professional and stakeholders [PS]; Politicians and Decision makers [PD].

Case study [Country]	Planning Process		Stakeholders				Ref
	Duration	Highlights	C	EA	PS	PD	
Sarnia Photovoltaic Power Plant [CA]	2008–2015	- Developed under the *Government of Ontario's Green Energy Act* to stimulate the diffusion of small-scale grid-connected renewable energy projects - After initial success, the scheme evolved into a Feed-In-Tariff program	✓		✓		[101]
Solar District Heating Brædstrup [DK]	2006-N/A	- Stage 1: solar thermal combined with natural gas fired CHP - Stage 2: borehole seasonal heat storage - Stage 3: aim to expand solar collectors area and seasonal heat storage			✓	✓	[61]
Agrienergie 5 [FR]	2009–2011	- Development of partnerships between agriculture, environment and energy actors - Demonstrate that solar panels can be integrated in an agricultural area without reducing the cultivated areas			✓	✓	
Les Cedres [FR]	2009–2015	- Best solution selected as compromise with solar efficiency, costs, esthetical features and social integration - Two main partners: *Aquanergie*® (fish farming), and *Agrinergie*® (permaculture)			✓	✓	
Agrovoltaico [IT]	2010–2012	- Need to install photovoltaics on agricultural land, without penalizing the agricultural productivity - Design that could overcome soft barriers for on ground PV due to legislation, which prohibits the realization of large PV systems on agricultural areas, or to the public opposition			✓	✓	[102]

Table 9
Formal functional features.

Case study [Country]	Formal functional features														
	Patch type			Grain type		Pattern			Pattern type				Edge/Borders		
	Small	Large	Straight borders	Convoluted borders	Small patches	Large patch	Porous	Dense	Stripes		Island		Radom	Continuous	Discontinuous
									Parallel	**Not parallel**	**Uniform patches**	**Varied patches**			
Sarnia Photovoltaic Power Plant [CA]		✓	✓			✓		✓	✓		✓			✓	
Solar District Heating Brædstrup [DK]		✓	✓			✓		✓	✓						✓
Agrienergie 5 [FR]		✓	✓			✓		✓	✓						✓
Les Cedres [FR]		✓	✓			✓		✓	✓						✓
Agrovoltaico [IT]		✓	✓		✓			✓	✓					✓	

Table 10
Features of solar system space in landscape case studies.

Case study [Country] (Type of system)	Features of solar system space		
	Connectivity	Added functions (multiple use of land and/or multiple functions of the supporting structure)	Other features (pattern and/or engineering)
Sarnia Photovoltaic Power Plant [CA] (PV)	- Tree-lined fence surrounding the solar power plant - Animals and people can access the site only from vehicular accesses - Solar module layout fits to the pattern of the surrounding farmland	- none	- Cost-effective structure - PV modules with 25° tilt - Structure designed to conform to site-specific wind- and snow-load requirements
Solar District Heating Brædstrup [DK] (ST)	- Two protected natural areas within the solar field and in its proximity - Free space between/under the solar panels as ecological connection between protected areas	- Grazing (underneath the thermal modules' surface)	- PV modules free-standing on grassland - PV modules have glass as cover of the fronts and aluminum as cover of the backs
Agrienergie 5 [FR] (PV)	- Looking from the top view there is a discontinuity area where the solar field is placed and the surrounding landscape	- Organic agriculture under greenhouses and recuperation of water.	- Height from the ground: minimum 3.5 m and maximum height 4.1 m.
Les Cedres [FR] (PV)	- The solar field landscaping considers the overall coherence of the surrounding territory - Attention focused on matching the existing landscape pattern	- PV modules are integrated in greenhouses - Organic agriculture in the greenhouses, water-waste treat system	- The PV modules are part of the envelope of the greenhouses, and this allows for hurricane-resistant crops
Agrovoltaico [IT] (PV)	- No enclosure around the solar field, people/animals can access the area - No discontinuity between solar field and the surrounding landscape, as specifically required by the local authorities	sbnd No land use change (still agriculture)	- Sun tracking system on double orientation - Supporting systems and foundations: steel structure with precast concrete poles and cables

development of innovative mobility concepts, and the organization of food cooperatives and local markets ensured the strengthening of the local micro-economy taking the overall idea of sustainability beyond technological development. In terms of social impacts, several case studies demonstrated the importance of co-creation and participation programs as well as the key role of cultural and public associations. In *Stadtwerk Lehen* (AT), a cooperative neighborhood management was organized to provide social organizational support, serving as a hub for district marketing and public information, and for developing networks and cooperation. In *Graz Reininghaus* (AT), a public and private participation process was started, allowing a dialogue between citizens, investors, urban planners, and the municipality. *FredericiaC* (DK), *Gehry City Harbor* (DK), and *The Sustainable City of Beausèjour* (FR) proved the role of physical planning in supporting the social sustainability through various aspects, such as common outdoor areas and open spaces, urban gardens and sport facilities, together with variation and flexibility in the building disposition and typologies. These inclusive economic and social approaches in planning aid in substantiating the environmental aims and goals for the long-term future.

4.9. Solar landscapes: planning process

The planning process of landscape scale solar systems takes from two to seven years (Table 8).

The *Sarnia Solar Project* (CA) was developed under *Ontario Power Authority's Feed-In-Tariff* (*FIT*) program. The goal of the project was to create the largest solar power plant on the planet, and to show that solar energy generation is economically feasible in *Ontario* (Canada) with the *FIT* program. The project had two main stakeholders: the developer, a solar module manufacturer, and the owner and financer of the project, a Canadian energy supply company. Differently, the *Solar district heating in Brædstrup* (DK) was framed in a local long-term strategic energy planning towards the goal of a DH system based on RES. This case study shows how large-scale ST plants are best suitable in towns equipped with an existing DH network. In this situation, the ST plants are a cost-competitive technology to substitute a share of the heat production from natural gas boilers. However, local conditions and context are fundamental for this competitiveness to take off.

In contrast, the planning process of *Agrinergie 5* (FR), *Les Cedres* (FR), and *Agrovoltaico* (IT) is characterized by a bottom-up approach. The developers had to spend a significant amount of time to find an approach with a good balance between landscape preservation issues, energy target, and agricultural production.

4.10. Solar landscapes: features

The main characteristics of the solar landscapes in terms of formal functional features (Table 9) and features of the solar system space (Table 10) have been analyzed, according to what proposed in Ref. [32].

With regard to formal functional features, all the case studies present a distribution of the solar modules with large patch type and straight borders, and a dense pattern with parallel stripes. In terms of grain type, the majority of the solar fields integrate large patches, with the exception of *Agrovoltaico* (IT), which is characterized by small patches, constituted by single sun-tracking PV modules above the cultivated agricultural land. In *Sarnia Photovoltaic Power Plant* (CA) and *Solar District Heating Brædstrup* (DK), the area of the solar field, once used for agriculture, does not implement other functions than energy production (Fig. 27).

While, *Agrinergie 5* (FR), *Les Cedres* (FR) and *Agrovoltaico* (IT) added to the area further land uses such as organic agriculture in greenhouses, whose structure integrates the PV modules, and waste-water treatment systems (Fig. 28).

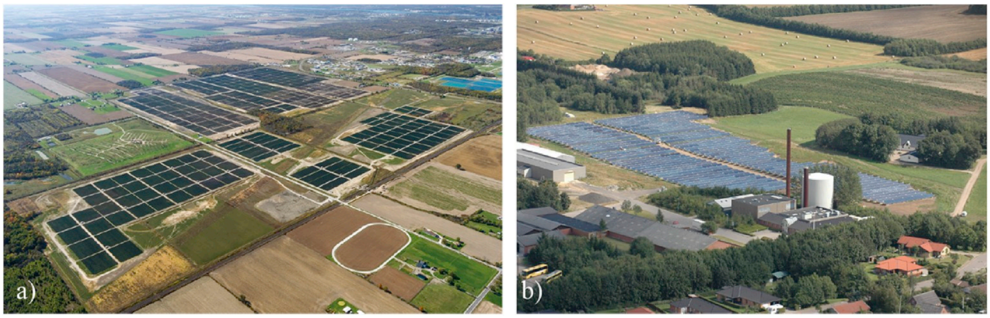


Fig. 27. Aerial view of the spatial system as the whole (pattern) solar systems of a) *Sarnia Photovoltaic Power Plant* (CA) (Source: © Daniel J Bellyk); and b) *Solar District Heating Brædstrup* (DK) (Source: © Brædstrup Fjernvarme).

Fig. 28. View of the “pore” space in the case study of a) *Agrinergie 5* (FR); b) *Les Cedres* (FR) (Source: © akuoenergy); and c) *Agrovoltaico* (IT) (Source: © REM).

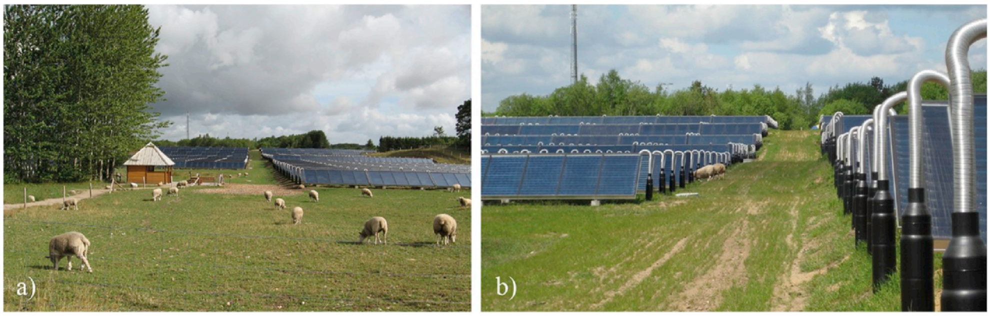


Fig. 29. *Solar District Heating Brædstrup* (DK): a) General view of the first phase of the project; b) Detailed view of the solar systems (Source: © Brædstrup Fjernvarme).

Fig. 30. *Agrovoltaico* (IT): a) view of the PV track system, and b) agricultural activities in the site (Source: © REM).

4.11. Solar landscapes: site potential

Sarnia Photovoltaic Power Plant (CA) is located in an agricultural landscape, mainly consisting of farmland surrounding. The area is valuable for its land use and it is not under preservation. A remediation program was initiated in 2015 to return the site to a bio-diverse and hospitable landscape for local flora and fauna. The plant of *Solar District Heating Brædstrup* (DK) was incorporated into the existing field structure in an area previously reserved for agricultural use, which still characterizes the surrounding fields (Fig. 29). The project area is not valuable as a whole, but contains groundwater interests, which limit its use. Furthermore, the territory contains a smaller sensitive natural area, which is protected from alterations by the Danish Planning Act.

Regarding the two projects in *La Réunion* (*Agrinergie 5* and *Le Cedres),* these were both designed to overcome a strict rule that does not allow to install on ground PV in the island, being the most of the areas in the UNESCO World Heritage Sites list. The landform of the site results in really high reliefs, without any presence of strong topography or distinctive landform features around the site area. However, the landform around *Agrinergie 5* is characterized by a cliff of a valley along the east side.

The project in *Les Cedres (FR)* included the installation of PV structures for enhanced development of organic farming. The project's challenge was the application of the principles of permaculture to restore a natural character to a former industrial site by erasing the harmful effects of past conventional farming practices. Finally, in *Agrovoltaico* (IT) (Fig. 30), the landscape has cultural value as the product of a long human transformation from swamp area into a productive land for agriculture. Thanks to the flat morphology of the terrain and to the abundant presence of water, the value of land for agricultural uses is very high. Table 11 presents in detail the sensitivity levels (i.e. low (L) and high (H) sensitivity) of the landscape factors in the analyzed case studies. In the five landscape solar systems, different approaches have been applied in terms of multi-functionality. This concept can be applied to the land use (multiple land use) or to the use of the structure supporting the solar modules. The collected case studies show some possibilities for the two approaches.

- In *Sarnia Photovoltaic Power Plant* (CA), the solar farm does not perform any additional function aside from energy generation.
- *Agrovoltaico* (IT) is an example of double use of land for agriculture and photovoltaics.
- *In Solar District Heating Brædstrup* (DK), part of the area was reserved for leisure and recreation.
- Both *Agrinergie 5* (FR) and *Les Cedres* (FR) are examples of dual use of land, with organic agriculture under greenhouses and recuperation of water, in the first case study, and permaculture practices, in the second one.

4.12. Solar landscapes: environmental, visual, economic and social impact

Table 12 presents the main environmental, visual, economic and social impacts of solar landscapes case studies. Land use impact of the case studies is mitigated by a remediation project to improve biodiversity in *Sarnia Photovoltaic Power Plant* (CA), and water purification measures in the case of *Agrinergie* (FR). Visual impact is mitigated by tree lines in the cases of *Sarnia Photovoltaic Power Plant* (CA) and *Solar District Heating Brædstrup* (DK). Environmental impact of the case studies implied the reduction of GHG emissions, and, in the cases of *Agrovoltaico* and *Les Cedres* (FR) (Fig. 31) the production of organic food. Public participation to the plant planning process was particularly encouraged in *Solar District Heating Brædstrup* (DK), where a public hearing period was part of the plan implementation.

5. Conclusions and future developments

This work presents an illustrative perspective of solar energy in urban planning through the analysis of 34 international case studies categorized in existing and new urban areas, and solar landscapes.

A common trend was observed concerning the duration of a planning process. In both existing and new urban areas, the duration depends primarily on the size of the area and on the level of complexity of its development. The involvement of stakeholders with specific competences and interests can strongly influence the temporal extent, and success or failure of the planning process. In solar landscapes cases, the

Table 11
Analysis of the landscape factors for the analyzed case studies. Sensitivity: low (L), high (H).

Case study [Country]	Landscape factor – Sensitivity																			
	Landform		Landscape pattern and complexity (patches and grain)		Land use		Land cover		Settlement and man-made influence		Historic landscape character		Distinctive landscape features		Inter-visibility with adjacent landscapes		Sense of remoteness/ tranquility		Sense of openness/ enclosure	
	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
Sarnia Photovoltaic Power Plant [CA]	✓		✓			✓		✓	✓		✓		✓		✓		✓			✓
Solar District Heating Brædstrup [DK]	✓		✓			✓	✓			✓	✓			✓		✓	✓			✓
Agrienergie 5 [FR]		✓	✓			✓		✓	✓		✓			✓	✓			✓		✓
Les Cedres [FR]		✓	✓			✓		✓	✓		✓			✓	✓			✓		✓
Agrovoltaico [IT]	✓		✓			✓		✓		✓		✓		✓		✓		✓		✓

Table 12
Environmental, visual, economic and social impact of solar landscapes case studies.

Case study [Country]	Environmental, visual, economic and social impact							
	Land use		Visual impact		Environmental impact		Public awareness and participation	
	Impact - Burden	Alleviation, Mitigation strategies	Impact - Burden	Alleviation, Mitigation strategies	Impact - Burden	Alleviation, Mitigation strategies	Impact - Burden	Alleviation, Mitigation strategies
Sarnia Photovoltaic Power Plant [CA]	Land useless for any purpose aside energy generation	Visibility from the street mitigated using a tree-lined fence	System located close to a town, within a flat agricultural landscape	Remediation project with local native plants rescue to improve biodiversity	Although the land was previously farmland, it was re-zoned as industrial		Concernings about water drainage, night lighting of the plant, and vegetation management	Biodiversity remediation, light pollution reduction, drainage measures
Solar District Heating Brædstrup [DK]	70 000 m^2 reserved to the content and functions within the project plans	ST most suitable technology to reach the goal of 100% renewables in district heating	Visual impacts assessed from visualizations of the project	In stage two, solar field expansions require establishment of visual shielding effect	Estimated annual reduction in CO_2 emissions by 3700 tons	Specific permission for the borehole storage not affecting groundwater interests	Public hearing period of eight weeks as part of plan's implementation	Citizens encouraged to share their opinions and suggestions during hearing period
Agrienergie 5 [FR]	Excessive run-off/ direct run-off into nearby rivers and sensitive areas	Water purification, water collection in a pond	Little inter-visibility with adjacent sensitive landscapes or viewpoints	Sense of physically or perceptually remote, peaceful or tranquility	Protection from insects results in reduction of the use of phytosanitary products	Production of organic vegetables and environmental-friendly electricity	Farmer uses one of the greenhouses to test new cultures and vegetable varieties	
Les Cedres [FR]	Flooding area with no possibility to build	Development of solar activity without perturbing the natural drainage	Porous photovoltaic structure covering the fish-farming basins	Raised semi-photovoltaic sunshades above growing ponds	Protection from predators, water temperature regulation		Cohabitation with farmers during construction and operation	
Agrovoltaico [IT]	Preservation of original land use	Pattern of the photovoltaic modules	Visual impact very low, thanks to accurate	design and porous pattern of the system	Entire system made of safe, non-polluting and			

(*continued on next page*)

Table 12 (*continued*)

Case study [Country]	Environmental, visual, economic and social impact							
	Land use		Visual impact		Environmental impact		Public awareness and participation	
	Impact - Burden	Alleviation, Mitigation strategies	Impact - Burden	Alleviation, Mitigation strategies	Impact - Burden	Alleviation, Mitigation strategies	Impact - Burden	Alleviation, Mitigation strategies
		matching the existing landscape pattern			fully recyclable materials	Low overall ecological impact, no mitigation or alleviation strategies	Close collaboration with local authorities resulted in a good design	

duration of the planning process is mainly influenced by the amount of time the developers spend to find a good balance between landscape preservation and energy targets. To ease the implementation process, guidelines should be developed based on urban and landscape quality objectives. Moreover, the appropriate planning should identify urban and landscape areas suitable for installing solar systems early in the planning process.

Several cases highlighted the usefulness of conducting preliminary analyses to compare the current situation with proposed planning alternatives in terms of solar accessibility, solar potential, daylight, and solar energy generation. In this sense, approaches, methods and tools play a key role to promote the implementation of solar energy strategies. Therefore, ad-hoc analyses (e.g. solar potential, daylight, energy) should be conducted throughout the different stages of the planning process taking into account multiple design and energy implications. However, a wider multidisciplinary usage and interpretation of solar energy opens new potential perspectives in the way to deploy approaches, methods and tools. Such tools, often, develop a co-simulation approach by coupling numerical radiation algorithms with tools for energy related simulations, which should allow overcoming the actual limit of most of the existing tools. In fact, they enabling evaluations based on single objective optimization, neglecting simultaneous evaluation of uncertain environmental conditions such as inter-buildings reflections and dynamic overshadowing effects. Quantifying these phenomena in a multi-objective approach will allow predicting simultaneously solar accessibility, solar energy potential, overshadowing, and daylight. In that sense, more accurate spatial (e.g. terrain, vegetation canopy, building structures) and temporal (e.g. annual, seasonal, hourly) levels of detail have to be reached without massively increase the computation time.

Regarding the solar systems implementation, in the existing urban areas, PV systems are widely applied in all the case studies, while ST systems are integrated only in half of the cases and they are usually not coupled with other energy systems. Whereas, more hybrid energy strategies are implemented in new urban areas, where PV and ST are often integrated with other energy systems such as DH networks, thermal storages or geothermal plants. Differently, in the solar landscapes cases, the planning process and the design phases are crucial to meet energy generation goals and to match the quality objectives set by local requirements. Coupling PV or ST with other functions, (i.e. agriculture) can positively influence the landscape. In fact, the design of solar landscapes systems should be based on formal functional and solar system space features in order to integrate solar panels as elements of the landscape, rather than focusing exclusively on the maximization of energy generation.

Concerning the architectural integration quality, context sensitivity and system visibility, the integration of solar systems in existing urban areas varies from very high-level to very low-level because solar strategies are usually designed at a later stage than the original project. Furthermore, most of the times buildings are protected for their heritage value. Whereas, in the studied new urban areas, the integration of solar systems was already embedded as part of the planning process and of the detailed architectural design of the buildings. As a result, the architectural integration quality varies from fully to partly coherent and none of the cases presents a not coherent level of solar system integration.

Another drawn conclusion is that it is important to conduct further in-depth quantitative analyses of economic and environmental impacts, which at present were only generally outlined and may provide interesting insights on the effects of the projects. Furthermore, as some of the cases are still under development, it may be relevant to re-examine them at their completion to understand better the issues faced during the process, and the results obtained. It might also be significant to interview some key actors to assess their role in the planning process, and vice versa and to what extent the planning process was influenced by their actions.

Fig. 31. Aerial view of a) *Agrinergie 5* (FR), and b) *Les Cedres* (FR) (Source: © akuoenergy).

Acknowledgement

The authors wish to thank all the experts within the research project IEA SHC Task 51, who contributed in the successful collection and analysis of the case studies within the subtask C "Case studies and actions research" and for the copyright of graphics, images, tables and figures.

The authors also wish to express their gratitude to the IEA SHC Executive Committee for supporting the Task 51 and in this way strengthen the international collaboration among researchers and practitioners. We are especially grateful for the financial support from the Swedish Energy Agency; The Research Council of Norway (NFR) and Norwegian University of Science and Technology (NTNU); Swiss Federal Office for Energy; Italian Government, Ministero dello Sviluppo Economico, under the programme Ricerca di Sistema Elettrico. Funding from these organizations enabled the leaderships of Task 51.

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